CHAPTER 2

THE RIVERINE ENVIRONMENT

Before beginning any bank stabilization project, it is important for designers to understand the physical and biological features of riverine environments. While it is necessary to understand the individual aspects, it is equally important to understand how these features interact. This chapter discusses the basic elements of river systems, the functions and values of riparian areas, and describes fish communities in Pacific Northwest rivers.

The western slope of the Cascade Range has a diverse array of rivers, including six major systems in King County: the South Fork Skykomish, Snoqualmie, Sammamish, Cedar, Green, and White (Figure 2.1). Within these river basins are hundreds of smaller streams that flow through forested, rural, and urbanizing watersheds. As the population of the area grows, the number of people who reside near rivers increases, placing a greater number of citizens at risk from naturally occurring river processes such as flooding and channel migration. Although dams on several of the larger rivers have reduced flooding, they have not eliminated it. This greater population also increases the number of human intrusions on watershed and riverine areas. These intrusions often modify flow regimes and local channel characteristics. Through the permitting process and protection of sensitive areas, various government agencies seek to minimize the adverse effects of human activities on the riverine areas.

2.1 STREAM DYNAMICS AND CHANNEL EROSION PROCESSES

2.1.1 FLOODPLAIN FORMATION

Most rivers in the inhabited areas of King County are entirely alluvial, i.e., their bed, banks, and floodplain are composed of materials deposited by water. Because this material can again be transported by the river, both the bed and the banks of the river are moveable boundaries. The floors of river valleys are composed of alluvium deposited by the river as it migrates back and forth across its floodplain. Floodplains are continually reworked as a river moves laterally, eroding one bank and depositing bedload material in a bar on the opposite bank. Under equilibrium conditions, erosion of one bank is balanced by deposition on the opposite bank. Because of this balance, the width and depth of the channel normally do not change appreciably over time.

As the river continues to move laterally away from a newly-formed bar, water-tolerant vegetation such as willows, cottonwoods, and alders begin to grow on the highest parts of the bar, furthest from the river channel. Deposits of large woody debris on gravel bars can facilitate the establishment of vegetation. During floods, this brushy young vegetation resists erosion and reduces water velocity enough to promote deposition of fine sediment suspended in overbank flows. This process results in the formation of a two-part bank, with coarser bed and bar sediment overlain by fine overbank deposits. As each flood deposits more sediment on the overbank area, the floodplain will continue to grow vertically. As the floodplain elevation increases, these areas are inundated less frequently which allows woody vegetation to become established. The original willows and alders grow into a more diverse riparian forest that is eventually succeeded by a coniferous forest. In time, when the river again reaches this part of the floodplain through lateral migration, these trees will be undercut by bank erosion and fall into the river, supplying large woody debris (LWD) to the river system.

The height of the banks above the river bed is governed by the size and frequency of flood flows which the river carries. Most natural rivers overtop their banks once every one to two years. Thus the floodplain is an integral part of the river system

Figure 2.1 Location of the major river systems in King County.

and water conveyance during floods. Due to changes in climate or other conditions, the valley floor may contain remnants of abandoned floodplains (i.e., terraces) that, depending on their height, are infrequently or never flooded (Figure 2.2). Unusually high terraces consisting of glacial sediments line the edges of some King County river valleys such as that of the Raging River.

2.1.2 SEDIMENT SIZE AND BANK COMPOSITION

In general, resistance to bank erosion increases with increasing grain size. Thus, a bank composed of cobbles is less erodible than a bank composed of sand. The presence of cohesive silt and clay also increases resistance to bank erosion.

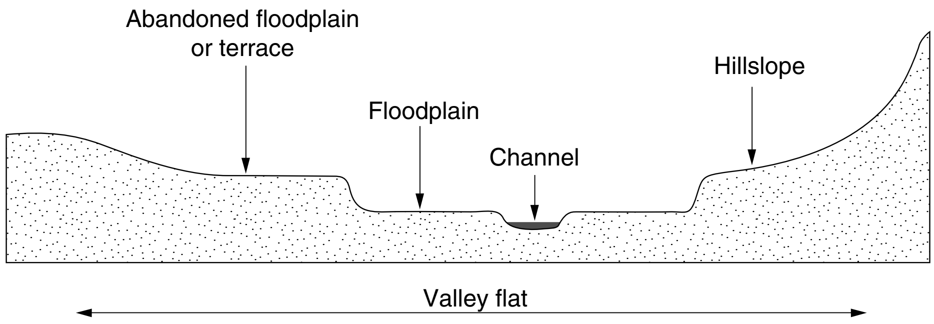
The size of sediment that a river transports is determined by basin geology, water discharge, and river bed (channel) gradient. As discussed later, sediment size affects bank erodibility, channel pattern, and the predictability of channel changes. In general, the smaller, steeper rivers in King County are gravel-bedded, while the largest, longest rivers are sand-bedded, particularly in their lower sections. Sediment size generally decreases with distance downstream from a river's mountainous headwaters because as channel gradient decreases, the river can no longer transport coarser sediment.

Sediment size can increase locally where steep tributaries or valley wall erosion deliver coarse sediment to the river channel. Bed material in the upper Snoqualmie River, for example, is dominated by gravel and cobbles. In the lower Snoqualmie River, the median bed material size declines to fine gravel and eventually sand, with coarser sediment occurring for short distances downstream of three major tributaries (Booth et al. 1991).

River banks composed of non-alluvial materials, such as bedrock or glacial deposits, are common on smaller King County rivers with narrow floodplains (e.g., the Raging River). Non-alluvial banks can also occur along large rivers where the channel abuts a glacial terrace or valley wall. While bedrock outcrops occur locally, the most frequently encountered non-alluvial materials in the Puget Lowland are glacial deposits. Although bedrock erodes over geologic time, it can be considered non-erodible for design purposes. However, glacial deposits exhibit varying degrees of erodibility depending on grain size and density. Deposits compacted by glacial ice (advance outwash, till, advance glaciolacustrine deposits, and all pre-Vashon deposits) are generally more erosion resistant than alluvium.

Glacial till, if not too fine-grained, can form nearly-vertical banks that erode very slowly. River banks composed of sediment deposited at glacial margins or by the retreating glacier and therefore not compacted by ice (e.g., recessional outwash, recessional glaciolacustrine deposits, and most ice-contact deposits) can erode very rapidly.

Figure 2.2 **Valley cross-section showing relation of present channel to the floodplain and a terrace (abandoned floodplain).**



In addition to simple bank retreat, deep-seated landslides can occur in high banks of fine-grained glaciolacustrine deposits undercut by a river. Due to the buildup of groundwater over relatively impermeable till or glaciolacustrine sediments, landslides can also occur in overlying layers of coarse-grained sediments. As a result, geotechnical advice should be sought for high non-alluvial banks if there is any possibility of slope instability.

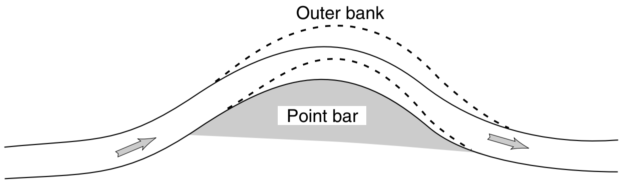
2.1.3 CHANNEL PATTERN AND CHANNEL MIGRATION PROCESSES

Although alluvial river patterns (planforms) are often classified as straight, meandering, or braided, there actually is a continuum of forms. Sinuosity, defined as channel length divided by valley length, is an index of the degree of meandering of single-thread rivers. Rivers with a sinuosity above 1.5 are referred to as meandering; rivers less than 1.5 are referred to as sinuous. Sinuosity correlates well with the type of sediment transport and hence channel slope and grain size. Meandering is best-developed in rivers whose banks contain sufficient silt and clay to be cohesive and to limit the rate of erosion. High sinuosity also occurs in reaches of coarse-sediment rivers where meander bends impinge on valley walls. Low sinuosity (less than 1.3) and shallow, wide channels are typical of bedload-transporting rivers with weak, non-cohesive gravel or sand banks (Schumm 1977). Straight channels (sinuosity of 1.0) are rare in alluvial rivers and often often short-lived, since meanders will tend to develop naturally. Straight channels are more common in steep, narrow mountain valleys.

Bank erosion occurs when the boundary shear stress (a measure of the force per unit area exerted by the water on the bank or bed) exceeds the shear strength (the internal resistance of the soil to movement) of the channel boundary. Shear stress, which increases with increased water surface slope and depth, tends to be greatest along the outside of river bends.

Lateral migration of meander bends is the dominant erosion process in meandering rivers. Convergence of flow causes erosion of the outer bank near the downstream end of a bend, concurrently with deposition of sediment in a point bar in the inside of the bend. If a bend already has a stable amplitude and wavelength, the entire bend moves laterally downstream while essentially maintaining its shape (Figure 2.3).

Figure 2.3 Lateral migration.



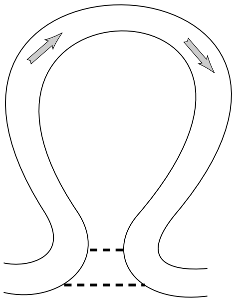
Note: Dashed lines denote channel position after migration takes place.

The same bend may last for years without major changes in planform. In a well-developed meander bend undergoing lateral migration, the locus and direction of future bank erosion are somewhat predictable over the short-term. If the bend is located in a river reach with a lower than characteristic sinuosity, it is likely that the bend will grow outward as well as downstream.

The size and tightness of meander bends are limited by cutoffs in which the river abandons a bend and takes a straighter, steeper path. As a meander bend develops (radius of curvature decreases), the water slope decreases upstream of the bend. This promotes deposition in the channel and diversion of flow and a consequent cutoff. Neck cutoffs (Figure 2.4) occur only on very tight bends, and hence are generally found on low-gradient rivers with fine-grained banks. Good examples of tight bends and the oxbow lakes left behind by neck cutoffs are found along the Snoqualmie River.

Formation of new channels by chute cutoffs and avulsions (Figures 2.5 and 2.6) is common in gravel-bed rivers with a large sediment load, particularly in reaches where decreasing gradient or widening of the valley causes sediment deposition. Under these conditions, sediment deposition can rapidly fill the existing channel and promote the rapid switching of flow (avulsion) into a backbar

Figure 2.4 Neck cutoff.



Note: *Dashed lines denote channel position after migration takes place.*

channel (Figure 2.5) or into an entirely new channel across the floodplain (Figure 2.6). Large woody debris jams that block a significant portion of the channel can also cause avulsions. The development and growth of meander bends in gravel-bedded rivers is severely limited by chute cutoffs and avulsions, which tend to destroy bends before they can become large. Consequently, gravel-bedded rivers tend to be straighter than rivers with cohesive, fine-grained bed materials. In extreme cases, multiple chute cutoffs and avulsions can produce a braided channel pattern.

Cutoffs and avulsions can occur abruptly and often catastrophically. After a cutoff or avulsion takes place, flow progressively diminishes in the abandoned channel as its entrance becomes plugged with sediment. Because the steep slope of the new channel enables rapid erosion, the new channel may widen and deepen rapidly as it progressively carries more of the flow. Erosion on such developing channels can be both rapid and unpredictable. Deposition of the eroded material from the developing channel will occur where the gradient decreases downstream of the cutoff or avulsion. This, together with the changed angle of attack of the river, promotes bank erosion downstream. Although the timing and precise location of cutoffs and avulsions cannot be predicted, inspection of bend and floodplain morphology and historic aerial photographs should occur as part of most bank stabilization projects. This analysis can yield valuable insights into the frequency of such events and possible paths which the river might take in the future. In reaches where cutoffs and avulsions have occurred or are anticipated, design of bank protection should be undertaken cautiously, realizing that the life of the project may be limited by changed conditions.

