**STREAM HABITAT RESTORATION GUIDELINES**
**CHAPTER 4**

# DEVELOPING A RESTORATION STRATEGY

The term "restoration" is often used loosely to refer to any project that strives to improve habitat conditions or re-create specific habitat features. However, the actual definition of the term is much narrower and involves bringing something back to its previous condition[1]. The condition of a stream at any given time is a reflection of current and past events and activities occurring within its watershed. As such, stream ecosystems are dynamic in space and time. Long-term restoration of stream ecosystems requires consideration of how past, current, and future events and activities have and will continue to influence their structure and function.

The processes that shape and create habitat (refer to Chapter 2 of this guideline entitled *Stream Processes and Habitat*) act as a form of natural disturbance to the system. Disturbance can come in a rare catastrophic event, such as a volcanic eruption, or in a more predictable pattern, such as the input of fine sediment by surface erosion off a steep hill slope. Disturbance may be from daily or seasonal events to events that happen on a geologic time scale. Spatially, disturbance may operate on a local scale, impacting an individual pool, or on a larger reach or watershed scale. Habitat complexity is a result of interactions between natural disturbance events and natural succession. Regular disturbance sustains a dynamic network of habitat that is spatially diverse. Considering the dynamic nature of the stream environment, these guidelines echo the recommendations of numerous other researchers[2 3 4 5] when suggesting that stream ecosystem restoration activities focus less on recreating and maintaining specific instream habitat forms, and more on reestablishing the processes responsible for creating and maintaining natural patterns of habitat diversity. Restoration should strive to provide sustainable long-term benefits to the stream ecosystem, not just a target species, by addressing the cause(s) of habitat degradation and by supporting natural succession and disturbance regimes, which, in turn, support long-term habitat and biological diversity[1 6].

Although the ultimate goal of restoration is to return an ecosystem to a close approximation of its pre-disturbance condition, existing infrastructure, invasive species, limited native species abundance and extinction, and past and current land use may prevent full ecosystem recovery from being achieved. In such systems, rehabilitation (returning the system, or a fraction of the system, to a state of ecological productivity and useful structure, but not necessarily its pre-disturbance condition[7]) or enhancement (an improvement in habitat structure or function) may be the only achievable goals. Rehabilitation generally consists of restoring select ecosystem functions and characteristics (e.g., water quality) in order to support a "potential natural community" that can be accommodated within the given land use and ecosystem constraints. Its priority should be to establish a self-sustaining ecosystem that is resilient in its recovery response to its disturbance regime, rather than one that will require repeat intervention by humans. Enhancement, on the other hand, typically involves manipulation of habitat at a relatively small, microhabitat scale, such as an individual pool, riffle, or an isolated reach. As a result, enhancement achieves lesser benefits for the overall ecosystem, unless it happens to address the most significant feature to have been degraded and the principle cause of its degradation [8]. When conducted without adequate consideration and knowledge of watershed and ecosystem processes and conditions, any measure (whether intended to provide restoration, rehabilitation, or enhancement) will be prone to failure, providing only short-term benefits, and having unintended adverse effects [4 8 9].

### *4.1 A Coordinated Strategy*

Restoration of the structure and function of stream ecosystems requires a coordinated and comprehensive strategy to reestablish and preserve the natural rates of physical, chemical, and biological processes and interactions that have been compromised by human activities. The reason for this is two-fold. First, aquatic and upland ecosystems are interconnected and interactive; the range for individuals of certain migratory species, such as ducks and whales, extends across entire continents. And second, the condition of wetlands, lakes, or streams reflects the cumulative effects of activities and events within their watersheds. As a result, ecosystem recovery efforts will be most effective when implemented on a scale that encompasses the entire range of affected species and the extent of activities that have led to their decline. The restoration strategy should take into account cumulative impacts to habitat abundance, quality, connectivity, and diversity on a watershed or other landscape scale appropriate to the affected plant and animal species. Individual projects must be considered within the context of the overall restoration strategy to ensure their incremental gains will collectively achieve restoration goals.

The following steps are suggested for inclusion in any stream habitat restoration strategy. They are a compilation of key aspects described by the National Research Council, Federal Interagency Advisory Group[10], and Hobbs and Norton[11] (cited by Roper et al.). Select steps are further described in succeeding sections of this chapter.

1. Form an advisory group.
2. Define the problems and deficiencies within the watershed, stream network, or other appropriate landscape unit and identify their root cause(s).
3. Define and prioritize realistic restoration goals and objectives.
4. Develop performance indicators to measure the success of the restoration program.
5. Develop a monitoring program to accurately and reliably measure performance indicators (refer to the *Monitoring Considerations* appendix).
6. Identify, prioritize, and implement tasks or techniques to achieve restoration goals and objectives.
7. Monitor performance indicators to determine progress towards meeting restoration goals and objectives.
8. Modify the restoration strategy, as necessary, to better meet goals and objectives.
9. Document and communicate successes, failures, and lessons learned so others may benefit from the knowledge and implement better projects.

### *4.2 Defining the Problem and Identifying Its Cause*

One of the first steps in the process of habitat restoration is to define the problem and the biological consequences of that problem. Habitat deficiencies may be expressed as a decline in the quantity or quality of specific types of habitat, a decline in habitat diversity, or as an accelerated rate of change. Habitat deficiencies are often revealed by their biological response. For instance, a decline in species' productivity, range, health, or population abundance is typically the driver for identifying whether or not habitat deficiencies exist within a watershed or ecosystem. Investigation into the nature and extent of habitat deficiencies may also be triggered by observed changes in the physical or chemical characteristics of habitat at a specific location (e.g., a change in channel bedform, characteristic size of streambed material, temperature, or dissolved oxygen level within a particular reach) or by perceived changes in stream or watershed stability (e.g., channel incision, aggradation, or migration rates; mass wasting occurrences in the watershed). As stream habitat is dynamic in space and time, even under pristine conditions, it is necessary to consider historic as well as current habitat conditions in order to draw conclusions with regards to the degree of change over time and whether the rate of change has accelerated, decelerated, or remained constant. One must also consider individual sites within the context of the overall ecosystem to determine if there is an actual net decline in the abundance of a specific habitat type (e.g., the number of acres of side channel habitat in a specific river system declined 85% in the last 50 years) or if the loss of an individual site has been offset by the creation of another (e.g., during a flood event, one side channel filled with sediment while another was formed).

Once the nature and extent of habitat degradation within an ecosystem has been clearly defined, the next step in the process is to identify the root cause(s) of degradation in order to develop a long-term solution. Rehabilitation measures that treat only the symptom of the problem and not the cause will provide only short-term benefit and will likely need to be repeated periodically to provide continued benefit in the long-term. Unfortunately, cause and effect relationships in stream environments can be extremely complex and are often difficult to define with certainty. A single habitat problem often has multiple causes, thereby confounding explanation. For example, stream incision may be due to an increase in the magnitude and frequency of peak flow events, a reduction in sediment supply, or a steepening of channel slope. And each cause or mechanism of habitat degradation may be attributed to a series of activities occurring with the watershed (urbanization, timber harvest, dam building). Similarly, a single activity can trigger a variety of channel responses. For example, channel straightening may cause a channel to incise or aggrade, depending upon the circumstances. Identification of activities and events that lead to a decline in habitat abundance, quality, stability, or diversity generally requires a thorough watershed assessment (refer to Chapter 3 of this guideline entitled *Stream Habitat Assessment*), unless the cause can be absolutely attributed to a specific activity on a more local scale.

The cause of habitat deficiencies may be related to site-, reach-, or watershed-scale activities or events. Understanding the spatial extent of habitat deficiencies can often help identify whether causes are site-specific or systemic. Site and reach scale problems may have similar causes, but the extent of their impacts differ. For instance, the impact of removing one log from the stream may be limited to the loss of one pool. However, removal of all wood from a four mile reach of stream may significantly reduce cover, pool habitat, invertebrate populations, and overall habitat diversity; reduce the quality and alter the gravel size distribution of salmonid spawning beds; and cause channel incision or aggradation due to a reduction in channel roughness and scour mechanisms. These effects may extend upstream and downstream of the wood removal site.

Stream habitat degradation may be caused by:

- Direct physical modification of the stream corridor;
- Changes in channel boundary conditions upstream, downstream, or laterally;
- Physical constraints placed on natural channel adjustment; or
- Changes in watershed management or land uses.

Direct physical modification of the stream corridor includes, but is not limited to, such activities as deliberate alteration of a channel's planform (e.g., straightening), cross-section (e.g., widening), profile (e.g., dredging, gravel mining), or roughness (e.g., removal or addition of wood, rock, vegetation, or other instream roughness elements, armoring of the stream bed or banks). It may also include removal or modification of riparian vegetation or filling of off-channel habitats. Although direct modification of the channel may be limited to a particular site or reach, the impact may extend upstream, downstream, or laterally by changing boundary conditions.

The conditions of a particular site may be affected by changes to its boundary conditions; that is, changes that occur upstream, downstream, or otherwise outside the site. For instance, a stream reach may down cut (vertically incise) in response to downstream dredging or gravel extraction operations. Other examples of boundary condition changes that impact a particular stream reach include modification or removal of riparian vegetation and levee construction. Although these changes occur outside the stream channel, they influence its bed and bank stability, channel form, water quality, water depth, bed material, and other habitat characteristics.

Physical constraints placed on natural channel adjustment include any structure that limits the natural migration and adjustment of a river system, either laterally through bank erosion or vertically through scour and deposition. Such structures will likely reduce habitat diversity and connectivity, wood and sediment recruitment, and initiate adjustments to the channel planform, cross-section, or profile upstream and downstream. Constraints may occur as a result of bank armoring, grade control, or similar structures.

Land use affects habitat structure, function, and availability by altering or disrupting the processes that create, connect, and maintain habitat. These processes include the supply and transport of water, sediment, solutes (including contaminants, nutrients, dissolved oxygen), energy (i.e., light and heat), and organic material (ranging from large wood to detritus) to the stream, floodplain, and riparian corridor. Watershed-scale causes of stream habitat degradation or loss may not be as obvious as reach- or site-scale causes. They may, therefore, be more difficult to link directly to habitat problems and more challenging to remedy.

The reader should note that, in some cases, land use activities might not yet have manifested themselves in a habitat or biological response as a result of their relatively small scale or recent occurrence. However, an increase in the extent or longevity of the activity, or the occurrence of a flood or other natural disturbance event may trigger a system response. Implementing responsible land management now, instead of waiting until a problem develops, will minimize threats to ecosystem decline and protect healthy high quality habitat.

### *4.3 Development and Prioritization of Ecosystem Recovery Goals, Objectives, and Activities*

Once the activities and events that have led to ecosystem decline have been identified, the next step is to develop a set of realistic goals and objectives to reverse or mitigate for the decline. The term realistic is emphasized here in recognition that past, current and future land use, water rights, species extinction, the presence of exotic species, and other factors may place physical, biological, or societal constraints on the outcome of ecosystem recovery efforts. The distinction between goals and objectives is subtle. Both define the purpose toward which restoration endeavors are directed. However, goals and objectives are generally considered to be hierarchal with goals being the most broad-based and over-arching of the two. Goals may be, for instance, to restore water quality or reduce the excessive sediment supply to the stream to a more natural rate. Objectives support and refine these goals, breaking them down into smaller steps. Objectives may define, for instance, which particular water quality parameters are to be targeted (e.g., temperature, turbidity, dissolved oxygen, fecal coliform), or which sediment supply processes are primarily responsible for excessive sediment loading to the stream (e.g., road-related mass wasting events, clear-cut-related mass wasting events, surface erosion off agricultural fields).

Most Washington watersheds and streams have been significantly modified and often suffer from channel instability and multiple habitat deficiencies. Because of limited resources, goals and objectives must be prioritized in order to target the dominant factors that prevent the reestablishment of pre-disturbance ecological conditions. Individual restoration activities implemented to achieve established short and long-term goals and objectives must also be prioritized so that effort is focused where and how it will yield the most benefit. Recent revelations concerning the important function of large wood in streams have spawned a multitude of wood placement projects. However, whether the absence of wood is the most pressing problem in a particular stream is not always given adequate consideration. Highly manipulated streams (such as those that were straightened, leveed, tide-gated, relocated, and dredged, or those in highly altered watersheds), where natural self-sustaining processes have been disrupted, may benefit more from projects that restore water quality, floodplain and/or tidal connectivity, natural channel location, pattern and configuration, riparian vegetation, or other self-sustaining processes and controls that have been altered or disrupted.

Restoration efforts should focus first on projects that offer the greatest potential for success and relatively rapid recovery[3 5 12]. Those projects that can do so at relatively low cost and risk to existing habitat, infrastructure, and the public will likely receive further priority. Roni et al. suggest the following stream ecosystem recovery prioritization.

1. Protect areas with healthy, high-quality habitat (strongholds, refugia, and key sub-watersheds) to prevent further degradation. Secure, expand, and link protected areas.
2. Connect and provide access to isolated habitat, including instream, off-channel, and estuarine habitat made inaccessible by culverts, levees, or other man-made obstructions.
3. Employ land use recovery and watershed restoration techniques to restore processes that create, maintain, and connect habitats, including restoration of sediment dynamics, large wood dynamics, flow regimes, adequately sized healthy riparian zones, floodplain connectivity, water quality, and channel evolutionary processes. Employ a combination

of passive and active restoration techniques, as necessary.

4. Modify or create stream habitat by such measures as installing instream structures, reconfiguring channel planform, cross-section or profile, or constructing a new side channel).

The above priorities are not mutually exclusive. An actual recovery plan will likely include a combination of all four approaches in order to ensure that short- and long-term restoration and recovery goals are met. For instance, if there is an immediate need to establish specific habitat features to foster recovery of a threatened or endangered species, site-specific habitat enhancement work that provides immediate but short-term benefits could be justified. However, it must be done within the context of a watershed recovery program that will eventually create and sustain the desired habitat conditions naturally in the long-term.

### *4.3.1 Habitat Preservation*

Preservation of relatively intact, functioning ecosystems is a far more cost-effective approach to conserving the integrity of biological communities than restoring an ecosystem after it has been degraded. Considering the mixed success of past recovery efforts and the limited knowledge and understanding of interactions among physical, chemical, and biological processes, preservation also offers a greater chance of success[3 12] and may be comparatively easier to implement. Preservation helps to conserve biodiversity, reference conditions, and a source of locally derived native plants, fish, and wildlife to recolonize nearby restored areas.

Doppelt et al. suggest that priority for preservation be given to:

1. Remaining healthy key biotic refuges, benchmark watersheds, floodplains, and riparian areas. Biological refuges are discrete ecologically intact areas that support biodiversity; larger refugia may encompass an entire watershed. Biological hotspots are smaller in scale and typically consist of isolated patches of relatively undisturbed habitat. Benchmark watersheds are remaining undisturbed watersheds. They represent ecosystem potential and can be used to establish restoration goals and measure restoration effectiveness.
2. Other biological hotspots that provide critical habitat for certain life stages of biodiversity or that control dominant physical, chemical, or biological processes.
3. Potential biological hotspots in close proximity to existing biotic refuges and hotspots that may be rapidly colonized as conditions become suitable following restoration activities.

Candidate sites for preservation should seek to collectively represent all orders of stream within every ecoregion, all community types[13], centers of species richness, and habitats that support rare, endangered, or endemic species. Redundancy in the types of habitat and biological communities that are represented in reserves is essential to accommodate future natural and anthropogenic disturbances.

Preservation often takes the form of land acquisition, however, it may also include such measures as conservation easements, zoning, or other land use policies and regulations. But preservation goes beyond preventing or limiting potentially destructive activities on protected areas; management measures (such as prescribed fires or invasive weed control) may be necessary to maintain ecosystem structure and function. It will also be necessary to reduce or eliminate threats to ecosystem integrity caused by past land use activities within the preserve and past, current, and future activities outside the preserve that can nevertheless impact the site. Such measures may include repairing or eliminating unstable road crossings, reforesting unstable slopes, and implementing best management practices for stormwater management and construction. Once the integrity of the preserves is secure, restoration activities should focus on improving the condition of land between individual preserves in order to eventually expand and link them.

### *4.3.2 Restoring Habitat Connectivity*

Connectivity within a stream system refers to "the flow, exchange, and pathways that move organisms, energy, and matter through these systems"[14]. Survival of a species depends on the existence of, and access to, its reproductive, feeding, and refuge habitats. Habitat requirements vary among aquatic species and among life stages of individual species; seasonal use of different habitats is common. Therefore, connectivity between habitats is essential. The movement of organisms, energy, and matter may occur in three physical dimensions: longitudinally (up- or downstream), laterally (between the channel, floodplain, and adjacent upland areas), or vertically (into and out of the substrate).

The focus of the following discussion is on physical, including hydrologic, barriers to habitat connectivity. But keep in mind that barriers may also be biological (e.g., invasive species, extinction of species) or chemical (e.g., water quality). Physical barriers to the movement of organisms are typically classified as complete, temporal, or partial. Complete barriers block the movement of the entire population of an organism all of the time; temporal barriers block the movement of the entire population of an organism some of the time; partial barriers block only the smaller or weaker individuals of a population all of the time, limiting the genetic diversity that is essential to support a robust population[15].

Reduced connectivity results in habitat fragmentation that reduces large expanses of habitat into a matrix of small, disconnected refugia. As patches of undisturbed areas become smaller and more isolated, the amount of "fringe" habitat (the interface between interior habitat and the outside world) increases relative to that of "interior" habitat. The exposure to non-native plant and animal species (e.g., predatory pets, invasive weeds) also increases, along with the proximity between adjacent patches. As a result, mobile fish and wildlife traveling between patches of natural habitat are subject to greater exposure to predators and other hazards (e.g., roads). Habitat fragmentation favors those species requiring a relatively small range to meet their needs and maintain a viable population, and those opportunistic species capable of adapting to this new environment. Sensitive interior species will be most affected by the change.

Roni et al. identify three basic habitat types that are commonly isolated from the main stream channel:

1) <u>Off-channel freshwater areas,</u> such as side channels, sloughs, off-channel ponds and wetlands, perennial or intermittent streams and springs, and other permanently or seasonally flooded areas. A diversity of off-channel areas in various stages of succession increases the diversity of aquatic habitat available within a stream corridor. Off-channel

areas can provide reproductive, rearing, and foraging habitats for fish, amphibians, invertebrates, and selected birds and mammals. And they frequently offer aquatic species refuge from main stem conditions during floods and other events. Off-channel areas also provide a source and sink for sediment, nutrients, wood, organic matter, food, and vegetation to and from the stream.

2) Stream reaches. Access to entire stream networks is critical to species whose survival depends upon their ability to migrate to find suitable habitat and food, and to species whose survival depends on those migrating species. As of April 2002, a total of 2,324 WA State Department of Transportation (DOT) road crossings of fish bearing streams had been inspected[16]; more than a third of those examined were barriers to passage of adult salmonids. But DOT road crossings represent only a fraction of statewide barriers. Currently, there are an estimated 33,000 blockages to salmonid passage in the state of Washington (Paul Sekulich, WDFW, personal communication 4-12-02). The number of blockages is likely higher if other migratory fish and wildlife species are considered. In addition to fish and wildlife passage concerns, road crossings, weirs, and dams disrupt the flow of sediment and organic material from the upper watershed and alter nutrient cycling and energy distribution within the stream network.

3) Estuarine habitat. An estuary is "the zone between the fresh water of a coastal stream and the seawater of an ocean influenced by the tide". As such, estuaries are interfaces between riverine, marine, and terrestrial ecosystems. Estuarine habitat includes the main channel, distributary channels, and tide flats. Collectively, these provide important foraging, reproductive, nursery, and refuge habitats for many species of fish, invertebrates, resident and migratory birds, and terrestrial, aquatic, and marine mammals[17]. They also provide physiological transition zones for salmon[18] and, presumably, other fish and aquatic organisms that move between freshwater and marine environments. Other functions provided by estuaries include groundwater recharge, flood desynchronization, sediment retention, shoreline erosion control, and water quality improvement[19]. Simenstad and Thom estimated that estuaries along the Pacific Northwest coast and in Puget Sound have lost approximately 42% and 71% of their tidal wetland habitat, respectively. Although the greatest magnitude of change occurred in the large, heavily urbanized river deltas of Puget Sound, the loss of estuarine wetlands to tidal action in agricultural areas is also significant.

#### 4.3.2.1 Activities that Impact Physical Habitat Connectivity

Habitat isolation may be caused directly through barrier construction or indirectly through land use and other activities that alter the rate of water, sediment, or wood supplied to the stream and eventually leads to barrier formation. Typical causes of habitat isolation vary. They include, but are not limited to:

**Off-channel freshwater areas**

*Direct causes*

- Levee construction limits the extent and frequency of floodplain inundation
- Floodplain fill may eliminate or reduce the extent and depth of off-channel habitats such as ponds, side channels, and wetlands. It can also limit the extent, frequency, and depth of floodplain inundation that forms a hydrologic connection between habitats.
- Stream straightening typically reduces the length of interface between the stream and its floodplain. It also alters the proximity of the channel to off-channel habitats and may sever the physical and hydrologic connections between them.
- Screens and water control structures, such as tide gates, standpipes, weirs, and sluice gates limit or prevent passage of aquatic species to and from off-channel habitats.
- Development, roads, agriculture, and other floodplain land uses eliminate native vegetation and fragment quality habitat. Roads that parallel a stream may also create a barrier to the movement of nutrients from the channel to the floodplain by hindering animals that drag carcasses from the channel.

*Indirect causes*

- Instream and watershed activities that contribute to channel incision, physically isolating the stream from its floodplain and lowering the water level of nearby groundwater and surface water bodies. Off-channel areas may become dewatered or inaccessible, especially because shallowing can cause stagnation, heating, and thus evaporative water loss. The habitat in these areas may also become unsuitable. Refer to Chapter 4.5.5, *Restoring Incised Channels*, in this guideline for a discussion of activities that may lead to channel incision.
- Disturbance of the natural stream flow regime so that the extent, depth, duration, or frequency of flooding is altered, or the water level of nearby groundwater and surface water bodies is lowered. Off-channel areas may become dewatered or inaccessible. The habitat in these areas may also become unsuitable. Refer to Chapter 4.4.2, *Restoring Stream Flow Regime*, in this guideline for a discussion of activities that may impact the natural flow regime of a stream.
- Tide gates along the main stem that alter the frequency, depth, and duration of floodplain inundation and so may limit or alter the hydrologic connection between the main channel and off-channel habitats.
- Activities that prevent or minimize opportunities for the natural formation and maintenance of off-channel habitats, including:
  - Bank armoring or hardening
  - Activities that reduce the extent, depth, duration, or frequency of flooding (e.g., dam release management, water withdrawals, levee construction)
  - Activities that reduce the supply of large wood to the stream (e.g., timber harvest, land clearing, stream cleaning)
- Watershed activities that increase the sediment supply to off-channel areas, accelerating the rate at which off-channel areas fill in. Coupled with activities that prevent creation and maintenance of off-channel habitat, habitat lost through sedimentation will not be replaced or renewed.

**Stream reaches**

*Direct causes*

- Culverts, dams, tide gates, or other artificial obstructions or constrictions can create drop, velocity, turbulence, depth, or other physical barriers to upstream fish and/or wildlife passage. Outfall drops may also create a barrier to safe downstream fish and/or wildlife passage.
- Modified channels that are steep, shallow, devoid of roughness elements, or have artificial smooth channel linings can create velocity, slope, or depth barriers to upstream fish and/or wildlife passage and eliminate holding habitat that facilitates passage.
- Road crossings may create physically challenging and potentially dangerous conditions for organisms that must climb the embankment and cross the road to reach upstream and downstream habitats.

*Indirect causes*

- Instream and/or watershed activities that lower the streambed elevation, physically isolating a stream reach from its tributaries and upstream reaches where opportunities for vertical channel adjustment have been constrained.
- Watershed activities leading to debris flows and landslides that block the channel[20].

**Estuaries**

*Direct causes*

- Tide gates reduce the inflow and outflow of the tidal prism necessary to move sediment, organisms, and water and to maintain the temperature, salinity, nutrients and temperature characteristics of an estuary
- Dredging and dredge spoil disposal, estuary fill, levees, docks, bulkheads, log dumping and storage, and jetties eliminate or alter the configuration and type of estuarine habitat, substrate, surface cover, patterns of sedimentation and scour, and estuarine circulation.

*Indirect causes*

- Instream and watershed activities that contribute to accelerated estuary aggradation or incision resulting in the loss of estuarine function and habitat.
- Upstream water diversions, storage reservoirs, withdrawals, and other activities that disrupt surface and groundwater hydrology and limit or alter the influx of freshwater

#### 4.3.2.2 Techniques to Restore Habitat Connectivity

Techniques used to restore habitat connectivity depend upon the type of habitat that has been isolated and the cause of its isolation. Providing a long-term, self-sustaining solution to the problem requires that the cause be addressed (e.g., removal of a barrier culvert) as opposed to simply treating the symptom (e.g., trap-and-haul fish to release them on the other side of the barrier culvert).

If habitat is in good condition, but is isolated from the main channel or adjacent reach by a direct cause, such as a man-made obstruction (e.g., a levee, dam, or culvert) or channel dredging, and the processes that otherwise maintain that habitat and its connection to the main channel are intact, then restoration efforts need only to address that direct cause of habitat isolation. Such techniques may include:

- Remove impassable culverts or replace them with non-barrier alternatives (see *Fish Passage* technique)
- Remove dams, diversions, and water control devices or modify them to accommodate fish passage
- Remove, breach, or relocate levees (see *Levee Removal and Modification*, and *Dedicating Land to the Preservation, Enhancement, and Restoration of Stream Habitat* techniques)
- Remove floodplain, estuary, or other fill that isolates the habitat
- Remove drainage systems that lower the local water table and drain nearby wetlands and ponds
- Stop dredging or otherwise manipulating the channel, remove artificial constraints on the channel (e.g., bank armor, channel lining, road crossings) and allow the channel to naturally recover to a self-sustaining condition (see *Bank Protection Construction, Modification, and Removal* technique). If recovery is unlikely to occur within the desired timeframe as a result of passive restoration efforts alone, or if land use imposes constraints on the outcome, planners may choose to accelerate natural recovery through actively modifying the channel to a more natural self-sustaining state (see *Channel Modification* technique). Note that if the original channel manipulation was conducted in response to channel instability, the cause of instability and its affect on the ecosystem and nearby land use will need to be assessed.

The probability of success for habitat reconnection projects such as those described above is moderate to high.

If the loss of habitat connectivity cannot be attributed to a direct cause, it is likely that the processes that naturally create and maintain the isolated habitat or the connection to that habitat have been disturbed. Restoration of habitat connectivity will require identification of disturbed processes (e.g., delivery of wood and sediment to the stream, stream flow regime) and the root cause(s) of their disturbance.

### *4.3.3 Restoring Habitat-Forming Processes*

Restoration of degraded habitat requires that the root cause of degradation be identified and addressed if the treatment is to provide long-term, sustainable results[3 4] . In doing so, benefits of the project can extend far beyond a target area or species and the probability of success in meeting long-term restoration goals is relatively high. Sometimes, the cause of degradation may be unequivocally attributed to a specific activity or occurrence within the stream reach (e.g., channelization, point-source discharge of contaminants). However, more often, habitat becomes degraded as a result of cumulative impacts from multiple activities and land uses occurring within the watershed. These activities collectively alter the habitat-forming processes, including the supply and transport of sediment, water, wood, solutes, and energy to streams. By focusing on restoring the processes responsible for forming, connecting, and maintaining stream habitat, rather than merely recreating a specific habitat feature, it's possible to nurture the watershed's recovery to a functional dynamic ecosystem that supports a range of habitat conditions and a diverse biological community over the long term .

Restoring stream processes requires an assessment to determine which processes have been altered, how, where, and to what degree [5 9]. This, in turn, requires knowledge of how an ecosystem functions and the dominant factors responsible for its structure, composition, and productivity[3 6] . Past, present, and future activities and conditions must be considered. Such an assessment must be conducted at a watershed scale, unless the cause of impairment is obviously limited to a smaller scale (refer to Chapter 3, *Stream Habitat Assessment*, in this guideline for further information on assessments). Consider whether disruption of each process is permanent (e.g., a dam) or temporary (e.g., mass wasting from a clear-cut hill slope that will recover over time). If temporary, how long will it take to recover (e.g., how long will it take for a forest to grow back to an adequate size, extent, and composition to become a functional source of shade, large wood, and bank stability to the stream)? Are further alterations expected under the current management plan (e.g., is the watershed subject to active, on-going expansion of development, timber harvest, or agriculture)? The reader should note that the interaction of processes and how they shape habitat is complex and often unpredictable. Our frame of reference is often limited. For instance, we may not have observed processes at play under particular flow events such as a flood with a 500-year recurrence interval. Similarly, we may not fully appreciate how significantly runoff patterns have changed with urbanization.

Once the activities causing habitat degradation are identified, the first step to restoring habitat is to halt those activities or modify them so as to minimize their impacts, prevent further degradation, and allow natural recovery to occur. This approach is referred to as "passive" restoration. It may include such activities as implementing best management practices to reduce stormwater runoff from urban areas, improve water quality, or reduce water withdrawals from a stream for irrigation, drinking water, or other purposes; modifying the rate and timing of water released from dams; reduce erosion from construction sites, agricultural fields, and timber harvest areas; or stopping livestock grazing in the riparian zone.

Ecosystems have the ability to recover from disturbance. Native species evolved with the natural (historic) disturbance regime of their stream system and have developed a suite of adaptations for survival[21]. Their response to disturbance, and the rate and likelihood of ecosystem recovery, depends on the duration, intensity, extent, distribution, and frequency of the disturbance; the sensitivity of the channel[22]; the abundance and distribution of suitable habitat; and the abundance, distribution, sensitivity and adaptive capability of the surviving populations. As cited by Reeves et al., Yount and Neimi[23] describe two types of disturbance, "pulse" and "press". A pulse disturbance occurs within the bounds of historic natural disturbance regimes and so, within the limits of conditions in which the ecosystem has evolved and from which it can recover. Press disturbance, on the other hand, pushes conditions to a state outside their normal range. A stream will respond and adjust to these new conditions and eventually reach a new equilibrium, provided it is not subjected to additional impacts and that the channel is allowed to evolve (i.e., the channel is allowed to migrate and its bed and banks to erode). Populations of certain affected species that are unable to adapt to these new conditions will decline while those of others that are favored by the new set of conditions will rise, thus fostering ecosystem succession. Ecosystem recovery to prior or a new set of conditions could take years, decades, or centuries depending on the extent and nature of changes in the watershed. Furthermore, the start time for recovery will be reset following every disturbance.

In systems with a potential for rapid natural recovery, passive restoration alone may be sufficient to reach long-term restoration goals. However, if recovery is unlikely to occur within the desired timeframe as a result of passive restoration efforts, or if the system is so badly degraded it cannot recover on its own, active restoration measures that accelerate the natural recovery of habitat-forming processes should be considered. Such activities may include road removal, reconstruction, and maintenance; revegetation; weed removal; reintroduction of species that have been extirpated from the area; removal of dams; removal of bank armoring; or removal or breeching of levees. Although some activities might occur instream (e.g., dam removal), the majority of activities necessary to restore stream habitat-forming processes will occur upslope.

In highly altered systems, the ability to restore all habitat-forming processes is limited. A more realistic goal in such environments is to restore as many processes as possible within given land-use constraints to create a self-sustaining potential biological community. Partial restoration of processes may have higher long-term costs if further activities are necessary to maintain habitat conditions in the long-term.

