BELLEVUE CRITICAL AREAS UPDATE
BEST AVAILABLE SCIENCE PAPER: STREAMS

March 2003

Table of Contents

I. INTRODUCTION

Overview of Growth Management Act Requirements

In 1995, Washington State's legislature added a new section to the state's Growth Management Act (GMA) to ensure that cities and counties consider reliable scientific information when adopting policies and regulations to designate and manage critical areas. The new section, RCW 36.70A.172, requires all cities and counties to include "best available science" in developing policies and regulations to protect the functions and values of critical areas. One of the objectives of GMA is to protect the functions and values of critical areas by (1) accurately describing these functions and values; (2) understanding the likely adverse impacts associated with proposed land use planning alternatives; and (3) making land use decisions that minimized or eliminated those adverse impacts to the extent possible.

In 2000, the state's Office of Community Development (OCD) adopted procedural criteria to implement these changes to the GMA and provided guidance for identifying best available science. The rule makers concluded that identifying and describing functions and values and estimating the types and likely magnitudes of adverse impacts were scientific activities. Thus, RCW 36.70A.172(1) and implementing regulations require the substantive inclusion of best available science in developing critical area policies and regulations.

In addition, these policies and regulations must give "special consideration" to preserve or enhance anadromous fisheries, including salmon. A local government adopting policies and development regulations to protect critical areas needs to document that it has given special consideration to conservation or protection measures necessary to preserve or enhance anadromous fisheries. Furthermore, local governments should document that these measures are grounded in the best available science.

Conservation or protection measures necessary to preserve or enhance anadromous fisheries are defined in the best available science rule to include measures that protect habitat important for all life stages of anadromous fish, including, but not limited to:

- Spawning and incubation;
- Juvenile rearing and adult residence;
- Juvenile migration downstream to the sea; and
- Adult migration upstream to spawning areas.

The rule states that special consideration should be given to habitat protection measures based on the best available science relevant to each of the following:

- Stream flows;
- Water quality and temperature;
- Spawning substrates;

- Instream structural diversity;
- Migratory access;
- Estuary and nearshore marine habitat quality; and
- The maintenance eof salmon prey species.

This report has been prepared to comply with these procedural criteria and includes a review of available peer-reviewed research, inventory reports, assessments, and other sources of scientific information relevant to stream and riparian systems. The purpose of this report is to summarize and discuss the best available science relating to the functions and values of streams and riparian areas, particularly relating to the needs of anadromous fisheries. This report also discusses both the opportunities and challenges of managing streams and their riparian areas in urban environments such as Bellevue. This review supplements the inventory of Bellevue's streams (see previous report) and together with the inventory, helps to provide information for policy recommendations. Together, these reports and findings will be considered by the City of Bellevue and its citizen's advisory committee to develop policy recommendations for the management of streams and riparian areas in the City.

Relation of Critical Area Regulations to Factors Outside the City

Many other factors necessary to maintain and restore viable salmonid populations to Bellevue streams are independent of policies that can be affected at the local level. Its streams are one link in the life cycle of anadromous salmonid fish. Conditions in Lake Washington, Lake Union, and the Hiram Chittenden Locks are important (Kerwin, 2001), as are rearing conditions in Puget Sound and the Pacific Ocean. Finally, human factors like harvest levels and fisheries management using hatcheries also influence salmon populations (WDFW, 1997).

Nevertheless, the City does exert substantial local control over the productivity of its streams and the health of its salmonid populations. Critical area regulations that protect the functions and values of stream systems will help to maintain and enhance these populations in the short-term, and will help to protect the multiple ecological and social benefits provided by streams. Over the long-term, the City's stewardship of its streams may also be an important component of larger regional, watershed-based recovery plans for salmonids as more is learned about the needs of salmonids and effective recovery strategies.

Referencing available and pertinent literature and information, the following sections provide an overview of the life histories of anadromous fish inhabiting Bellevue's streams and the particular biological and habitat requirements of salmonids. The functions and values of riparian areas that help support these requirements are then discussed, along with enhancement/restoration considerations.

II. OVERVIEW OF ANADROMOUS FISH LIFE HISTORY

The term "anadromous" refers to fish that reproduce in fresh water streams or lakes, migrate to salt water for some portion of their life, and then return to fresh water. Some anadromous fish die after completing this cycle, while others do not and may repeat the cycle more than once. There are many groups of fish that exhibit anadromy. Pacific salmon are familiar examples of anadromous fish common in the Pacific Northwest and, as discussed in the stream inventory report, inhabit many of Bellevue's streams. Many other salmonid fish, including trout and char, also have this characteristic, although not all species of salmonid fish or all individuals of a certain population express this trait. In addition, some species, such as coastal resident/sea-run cutthroat trout and rainbow trout/steelhead, likely have a lake-migrating population in Lake Washington and Lake Sammamish. Life histories of lake migrating populations are similar to anadromous populations, except that juveniles mature in lakes instead of salt water.

Although the term "anadromous fish" is often used as a synonym of salmonids, many other species of fish are anadromous. Several of these species inhabit City of Bellevue streams (Table 1).

Table 1. Species of fish present or potentially present* in Bellevue streams that may exhibit anadromy

Common Name	Scientific Name	Type
Chinook salmon[1]	*Oncorhynchus tshawytscha*	Pacific salmon
Coho salmon[1]	*O. kisutch*	Pacific salmon
Sockeye salmon[1] (anadromous form) Kokanee[2] (fresh water resident form)	*O. nerka*	Pacific salmon
Sea-run cutthroat trout[1,3] (anadromous form) Coastal cutthroat trout[2,3] (fresh water resident form)	*O. clarki* clarki	Native trout
Steelhead[1,3] (anadromous form) Rainbow trout[2,3] (fresh water resident form)	*O. mykiss*	Native trout
Bull trout[3,5]	*Salvelinus confluentus*	Native char
Dolly Varden[3,5]	*Salvelinus malma*	Native char
Pacific lamprey[1,7]	*Entosphenus tridentatus*	Lamprey
River lamprey[1,7]	*Lampetra ayresi*	Lamprey
Long-fin smelt[4,5]	*Spirinchus thaleichthys*	Smelt
Three-spined stickleback[3,6]	*Gasterosteus aculeatus*	Stickleback

Source: Wydoski and Whitney, 1979; The Watershed Company, 2001; WDFW, 1998.

* "Potentially present" means fish use is only occasional or unknown, but suitable habitat exists.

1. Generally or completely anadromous
2. Fresh-water resident form
3. Both fresh water resident and anadromous forms can occur together.
4. Has both fresh water resident and anadromous forms, but usually occur separately. Fresh water resident form present in Lake Washington.
5. Expected to be only occasional visitors to Bellevue streams, if present at all.
6. Anadromous form expected to be only occasional visitors to Bellevue streams, if present at all. Fresh water resident form is common.
7. Little information is known regarding occurrence or distribution. Some Bellevue streams may provide suitable habitat.

While several species of anadromous fish are or may be present in Bellevue streams, the distinction made by the Washington Administrative Code (WAC) is that special consideration must be given to "measures necessary to preserve or enhance anadromous *fisheries (*emphasis added)." The term fisheries commonly refers to stocks of fish that are managed for commercial, recreational, cultural, or ceremonial uses. These types of fish are regulated as game fish and/or food fish by the state. The species from Table 1 known or potentially present in Bellevue that are managed by the state as game and/or food fish include all Pacific salmon (except pink salmon), bull trout/Dolly Varden, coastal resident/sea-run cutthroat trout, rainbow trout/steelhead, and long-fin smelt. Long-fin smelt in the Lake Washington basin, however, are not anadromous (Wydoski and Whitney, 1979). In addition, anadromous bull trout and Dolly Varden may occasionally stray into Lake Washington, but are not known to be present as a population in Bellevue streams or other Lake Washington tributaries (WDFW, 1998). Resident populations of bull trout are known to inhabit Chester Morse Lake in the upper Cedar River watershed, but are not known to inhabit other Lake Washington tributaries (WDFW, 1998).

While there can be variations in species or even populations, as a generalized group, anadromous salmonids undergo several development phases during their life history, utilizing different portions and habitat elements of Bellevue's streams across space and time. Newly hatched young, which develop from eggs, are referred to as aelvins and usually remain hidden in stream bottom gravels until they emerge as fry or fingerlings. After rearing for some time in fresh water, ranging from days to years depending on species and individual traits of specific fish, anadromous salmonids outmigrate to salt water as smolts. Anadromous salmonids can spend from several months to years in salt water before returning to spawn. Some species or populations sexually mature at sea, while others mature after returning to fresh water. Adults that migrate to fresh water to reproduce are commonly called spawners. Post-spawn adults for species that can spawn more than once are called kelts. As an illustration, Table 2 shows the general seasonal variation of spawning, rearing, and outmigration of chinook and coho salmon for Lake Washington.

Table 2. Life History of Lake Washington chinook and coho salmon

Month	J	F	M	A	M	J	J	A	S	O	N	D
adult spawning –chinook									■	■		
adults spawning –coho										■	■	■
intragravel development – Chinook	■	■							■	■	■	■
intragravel development –coho	■	■	■	■						■	■	■
rearing –chinook	■	■	■	■	■	■	■					
rearing –coho	■	■	■	■	■	■	■	■	■	■	■	■
smolting & migration –chinook				■	■	■	■					
smolting & migration –coho				■	■	■	■					

Source: WDFW, 1994.

III. STREAM PROCESSES AND BIOLOGICAL REQUIREMENTS OF SALMONID FISH

The use of stream habitats varies by species, by developmental phase, or even by individuals within the larger population. There are, however, many needs that are common to all anadromous salmonids, as well as to the overall health of many other aquatic organisms native to Bellevue's streams, including benthic macroinvertebrates, which are an important food source for salmonids and other animals. These elements include clean and cold water, suitably-sized spawning gravels and other suitable substrate for use as habitat, food sources, rearing habitats in proximity to food, refuges from predators and environmental conditions such as sufficiently high flows, and unconstrained migration routes.

The geographic location, topography, geology, and level of existing urbanization in the City of Bellevue limit the extent to which its streams can provide the necessary biological requirements for salmonid species and other aquatic organisms. However, even in urban settings where individual functions and elements of stream habitat are not optimal for salmonids, the combined effect of conditions in a stream basin may allow salmonids to successfully use its habitats. For example, although streambed conditions and flow regimes in Kelsey Creek are not functionally optimum to support salmonids, chinook salmon are reproducing in this basin, as are salmonids in other basins in the City. The synergistic effects of individual processes that form and support habitat, such as flow and input of organic material and substrate, are sufficient to allow some salmonids to live and reproduce in Bellevue's streams. In addition, small changes in stream function (e.g. improving habitat access by removing a fish-passage barrier), in combination with watershed-based restoration strategies, may provide substantial benefits to salmonid populations in urbanized settings such as those found in Bellevue.

Described below are the general biological requirements and a discussion of how habitat conditions may influence these requirements. These requirements and impacts to salmon are summarized in Table 3. Appendix BAS-S-3 also summarizes alterations to various habitat parameters and effects on salmonids.

Table 3. Summary of major habitat requirements and concerns during each stage of the salmon's life cycle.

HABITAT REQUIREMENTS	HABITAT CONCERNS
Adult Migration Pathways Adult salmon leave the ocean, enter fresh water, migrate upstream to spawn in the stream of their birth.	Passage blockage (e.g., culverts, dams, low flows, fluctuation of Lake Washington levels) Water quality (high temperatures, pollutants) High flows/low flows/water diversions Channel modification/simplification Reduced frequency of holding pools Lack of cover, reduced depth of holding pools Reduced cold-water refugia Increased predation resulting from habitat modifications
Spawning and Incubation Salmon lay their eggs in gravel or cobble nests	Availability of spawning gravel of suitable size Siltation of spawning gravels

HABITAT REQUIREMENTS	HABITAT CONCERNS
called redds. To survive eggs (and the alevins that hatch and remain in the gravel) must receive sufficient water and oxygen flow within the gravel.	Redd scour caused by high flows Redd de-watering Temperature/water quality problems Redd disturbance from trampling (human, animal).
Stream Rearing Habitat Juvenile salmon may remain in fresh water streams over a year. They must find adequate food, shelter, and water quality conditions to survive, avoid predators, and grow. They must be able to migrate upstream and downstream within their stream and into the estuary to find these conditions and to escape high water or unfavorable temperature conditions.	Diminished pool frequency, area, or depth Diminished channel complexity, cover Temperature/water quality problems Blockage of access to habitat (upstream or down) Loss of off-channel areas, wetlands Low water flows/high water flows Predation caused by habitat simplification or loss of cover Nutrient availability Diminished prey/competition for prey
Smolt Migration Pathways Smolts swim and drift through the streams and rivers, and must reach the estuary or ocean when there are adequate prey and water quality conditions and must find adequate cover to escape predators as they migrate.	Water quality Low water flows/high water flows Altered timing/quantity of water flows Passage blockage/diversion away from stream Increased predation resulting from habitat simplification or modification

Water Quality

Salmonid fish require water that is both colder and cleaner (meaning having lower nutrient levels) compared to requirements for many other types of fish. High water quality is a particularly crucial need of all native salmonid fish and is important to other aquatic species adapted to living in Pacific Northwest streams. Parameters for salmonids in particular are discussed below.

Temperature

While no single temperature provides for all of the needs of all species or life stages of salmonid fish, many authors have identified water temperature ranges suitable for the various species and developmental stages of salmonids (City of Portland, 2001). Water temperature is affected by several factors, including:

- Base temperature (the temperature of water upon emerging from the ground);
- Discharge (flow) rate;
- Air temperature;
- Solar insolation (the intensity and duration of sunlight reaching the water body);
- Temperature of stormwater runoff; and
- Area-to-depth ratios (City of Portland, 2001).

The general range of temperatures required to support healthy salmonid populations is generally considered to be between about 39? and 63? F (NMFS, 1996; USFWS, 1998). Cutthroat trout have the highest range of temperature tolerances of native salmonids inhabiting Bellevue's streams and are able to withstand short periods of temperatures as high as 79? F (Pauley et al., 1989 *in* City of Portland, 2001). Above 63? F, however, salmonids begin to exhibit stress that may cause sublethal effects including reduced growth and overall survival. Productivity also declines due to thermal impact on gamete survival. Stresses increase until temperatures exceed lethal limits (Moyle and Cech, 1988; Thomas et al., 1986). Lethal limits vary widely by species and development stage; constant temperatures in excess of 78? F, as one example, are within the lethal range for coho salmon (Thomas et al., 1986). Adult fish are also affected by high temperatures. Temperatures of 69.8? to 71.6? F were reported to be lethal to adult chinook salmon in the Columbia River (McCullough, 1999). Coho salmon are less tolerant of high stream temperatures than other salmonids because they usually spend a full year in freshwater. Table 4 below summarizes general temperature effects on salmonids.

High summer temperatures are generally a concern related to increased mortality for rearing juvenile or resident fish. In addition to the lethal effects of increased temperature and decreased dissolved oxygen, high temperatures increase stress levels, which may have both acute adverse sublethal impacts on salmonids. The direct effect of high stream temperatures is less of a consideration for adult fish since most spawning occurs in the fall and winter when temperature is not a critical factor for survival. Also, early spawning species like chinook will not usually enter to spawn in a stream with high temperatures. This protects them from the lethal effects of high instream temperatures, but may have indirect impacts as a result of delayed spawning or increased competition for limited spawning habitats.

High water temperatures also affect other organisms in streams such as benthic macroinvertebrates and aquatic amphibians. In addition, temperature affects many other biological, physical, and chemical processes that occur in aquatic systems. Most importantly, this includes the level of dissolved oxygen that can be held by surface waters.

Table 4. General Temperature Effects on Anadromous Salmon

Consideration	Thresholds of Effects on Anadromous Salmon
Temperature of common summer habitat use	50° - 63°F
Lethal temperatures (one week exposure)	Adults: >70° - 72°F Juveniles: >73° - 75°F
Adult migration	Blocked: >70° - 72°F
Swimming speed	Reduced: >68°F Optimal: 59° - 66°F
Gamete viability during holding	Reduced: >55° - 61°F
Disease rates	Severe: >64° - 68°F Elevated: 57° - 63°F Minimized: <54° - 55°F
Spawning	Initiated: 45° - 57°F
Egg incubation	Optimal: 43° - 50°F

Optimal growth	Unlimited food: 55° - 66°F Limited food: 50° - 61°F
Smoltification	Suppressed: >52° - 59°F

Source: U.S. EPA, 2001.

As indicated in the stream inventory, documented summer temperature ranges for Bellevue streams commonly fall within the levels of acceptable limits for healthy salmonid populations. Summer water temperatures at or in excess of 63? F, however, have been observed in the Kelsey Creek and Coal Creek basins (University of Washington, 1998, 1999). High water temperatures are thought to limit salmonid fish production in Coal Creek (Kerwin, 2001). As with many urban stream systems, the likely contributors to increased stream temperatures in Bellevue are air temperature, the lack of shade, low baseflows, degraded channels (high width to depth ratios), and warm water inputs from stormwater.

Biological

Dissolved Oxygen

One of the most influential water quality parameters on stream biota, including salmonid fish, is dissolved oxygen (Lamb, 1985). Salmonids inhabiting Bellevue's streams have gill structures that are unable to extract oxygen from the surrounding water once oxygen levels drop below approximately 3 parts per million (ppm). While this is the lower limit considered necessary for salmonid survival, negative effects on salmonid egg development may occur at levels below 8 ppm (City of Portland, 2001). Levels below 5 or 6 ppm may result in behavioral changes and increased stress in adults or rearing juveniles (Pauley et al., 1986 *in* City of Portland, 2001).

The most significant factor affecting dissolved oxygen levels in most streams is temperature, with cooler waters maintaining higher levels of oxygen than warmer waters (Lamb, 1985). Other factors that can contribute to oxygen levels include turbulence of the water (the amount of aeration) and biochemical oxygen demand created by organic decomposition from natural organic materials, organic pollution (pet waste, sewage, etc.), and aquatic algae respiration (during sunlight hours only). Nutrients contribute to biochemical oxygen demand by stimulating algal growth, increasing respiration from live algae and organic decay. Nutrients may originate from human-induced sources such as fertilizers (both chemical and natural), pet waste, and leaking sewers, or from natural processes such as decomposing algae or dead plant materials that fall into streams (Lamb, 1985).

In Bellevue, available information on dissolved oxygen in the City's streams is limited. Previous sampling in Kelsey Creek found dissolved oxygen levels low enough to depress salmon embryo survival (City of Bellevue, 1984, *in* City of Bellevue, 1995). As discussed above, water temperatures likely exert some influence on dissolved oxygen levels in the City's streams, meaning that factors affecting stream temperatures also could influence on dissolved oxygen levels.

Food and Energy Flow

Salmonids consume a wide range of food sources throughout their life cycles. As discussed in the inventory report, most juvenile salmonids that rear in Bellevue streams prey on aquatic invertebrates and terrestrial insects that fall into streams from overhanging vegetation. In some streams during the summer, an estimated 50 percent of the diet of juvenile salmonids is comprised of terrestrial insects (City of Portland, 2001). Availability of stream invertebrates as a prey source for salmonids depends on both, habitat area and habitat quality, specifically the amount of stream that can produce prey organisms and the amount of habitat that provides opportunity for fish to exploit the prey base. Aquatic invertebrate populations and abundance have been found to be depressed in Bellevue's streams (Fore, 1999).

The health of terrestrial and aquatic insect populations is also related to primary production in and organic input from vegetated riparian areas. Organic litter input from riparian areas provides the food supply for aquatic invertebrates. In Puget Sound lowland streams such as those in Bellevue, leaf litter from adjacent forested riparian areas is a primary source of organic carbon and nutrients (May and Horner, 2000). Many species of aquatic invertebrates have become adapted to feed on dead and decomposing organic material that has fallen or washed into the stream from adjacent uplands (Benfield and Webster, 1985).

Chemical

Toxic substances can wash into streams through both point sources (like industrial discharges that flow from a pipe) and non-point sources (like runoff from areas treated with pesticides). Common urban pollutants include nutrients such as phosphorus and nitrogen, pesticides, bacteria, and miscellaneous contaminants such as PCBs and heavy metals. Impervious surfaces collect and concentrate pollutants from different sources and deliver these materials to streams during rain storms, and concentrations of pollutants increase with total impervious area (May, et al., 1997).

Metals and hydrocarbons may be toxic to fish, and are often transported with sediments. Heavy metals, PCBs, and other contaminants harm fish and wildlife (Rutherford and Mellow, 1994 *in* Metro, 2001). Metal contaminants increase in direct proportion to total impervious area; industry and automobiles appear to be the primary sources in urban areas. Gas and oil, toxins from rooftops, and industrial and household chemicals (paint, cleaning products, etc.) can also pollute streams.

Nitrogen and phosphorus levels in runoff also increase in direct proportion to total impervious area (U.S. EPA, 1983, in Metro, 2001). Excessive phosphorus is typically a larger problem in urban watersheds and can lead to increased instream plant growth. Plant decay, in turn, consumes oxygen in streams and reduces aquatic habitat quality (Arnold and Gibbons, 1996 *in* Metro, 2001).

In Washington state, only a small number of pollutants are regularly monitored during water quality monitoring, and the extent to which salmonids are exposed to toxic substances such as pesticides is largely unknown (Washington Department of Agriculture et al., 2001). Toxic substances can have an acute and/or chronic effect on salmonids and other aquatic organisms, and the toxicity of many elements depends on independent factors, such as the pH of receiving waters. Low levels of neurotixic pesticides such as Diazinon impair chinook salmon's defensive olfactory responses and homing behaviors (Scholz, et al., 2000 *in* Metro, 2001). The acute effects of toxic discharges are easy to observe as they often result in "fish kills," where large numbers of fish are poisoned. Chronic impacts, however, such as effects on growth or reproduction or reduced prey availability, occur over time and may not be readily connected to a single event such as a fuel spill.

Little specific information is known about the presence of toxic substances in Bellevue's streams. As noted in the inventory report, in previous years, Kelsey Creek was previously listed on Washington state's 303(d) list for three pesticides: Dieldrin, Heptachlor epoxide, and DDT. However, it has recently been removed from this list. Lewis Creek, Sunset Creek, and Valley Creek were included among seven other urban stream basins in a study conducted by the U.S. Geological Survey, Washington Department of Ecology, and King County to evaluate the transport of pesticides applied in residential areas to urban streams. A total of 23 pesticides were detected in water from urban streams during rainstorms; the concentrations of five of these pesticides exceeded limits established to protect aquatic life (USGS, 1999). Studies indicated the presence of several pesticides used in residential applications (Diazinon, 2,d-D, MCPP, etc.) However, studies also showed that application of pesticides in non-residential areas such as right-of-ways and recreational areas contributed to pesticide levels in urban streams. Ecological effects in specific streams included in the study are unknown because the study did not evaluate duration of exposure or combined effects of several pesticides. Given the absence of industrial activities in the City, common sources of toxic discharge likely include chemical landscaping applications and petroleum based products such as auto fuel, or solvents used in commercial processes. These latter materials could enter the water following a spill, from leaking storage tanks, or from stormwater runoff from roads.

Discharge (Flow)

Discharge, or the amount and velocity of water flowing in a stream, has a significant influence on the ability of salmonids and other aquatic species to effectively utilize habitats in a particular basin. The most direct connection between stream discharge and fish use is related to the quantity of stream water available for use by fish during their various life stages. The adults of some larger species of salmon, such as chinook and steelhead, require greater water depths to spawn and commonly spawn in larger streams. While not among the largest of Pacific salmon, sockeye salmon commonly spawn early in the fall when water levels are seasonally low (Wydoski and Whitney, 1979). Still other smaller species, such as cutthroat trout and coho salmon, can successfully spawn in smaller headwater streams (Wydoski and Whitney, 1979). The life history of each species is also important in relation to the amount of seasonal discharge within a given stream. Cutthroat trout, steelhead, and coho salmon juveniles can spend one or more seasons rearing in stream systems before moving to Lake Washington or to salt water. Reaches of streams that are dry or have low flows in summer may limit summer rearing habitat for these species.

While low flows may limit access to some streams or reaches and increase thermal impacts, excessively high flows can affect both stream habitat and reproductive success. Excessively high peak flows can affect both stream morphology and habitat use by salmonids by destabilizing stream channels, causing rapid incision or other channel changes, disturbing eggs, and eliminating refuge habitat for juvenile salmonids and other aquatic organisms. Excessive flows can also scour stream beds and banks and can disturb redds, killing eggs or fry.

Discharge regimes, including high and low flows, can be substantially altered in urban or urbanizing basins, primarily due to runoff from impervious surfaces. As discussed in the stream inventory report, total impervious surface area in Bellevue's stream basins ranges from 24 percent to as high as 68 percent, indicating that all of the City's streams are affected to some degree by altered discharged regimes. The quantity of impervious surface in a basin (often termed Total Impervious Area, or TIA) has been associated with stream degradation (Booth, 2000; May et al., 1997; Horner and May, 2000). Studies in Puget Sound lowland streams show that alteration can occur in basins with as little as 10 percent total impervious surface. Dramatic effects can be seen relative to discharge in basins where impervious surface exceeds 40 percent (May et al., 1997).

Changes related to increases in impervious surface may include excessively high runoff rates during heavy or prolonged rainfall, low baseflow rates as a result of limited groundwater infiltration from precipitation, or both (City of Portland, 2001). Urbanization also changes the volume, rate, and timing of water flowing through stream systems, which can impact the physical characteristics of the stream channel (Booth, 1991). Peak-flow increases of two- to three-fold are common for medium-sized floods in moderately urbanized watersheds (Booth et al. 2000). Increases in peak flow are more apparent with smaller, more frequent floods (e.g. 0.5-year floods, which occur twice a year on average) relative to larger floods (Booth et al. 2001).

Excessively low base flows have been reported on some streams in the Lewis Creek basin; low flows may limit access for salmonids to certain streams and increase temperatures in the City during low flow periods. Wetherbee (2000), however, found that 7-day low flows are increasing in Kelsey Creek, as are peak daily flows. Increases in base flows may be due to increases in irrigation by land owners in the basin.

IV. SALMONID HABITAT NEEDS

The salmonid body form and physiology allows salmonids to utilize a wide variety of both fresh and salt water habitats. They successfully inhabit lakes and ponds (lotic habitats) and thrive in stream and river environments (lentic habitats) (Moyle and Cech, 1988). As discussed above, each salmonid species found in Bellevue's streams has differing habitat needs that vary depending on the season and/or their stage of development. However, there are several general habitat elements that support many species of salmonid fish. The National Marine Fisheries Service (NMFS, 1996) and U.S. Fish and Wildlife Service (USFWS, 1998) have developed guidelines to address habitat physical elements necessary to support healthy salmonid populations across this range of variability. These physical habitat elements include the following:

- Substrate;
- Large woody debris;
- Pool quality and quantity; and

- Floodplain connectivity/off-channel refugia.

Substrate

All species of salmonids present in Bellevue streams require clean gravel in which to spawn. Each species has a general preference for a specific size of gravel used to construct redds (nests) for spawning; preferred substrate size is loosely correlated to the size of the fish, although there can be significant overlap. Larger-bodied chinook and steelhead generally spawn in cobble (orange to golf ball-sized gravel substrates), while coho, sockeye, and cutthroat are smaller fish and may spawn in golf-ball to pea-sized gravels. Therefore, a wide variety of substrate sizes within a stream may provide habitat for use by several different salmonid species.

In urban stream basins such as those in Bellevue, substrate quality and quantity can be affected by a variety of factors. As discussed in the inventory report, there has been limited documentation of substrate types in Bellevue. However, given the extent of impervious cover in the City's basins and the likely associated high flows, it is probable that native substrate has been altered by erosion and sedimentation. In undeveloped watersheds, the movement and redistribution of substrate is a natural occurrence and is necessary to maintain clean, sediment-free gravels. However, increases in stormflow quantities and velocities in urban basins can cause scouring that can displace stream substrates, reducing the quality and quantity of spawning areas (May et al., 1997). Scouring can result from increased runoff from impervious surfaces and from increases in velocities as a result of channelization (straightening) and the removal of streamside vegetation. Scour can also directly impact salmonids where eggs are present in gravels.

To balance the displacement of gravel resulting from natural redistribution or scour, streams must have a constant source of new material. Under natural conditions, bank erosion and channel movement would replace gravels and undercut trees would supply large woody debris. However, when vegetated riparian corridors have been developed with urban land uses and stream banks stabilized to protect development, there is little gravel or woody debris that are allowed to move to the stream system (May et al., 1997).

While gravel recruitment is a necessary element in sustaining healthy salmonid habitat, too much erosion and subsequent sedimentation can have negative effects on aquatic organisms and salmon production. The deposition of sand, silt, and other fine sediments can fill spaces between gravels and reduce the amount of oxygen that reaches developing salmon eggs. In addition, fine material can embed gravels, effectively cementing stream beds. Such conditions make it difficult for salmonids to excavate redds and for deposited eggs to be placed in protected spaces in the gravels. For example, studies have found that in streambed gravels containing more than 13 percent fine sediment (<0.85 mm), almost no steelhead or coho salmon eggs survive (McHenry et al., 1994). Turbidity caused by suspended sediment also impacts feeding by juvenile salmon (Newcomb and MacDonald, 1991). In Kelsey Creek, previous studies have documented fine sediment levels ranging from 22 percent to 39 percent (Scott, et al., 1992; May, 1996).

Large Woody Debris

Many authors have discussed the importance of large woody debris as a critical habitat element in stream systems (Murphy and Koski, 1989; McDade et al., 1990; Van Sickle and Gregory, 1990; McKinley, 1997). Wood, either as individual logs, root balls, or piled in jams, serves many functions in the stream environment, including:

- Creating pool habitat and cover from predators;
- Adding roughness (friction) to the stream channel to slow water velocities and trap sediment; and
- Creating habitat diversity.

Water flowing over and around large woody debris creates pools that provide habitat for rearing salmonids, while overhanging wood provides cover and protection from predators. Woody debris adds roughness to the stream channel, which slows water velocities and reduces the scour potential of floodwaters. Log jams and other in-channel large woody debris trap and store sediment, reducing downstream sediment transport and sedimentation. The importance of wood as a sediment storage mechanism is a factor not only in streams with fish presence, but also in non-fish bearing tributaries where it reduces the velocity of floodwaters and stores sediments that are a source of sedimentation in lower basins.

The quantity and quality of large woody debris in a given stream is related to three primary factors:

- The composition of the adjacent and upstream riparian vegetation;
- The discharge of the stream; and
- Past management practices in the watershed.

Coniferous logs generally provide more benefit as woody debris than deciduous species because they are slower to decompose. Riparian forests that retain high numbers of standing and downed coniferous logs provide a source of high quality woody debris. Recruitment to the stream occurs when a tree falls into the stream, often as a result of the lateral movement of the channel and bank undercutting, or from windthrow, or when a downed log is washed into the stream during a flood. Floods are also responsible for distributing downed wood within the stream channel; culverts or bridges that restrict the ability of the stream to pass woody debris downstream often hinder this process. Increased runoff rates from impervious surfaces can also flush large woody debris and spawning gravel from streams (Bledsoe and Watson, 2001).

Standards for properly functioning levels of large woody debris within western Washington streams are 80 pieces per mile or greater (NMFS, 1996) (Appendix BAS-S-3). In addition, for riparian areas to be properly functioning for this habitat element, streamside areas should be capable of sustaining these levels of woody debris over the long term through adequate recruitment of woody debris to the stream.

In urban stream systems, sources of large woody debris are often limited. As discussed in the stream inventory report, there are several breaks in vegetation along Bellevue's streams where land has been cleared for development, suggesting that large woody debris recruitment potential has been eliminated or reduced. Under natural conditions, stream bank erosion and channel migration undercuts trees that supply woody debris. However, when riparian areas have been cleared and developed and the stream bank stabilized for development, there is little large woody debris available to recruit (May et al., 1997). Land management practices that reduce the number of standing and downed tress in riparian areas or reduce the width of riparian areas also reduce the ability of riparian forests to provide a source of wood to the stream system. Along urban streams in general, large conifers may be removed for safety reasons, or during land clearing and development activities in or adjacent to riparian corridors. Large woody debris may also be removed from streams to reduce perceived hazards associated with flooding in the event that large woody debris blocks culverts during storms.

Pool Quality and Quantity

The various species of salmonids found in Bellevue streams rely on the presence of high quality pools to differing degrees for holding, feeding, and refuge from winter floods. Three primary factors affect pool quality:

- Depth;
- Surface Area; and
- Cover.

Large, deep pools with cover provided by woody debris, overhanging vegetation, or other features such as boulders typically provide more habitat value than smaller, shallow pools. Adult salmonids of all species require pools with sufficient depth and cover to protect them from predators during their spawning migration. Adult salmon often hold in pools during daylight, moving upstream from pool to pool at night. Juvenile coho utilize quiet pools with ample cover as refuge from winter floods. Chinook salmon juveniles rarely spend more than one season in their natal streams but require pool habitats in late winter and spring after emergence to feed and grow before outmigrating to Lake Washington or Puget Sound. Other species like sockeye spend little time in streams after emerging from spawning gravels and are less pool-dependent.

Pools, although important for most species of salmonid fish, are just one type of habitat that salmonid fish require. Multiple habitats allow niche separation to occur so multiple populations of fish with similar habitat needs can be maintained. Pools associated with other habitats, like riffles and glides, are also needed to provide the full complement of habitats necessary to support the range of salmonid species and development stages present in Bellevue's streams. Riffles provide habitat for many of the aquatic insects that rearing salmonids utilize as food. Riffles and cascades create turbulence that contributes to increased stream dissolved oxygen levels. Some salmonids may prefer pools, but can also successfully compete using other habitat types. Cutthroat trout are often found in faster water habitats such as glides and riffles. One study of urbanizing basins, including some Bellevue streams, found that, for multiple reasons including competition, physiology, and food preferences, cutthroat trout densities may actually increase in streams that have lower pool frequencies compared to more diverse pristine systems (May, 1997).

As discussed in the stream inventory report, there is little documentation related to specific pool quality or habitat frequency in Bellevue's streams. Studies have shown, however, that stream habitat in urban and urbanizing streams typically includes reduced pool frequency and reduced overall habitat quality. As one example, May, et al. (1997) found a dramatic decline in habitat quality as total basin impervious area increased above the 5 to 10 percent range. Two significant factors limiting stream habitat structure in urban areas include the lack of pool-forming large woody debris and increased frequency and magnitude of peak discharge rates, which may scour pools and woody debris from the channel.

Floodplain Connectivity and Off-Channel Refugia

Off- channel wetlands and side channels in riparian areas provide foraging habitat, over-wintering habitat, and refuges for rearing fish (Swales and Levings, 1989; City of Portland, 2001). These areas, which include wetlands connected to the stream channel and side channel habitats, also have high levels of productivity and provide areas for juvenile fish to forage and grow before outmigrating to Lake Washington and/or out to saltwater. Previous studies have shown the importance of off channel and river margin rearing habitat to juvenile chinook (Bjornn and Reiser, 1991). Juvenile coho salmon, which are not strong swimmers compared to other juvenile salmonids, often spend the winter rearing in quieter off-channel pools and wetlands with ample woody debris cover (Bisson, et al., 1988). Studies in urban and urbanizing areas indicate that off-channel habitat and refugia may be reduced by urban development. Causes of this loss include channel straightening and disconnection from adjacent wetland areas.

V. FUNCTIONS AND VALUES OF RIPARIAN AREAS

While salmonids as well as many other aquatic organisms are confined to waters in the stream channel, the discussion of the various elements necessary for healthy salmonid and aquatic life populations above highlights that few, if any, functions rely solely on in-stream processes. Instead, most of the elements necessary for healthy salmonid populations rely on processes sustained by dynamic interaction between the stream and the adjacent riparian area (Naiman et al., 1992).

Along western Washington lowland streams, forest, either in upland or wetland areas, is the dominant pre-development vegetative land cover. Under such conditions, upland disturbances such as fire or windthrow and stream processes such as flooding create structurally and compositionally diverse stands of vegetation (Gregory, et al, 1991 *in* City of Portland, 2001). In Bellevue, aside from those riparian areas impacted by urban development, the most notable exceptions to the native forested condition are the large wetlands located along many stream systems, where shrub habitat can be locally dominant

Riparian vegetation in floodplains and along stream banks provides a buffer to help mitigate the impacts of urbanization (Finkenbine et al., 2000 *in* Bolton and Shellberg, 2001). Riparian areas support healthy stream conditions through two main groups of functions: "sink" functions and "source" functions. Generally, recommended buffer widths for sink functions are lower than those for source functions.

First, riparian areas can act as "sinks," removing unwanted elements from the stream environment (Castelle and Johnson, 2000). Sink functions include:

- Maintaining water temperature through shading;
- Improving water quality through sediment and pollutant retention; and
- Attenuating flood waters.

Riparian areas also provide "source" inputs that are critical to healthy salmonid streams (Castelle and Johnson, 2000). Source inputs include:

- Stream baseflows from groundwater;
- Large woody debris;
- Gravel for spawning substrate; and
- Insects and organic matter for food supply.

Sink Functions

Shading

Riparian vegetation, particularly forested riparian areas, can affect water temperature by providing shade to reduce solar exposure and regulate high ambient air temperatures, slowing or preventing increases in water temperature (Brazier and Brown, 1973; Corbett and Lynch, 1985).

Water Quality Improvement

Upland and wetland riparian areas can retain sediments, nutrients, pesticides, pathogens, and other pollutants that may be present in runoff, protecting water quality in streams (Ecology, 2001; City of Portland 2001). The roots of riparian plants also hold soil and prevent erosion and sedimentation that may affect spawning success or other salmonid behaviors, such as feeding by juveniles.

Flood Water Attenuation

Both upland and wetland riparian areas can reduce the effects of flood flows. Riparian areas and wetlands can reduce and desynchronize peak crests and flow rates of floods (Novitzki, 1979; Verry and Boelter, 1979 *in* Mitsch and Gosselink, 1993). Upland and wetland areas can infiltrate floodflows, which in turn, are released to the stream as baseflow (described below).

Source Functions

Stream Baseflow

Riparian areas often have shallow groundwater tables, as well as areas where groundwater and surface waters interact. Groundwater flows out of riparian wetlands, seeps, and springs to support stream baseflows. Surface water that flows in to riparian areas during floods or as direct precipitation can infiltrate into groundwater in riparian areas and be stored for later discharge to the stream (Ecology, 2001; City of Portland, 2001).

Large Woody Debris

As previously discussed, riparian areas also provide a source of large woody debris that helps create and maintain diverse in-stream habitat, as well as create woody debris jams that store sediments and moderate flood velocities.

Streambed Gravel Input

All species of salmonids present in Bellevue streams require clean gravel to spawn, and under natural conditions, bank erosion and channel movement replaces stream gravels, providing new gravel for spawning. A wide variety of substrate sizes within a stream may provide habitat for use by several different salmonid species. However, gravel recruitment as a function of riparian condition has not been specifically studied..

Biotic Input

Riparian areas provide food, both directly and indirectly, to the stream system. Insects falling from overhanging vegetation provide food for fish, while leaves and other organic matter falling into streams provide food and nutrients for many species of aquatic insects.

Riparian Function as a Factor of Buffer Width

Overview of Literature Review

The literature review conducted for this report included an analysis of buffer widths from research primarily conducted in Washington, Oregon, Idaho, and British Columbia during the last 20 years. Many authors have addressed the effects of a wide variety of land management practices on streams and riparian areas (Rinne, 1990). As shown in Table 1 in Appendix BAS-S-1, much of the literature has focused on specific riparian functions and characteristics, such as the effects of streamside vegetation on temperature, or the ability of riparian vegetation to remove sediment or specific nutrients such as nitrogen. Knutson and Naef (1997) also summarize many of these functions for Washington; the Washington Department of Fish and Wildlife's (WDFW) recommended standard buffer widths for the state's five-tier stream typing system is based on this latter research (Appendix BAS-S-2) (OCD, 2002). Many other studies have focused on the ability of riparian areas to provide for source functions, such as woody debris or nutrient inputs. These and similar studies have largely been conducted to determine the widths of riparian buffers necessary to counter potential adverse impacts from specific land management activities such as silvaculture or agriculture. Only recently have studies begun to focus on the needs of streams in urban environments (May and Horner, 2000).

Table 1 in Appendix BAS-S-1 shows that the buffer widths reported to be effective for these functions vary considerably; the literature is not definitive in identifying an ideal buffer width for each function studied. The wide range of reported effective buffer widths indicates that site-specific factors are important in determining the outcome of each study. Buffer studies have been conducted in a wide variety of locations (e.g., Puget Sound lowlands, montane forests of the Cascade), and land use settings (primarily agricultural and forestry) using a variety of research methods. Moreover, studies have been conducted in a wide range of channel types (e.g., stream order, channel size, channel morphology) and site characteristics (e.g., slope, aspect, soil type, vegetative cover). In some cases, the salient site conditions were not fully reported in the literature.

In addition, other factors in urban areas indicate that buffer functions relevant to forest management or agricultural settings may not be as applicable urban areas. For example, other infrastructure considerations, such as the presence of storm drains, alter pollutant removal and flood water attenuation functions of buffers (Leavitt, 1998; May and Horner, 2000).

Application of Buffer Widths

A general relationship between buffer width and buffer effectiveness is apparent in the research findings. The studies indicate that buffers 100 to 150 feet (30 to 45 meters) wide provide most (on the order of 80 percent) of the potential functions, particularly for sink functions, in most situations. Buffer requirements for wildlife habitat are typically larger, on the order of 100 to 600 feet.

The literature also indicates that particularly for "sink" functions, the relationship between buffer width and effectiveness is logarithmic, so that after a certain width an incremental increase in buffer width provides diminishing functional effectiveness. For example, Wong and McCuen (1982) indicate that 90 percent of sediment removal can be accomplished within the first 100 feet of a riparian buffer, but an additional 80 feet of buffer is required to remove five percent more sediment (Table 1, Appendix BAS-S-1).

In general, buffer distances should be viewed mainly as guidelines, as the literature shows that site-specific factors may impact buffer effectiveness just as much as buffer width (Naiman et al., 1992; Castelle et al., 1994). The differing geomorphic profiles of different streams influence their fluvial characteristics, which in turn influences their channel migration zone, ability to absorb flood flows, and the ability of buffers to provide their various functions. An overall conclusion of review of the scientific literature is that buffer widths required to protect a given habitat function or group of functions depends on numerous site-specific factors, such as:

- Stream size/channel width: The importance of riparian functions can vary by stream size. Small headwater tributary streams are strongly influenced by riparian vegetation, where such vegetation provides shading of waters and contributes large amounts of organic material. As stream size increases, the importance of terrestrial organic inputs decrease, with a increasing significance of algal or rooted vascular plant production and organic transport from upstream (Vannote, et al., 1980).

- Plant community (species, density, age): As discussed below under the Wildlife section, buffers vegetated with native forest that have multiple-storied canopies and down wood perform better for some "source" functions, such as providing large woody debris and wildlife habitat.
- Aspect, soil type and slope: Factors influencing the stability of stream banks includes the cohesive, frictional, and interlocking properties of soil; riparian vegetative characteristics; and abundance of stream bank roots (Castelle and Johnson, 2000). In riparian areas located on steep slopes and/or highly erodible soils, larger buffers may be appropriate to reduce risks of erosion and delivery of fine sediment to streams. Streams in deeply incised ravines, may benefit from slope shading (Vannote et al., 1980).
- Land use impacts: Higher-intensity land uses, such as high-density residential development or commercial development, located adjacent to riparian areas could result in greater impacts than lower density single-family residential uses. Impacts may differ due to factors such as disturbance from light, noise, human intrusion, and edge effects on wildlife. Riparian areas, if intact, can separate streams from uplands and surrounding development, protecting streams from human encroachment, which can result in direct impacts to stream banks or channels, as well as aquatic life from increased access by humans or pets, and increased light or noise (Leavitt, 1998).
- Presence of sensitive resources: Larger buffers may be appropriate in areas inhabited by fish or wildlife species of special concern, particularly during sensitive nesting or spawning life stages (See Table 1, Best Available Science paper, Section B, Wildlife). Wider, vegetated buffers may minimize impacts to such species from impacts such as human intrusion, light and glare, and noise.

"Sink" Functions

Studies of sink functions associated with riparian areas demonstrate some trends. For sink functions like sediment or pollutant removal, buffers ranging from 15 to 125 feet in width may provide benefits (Appendix BAS-S-1) (URS, 2002; Knutson and Naef, 1997) (Figure 1). Specific studies have concluded that buffers of 100 feet can achieve sediment removal efficiencies of 75 to 100 percent; while depending on site-specific conditions and buffer type, buffers of 100 feet or less may provide substantial pollutant removal benefits. Finally, well vegetated, forested buffers of 35 to 125 feet may help to moderate stream temperatures (Appendix BAS-S-1; Knutson and Naef, 1997).

Water Temperature

Studies indicate that buffer widths ranging from 35 to 150 feet can moderate stream temperatures (Table 1 in Appendix BAS-S-1). The largest buffers were found to maintain temperatures similar to fully forested conditions (Jones et al., 1988). Much of the variability in the literature is related to the presence or absence of a mature tree canopy. For example, forested buffers of 75 to 100 feet were found to provide 60 to 80 percent of the shade of conditions in fully forested watersheds (Brazier & Brown, 1973; Steinblums et al., 1984) or old-growth forest (Beschta et al., 1987).

While the importance of shade for maintaining stream temperatures is well documented, there is a growing body of information relative to the effects of microclimate on regulating stream temperatures, although few studies have examined the effects of buffers specific to microclimate on water temperature (Ledwith, 1996). Forest riparian zones provide localized areas with lower air temperature and higher relative humidity than surrounding areas. The cooler, humid air mitigates the heating effect of solar insulation and decreases the effect of evaporation, especially during the summer. Ledwith (1996) found that air temperature and relative humidity were correlated to buffer width. Stream corridors with narrow buffers, on average, had significantly higher air temperatures and lower humidity than similar areas with wider riparian buffers. The effect of buffer width on temperature and humidity was highest in areas with buffers ranging from 0 to approximately 100 feet. The effect of buffer width was more moderate, but still measurable, for buffer widths ranging between approximately 100 and 500 feet.

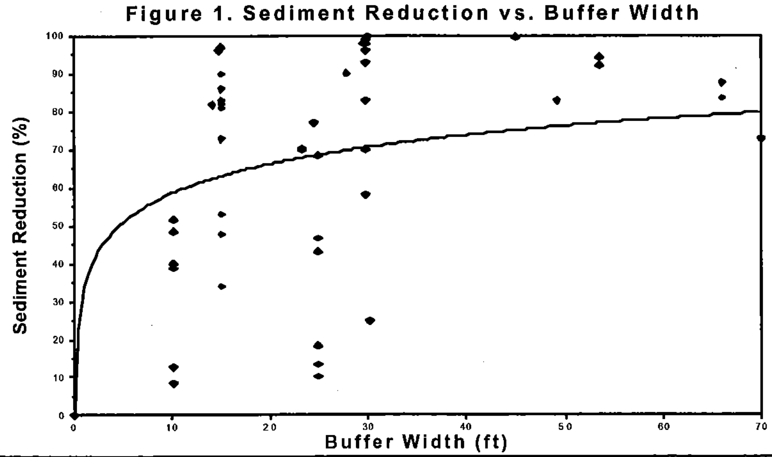
Sediment and Pollutant Retention

Recommended buffer widths for sediment and pollutant retention vary from 15 to 860 feet. This wide variation is due in general to the particular pollutant being evaluated. As an example, studies on the low end of the range of recommended buffers were focused on nutrient removal in agricultural situations and conducted by evaluating grass buffers (Daniels & Gilliam, 1996; Doyle et al., 1975) . Overall, however, many of the studies suggest that buffers of 50 to 100 feet can remove 75 to 80 percent of pollutants (Lynch et al., 1985; Castelle & Johnson, 2000; Wong & McCuen, 1982; Castelle et al., 1992). Most papers also conclude that larger buffers are required on steeper slopes to reach the same level of pollutant removal.

Flood Water Attenuation

Trees and shrubs located in the riparian zone slow flood waters, allowing infiltration, and lessen downstream flooding (Bolton & Shellberg, 2001). However, buffer widths have not been specifically studied or specified for achieving this function, as they are significantly influenced by site conditions, including the morphology of the streambed and floodplain area, rate and volume of stream flow, and other factors.

Figure 1. Sediment Reduction vs. Buffer Width



Source: URS, 2002.

Note: Points represent findings from individual studies.

"Source" Functions

Research on providing adequate source functions, such as large woody debris recruitment, groundwater/surface water interchange, or adequate nutrient input suggest larger streamside buffer areas than those identified for sink functions discussed above (Appendix BAS-S-1). Specific functions are discussed below.

Groundwater Supply to Support Base Flows

Riparian areas and wetlands can provide a continuous flow of water to streams because of their ability to store and slowly release water. This function is particularly important to stream flow-sensitive salmonids in the Pacific Northwest, because wetlands provide baseflow during the region's typically dry season (City of Portland, 2001; Booth, 2000; May et al., 1997; Mitsch and Gosselink, 1993; Schueler, 2001; Brinson, 1993). However, a standardization of buffer width has not been studied, as the effectiveness of the buffer for this function is significantly influenced by site-specific conditions such as soil type, subsoil permeability, and topography, among other factors.

Large Woody Debris

The contribution of riparian areas to large woody debris in streams, particularly in silvicultural applications, is one of the more frequently studied buffer functions. Much of the work regarding adequate riparian buffer widths has been based on "site-potential tree height" (SPTH), defined as the height that mature trees in a climax forest will reach given local conditions. SPTH is considered the maximum horizontal distance from which large woody debris will be recruited to the stream by falling trees. Generalized SPTHs that range from between 175 feet (FEMAT, 1993) to 250 feet (Pollock and Kennard, 1998) for western Washington have led many researchers to recommend buffer widths of 150 feet or more (Castelle et al, 1992).

While SPTH is a term that is common in the forest management field, its application may be more limited when applied to urban areas with significantly modified vegetation since it may take several hundred years for a tree to grow to its full height (City of Portland, 2001). Several authors have also found that large woody debris recruitment from riparian areas occurs at distances less than one SPTH (Castelle, et al., 1992) (Figure 2). Figure 2 shows, for example, that some studies have found that more than half of all large woody debris is recruited from within 15 feet of streams, and about 90 percent comes from trees growing within about 50 feet of streams (Murphy and Koski, 1989; McDade et al., 1990; Van Sickle and Gregory, 1990; McKinley, 1997).

Gravel for Spawning Substrate

The ability of a stream system to recruit additional gravels is largely related to the presence of non-armored banks that may be undercut to release gravel to the stream. While this is not a specific function of buffer width, a sufficient channel migration zone must be present to let natural recruitment occur (City of Portland, 2001). Buffer widths associated with gravel recruitment are not documented in scientific literature; however, hardening of stream banks with riprap or revetments reduces the supply of gravel (May et al., 1997).

Biotic Input

Budd et al. (1987) found that riparian vegetation can contribute up to 90 percent of the biotic input in stream systems. Recommended buffers for maintenance of benthic communities range from 33 feet to greater than 100 feet. This range reflects the complex interaction of other buffer functions such as solar insolation, pollutant removal, and flood flow attenuation with the biotic elements in the stream. Most studies found that buffers of 100 feet were necessary maintain healthy benthic communities (Roby et al., 1977; Newbold et al., 1980; Castelle & Johnson, 2000). Buffers exceeding 100 feet were found to maintain the benthic diversity of unlogged forested basins (Erman et al., 1977; May et al., 1997).

Buffer areas also provide biotic input to the stream system in the form of insects falling from overhanging vegetation, and input of leaves and other organic matter. This biotic matter provides food and nutrients for many species of aquatic insects and detritovors. Although vegetated buffers are necessary for organic input, no studies have focused on effective buffer widths specifically for biotic input functions.

Wildlife Habitat

Riparian buffer widths for wildlife habitat vary greatly depending on individual wildlife species (Appendix BAS-S-1; Knutson and Naef, 1997). Studies have found that a buffer of 100 feet is necessary to maintain macroinvertebrate diversity (Gregory et al., 1987); buffers of 100 to 165 feet are required for most amphibian and reptile species (Dickson, 1989). Larger riparian buffers of 300 to 650 feet are needed to provide adequate migration corridors for certain species of wildlife (such as birds and elk) (Table 1 in Appendix BAS-S-1).

Quality of the buffer can also be a significant factor in determining the quality of wildlife habitat. For example, buffer zones comprised of native vegetation with multi-canopy structure, snags, and down logs provide habitat for the greatest range of wildlife species (McMillan, 2000).

VI. URBAN ISSUES AND CONSIDERATIONS FOR STREAM MANAGEMENT

A general trend that is evident in the literature is the greater emphasis on evaluation of buffer effectiveness in the context of other watershed processes. This shift is a result of the evolution of the science away from studies that evaluate site-specific management techniques to studies that evaluate landscape-level alterations to watersheds. The implication of this shift is that much of the previous work that served as scientific support for land use regulations and polices, like setting buffer widths, can be addressed again to focus on what is now known about the effects to streams from land use practices at the watershed level.

The general effects of urbanization on salmonid streams have only more recently been well documented (Booth, 2000; May and Horner, 2000). Much of this recent literature is also relevant since it has been based on studies from lowland streams in the Puget Sound region, including some streams in Bellevue. In general, as discussed throughout this report, urbanized streams typically:

- Are warmer and have poorer water quality;
- Have wide differences between winter and summer base discharge;
- Have fewer and less diverse types of habitats;
- Lack large woody debris;
- Have higher levels of nutrients;
- Have fewer and lower quality spawning areas; and
- Have fewer side channels and off-channel wetlands than their counterparts in less urbanized basins (May et al., 1997).

While the effects of urbanization on a watershed are closely tied to the loss or disturbance of native riparian area (May and Horner, 2000; Leavitt, 1998), loss or alteration of native riparian vegetation is not the single cause of stream degradation in urban areas. As previously discussed, TIA has also been associated with stream degradation. Many of the adverse impacts of TIA, including flushing of large woody debris and spawning gravel from streams, are compounded by degradation of riparian areas (Bledsoe and Watson, 2001; May et al., 1997). Degraded riparian areas are less effective at removing sediments and pollutants washed from parking lots and roads where native vegetation has been replaced with lawns. Riparian area effectiveness is also limited where streams have been channelized or drainage routed through stormwater detention and treatment systems such that stormwater is not able to interact with streamside vegetation, except vegetation in the stream channel.

Under such conditions, the simple application of prescriptive buffers may not be adequate to restore urban streams because most of the source functions of buffers have been compromised by past land use actions. For example, along most stream segments in urban areas it will be difficult to restore natural woody debris recruitment function of riparian areas due to the difficulties in restoring mature forests and because of safety and land use factors (Larson, 2000). It may be necessary to develop new watershed-based strategies that address hydrology, water quality, and riparian functions to successfully address the issue of riparian areas and adequate buffers in the context of basin-wide change (Booth, 2001; May and Horner, 2000; Beschta and Kauffman, 2000). As a result, multiple-pronged strategies that address multiple functions by managing buffer width and quality, controlling land use, and managing stormwater may most effectively address protecting, enhancing, and restoring stream systems.

Other Considerations: Instream Restoration

Some authors have suggested that, due to altered hydrology, water quality, and stream channel stability, stream rehabilitation in watersheds with high levels of impervious surface may be less feasible compared to watersheds with less impervious cover (Booth, et al., 2001). Roni, et al. (2002) suggest that the simplest way to avoid problems associated with restoration is to focus on restoring processes that form, connect, and sustain habitats such as woody debris recruitment, shading of streams, and the delivery of water to the stream channel. However, in the context of a comprehensive, watershed-based restoration strategy, instream restoration can be an effective tool in restoring and enhancing salmonid habitat and populations.

Barriers like culverts and stormwater control structures can inhibit fish migration and prohibit fish from accessing upstream habitats. Barriers that do not prevent the migration of fish may limit many natural processes necessary for salmonid fish production including the natural redistribution of substrate and woody debris. Restoring fish passage is an effective way to increase the quality and accessibility of habitat and can result in relatively large increases in potential fish production at a nominal cost (Roni, et al., 2002). Stream channels with high quality habitat (low gradient, high pool frequency, high wood loading from riparian areas) produce greater benefits (Roni, et al., 2002). Land use actions or incentives that address such issues can help conserve and enhance Bellevue stream functions necessary to maintain and restore populations of anadromous fish.

Instream restoration projects, however, should be planned carefully in the context of basin-wide conditions. In one study of 15 streams in Oregon and Washington, more than half of instream restoration structures (e.g. pieces of large woody debris) failed before the expected lifetime of 20 years (Frissell, C.A. and R.K. Nawa *in* McClean, J., 2000). Roni, et al. (2002) reported highly variable results; some studies suggested that 85 percent of wood remains in place and contributes to habitat formation. Often in urban systems, more "engineered" methods of bed and bank stabilization may be necessary to address high hydraulic forces, space constraints, and infrastructure and property protection restrictions (Miller et al., 2001). Instream restoration projects appear to particularly benefit coho salmon because many restoration efforts have been targeted at smaller coho streams (Roni, et al., 2002).

VII. STREAM MANAGEMENT APPROACHES

The most common regulatory strategy employed throughout local jurisdictions of western Washington to conserve and protect streams and fisheries resources is the use of a set-width prescriptive buffer. Under this approach, buffer setback distances are determined based on the various classifications of stream and are applied uniformly throughout the jurisdiction. Increasingly, jurisdictions are also developing multiple-pronged strategies that address the following:

- Stream classification based on habitat and function potential;
- Priorities based on habitat/species potential for each basin;
- Buffer zones to delineate sensitivity for various functions;
- Buffer widths to control effectiveness of buffer functions;
- Management activity in the buffer to regulate access and effectiveness; and
- Control of wetland TIA, non-point pollution, and channel alterations.

There are several options for implementing critical area policies and regulations. Two examples in this region include those that have been adopted by the City of Kirkland and Snohomish

County. Kirkland's system separates stream basins into "Secondary" and "Primary" basins. Secondary basins are those that are located in the urban core of the City. Most of the streams in secondary basins are constrained and have been highly modified by development that occurred prior to the establishment of local regulation to protect sensitive areas. Most of these streams are enclosed in culverts or storm drainage pipes and drain basins with high quantities of impervious surface. Primary basins have experienced less modification and there are fewer constraints relative to the use of the basin by fish or wildlife. The classification method used for streams and buffers is the same for the two different management areas; the primary differences are that the allowable uses in critical areas in secondary basins are more consistent with urban development, the buffer widths are lower to recognize that there is little native vegetation remaining to protect, and resulting mitigation requirements are lower.

The Snohomish County system separates the traditional buffer zone into two areas, an inner "no touch" zone and an outer "management zone." In most other jurisdictions that regulate streamside areas using buffers, there is no distinction made between outer and inner buffer areas. The Snohomish County system recognizes that the land directly adjacent to streams has the potential to offer higher levels of functions and values than areas farther from the stream. This method reflects, in large part, the findings of literature reviews that show many of the critical functions of riparian areas occur in those areas directly adjacent to streams and that the ability of the buffer to provide beneficial functions and values plateaus at a given distance (relative to the function that is the focus of the investigation). Under this system, the interior one-half of the regulated area, known as the "buffer", is managed to allow limited disturbance. Some level of alteration or use is allowed in the outer one-half of the regulated area, known as the "management zone," but more intensive development is still discouraged. For example, no effective impervious surface may be constructed in the management zone, but this area can be developed for other uses. In addition, Snohomish County only requires this approach in basins that contain species listed as threatened or endangered, and does not implement this approach on non-fish bearing waters.

Both approaches have benefits and limitations. The Kirkland approach places greater emphasis on less disturbed basis while reducing regulation in more urbanized areas. The benefit of this approach is that future growth may be concentrated in already urbanized secondary basins, reducing the effects of further urbanization in primary basins. The limitation of this approach is that management of secondary basins may limit or preclude future rehabilitation. For cities with already developed urban cores, this trade-off may be acceptable, particularly in the context of regional salmon recovery efforts, given the already prohibitive effort that would be needed to restore highly urbanized basins. The Snohomish County approach places greater emphasis on protecting habitat closer to the stream. This approach may be more consistent with the current state of the science. This method also attempts to reduce potential long-term impacts in basins with listed fish by managing other types of development in areas in proximity to streams and riparian corridors; however, this approach may be difficult to fully implement in already developed areas where there is little practical difference between no-touch "buffer" and "management zone."

VIII. REFERENCES

Adams, T.A. and K. Sullivan. 1990. The Physics of Forest Stream Heating: A Simple Model. Timber-Fish-Wildlife Report No. TFW-WQ3-90-007, Wash. Dept. of Natural Resources, Olympia, WA.

Addy, K.L., A.J. Gold, P.M. Groffman, and P.A. Jacinthe. 1999. Ground Water Nitrate Removal in Subsoil of Forested and Mowed Riparian Buffer Zones. *J. Environ. Qual.* 28:962-970.

Ahola, H. 1990. Vegetated Buffer Zone Examinations on the Vantaa River Basin. *Aqua Fennica* 20:65-69.

Andrus, C.W., and H.A. Froehlich. No Date. Wind Damage within Streamside Buffers and its Effect on Accelerated Sedimentation in Coastal Oregon Streams. Department of Forest Engineering, Oregon State Univ., Corvallis, OR.

Barling, R.D, and I.D., Moore. 1994. Role of Buffer Strips in Management of Waterway Pollution: A Review. *Environ. Management* 18:543-558.

Barton, D.R. 1996. The Use of Percent Model Affinity to Assess the Effects of Agriculture on Benthic Invertebrate Communities in Headwater Streams of Southern Ontario, Canada. *Freshwater Biology* 36:397-410.

Barton, D.R., W.D. Taylor, and R.M. Biette. 1985. Dimensions of Riparian Buffer Strips Required to Maintain Trout Habitat in Southern Ontario Streams. *N. Am. J. Fish. Manage.* 5:364-378.

Belt, G.H., and J. O'Laughlin. 1994. Buffer Strip Design for Protecting Water Quality and Fish Habitat. *Western J. of Appl. Forestry* 9:41-45.

Belt, G.H., J. O'Laughlin and T. Merrill. 1992. Design of Forest Riparian Buffer Strips for the Protection of Water Quality: Analysis of Scientific Literature. Idaho Forest, Wildlife and Range Policy Analysis Group Rept. No. 8. Univ. of Idaho, Moscow, Idaho.

Benfield, E. F. and J. R. Webster. 1985. Shredder abundance and leaf breakdown in an Appalachian Mountain stream. Freshwater Biology. Volume 15.

Beschta, R.L. 1978. Long-Term Patterns of Sediment Production Following Road Construction and Logging in the Oregon Coast Range. *Wat. Resour. Res.* 14:1011-1016.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream Temperature and Aquatic Habitat: Fisheries and Forestry Interactions. *In*: Salo, E.O. and T.W. Cundy, eds. Streamside Management: Forestry and Fishery Interactions. University of Washington, Institute of Forest Resources, Contribution No. 57.

Bilby, R.E. and P.A. Bisson. 1992. Allochthonous versus Autochthonous Organic Matter Contributions to the Trophic Support of Fish Populations in Clear-Cut and Old-Growth Forested Streams. *Can. J. Fish. Aquat. Sci.* 49:540-551.

Bingham, S.C., P.W. Westerman, and M.R. Overcash. 1980. Effect of Grass Buffer Zone Length in Reducing the Pollution from Land Application Areas. *Transactions of the ASAE – 1980*:330-342.

Bisson, P.A., et al. 1987. Large Woody Debris in Forested Streams in the Pacific Northwest: Past, Present, and Future. *In*: Cundy, T.; Salo, E., eds. Proceedings of a Symposium; Streamside Management - Forestry and Fisheries Interactions. University of Washington, Seattle, Washington.

Bisson, P.A., K. Sullivan, and J.L. Nielsen. 1988. Channel Hydraulics, Habitat use, and Body form of Juvenile Coho Salmon, Steelhead, and Cutthroat Trout in Streams. Transactions of the American Fisheries Society 117: 262-273.

Bjorn, T.C. and D.W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. In Meehan, W.R., ed. Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society Special Publication 19.

Bledsoe, B. P., and C.C. Watson. 2001. Effects of Urbanization on Channel Instability. Journal of American Water Resources Association. Volume 37.

Bolton, S. and Shellberg, J. 2001. Ecological Issues in Floodplains and Riparian Corridors. Center for Streamside Studies, University of Washington, Seattle, WA.

Booth, D.B. 1991. Urbanization and the Natural Drainage System—Impacts, Solutions, and Progress. *Northwest Environmental Journal* 7(1): 93-118.

Booth, D. B. 2000. Forest cover, impervious-surface area, and the mitigation of urbanization impacts in King County, Washington. Prepared for King County Water and Land Resources Division. Seattle, Washington.

Bosch, D.D., R.K. Hubbard, L.T. West, and R.R. Lowrance. 1994. Subsurface Flow Patterns in a Riparian Buffer System. *Trans. of the Am. Soc. of Ag. Engineers* (ASAE) 37:1783-1790..

Brazier, J.R. and G.W. Brown. 1973. Buffer Strips for Stream Temperature Control. Research Paper No.15, Forest Research Lab, Oregon State Univ., Corvallis, OR. 9 pp.

Brenner, R.P. and S.M. James. 1977. Effect of Roots on the Shear Strength of a Colluvial Soil. *Proc., 5th Danube European Conf. Soil Mech. and Foundation Engr.*, CSSR, Bratislava., pp. 77-78.

Brett, J.R. 1956. Some principals in the thermal requirements of fishes. *Quart. Rev. Biol.* 31(2):75-87

Broderson, J. Morris. 1973. Sizing Buffer Strips to Maintain Water Quality. M.S. Thesis, University of Washington, Seattle.

Brown, E.R., (ed.). 1985. Riparian Zones and Freshwater Wetlands. Management of Wildlife and Fish Habitats in Forests of Western Oregon and Washington, Part I - Chapter Narratives. pp. 57-80.

Brown, G.W. 1969. Predicting Temperatures of Small Streams. *Wat. Resour. Res.* 5(1):68-75.

Brown, G.W., and J.T. Krygier. 1970. Effects of Clear Cutting on Stream Temperature. *Wat. Resour. Res.* 6:1133-1139.

Budd, W.W., P.L. Cohen, P.R. Saunders, and F.R. Steiner. 1987. Stream Corridor Management in the Pacific Northwest: I. Determination of Stream-Corridor Widths. *Environmental Management* 11:587-597.

Burns, J.W. 1972. Some Effects of Logging and Associate Road Construction on Northern California Streams. *Transactions of the American Fisheries Society* 101:1-17.

Burroughs, E.R. and B.R. Thomas. 1977. Declining Root Strength in Douglas-fir after Felling as a Factor in Slope Stability. *USDA Forest Service Research Paper INT-190.* 27 pp.

Castelle, A.J., A.W. Johnson, and C. Conolly. 1994. Wetland and Stream Buffer Size Requirements - A Review. *J. Environ. Qual.* 23:878-882.

Castelle, A.J., and A.W. Johnson. 2000. Riparian Vegetation Effectiveness. National Council for Air and Stream Improvement Tech. Bull. No. 799.

Castelle, A.J., C. Conolly, M. Emers, E.D. Metz, S. Meyer, and M. Witter. 1992. Wetland Buffers: An Annotated Bibliography. Publ. 92-11. Adolfson Assoc., for Shorelands and Coastal Zone Manage. Program, Washington Dept. of Ecology, Olympia, WA.

Castelle, A.J., C. Conolly, M. Emers, E.D. Metz, S. Meyer, M. Witter, S. Mauermann, T. Erickson, and S.S. Cooke. 1992. Wetland Buffers: Use and Effectiveness. Publ. 92-10. Adolfson Assoc., for Shorelands and Coastal Zone Manage. Program, Washington Dept. of Ecology, Olympia, WA.

Chapman, D.W. and E. Knudsen. 1980. Channelization and Livestock Impacts on Salmonid Habitat and Biomass in Western Washington. *Trans. Am. Fish. Soc.* 101:357-363.

City of Bellevue. 1995. *Characterization and Source Control of Urban Stormwater Quality*, Bellevue Utilities Department, Bellevue, WA.

City of Portland. 2001. Streamside Science and an Inventory of Significant Riparian and Wetland Resources. Discussion Draft. City of Portland, Oregon Bureau of Planning.

Clark, J.R. 1977. Coastal Ecosystem Management: A Technical Manual for the Conservation of Coastal Zone Resources. John Wiley and Sons, New York.

Cole, J.T., J.H. Baird, N.T. Basta, R.L. Huhnke, D.E. Storm, G.V. Johnson, M.E. Payton, M.D. Smolen, D.L. Martin, and J.C. Cole. 1997. Influence of Buffers on Pesticide and Nutrient Runoff from Bermuda grass Turf. *J. Environ. Qual.* 26:1589-1598.

Cooper, J.R., J.W. Gilliam, R.B. Daniels, and W.P. Robarge. 1987. Riparian Areas as Filters for Agricultural Sediment. *Soil Sci. Soc. Am. J.* 51:416-420.

Corbett, E.S. and J.A. Lynch. 1985. Management of Streamside Zones on Municipal Watersheds. pp. 187-190. *In* R. R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Folliott, and R.H. Hamre (eds.), Riparian Ecosystems and their Management: Reconciling Conflicting Uses. First North American Riparian Conference, April 16-18, 1985, Tucson, Arizona.

Coyne, M.S., R.L. Blevins, and R. Rhodes. 1994. Sediment and Fecal Bacteria Containment by Vegetative Filter Strips. *J. Soil Water Conserv*.

Culp, J.M. and R.W. Davies. 1983. An Assessment of the Effects of Streambank Clear-Cutting on Macroinvertebrate Communities in a Managed Watershed. Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1208: 115 p. Dept. Fish. Oceans; Fisheries Res. Branch; Pacific Biological Station; Nanaimo, B. C.

Daniels, R.B., and J.W. Gilliam. 1996. Sediment and Chemical Load Reduction by Grass and Riparian Filters. *Soil Sci. Soc. Am. J.* 60:246-251.

Darling, N., L. Stonecipher, D. Couch, and J. Thomas. 1982. Buffer Strip Survival Survey. Hoodsport Ranger District, Olympic National Forest.

Darveau, J., P. Beauchesne, L. Bélanger, J. Huot, and P. Larue. 1995. Riparian Forest Strips as Habitat for Breeding Birds in Boreal Forest. *J. Wildl. Manage.* 59:67-78.

Darveau, M., J. Huot, and L. Bélanger. 1998. Riparian Forest Strips as Habitat for Snowshoe Hare in a Boreal Balsam Fir Forest. *Can. J. For. Res.* 28:1494-1500.

Davies, P.E., and M. Nelson. 1994. Relationships between Riparian Buffer Widths and the Effects of Logging on Stream Habitat, Invertebrate Community Composition and Fish Abundance. *Aust. J. Mar. Freshwater Res.* 45:1289-1305.

Desbonnet, A., P. Pogue, V. Lee, and N. Wolff. 1994. Vegetated Buffers in the Coastal Zone. Coastal Resources Center, , Rhode Island Sea Grant, Univ. of Rhode Island.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control. *ASAE* 32:513-519.

Doley, D. 1981. Tropical and Subtropical Forests and Woodlands. *In* Kozlowski, T.T., ed. Water Deficits and Plant Growth. Academic Press, New York.

Doyle, R.C., D.C. Wolf, and D.F. Bezdicek. No Date. Effectiveness of Forest Buffer Strips in Improving the Water Quality of Manure Polluted Runoff. *Managing Livestock Wastes*, 299-302.

Doyle, R.C., G.C. Stanton, and D.C. Wolf. 1977. Effectiveness of Forest And Grass Buffer Strips in Improving the Water Quality of Manure Polluted Runoff. American Society of Agricultural Engineers, Paper No. 77-2501.

Duncan, W.F.A. and M.A. Brusven. 1985. Energy Dynamics of Three Low-Order Southeast Alaska Streams: Allochthonous Processes. *J. Freshwater Ecology* 4:233-248.

Dunne, T., and L. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Co., New York.

Ecology. 2001. Focus: Riparian Areas. Washington Department of Ecology. Available online at: http://www.ecy.wa.gov/pubs/0010023.pdf

Elmore, W., and R.L. Beschta. 1987. Riparian Areas: Perceptions in Management. *Rangelands* 9:260-265.

Endo, T., and T. Tsurata. 1969. Effect of Trees' Roots upon the Shearing Strength of Soils. pp. 167-179. Annu. Rep. Hokkaido Branch, Tokyo For. Exp. Stn. 18:168-179.

Erman, D.C. and D. Mahoney. 1983. Recovery after Logging With and Without Bufferstrips in Northern California. Contribution No. 186. California Water Resources Center, Univ. of California, CA. 50 pp.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. Evaluation of Streamside Bufferstrips for Protecting Aquatic Organisms. Technical Completion Report, Contribution #165, California Water Resources Center, University of California, Davis, CA.

Fennessy, M.S., and J.K. Cronk. 1997. The Effectiveness and Restoration Potential of Riparian Ecotones for the Management of Nonpoint Source Pollution, Particularly Nitrate. *Critical Reviews in Environmental Science and Technology* 27:285-317.

France, R., R. Peters, and L. McCabe. 1998. Spatial Relationships among Boreal Riparian Trees, Litterfall, and Soil Erosion Potential with Reference to Buffer Strip Management and Coldwater Fisheries. *Ann. Bot Fennici* 35:1-9.

Gallagher, J.L., and H.V. Kibbey. 1980. Marsh Plants as Vectors in Trace Metal Transport in Oregon Tidal Marshes. *Am. J. Bot*. 67:1069-1074.

Ghaffarzadeh, M., C.A. Robinson, and R.M. Cruse. 1992. Vegetative Filter Strip Effects on Sediment Deposition from Overland Flow. *In* Agronomy Abstracts. ASA, Madison, WI.

Gilliam, J.W. 1994. Riparian Wetlands and Water Quality. *J. Environ. Qual.* 23:896-900.

Gilliam, J.W., and R.W. Skaggs. 1986. Natural Buffer Areas and Drainage Control to Remove Pollutants From Agricultural Drainage Water. *In*: Proceedings of National Wetland Symposium: Mitigation of Impacts and Losses, New Orleans, LA, Oct. 8 – 10, 1986.

Gregory, S.V. 1980. Effects of Light, Nutrients, and Grazing on Periphyton Communities in Streams. Ph.D. thesis. Oregon State University, Corvallis, OR. 151 pp.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An Ecosystem Perspective of Riparian Zones: Focus on Links Between Land and Water. *BioScience* 41:540-551.

Grismer, M.E. 1981. Evaluating Dairy Waste Management Systems Influence on Fecal Coliform Concentration in Runoff. M.S. Thesis, Oregon State University, Corvallis, OR.

Groffman, P.M., A.J. Gold, T.P. Husband, R.C. Simmons, and W.R. Eddleman. 1990. An Investigation into Multiple Uses of Vegetated Buffer Strips. Publ. No. NBP-90-44, Dept. of Natural Resources Science, Univ. of Rhode Island, Kingston, RI.

Hairston-Strang, A.B., and P.W. Adams. 1998. Potential Large Woody Debris Sources in Riparian Buffers after Harvesting in Oregon, USA. *Forest Ecology and Management* 112:67-77.

Harris, R.A. 1986. Vegetative Barriers: An Alternative Highway Noise Abatement Measure. *Noise Control Engineering Journal*, July-August 1986.

Haussman, R.F. and E.W. Pruett. 1978. Permanent Logging Roads for Better Woodlot Management. U.S. Dept. Agriculture, Forest Service, Northeast Area. Broomall, Pa.

Hayes, J.P., M.D. Adam, D. Bateman, E. Dent, W.H. Emmingham, K.G. Maas, and A.E. Skaugset. 1996. Integrating Research and Forest Management in Riparian Areas of the Oregon Coast Range. *Western J. of Appl. Forestry* 11:85-89.

Henderson, J.E. 1986. Environmental Designs for Streambank Protection Projects. *Water Res. Bull.* 22:549-558.

Herson-Jones, L.M., M. Heraty and B. Jordan. 1995. Riparian Buffer Strategies for Urban Watersheds. Metropolitan Washington Council of Governments, Publ. No. 95703, Washington, D.C.

Hewlett, J.D., and J.C. Fortson. 1982. Stream Temperature Under an Inadequate Buffer Strip in the Southeast Piedmont. *Wat. Resour. Bull.* (AWRA) 18:983-988.

Higgs, D.A., J.S. McDonald, C.D. Levings, and B.S. Dosanjh. 1995. Nutrition and Feeding Habits in Relation to Life History Stage. *In* Groot, C., L. Margolis, and W.C. Clarke, eds. Physiological Ecology of Pacific Salmon. UBC Press, Vancouver, B.C.

Hill, A.R. 1996. Nitrate Removal in Stream Riparian Zones. *J. Environ. Qual.* 25:743-755.

Horner, R.R., and B.W. Mar. 1982. Guide for Water Quality Impact Assessment of Highway Operations and Maintenance. Washington Department of Transportation. Rpt. No. WA-RD-39.14. Olympia, WA.

Horner, R.R., and C.W. May. 1999. Regional Study Supports Natural Land Cover Protection as Leading Best Management Practice for Maintaining Stream Ecological Integrity.

Comprehensive Stormwater & Aquatic Ecosystem 1999 – Conference Papers Vol. 1:233-247, Feb. 22 – 26, 1999, Auckland, New Zealand.

Horner, R.R., and C.W. May. May. 2000. Watershed Urbanization and the Decline of Salmon in Puget Sound streams. Center for Urban Water Res. Management, University of Washington, Seattle.

Huang, C. 1998. Sediment Regimes under Different Slope and Surface Hydrologic Conditions. *Soil Sci. Soc. Am. J.* 62:423-430.

Hubbard, R.K., and R.R. Lowrance. 1992. Solute Transport through a Riparian Forest Buffer System. *In* Agronomy Abstracts. ASA, Madison, WI.

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press. 555 pp.

Isenhart. T.M., R.C. Schultz, and J.P. Colletti. 1997. Watershed Restoration and Agricultural Practices in the Midwest: Bear Creek in Iowa. *In*: J.E. Williams (ed.) Watershed Restoration: Principles and Practices, American Fisheries Society, MD.

Jacobs, T.C. and J.W. Gilliam. 1985. Riparian Losses of Nitrate from Agricultural Drainage Waters. *J. Environ. Qual.* 14:472-478.

Jarvis, P.G. 1981. Stomatal Conductance, Gaseous Exchange and Transpiration. *In* Grace, J., E.D. Ford, and P.G. Jarvis, eds. Plants and Their Atmospheric Environment. Blackwell, Oxford.

Johnson, A.W., and D. Ryba. 1992. A Literature Review of Recommended Buffer Widths to Maintain Various Functions of Stream Riparian Areas. King County Surface Water Management Division, Seattle, WA.

Jordan, T.E., D.L. Correll, and D.E. Weller. 1993. Nutrient Interception by a Riparian Forest Receiving Inputs from Adjacent Cropland. *J. Environ. Qual.* 22:467-473.

Karssies, L., and I.P. Prosser. No Date. Sediment Storage Capacity of Grass Buffer Strips. Cooperative Research Centre for Catchment Hydrology and CSIRO Land and Water, Canberra, Australia.

Keller, C.M.E., C.S. Robbins, and J.S. Hatfield. 1993. Avian Communities in Riparian Forests of Different Widths in Maryland and Delaware. *Wetlands* 13:137-144.

Kerwin. 2001. Salmon Habitat Limiting Factors Report: WRIA 8. Washington State Conservation Commission, Olympia WA.

Kleinfelder, D., S. Swanson, G. Norris, and W. Clary. 1992. Unconfined Compressive Strength of Some Streambank Soils with Herbaceous Roots. *Soil Sci. Soc. Am. J.* 56:1920-1025.

Knutson, K.C. and V.L. Naef. 1997. Management Recommendations for Washington's Priority Habitats: Riparian. Washington Department of Fish and Wildlife, Olympia WA.

Lamb, J. C. 1985. *Water Quality and Its Control*. John Wiley and Sons. New York, New York.

Lantz, R.L. 1971. Guidelines for Stream Protection in Logging Operations. Oregon State Game Commission. Portland, Ore. 29 pp.

Larson, M. 2000. Effectiveness of Large Woody Debris in Stream Rehabilitation Projects in Urban Basins. Center for Urban Water Resources Management.

Leavitt, J. 1998. The functions of riparian buffers in urban watersheds. Masters Thesis. University of Washington. Seattle, Washington.

Ledwith, T. 1996. The Effects of Buffer Strip Width on Air Temperature and Relative Humidity in a Stream Riparian Zone. Proceedings of the 1996 Watershed Management Council. Watershed Management Council. Available online at: http://watershed.org/news/sum_96/buffer.html.

Lee, K., T.M. Isenhart, R.C. Schultz, and S.K. Mickelson. 2000. Multispecies Riparian Buffers Trap Sediment and Nutrients during Rainfall Simulation. *J. Environ. Qual.* 29:1200-1205.

Lowrance, R., R.Todd, J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, and L. Asmussen. 1984. Riparian Forests as Nutrient Filters in Agricultural Watersheds. *BioScience* 34:374-377.

Lynch, J.A., E.S. Corbett, and K. Mussallem. 1985. Best Management Practices for Controlling Nonpoint-Source Pollution on Forested Watersheds. *J. Soil Wat. Conserv.* 40:164-167.

Lyons, J., S.W. Trimble, and L.K. Paine. 2000. Grass Versus Tress: Managing Riparian Areas to Benefit Streams of Central North America. *J. Am. Water Res. Assoc.* 36:919-930.

Machtans, C.S., M. Villard, and S.J. Hannon. 1996. Use of Riparian Buffer Strips as Movement Corridors by Forest Birds. *Conservation Biology* 10:1366-1379;

Madison, C.E., R.L. Blevins, W.W. Frye, and B.J. Barfield. 1992. Tillage and Grass Filter Strip Effects upon Sediment and Chemical Losses. *In* Agronomy Abstracts. ASA, Madison, WI.

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar, and E.B. Welsh. 1997. Effects of Urbanization on Small Stream in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques, 2:483-494.

May, C.W., E.B. Welch, R.R. Horner, J.R. Karr, and B.W. Mar. 1997. Quality Indices for Urbanization Effects in Puget Sound Lowland Streams. Wat. Res. Tech. Rep 154. Washington Department of Ecology, Olympia WA.

McCullough, D. 1999. A Review and Synthesis of Effects of Alteration to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. Columbia Intertribal Fisheries Commission, Portland, OR. Prepared for the U.S. Environmental Protection Agency Region 10. Published as EPA 910-R-010. http://www.critfc.org/tech/EPAreport.htm

McDade, M.H., F.J. Swanson, W.A. McKee, J.F. Farnklin, and J. Van Sickle. 1990. Source Distances for Coarse Woody Debris entering Small Streams in Western Oregon and Washington. *Can. J. For. Res*. 20:326-330.

McLean, J. 2000. The Longevity of Instream Habitat Structures. In *The Practice of Watershed Protection*, Article 148. Thomas R. Schueler and Heather K. Holland, eds. Center for Watershed Protection, Ellicott City, MD.

McMillan, A. 2000. *The Science of Wetland Buffers and Its Implications for the Management of Wetlands.* Masters Thesis, The Evergreen State College and Washington Department of Ecology, Olympia, WA.

Meehan, W.R., F.J. Swanson, and J.R. Sedell. 1977. Influences of Riparian Vegetation on Aquatic Ecosystems with Particular Reference to Salmonid Fishes and Their Food Supply. USDA Forest Service General Technical Report MR-43. Contributed paper, Symposium on the Importance, Preservation and Management of the Riparian Habitat, July 9, 1977, Tucson Arizona.

Megahan, W.F., K.A. Seyedbagheri, T.L. Mosko, and G.L. Ketcheson. 1986. Construction Phase Sediment Budget for Forest Roads on Granitic Slopes. *In* Proceedings: Drainage Basin Sediment Delivery. IAHS Publication 159, Wallingfor, Oxon, U.K. pp. 31-39.

Megahan, W.F., N.F. Day, and T.M. Bliss. 1978. Landslide Occurrence in the Western and Central Northern Rocky Mountain Physiographic Province of Idaho, *In* C.T. Youngberg (ed.), Proceedings: Forest Soil and Landuse. Colorado State University, Fort Collins, CO. pp. 116-139.

Megahan, W.R., and G.L. Ketcheson. 1996. Predicting Downslope Travel of Granitic Sediments from Forest Roads in Idaho. *Water Resources Bull.* 32:371-382.

Mendez, A., T.A. Dillaha, and S. Mostaghimi. 1999. Sediment and Nitrogen Transport in Grass Filter Strips. *Journal of the American Water Resources Association*. 35:867-875.

Mersie, W., C.A. Seybold, C. McNamee, and J. Huang. 1999. Effectiveness of Switchgrass Filter Strips in Removing Dissolved Atrazine and Metolachlor from Runoff. *J. Environ. Qual*. 28:816-821.

Meyers, J. M, R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. 1998. NOAA Technical Memorandum NMFS-NWFSC-35 Status Review of Chinook Salmon From Washington, Idaho, Oregon, and California. NOAA. Seattle, WA.

Miller, D.E., P.B. Skidmore, and D.J. White. 2001. White Paper: Channel Design. Interfluve, Inc.

Moyle, P. B. and J. J. Cech, Jr. 1998. *Fishes, An introduction to Ichthyology*. Second Edition. Prentice Hall. Englewood, California.

Murdock, A., and J.A. Capobianco. 1979. Effluent on a Natural Marsh. *J. Wat. Pollut. Control Feder.* 51:2243-2256.

Murphy, M.L. and K V. Koski. 1989. Input and Depletion of Woody Debris in Alaska Streams and Implications for Streamside Management. *N. Am. J. Fish. Mang.* 9:427-436.

Murphy, M.L. and W.R. Meehan. 1991. Stream Ecosystems. *In* Meehan, W.R., ed. Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society Special Publication 19:17-46.

Murphy, M.L., and J.D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. *Can. J. Fish. Aquat. Sci.*38:137-145.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. *Trans. Am. Fish. Soc.* 110:469-478.

Naiman, R., T. Beechie, L. E. Benda, D. R. Berg, P. A. Bisson, L. H. MacDonald, M. D. O'Conner, P. L. Olson, and E. A. Steel. 1992. "Fundamental Elements of Ecologically Healthy Watersheds in the Coastal Pacific Northwest Coastal Ecoregion." *in Watershed Management, Balancing Sustainability and Environmental Change*, R. J. Naiman, ed. Springer-Verlang. New York, NY.

Naiman, R.J., T.J. Beechie, L.E. Benda, D.R. Berg, P.A. Bisson, L.H. MacDonald, M.D. O'Connor, P.L. Olson, and E.A. Steel. 1992. Fundamental Elements of Ecologically Healthy Watersheds in the Pacific Northwest Coastal Ecoregion. *In* Naiman, R.J., ed. Watershed Management. Balancing Sustainability and Environmental Change. Springer-Verlang. New York, New York. 542 p.

National Marine Fisheries Service. 1996. Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale. NMFS Environmental and Technical Services Division.

Natural Resources Conservation Service. 1997. Alley Cropping. USDA NRCS Conservation Practice Job Sheet No. 311.

Natural Resources Conservation Service. 1997. Contour Buffer Strips. USDA NRCS Conservation Practice Job Sheet No. 332.

Natural Resources Conservation Service. 1997. Field Borders. USDA NRCS Conservation Practice Job Sheet No. 386.

Newbold, J.D., D.C. Erman, and K.B. Roby. 1980. Effects of Logging on Macroinvertebrates in Streams With and Without Buffer Strips. *Can. J. Fish Aquat. Sci.* 37:1076-1085.

Norris, V. 1993. The Use of Buffer Zones to Protect Water Quality: A Review. *Water Resources Management* 7:257-272.

Osborne, L.L., and D.A. Kovacic. 1993. Riparian Vegetated Buffer Strips in Water-Quality Restoration and Stream Management. Freshwater Biology 29:243-258.

Packer, P.E. 1967. Criteria for Designing and Locating Logging Roads to Control Sediment. *For. Sci.* 13:2-18.

Palfrey, R. No Date. Natural Buffer Areas: An Annotated Bibliography. Coastal Resources Division, Maryland Dept. of Natural Resources, Annapolis, MD.

Patton, D.R. 1973. A Literature Review of Timber Harvesting Effects on Stream Temperature. Research Note RM-249. Rocky Mountain Forest and Range Exp. Sta. U.S. Forest Service. Fort Collins, Colorado.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest. *Ecology* 65:1466-1475.

Pinay, G., and H. Decamps. 1988. The Role of Riparian Woods in Regulating Nitrogen Fluxes Between the Alluvial Aquifer and Surface Water: A Conceptual Model. *Regulated Rivers: Research and Management* Vol. 2:507-516.

Pitt, D.G., W.G. Gould, and L. LaSota. 1986. Landscape Design to Reduce Surface Water Pollution in Residential Areas. Water Resources Information Bulletin No. 5. Univ. of Maryland. Cooperative Extension Service. 10 p.

Qiu, Z., and T. Prato. 1998. Economic Evaluation of Riparian Buffers in an Agricultural Watershed. *Journal of the American Water Resources Association* 34:877-889.

Reiser, D.W. and T.C. Bjornn. 1979. Habitat Requirements of Anadromous Salmonids. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-96.

Richards, C., L.B. Johnson, and G.E. Host. 1996. Landscape-Scale Influences on Stream Habitats and Biota. *Can. J. Fish Aquat. Sci.* 53:295-311.

Richards, K.S. 1977. Channel and Flow Geometry: A Geomorphological Perspective. *Prog. Phys. Geogr.* 1:66-102.

Rinne, J. N. 1990. "The utility of stream habitats and biota for identifying potential conflicting forest land uses: Montane riparian areas." *Forest Ecology and Management*. Volume 33/34.

Robison, G.E. and R.L. Beschta. 1990. Identifying Trees in Riparian Areas That Can Provide Coarse Woody Debris to Streams. *Forest Science* 36:790-801.

Roby, K.B., D.C. Erman, and J.D. Newbold. 1977. Biological Assessment of Timber Management Activity Impacts and Buffer Strip Effectiveness on National Forest Streams of Northern California. USDA - Forest Service, California Region.

Roni, P., T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M. Pollock, and G.R. Pess. 2002. A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds. North American Journal of Fisheries Management. 22:1-20.

Roman, C.T., and R.E. Good. 1985. Buffer Delineation Model for New Jersey Pinelands Wetlands. Division of Pinelands Research, Center for Coastal and Environmental Studies, Rutgers State University, New Brunswick, NJ.

Rudolph, D.C., and J.G. Dickson. 1990. Streamside Zone Width and Amphibian and Reptile Abundance. *The Southwestern Naturalist* 35:472-476.

Schellinger, G.R., and J.C. Clausen. 1992. Vegetative Filter Treatment of Dairy Barnyard Runoff in Cold Regions. *J. Environ. Qual.* 211:40-45.

Schlosser, F. and N.T. Long. 1974. Recent Results in French Research on Reinforced Earth. *J. Const. Div.*, ASCE 100:223-237.

Schlosser, I.J., and J.R. Karr. 1981. Water Quality in Agricultural Watersheds: Impact of Riparian Vegetation During Base Flow. *Wat. Res. Bull.* 17:233-240.

Schmitt, T.J., M.G. Dosskey, and K.D. Hoagland. 1999. Filter Strip Performance and Processes for Different Vegetation, Widths, and Contaminants. *J. Environ. Qual.* 28:1479-1489.

Sedell, J.R. and R.L. Beschta. 1991. Bringing back the "Bio" in Bioengineering. *American Fish. Soc. Symposium* 10: 160-175.

Sedell, J.R., F.J. Swanson, and S.V. Gregory. 1984. Evaluating Fish Response to Woody Debris. *In*: Proceedings of the Pacific Northwest Stream Habitat Management Workshop, Western Division, American Fisheries Society and Cooperative Fisheries Unit, Humbolt State University, Arcata, CA. pp. 222-245.

Shields, Jr., and R. H. Smith. 1992. Effects of Large Woody Debris Removal on Physical Characteristics of a Sand-Bed River. *Aquatic Conservation: Marine and Freshwater Ecosystems* 2:145-163.

Shields, Jr., F.D., C.J. Gippel. No Date. Prediction of Effects of Woody Debris Removal on Flow Resistance. Journal of Hydraulic Engineering Vol?:341-354.

Shirvell, C. S. 1990. "Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows." *Canadian Journal of Fisheries and Aquatic Science*. Volume 47.

Shisler, J.K., P.E. Waidelich, and H.G. Russell. 1985. Coastal Wetlands: Wetlands Buffer Delineation Study – Task 1. New Jersey Agricultural Experiment Station Publ. No. P-40502-02-85, New Brunswick, NJ.

Shisler, J.K., R.A. Jordan, and R.N. Wargo 1987. Coastal Wetland Buffer Delineation. New Jersey Dept. of Environmental Protection, Division of Coastal Resources, Trenton, New Jersey. 102 pp.

Snyder, N.J., S. Mostaghimi, D.F. Berry, R.B. Reneau, S. Hong, P.W. McClellan, and E.P. Smith. 1998. Impact of Riparian Forest Buffers on Agricultural Nonpoint Source Pollution. Journal of the American Water Resources Association 34:385-394.

Steinblums, I., H. Froehlich, and J. Lyons. 1984. Designing Stable Buffer Strips for Stream Protection. U.S. Forest Service, 2520 Watershed Protection and Management.

Sullivan, K., J. Tooley, K. Doughty, J.E. Caldwell, and P. Knudsen. 1990. Evaluation of Prediction Models and Characterization of Stream Temperature Regimes in Washington. Timber/Fish/Wildlife Rep. No. TFW-WQ3-90-006. Wash. Dept. of Nat. Res., Olympia, WA. 224 pp.

Swales, S. and C. D. Levings. 1989. "Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia." *Canadian Journal of Fisheries and Aquatic Science*. Volume 46.

Thomas, R. E., J. A. Gharrett, M. G. Carls, S. D. Rice, A. Moles, and S. Korn. 1986. "Effects of fluctuating temperature on mortality, stress, and energy reserves of juvenile coho salmon." *Transactions of the American Fisheries Society.* Volume 115.

Thorne, C.R., and N.K. Tovey. 1981. Stability of Composite River Banks. *Earth Surf. Processes Landforms* 6:469-484.

Thornton, C.I., S.R. Abt, and W.P. Clary. 1997. Vegetation Influence on Small Stream Siltation. Journal of the American Water Resources Association 33:1279-1288.

Trimble, S.W. 1997. Stream Channel Erosion and Change Resulting from Riparian Forests. *Geology* 25:467-469.

Turmanina, V.I. 1965. The Strength of Tree Roots. *Bull. Moscow Soc. Naturalists, Biol. Section* 70:36-45.

United States Environmental Protection Agency. 2001. Technical Synthesis: Scientific Issues Relating to Temperature Criteria for Salmon, Trout, and Char Native to the Pacific Northwest. EPA 910-R-01.

United States Department of the Interior Fish and Wildlife Service (USFWS). 1998. *A Framework to Assist in the Making of Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Bull Trout Subpopulations Watershed Scale (Draft).* USFWS, Washington, DC.

United States Department of the Interior, Geological Survey (USGS). 1999. Pesticides Detected in Urban Streams During Rainstorms and Relations to Retail Sales of Pesticides in King County, Washington. USGS Fact Sheet 097-99. USGS, Tacoma, WA.

URS. 2002. *Whatcom County Endangered Species Act Response Plan: Evaluation of County Policies, Regulations, and Programs.* Prepared by URS Greiner Woodward Clyde and Adolfson Associates, Inc., 2002.

Uusi-Kämppä, J., B. Braskerud, H. Jansson, N. Syversen, and R. Uusitalo. 2000. Buffer Zones and Constructed Wetlands as Filters for Agricultural Phosphorus. *J. Environ. Qual.* 29:151-158.

Van Sickle, J. 2000. "Modeling variable-width riparian buffers, with an application to woody debris recruitment." *International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds.* American Water Resources Association.

Van Sickle, J. and S.V. Gregory. 1990. Modeling Inputs of Large Woody Debris to Streams from Falling Trees. *Can. J. For. Res.* 20:1593-1601.

Vanderholm, D.H., and E.C. Dickey. 1978. ASAE Paper No. 78-2570. ASAE Winter Meeting, Chicago, IL.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Science 37:130-137.

Verchot, L.V., E.C. Franklin, and J.W. Gilliam. 1997. Nitrogen Cycling in Piedmont Vegetated Filter Zones: II. Subsurface Nitrate Removal. *J. Environ. Qual.* 26:337-347.

Waldron, L.J. 1977. The Shear Resistance of Root-Permeated Homogeneous and Stratified Soil. *Soil Sci. Soc. Am. J.* 41:843-849.

Waldron, L.J., and S. Dakessian, 1982. Effect of Grass, Legume, and Tree Roots on Soil Shearing Resistance. *Soil Sci. Soc. Am. J.* 46:894-899.

Waring, R.H., and W.H. Schlesinger. 1985. Forest Ecosystems Concepts and Management. Academic Press, Orlando, FL.

Washington Department of Fish and Wildlife (WDFW) and Western Washington Treaty Indian Tribes. 1994. *1992 Washington State Salmon and Steelhead Stock Inventory*. Olympia, Washington.

Washington Department of Fish and Wildlife (WDFW). 1997. *Wild Salmonid Policy. