Stream Systems

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Restored, high-quality streams provide innumerable benefits to society. In the Pacific Northwest, high-quality stream habitat often is associated with an abundance of salmonid fishes such as chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*). Many other native fish species, such as lampreys (*Lampetra* spp.), sturgeons (*Acipenser* spp.), sculpins (*Cottus* spp.), and suckers (*Catostomus* spp.), may be of less economic importance but are of high value to stream ecosystems. Northwest streams and rivers also are valuable for numerous beneficial uses besides fisheries, such as providing high-quality water to municipal and industrial users, ameliorating damage from high flood flows, recharging groundwater aquifers, and routing sediment. Benefits arising from healthy rivers may go unnoticed by the average person but nonetheless are important to society. Of course, healthy streams also are more attractive than degraded systems and often serve as focal points for water-based recreation.

Many streams in the Pacific Northwest, and across the entire nation, are so degraded that they no longer support these beneficial uses. Nearly one in three of our native fish species are so rare as to deserve some sort of protective classification, and hundreds of stocks of salmon and steelhead, the signature fish of the Pacific Northwest, are threatened with extinction or already have been extirpated (Nehlsen et al. 1991, Stein et al. 2000). For example, 80% of fish habitat in Oregon's upper Grande Ronde River failed to meet forest plan standards for water temperature, stream sediment, and riparian conditions. In Idaho's Clearwater National Forest, 70% of streams failed to meet similar standards for temperature, sediment, and riparian vegetation (U.S. Forest Service and U.S. Bureau of Land Management 1994). Many urban streams are channelized and contaminated by runoff containing road surface oils, fertilizers, and other chemicals. Clearly, there is much work to do.

If we seek to restore a stream, it is important to know what a healthy stream looks like and how it functions. Over the years, human activities in many watersheds have simplified stream channels, separated streams from their floodplains, fragmented streams, altered flows, and introduced toxic contaminants (Stanford and Ward 1992, Frissell 1997). Restoration seeks to reverse such changes. It may be impractical to restore streams to historical condition, even if we know what that condition was, but it is important to reverse the primary causal factors in the degradation process. Sometimes, the cause of stream degradation may be far upstream or upslope from where the symptoms of the problem appear. Regardless, stream restorationists often seek to reintroduce channel complexity, reconnect fragmented systems, restore natural flow regimes, revegetate riparian areas, and eliminate sources of chemical pollution.

The restoration potential of a degraded stream depends on its historical condition, cumulative impacts, soils, topography, and other factors. Nonetheless, many traits are common among healthy streams. Characteristics of a healthy stream include diverse habitat types, sufficient structural diversity provided by large woody debris and boulders, well-vegetated riparian areas, and deep pools (Table 13.1). However, a successfully restored stream is more than a mere compilation of these characteristics. It must function properly as well. Key concepts for stream function are outlined in the next section.

TABLE 13.1.

Characteristics of healthy stream systems in the Pacific Northwest.

Characteristic	Description
Habitat diversity	Roughly equal numbers of pools, riffles, and runs should be present. Complex braided channels are preferred over simple, straight streams.
Large wood	Downed trees and other large woody debris creates pools, stores sediments, and provides organic matter.
Water quality	Cool, pollutant-free water is critical to spawning, juvenile rearing, and adult resting habitat for many fish species. Generally, <16°C is needed for spawning and <18°C for rearing.
Flow regime	The hydrograph is similar in intensity and flow amounts to historical conditions. High flows may be needed at certain times to dig pools and move sediment.
Riparian vegetation	Adequate riparian vegetation is needed to shade streams, protect banks from severe erosion, and provide nutrients.
Deep pools	Sufficient deep pools are necessary as thermal refuges and holding habitat for many fish species.
Width-to-depth ratio	Ratio should be less than 10. Generally, deeper and narrower streams provide better habitat.
Bank stability	Banks should be 80–90% stable. Some erosion is needed, but too much is detrimental.
Fine sediments	Stream substrates should not exceed 20% fine materials (clay, silt, and sand) in riffles. Most streams suffer from high sediment loads.

Key Concepts for Stream Restoration

Rivers and streams represent a small percentage of the landscape, but their values to ecological functions and biological diversity far outweigh their size. Streams carry water and sediment downstream, eventually into estuaries and the ocean. They also provide habitat for many aquatic and semiaquatic organisms such as fish, amphibians, aquatic insects, mollusks, and plants. But this simple picture belies a surprising degree of dynamic movement and complexity. Water flows into streams from upstream channels, surface runoff, and groundwater aquifers. Streams that appear stable often may be eroding their banks and moving laterally over time. During floods, streams reconnect with their floodplains and may form new channels or reconnect with formerly abandoned ones. Erosion and sediment deposition are natural features of the stream channel. The species in streams may be equally mobile and subject to broad migratory patterns.

Successful stream restoration projects not only incorporate this complexity but also need to embrace it. Understanding the interactions between stream channels, riparian areas, and broader watersheds is an important component of stream restoration. That said, successful stream restoration projects may focus on a small stream reach or entire watershed, but even the small projects must be embedded in the broader context in which the work is occurring. Knowing some key hydrologic concepts will help get a project off on the right foot.

The size and flow of a stream are directly related to the size and shape of its watershed, or drainage area. Within this watershed, soil types, topography, and land use all play critical roles in further defining flow regimes. Most restoration projects are concerned with a particular stream or stream segment. However, because streams are defined by the conditions in their watersheds, the proper focus of restoration efforts often is much broader than one would initially imagine. As eminent hydrologist H. B. N. Hynes (1975) admonished, we must not divorce the stream from its valley in our thought process because to do so is to lose touch with reality.

Because understanding the proper size, or scale, of restoration work is so important in streams, it is necessary to understand how streams are organized, connected, and classified within watersheds. There are three separate classification schemes that look at streams from different perspectives. The first approach describes a hierarchical arrangement of streams in relation to broader valleys and watersheds. In this classification system, stream organization would proceed from a channel unit (such as a pool or riffle) to a stream reach, to valley segment, to watershed, to geomorphic province (Frissell et al. 1986). Each hierarchical level has independent drivers and sources of variability. A second approach is to classify streams according to function, as described by a hierarchy of channels from headwaters to larger, downstream sections (Figure 13.1).

