Science Question 3 – What is the current state of knowledge for rehabilitating adverse ecological effects associated with rural-residential and urban development?

Pacific salmonids require access to estuarine and freshwater habitats with clean, cold, well-oxygenated water. Such environmental conditions are created and maintained by physical, chemical, and biological processes that shape hydrology, structural habitat, fish passage, and water quality. Pressures from urban and rural-residential development alter aquatic ecosystems and the processes that form and maintain them. Once altered, several options are available to "fix" the alterations to varying degrees of success. This Science Question evaluates rehabilitation and enhancement techniques in terms of salmonid recovery in urban and rural-residential areas.

Section 10.0: Rehabilitating Aquatic Ecosystems in Developed Areas

In urban and rural-residential areas, efforts to restore ecosystem processes[106] that sustain suitable conditions for salmonids are constrained by municipal infrastructure, such as bridges, dams, roads, buildings, and stormwater and sewage treatment systems (Carpenter *et al.* 2003; Booth 2005; Bernhardt & Palmer 2007). In addition, developed areas have persistent sources of point and nonpoint pollution that could undermine the effectiveness of habitat rehabilitation projects (Paul & Meyer 2001). Consequently, rivers, streams, and estuaries in developed areas cannot be fully restored to unimpaired conditions, but in some cases can be rehabilitated to support salmonid populations (NRC 1996; Booth 2005; Simenstad *et al.* 2005; Roni *et al.* 2008).

In this report, the IMST uses the terms *rehabilitation* and *enhancement* rather than *restoration* when referring to improving environmental conditions for salmonids in developed areas (refer to Text Box on the following page); however, other authors cited herein do not always differentiate between the terms. The general goals of watershed rehabilitation actions are to improve ecosystem processes so that they promote and sustain habitat connectivity, riparian vegetation, water quality, and streamflow regimes (Roni *et al.* 2002; Beechie *et al.* 2008). Enhancement approaches are used as short-term, stream-reach measures that often provide only temporary local benefits to aquatic ecosystems until self-sustaining, habitat-forming processes have been rehabilitated.

In urban and rural-residential areas, rehabilitation actions are frequently planned and implemented at the reach scale and may incorporate one or more techniques. Most rehabilitation and enhancement techniques (e.g., floodplain reconnection, meander construction, fish passage improvement) are implemented throughout the landscape and are not unique to developed areas. However, several water quality improvement approaches (i.e., actions under stormwater management and wastewater treatment) are primarily used in urban and rural-residential areas. Both stormwater management (Section 2.0) and wastewater treatment (Section 3.0) are discussed earlier in this report and are not further reviewed in this Science Question.

[106] Ecosystem processes are basic processes (water and nutrient cycles, energy and material flow, and community dynamics) that work in all landscapes and link organisms to their environment.

Ecological Restoration Terms

In this report, IMST uses the following definitions to distinguish among the terms ***restoration***, ***rehabilitation, mitigation***, and ***enhancement*** when referring to techniques that are intended to improve environmental conditions for salmonids. The following are definitions commonly used for each of these terms. It is important to note that variations do exist depending on the user, but these definitions embody many of the common principles used with the terms.

RESTORATION

'*Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed'.* An ecosystem is considered to be restored '*when it contains sufficient biotic and abiotic resources to…sustain itself structurally and functionally...and demonstrates resilience to normal ranges of environmental stress and disturbance*' (SER 2004, p 3).

The goal of *ecological restoration* is to recover:

- **Ecological function by repairing ecosystem processes, which in turn sustain ecological structure** (NRC 1996; SER 2004); and
- **Biotic integrity by re-establishing pre-disturbance species composition and community structure** (NRC 1996; SER 2004).

REHABILITATION

'*Rehabilitation emphasizes the [repair] of ecosystem processes, productivity and services*' (SER 2004, p 12).

Rehabilitation re-establishes '*self-sustaining conditions that are able to provide some of the ecological requirements'* of the target organisms. In these instances, '*full restoration to pre-disturbance functions and characteristics is unlikely*' (NRC 1996, p 211).

A common goal of *ecological rehabilitation* is to improve ecological function by repairing ecosystem processes, which in turn sustain ecological structure (NRC 1996; SER 2004)

MITIGATION

Habitat mitigation is a substitution technique '*that is intended to compensate environmental damage*'. In the US, mitigation is often '*a condition for the issuance of permits for private development and public works projects that cause damage to wetlands*' (SER 2004, p 120).

A common goal of *habitat mitigation* is to artificially create new habitats at one site to legally compensate for the damage and destruction of habitats at another site (NRC 1996; SER 2004).

ENHANCEMENT

Habitat enhancement is a substitution technique that '*selectively alter*[s] *or modify*[ies] *habitat features to offset the effects of anthropogenic impacts*'. Enhancement techniques can aid in '*improving fish habitat in some instances, but it has not been very successful in improving conditions that sustain productivity*' (NRC 1996, p 212).

A common goal of *instream habitat enhancement* is to improve degraded habitats through the introduction of artificial or temporary structures (NRC 1996).

Within the US, numerous aquatic restoration, rehabilitation, and enhancement projects have been implemented across various land uses, particularly in the Chesapeake Bay region, California, and the Pacific Northwest (Bernhardt *et al.* 2005). In Oregon, several hundred aquatic projects have been funded by OWEB since 1997 with more than 50 of these OWEB-funded projects implemented within urban growth boundaries (Gibbs 2009 pers. comm.[107]; OWEB 1999, 2008). Other local, state, and federal agencies in Oregon have funded numerous projects within urban and rural-residential areas but these projects are not tracked and information on them is not readily available through comprehensive databases.

Section 10.1: Determining Rehabilitation and Enhancement Success

Monitoring the condition of stream biota and various physical, chemical, and landscape features in reference and target areas allows managers to determine the causes and magnitude of degradation and to track the effectiveness of management programs and actions (Booth *et al.* 2004). Implementation and effectiveness monitoring may be conducted on rehabilitation projects. Implementation monitoring determines whether rehabilitation projects were done according to the project design. Effectiveness monitoring determines whether the objectives of the rehabilitation project are being met. Effectiveness monitoring incorporates information from pre-activity assessments, implementation monitoring, and post-activity assessments, which may include data collected several years after implementation.

How or when an activity or project is determined to be successful is influenced by the physical, biological, and social contexts surrounding it. The context, including natural and anthropogenic constraints and desired future conditions, should be established and clearly articulated when the rehabilitation action is planned but are often not specified (IMST 2006). Ideally, rehabilitation plans and effectiveness monitoring plans should be developed simultaneously, carried out at appropriate spatial and temporal scales, and guided by well-articulated goals that can be evaluated using measurable and quantifiable indicators (IMST 2006). In aquatic ecosystems, desired endpoints could include physical (e.g., channel stabilization, decreased bank erosion, improved fish passage, spawning gravel accumulation, or instream cover for fish), chemical (e.g., decreased nutrient loads and concentrations), biological (e.g., more juvenile salmon, more riparian trees), and social (e.g., increased public awareness, project acceptance, or recreational value) outcomes (Woolsey *et al.* 2007). In general, implementation monitoring is more likely to be incorporated into a rehabilitation project than effectiveness monitoring.

SECTION 10.11: FREQUENCY OF MONITORING

Several investigators have concluded that available research and effectiveness monitoring of commonly used rehabilitation techniques are inadequate to evaluate whether or not the goals have been met (e.g., Roni *et al.* 2002; Bernhardt *et al.* 2005; Alexander & Allan 2006; Palmer & Bernhardt 2006). A review the National River Restoration Science Synthesis database of 37,000 projects demonstrated that only 10% of project records reported any type of monitoring (Bernhardt *et al.* 2005). However, in a follow-up study that involved interviewing 317 managers of large projects, 83% of those projects were found to include some type of monitoring

[107] Courtney Gibbs, Oregon Watershed Enhancement Board, Salem, Oregon, personal communication, 2009.

(Bernhardt *et al.* 2007). Reviewing a regional database containing data on over 23,000 restoration and rehabilitation projects in the Pacific Northwest, Katz *et al.* (2007) found that only 6.7% of project records reported any type of monitoring. From that same database, 47 project managers were interviewed and 70% of interviewees felt that their projects had been successful (Rumps *et al.* 2007). However, specific criteria for determining success were not identified for 43% of these projects by the interviewees, and 34% of the projects did not include monitoring sufficient to determine project effectiveness (Rumps *et al.* 2007). Discrepancies between project managers' assessments of success and the amount of monitoring used to document success also occurred in phone interviews conducted in the Chesapeake Bay area (Hassett *et al.* 2007), southwestern states (Follstad-Shah *et al.* 2007), upper Midwest (Alexander & Allan 2006), and southeastern states (Sudduth *et al.* 2007).

Even projects that include monitoring may not produce information that can be compared to or combined with monitoring results from other projects. The lack of standardized monitoring protocols and indicators[108] hinder broad, integrative rehabilitation assessments. In a call for better coordinated monitoring and analyses, Scholz & Booth (2001) recommended several standardized parameters for projects in urban watersheds that can be used with minimal training and equipment (e.g., riparian canopy cover, large wood density) and those that would need additional expertise (e.g., channel gradient, substrate composition). Alexander & Allan (2006) found that only 11% of projects in the upper Midwest had been monitored for effectiveness, that those studies were of dubious quality, and that standardization of monitoring protocols and documentation were urgently needed. In their global review of rehabilitation and restoration studies, Roni *et al*. (2008) were unable to quantitatively compare or analyze information from published studies because of the lack of similarity between protocols used to collect data. In a meta-analysis to determine whether engineered in-stream structure installations (e.g., weirs, large wood, revetments, boulders) effectively increased salmonid abundance, Stewart *et al.* (2009) were only able to use data from 17 of 179 relevant studies.

Once monitoring data have been collected for individual projects or have been combined from multiple projects, the data still may not be adequate to show rehabilitation benefits to salmonid populations or ecosystem processes. Shields *et al.* (2003) concluded that stream ecosystems are highly complex and heterogeneous so they do not meet the assumptions of rigorous experimental designs, are not scalable, and tend to have very long response times which have led to experiments that are not reproducible. Thompson (2006) found that only 12 of 79 published studies on fish habitat improvement structures installed prior to 1980 contained sufficient data to evaluate the effects of the structures on trout populations, independent of fishing pressure. Of these 12 studies, only two analyses demonstrated benefits to trout populations (Thompson 2006). Stewart *et al.* (2009) found that the heterogeneity of salmonid population size and local habitat preference was significant and the effectiveness of instream structures to increase salmonid abundance was ambiguous. More empirical data were needed to determine effectiveness of the structures.

[108] Indicators are characteristics that are chosen to directly or indirectly quantify ecological or environmental conditions. Single-metric indicators are specific biotic (e.g., number of coho salmon) or abiotic (e.g., water temperature) measures while multi-metric indicators are multiple variables integrated into a single index score (e.g., macroinvertebrate IBI; IMST 2007). Which indicators are chosen depend on rehabilitation objectives, on appropriate temporal and spatial scales over which projects will be completed, and on statistical design needs (ISP 2000).

In some situations insufficient monitoring can be corrected. For example, Tompkins & Kondolf (2007) used systematic post-project appraisals (Kondolf & Micheli 1995; Downs & Kondolf 2002) to supplement existing data with new field data and assess seven complex channel rehabilitation projects in California. They found that two projects achieved geomorphic objectives, three were likely to achieve geomorphic objectives, and two were not likely to achieve geomorphic objectives (Tompkins & Kondolf 2007).

Section 10.2: Current State of Knowledge of Various Rehabilitation Approaches

Because of the diverse effects development can have on aquatic ecosystems and the physical, legal, or landowner constraints on rehabilitation that can be present, rehabilitation in urban and rural-residential areas is difficult and the level of success that can be achieved is uncertain (e.g., Paul & Meyer 2001; Booth 2005; Bernhardt & Palmer 2007). At present, what we know about aquatic rehabilitation in developed areas is based on a few case studies and limited monitoring (e.g., Alexander & Allan 2006; Roni et al. 2008) or is anecdotal (e.g., Booth 2005). This section summarizes what is known about the effectiveness of various rehabilitation and enhancement techniques that are being used within urban and rural-residential areas. Published research and monitoring results from developed areas in the western US are emphasized.

SECTION 10.21: EROSION CONTROL

Erosion control of stream banks is common in urban and rural-residential areas for the protection of property and infrastructure (Bernhardt *et al.* 2005; Alexander & Allan 2006; Bernhardt & Palmer 2007). Stream bank erosion control is also incorporated into aquatic rehabilitation and enhancement projects. Stream bank erosion can be addressed using engineered (armored) or bioengineered (vegetative) methods.

Engineered or Armored Bank Stabilization – Stabilizing banks with large rocks (rip-rap) has been a common practice to prevent river and stream banks from eroding. While rip-rap may protect property and infrastructures (e.g., roads), slow local bank erosion rates, and decrease the amount of sediments entering the channel, it may not benefit salmonids. Schmetterling *et al.* (2001) reviewed an unspecified amount of peer-reviewed and non-peer-reviewed literature on the effects of rip-rap on salmonid populations. They concluded that rip-rap did not provide habitat for multiple salmonid species or age classes, rather it reduced the development of salmonid habitats such as undercut banks that provide cover, river channel gravels, and cover provided by streambank vegetation (Schmetterling *et al.* 2001). Kondolf *et al.* (2006) found that bank armoring can increase downstream bank and/or channel erosion in some rivers.

Bioengineered Streambank Stabilization –Vegetation and geotextile fabrics can be used in place of rip-rap or concrete to stabilize streambanks. This process is referred to as bioengineered streambank stabilization (Sudduth & Meyer 2006). Re-vegetation of banks can increase bank stability and may increase aquatic biodiversity (Bernhardt & Palmer 2007). In an urban study in Atlanta (Georgia), bioengineered stream banks improved the diversity of shredder macroinvertebrates (Sudduth & Meyer 2006), but the direct effects on salmonids in developed areas have not been determined.

SECTION 10.22: FISH PASSAGE IMPROVEMENT

Improving fish passage has a long history in the Pacific Northwest and can involve removing, replacing or retrofitting culverts and dam. Bridges typically allow passage of juvenile and adult salmon, as well as sediments and pieces of large wood and can be used as an alternative to culverts (Roni *et al.* 2005, 2008). Most culvert evaluations have been conducted in steep, forested settings, not low-gradient urban and rural-residential areas or in arid, high desert areas. In general, when properly designed, new and retrofitted culverts have been found to produce fairly rapid, positive responses from fish populations with moderate or high abundances (Beechie *et al.* 2008; Roni *et al.* 2008). However, the seasonal and yearly effectiveness of fish passage structures can be limited by low streamflow levels or high water velocities (Roni *et al.* 2008). Some culvert types that allow passage of adult salmonids may not allow juvenile fish passage or may impede movement of other habitat components such as large wood and sediment (Table 10-1; Roni *et al.* 2005, 2008). Current culvert types have also been shown to constrain channels if the culverts are not sufficiently large enough to allow for large flow events or heavy amounts of sediment and wood transported during those events (Roni *et al.* 2005, 2008).

Table 10-1. Summary of culvert types and how they can affect passage of salmonids, sediment, and large wood during large flow events. Table is based on Roni *et al.* (2005).

Culvert type	Provides for salmonid passage		Allows for transport	
	Juvenile	Adults	Large wood	Sediment
Bottomless pipe arch	Yes	Yes	No	Yes
Round corrugated, baffled	Yes	Yes	No	No
Round corrugated, no baffles	*Depends on culvert length and slope*	*Depends on culvert length and slope*	No	No
Smooth, round or box	*Depends on culvert length and slope*	*Depends on culvert length and slope*	No	No
Squash pipe or countersunk	Yes	Yes	No	Yes

Modification and/or removal of dams in developed areas can also provide fish passage to upstream reaches (Berhardt & Palmer 2007), but few cases have been documented. One of the earliest actions was the breaching of the Jackson Street irrigation dam in Medford (Oregon) in the late 1990s (Smith *et al.* 2000). It was assumed that breaching the Jackson Street dam improved passage for coho, Chinook salmon, and steelhead; however, fish numbers were not reported. Other dams on the same waterway continued to prevent fish passage further upstream and to negatively affect water quality (Smith *et al.* 2000) making it difficult to draw conclusions about whether the Jackson Street dam project benefited salmonids.

SECTION 10.23: HYDROLOGICAL CONNECTIVITY

Hydrological connectivity within aquatic systems includes longitudinal, lateral, and vertical movement of water, sediments, and organisms. *Longitudinal connectivity* refers to movement through a stream or river network and can be restricted by dams and reduced flows. *Lateral connectivity* refers to the exchange of materials and organisms between aquatic/floodplain ecosystems and terrestrial ecosystems (Woolsey *et al.* 2007) and can be restricted by levees, mainstem channel incision, and reduced flows (Kondolf *et al.* 2006). The channel modifications that lead to losses in lateral connectivity also restrict access to off-channel habitats such as side channels, backwater sloughs, wetlands, and floodplain habitats during high flows. *Vertical connectivity* is the exchange between groundwater and surface water within a river system (Boulton 2007) and can be restricted by reduced streambed permeability and hydraulic gradient, by siltation of streambed gravels and by channel simplification (Kondolf *et al.* 2006)[109].

In their literature review of rehabilitation technique effectiveness, Roni *et al.* (2008) located 84 papers from 16 countries reporting on attempts to improve hydrological connectivity. Included were papers on levee removal or setbacks (7 total), reconnecting off-channel habitats (11), meander creation (20), constructed habitats (17), dam removal (14), and flow modifications (15). The general consensus by Roni *et al.* (2008) was that rehabilitation techniques tended to improve various physical or biological characteristics, but long-term information was lacking. This was especially the case for urban areas, particularly in arid, high desert regions. Most of the published studies were from forested and rural areas. Only one paper cited by Roni *et al.* (2008), the removal of an irrigation dam in Medford, Oregon (Smith *et al.* 2000), was from a western US urban area. The applicability of the North American forested and rural area studies to Oregon urban and rural-residential areas is not clear because so few studies have documented rehabilitation attempts within developed areas. Modeling results indicate that allowing lateral channel migration improves hydrological processes that benefit salmonids (Hall *et al.* 2007). Levee breaching, establishing set-back levees further away from the channel, and removing rip-rap can re-establish lateral connectivity (Beechie *et al.* 2008; Roni *et al.* 2008), but such actions are constrained in developed areas because of existing municipal infrastructure (Bernhardt & Palmer 2007). Since the completion of Roni *et al.*'s (2008) review, a few other studies have been published covering rehabilitation actions implemented in developed areas. These are summarized below.

Levell & Chang (2008) reported the results of a case study on a channel restructuring project carried out on a reach of Kelley Creek (a tributary of Johnson Creek in Portland, Oregon) that had been previously widened, deepened, and armored for flood control. The rehabilitation project reconnected historical meanders, re-graded the channel slope, removed channel fill, created backwater channels, and added instream structures (large wood, cobbles, and gravels) to the channel. The project reach was compared to reaches of Kelley and Richardson Creeks that had been either disturbed by development or that represented pre-development conditions. Comparisons were made one and two years after the project was completed. In that time-frame, the authors reported that residual pool dimension did not substantially change, but particle size

[109]Hyporheic rehabilitation of stream channels attempts to improve vertical connectivity. Boulton (2007) speculated that the removal of fine sediments from gravel and cobble or placement of wood and other structures could improve movement of water between the surface and hyporheic zone but available approaches have not been studied in any ecosystem and are not covered in this report.

and cross sectional geometry did change on the project reach. The authors concluded that the change in particle size likely indicates that the channel is aggrading (thereby negatively affecting pool-riffle sequences and spawning gravels) and may be reflecting larger sediment problems in the watershed (Levell & Chang 2008). The authors also concluded that the project reach appeared more stable than the reach affected by development but was less stable than the reach representing pre-development conditions.

In urbanizing areas of the San Francisco Bay region (California), Tompkins & Kondolf (2007) conducted post-project evaluations on seven compound channel rehabilitation projects. The compound channels were designed to maintain low flow channel areas to convey water year around and included adjacent, flat constructed floodplains to convey water during high flows. Tompkins & Kondolf (2007) found that two projects (Green Valley and Miller Creeks) achieved geomorphic objectives and three projects were likely to achieve geomorphic objective with time (Lower Guadalupe River, Lower Silver and Tassajara Creeks). Four projects met in-channel and floodplain habitat objectives (Lower Guadalupe River, Alamo, Green Valley, and Miller Creeks) and one was likely to do so with more time (Lower Silver Creek) and the other two (Wildcat and Tassajara Creeks) likely would require minor interventions to achieve objectives. Four projects also met water conveyance objectives (Lower Guadalupe River, and Alamo, Miller, and Tassajara Creeks) with the other three (Wildcat, Green Valley, and Lower Silver) likely to meet objectives after minor interventions.

A rehabilitation approach that was not addressed in the review by Roni *et al.* (2008) is s*tream daylighting*. The technique is unique to urban areas and re-exposes covered stream channels to daylight and allows for seasonal flooding. Converting piped streams to open streams may be very important in urban areas for improving water quality and fish passage to upstream areas (Berhardt & Palmer 2007). Stream daylighting has been accomplished in several places in the US, but no comprehensive studies documenting changes in aquatic ecosystems and fish populations have been conducted. Buchholz & Younos (2007) reviewed 19 stream daylighting case studies across the US and found 8 that had been completed in western states. Of the 19 projects, Buchholz & Younos (2007) found that only five had been done to improve aquatic habitat or water quality. The majority of the projects were done to benefit people and most often were included as part of newly created parks or to alleviate flooding problems associated with piped streams and stormwater. Only 1 of the 5 projects completed to improve aquatic ecosystems had implemented post-treatment monitoring that included vegetation, stream, and fish responses over a three year period. The other 4 included minimal "unofficial" monitoring (i.e., not a post-project requirement) consisting of short-term visual assessments. Because of the lack of available projects and monitoring, Buchholz & Younos (2007) were not able to draw any comprehensive conclusions about water quality improvements, aquatic ecosystem benefits, or fish responses to stream daylighting.

SECTION 10.24: RIPARIAN VEGETATION

Rehabilitation of riparian vegetation in developed areas may focus on providing stream bank stability, channel shading, filtering sediment and nutrients or other compounds from stormwater runoff, or the control of non-native invasive plant species.

Native Riparian Vegetation – Riparian vegetation plantings are one of the most frequently implemented rehabilitation techniques (Bernhardt & Palmer 2007). Riparian tree plantings are frequently conducted in the Pacific Northwest using techniques based on silvicultural practices that emphasize the replacement of hardwoods with conifers along forested streams (reviewed by Roni *et al.* 2002). Despite the frequency of riparian plantings in forested, rural, and urban areas there have only been few a short-term, and no long-term (> 10 years), evaluations of plantings in developed areas. Available information is typically anecdotal (e.g., Booth 2005).
In the evaluations of riparian vegetation plantings in temperate Pacific Northwest forests, herbivory by wildlife was commonly identified as a problem that restricted planting success (reviewed by Roni *et al.* 2002). Wildlife herbivory may not be a primary constraint in developed areas that have experienced soil compaction and changes in water tables and seasonal drainage. In general, authors have suggested riparian vegetation plantings along developed stream channels are more likely to persist if hydrological impacts related to increased impervious surfaces and flow modifications are also addressed (e.g., Groffman *et al.* 2003). Others suggest that replanting aquatic vegetation in native wetlands and estuaries in developed areas can be successful if hydrological connections remain intact (e.g., Roni *et al.* 2008). These conclusions, however, are not currently supported by monitoring or research data because of the lack of long-term monitoring of riparian plantings.

Non-Native, Invasive Plant Species – Riparian plantings are often conducted in concert with the removal of non-native, invasive plant species (Bernhardt & Palmer 2007). Once non-native, invasive plants have been removed, ongoing control and ecosystem improvement are often required to prevent their re-establishment (Bernhardt & Palmer 2007). As with general riparian plantings, no large-scale or long-term evaluations have been conducted on the effectiveness of removing invasive species and replanting with native or non-invasive, non-native species. In a review of the scientific literature on urbanization effects of soils, Pavao-Zuckerman (2008) found that developed land uses can create new soil conditions not found in natural areas by removing organic and topsoil layers or by raising or lowering the water table. These modified soils may not be able to support native vegetation without considerable effort to change the altered physical, chemical, and biological characteristics of the soil. Urbanized soils may also promote invasion and establishment of non-native organisms, including plants and soil invertebrates. For example, Sharp (2002) found Portland (Oregon) riparian area soils had been modified by urbanization. The modified soils contributed to the establishment and perpetuation of non-native plant species including reed canary grass (*Phalaris arundinacea*) and Himalayan blackberry (*Rubus armeniacus*).

SECTION 10.25: INSTREAM HABITAT IMPROVEMENT

Installing habitat structures such as gabions, weirs, large wood, boulders, or gravel substrate in streams, rivers, and estuaries is commonly done to improve salmonid habitat by increasing the size and numbers of pools or accumulations of spawning gravels. Most available research and published evaluations (e.g., Thompson 2006; Roni *et al.* 2005, 2006, and 2008) are on instream structures placed in forested stream reaches that were altered by logging operations. Roni *et al.* (2008) found in a comprehensive review that results were highly variable, but tended to have positive impacts on physical habitat. Positive fish responses to instream structures have also been reported, but Roni *et al.* (2005) found that most results were inconsistent because of the variability associated with the techniques and the ecosystems treated, and few responses were monitored sufficiently to detect statistically significant changes. In a recent meta-analysis of data from 17 engineered instream structures (e.g., weirs, revetment, deflectors), Stewart *et al.* (2009) found the evidence for structure effectiveness to be ambiguous. While information can be gleaned from these studies, the overall effects instream habitat structures may have in aquatic ecosystems affected by development, particularly low-gradient channels in extensively urbanized areas, may not be similar to those reported in high-gradient, forested streams. Urban watersheds may experience more severe hydrologic conditions than forested streams that could limit the effects that instream structures have on salmonid habitat in urban areas (e.g., Larson *et al.* 2001; Booth 2005).

Water quality impairment in urban and rural-residential areas may also mask biological responses to instream structures. Larson *et al.* (2001) examined the effectiveness of large wood placed at six urban stream reaches in the Puget Sound region (Washington). Wood was installed at five of the sites within 4 years of the study while the wood at the sixth site had been placed 10 years earlier. Half of the projects used anchored wood pieces. Based on physical stream conditions, Larson *et al.* (2001) found that the wood did increase, at least slightly, sediment storage and habitat complexity. Larson *et al.* (2001) also found that benthic macroinvertebrates did not increase with large wood placements in Seattle (Washington), and concluded that the IBI scores were directly related to watershed condition not local habitat structures.

Substrate improvement is used to diversify fine and coarse bed materials and to replace lost spawning gravels for salmonids in streams affected by development. The natural recruitment of spawning gravels is reduced by dams constructed upstream of urban areas that block the downstream movement of fine sediments and gravels during high flows. Projects can include the installation of gabions and weirs to trap gravels as they move downstream or adding gravel directly to the stream bed. Roni *et al.* (2008) reviewed 14 published studies (worldwide) that examined salmonid responses to these types of instream habitat improvement. Of those, 13 reported some type of positive response in terms of salmonid spawning activity or of abundance of adult or fry fish, but none were from developed areas in western North American.

A few gravel augmentation studies in highly degraded stream systems are available for the Pacific Northwest but most are anecdotal (e.g., Madsen Creek in Seattle, Washington reported by Booth (2005)). Merz & Setka (2004) evaluated the effect augmented gravel had on Chinook spawning in the Mokelumme River, a flood-controlled river in central California that is highly disturbed by instream gravel and gold mining plus other activities. Adult Chinook salmon used the site for spawning during the three spawning seasons studied and redds were present but no assessment of egg development or fry production was done (Merz & Setka 2004). In a companion study, Merz *et al.* (2004) found that Chinook salmon embryos planted (in egg-incubation tubes) in enhanced gravel areas had higher rates of survival to the alevin stage than those in non-enhanced areas. Merz & Ochikubo Chan (2005) reported that benthic macroinvertebrates quickly colonized added gravels and macroinvertebrate biomass and densities of the enhanced sites were similar to non-enhanced sites within four weeks. Problems associated with substrate augmentation include the gravels being covered by fine sediments or moved downstream during high flows requiring additional augmentation over time (Roni *et al.* 2002), or gravels being colonized by aquatic vegetation in dam regulated reaches (Merz *et al.* 2008).

Section 10.3: Common Assumptions about Successful Aquatic Rehabilitation

Authors discussing rehabilitation efforts and apparent short-falls of actions implemented on the ground often conclude that unless reach-scale rehabilitation projects are coordinated with efforts that address watershed-scale constraints governing flow regimes and water quality, the reach-scale efforts will not be successful (e.g., Frissell & Nawa 1992; Muhar 1996; Booth 2005; Wohl 2005; Bernhardt & Palmer 2007; Jansson *et al.* 2007). Based on their conceptual model, Booth *et al.* (2001) argued that the failure to consider all factors limiting stream biota such as flow regime, physical habitat structure, water quality, energy source, and biotic interactions is a common reason for the failure of rehabilitation projects. In general, re-establishing natural flow regimes and improving water quality are of primary importance for success of many rehabilitation actions, but are difficult to accomplish (Carpenter *et al.* 2003; Booth 2005; Simenstad *et al.* 2006; Bernhardt & Palmer 2007). It is also assumed that rehabilitation project success is severely limited if the projects or actions are implemented at the wrong spatial and/or temporal scales, if base causes of impairment are not addressed, and new development continues in the watershed. This is not to say the authors are incorrect; however, the information to support or oppose their assumptions are not currently available. Stewart *et al.* (2009) also came to a similar conclusion on the effectiveness of engineered in-stream structures. Monitoring data are also not available to determine when certain types of rehabilitation actions in developed areas will be most successful at achieving ecological goals under a given set of conditions (Bernhardt & Palmer 2007; Stewart *et al.* 2009).

The following section discusses some of the common assumptions of watershed and aquatic rehabilitation as the basis for determining monitoring and research needs for Oregon.

SECTION 10.31: PRIORITIZING REHABILITATION EFFORTS

Remedying the effects of existing developed areas on water quality, flow regime, and aquatic ecosystem function is challenging. Given the millions of dollars committed to watershed rehabilitation and the uncertainty associated with rehabilitation effectiveness, there is a need to prioritize rehabilitation actions based on their potential for benefiting salmonids and watershed functions (Roni *et al.* 2002; Jenkinson *et al.* 2006; Bernhardt & Palmer 2007; Jansson *et al.* 2007). Rehabilitation of ecosystem processes at the watershed-scale is assumed to have a much greater likelihood of long-term success (as reflected in salmonid recovery) than enhancement of individual habitat characteristics at the reach-scale (Beechie & Bolton 1999).

In recent years the focus of some rehabilitation projects has shifted from localized reach-scale actions to watershed-scale approaches, but most urban rehabilitation projects are still planned at the reach scale (Beechie *et al.* 2008). Ideally, aquatic rehabilitation actions would be planned at the watershed-scale and involve establishing rehabilitation goals and determining a sequence of actions that progress toward those goals (Beechie *et al.* 2008). The following priority of actions has been suggested for watershed level aquatic restoration and rehabilitation actions (Bradbury *et al.* 1995; Roni *et al.* 2002; Beechie *et al.* 2008):

1. Protect intact habitats.
2. Rehabilitate ecosystem processes in degraded habitats.
3. Enhance instream habitat in degraded habitats.

There is general agreement among scientists and land managers that maintaining ecological processes and existing high-quality habitat is much easier than rehabilitating degraded ecological processes and habitat (NRC 1992; Bradbury *et al.* 1995; NRC 1996; Booth *et al.* 2001, 2004; Roni *et al.* 2002; Bernhardt & Palmer 2007; Beechie *et al.* 2008; Roni *et al.* 2008). Protecting high quality habitat through low impact development techniques (LID), mitigation, and other measures was addressed in Science Question 2.

Roni *et al.* (2008) further developed sub-priorities for rehabilitating ecosystem processes. Under their prioritization, the factors that are most limiting the biological responses to rehabilitation should be addressed first, such as water quality and flow regime (Roni *et al.* 2008). As addressed in Science Question 1, stormwater runoff and wastewater effluent are significant sources of water quality impairment in aquatic ecosystems affected by urban and rural-residential development. Stormwater is also a major contributor to channel erosion, high instream sediment levels, and loss of hydrologic function. Water impoundments, including flood control systems, also alter flow regime in watersheds where large urban and rural-residential developments are present (Carpenter *et al.* 2003; Booth 2005; Simenstad *et al.* 2006; Bernhardt & Palmer 2007). Reach-scale habitat actions may be short-term, small-scale fixes that occasionally benefit aquatic biota, but they should not be expected to rehabilitate aquatic community structure unless the hydrologic regime and water quality are also returned to a more natural state (Blakely & Harding 2005; Bernhardt & Palmer 2007). Therefore, several authors suggest that it is important to begin to address major streamflow and water quality issues early in the process of rehabilitation (e.g., Booth 2005; Bernhardt & Palmer 2007; Roni *et al.* 2008).

SECTION 10.32: TIME DURATIONS ASSOCIATED WITH REHABILITATION EFFORTS

The length of time it takes for a stream reach or watershed to respond to rehabilitation actions or structures and how long those actions or structures may last on the ground have also been considered important issues by several authors (Table 10-2). Since many rehabilitation techniques are fairly new and have not been implemented across a wide variety of regional or climatic conditions or monitored in-depth, these timelines at best can be considered as general guidelines for management and monitoring. This is particularly the case for applying the information to urban and rural-residential areas because most of the information for the Pacific Northwest is based in west-side forests.

Table 10-2. Rehabilitation characteristics. This table gives a summary of general spatial and temporal characteristics of rehabilitation and enhancement categories that have been or could be used in developed areas (based on Bernhardt & Palmer 2007; Beechie *et al.* 2008; Roni *et al.* 2002, 2008).

Approach	Approach Characteristic		
	Spatial Influence	Longevity of Action (years)	Lag-time until Influence (Years)
Erosion Control	channel network/ stream-reach	Variable	~1–5
Fish Passage Improvement	watershed/ stream-reach	10–50+	~1–5
Hydrological Connectivity			
o Flood Plain Reconnection	watershed	10–50+	1–20
o Off-Channel Habitat Creation	watershed/ stream-reach	10–50+	1–10
Riparian Area Vegetation	watershed/ stream-reach	10–50+	1–50
Instream Habitat Improvement			
o Structures	watershed/ stream-reach	~5–20	~1–5
o Substrate	stream-reach	~1–5	~1–5

Section 10.4: Information Needs for Rehabilitation in Developed Areas

Rehabilitation of aquatic ecosystems in urban and rural-residential areas can be expected to have a high level of uncertainty for success (i.e., positive impacts on native salmonids). As has been discussed, the empirical evidence to support which rehabilitation or enhancement techniques are effective under any given situation in developed areas is not generally available. As with aquatic ecosystem restoration and rehabilitation in general, the following major elementary knowledge gaps remain:

- The selection and implementation of techniques for specific regional, site, and watershed conditions;
- The level and timing of specific physical and biological (including salmonid) responses to various rehabilitation and enhancement techniques; and
- How multiple rehabilitation efforts within watersheds affect salmonid populations and their habitats.

While cumulative, global information is being synthesized (e.g., Roni *et al.* 2008) it has not been established if and how these results are applicable to developed lands in Oregon, particularly among the climatic differences between Oregon regions (i.e., coastal, temperate west-side, arid central and eastside). In order to address these information needs and to allow managers to determine rehabilitation goals, proper rehabilitation actions and comprehensive monitoring networks are needed. These would include the establishment of standardized monitoring parameters and protocols that could be integrated into regional analyses by multi-institutional monitoring programs (e.g., Paulsen *et al.* 2008; Mulvey *et al.* 2009).

Key Findings: Rehabilitation effectiveness
• Without the availability of comprehensive, long-term, and integrative monitoring data, it will not be possible to determine how rehabilitation actions are affecting aquatic ecosystems and salmonids in developed areas and how those actions are contributing to salmonid recovery in Oregon.
• Rehabilitation and enhancement techniques are being implemented in urban and rural-residential areas but the effectiveness of these actions is unknown.
• Current levels of monitoring are not adequate to determine the effectiveness of rehabilitation techniques and actions being used, either individually or in concert, in urban and rural-residential areas.
• The current state of knowledge of common rehabilitation techniques implemented in urban and rural-residential areas is based on forested and rural areas which may not be directly applicable to highly altered or degraded stream systems present in many developed areas, or to arid conditions in central and eastern Oregon.