Because of limited resources, it is not feasible or necessary to restore all disrupted processes throughout all watersheds or ecosystems simultaneously to achieve long-term goals. Restoration will likely occur in stages. Prioritization of watersheds and prioritization of actions within each watershed is recommended in order to target the dominant factors that prevent the reestablishment of pre-disturbance ecological conditions. Kauffman et al. and the Natural Research Council suggest prioritizing target systems by focusing first on those with a greater potential for recovery at the least amount of risk and cost. Then focusing on those systems requiring greater intervention for recovery. Enhancement activities at sites that are incapable of restoration in the true sense of the word should be given lowest priority. The sequence suggested above is simply a guideline. Restoration, rehabilitation, or enhancement of degraded habitat for species near extinction, as well as locally-defined restoration priorities, may alter the actual sequence of restoration activities[3,9]. However, such considerations should not alter the types of activities undertaken in the overall restoration plan, as they are all necessary to collectively achieve the ultimate goal of reestablishing a dynamic, self-sustaining system.

Active and passive restoration of habitat-forming processes may or may not provide immediate habitat benefits, but should provide long-term benefits. This approach can be used in combination with direct modification or creation of habitat to provide immediate as well as long-term benefits.

#### 4.3.3.1 Managed Inputs of Material to a Channel

There may be instances where processes that are essential to ecosystem health have been disrupted and cannot recover to pre-disturbance levels in the near-future (e.g., it will take decades for a newly planted riparian zone to provide a source of large wood to the stream), or in the long term (e.g., a dam will block downstream passage of bedload until it its removal, reduced numbers of salmon returning to their natal stream decrease the supply of nutrients provided by their rotting carcasses). Where this occurs, some processes may be artificially simulated through a deliberate, managed input of material to the stream. This approach is most commonly used to supplement the supply of sediment, wood, or nutrients to the stream, although instream flow

requirements could also be considered to fall under this category. For the purpose of this guideline, supplementation is defined as the direct feeding of materials, including gravel and wood, into a channel without specialized placement.
Material supplementation is only effective in situations where stream processes have not been altered to the point of impacting material transport and delivery. Material distribution often relies on flow events. Consequently, this approach will not provide immediate benefits to stream habitat. After a supplementation project has been implemented, it may take weeks, months, or years before benefits are realized, depending on the magnitude and timing of flows. As hydrology is difficult to predict, the timing, extent, and longevity of material distribution is also difficult to predict. There is also a risk of undesirable consequences if the material gets deposited where it compromises infrastructure, property, public safety, or valuable habitat.

Sustained benefits to fish and wildlife from a managed inputs approach can only be achieved through periodic re-application for as long as the natural supply and delivery of material to the system is constrained. Supplementation should be suspended when the natural supply processes have recovered (e.g., the riparian zone is capable once again of providing a source of large wood to the system). In some instances, supplementation may require a substantial commitment of resources to achieve the desired result in both the short- and long-term, especially in instances where the disturbed processes will likely never be restored.

### *4.3.4 Modifying and Creating Stream Habitats*

Direct creation of habitats involves actively constructing a specific habitat feature to address an identified or perceived problem or deficiency in the system. For instance, it may involve constructing a salmonid spawning pad, excavating pools, constructing large wood complexes, reestablishing pre-disturbance channel morphology, or constructing a side channel or wetland. This approach is often undertaken for in-kind mitigation to offset the deleterious impacts of other construction projects or land use activities. It is also used to enhance, rehabilitate, or restore habitat conditions. But planners and designers should note that the success rate associated with creating habitats is highly variable[5 17]. There is a tendency with this approach to over-emphasize habitat benefits for a specific target species and to not give full consideration to the habitat needs of other fish and wildlife species also present in the system. As a result, the potential benefits of created habitats may be limited in comparison to natural habitats. Emphasis on *ecosystem* restoration, which *supports* target species may be more effective than creation of site-specific habitat elements that directly benefit target species.

Habitat modification and creation projects are sometimes implemented without regard to whether or not the constructed habitat is or was a natural feature in the landscape and, similarly, without regard to whether or not the processes that naturally create and maintain that habitat in the long-term are present. Consequently, the project may simply create form without function and benefits, if achieved, may be short-lived without regular, long-term maintenance. For example, constructing a salmonid spawning pad in a stream using optimal “spawning-sized material” will be a wasted effort if the material is too small to be maintained in the reach and gets transported downstream during the first storm event. Such measures may even harm the very resource they are intended to benefit if they lure fish to spawn there only to have all their eggs wash out. In addition to simply not providing the benefits being sought, projects undertaken without knowledge of the condition of the stream and watershed and without understanding of the relationship between stream variables (channel slope, width, sinuosity, velocity, sediment transport, etc.) may have unintended consequences by causing channel avulsion, meander migration, or bed and bank erosion or deposition. Such consequences may be advantageous, harmful, or have no significant effect on biota, infrastructure, property, and public safety, depending on the circumstances. Even where habitat-forming processes are considered, project success may be inhibited by a limited understanding of the complexity of process interactions; the limited accuracy of models, predictions, and estimates; the presence of non-native species; the unpredictable behavior of organisms; and unforeseen circumstances. In summary, it can be difficult to predict what a constructed habitat will be like and what species will benefit[24]. Developing and defining realistic goals and objectives is essential.

The value of constructed habitat will be enhanced when implemented in conjunction with other activities that address the root cause of habitat degradation. Constructed habitats complement efforts to restore disrupted habitat-forming processes by providing short-term benefits during the years, decades, or longer timeframes necessary for certain processes to fully recover. For instance, adding large wood to a stream channel in a historically forested watershed can provide short-term benefits while the riparian zone is recovering from past land use activities. However, if wood is added to the stream in the absence of activities that restore a long-term source of wood to the channel, benefits will last only until the wood decays or floats away.

Modifying or creating stream habitat may also be appropriate to enhance instream conditions when the natural processes that create and maintain habitat have been severely constrained or eliminated and cannot be effectively restored. This is most commonly the case in urban settings, but may also be a consequence of hydro-modification, tide gates, levees, bank armoring, or similar structures where current land use prevents their removal or modification. The longevity of created habitat in such settings will depend largely on the stability of the channel and the watershed. While some short-lived habitat enhancement measures in dynamic systems may be appropriate in certain circumstances, created habitat will provide the longest benefit to relatively stable channels and watersheds that are not undergoing rapid change.

The process of habitat creation, evolution, and destruction in a natural system is spatially and temporally dynamic. Therefore, the quantity, quality, and distribution of specific habitats are constantly changing. Creation of certain habitat types, such as plunge pools, using rigid, fixed instream structures, such as log weirs, constrictors, or deflectors, is less common in modern enhancement projects than in the past. Experience has demonstrated that such habitats are often short-lived and less sustainable than those created using "process-based" or "land use-based” recovery actions. Instream structures typically treat only the symptoms of the problem, not the cause. In addition, rigid structures have a limited ability to adjust and adapt to dynamic stream conditions and, so, are more prone to failure or creating a barrier to fish passage when conditions around them change over time. Rigid structures may also serve to prevent or limit natural habitat-forming processes from occurring, including channel migration and sediment transport.

Habitat creation and modification techniques can provide immediate benefits to affected fish and wildlife. However, projects that rely on hydraulic forces to reshape the channel bedform and sort sediment may take months or years to achieve their full potential.

## *4.4 Factors to Consider When Identifying and Selecting Ecosystem Recovery Alternatives*

Habitat restoration projects will be more successful at producing desired habitat and ecological benefits in the long-term if the implications of various alternatives are carefully considered during the selection process. Every watershed is unique in terms of its restoration objectives, limitations, and priorities. As a result, no single set of selection criteria can be developed and universally applied. Common factors to consider when selecting and prioritizing alternatives are described below and include existing or future watershed condition; project scale; the time frame necessary to achieve desired results; the longevity of benefits; operations and maintenance needs; risks associated with implementation; uncertainty of achieving desired results; and cost effectiveness.

Consider the “do-ability” and “durability” of the project. “Do-ability” refers to the degree to which an approach is technically and financially sound and feasible. Is the design likely to achieve restoration goals and objectives? Are equipment, materials, labor, and funding available for project implementation and necessary monitoring, operations, and maintenance (weed control, irrigation, repairs)? Has the responsibility for necessary post-construction operations, monitoring and maintenance been clearly assigned? Is the timing right? What permit conditions, bid package provisions, contract provisions, expert construction oversight, contingency planning, environmental monitoring, and inspection requirements are in place to assure the project is completed as designed, and that the desired future condition is achieved?

“Durability” refers to the probability that the desired future condition will occur and persist in the landscape. Can the design be supported by existing and anticipated future stream and watershed conditions? Will it promote or maintain a level of resiliency to disturbance or will it require repeat application to provide long-term benefits? Does the proposal address the cause of the problem or merely treat its symptoms? Have necessary complementary projects and land management been implemented to maximize the longevity of results (e.g., upland slope stabilization to reduce fines delivered to the stream prior to implementing salmonid spawning gravel cleaning)? Consideration of all aspects of do-ability and durability will help frame the possible alternatives from which final restoration projects and tasks may be selected.

### *4.4.1 Existing or Future Watershed Condition*

Habitat restoration, ideally, will result in “natural” conditions where natural geomorphic and ecological processes maintain habitat function. However, “natural” conditions must be viewed in the context of current and future conditions of land use and development within a watershed. Natural, in the purest sense of pristine, pre-settlement condition, may be impossible to achieve given permanent or predicted landscape changes. Thus, desired conditions must be considered within the context of realistic rehabilitation of site, reach, and watershed landscapes.
When selecting projects within watersheds that have been, or are in the process of being subjected to permanent or semi-permanent landscape change (such as urban development or widespread agricultural land use), achieving natural conditions may be limited to the creation of a channel system which promotes natural process and function under the new hydrologic and sediment regime.

### *4.4.2 Scale of Project*

Stream habitat restoration may be implemented at virtually any scale, ranging from placement of a single habitat structure, to alteration of watershed-wide land use practices. The later will generally necessitate a conscious decision to alter land use and management practices, which have political, social, and economic implications.

The appropriate scale of the project or series of projects will be highly dependent upon restoration objectives, the size of the stream in question, and the scale of the problem and its cause. Site-specific disturbances may be remedied on small scales; systemic disequilibrium and watershed-scale causes of stream degradation generally require watershed-wide restoration activities to yield measurable benefits. Many restoration endeavors require some minimum level of implementation before measurable benefits are realized. For instance, if livestock are fenced from the stream on one property, but continue to have unlimited access to the stream on a number of other properties, the resulting decline in fecal coliform levels expected in response to that single treatment may be negligible. That is not to say that restoration activities to address large-scale problems must occur all at once to be effective. Even small improvements may be beneficial. Habitat improvements, like habitat impairments, are cumulative. Incremental improvements resulting from multiple small-scale projects over time can collectively achieve restoration goals.

Despite the value of incremental gains, the logistics of certain restoration activities require some threshold scale of application to be worthwhile. Where the scale of an achievable project is dictated by property ownership, jurisdictional boundaries, and funding limitations, these limitations must be weighed against the reduced potential for success that they impose. For example, if lack of willing landowner participation will limit a proposed levee setback or removal project to a few select properties, careful consideration must to given to whether such limited application of the treatment will be capable of achieving project goals. Logistics make it difficult to apply such a treatment on an incremental property-by-property basis as additional landowners choose to participate over time.

Consider the full extent of project effects and contact all potentially affected landowners early in project planning in order to address their concerns and document project constraints and ecological benefits. The effects of certain restoration actions may extend beyond the immediate localized area of treatment. For instance, a proposal to raise the profile of an incised stream to reconnect it with its floodplain may cause flooding of neighboring property; a fact that must be given careful consideration during project planning and deign.

The size of the stream will not likely determine the scope of the project. Either a small stream or a large river with systemic habitat degradation resulting from watershed scale impacts may require a watershed-scale approach to restoring disturbed processes. Alternatively, a site-specific problem on a large river or small stream may be appropriately remedied through a site-specific technique. Thus, the size of the stream or river dictates the scale of the effort, but not necessarily the scope of the project.

### *4.4.3 Delay to Results*

Healthy natural systems are the product of complex interactions of multiple variables over time.

Restoration activities give a stream a starting point from which further interaction, and time, will bring about natural function and health. Realistic objectives for restoration activities will likely have to accept some lag time between completion of physical restoration activities and realization of full recovery potential, especially when passive restoration techniques are employed. Furthermore, different processes and functional components will recover or regenerate at different rates:

- Food (macroinvertebrate and plant) production may be restored on a scale of months to years following restoration activities (and associated disturbance).
- Physical habitat features (pools, rearing, etc.) may be immediately available or may depend on high flow events to achieve desired function (such as sorting or scouring of bed substrate). As a result, the desired function may not be achieved until after a number of seasons or years.
- Vegetation may require decades to centuries to recover. While riparian shrub species may reach maturity in both size and composition within decades, riparian forests may require centuries for full recovery.
- Geomorphic processes may be restored within a time frame of immediate recovery to years.

Oftentimes, passive restoration is all that is necessary for successful long-term ecosystem recovery and it is generally less expensive and invasive than active restoration techniques that achieve the same goal. However, during the time lag between restoration activities and habitat recovery there may be lost opportunity for habitat function and value. Depending upon the urgency for realizing short-term benefits and the likelihood of the system to fully recover, planners may choose to implement a strategy that combines direct habitat creation techniques (providing relatively immediate, though possibly short-lived, benefits) with others whose benefits will be longer-lived but require years to be fully realized.

### *4.4.4 Durability and Longevity*

Varying approaches to habitat restoration will have varying durability and longevity. Durability refers to a specific feature's ability to withstand the various forces that it is subjected to. For example, a log jam may be designed to withstand a moderate flow (low durability) or an extreme flow (high durability). Longevity refers to the duration of benefit gained by restorative action, or quite simply, how long it will last.

The ideal objective is to strive for self-sustaining and adaptive projects, thereby creating indefinite longevity. Activities that restore the natural rates and types of habitat-forming processes rather than creating specific habitats will generally result in greater longevity. The design life (longevity) of most direct habitat creation projects, and particularly structural treatments such as log and boulder placements, will be related to the magnitude of hydrologic events which may destabilize them. Because the magnitude of hydrologic events is a largely unpredictable variable, it may be impossible to determine the longevity of created habitat. Furthermore, structural approaches may have design lives that exceed functional life. For example, while a structural approach may survive a design flow event, and last through a predicted design life, the function provided by that structure may be lost due to a change in the channel relative to the structure. For example, a log jam placed to create scour, deposition and provide cover and spawning habitat may be left high and dry by a natural shift in channel location.

The functional life of restoration projects will be influenced by:

- Chance and random geologic and hydrologic events, including erosion, mass wasting events, and floods;
- Land use and land tenure arrangements, including changes in land use regulations, easements, and ownership; and
- Stream and watershed stability.

### *4.4.5 Operations and Maintenance Needs*

An emphasis on self-sustaining habitat restoration will promote development of projects that are operation and maintenance-free in the long term. The best restoration project design and approach, however, may still require some period of operation and maintenance to maximize the rate and likelihood of recovery. Operations are activities that are anticipated and required by design for proper function of implemented projects. Examples of operations may include weeding and irrigation of planted materials, management of flows from impoundments, managed grazing of riparian corridors, inputs of gravels, wood, or nutrients in systems where the natural input of such material has been disrupted, or the removal of any temporary project construction components such as erosion control measures. Maintenance is any activity that becomes necessary through normal degradation or as a result of unexpected conditions before a project becomes self-sufficient. Examples of maintenance may include the repair or replacement of damaged structures or failed project components.

Operations and maintenance requirements are project- and site-specific considerations and will be dictated by both anticipated and unanticipated conditions and events. Typical operations and maintenance requirements are provided for each technique described in Chapter 5 of this guideline entitled *Designing and Implementing Stream Habitat Restoration Techniques*. Maintenance needs are highest when using a managed inputs approach or a direct habitat creation approach. Maintenance needs increase when the restoration design does not take into account existing and future watershed conditions, the location of the project within the stream network, or when design treats only the symptom and not the cause of a problem.