2.1.4 RIVER DYNAMICS

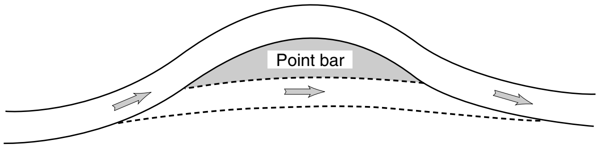
A river adjusts its bed, banks, channel location and pattern to transport the water and sediment discharge it receives from upstream. By depositing or eroding sediment from its bed and banks, it can adjust its width, depth, slope, size of bed material armor and channel pattern. Since multiple adjustments can occur in response to a change in water and sediment load, it is not always possible to predict the nature of a river's response. Nevertheless, generalized relationships have been developed which relate changes in sediment or water discharge to possible changes in channel morphology (e.g., Schumm 1977; Heede 1986). Given enough time, these changes in channel morphology enable the river eventually to adjust to the new water and sediment regime, at which point it will stabilize.

An increased load of sediment (in particular, coarse sediment transported by the river as bedload) into a reach will result in deposition if the river cannot transport sediment through the reach as fast as it is supplied. Depositional zones generally occur where channel slope decreases abruptly, where a river widens downstream, in backwater areas upstream from channel constrictions, or where a steep tributary enters a larger river. By depositing sediment and raising its bed (aggradation), the river locally increases its slope and the energy with which it can transport sediment through the reach. Another common response to an increase in sediment load is widening of the river channel. Deposition of sediment will also tend to promote cutoffs and avulsions, which straighten the channel and increase its slope. Channels in which deposition has occurred can often be recognized by their high width-to-depth ratios and the presence of voluminous sediment deposits.

If sediment load decreases, the opposite responses will occur. The channel may narrow (as vegetation grows on formerly active bars), deepen, or become more sinuous. If braided, it may revert to a single-thread pattern. Channels which are becoming narrower and deeper can often be recognized by their lower width-to-depth ratio, unusually high banks, and small or absent bars.

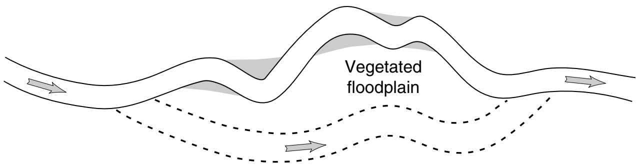
An increase in discharge (the size and number of floods) increases the energy available for erosion, causing the channel to enlarge to accommodate the increased flows. Enlargement may involve both widening and deepening and an increase in bend wavelength. If the increase in discharge is not accompanied by an increase in sediment load, the slope of the river bed will decrease. In some cases, this will result in a coarser streambed until the river's sediment transport capacity again matches its sediment load. Slope may decrease due to erosion of the bed (degradation) or due to increases in bend wavelength or sinuosity. A decrease in discharge will tend to promote the opposite responses.

Figure 2.5 Chute cutoff.



Note: *Dashed lines denote channel position after migration takes place.*

Figure 2.6 Avulsion.



Note: *Dashed lines denote channel position after migration takes place.*

As the above examples imply, river channel responses to changes in sediment or water discharge are complex. A change in one reach of river can result in slope adjustments to which reaches upstream and downstream may also adjust. In addition, the cause or nature of the changes to which the river is responding may not be identifiable. Often, simple field observations will enable the designer to determine whether the river reach of interest is aggrading, degrading, or relatively stable.

2.2 FUNCTIONS AND VALUES OF RIPARIAN SYSTEMS

When evaluating various project designs, it is important to consider not only the physical setting and effects of the project, but also its biological context. Projects installed without considering the surrounding biological communities can have negative effects on fish and wildlife resources. The presence of valuable fisheries resources in many King County rivers makes biological considerations particularly important issue in bank stabilization design.

2.2.1 THE RIPARIAN CORRIDOR

The riparian corridor is an ecologically distinct area bordering rivers and streams. The width of this zone varies with the topography, climate, and other factors. It is an area where soils are often saturated and periodically inundated. Because of the proximity of surface and ground water, which produces unique water and soil conditions, vegetation in riparian areas is usually very different from that of upland areas. This is especially true in larger, low-gradient rivers such as the Snoqualmie River, where cutoff oxbows, backwaters, and high water tables create unique biological communities not found in smaller, steeper streams.

To understand the effects of various project design options, it is important to understand the influence of riparian systems on streams. The various functions of riparian systems have been reviewed by many authors (Karr and Schlosser 1977; Meehan et al. 1977; Budd et al. 1987; Raedeke 1988; Bilby 1988; Murphy and Meehan 1991; Gregory et al. 1991; Beschta 1991; Castelle et al. 1991).

Bilby (1988), in discussing the major interactions between aquatic and terrestrial ecosystems, says that upland and aquatic systems are intricately interconnected physically, chemically, and biologically. Thus, because they affect one another, impacts to either can impact the other.

Upland areas influence riparian areas by affecting the shape of stream channels, by controlling the type, rate, and amount of material passing through the system, and by providing a primary source of food and other nutrient inputs to the stream channel. Changes in these factors often lead to changes in the species composition and age structure of plant, fish and wildlife populations.

Some commonly recognized functions of riparian zones include (adapted from Castelle et al. 1991):

- stabilizing streambanks and resisting erosion;
- filtering suspended solids, nutrients, and harmful or toxic substances;
- moderating the microclimate of the riparian system; and
- supporting and protecting fish and wildlife species.

Other important functions are not commonly recognized. These include moderating impacts of stormwater runoff, protecting and buffering stream habitats from adverse impacts, and maintaining and enhancing habitat diversity and integrity, and providing migration corridors for fish and wildlife. Riparian zones are also sources of large woody debris which is an important habitat component in aquatic ecosystems.

The composition of riparian plant communities is defined by the interaction of several environmental factors including available soil moisture, light, and length of growing season. Each of these factors results from interactions of other variables. For example, soil moisture is dependent on precipitation, depth to water table, drainage and permeability. Precipitation and growing season, which are affected by climate and elevation, also influence species composition. Composition and density of the overstory determines light levels on the ground, and thus affects understory composition.