A third classification system for streams is the channel type method of Rosgen (1996). Rosgen developed a system of naming streams by letters, Aa+ to G, in which slope, width-to-depth ratio, entrenchment, sinuosity (amount of curvature in the channel), and channel material are key defining characteristics (Figure 13.2). Type A streams are steep, with low sinuosity, whereas type E streams are meandering streams in flat valley bottoms. Rosgen lists four specific objectives against which the utility of any classification system for restoration efforts should be evaluated. Classification systems should inform restoration efforts in the following manner:

- Predict a stream's behavior from its appearance.
- Develop specific hydraulic and sediment relationships for a given channel type.
- Facilitate extrapolation of site-specific data to stream reaches having similar channel types.
- Provide a consistent frame of reference for communicating stream morphology and condition.

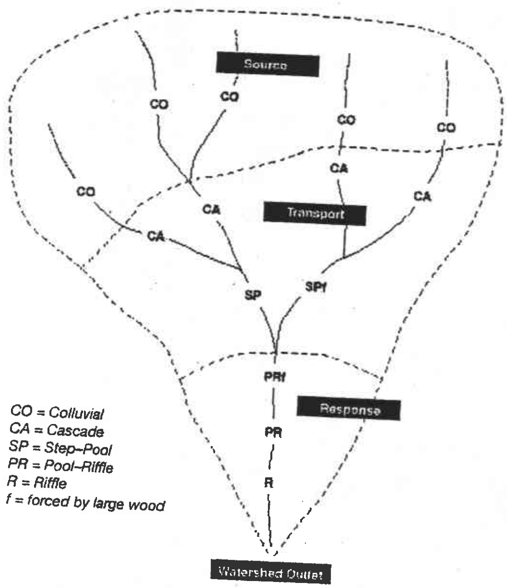

FIGURE 13.1. Watershed classification diagram based on stream gradient and stream function. Steeper headwater streams often serve as source habitats for wood and sediments that move downstream through middle-elevation transport reaches and ultimately arrive in valley bottom response streams. *(From Montgomery and Buffington 1993)*

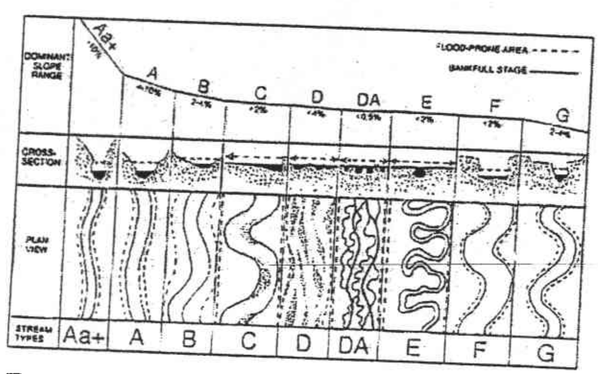

FIGURE 13.2. Diagram of Rosgen's stream classification system based on slope, cross-section channel configuration, and meandering. *(Figure provided by Wildland Hydrology and Dave Rosgen)*

Understanding the connections between streams and their surrounding lands also is critical for successful restoration. Water provides many of these connections. Obviously, streams are connected in a longitudinal sense, that is, from upstream to downstream. Streams also connect to land laterally, when floodwaters spill onto floodplains, and vertically, when surface flows connect to subsurface and groundwater systems. In many watersheds, human activities such as dam construction and stream channelization have severed these connections. Yet productive streams need woody debris from adjacent riparian areas and nutrients from upstream reaches. Restoring connectivity within watersheds often is needed to maintain healthy and productive river systems (Naiman et al. 1992, Williams et al. 1997). For example, connectivity could be restored between a river and its floodplain by removal of riprap and other hard channel structures. Flood energy is more likely to dissipate as high flows broaden out and silt is trapped to fertilize floodplains. One important caveat in reconnecting headwaters with downstream reaches involves nonnative species. If undesirable fish species or fishborne diseases occur in downstream reaches but not upstream, then efforts to reconnect stream systems could inadvertently facilitate spread of nonnatives or pathogens.

River channels seldom are straight. Normally, channels are curved, with the outside bend slowly eroding and the inside point bar building outward. In this way, the channel width remains roughly the same. The level of the floodplain typically is equal to the top of the point bar, except where channels have become significantly degraded and downcut over time.

Natural channels have sequences of riffles, runs, and pools that provide diverse habitats important to many aquatic species (Figure 13.3). Some species favor the shallow, rocky substrates often

FIGURE 13.3. Restoring habitat diversity in streams often depends on an adequate riparian zone. Riparian areas serve as a source of large woody material, which contributes to habitat complexity. In this photo of the Scott River near Ft. Jones, California, note that the riparian area is wide enough to allow natural steam meanders, which facilitates development of pool–riffle complexes. (*Photo by Brian Barr, World Wildlife Fund*)

associated with riffles, whereas others need the greater depths and often cooler conditions found in the pools along outside stream meanders. A run is a transitional habitat type found between riffles and pools and often is shallow but with smooth surface flow. The numbers, size, and shape of these habitat features may be critical to certain fish species or life history stages. One fascinating study documented a 33–73% loss of deep pool habitats and subsequent impacts to salmon and steelhead in eastern Washington and Oregon river systems over a 40-year period as large silt and sediment loads moved from upslope into downstream reaches (McIntosh et al. 1994). Such historical comparisons identify restoration needs that otherwise might not be obvious.

Floods and drought can be powerful drivers in stream shape and condition as erosion increases and sediment is deposited. Interestingly, climate change and urbanization alter the timing and intensity of such events. With increased urbanization in one well-studied watershed, the mean annual flood increased from 2,300 cubic feet per second to 3,490 cubic feet per second, and the 10-year flood increased from 7,300 cubic feet per second to 16,000 cubic feet per second (Leopold 1994). With more hardened surfaces in our urban and suburban areas, flood peaks occur sooner and at greater intensities, with significant stress to channel conditions.

Increasing frequency and intensity of flood events is not the only change wrought by urbanization. Stormwater runoff from city streets also carries a toxic brew of pesticides, herbicides, hydrocarbons, and other chemical contaminants. Riparian zones in urban areas often are highly constrained, further reducing the ability of vegetation to filter pollutants.

In the Pacific Northwest, many streams are dynamic and may change in condition every 1–10 years in response to floods and debris flows. Many stream systems are surprisingly well adapted to intense but short-duration disturbances. For example, in the central Oregon Coast Range infrequent stand-replacing wildfires may combine with intense winter rainstorms to produce landslides and debris flows. There may be short-term detrimental impacts such as reduction in food resources and higher sedimentation, but longer-term effects may be positive, with introduction of large wood and rebuilding of pools (Reeves et al. 1995). However, changes in the frequency, magnitude, or duration of such disturbances and the materials they leave behind can alter species composition, habitat features, and resilience of a stream system. Sometimes human activities result in longer-lasting disturbances that may force a system to a different endpoint. For example, roads built across streams may alter hydrology and sediment regimes for decades and may combine with natural disturbances for more severe impacts. The important point from a restoration perspective is to understand the broader context that is driving watershed condition and stream responses.

Choosing the Correct Restoration Approach

A key to successfully restoring streams is to properly understand the objectives of the effort and to use the correct management strategy, particularly with regard to expectations for the watershed in which the stream of interest resides. Recovery of fish populations generally is a primary motivator for undertaking restoration efforts. Expectations for a watershed with regard to recovery and the degree to which it has been modified influence potential courses of action and guide the management direction from restoration to rehabilitation, enhancement, or mitigation (National Research Council 1992). Systems that are currently in good condition and have intact native fish communities are candidates for *protection* rather than restoration. Habitat restoration should never be viewed as a substitute for or confused with habitat protection (Narver 1973, Reeves et al. 1991). There is no guarantee that restoration efforts will be successful, even with the most careful analysis, design, and execution. Preventing initial degradation is more economically and ecologically sound than repairing it, and some damage simply is not reversible. Protecting intact watersheds and streams should be part of any broader management effort.

For slightly altered systems, *restoration* can proceed either as natural restoration or as active restoration (National Research Council 1992). Natural restoration works best in systems that have the suite of key ecological processes intact but are slightly degraded biologically, physically, or chemically. The key is to remove or modify the causes of the degradation. Active restoration involves eliminating activities causing degradation and implementing additional efforts such as wood additions in channels or replanting of riparian zones. The latter efforts are viewed as catalysts that jumpstart the recovery process and are intended to be used only during the initial phases of recovery.

Rehabilitation occurs in systems where natural processes and conditions cannot be reestablished and restoration is not possible (National Research Council 1992). In highly developed urban streams, rehabilitation is the appropriate objective. These systems have diminished capability for developing and maintaining productive habitats and need more human effort and money to provide fish habitat and other beneficial uses. An example of rehabilitation would be continuous additions of wood into streams over time into riparian areas that no longer contain large trees. Rehabilitated watersheds can provide refuges for fish, but they are vulnerable to change and cannot be expected to supply long-term habitat (National Research Council 1992). Addressing the causes of degradation as part of the rehabilitation effort can improve the response of the system.

More degraded streams need extensive efforts to become productive. *Enhancement* is the intentional effort to increase a particular feature of the stream, often developing conditions that are outside the range normally found there (National Research Council 1992). Examples of enhancement include the use of gabions (wire baskets filled with rocks) to collect gravels and create pools and the introduction of wood into meadow streams. Successful enhancement efforts entail an understanding of the operation and behavior of stream systems. The risk of conducting enhancement without this understanding is that the system may shift from one degraded state to another.

Because they generally introduce materials to the system that may not be natural, enhancement efforts require long-term commitments of time, energy, and funding to maintain productivity and generally do not provide a good model for success.

Mitigation may be the primary approach in systems where there is habitat loss with little or no potential to recreate natural conditions. It attempts to minimize or offset the effects of loss of a habitat by creating new habitat, generally in restricted areas, within the system. This may seem straightforward, but it is not (National Research Council 1992). Generally, degradation or loss of habitat results from a suite of factors. Offsetting the loss of a particular habitat type may not mitigate for the loss of ecological processes and connections, and this may limit the potential success of any mitigation effort. Furthermore, evaluations of "new" habitat creation efforts have demonstrated limited success in our efforts to create substitute habitat that possesses the full suite of functions and benefits found in nature (Frissell 1997). Like enhancement, mitigation may entail a long-term commitment to maintain desired conditions.

Assessing Problems and Opportunities

Understanding the ecological context and potential of the watershed is another key to successful restoration. The types of habitats that may be found in a particular watershed and the types and productivity of fish populations are a function of its geomorphic features (Montgomery and Buffington 1997, Burnett et al. 2003). For example, the most productive habitats for coho salmon are low-gradient (less than 2%) watersheds with wide valleys and intermediate-sized streams (Burnett et al. 2003) (Figure 13.4a). The most productive habitats for steelhead, a sea-going rainbow trout, are in steep-gradient (3–5%) intermediate-sized systems with narrow valleys (Burnett et al. 2003) (Figure 13.4b). Prime areas for coho salmon tend to have more pools with slower velocities and large accumulations of gravel. Steelhead habitats have smaller pools with higher velocities. These fish have body forms and behaviors suited for each habitat type (Bisson et al. 1988). Coho salmon are surface oriented, with bodies that are able to maneuver quickly. In contrast, steelhead are more oriented toward the bottom, with large pectoral fins to help them hold position in the current and narrow, laterally compressed bodies.

Working in areas that have the inherent capacity to provide habitat for the fish of interest increases the likelihood that restoration efforts will be successful and maximizes the potential response of the fish. Recognizing the inherent potential of an area to provide habitat for a given species helps identify the types of habitats that can be created, thus increasing the likelihood that a restoration effort will be successful and cost effective (Burnett et al. 2003). It is important to recognize that not every watershed or portion of it can provide favorable conditions for every fish. Every stream system has limits that must be recognized.

Additional insight about identifying priority areas for restoration can be gained by looking at historical conditions or by comparisons to a similar type of stream in unaltered condition. Many systems have been altered so extensively that we have little appreciation for the extent of change or the range of potential restoration opportunities. A good source of information on historical conditions, particularly in the western United States, is the Secretary of War (the forerunner to the Department of Defense) records, which can be found in archives and libraries. These records contain the first surveys of areas and were made by the U.S. government before settlement. These reports offer verbal descriptions of physical and biological conditions and often are accompanied by detailed maps. Early land surveys, historical society photos and records, old aerial photos, and older agency files may contain valuable information on past conditions. It may not be feasible to recreate historic conditions in most restoration efforts, but this information can help develop potential approaches and options that best fit the system.

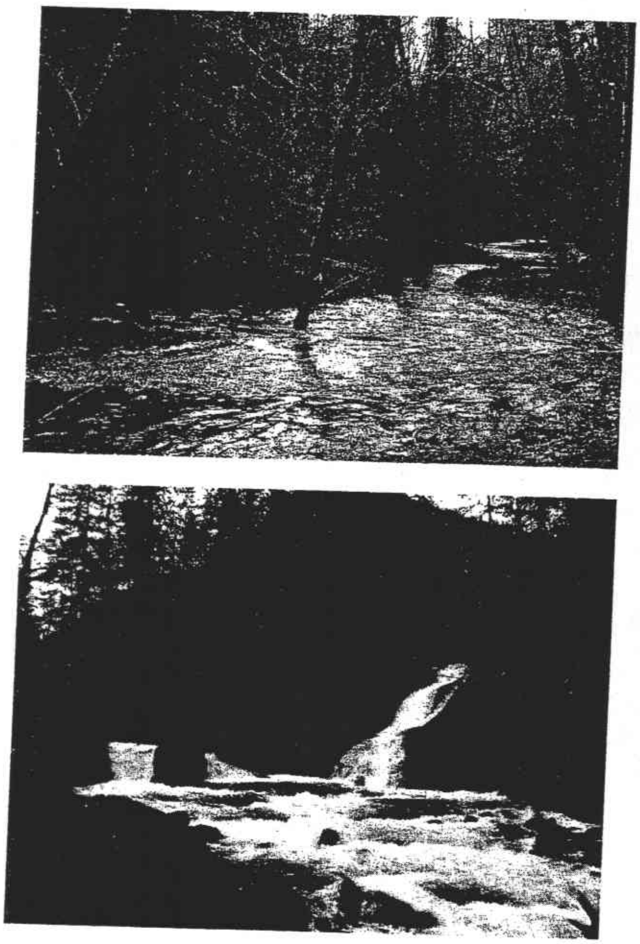

FIGURE 13.4. *Top*, Productive coho salmon habitat is found in low-gradient stream sections (*photo by Jack Williams, Trout Unlimited*). *Bottom*, Productive steelhead trout habitat is found in higher-gradient stream sections (*photo by Kelly Burnett, Pacific Northwest Research Station*).

Identifying the factors that limit the production of fish or the productivity of a given watershed is difficult (Reeves et al. 1991). Myriad factors influence the creation and maintenance of fish habitat, often in complex and little understood ways. Restoration efforts often are based on the best judgment of people most familiar with the watershed or stream of interest. These generally are educated guesses based on experience in and knowledge of the system. The likelihood that this approach will work depends on the people doing the assessment and how well they know and understand the system. Obviously, the better their knowledge and understanding, the more likely it is that they will be able to identify the factor or factors that must be addressed.

Decision support models offer another potential option for better identifying factors that should be addressed in restoration efforts. These models often are used to help determine courses of action when there are multiple factors to consider. They also have been used recently to determine options for managing fish harvests (Mackinson et al. 1999) and to assess environmental conditions (Meesters et al. 1998). Decision support models are being used to evaluate watershed condition as part of the monitoring program for federal lands in the Pacific Northwest of the United States and northern California that are managed under the Northwest Forest Plan (Reeves et al. 2004). These models are built on empirical evidence and, where that is not sufficient, on professional judgment. They also can be constructed to accommodate the variation in inherent conditions between watersheds from different areas. These models allow identification of the factors most responsible for the condition of a watershed or stream reach. These factors then can be prioritized within the restoration framework. Examples of these models can be found at www.reo.gov/monitoring/watershed/AREMP/2004/aremp.htm.

The models can be built collaboratively by interested groups and provide a framework for the group to articulate a common vision and understanding of how the stream or watershed of interest operates. The development of consensus actually may be the real strength of this approach. It fosters a dialogue that can lead to a better understanding and appreciation of different points of view and improved collaboration within a group.

Watershed analysis is another process for identifying features to be addressed in a restoration effort. Watershed analysis has taken many forms since its formal inception in 1993 (FEMAT 1993, Ziemer 1997). On federally managed lands, it is an interdisciplinary effort by physical and biological specialists that identifies, among other things, factors that influence the current condition of a watershed, portions of the watershed that may need activity to prevent or correct degradation, and priority sites where various management activities could occur. The *Federal Guide for Watershed Analysis* (U.S. Department of Agriculture and U.S. Department of the Interior 1995) provides a good description of the watershed analysis process. Like the development of decision support models, this is a collaborative undertaking that can foster communication between individuals and interest groups that, in turn, result in a better understanding of limiting factors and restoration opportunities.

Formal approaches for identifying potential factors that must be addressed in a restoration are limited. One example is a dichotomous key developed by Reeves et al. (1988) that helps identify habitat factors that limit the production of juvenile coho salmon. This approach estimates the amount of given habitats (e.g., spawning, early rearing) needed to maximize density-dependent survival from one life history stage to another. Restoration efforts then determine the type and amount of habitat that should be created. The shortcoming of this approach is that it does not foster an ecosystem perspective.

Long-term success of any restoration effort depends to a large extent on not just correcting habitat problems but addressing the causes of degradation. Factors or processes in one part of a watershed may be responsible for the condition in another. For example, pool numbers may decline because of increased sedimentation. Creating new pools may prove futile unless the sources of sediment are identified and corrected. In other cases, restoration may entail action in a part of the watershed away from where the symptoms of the problem are most obvious. For example, stream temperature may be high in a portion of stream that is important to fish. If the stream is large, improving riparian shade in the immediate vicinity may not solve the problem because the influence of riparian shade is minor on larger streams. The best solution in such a case would be to examine the area higher in the watershed or in tributaries that enter the segment of interest to locate the source of warm water and try to reduce water temperatures there so that cooler water is delivered to the reach of interest. Similarly, changing chemical practices on agricultural lands and addressing stormwater management issues are the only ways to resolve downstream water quality problems traceable to these sources of chemical contamination. Considering the watershed as a whole and the relationships between its pieces are important for a successful restoration effort.

Planning a Stream Restoration Project

The National Research Council (1992) provides a straightforward template to planning stream restoration projects and provides a more detailed discussion of what is summarized here. Stream restoration planning should begin with a careful analysis of the problem to be treated and an understanding of the broader watershed context in which the stream occurs. As described earlier, watershed analysis is a good tool for understanding appropriate restoration needs. Once the problem is understood clearly, the project's goal and objectives should be developed. Typical goals might include restoring water quality, channel condition, or flow regimes or might relate to restoring steelhead trout or other components of the biotic community. Objectives detail more specific components that must be addressed to reach the goals. For example, to restore water quality, objectives might include reducing stream temperature, reducing sediment input, and achieving other specific characteristics of water quality. Objectives for channel condition might include reestablishing deep pools or spawning beds. At some point, quantifiable performance indicators must be developed for each objective. Thus, the number of deep pools per stream reach and depth of pools should be determined as a part of the relevant objective. For reestablishment of spawning beds, a performance indicator might be the presence of five riffles with at least 30% substrates in gravel. These quantifiable measures are critical in effectiveness monitoring and in being able to evaluate the ultimate success of the project. A monitoring program should be an integral part of any restoration effort.

Stream Restoration Techniques

Riparian areas are critical to the health and integrity of stream systems and often are an appropriate place to start in stream restoration efforts (see Chapter 6). Riparian areas provide many benefits to streams. If sufficient riparian vegetation is present along streams, the riparian areas will provide shade to cool stream temperature, serve as a source of woody material into stream channels, filter large quantities of fine sediment from upland erosion, and provide an important source of nutrients in the form of leaves and smaller woody material. Guidelines for federal land management in the Pacific Northwest call for riparian buffer zones of 300 feet on each side of fish-bearing streams (FEMAT 1993). For private lands, establishing riparian buffer zones 100 feet wide on each side of streams is a good starting point for balancing ecological and social imperatives, but steepness of slope away from streams, unstable soils, and increased intensity of nearby human activity all are important factors that could necessitate wider riparian buffer zones.

Riparian protection zones provide space for stream meandering, buffer the impacts of upslope management activities, and facilitate vegetative growth that will shade streams and help filter out sediment. Buffers along small streams, even intermittent streams, are critical because these channels often greatly influence water quality and provide critical pathways for wood and sediment into larger, fish-bearing streams. Certain activities such as extensive tree harvest, removal of large trees, road building, and livestock grazing should be excluded from riparian buffers.

Another critical component of healthy stream systems is habitat diversity and patchiness. Streams with diverse habitat types, deep and shallow pools, pocket pools behind boulders, riffles, and runs provide a variety of physical habitats that in turn support diverse species and life history stages of fishes and macroinvertebrates. Many degraded streams lack this habitat diversity as silt has filled pools and channelization has eliminated riffles and structural diversity (Williams and Williams 2004). Habitat diversity often can be restored through reintroduction of large wood pieces and boulders and removal of hardened stream banks and berms, allowing streams to begin natural meanders.

Many stream restoration projects consist of placing logs, tree stumps, and boulders into stream channels in an effort to create pools and diversify habitats. The importance of large wood, boulders, and other instream structures relates to their ability to control routing of water and sediment, shape pools and riffles, and serve as a substrate for macroinvertebrates (Naiman et al. 1992). The amount of large wood needed in streams to meet proper functioning condition can be substantial. An analysis from reference streams in western Washington yielded the following large wood targets based on stream width classes to achieve a "good" rating (large wood is defined as greater than 10 centimeters in diameter and 2 meters in length): Streams 0–6 meters in bank full width need more than 38 pieces, streams 6–30 meters wide need more than 63 pieces, and streams 30–100 meters wide need more than 208 pieces (Fox et al. 2003). For forested streams east of the Cascade crest, the U.S. Forest Service and Bureau of Land Management established objectives for large wood of at least thirty-two pieces more than 10 meters long per kilometer (U.S. Forest Service and U.S. Bureau of Land Management 1994).

In some restoration projects, boulders, stumps, and logs have been placed into streams and anchored with cables for good long-term success (Schetterling and Pierce 1999). In other projects, high flows and unstable banks have undermined anchored wood pieces, resulting in the tearing away of cabled materials during peak flows and creation of new erosion problems (Frissell and Nawa 1992). The importance of understanding the broader watershed context of stream restoration work is evident. Cabled structures are more likely to fail in wider, Rosgen C channel types, which meander more and have a larger floodplain, than in B channel types that are more confined by valley walls (Schetterling and Pierce 1999). In the long run it may be more satisfactory to simply place boulders, stumps, and logs loosely into stream channels or along stream banks in riparian areas and let higher stream flows distribute them naturally. In general, we favor working with the forces of flow, erosion, and deposition inherent in particular stream systems. In this way, we can capitalize on the natural healing capacity of streams and allow the river to do most of the work.

In some cases, a compromise may be needed between the desire to let a stream meander naturally and the need to protect a particular site from erosion. Riprap and other hardened bank techniques are undesirable because they decrease habitat quality for fish and other species, and they may deflect erosion forces further downstream, creating additional concerns. An alternative that may be worth examining is the use of long-line cabled logs that are placed in slack water along eroding banks so that they remain floating during high flows (Nichols and Sprague 2003). The cabled logs will capture additional wood and debris during high flows and help stabilize erosion while improving habitat conditions.

Large amounts of fine sediment in stream substrates are a common concern for fishery biologists and land managers. Amounts of fine materials (clay, silt, and sand) exceeding 20% of stream substrates result in increased embeddedness and loss of interstitial space between gravels and cobble. The loss of this space diminishes the habitat for many aquatic insects, degrades spawning habitat, and reduces egg survival. Fine materials come from many sources, including row crop agriculture, livestock grazing, mining, timber harvest, road construction, and urban development. Many of the preferred methods to reduce the input of fine materials involve modifications to the upslope activities that cause the erosion in the first place and are summarized in Waters (1995). As discussed earlier, vegetation in riparian zones helps filter out silt and sediment before they enter streams. Once the causes of sediment production have been reduced, flushing or pulse flows may be needed to distribute fine sediments to channel margins or downstream and out of the system. In some situations, instream structures can be installed to increase current velocity and scour certain stream segments favorable to fish production (Waters 1995).

Bridges, culverts, and other stream crossings modify hydrologic processes by restricting flows and sediments and alter movement of fish and other stream biota. Stream crossings result in direct loss of instream and riparian habitat. Poorly designed or undersized culverts may impede fish by creating vertical barriers or velocity barriers. In addition, culverts and other water crossings pose a risk to downstream habitat if structural failure occurs during high flows. For all these reasons, stream crossings provide many restoration opportunities. Common restoration work may reengineer placement of the culverts, install larger culverts, or install baffles in the culverts to provide more suitable flows for fish passage. Ideally, circular culverts are replaced with bridges or bottomless archway culverts that retain natural stream substrates. The Washington Department of Fish and Wildlife provides a useful handbook for proper design of road culverts that is available online (Washington Department of Fish and Wildlife 2003). When designing fish passage through road crossings it is important to consider flow variation and its impact on movement of the full range of native fishes, juveniles and adults, and macroinvertebrates present in the system. A properly designed stream crossing does not impede any species or substrate.

Many thousands of dams and diversions exist in the Pacific Northwest and are the single leading cause of stream degradation and loss of fisheries (Collier et al. 1996). Although many dams provide important economic and social benefits, for others cost–benefit analyses indicate that removal should be considered. Like any constructed feature, dams have finite lifetimes and costs associated with their safety or maintenance that may present opportunities for removal. In some cases, pumps or other technologies that do not entail complete stream blockage can provide the service that a dam provides, such as irrigation water diversion. This would address concerns with fish passage but not flow problems. In other cases, the benefit accruing from the diversion may be so minimal that acquisition of the water right and conversion to an instream right is feasible. Numerous case studies of dam removal in the Pacific Northwest, including Jackson Street Dam and Marie Doran Dam in Oregon, four dams along Butte Creek in California, and the Rat Lake Dam in Washington, detail successful stream restoration efforts. At least 177 dams were removed in the 1990s in the United States (Friends of the Earth et al. 1999). Several excellent information sources exist on the various costs and benefits associated with maintaining or removing dams and the numerous environmental concerns related to either choice (River Alliance of Wisconsin and Trout Unlimited 2000, American Rivers and Trout Unlimited 2002).

Case Study: Restoring Large Wood Structure in Tenmile Creek

Addition of large wood to stream channels is one of the most common components of habitat restoration efforts. Large wood is an important element of good habitat and provides structure for scouring pools, storing and sorting gravel, and retaining organic material that forms the energy base for organisms that are eaten by fish. Many streams currently lack large wood because of past activities that removed instream structure or because of the harvest of trees from riparian areas.

Tenmile Creek, on the central Oregon coast, was the site of a major restoration effort that began in 1996 and was undertaken by local landowners, the Oregon Department of Fisheries and Wildlife, Siuslaw National Forest, and the National Audubon Society. The stream had been affected by activities such as channel clearing during initial settlement and by more recent activities, primarily timber harvest. Surveys conducted at the start of the restoration program found that the amount of large wood was low, only 4–33% of that found in a reference stream in a nearby wilderness area. The consequence was that large, deep complex pools were lacking in Tenmile Creek, and the stream channel was isolated from the floodplain in many sections.

A total of 240 pieces of large wood were added to fifty-four locations in the channel. Two hundred of the pieces were whole trees, including branches (31-inch butt diameter and 110 feet long). The remainder were primarily root wads. Whole trees were taken from adjacent ridges, away from the stream. The other pieces were taken from landslide deposits high in the watershed. All wood was moved with a helicopter and was placed in clusters of three to eight pieces in lower-gradient portions of the network, near the upper or lower entrance to old side channels or in natural bends where wood naturally accumulates (Figure 13.5). Some pieces were wedged between live trees in the riparian zone to increase stability, but the majority were not cabled or attached so that they could move downstream and settle in areas where they could provide the most benefit. Allowing natural wood

Figure 13.5. Large wood restoration in a coastal Oregon stream. Log jams were placed where they could increase the stream's connections with its floodplain during moderate stream flow. *(Photo by Jack Sleeper, Siuslaw National Forest)*

movement is preferred, but in situations where such movement is undesirable, pieces can be cabled together or attached to streamside trees. Cost for the wood placement in Tenmile Creek was $140,000, about 3% of the total project costs.

Wood placement increased the number of pools deeper than 3 feet in the summer and the amount of side channel area available in winter, important rearing habitat for juvenile salmonids (Figure 13.6). The abundance of steelhead smolts and the freshwater survival of coho salmon and steelhead increased in Tenmile Creek after wood placement.

The other components of the restoration effort in Tenmile Creek contributed to the success of the wood placement. Roads were realigned and stabilized, which allowed the stream to move onto floodplains. Riparian zones that were in poor condition were planted with conifers or thinned where conifers were present but showed poor growth. The comprehensive nature of this effort was the key to its success.

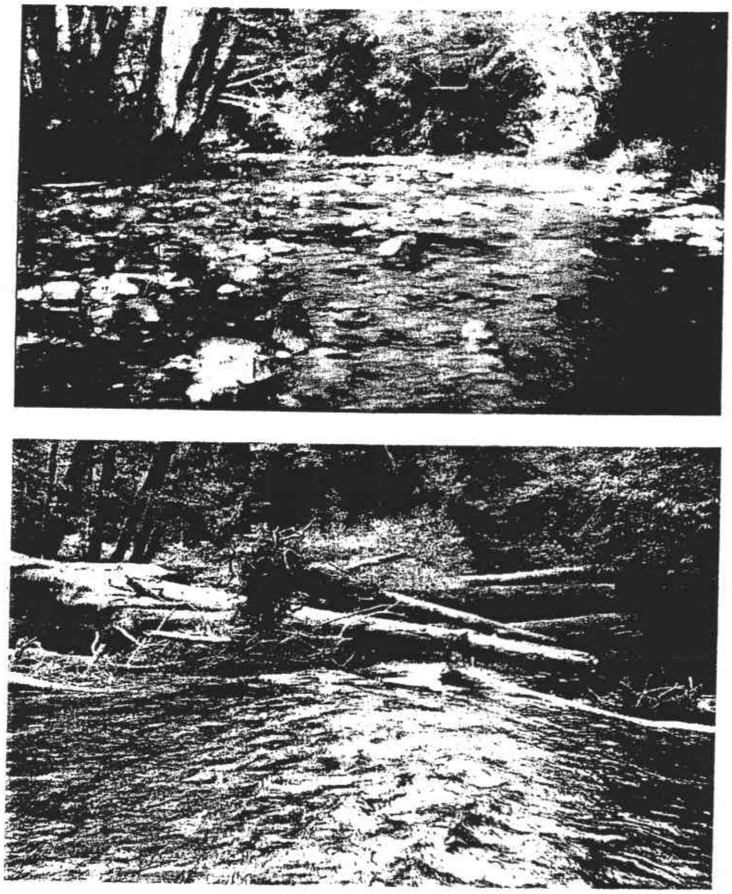

FIGURE 13.6. Habitat conditions in Tenmile Creek *(a)* before and *(b)* after the addition of large wood. *(Photos by Jack Sleeper, Siuslaw National Forest)*

Rehabilitating Urban Streams

Urban streams present some of the most important but challenging restoration opportunities. Although urban lands make up less than 2% of the land base in the Pacific Northwest (Pease 1993), they have a disproportionately large influence on fisheries because their valley bottom locations historically were occupied by complex, braided-channel stream systems. Such areas were very important for rearing juvenile salmon, providing cold water refuges for adults, and facilitating migration. Urban stream systems present a formidable challenge to land managers because they have been so dramatically altered. Because of the extent of this alteration and infeasibility of returning these systems to historic conditions, it typically is more appropriate to speak of rehabilitating urban streams rather than achieving full restoration.