### *4.4.6 Risk Assessment*

Different approaches to achieving a given project objective may involve varying degrees of risk to public safety, natural resources, property, or infrastructure. They may also offer varying certainties for success. These risks and the probability for success must be weighed against other project considerations when selecting and prioritizing projects.

Risk should be considered in both the long-term and short-term. Short-term risks are those associated with project implementation. Construction projects invariably involve some degree of disturbance. The following detrimental environmental impacts commonly occur either on-site or off-site as a result of project implementation:

- Aquatic impacts associated with construction and equipment:
  - Water quality impacts such as increased turbidity or fuel spills

    - Disturbance of existing aquatic life and habitat.
- Riparian and terrestrial impacts, particularly those associated with access and staging areas for any construction components of the project.
    - Soil compaction and disturbance
    - Removal of vegetation, snags, wood, and duff layer
    - Spreading noxious weeds
    - Disturbance of wildlife
- Marine impacts may be realized if the project scale includes a significant portion of a watershed or if it is in close proximity to marine environments.

Disturbance can be greatly minimized if the project is properly designed and constructed, and if ongoing monitoring and maintenance is conducted. For example, access to a stream channel may require transport of materials and equipment across a healthy riparian plant community. In such a case, extreme measures may be necessary to minimize disturbance, and to reclaim all impacts, including soil decompaction, reestablishment of vegetation, and control of noxious weeds that colonize the disturbed soil.

Long-term risks include those associated with the eventual failure of structural features or the potential for the project to have unexpected impacts over time. For example, elements of a constructed log jam may wash downstream and damage downstream property or infrastructure such as bridges. Long-term risks may also include anticipated or unexpected impacts upstream, downstream and adjacent to the site. For instance, installing a series of boulder clusters in a stream may increase the roughness of the channel or constrict flow such that upstream sediment deposition and bank erosion occurs and compromises adjacent roadways through undermining and increased flooding. Risks that are commonly associated with specific techniques are discussed in the individual technique descriptions included in Chapter 5 of this guideline.

Certainty of success is the likelihood that a project will meet its objective. The possibility that a project will not meet its objectives can be considered a risk. Certainty varies among techniques, the level of design effort, the information available, and familiarity and experience of the designer with the technique.

Following are example situations that may result in higher risk or reduced certainty of success:

- Failure to perform thorough reach and watershed assessments can reduce the certainty of success and increase risk if stream and watershed conditions are not fully understood.
- Projects that address problem symptoms rather than their cause have less certainty of success compared with projects that address the root cause of the problem.
- Instream activities generally pose higher risks than those occurring outside the stream channel. Proximity to infrastructure can increase risk associated with instream activities.
- Certainty of success for passive or managed input approaches to restoration may be less than that associated with a more active approach.

### *4.4.7 Cost Effectiveness*

The cost of a project relative to the benefits it provides is one of several criteria commonly used to evaluate and prioritize alternative restoration projects and to examine the trade-off between pursuing restoration and maintaining current conditions. A benefit-cost analysis has traditionally been employed where the value of benefits is expressed as a monetary equivalent or as a specific rating along some other numerical scale. The challenge in consideration of cost: benefit ratios lies in determining the value of the benefit. Costs can usually be readily determined in dollar units; however, benefits are often impossible to evaluate quantitatively. Benefits are usually based on anticipated recovery of habitat and production values that don't easily have a monetary worth. Additionally, there may be ancillary benefits, such as a stabilized channel that prevents the future need for rock armoring or dredging, that cannot be easily measured. In addition, not all projects are subject to cost effectiveness considerations; fish passage is required by law, independent of cost: benefit considerations, although cost: benefit will certainly be considered in project prioritization.

As an alternative to benefit-cost analysis, the National Research Council recommends using an opportunity cost assessment to determine the appropriate level of restoration. In an opportunity cost assessment, a comprehensive list of benefits is compiled for every restoration alternative under consideration, but no attempt is made to assign those benefits any particular value. Instead, interested parties responsible for evaluating and prioritizing proposed restoration projects make their decision by weighing the qualitative list of anticipated benefits against the estimated opportunity cost, risks, and other decision criteria associated with each project or restoration task under consideration. Opportunity costs are quantitative and include not only direct financial payouts (for assessment, design, construction, long-term monitoring, operation, and maintenance requirements), but also the current benefits derived from existing conditions that will be lost following implementation of the restoration project (e.g., land set aside for riparian restoration will displace that available for livestock grazing or other land use activities). The primary benefit of conducting an opportunity cost assessment over a cost-benefit analysis is that it is not necessary to seek agreement on a single method of assigning value to various benefits. The value placed upon each of these benefits may differ among stakeholders and change over time or from watershed to watershed in response to the needs of the resource, social preference, and lessons learned regarding the effectiveness of various techniques.

### *4.5 Approaches to Achieving Common Restoration Goals*

Processes that determine the abundance, diversity, form, and quality of stream habitat are the supply and transport of sediment, water, solutes (including nutrients and contaminants), organic matter (ranging from large wood to detritus), and energy (light and heat) to the stream. For this reason, common restoration goals included in the following discussion are:

- Restoring Sediment Supply
- Restoring Stream Flow Regime
- Restoring Energy Inputs to the Stream, and
- Restoring Water Quality

Restoring large wood to the stream is discussed at length in the *Large Wood and Log Jams* technique.

Other more site- and species-specific restoration goals are also included to illustrate their dependence on restoring habitat-forming processes. These include:

- Restoring Incised Channels
- Restoring Aggrading Channels

- Restoring Salmonid Spawning Habitat, and
- Restoring Salmonid Rearing Habitat

The focus of the discussion is on addressing anthropogenic (human-made) causes of stream and habitat degradation. Potential causes of degradation that are identified in the text are not exhaustive but are meant to provide the reader with a sense of the variety and types of problems that may need to be addressed. It is also intended to reinforce the need to conduct a site, reach, and/or watershed assessment before proceeding to restoration design.

Many of the techniques listed below provide long-lasting benefits by restoring disrupted landscape processes while others provide immediate but short-term benefits. Some provide more predictable results than others. These techniques are broad suggestions offered as guidance and are not intended to limit the designer. Actual designs may include a combination of techniques to fully address restoration goals and objectives. Details of select techniques are described in Chapter 5 of this guideline entitled *Designing and Implementing Stream Habitat Restoration Techniques*. To achieve long-term stream habitat restoration, the root cause of habitat degradation must be addressed, not just the symptoms. All restoration work should be coupled with a change in watershed management to prevent further degradation and maximize the benefits and longevity of the restoration project.

### *4.5.1 Restoring Sediment Supply*

Sediment is the product of erosion and may be derived from within a stream channel via bed and bank erosion and from sources outside the channel via surface erosion and mass wasting events (slumps, landslides, debris flows, and soil creep). Erosion tends to be episodic and linked to disturbance and weather. Erosion processes and rates (see Chapter 2 of this guideline) are controlled by climate, topography, soil type and organic matter content, soil depth, soil saturation, and surface cover. As a result of these factors, the type and volume of sediment delivered to a stream varies over both space and time.

Once sediment enters the stream, it is subject to transport, deposition within the channel or floodplain, and re-entrainment by flowing water. The sediment transport capacity of a stream is related to channel hydraulics and geometry. Moving water exerts a force on the bed and banks of the channel. That force, referred to as shear stress, moves sediment grains downstream. Shear stress is a function of the slope of the water surface and the hydraulic radius of the channel (cross-sectional area divided by the cross–sectional length of the wetted channel). In very wide shallow channels, the hydraulic radius approximates the depth of flow. Since the shear stress required for sediment transport increases with the size of the particle, smaller particles move more easily and can travel longer distances than larger particles. Shear stress and sediment transport are discussed more thoroughly in the *Sediment Transport* and *Hydraulics* appendices. The supply of sediment relative to the sediment transport capacity of the stream can affect the stability of a channel, causing channel aggradation if the volume delivered exceeds the available sediment transport capacity, and causing channel incision if the volume is insufficient[25].

The sediment load transported by stream flow is comprised of a suspended load and a bedload. The suspended load refers to sediment that is carried and supported by flow. It generally consists of relatively fine material (clay and silt sized particles). Bedload consists of larger particles that are pushed along by the flow but are supported by contact with the bed of the stream. Suspended sediment plays a significant role in water quality and affects the ability of fish and other organisms to live in the stream[26]. It also provides a source of nutrients, silt, and organic material to floodplains[2 27]. Bedload transport dominates channel morphology; it determines the nature of the bed material and provides a source for its renewal.

Sediment size, sorting, volume, and transport dynamics exert a major control on channel form, which describes the pattern, cross-section, and profile of the stream as well as its internal relief. Channel form controls the physical state of the stream (e.g., temperature, depth, substrate, and velocity) that collectively influence the abundance and diversity of aquatic life[28]. The size and sorting of bed material influence plants, fish, macroinvertebrates, and other stream life. Coarse bed materials (e.g., gravel, cobble, boulders) have a higher porosity than fine sediments (e.g., sand, silt, clay); likewise, well-sorted materials have a higher porosity than materials that are poorly sorted. Higher porosities allow for higher rates of interstitial flow[29] and yield greater amounts of interstitial habitat. Such habitat is critical to macroinvertebrates, most of which spend the majority of their lives attached to bed material[30], as well as to fish and wildlife that feed on macroinvertebrates and that spawn or rear in the bed. The preferred substrate composition varies among species.

Sediment supply is also a critical element of marine and lacustrine habitats. It is hard to separate estuarine habitats from river processes so they are mentioned here. However, the focus of this guideline is riverine habitats. It is intended that a future guideline within the Aquatic Habitat Guideline program series will focus on marine and estuarine habitat restoration.

#### 4.5.1.1 Activities that Impact Sediment Supply

The sediment supplied to a stream varies naturally over time due to climatic variability and periodic natural events such as landslides, debris flows, wildfire, wind, and volcanic eruptions. But anthropogenic influences, stemming from land use and stream alterations, can significantly alter the rate and types of sediment supplied to the stream and, thus, severely impact the stream and aquatic habitat. Such influences include human activities that affect the sediment supply from the watershed and those that affect the sediment supply and transport from upstream reaches and tributaries. These include, but are not limited to:

*Direct Causes:*

- Direct dumping or stockpiling of material in the active channel or floodplain increases the supply of readily erodible material to the stream.
- Removal of bedload material from the stream (e.g., instream gravel mining or dredging operations) reduces the supply of sediment to the downstream reach and may lower the baseline elevation for the upstream reach. These activities can cause upstream and downstream channel incision[31].
- Instream activities, such as operation of equipment and vehicles within a stream channel, yarding of logs through a channel, and foot traffic by livestock, people and pets, stir up sediment in the vicinity of the activity, increasing its availability for downstream transport.

*Indirect Causes:*

- Land-use activities that, through alteration of soil structure, vegetation, topography, and hydrology, significantly increase the delivery of fine and coarse sediments to streams. Such activities include road construction, maintenance, and use; livestock grazing; placer mining; urbanization; agriculture; timber harvest; and general land clearing. Increases in sediment supplied to a stream may be chronic, via accelerated rates of surface erosion, and/or abrupt, via mass wasting events. Refer to **Table 4.5.2** for further information on land use activities that impact stream sediment supply.

- Riparian management practices leading to the removal or alteration of riparian vegetation. Vegetated riparian zones trap sediment contained in surface runoff and floodwater and provide streambank resistance to the erosive forces of flowing water. Loss of riparian vegetation may increase the supply of sediment to the stream via surface runoff and accelerated rates of bank erosion. Loss of riparian vegetation can also lead to channel widening that reduces the sediment transport capacity of the reach.
- Channel modifications that alter the slope or cross-section of the channel, thereby altering its sediment transport capacity. Increases in the sediment transport capacity of a reach (by channel dredging, narrowing, steepening, or straightening; levee construction; or removal of wood or other roughness elements) may increase bed and bank erosion in the affected and upstream channel reaches, resulting in an increased supply of sediment downstream. Decreases in the sediment transport capacity of a reach (by channel widening or flattening, installation of channel roughness elements, or by levee construction in tidal areas) may cause aggradation in the affected and upstream channel reaches, resulting in a decreased supply of sediment downstream.
- Land use change and flow management practices within the watershed that alter the flow regime of the stream, thereby altering its sediment transport capacity (by changing the depth of flow) and the degree of connectivity between the channel and its floodplain. Depending on their nature and scale, altered flow regimes (among other causes) may cause channel widening or incision, which can supply extraordinary amounts of sediment to the downstream channel, or they may cause channel aggradation, decreasing the downstream sediment supply. They may also alter the level of the surrounding water table that directly impacts the extent and species composition of riparian vegetation, which, in turn, influences the stability of the banks and sediment detention from surface runoff and floodwater. Land uses and flow management practices that may alter streamflow regimes are discussed under Chapter 4.5.2, *Restoring Stream Flow Regime*.
- Stream bank protection and armoring reduce the natural recruitment of sediment, including gravels, to the stream.
- Capping floodplain sediment sources by impervious surfaces prevents the natural recruitment of sediment during flood events.
- Activities that directly or indirectly reduce natural sediment storage sites within the stream corridor increase the supply of sediment to adjacent and downstream channel reaches. Such natural storage sites include floodplains, backwater areas, alluvial fans, bars, deltas, wood accumulations, and bank, bed, and floodplain vegetation.
- Installation or removal of channel obstructions and constrictions that increase channel roughness, create backwater, physically intercept downstream sediment transport, and reduce the supply of sediment to downstream reaches. Such structures include dams, undersized culverts, boulders, large wood, and beaver dams, among others.

#### 4.5.1.2 Techniques to Restore Sediment Supply

The most effective long-term solution to restoring stream sediment supply must address the cause of altered supply, not just the symptom. Most causes of altered sediment supply are indirect in nature and many derive from non-point sources. As a result, restoration will likely need to occur upstream of the affected stream reach and/or outside the channel. Appropriate techniques used to restore the historic sediment supply to the channel may include:

- To restore sediment supply that has been lost
    - Stop instream and floodplain dredging and sand and gravel mining operations
    - Remove or modify existing bank protection. This may require land use modification (see *Bank Protection Construction, Modification, and Removal* and *Dedicating Land and Water to the Preservation, Enhancement, and Restoration of Stream Habitat* techniques).
    - Restore sediment transport from upstream reaches by removing or modifying upstream dams or by modifying their operation. Management of sediment stored in dammed reservoirs is a key element of dam removal design.
    - Artificially place bed material in discrete locations or implement a periodic or continuous gravel supplementation/feeding plan for an affected reach (see *Salmonid Spawning Gravel Cleaning and Placement* technique). Note that these techniques will provide only short-term benefits without periodic repetition. They do not address the source of the problem, only the symptom.
    - Restore the sediment transport capacity of a disturbed upstream channel. The sediment transport capacity may have been reduced by a decrease in channel slope, altered channel cross-section, altered streamflow regime, or by installation of channel obstructions and constrictions that create roughness, backwater or physically intercept downstream sediment transport. See *Channel Modification* technique, *General Design and Construction Considerations for Instream Structures*, and Chapter 4.5.2, *Restoring Stream Flow Regime*.
- To reduce the excessive supply of sediment to the stream
    - Stop dumping and stockpiling sediment in the active channel or floodplain
    - Prevent or minimize direct access of livestock, people, and vehicles to the channel
    - Implement upland best management practices for existing land use activities within the watershed and/or modify land use to increase upland stability and to reduce surface erosion and mass wasting events (see *Dedicating Land and Water to the Preservation, Enhancement, and Restoration of Stream Habitat* technique and Chapter 4.5.4, *Restoring Water Quality*). Road removal, reconstruction, and maintenance and replacement of undersized culverts with larger culverts or bridges reduce the risk of landslides, debris flows, and surface erosion.
    - Restore the sediment transport capacity of a disturbed upstream channel. The sediment transport capacity may have been raised by an increase in channel slope, altered channel cross-section, loss of floodplain connectivity, an altered streamflow regime, or by removal of channel obstructions and constrictions that create backwater or physically intercept downstream sediment transport. See *Channel Modification, Levee Removal and Modification*, and *General Design and Construction Considerations for Instream Structures* techniques, and Chapter 4.5.2, *Restoring Stream Flow Regime*.
    - Restore natural sediment detention within the stream corridor by removing

channel constraints (e.g., bank protection and levees) and ceasing activities (e.g., dredging, straightening) that simplify the channel; restoring natural channel geometry, large wood and other roughness elements to the stream, riparian vegetation, and historic floodplain connections; and reintroducing beavers to the stream corridor. See Chapter 4.5.2, *Restoring Stream Flow Regime* and the *General Design and Construction Considerations for Instream Structures, Large Wood and Log Jams, Riparian Restoration and Management, Channel Modification, Bank Protection Construction, Modification, and Removal, Levee Removal and Modification, Beaver Reintroduction,* and *Dedicating Land and Water to the Preservation, Enhancement, and Restoration of Stream Habitat* techniques.

- Construct sediment detention basins throughout the watershed or within the stream to intercept sediment transport. Note that sediment detention basins do not address the source of the problem, only the symptom, and will provide only short-term benefits without regular maintenance. Use of instream sediment detention basins has limited application (see *Instream Sediment Detention Basins* technique).
- Restore or increase the width and extent of vegetated riparian zone to increase the detention of sediment from surface runoff and floodwater and increase bank stability (see *Riparian Restoration and Management* technique).
- Implement bank protection techniques on severely eroding banks. Note that this technique is an acceptable habitat restoration technique only in limited applications (see *Bank Protection Construction, Modification, and Removal* technique).

### *4.5.2 Restoring Stream Flow Regime*

According to the National Research Council, flow regime restoration is one of the most neglected aspects of stream restoration, despite the fact that streamflow is a driving force with regards to channel form and a key element of aquatic habitat and habitat connectivity. Stream flow provides the energy needed to transport water, sediment, organic material, nutrients, and thermal energy within the stream corridor[32]. The flow that transports the largest amount of bedload over time is referred to as the "effective" discharge. This discharge has the most influence on creating and maintaining alluvial stream channels and the physical habitat they provide. In streams that are neither incised nor actively aggrading, effective discharge typically fills the channel to the top of the banks[33]. See the *Hydrology* appendix for further discussion regarding effective discharge.

Streamflow influences the water level of nearby groundwater and surface water bodies (such as wetlands, lakes, and ponds) and dictates the frequency, extent, and duration of floodplain inundation. These, in turn, influence the distribution and composition of riparian vegetation and wildlife, and the exchange of nutrients, water, sediment, vegetation, contaminants, organisms, and organic material between the floodplain and the stream. High flows transport sediment, control vegetation encroachment into the active channel, and influence the structural stability of streambanks. They also contribute to the disturbance regime of a stream serving as a mechanism for creating and maintaining diverse aquatic floodplain, and riparian habitat[14,21].

Flow determines the amount of available aquatic habitat. At its simplest, aquatic habitat is living space or volume; volume increases with flow. However, the quality of living space (or spawning or incubation space) is determined by other flow-related factors, such as depth, velocity, cover, bottom material (substrate), and water quality[14]. Despite the variability of streamflow during the course of a year, the seasonal timing of high and low flows (i.e., the flow regime) may be quite predictable. Native fish and wildlife have adapted to, and in some cases are dependent on, the natural flow regime to provide them access to suitable feeding, reproduction, and refuge habitat, and to serve as a cue for breeding or other features in their life cycle. For instance, the timing of returning salmon to western Washington streams in the fall coincides with the start of the rainy season. The fall freshets are necessary in some streams to provide the salmon passage to their spawning grounds. Streamflow controls the movement of fish and aquatic wildlife up and down the stream corridor, and between the floodplain and the stream.

Alterations to a stream's flow regime may limit the amount of quality habitat available to fish and wildlife. Higher-than-normal flows can flush fish, wood, food, and substrate out of a reach. Lower-than-normal flows can increase fish vulnerability to predators, heighten competition for food, and may dewater redds or cause stranding. In addition, low flows during warm weather often lead to warmer water temperatures and reduced oxygen levels, potential contributors to increased fish mortality[34]. Low flows during cold weather can lead to freezing, which can kill eggs in the gravel, depending on conditions. For a more thorough review of the importance of streamflow in the context of stream ecology, refer to *Instream Flows for Riverine Resource Stewardship*.

In addition to the ecological benefits, streamflow serves humans in many ways. These include consumptive uses (such as irrigation and domestic and industrial water supply), hydroelectric power generation, navigation, and recreational activities (such as boating, rafting, swimming, water skiing, and kayaking). The flow level in a stream also influences aesthetic and scenic qualities of natural settings.

#### 4.5.2.1 Activities that Impact Natural Stream Flow Regime

Land use and water management activities can alter the magnitude, timing, and duration of flow in streams. The most common causes of altered flow regime include:

*Direct causes*

- Controlled releases from dams that optimize the availability of water for power production, irrigation, water supply, recreation, or flood control.
- Water withdrawals from the stream and aquifer for power production, irrigation, and water supply. Where water withdrawn from the stream is stored for a period of time and later released back into it, flow regimes may shift in time[14], possibly causing high flows during historic low flow periods and low flows during historic highs. This can have a major impact on aquatic biota and riparian vegetation.

*Indirect Causes*

- Loss of water retention and acceleration of runoff in the watershed. Loss of retention combined with accelerated runoff typically increases the frequency and magnitude of flood peaks and reduces the availability of water to streams during low flow (base flow) periods. Loss of water retention and acceleration of runoff may be caused by:

- Altered land cover (e.g., removal of native vegetation, increased impervious surface area) due to development, road construction, timber harvest, and agriculture, among others.
- Compaction of soils throughout the watershed.
- Construction of drainage networks to dry wetlands and floodplains for agriculture, development, and other land uses. This may also lower the water table and surface elevation of nearby waterbodies.
- Traditional stormwater management practices that focus on getting water off the land and into the streams as quickly as possible to reduce localized flooding.
- Loss of floodplains and isolation of streams from their floodplains due to levee construction, floodplain fill, channelization activities, and channel incision. These activities reduce floodplain storage during high flow events, thereby increasing flow within and downstream of the affected reach in non-tidal channels.

#### 4.5.2.2 Techniques to Restore Stream Flow Regime

With the exception of flow regulation of dams, alterations in stream flow regimes are the result of cumulative impacts to the watershed. Therefore, restoration of stream flow generally requires a watershed-scale land restoration and management strategy. In highly urbanized areas and in stream reaches with water regulated by active dams, it may be impossible to restore the flow regime to pre-disturbance conditions. However, strategies can be employed to reduce the impacts of existing infrastructure and to minimize or eliminate the impacts of future development.

- Techniques to Increase Base Flow
  - Remove dams, modify dam impoundments, or modify the water release management plan
  - Reduce water withdrawal/diversion
    - Reduce water consumption
      - Reduce irrigation needs by replacing traditional crops and landscapes that require large amounts of supplemental water with ones whose needs more closely match natural precipitation patterns (including use of native plants)
      - Improve irrigation practices and systems to maximize their efficiency
      - Decrease energy demands (Washington is primarily dependent upon hydroelectric power) and use alternative energy sources
      - Improve soil water retention (organics, mulch)
      - Use water efficient appliances and reduce non-essential water use
    - Improve efficiency of water delivery systems (e.g., fixing leaks and using systems that minimize loss of water to evaporation and infiltration)
  - Increase stormwater retention and groundwater recharge
    - Improve stormwater management
    - Reduce and limit the amount of impervious surfaces in the watershed
      - Change land use practices and zoning regulations to limit the allowable percent of impervious surface in the watershed

            - Decommission roads
            - Use pervious pavement alternatives where feasible
        - Minimize the extent and degree of soil compaction
        - Restore stream connectivity to floodplains (see *Channel Modification, Levee Removal and Modification, Dedicating Land to the Preservation, Enhancement, and Restoration of Stream Habitat* techniques)
        - Revegetate denuded areas within the watershed
        - Protect, restore, and create wetlands and other infiltration areas
- Techniques to Restore the Magnitude and Frequency of Peak Flow Events
    - Remove dam, modify dam impoundments, or modify the water release management plan
    - Increase stormwater retention and groundwater recharge (as outlined above)
- Techniques to Restore the Natural Flow Regime (distribution of flow over time)
    - Remove dam, modify dam impoundments, or modify the water release management plan
    - Restore base flow (as outlined above)
    - Restore peak flow magnitude and frequency (as outlined above)

### *4.5.3 Restoring Energy Inputs to the Stream*

**[This section consists strictly of notes and is incomplete at this time.]**

Sources of light and heat to the stream are controlled primarily by climate, the degree of shade (from vegetation, hillsides, buildings) and the source of water (groundwater is typically cooler than surface water in the summer, and warmer than surface water in the winter; the temperature of stormwater, irrigation returns, and other discharges may differ significantly from that of the stream). The effect of light and heat to the stream is controlled by water width, depth, velocity, substrate, and turbidity (as turbidity increases, light penetration decreases). Temperature of the stream may be elevated or suppressed by relatively warm or cool discharges from irrigation returns, industrial, stormwater, and other discharges, and temp of other waterbodies connected to the stream. Urban areas tend to be warmer than rural areas (pavement, concrete, brick, etc. retain heat). Loss of connectivity with hyporheic zone can also alter the temperature of the stream.

Reference: Spence, B. C., G. A. Lonnicky, R. M. Hughes and R. P. Novizki. 1995. An Ecosystem Approach to Salmonid Conservation, Volume 1: Technical Foundation. Prepared by Man Tech Environmental Research Services Corporation, Corvallis, Oregon, for the National Marine Fisheries Service, U.S. Environmental Protection Agency, and Fish and Wildlife Service.

### *4.5.4 Restoring Water Quality*

Water quality, or the *physical, chemical, and biological characteristics of water,* is a critical factor to the existence, abundance, and diversity of aquatic life in a stream. Temperature, streamflow, turbidity, dissolved gases, nutrients, heavy metals, inorganic and organic chemicals, pH, and biota (pathogenic bacteria, viruses, etc.) are among many parameters that influence water quality. If the magnitude or concentration of any of these factors falls outside the natural range for a specific location and time of year, biological processes may be altered or impaired[35].

Pollution affects organisms in a number of ways. The toxicity of the chemical may cause an organism to suffer acute or chronic effects, depending upon the concentration and period of exposure of the chemical concerned, the condition of the organism at the time of exposure, and other factors such as water temperature, turbulence, and synergistic effects[36]. Substances that are acutely toxic cause death or severe damage to an organism by poisoning during a brief exposure period (i.e., ≤days). Substances that are chronically toxic cause death or damage to an organism by poisoning during prolonged exposure. Pollution may also affect organisms by creating conditions unsuitable for the organism; increasing the organism's susceptibility to disease and pathogens; changing metabolic requirements, behavior, rate of growth and development, or migration timing; or causing mortality from predation and competition with other organisms more tolerant of the change [37] .

Water quality standards for surface waters of the state of Washington are provided by the Washington Administrative Code (WAC) Chapter 173-201A and are summarized in **Table 4.5.1**.

In 2001, the Washington Department of Ecology reported that 48 percent of all river and stream reaches monitored did not meet state water quality standards[38]. The primary water quality problems identified were temperature, pH, and fecal coliform bacteria. For this reason, it is important to examine the water quality of a particular stream or reach being considered for restoration prior to project initiation. To learn more about the water quality and quantity issues within a particular watershed, consult the Washington State Department of Ecology's website at: http://www.ecy.wa.gov/programs/wq/watershed/index.html. Additional flow and water quality information can be obtained at the United States Geological Survey site at http://wa.water.usgs.gov/.

**Table 4.5.1**. Water quality standards for surface waters of the state of Washington.

| Water Quality Parameter | Class AA Waters[a] (Extraordinary) | Class A Waters[a] (Excellent) | Class B Waters[a] (Good) | Class C Waters[a] (Fair) |
|---|---|---|---|---|
| **Fecal Coliform Organisms** | Geometric mean = 50 colonies/100ml | Geometric mean = 100 colonies/100ml | Geometric mean = 200 colonies/100ml | Geometric mean = 200 colonies/100ml |
| **Dissolved Oxygen** | >9.5 mg/L | >8.0 mg/L | >6.5 mg/L | >4.0 mg/L |
| **Total Dissolved Gas** | ≤110% saturation | ≤110% saturation | ≤110% saturation | ≤110% saturation |
| **Temperature** | ≤16.0°C | ≤18.0°C | ≤21.0°C | ≤22.0°C |
| **PH** | 6.5 to 8.5 | 6.5 to 8.5 | 6.5 to 8.5 | 6.5 to 9.0 |
| **Turbidity** | ≤5 NTU over background | ≤5 NTU over background | ≤10 NTU over background | ≤10 NTU over background |
| **Toxic radioactive, or deleterious material** | Concentrations shall be below those that have the potential either singularly or cumulatively to adversely affect characteristic water sues, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health. | | | |

[a] Classes of surface water are established based upon the characteristic use of the water body. See WAC 173-201A-030 and WAC 173-201A-130 for details.

Source: WAC 173-201A, Revised November 18, 1997

Note: Water quality standards are intended to protect designated uses, such as drinking water supplies or cold-water habitat. However, they do not offer the same degree of safety for survival and propagation at all times to all organisms within a given ecosystem[39].

#### 4.5.4.1 Activities that Impact Water Quality

The water quality of a stream can be affected by both point and non-point sources of pollution. Point sources are those that can be traced back to a discrete discharge, such as an industrial outfall. Non-point pollution stems from diffuse inputs to a water body with the pollutant traveling via air, groundwater, or surface water runoff. Land use practices, if not managed effectively, provide the opportunity for pollutants to enter these transport pathways. Examples of non-point source pollution include groundwater infiltration and runoff from agricultural operations (nutrients, sediment, salts, bacteria, pesticides, and other chemicals), mining (acid drainage, sediment), urban stormwater runoff (increased peak storm flows, low base flows, heavy metals, sediments, lawn and garden chemicals, bacteria, temperature, petroleum products, and nutrients), roads (sediment, gasoline, oil, other fluids, litter), managed forestlands (sediment, temperature), construction sites (sediment), and septic systems (bacteria, nutrients). A further break down of pollutants commonly associated with various land use activities has been included in **Table 4.5.2**.

**Table 4.5.2**: Sources of Pollution by Land Use Activities

| Non-point Source | Nitrogen | Fecal Coliform | Sediments | pH | Dissolved oxygen | Pesticides | Flow | Temperature |
|---|---|---|---|---|---|---|---|---|
| Agriculture | | | | | | | | |
| Animal Feeding Operations | X | X | X | X | X | | | |
| Dryland | X | | X | | | X | | X |
| Irrigation | X | | X | X | X | X | X | X |
| Non-commercial | X | X | X | | | | | X |
| Forest Practices | | | | | | | | |
| Road construction | | | X | | | X | X | X |
| Timber harvesting | | | X | | | | X | X |
| Reforestation | X | | | | | X | | X |
| Urban/Rural | | | | | | | | |
| Construction | | | X | | | | | X |
| On-site sewage systems | X | X | | X | X | | | |
| Stormwater runoff | X | | X | X | | X | X | X |
| Hydromodification | | | | | | | | |
| Channelization | | | X | | X | | X | X |
| Dams | | | X | | X | | X | X |
| Wetlands and riparian Areas | | | | | | | | |
| Vegetative clearing | | | X | | X | X | X | X |
| Draining of wetlands | X | | X | | | | X | X |
| Recreation | | | | | | | | |
| Marinas and boats | X | X | X | X | X | | | |
| Off-road | | X | X | | | | | |
| Hiking, fishing | | X | | | | | | |

Source: Green, W. P., W. A. Hashim, and D. Roberts. 2000. Washington's Water Quality Management to Control Non-point Source Pollution. Washington Department of Ecology Publication Number 99-26, Olympia, Washington. 583 pp.

As cited by Green et al.[40], the Washington Department of Ecology in their Report on Water Quality in Washington State[41] found "only 22% of the problems in [Washington] streams that don't meet water quality standards could be traced to point sources". The rest were attributed to non-point sources of pollution. While the majority of lake and groundwater pollution is also attributed to non-point sources, point sources are the dominant cause of estuary pollution.

Even if the magnitude of a pollutant source remains unchanged, the amount of pollutant reaching a stream can increase or decrease if the pollutant's pathway to the stream is altered. For instance, shortening the distance or travel time along a pollutant's pathway to a water body. This can occur through removal or modification of vegetation or wetlands along a flow path, resulting in the reduction of opportunities for interception, uptake, or degradation of the pollutant prior to its entering a water body.

Intact riparian zones buffer waterways from disturbances in the watershed; moderate water temperature and, thus, dissolved oxygen concentrations; limit the rate of bank erosion; and provide wood to streams that control the instream storage and transport of sediment and organic matter. Vegetated riparian zones, along with vegetated uplands and wetlands, increase flow complexity and, therefore, travel time to the stream, increasing the opportunity for pollutant uptake, degradation, sorption, and transformation. They filter sediment, pollutants sorbed to the sediment (e.g., phosphorus, heavy metals), and insoluble pollutants from overland flow and from flood flows . Aerobic and anaerobic processes operating within a wetland allow certain chemicals to volatilize or precipitate out of the water column. And, the accumulation of organic matter that occurs in many wetlands provides a permanent sink for many chemicals.

Once the pollutant reaches the stream, its impact on stream water quality depends, in part, upon its dilution by flow. As the amount of water mixing with the pollutant increases, the pollutant's concentration decreases. Thus, activities that remove water from the stream (e.g., for irrigation or domestic or industrial water supply), that regulate flow (e.g., dams), and that limit base flow (e.g., development of impervious surface which limits groundwater recharge opportunities) increase the likelihood of a stream not meeting water quality standards. Shallow flow is also more prone to temperature increases and, thus, reduced dissolved oxygen content.

In the stream, nutrients and contaminants may cycle between a dissolved form, a gaseous form, and a particulate form (as a precipitate, sorbed to organic matter, or contained within living organisms). As a particulate, their movement is influenced by downstream fine particle transport (cited by Paul and Hall[42]). Thus, depositional sites that provide temporary or long-term storage of sediment and organic matter, also provide storage for particulate forms of contaminants. Depositional areas include floodplains and floodplain features (e.g., relic channels, alluvial wetlands and ponds)[43 44 45 46], backwater areas, alluvial fans, bars [45], log jams[43 47 48 49 50 51], low gradient channel reaches[52], and bank, bed, and floodplain vegetation. The duration of storage may range from a few days to hundreds of years or longer, depending on the type of storage site, the frequency, magnitude, and duration of storm events, stream power[46 53], and sediment supply[54], among other factors. During storage, many contaminants degrade, transform, are taken up by plants, bacteria, fungi, and other organisms, or become buried in sediment and organic matter. However, others may retain their toxicity and pose a further threat when disturbed by erosion or released back (desorbed) into the water column. Note that, during storage, contaminants may pose a threat to the organisms that reside there. Activities that simplify the channel or limit the extent, frequency, or duration of floodplain inundation will reduce the magnitude and alter the distribution of storage sites within the stream corridor. Such activities include straightening, dredging, and removing wood from streams; constructing levees; filling the floodplain; and altering the stream hydrology so that the channel becomes incised or is no longer subject to flows capable of accessing its floodplain.

#### 4.5.4.2 Techniques to Restore and Improve Water Quality

If there are identified water quality problems in a stream, water quality restoration should be implemented prior to instream restoration measures. Ecosystem restoration plans that alter the physical form of the stream corridor are of limited use if the quality of water is inadequate to sustain life.

#### 4.5.4.2.1 Point Source Pollution

Within the state of Washington, pollution caused by point source discharges of wastewater and stormwater to surface water are controlled through National Pollutant Discharge Elimination System (NPDES) permits issued by the Washington State Department of Ecology. NPDES permits are required for wastewater discharges to surface water from industrial facilities and municipal sewage treatment plants, and for stormwater discharges from industrial facilities, construction sites of five or more acres, and municipal storm sewer systems that serve populations of 100,000 or more[55]. For further information on point source discharges within a particular drainage, consult the Washington State Department of Ecology's website at http://www.ecy.wa.gov/programs/wq/permits/index.html or contact their Water Quality Program.

#### 4.5.4.2.2 Non-point Source Pollution

Non-point source pollution is derived from diffuse sources spread throughout a watershed and is, therefore, more difficult to control than point source pollution. The specific water quality restoration technique employed to control non-point source pollution depends on the specific water quality parameter that has been identified as causing impairment, its source(s), the pollutant's transport pathway, and it's eventual fate within the ecosystem.

**Treating the Source**

Preventing the introduction of a pollutant to the environment is the most effective means of avoiding its detrimental impacts and should be a priority in any pollution management plan. Effective management of non-point source pollution can best be achieved through a combination of: 1) thoughtful land use management that restricts the type of activity allowed in an area (e.g., zoning restrictions, land use plan development and implementation), and 2) the use of best management practices (measures implemented to control and minimize the source or transport of pollution) that minimize the impact of an activity. Because of the vast array of sources of non-point source pollution and the complexity of its control, the restoration of stream water quality impacted by non-point source pollution requires a watershed-scale land restoration and management strategy. Many resources are available for guidance on the prevention and management of non-point pollution. Some are listed below. Consult the U.S. Environmental Protection Agency and the Washington Department of Ecology web sites for further information.

- *Guidance Specifying Management Measures for Sources of Non-point Pollution in Coastal Waters*[56] provides management measures and fact sheets for agricultural sources; forestry; urban areas; marinas and recreational boating; hydromodification; channelization and channel modification, dams, and streambank and shoreline erosion; wetlands, riparian areas, and vegetated treatment systems.
- *Washington's Water Quality Management Plan to Control Non-point Source Pollution* describes a holistic approach to controlling and cleaning up non-point source pollution. The plan reflects current efforts and creative, practical new ideas from all partners and interested citizens. The recommendations focus on how to improve existing efforts through stronger implementation, increased funding, or alternative techniques. The document describes current laws, regulations, programs and technical assistance available to control non-point pollution as it relates to agriculture, forest practices, urban areas, recreation, hydromodification, and loss of aquatic ecosystems.

- *Stormwater Management Manual for Western Washington*[57]. The objective of this manual is to provide a commonly accepted set of technical standards and guidance on stormwater management measures that will control the quantity and quality of stormwater produced by new development and redevelopment. The Department Ecology believes that when the standards and recommendations of this manual are properly applied, stormwater runoff should generally comply with water quality standards and protect beneficial uses of the receiving waters. Local governments and businesses statewide use the manual to help design their stormwater programs. The manual is useful for anyone needing guidance on sediment and erosion control for construction sites. Operators, or engineers, representing industrial facilities will benefit from the technical volumes.
- *Stormwater Management Manual for Eastern Washington*—in development http://www.ecy.wa.gov/programs/wq/stormwater/eastern_manual/index.html
- *Management Recommendations for Washington's Priority Habitats*. Management recommendations for riparian habitat were developed to meet the goal of maintaining or enhancing the structural and functional integrity of riparian habitat and associated aquatic systems needed to perpetually support fish and wildlife populations on both site and landscape levels. These recommendations consolidate existing scientific literature and provide information on the relationship of riparian habitat to fish and wildlife and to adjacent aquatic and upland ecosystems. Recommendations on major land use activities commonly conducted within or adjacent to riparian areas are provided, including those relative to agriculture, chemical treatments, grazing, watershed management, roads, stream crossing and utilities, recreational use, forest practices, urbanization, comprehensive planning, restoration, and enhancement.
- *On-site Sewage Treatment and Disposal Information Tool Kit*[58]. This tool kit demonstrates to homeowners how they can easily participate in preventing water quality degradation by informing themselves about their on-site sewage disposal systems. The materials included in the kit illustrate what action individuals can take to protect the water supply by properly maintaining and utilizing their on-site sewage disposal systems. Further information, including Homeowner's Manuals for the Operation, Monitoring and Maintenance of On-Site Sewage Treatment and Disposal Systems are available on line at http://www.wsg.washington.edu/outreach/mas/water_quality/onsite_sewage_treatment/maintenance.html#manuals

**Controlling Transport**

Controlling a pollutant's transport to the stream involves 1) intercepting the pollutant before it reaches the stream, and 2) controlling the capacity of surface runoff, wind, or other transport pathways to carry pollutants from their source to the stream.

Intercepting the pollutant before it reaches the stream includes such activities as establishment and preservation of vegetated riparian zones, upland vegetation, and wetlands between the source of the pollutant and the stream. As discussed above, vegetated buffers and wetlands delay transport of a pollutant, thereby providing further opportunity for interception, uptake, or degradation of the pollutant. However, the pollutant may still harm the ecosystem within the buffer or between the buffer and the pollutant source.

Controlling the capacity of transport pathways to carry pollutants from their source includes such activities as creating "wind breaks" to minimize the capacity of wind to blow soil and airborne pollutants from fields and construction sites; or implementing stormwater management techniques to limit the rate of surface runoff and, thus, its capacity to transport waterborne pollutants from the watershed.

Resources available for guidance on limiting the transport of non-point pollution from the source to the stream are the same as those for addressing the source of non-point source pollution. See also *Riparian Restoration and Management* and *Dedicating Land to the Preservation, Enhancement, and Restoration of Stream Habitat* techniques in this document.

**Instream Treatment**

Water quality improvement techniques that focus on a pollutant's fate are those that minimize the effect a pollutant has on stream water quality once it reaches the stream. Such techniques may focus on:

- Removal of the pollutant once it reaches the stream (e.g., dredging, pump and treat systems).
  This approach is a short-term enhancement technique that treats the symptoms of the problem rather than the cause. As a stand-alone treatment approach, it will require repeat application until the source of water quality impairment has been addressed. It is generally less cost effective and more disruptive to the ecosystem than addressing the source or transport of a pollutant. However, depending on the contaminant, its toxicity, and the removal method employed, used in combination with techniques that control the source and transport of pollutants, it can accelerate ecosystem recovery and minimize harm.
- Counteracting the effects of the pollutant. This includes such activities as buffering acidic water or aerating water depleted in oxygen. This approach is also a short-term enhancement technique that treats the symptoms of the problem rather than the cause. As a stand-alone treatment approach, it will require repeat application until the source of water quality impairment has been addressed.
- Increasing streamflow to minimize a stream's susceptibility to temperature increases and to dilute pollutants already in the stream. This approach is an acceptable stand-alone treatment when it fully addresses the cause of water quality impairment. It may include such activities as minimizing and eliminating water withdrawals (e.g., for irrigation or domestic or industrial water supply) or restoring stream base flow through modification of regulated flow regimes and by restoring and preserving groundwater recharge in the watershed during precipitation and snowmelt events. (See Chapter 4.5.2, *Restoring Stream Flow Regime* for further information.) If this approach does not fully address the cause of water quality impairment, it is best used in combination with techniques that address the source and transport of pollutants to the stream. Note that dilution does not modify the load of pollutant. Impacts to aquatic life downstream may still occur even if problems within the reach are reduced.
- Restoring storage sites within the stream corridor for sediment, organic matter and the nutrients and contaminants adsorbed to them. Note that, depending on the pollutant, it may impact fish and wildlife within the storage site or it may be released back into the stream through overland flow, flood flow, groundwater transport, and desorbtion.

Restoration activities that increase sediment storage within the stream corridor are described in Chapter 4.5.1, *Restoring Sediment Supply*.

### *4.5.5 Restoring Incised Channels*

Channel incision is the progressive lowering of the channel bed relative to its floodplain elevation. Incised channels are transitional forms which are unstable for a period of time and result in erosion of the bed and banks, the transport of considerable quantities of sediment to downstream reaches, dewatering of the riparian zone[59], destruction or degradation of existing aquatic habitat[60], and the undermining of infrastructure such as bridges and utility crossings. Schumm and others [61] describe an incised channel-evolution sequence that consists of five successive stages, assuming that the base level for the channel does not change and that land use in the watershed remains relatively constant. These stages are Stable (Stage I), Incising (Stage II), Widening (Stage III), Stabilizing (Stage IV), and a new, dynamic equilibrium (Stage V). Once channel incision has been initiated, the channel will become increasingly isolated from its floodplain as bed erosion proceeds. Higher flows are contained within the channel, which further accelerates erosion. This process usually continues until a more resistant layer, such as bedrock or clay hardpan, is exposed. Tributaries to incised channels erode in the upstream direction (i.e., 'headcut') as they adjust to the lower base level of the main channel. This process can propagate long distances upstream and upslope, extending throughout the drainage network. The deepening of the drainage network causes more rapid draining of the soil mantle and a lowering of the water table.

After an incised channel reaches vertical stability, the erosive power of high flows is expended on the banks. Often the channel has incised below the root zone of the riparian vegetation, exposing bank material that is not stabilized by root strength and lowering the water table to a depth that no longer supports the riparian community. Channel widening proceeds until the stream has developed enough width to begin depositing and stabilizing sediment. When vegetation is able to persist within the incised cross-section and stabilize sediment through high flow periods, floodplain rebuilding at the new base level (i.e., channel recovery) has begun. A more detailed look at the process and restoration of channel incision can be found in Schumm *et al.* and Harvey and Watson, the latter includes a comprehensive bibliography.

#### 4.5.5.1 <u>Activities that impact channel incision</u>

Channel incision may be initiated by lowering the base level of the affected channel reach (e.g., by dredging or downstream incision), removal of bed stabilizing features (including grade control, large wood, and boulders), decreasing the sediment supply to the reach (e.g., by the presence of an upstream dam), or when the erosive forces and transport capacity of stream flow exceed the resistance of the bed materials. The later may occur as a result of an increase in the magnitude and frequency of high flows to which the channel is subjected or channel modifications that increase the slope or depth of streamflow. Channels with erodible beds may downcut in response.

Incision may occur on a watershed or reach scale. Reach scale channel incision is generally initiated by the removal of grade control, roughness elements (including large wood), dredging or channelization. Watershed scale channel incision may result from intrinsic factors, such as the evolution of the valley slope and geology, or extrinsic factors, such as climate, land use or base level change, which force the channel over the threshold to the new, distinct state. With the exception of land use, watershed factors are largely outside our control, and in some instances, land use is difficult to control. For instance, in highly urbanized areas and in stream reaches with water regulated by active dams, it may be impossible to modify existing land use sufficiently to restore the flow and sediment regime to pre-disturbance conditions. As a result, remediation of incised channels is often a reach level activity. What follows is a list of human activities that impact channel incision.

- Booth[62] clearly linked impervious surface area to incision. As runoff per unit watershed area increases, the stream channel, accustomed to lower flows, must increase its cross sectional area. If the bed is readily eroded, incision occurs.
- Channelization (straightening, confining, or shortening a channel) is singled out as a major cause of incision.
- Dredging and gravel mining may trigger incision, sending the upstream channel into a condition not easily reversed[63].
- The removal of large, channel-stabilizing wood results in lowering of the bed and release of stored sediment[64 65 66], a potentially reversible impact.
- Dams may lead to incision by halting the natural flow of sediment from the upper watershed.
- Culverts act as control points in channel incision and may affect the immediate reach, although the general cause of incision will remain regardless of the treatment at the road crossing. Undersized culverts may cause localized downstream incision.

#### 4.5.5.2 Techniques to restore incised channels

Incised channels are a transitional form between one dynamic equilibrium and another[67]. A stream's progress through time is punctuated with periods of disequilibrium, some more so than others. On a geologic timescale vertical instability was found to be common in one study looking back over 7,000 years of channel history. In this context, applying techniques to stabilize stream elevation amounts to human meddling in a natural process. While channelization, gravel extraction and land development are artificial causes of incision, the general tendency toward equilibrium is not precluded, baring bank hardening, which prevents the channel from widening and reestablishing equilibrium.

Rosgen[68] points out that incised channels may be in geologies or land forms that are naturally associated with entrenched channels. We must recognize the naturally occurring channel type before planning projects to restore wide flood plains to endemically entrenched channels.

When possible, efforts to restore incised channels should address the root cause of incision, rather than only the symptoms. For instance:

- If incision is caused by altered flow regime, take measures to restore a more natural flow regime (see Chapter 4.5.2 *Restoring Stream Flow Regime*);
- If incision is caused by interruption to sediment flow, take measures to restore that flow (see Chapter 4.5.1 *Restoring Sediment Supply*).

Major objections to allowing natural stream evolution to bring about equilibrium include the length of time required to reach equilibrium (considered to be decades[69]) and the increase in width necessary for the reestablishment of a functioning channel at the new elevation. There are many situations in which allowing the channel to evolve to a new equilibrium creates unacceptable risks to property, infrastructure, and habitat[70]. These factors lead to active channel modification to restore a more acceptable equilibrium more quickly.

There are a variety of well-documented channel restoration projects in incised channels.

- Shields *et al.* uses stone weirs as grade control to arrest the erosion process and elevate the stream bed. Later, Shields *et al*.[71] uses large wood to accomplish similar goals with greater ecological benefits and lower cost.
- Rosgen uses his channel classification scheme to guide restoration efforts. He recommends first identifying the cause of instability, then recognizing the appropriate stream classification for the channel, finally selecting a reference reach with the characteristics of the intended channel. For stream types that are not naturally entrenched, the key is to restore floodplain connectivity through the use of grade control or to construct a new channel at a higher elevation to bypass the incised channel. See *Channel Modification*, *General Design and Construction Considerations for Instream Structures*, *Large Wood and Log Jams*, and *Drop Structure* techniques for design guidance.
- In a recent article, Watson *et al.* [72], used an incised channel evolution model to guide the selection of design alternatives. Two dimensionless ratios define a channel stability diagram that contains the five phases of incised channel evolution. One is a bank stability ratio where the existing bank height is divided by a critical bank height for that geology and vegetation. When bank height exceeds the critical bank height it is considered unstable. The other is a hydraulic stability number, defined as the ratio of sediment transport capacity to the target sediment supply. Watson *et al.*[72] discuss the merits of various remediations on the basis of this analysis. This process recognizes the evolution of incised channels and attempts to select measures that compliment the morphologic phases.
- Some incised streams in western Washington may not follow precisely the same recovery sequence outlined in Schumm *et al.* and other references. These streams show a resistance to bank erosion atypical of those studied by researchers in other parts of the country and, as a result, they may remain in an entrenched condition for a considerable amount of time. A typical situation in western Washington: a stream that lacks large wood, becomes entrenched in a coarse glacial soil during an exceptional storm event, or due to the lowering of base level (as opposed to the chronic entrenchment in fine grained soils as found in other parts of the country). Over time, riparian vegetation recolonizes and hardens the banks, and repeated smaller storms winnow fine bed material to armor the channel bottom. This channel will remain entrenched (a Rosgen F or G channel[73], entrenchment ratio $<1.4$ ) and stable since it is not actively widening or lowering, nor is it sending a large sediment load to the downstream channel. We would consider it incised during a field inspection and note a lack of habitat, poor channel complexity with low residual pool depths. One restoration strategy that has successfully restored channels like this is to add large wood. This will trigger channel widening, renew the recovery sequence common to other incised channels, and restore a diverse fish habitat (pools, spawning gravel, delivery of wood and nutrients). Large wood placements occupy channel cross-section, increase velocity and turbulence thereby increasing local scour and

channel widening. They also encourage sediment deposition and reestablish floodplain connectivity (See *Channel Construction and Modification, General Design and Construction Considerations for Instream Structures, Large Wood and Log Jams* techniques for design guidance).

The response of a given reach to incision restoration techniques depends on the peculiarities of that geomorphic system. Sediment supply and the availability of large wood or the use of large wood in the restoration effort is especially important. Some sections of the Murray River, Australia are still adjusting 54 years after constructing weirs to correct for incision, an observation that should make us realize the role of time in restoration activities.

### *4.5.6 Restoring Aggrading Channels*

Aggradation is the progressive accumulation of in-channel sediment resulting in increased channel bed elevation. The characteristics of aggrading streams are covered in the *Geomorphology* appendix. Generally, bed material from upstream sources is transported by flow and deposits:

- at a grade break (transition from higher to lower gradient),
- at an expansion (from a narrow to wider channel cross section),
- upstream of a constriction (upstream of an undersized bridge, culvert or natural channel constriction),
- or at the confluence of a river and a tributary.

Change is inherent in aggrading reaches. The channel widens as material is deposited, often forming a delta or area of increased slope. The resulting shallow depth reduces the capacity of the stream to transport sediment, which leads to more deposition. An aggrading channel commonly evolves in one of two ways. In one scenario, the leading edge of the deposited material increases slope with time until it reaches a critical threshold and a head-cut trench works back through the aggraded bed, cutting a channel that flushes out a portion of the alluvial deposits and the cycle is renewed. The cycle may be repeated on a yearly basis or it may take hundreds of years to complete[74]. The other scenario is where aggradation continues to a point where the channel elevation increases high enough to force an avulsion, the channel rapidly moves laterally, cutting a new bed in the adjacent soil, abandoning the aggraded reach.

Both scenarios can become a problem when they impact infrastructure and habitat through increased flood elevations, reduced bridge capacity, channel widening with associated bank erosion, temporary loss of fish habitat, increased summer stream temperature due to decreased depth, or channel migration into developed land.

#### 4.5.6.1 Activities that impact aggrading channels

As outlined in the *Geomorphology* appendix, increased sediment supply and reduced stream power are the primary causes of aggradation. Aggradation is part of the natural valley-building process in a watershed context, ultimately the consequence of hill slope erosion and valley deposition[75]. On a reach scale, local sources of sediment (*e.g.*, avulsion) are deposited a short distance downstream (fluvial fan). Human activities that affect aggrading channels come under three main headings.

- Increased Sediment Supply:
  - Increased erosion caused by development, agriculture, and land clearing on erodible or unstable soils, concentration of overland flow into discrete channels, or re-routing of runoff into other drainages (often caused by road building and culverts);
  - Increased number and extent of debris flows and mass-wasting events as a result of land clearing, saturation of unstable soils on valley walls (often caused by routing stormwater onto steep slopes), or road failure;
  - Upstream channel incision.
- Decreased Sediment Storage, primarily the isolation of the channel from the flood plain:
  - channelization;
  - Levee construction.
- Decreased Sediment Transport:
  - Channel widening from livestock grazing [76], riparian vegetation removal, or other causes;
  - Decreased channel slope as a result of channelization or installation of channel obstructions that raise the channel bed;
  - Channel and floodplain constrictions, such as bridges, road fills that backwater the upstream channel,
  - Reduced stream flows caused by water withdrawals and managed water releases from reservoirs.

If manipulations such as these lead to aggradation, then watershed and channel restoration techniques can be used to restore the channel to pre-disturbance conditions.

As a word of caution, keep in mind that many streams do not have equilibrium channels and that periods of aggradation leading to widening and flooding may be normal[77] and do not attention for the sake of the resource.

### 4.5.6.2 Techniques to restore aggrading channels

Past methods for dealing with aggrading channels included channelization, sediment basins and dredging. Channelization has generally proven unsuccessful and dredging unreliable[78]. These techniques have yielded only short-lived benefits without repeat treatment and resulted in severe detrimental impacts to stream health and geomorphology. We are now charged with developing more acceptable solutions.

If the effects of aggradation are intolerable, then sediment continuity should be examined at the site, looking at it in a watershed context. Through this process one can identify source, transport and response reaches and how each contributes to the problems at the site[79]. It is important to recognize that channel mechanisms are complex and episodic so that conditions may lead to aggradation one time and then scour the next. The time scale of these trends may be short or very long and determining this scale leads to different management approaches.

- Anthropogenic channel aggradation may be caused by poor land use practices that yield excessive sediment supply to the stream. Solutions should focus on watershed-wide land use management (see Chapter 4.5.1, *Restoring Sediment Supply,* Chapter 4.5.4, *Restoring Water Quality*, and *Dedicating Land to the Preservation, Restoration, and Enhancement* *of Stream Habitat* technique).

- Aggradation may also be caused by intensive flow modification through water withdrawals or dam management, issues that should be addressed in conjunction with any instream restoration measures (see Chapter 4.5.2 *Restoring Stream Flow Regime*).
- A sediment pulse or wave, such as from an isolated landslide, creates a one-time increase in sediment that moves through a stream system creating local aggradation. If the short-term effects of such a wave are unacceptable, then a sediment trap may be approved where it can be shown that it will solve the problem and the site can be effectively restored. This option in thoroughly explored in the *Instream Sediment Detention Basins* technique.
- Channel incision or chronically unstable hill slopes, on the other hand, can supply an endless stream of bedload that may deposit in ways that interfere with developed lands and fish and wildlife habitat, requiring long-term solutions. Schumm describes the formation of natural alluvial fans, a study that can help planners incorporate natural patterns into engineering solutions. In two papers Parker *et al.*[80 81]develops the theory and application of alluvial fan formation for optimizing a tailings basin. This model could help designers engineer alluvial fans as solutions to aggradation at a grade break (high to low stream slope transitions at valley floors and elsewhere) or channel expansions (confined to unconfined valleys) for a long-term, environmentally responsible alternative to dredging or sediment basins.
- Purchase land or easements to remove valuable infrastructure or impacted uses from areas surrounding an aggrading reach. Cost analysis may reveal that such purchases are cheaper than sediment management or chronic bank repair. Aggrading reaches are inherently unstable and incompatible with development. See *Dedicating Land to the Preservation, Enhancement, and Restoration of Stream Habitat* technique.
- Large instream wood plays a significant role in the staging and storing of sediment in mountain streams [65 66]. Storage in many of these channels has been eliminated through stream cleaning, salvage operations, splash damming, as well as harvesting large logs from riparian forests. Aggradation in valley bottoms may be reduced through the placement of large wood in source and transport reaches. See *General Design and Construction Considerations for Instream Structures* and *Large Wood and Log Jams* technique.

### *4.5.7 Restoring Salmonid Spawning Habitat*

Adequate high quality spawning habitat is key to preserving native salmonid populations in our streams. Spawning habitat requirements vary among species but in general all salmonids need stable, relatively clean and appropriately sized gravels that are supplied with an adequate flow of clean, cold, oxygen-rich water. Restoring or creating these conditions can increase salmonid reproductive efficiency (fry per female).

According to a literature review conducted by Schuett-Hames and Pleus[82], favorable spawning sites often form upstream of obstructions to flow, such as bedrock outcrops, boulders, and large woody material, and in the tail-outs of scour pools. These scour pools may be associated with instream structures (e.g. large wood and boulders) or with stream meanders. The relative importance of these two features in spawning habitat development depends on the morphology of the stream. Low gradient channels with meandering pool/riffle morphology often have abundant deposits of gravel in pool tailouts, riffles, and point bars. Whereas in steeper channels, spawning habitat is often limited to small patches of coarse gravel associated with obstructions. Characteristics used by salmonids to select spawning sites include substrate size, water velocity, water depth, gravel permeability, surface and sub-surface flow conditions (e.g., up sloping microhabitats with downwelling flow), dissolved oxygen, water temperature, and cover .

#### 4.5.7.1 Activities that Impact Spawning Habitat Quality, Quantity, and Availability

Spawning habitat may have been lost or degraded for a number of reasons, both natural and anthropogenic. Anthropogenic impacts to salmonid spawning habitat availability include:

*Direct Causes:*

- Replacement of natural streambed materials with hardened structures like concrete linings and riprap or scoured structures like undersized culverts and flumes.
- Impassable culverts, dams, weirs, tide gates, sluice gates and other objects that limit or eliminate access to spawning habitat (see Chapter 4.3.2, *Restoring Habitat Connectivity*).
- Loss of channel length and complexity from realignment and straightening.
- Unregulated access by livestock, people, pets and vehicles which collectively reduce the amount of cover, compact and vibrate the beds, greatly reduce water quality, and smother the beds with fine material, reducing inter-gravel flow. All of these impacts can significantly reduce the survival of eggs in the gravel.
- Removal of instream and overhead cover available to adult fish including wood, boulders, and riparian vegetation.
- Activities, such as filling or draining of off-channel habitat, which eliminates the existence or quality of spawning habitat.
- Changes in the natural flow regime from activities such as upstream diversions and hydroelectric operations that alter the amount, accessibility, stability, and physical characteristics (e.g., water depth, sediment size and sorting) of spawning habitat.

*Indirect Causes:*

- Land use change within the watershed that alters the type or amount of sediment delivered to streams (see Chapter 4.5.1, *Restoring Sediment Supply*). A decrease in sediment supply may reduce the amount and stability of suitable spawning substrate. An increase in supply may bury redds or cause channel instability through aggradation.
- Land use change and unregulated stormwater runoff within the watershed that alter the flow regime and sediment transport capacity of the channel, causing subsequent change in the amount, accessibility, stability, and physical characteristics (e.g., water depth, sediment size and sorting) of spawning habitat.
- Channel modification and removal or addition of instream and shoreline roughness elements that alter the channel’s sediment transport capacity, stability, flow depth, and velocity, all of which impact the stability and suitability of spawning habitat.
- Manmade structures such as dams and road crossings with undersized culverts that create large-scale backwatered conditions unsuitable for salmonid spawning upstream (however, they may be suitable for rearing).
- Undersized culverts or other obstructions to flow that produce relatively high velocity jets that scour downstream reaches.
- Watershed modifications that degrade water quality creating unsuitable conditions for salmonids and other aquatic life (see Chapter 4.5.4, *Restoring Water Quality*). High

turbidity levels reduce inter-gravel flow and can smother or suffocate incubating eggs.
- Timber harvest and other land use practices that remove vegetation from the riparian zone so recruitment of large wood to the channel and overhead cover is effectively eliminated for many years, and water quality is degraded.
- Ramping rates from flow regulation that dewater and strand redds.
- Poor quality forest practices that yard logs across and along stream channels scouring and/or eliminating natural instream cover and altering overhead cover that eliminates shade and protection from predators.

#### 4.5.7.2 Techniques to Restore, Enhance, and Create Spawning Habitat

Due to the many possible causes of salmonid spawning habitat degradation, no single technique is applicable to every situation. The most effective long-term solution is to address the cause of salmonid habitat degradation, and not just the symptoms. For instance, if a channel has been narrowed, deepened, and made steeper to the point that the resulting increased water velocity does not allow spawning sized material to collect and remain stable in the reach, then the artificial placement of spawning sized gravel may serve to lure salmonids to spawn there only to have their eggs and the gravel washed out during periods of high flow.

Because of the high risk of producing only short-term benefits or even negative effects, spawning habitat creation as a mitigation or enhancement technique has limited application and should be done only with a clear understanding of the physical processes involved and the specific habitat needs of the target species. Planners must determine whether lack of suitable habitat may be limiting the population recovery and what can be realistically done to improve conditions. True restoration of salmonid spawning habitat requires reestablishment of the physical processes that naturally create and maintain spawning habitat. An approach that restores these natural processes and habitat diversity will produce long-lasting, high quality salmonid spawning habitat, and benefit other fish and wildlife species as well. Rigorous enforcement of forest practice rules, stormwater management guidelines, critical areas ordinances, agricultural setbacks and similar protective measures can correct many deleterious activities associated with land use activities.

Techniques to consider include:
- Stop operating equipment and vehicles within the stream and exclude livestock, people and pets with durable fencing and rerouting of traffic and use areas. Use alternative methods to skidding logs through a channel.
- Increase Spawning Gravel Availability—
    - Restore the natural gravel supply that has been lost (see Chapter 4.5.1, *Restoring Sediment Supply*). Where the supply of gravel cannot be restored, consider on-going gravel supplementation and spawning pad construction, if warranted and appropriate (see *Salmonid Spawning Gravel Cleaning and Placement* technique).
    - Encourage gravel stability
        - Restore the balance between sediment transport capacity and sediment supply. The sediment transport capacity may have been raised by an increase in channel slope, altered channel cross-section, loss of floodplain connectivity, removal of channel obstructions and constrictions that create

backwater or physically intercept downstream sediment transport, or by an altered streamflow regime (see *Channel Modification* and *Levee Removal and Modification* techniques, *General Design and Construction Considerations for Instream Structures*, Chapter 4.5.2, *Restoring Stream Flow Regime*, and Chapter 4.5.5, *Restoring Incised Channels*).

- Restore channel features that naturally encourage the deposition and maintenance of spawning gravel, including meander bends, instream wood and other roughness elements, and riparian vegetation. See *Channel Modification, Riparian Restoration and Management, Dedicating Land and Water to the Preservation, Enhancement, and Restoration of Stream Habitat, General Design and Construction Considerations for Instream Structures, Large Wood and Log Jams, Boulder Clusters,* and *Porous Weirs* techniques.

  - Increase available spawning area
    - Pursue opportunities to restore a diverted stream to its former channel or to restore a straightened channel to a more natural meander and length. Adequate consideration will have to be given to site-specific hydrology, channel hydraulics, geomorphology and similar issues to develop a practical and durable design (see *Channel Modification* technique)
    - Restore fish access to isolated spawning habitat through such actions as culvert, tide gate, bank protection, and levee removal or modification. See Chapter 4.3.2, *Restoring Habitat Connectivity* and *Fish Passage Restoration, Bank Protection Construction, Modification, and Removal, Levee Modification and Removal* and *Dedicating Land to the Preservation, Enhancement, and Restoration of Stream Habitat* techniques.
    - Remove structures that create artificial surfaces unsuitable for spawning (e.g., culverts, concrete liners)
    - Remove constraints that prevent creation and maintenance of new side channels, restore access to existing side channels, and restore processes that maintain existing and new side channels. Where such activities cannot occur, constructing a new side channel may be an option. See *Side Channel / Off-Channel Habitat Restoration, Bank Protection Construction, Modification, and Removal* and *Levee Removal and Modification* techniques, and Chapter 4.3.2, *Restoring Habitat Connectivity*.
    - Restore natural flow regime. Streamflow at the time of spawning determines the available amount of submerged spawning habitat, the ability of fish to access spawning grounds, and the water depth and velocity over the spawning bed. Flow regulation and ramping rates from hydroelectric dams can be changed to prevent redd dewatering and stranding. See Chapter 4.5.2, *Restoring Stream Flow Regime*.
- Improve the Quality of Spawning Habitat
  - Reduce excessive supply of fine sediment (see Chapter 4.5.4, *Restoring Water Quality* and Chapter 4.5.1, *Restoring Sediment Supply*)
  - Sort and clean gravel—

    - Restore channel features that naturally encourage the sorting and maintenance of spawning gravel, such as instream structures (including large wood) and meander bends. Structures form obstructions to flow causing local scour pools to form. The velocity gradient around and downstream of the obstruction forms pool tailouts comprised of naturally sorted spawning gravel. In low gradient channels with pool/riffle morphology, velocity differences between pools and riffles during peak flows result in sorting of sediments and deposition of coarse gravel in bars and riffles[83]. Note that a pool-riffle morphology is not appropriate for all stream reaches. See *Channel Modification, General Design and Construction Considerations for Instream Structures, Large Wood and Log Jams, Boulder Clusters,* and *Porous Weirs* techniques.
    - Artificially clean gravel (e.g., Gravel Gertie) (see *Salmonid Spawning Gravel Cleaning and Placement* technique). It should be noted that if the source of fine sediment is not identified and corrected prior to gravel cleaning, the benefits would be short lived without repeated maintenance.

- Improve water quality (see Chapter 4.5.4, *Restoring Water Quality*)
- Restore or increase instream and overhead cover (see *General Design and Construction Considerations for Instream Structures, Large Wood and Log Jams, Boulder Clusters,* and *Riparian Restoration and Management* techniques)
- Restore flow regime and channel morphology to ensure that adequate water depth and velocity and sediment conditions are present during spawning and egg incubation (see *Channel Modification* technique and Chapter 4.5.2, *Restoring Stream Hydrology*)
- Eliminate or reduce human-caused channel aggradation to increase the stability of spawning habitat and egg survival (see Chapter 4.5.6, *Restoring Aggrading Channels*)

### *4.5.8 Restoring Salmonid Rearing Habitat*

Abundant well-dispersed rearing habitat appropriate to the salmonid species that inhabit a stream is essential to the maintenance and recovery of depressed populations. Without adequate rearing habitat, preferably near desired spawning habitat, survival and health of emergent fry and juvenile fish will be reduced as these fish are forced downstream to find suitable areas. If downstream areas are already at or near carrying capacity, these fish may be lost from the system altogether and not able to help in stock maintenance and/or recovery.

Prior to evaluating the need for restoring rearing habitat quality and quantity, however, there must be an assessment of the habitat requirements for the species to be enhanced. For example, since pink and chum salmon have such a short freshwater residence time, measured in just a few days or a couple weeks at most, little can be done in the freshwater environment to enhance rearing conditions and improve survival. The predominant rearing area for these species is the estuarine marsh, beach and near-shore marine areas that can be protected and oftentimes recovered through improved fish passage at tide gates, setback of levees, removal of bulkheads, island creation and similar projects. By contrast, Chinook and coho salmon and steelhead rear anywhere from a few months up to several years in the riverine system and freshwater enhancements are possible. However, each species generally uses a different part of the system to avoid competition and these specific habitat needs must be understood to assess whether lack of suitable habitat may be limiting the population recovery and what can be realistically done to improve conditions. Where rearing habitat requirements do overlap, such as in the estuary for Chinook and chum salmon, single projects can have multiple species benefits.

Efforts to improve conditions for spawning may also increase the amount of rearing habitat depending on species-specific requirements. Reactivating an abandoned slough, for instance, with some gravel supplementation to provide off-channel spawning habitat for coho salmon will likely improve and/or restore high quality rearing habitat for the juveniles since these are the preferred rearing locations as well. However, these ancillary benefits may not always be realized. In the Big Qualicum River in British Columbia, specific flow improvements for coho spawning did improve conditions with increased egg-fry survival but there was no subsequent increase in the number of rearing juveniles[84]. Apparently, the amount or volume of slack water and/or pools, the needed rearing habitat, did not change. Careful evaluation of the probable outcome(s) of the proposed enhancement action can be very useful in deciding whether the desired habitat objectives will be achieved.

Generally, freshwater rearing habitat for salmonids tends to be the lower velocity areas either mid channel, along the bank, or in active sloughs often associated with either overhead and/or instream vegetative or wood cover. Since different species use different areas, enhancement options can vary widely. Juvenile Chinook, for instance, tend to rear over shallow bars and along natural banks in the main stem making for few types of improvement opportunities. Projects may be restricted to restoring natural bank lines through removal of bank hardening and reactivation of major river channels. Enhancements for steelhead can be even more challenging since they often prefer the faster water of streams and tributaries in association with large cobble or wood for velocity breaks where small eddies make for energy efficient holding and capture of forage items that wash by. Opportunities for steelhead may only exist in higher gradient streams that are devoid of wood or fast rocky pools that can be enhanced to provide these rearing conditions. Juvenile coho, though, prefer slower moving pools and flowing backwaters and sloughs in association with in and out of stream cover and these preferences do offer many types of effective improvement opportunities with proven techniques. The cover element, whether it is large rock, wood, emergent and submergent vegetation, exposed root bundles, a bubble screen, or any combination is needed for protection from predators and often provides an important substrate for invertebrates that can be a vital food supply.

The amount of rearing area and the number of juvenile fish that can be accommodated will often be dependent on channel length in a given reach and the structural complexity within that length. Restoration of both features could be goals of restoration.

Estuarine and near shore rearing habitat has not been as well studied but is believed to be very important for some species even though the use period may be relatively short, perhaps only weeks or several months at most. Since most of these areas have been severely altered or lost altogether, almost any recovery work will likely be beneficial. But local knowledge and information will be very important in designing any project to maximize its success. Some of the best information to date is coming from the Skagit River delta in Washington State by the

Skagit System Cooperative that has been carefully evaluating estuary use by salmonids.

#### 4.5.8.1 Activities that impact Rearing Habitat Quality, Quantity and Availability

Rearing habitat, like spawning habitat, may have been lost or degraded for a number of reasons both direct and indirect.

*Direct Causes:*

- Loss of natural stream reaches by replacement of normal streambed materials with hardened structures like concrete linings and riprap or scoured structures like undersized culverts and flumes.
- Loss of channel length and complexity from realignment and straightening.
- Changes in the natural flow regime from activities such as upstream diversions or hydroelectric operations that alter the amount, accessibility, stability, and physical characteristics (e.g., water depth, sediment size and sorting) of habitat.
- Loss of channel complexity and cover from significant removal of both instream and overhead cover, sometimes referred to as "stream cleaning".
- Unregulated access by livestock, people, pets and vehicles that can reduce the amount of cover, cause major disruptive disturbance and greatly reduce water quality.
- Activities that reduce access to habitat such as impassable culverts, dams, weirs and levees.
- Wood removal operations in the estuary that significantly reduce habitat complexity and carrying capacity for juvenile salmonids and their prey organisms.
- Levees that eliminate off-channel and side channel habitat.
- Bank armoring with materials such as large rip rap rock that eliminate natural stream margins characterized by wood accumulations, protruding root masses, alcoves and similar natural conditions.

*Indirect Causes:*

- Timber harvest and other land use practices that remove the riparian zone so recruitment of large wood to the channel for both instream and overhead cover is effectively eliminated for many years and water quality is degraded.
- Ramping rates from flow regulation that strand juvenile fish in otherwise good quality habitat or expose them to excessive predation.
- Unscreened diversions such as those for irrigation or other types of water withdrawal like pumps.
- Land use changes such as urban development with increased hardened surfaces that reduce infiltration and storage leading to increased high velocity winter flows and reduced summer flows.
- Permanent reduction in water quality from land use activities that increase turbidity above background levels and introduce toxins from industry and runoff.
- Poor quality forest practices that yard logs across and along stream channels scouring and/or eliminating natural instream cover and altering overhead cover that eliminates shade and protection from predators.
- Long-term seasonal turbidity increases from perennial slope failures, landslides, surface erosion, and similar sources.

#### 4.5.8.2 Techniques to Restore, Enhance and Create Rearing Habitat

Restoration and recovery of high quality rearing habitat will depend on the requirements of the target species. As for spawning habitat, an effort should be made to understand the ultimate cause for the loss of quality or quantity of the appropriate rearing habitat feature(s) and ensure it is being addressed either prior to undertaking instream work or in coordination with it. In some cases, such as permanently hydro-modified reaches (i.e. hydroelectric dams), the natural processes of channel meander, wood accumulation and seasonal flow will never be restored and specific focused measures will be required to restore valuable rearing areas.

Correct direct and indirect causes as listed above to the greatest extent possible. For example, flow regulation and ramping rates from hydroelectric dams can be changed to allow fish redistribution that avoids stranding. Livestock and people can be excluded from streams with durable fencing and rerouting of traffic and use areas. Shading cover can be re-established with riparian plantings of appropriate species (see *Riparian Restoration and Management* technique). Culverts can be replaced that not only restore access to habitat but can also provide habitat inside if they accommodate a natural channel bed with capability for some limited wood accumulation (properly sized and placed culverts should be able to provide this benefit without threat to the structure, see *Fish Passage Restoration* technique).

Other specific measures will depend on the target species and can vary greatly in expense. Techniques to consider include:

- Groundwater fed channels, sloughs, ponds and wetlands can be constructed to provide valuable off-channel rearing habitat for coho and chum salmon when these areas will no longer be created as a consequence of hydro-modification, development, levee construction, or bank armoring that limit flooding and channel migration. The key element of these sites will be their perennial flow of generally cooler water in summer and warmer water in winter that increases fish survival and growth. See *Side Channel / Off-Channel Habitat Restoration* technique.
- Instream structures that create depth, velocity and substrate variation, scour pools and backwater ponds or restore wood accumulation can be built using a variety of techniques as long as they consider the existing and anticipated flow regime of the system. See Section *General Design and Construction Considerations for Instream Structures* and the *Large Wood and Log Jams*, *Boulder Clusters*, and *Porous Weirs* techniques). A summary of criteria and methods for this type of enhancement can also be found in Slaney and Zaldokas[85]. Generally, this type of work will be easier to implement in small streams. In large streams or main river channels, planning, permitting, design and construction will be much more complex and liabilities considerably greater. Large-scale implementation of this technique can be very expensive with less certain outcomes, although it may be the only way to restore holding and rearing areas in the main channel preferred by Chinook salmon, for example.
- Within the estuary, opportunities may exist to restore or improve juvenile fish access to sloughs and distributary channels through removal or modification of tide gates and levees (see *Levee Removal and Modification* technique). Tide gates can be modified or replaced to be open longer during each tidal cycle and with reduced velocities to provide a wider window of access that can match the swimming abilities of juvenile fish. In several cases, tide gates were removed entirely and an appropriately sized culvert installed that by careful

design of its size controlled the amount of water inside the diked area on each tidal exchange. Evaluation has shown juvenile salmonids readily migrate through the culvert and rear in the slough. Dike removal, breaches and setbacks can restore natural freshwater and estuary processes and channels increasing the total amount of freshwater and estuarine area available. Dike or levee modification may require additional work in the slough to hasten recovery.

- Near shore areas can be improved by removal of bulkheads to restore natural shoreline vegetation and beach processes including gravel enrichment that provide the necessary substrate for rearing of some species. Near shore islands can also be built to provide shallow water habitat rich with eelgrass that mitigate for permanent loss of high quality shoreline habitat.
- Hardened bank protection can be removed to not only restore a natural channel bank dominated by native vegetation but also restore flow to side channel and back water areas that can be of critical importance to some species. It can also lead to the natural creation of new channels (see *Bank Protection Construction, Modification, and Removal* technique).
- Rigorous enforcement of forest practice rules, stormwater management guidelines, critical areas ordinances, agricultural setbacks and similar protective measures can correct many deleterious activities associated with land use activities.
- Occasionally, opportunities exist to restore a diverted stream to its former channel or to restore a straightened channel to a more natural meander and length that can greatly restore rearing capability of the reach. Adequate consideration, though, will have to be given to site-specific hydrology, channel hydraulics, geomorphology and similar issues to develop a practical and durable design (see *Channel Modification* technique).
- Where increased pool habitat is desirable for high quality rearing areas and beavers have been exterminated, they can be successfully re-introduced. Beavers and their dam activities were often extremely important in maintaining stream stability, capturing wood, storing water and promoting a well-developed riparian corridor in the pre-European era (see *Beaver Reintroduction* technique).

#### 4.5.8.3 Monitoring

Monitoring will be an important part of the enhancement effort to measure project success and learn what features either need to be changed and/or included or modified in the next effort. The method and timing of evaluation will depend on the species and nature of the habitat. Options include snorkeling, electrofishing, trapping, seining or other safe-capture methods. Levels of use should be evaluated relative to parent escapement to the vicinity and/or river basin, seasonal or annual hydrology in the year of evaluation, degree to which the project has been functioning, and similar factors that can strongly affect findings of fish use.

## *4.6 Glossary*

*Benchmark watershed* – remaining undisturbed watersheds that may be used to research, compare, and monitor stream ecosystems over time[12]

*Biological hot spot* – relatively small intact riverine habitat patches that provide critical functions for the stream or biodiversity. Hot spots can include deep pools for fish habitat, a cold-water tributary junction that provides a small thermal refuge for biodiversity, or a small section of complex, healthy Riverine habitat.[12]

*Passive restoration* - cessation of anthropogenic activities that are causing degradation or preventing natural recovery[3]

*Refugia* – areas with relatively undisturbed healthier habitat and processes that serve as refuges for biodiversity

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