In the Pacific Northwest, riparian vegetation can directly and significantly influence the physical conditions of the stream environment. The roots of riparian vegetation stabilize streambanks, retard erosion, and create overhanging cover for fish. The above-ground portions of plants dissipate the energy of stormflows, obstruct the movement of sediment and detritus, and provide large organic debris to streams (Meehan et al. 1977; Bottom et al. 1985; Hunter 1991; Sedell and Beschta 1991). Sedell and Beschta provide many insights on the interaction and influence of streamside vegetation on stream hydraulics.

Erman et al. (1977), Roby et al. (1977), Meehan et al. (1977) and Murphy and Meehan (1991) discuss the importance of overhead canopy shade and input of organic matter from the riparian zone to the aquatic and terrestrial invertebrate communities. Meehan et al. state that the food base for the benthic invertebrate communities of forest streams consists of leaves, needles, cones, twigs, wood, and bark. The insect communities that live on this plant material are a significant food source for trout and juvenile salmon. In fact, the most widespread and important foodstuff of running-water fishes is invertebrates (Hynes 1970; Meehan et al. 1977; and Reiser and Bjornn 1979). During summer periods, 40 to 50 percent or more of the diet of stream- dwelling trout and juvenile salmon consists of terrestrial insects (Hynes 1970). These insects usually enter streams by falling off riparian vegetation (Reiser and Bjornn 1979). When terrestrial insects become scarce during winter periods, trout feed almost exclusively on aquatic insects.

Many species of Pacific Northwest wildlife are either dependent on or find optimum habitat in riparian systems. Phinney et al. (1989) state that of the approximately 480 species of terrestrial and shoreline wildlife in Washington, 291 (60%) are regularly found in wooded riparian habitats. The reasons for this include the proximity of habitat requirements (i.e., food, cover, and water), the increased number of niches because of wider diversity of plant species and structure, and the high edge length-to-area ratio that result from the linear shape of most riparian zones. Edge areas are the border or interface between open and wooded areas.

2.2.2 RIPARIAN SHADE AND STREAM TEMPERATURES

Water temperature regulates the biological functions, distribution and behavior of stream fish and invertebrates. High water temperatures in streams can change the distribution of juvenile fish, cause thermal stress or death of juvenile and adult fish, or delay the upstream migration of adult fish returning to spawn (Bjornn and Reiser 1991).

The range of water temperatures in a given stream, in particular the maximum temperature, is a function of heat gains and losses (Beschta et al. 1987). Water temperatures are influenced by regional climate conditions, such as air temperature and relative humidity, and by channel characteristics such as stream width, depth and shade level. As air temperatures increase or streams become larger, water temperatures tend to increase. Since air temperatures are warmer at lower elevations, the warmest water is generally found in low elevation, large rivers. Conversely, the coldest water is generally found in high elevation mountain streams.

Riparian shade and groundwater inflow rates are other important factors in determining stream temperatures. As the amount of riparian shade increases or the proportion of groundwater to total flow increases, stream temperatures tend to decrease. A heavily shaded stream in summer, for example, will generally be two to five degrees Centigrade cooler than nearby unshaded streams of the same size. Because of the smaller total flows, smaller streams are influenced more by cool groundwater temperatures than larger streams (Beschta et al. 1987; Sullivan et al. 1990).

Riparian shade also influences the water temperatures of large, wide rivers but to a lesser extent than small streams. Shade from riparian vegetation can cool shallow nearshore areas. These shallow, nearshore areas are often critical rearing areas for juvenile fish.

As a stream flows between shaded and unshaded reaches, the rate at which water temperatures rise or fall is influenced mostly by stream size. Small streams heat and cool quickly, while larger streams will respond more slowly. Between sampling points in very small streams, changes in riparian shading can change water temperatures in minutes. Temperature changes in larger rivers require hours to days (Caldwell et al. 1991).

For smaller streams with relatively narrow widths (1-15 feet), a combination of understory and larger vegetation is very effective in providing riparian shade. For medium-width streams (15-30 feet), larger vegetation, even when set back from the water's edge, can effectively shade the stream. Taller vegetation will only partially shade larger streams and rivers (i.e. wider than 50 feet); complete shade coverage on large rivers is generally not possible. Even partial riparian shade, however, will contribute to cooler air and water temperatures.

2.2.3 IMPACTS TO RIPARIAN AREAS

The effects of land uses on riparian areas can be multiple and varied, depending on the type of land use, degree of disturbance to streamside vegetation, size of stream, physical setting, and succession after disturbance. While land use may vary, the resulting environmental alterations generally affect riparian systems in similar ways. Increases in sediment to streams from the loss of riparian vegetation, for example, will occur whether the loss of vegetation results from road construction, logging or livestock grazing.

The effects of altering streamside vegetation, particularly overhead canopy, have been the subject of considerable research and many reviews (Brett 1956, Brown 1969, Patton 1973, Beschta et al. 1987). Significant alteration to or removal of overhead canopy allows increased direct sunlight to reach the stream. This is especially true when the canopy extends all the way across the stream, limiting the amount of light that reaches the ground. Direct sunlight, especially in summer, can increase water temperatures and in turn affect fish and aquatic insect species composition and growth. High summer water temperatures can kill salmon and trout, increase the incidence of many fish diseases, provide a habitat that favors less desirable fish, inhibit spawning activity, block spawning runs into streams, affect the quantity of food available, and alter the feeding activity and body metabolism of fish (Lantz 1971).

Hicks et al. (1991) report that several studies have shown the importance of streamside management as a tool to protect fishery values. These studies compared fish habitat and salmonid populations in streams that were and were not given riparian protection during timber harvests. The evidence shows that maintaining riparian zones--zones in which specific measures are taken to protect water quality and fish and wildlife habitat--can reduce damage to habitat and helps maintain the integrity of fish populations. This evidence is generally consistent over a wide span of time and space.

Soil compaction can be caused by many events, including passage of heavy equipment, livestock, humans, and even rainfall. Because of the variability of site conditions, impacts from the same event may vary from negligible to severe on different sites. Extensive soil compaction can result in reduced growth of vegetation, increased runoff, and heavier storm flows (Adams and Froehlich 1984). Compacted soils reduce the vigor of vegetation in several ways. The greater density of the soil provides more resistance to the expanding root system; air, water, and nutrients also move more slowly through soils with minimal pore space. Water can collect on the surface of slow-draining compacted soils, further reducing air movement to the root zone (Adams and Froehlich 1984). Although compacted soils can be a good site for seed germination, development is frequently stunted. The presence of stunted vegetation may indicate severe soil compaction. In addition, the events that caused compaction (e.g., grade changes, road or home construction) may also have damaged roots of trees and shrubs, stressing the plant and potentially introducing disease organisms to the damaged areas (Davidson and Byther 1982.)

2.3 FISH COMMUNITIES IN PACIFIC NORTHWEST STREAMS

The fish habitat components of most stream projects in the Pacific northwest are intended to meet the needs of one or more salmon or trout species. Generally, salmonids are typically the species of interest because of their aesthetic, recreational and commercial value.

While the focus is generally on salmonids, it is important to note that healthy stream systems harbor fish assemblages encompassing many more species. More than 50 non-salmonid fish species inhabit the streams of western Washington. When designing stream modification projects the habitat requirements of natural fish assemblage's, not just single target species, should be met. Because the distribution and habitat requirements of salmonid and non-salmonid species overlap, it is generally assumed that meeting the habitat requirements of salmonids will meet the requirements of non-salmonids. For each proposed project, this assumption should be verified. Wydoski and Whitney (1979) provide an excellect overview of Washington's fishes and their life-history and habitat requirements.

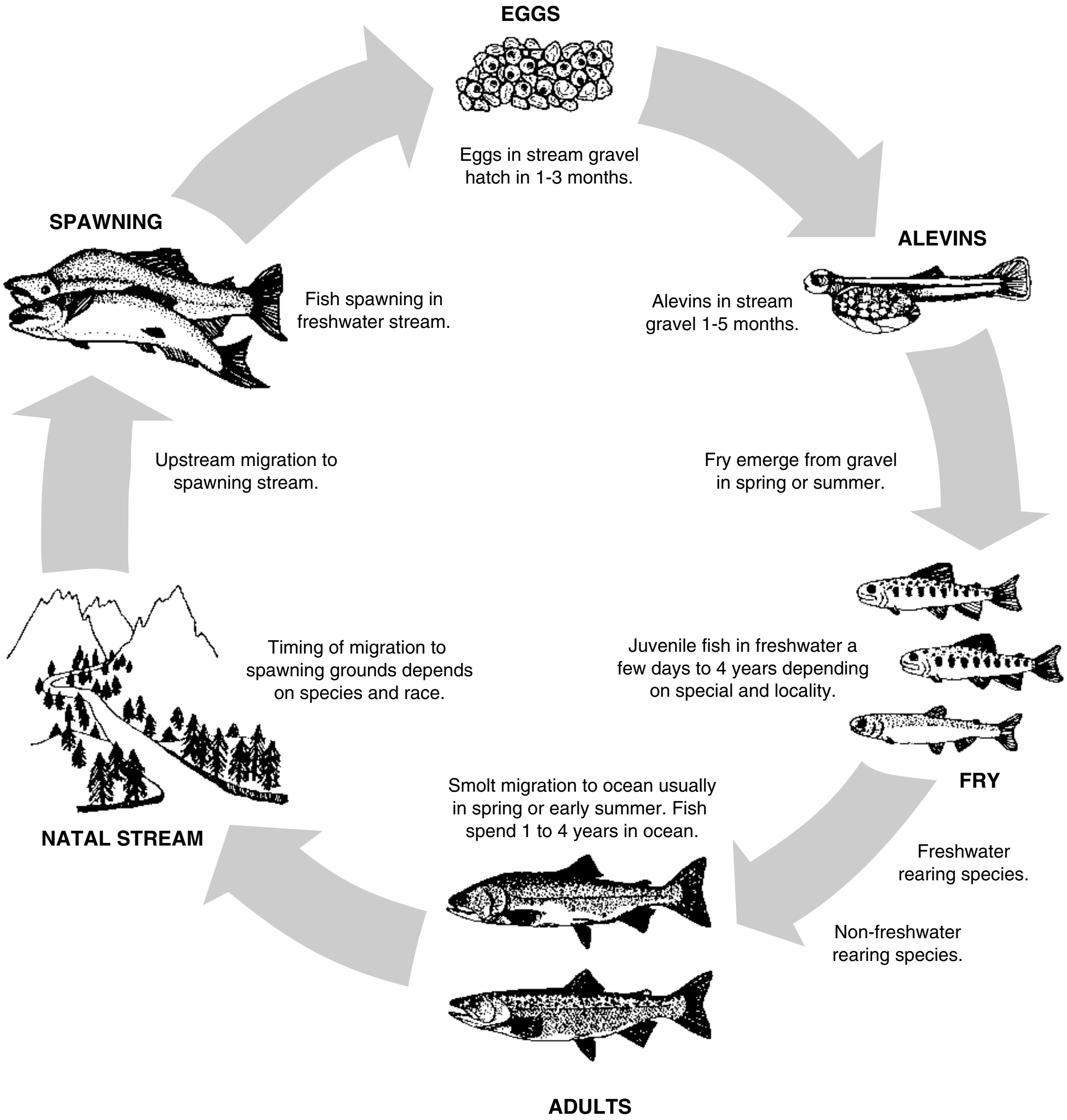
2.3.1 SALMONID LIFE HISTORIES

The Pacific salmon life cycle is often displayed as a generic pattern common to all species (Figure 2.7). While each species generally has the same life history stages, there are variations in life history, not only between species, but also among stocks within species. These variations are reflected in habitat use. The between-species variations represent the individual niches occupied by each species. The between-stock variations represent the myriad of adaptations to local habitats and conditions.