Urban streams typically are affected by stream channelization and loss of instream habitat, changes in hydrologic regimes, pollution, and loss of riparian habitat. Urban areas have higher densities of roads and more parking lots, rooftops, and other impermeable surfaces and often are characterized by extremely constructed floodplains. This means that rains run off more quickly, often carrying pollutants such as hydrocarbons, phosphorus, insecticides, and heavy metals. In some urbanized Puget Sound streams, for example, what used to be a 10-year flood event before urbanization now occurs every 1 to 4 years (Moscrip and Montgomery 1997). Although such changes have profound impacts on hydrologic regimes and macroinvertebrate and fish communities, there have been several recent case studies of successful urban stream rehabilitation (Fresh and Lucchetti 2000, Konrad 2003).

The first step in restoring urban streams is properly diagnosing problems and identifying their causal factors. Rehabilitation projects should be designed to address as many of these causal factors as possible. Often, problems include degraded instream habitat, loss of riparian habitat, reduced water quality, and altered flows. Although rehabilitation of urban streams may be a compromise between social constraint and ecological need, watershed-scale analysis, application of scientific principles, monitoring, and adaptive management will benefit those working in urban zones as much as it benefits those focusing on wild areas.

Perhaps because of the extent of modifications, incremental improvements to almost any urban streams are achievable. However, restoration of natural flows in urban streams is difficult because of the extent of development in the watershed and construction on the floodplain. Recreating wetlands and constructing sedimentation basins and stormwater retention systems are effective in slowing down urban runoff (Konrad 2003). Stream habitats in urban areas often are channelized and lack the structural diversity found in more natural environments. Pool habitats often are lacking. Efforts to slow flows in higher-gradient (more than 2%) streams can be achieved by reintroducing boulders and large wood that reduce flows and recreate pool conditions. Riprap and concrete stream banks should be removed when practical. One of the most effective rehabilitation techniques is to provide a protected riparian buffer and reestablish streamside vegetation. If riparian areas cannot be widened, removing riprap and concrete and replacing them with woven mats and other materials that will protect soils from erosion but still allow planting and revegetation of stream banks will aid rehabilitation of urban streams.

Commercially produced polyethylene grids (known by trade name Geoweb) are available in 8- by 4-foot sections with 8-inch honeycomb cells that can be anchored in place, filled with substrate, and planted (Hunt 1993). Revegetating with native plants should be emphasized. Nonnative plants, including Himalayan blackberries, purple loosestrife, and reed canary grass, should be controlled because they often are detrimental to native wildlife and overtake native plant species. Typical impacts to urban streams and appropriate rehabilitation measures are described in Table 13.2.

TABLE 13.2.

Common problems in urban streams and appropriate rehabilitation responses.

Modification	Resulting Impact	Rehabilitation Techniques
Channelization and filling of instream habitat	Loss of instream habitat; loss of instream structure and habitat diversity	Where practical, remove hardened stream bank material and widen channel.
Channelization and lack of stream meandering	Loss of gravel bars and spawning habitat	Where practical, remove hardened stream bank or introduce spawning gravels.
Dams, diversions, and instream blockages	Impeded movement of fish, invertebrates, and stream substrates; altered flow regimes	Replace dams and diversions with pumps or install fish ladders if blockage cannot be removed.
Increased pavement and other impermeable surfaces	Increased runoff; increased intensity and frequency of floods	Construct sediment basins to slow inflow; increase channel width, culvert size, and other stream crossings to accommodate higher flows.
Loss of riparian habitat and streamside vegetation	Increased erosion; increased water temperature; substrates >20% fine materials	Provide undisturbed riparian buffers; replant native vegetation along streams; introduce wood and boulders into streams.
Increased pollution from streets and industrial sources	Reduced water quality and impaired fish and macroinvertebrate communities	Install bioswales and sedimentation basins to reduce runoff; treat inflows; educate public about need to reduce polluted runoff.

Case Study: Removing a Small Irrigation Dam in Bear Creek

Thousands of small, older dams impede fish movement, degrade water quality, and alter temperature and sediment regimes in streams across the West. Some of these dams have been torn down as they became unsafe or obsolete. In recent years, the need to restore streams and rehabilitate fisheries has provided additional incentives for dam removal.

Breaching of the Jackson Street Dam, a small irrigation diversion dam on Bear Creek in southwestern Oregon, provides a case study of dam removal for the purpose of restoring natural stream conditions and anadromous fish passage while maintaining the initial purposes of the dam (Smith et al. 2000). The dam was constructed in downtown Medford in 1960 to divert water from Bear Creek into irrigation canals operated by the Rogue River Valley Irrigation District. The dam consisted of an 8-foot-high concrete structure that was raised another 3 feet with the addition of stoplogs during irrigation season. When full, the 11-foot-high structure created a 2-acre reservoir. Over time, sediment had filled the reservoir to the top of the 8-foot concrete dam level.

Despite its location in the middle of a growing urban zone, steelhead, coho salmon, chinook salmon, and Pacific lamprey all ascend Bear Creek from the Rogue River to spawn. A fish ladder existed on the dam, but it was constructed on the opposite side of the channel from the main flow, creating a near total blockage of adult fish moving upstream under certain flows (Smith et al. 2000). In addition to fish passage problems, the Jackson Creek Dam contributed to poor water quality in Bear Creek, where high water temperature is a chronic summer problem. The dam and silt-filled reservoir also were considered an eyesore in downtown Medford (Smith et al. 2000).

In the 1980s, there was broad community consensus that removing or breaching the dam was in the community's best interest, but there also was recognition that any such project should incorporate an alternative that would provide irrigation water to surrounding agricultural lands. In 1985, the Rogue Valley Council of Governments approached the irrigation district about conducting a feasibility study to remove the dam. The irrigation district agreed to a study provided that the district could still obtain irrigation water, would not have to pay for dam removal, and would not have to pay higher maintenance costs for its irrigation system. The feasibility study, completed in 1987, found that removing the dam would improve water quality and restore stream habitat but also would entail relocation of a buried fiber optic cable, which would add $350,000 to the cost of the project. Instead of a total removal, project cooperators opted to breach the dam and retain 3 feet of the foundation in order to protect the fiber optic cable. Breaching reduced the dam to a series of three 1-foot drops. A new, 3-foot-high irrigation diversion was proposed nearby, with an effective fish passage structure for adults and a rotary screen to prevent loss of juvenile fish. The new structure would be removed from October through April (nonirrigation season), preventing buildup of sediment. An underground pipeline also was needed from the new diversion to the existing irrigation delivery system. The feasibility study estimated a cost of $500,000 for breaching the old dam, creating the new seasonal diversion with appropriate fish passage and screens, and connecting the new diversion to the existing irrigation delivery system. Ultimately, the cost reached $1.2 million to address all environmental, irrigation, operational, and engineering requirements. The new 3-foot diversion, consisting of collapsible steel supports, wooden stoplogs, fish screens, and fish passage facilities, was completed in 1995. The Jackson Street Dam was breached in 1998 after the creek was diverted around the dam to provide a dry workplace.

Thirteen years elapsed from initial proposal of the feasibility study to completion of the project. Twenty major stakeholders were involved, including five local government agencies, the irrigation district, the local watershed council, seven state agencies, two federal agencies, the project contractor, and local partners. Smith et al. (2000) provided the following lessons learned from efforts to remove the Jackson Street Dam:

- Select candidate dams whose functions can be accomplished by alternative means.
- Identify objectives for the stream and determine how removal of the dam can contribute to their accomplishment.
- Identify a project champion who will lead the effort.
- Identify all potential stakeholders, often a longer list than first anticipated.

- Obtain informal agreement to the project individually from each stakeholder.
- Strive to understand all stakeholder perspectives.
- Implement a public education campaign about the project that is supported by all stakeholders.
- Seek support for the project from elected officials.
- Develop a detailed project budget, including feasibility study and engineering estimates.
- Ensure that all stakeholders understand that the project will take time, effort, and money and that unexpected complications are likely to arise.

Monitoring and Evaluating Stream Restoration

Monitoring and evaluation determine the effectiveness of restoration efforts, suggest appropriate modifications to future restoration actions, help ensure the best results for restoration dollars, and communicate results to interested parties. Despite their importance, monitoring and evaluation often are overlooked, in part because streams pose some unique problems and opportunities that can confound efforts to design an appropriate monitoring program.

Special considerations in stream monitoring include seasonal and annual variability in streams, caused by changes in flows and weather, and natural variability in fish populations, which often are the target of stream restoration efforts. Monitoring the response of salmon or steelhead or other migratory fishes may take a long time because of the 2- to 5-year return interval, depending on life history of the species in question. For instance, it may take more than 15 years of monitoring to gauge the response of three fish generations to restoration work. Another special consideration in streams is whether to focus monitoring at the level of the stream reach or watershed scale (Roni et al. 2003).

Monitoring the effectiveness of physical habitat changes, such as reductions in stream temperature or increases in pool frequency, is easier than determining success of desired increases in fish populations or other biological changes. Clearly, the inherent complexity of many streams and aquatic communities necessitates careful planning for monitoring information to be useful.

Monitoring must be designed to detect changes and be able to distinguish the effects of restoration treatments from other sources of variability. This may entail comparison of treated areas with control areas (i.e., areas without restoration efforts) and the collection of multiple samples across broader watershed areas or over longer time periods. Kershner (1997) provides some good examples of monitoring programs in stream settings. Each example includes the following elements:

- A concise goal statement for the restoration project
- Detailed objectives of the restoration treatments
- Implementation monitoring to determine whether the restoration treatments were implemented as planned
- Identification of control stream reaches that are not influenced by restoration activity

- Repeated measurements of treatment and control areas to determine effectiveness of restoration
- Analysis of monitoring results

Collecting monitoring information without proper analysis and reporting on the analysis to interested parties amounts to wasted effort. The concept of adaptive management is central to working in complex and naturally variable ecosystems. Successful adaptive management depends on sound monitoring and proper use of monitoring results to inform future restoration and management. Most problems in stream restoration can be attributed to failures to understand the watershed context of the problem, failure to understand and treat the root causes of degradation, or failure to adequately monitor and adapt management accordingly (Williams et al. 1997).

Stream restoration is a long-term investment in understanding a watershed. Observing streams during periods of high and low flow can inform the astute restoration practitioner. Streams that appear small and tame during times of drought may overflow their banks during spring runoff. Accelerated erosion and sources of siltation may be visible only during high flows. What are stressors in periods of high flows may not be noticeable at other times. Viewing restoration actions over sufficiently long time periods that include drought and flood may be necessary before success or failure can be determined. Merely understanding the variability of stream systems may not be sufficient to ensure success. Successful restoration will embrace variability, complement natural recovery, and work with changing flow regimes. By patiently observing the complex stream ecosystem, we may learn what restoration practices work best and why.

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Resources on the Web

Many agencies and organizations maintain valuable Web sites on stream restoration techniques. The following sites maintain a long list of useful references that are linked for quick access.

Links to various publications and reference materials on stream restoration provided by California Department of Water Resources: www.watershedrestoration.water.ca.gov/urbanstreams/reference/bibliography.cfm.

Links to various stream restoration manuals and case studies from throughout the Pacific Northwest: wildfish.montana.edu/resources/manuals.asp.

Trout Unlimited maintains a Web site about small dam removal, including case studies and a citizens' guide: www.tu.org/small_dams.

Recommended Books

Montgomery, D. B., S. Bolton, D. B. Booth, and L. Wall, eds. 2003. *Restoration of Puget Sound Rivers*. University of Washington Press, Seattle. Eighteen chapters on salmon recovery, fluvial processes, floodplain forests, instream wood, urban issues, and monitoring. Available at www.washington.edu/uwpress or by calling (800) 441-4115.

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Williams, J. E., C. A. Wood, and M. P. Dombeck, eds. 1997. *Watershed Restoration: Principles and Practices*. American Fisheries Society, Bethesda, MD. Ecological principles and numerous case studies of what works and what does not for watershed-scale restoration, with an emphasis on stream systems. Available at www.fisheries .org or by calling (678) 366-1141.