Pacific salmonids depend on stream habitat in different ways and for different lengths of time at each life history stage. These life history-specific habitat requirements are modified by important species-specific and stock-specific requirements and by local conditions. Local adaptations appear in such traits as:

- time of entry to the stream;
- distance adults travel upstream on their spawning migration;
- types of watersheds and gradients preferred;
- ability to navigate obstacles;
- type and location of spawning habitat;
- time at which they spawn;
- survival after spawning;
- length of juvenile freshwater rearing;
- habitat types required for juvenile freshwater rearing;
- level of social interaction among juveniles;
- length of time spent in saltwater; and
- distance traveled offshore.

Figure 2.7 Typical life cycle of anadromous salmonids. (Adapted from Adams and Whyte 1990.)



This document focuses on streams with mean annual flows of 20 cfs and greater. Salmonids use such streams and the habitats they provide in every stage of their freshwater lifecycle. Virtually all of King County's river systems historically provided habitat suitable for the spawning, rearing, and migration needs of many anadromous and resident fishes. The following is a general summary of the life history characteristics of the salmonids found in King County. Further information on the fish life history and their use of the major river systems of King County is discussed in Appendix A. Detailed information and specific requirements can be obtained from the references listed at the end of this chapter.

Pink salmon (*Oncorhynchus gorbuscha*): Pink salmon have a two-year life span from egg deposition until death. Puget Sound stocks of pink salmon, which spawn in odd numbered years, migrate only short distances upstream to spawn. Adults spawn once and then die. Fry emerge from the gravel in late February through March and immediately migrate to saltwater (Groot and Margolis 1991).

Chum salmon (*O. keta*): Chum salmon spawn as three-, four-, or five-year olds in the fall or early winter. While adults generally travel a bit further upstream than pink salmon, they may be stymied by obstacles other salmonids navigate with ease. Adults spawn once and then die. Fry emerge from the gravel in March or April, and migrate to saltwater quickly after emergence (Groot and Margolis 1991).

Chinook salmon (*O. tschawytscha*): Chinook salmon are the largest of the Pacific salmon. Generally considered to be fall spawners, some stocks spawn as late as January. Although adults return from saltwater as three-, four- or five-year olds, some stocks have high proportions of small but sexually mature two-year old "jacks." Depending on the distance to be traveled and time of spawning, upstream migrations may occur in anytime of the year. Spring and fall stocks are most common in Puget Sound. Mainstem reaches are generally chosen for spawning. Adults spawn once and then die. Fry emerge from the gravel in spring, mostly at night. Juveniles may spend weeks to a year or more in freshwater depending on the stock (Groot and Margolis 1991).

Sockeye salmon (*O. nerka*): Sockeye salmon spawn in the fall as three-, four-, five- and sometimes six-year olds. They choose rivers and small streams flowing into lakes, lake outlets, and sometimes lakeshores for spawning. Some populations are known to spawn in streams without associated lakes. Adults spawn only once and then die. Juveniles spend one to three years rearing in freshwater; most (but, as noted, not all) populations rear in lakes. There is also a resident form (kokanee) that matures at a smaller size after rearing and feeding in lakes (Groot and Margolis 1991).

Coho salmon (*O. kisutch*): Most coho spawn in the fall or early winter as three-year old fish and occasionally as four-, or sometimes five-year old fish, or in some stocks as two-year old "jacks." Adults can travel far upstream into a variety of habitats, passing formidable barriers to reach small tributaries for spawning. Adults spawn only once and then die. Fry emerge from the gravel in spring. Juveniles rear in streams one to two years primarily in pool habitats (Groot and Margolis 1991).

Steelhead (*O. mykiss*): Depending on the stock, adults return to freshwater after one, two, or three years in saltwater. They can travel long distances, and seem to prefer large or moderate-size watersheds with high gradient throughout. While most steelhead return to freshwater in winter, some drainages have spring, summer, or fall-run fish. These fish return at an earlier stage of maturity and wait in freshwater until spawning. Spawning occurs in late winter to spring in mainstem reaches or in swifter tributaries. While some adults survive spawning, multiple spawning is not common. Juveniles rear one to three years in freshwater pool and riffle habitats (Meehan and Bjornn 1991).

Resident rainbow trout (*O. mykiss*): Both freshwater migratory and stream resident life histories occur. In stream resident forms, maturity may be reached at age two or three, and, depending on the size and productivity of the stream, at a very small size. Maximum age may be only four or five years. These fish show a preference for riffles and habitats with swifter flows.

Searun coastal cutthroat trout (*O. clarki clarki*): Adult cutthroat trout return to freshwater in the late summer, fall, or winter of the year they first go to sea, and typically do not overwinter in saltwater. They favor small or moderate-size watersheds with extensive low-gradient areas in their lower reaches. Adults typically spawn for the first time at age three (males) and age four (females), at a length of about 12-14 inches. Some fish returning to freshwater for the first time overwinter without spawning. Spawning occurs in late winter to early spring in small tributaries, preferably in reaches above those utilized by coho. Adults survive spawning very well, and repeat spawning is common. Fry emerge in the spring to reside two, three, or more years in freshwater. Juvenile cutthroat trout defend territories in streams, but are usually dominated by both coho and steelhead juveniles (Trotter 1989).

Resident coastal cutthroat trout (*O. clarki clarki*): Both freshwater migratory and stream resident life histories occur. The age structure of these populations is similar to searun cutthroat trout, except non-migratory populations mature about one year earlier (age two or three) and are shorter-lived and generally smaller than searun fish. When cutthroat and rainbow trout exist in the same stream, the cutthroat trout occupy the upper reaches and the rainbow trout the reaches further downstream. Cutthroat trout prefer quieter water than rainbow trout and are often found in pool habitats (Trotter 1989). Spawning occurs in the spring.

Dolly Varden (*S. malma*) **and bull trout** (*S. confluentus*): Although considered to be different species, Dolly Varden and bull trout are similar in appearance and behavior and in the Pacific Northwest, their ranges overlap. Both species exhibit andromous and freshwater migratory and non-migratory life histories. Like searun cutthroat trout, anadromous fish return to freshwater the same year they go to sea; these fish do not typically overwinter in saltwater. While they attain maturity at age five or six, and may spawn again every year or every other year thereafter, maximum age may be 12 years or more. Dolly Varden and bull trout seem to prefer larger watersheds or stream systems with a lake for overwintering. There is evidence that these species may they may migrate higher in the watershed than any other Pacific salmonid for spawning, and overcome barriers impassible to other large fish (C. Kraemer, WDW, per. comm. 1991). These fish return from saltwater in late summer or fall and spawn in the fall; adults survive spawning very well. Fry emerge from the gravel in the spring with juveniles rearing 3, 4 or more years in freshwater (WDW 1992).

2.3.2 STREAMBANK STABILIZATION AND FISH HABITAT

Rivers are active systems that naturally change their configuration from year to year. One of the principal processes that brings this change about is streambank erosion. Erosion is a natural process that can be either positive or detrimental, depending on the type of materials being eroded, the rate at which erosion occurs, and socioeconomic concerns.

Streambanks composed of gravels and coarse materials are good sources of spawning and rearing substrates. Gravel streambanks subject to erosion, often the targets of bank stabilization projects, can be the primary sources of new spawning substrate within the stream. Conversely, streambanks made up mostly of sand, silts, and other non-cohesive materials can be sources of fine sediment and debris that may adversely affect fish habitat. Streams with excessive amounts of fine sediment may be incapable of transporting it through reaches of larger gravels used by salmonids for spawning. When this fine material is deposited, it fills the voids between the larger gravels. This decreases the flow of water to incubating embryos and smothers aquatic invertebrates that provide food for juvenile and adult fish.

The rate at which erosion occurs is a major factor in determining whether it is beneficial or detrimental. A gradual process of natural erosion promotes habitat diversity by creating features such as pools with undercut banks, rootwads exposed in the bank, eddies, backwaters, sloughs and oxbows. These features provide stable habitat for multiple species and stages of the salmonid lifecycle. In contrast, if erosion is rapid or abrupt, land is simply lost without creating any of these important habitat features.

Stream margins are the principal habitats of newly emerged salmonids during the first few crucial weeks after emergence. Smolts also make use of stream margins for shelter during their passive migration to saltwater. Loss of these habitats through any activity that removes cover or reduces the roughness of the stream margin can adversely affect salmonid productivity. For species such as fall chinook salmon and steelhead that often spawn in mainstem reaches and larger tributaries, alteration of spawning habitats by inadvertent changes in the stream channel or velocity profile can also be detrimental.

Figures 2.8 and 2.9 illustrate bankside features and Figure 2.10 shows large in-channel boulders where fish may find energy-efficient positions. Streambank stabilization structures that emulate the desirable features will benefit fish and help maintain the productivity of the stream. Structures that channelize the river or change the basic channel configuration (e.g., increase stream gradient, increase water velocity, reduce streamside cover, or decrease overall habitat diversity) do neither.

Riprapping or rock cribbing can be beneficial to fish if the banks are left with irregular surfaces to create turbulence and pockets. Riprapping projects that severely alter a natural stream channel, however, will have a detrimental effect. Knudsen and Dilley (1987) found that the severity of the alteration depended on how much of the streambed was graded and leveled by equipment working in the stream, the amount of streamside cover that was replaced by riprap, and the degree to which machinery operated within the streambed to place riprap.

Figure 2.8 Rock outcrop-natural bankside feature showing postions typically occupied by fish.

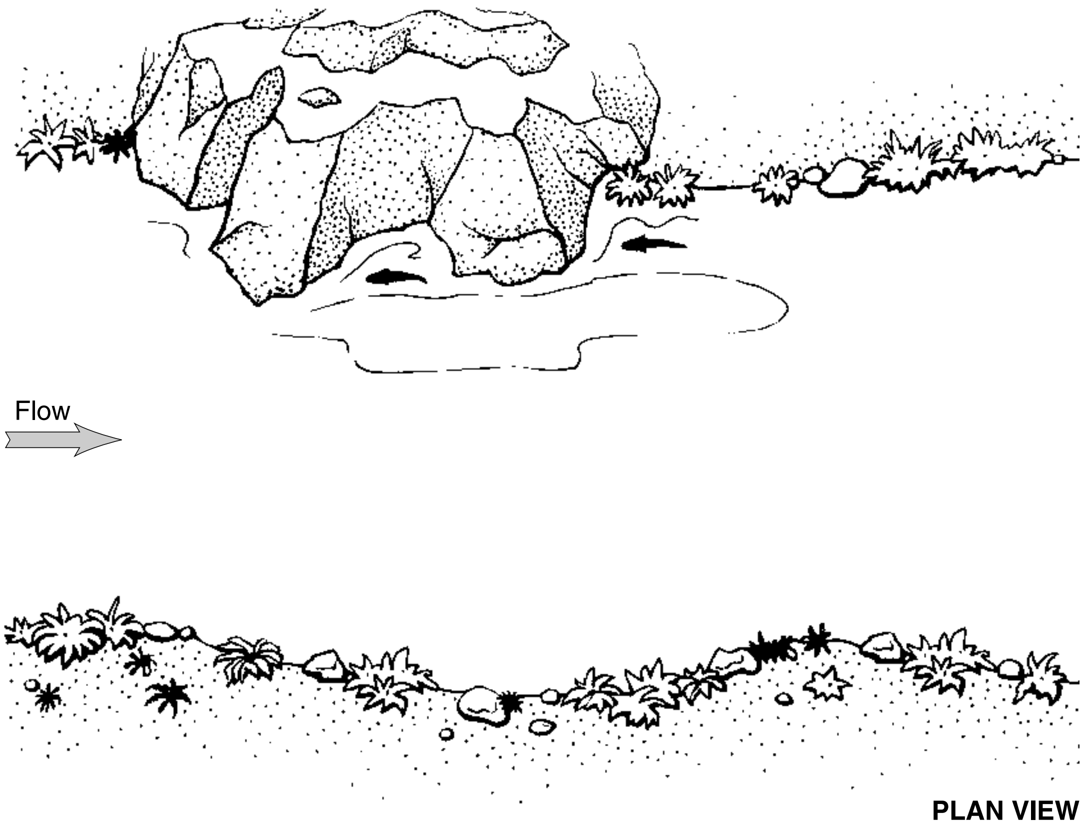


Figure 2.9 Uprooted tree–natural bankside feature showing positions typically occupied by fish.

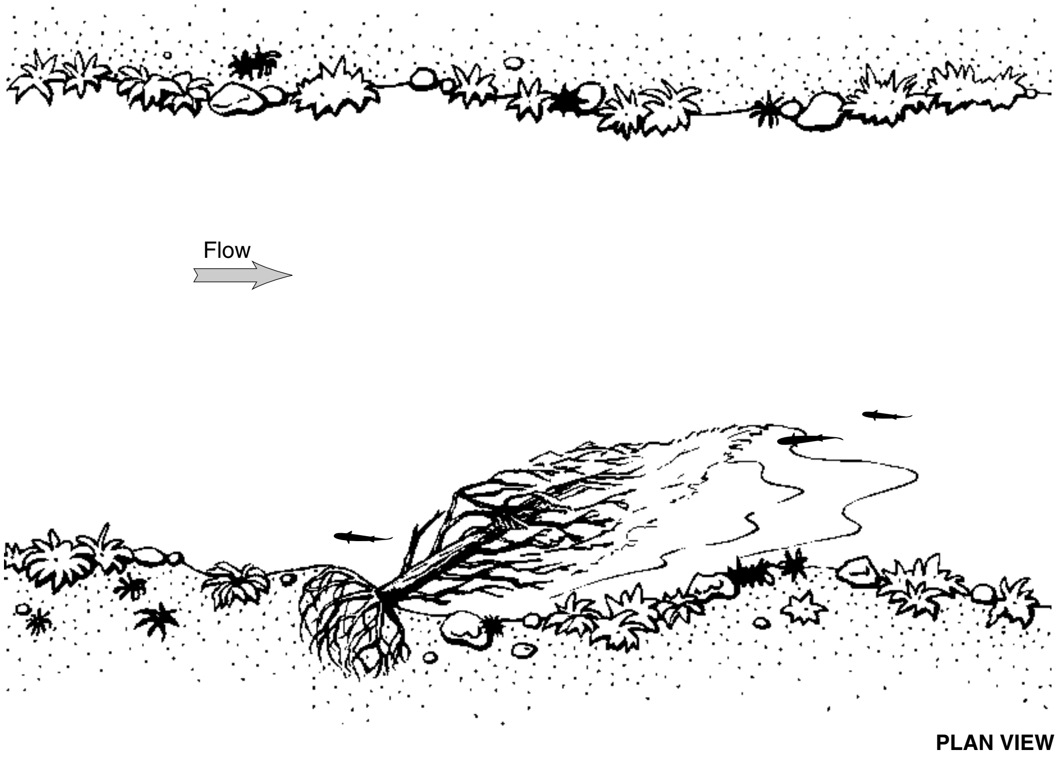
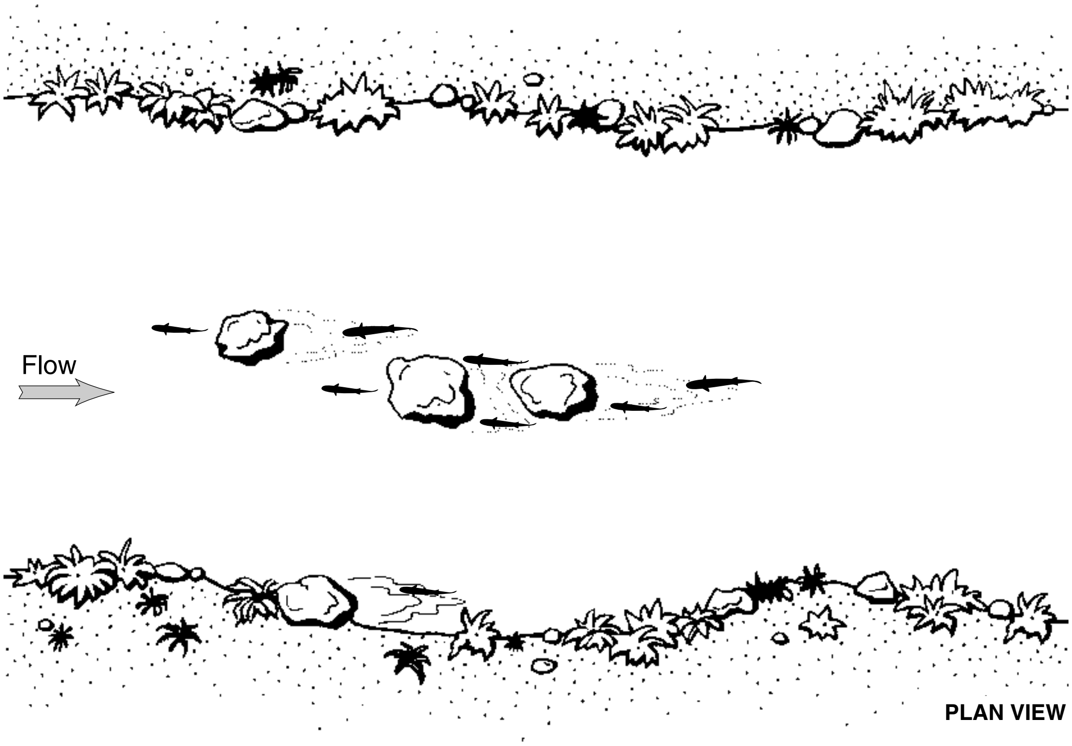


Figure 2.10 Natural in-channel boulders showing positions typically occupied by fish.



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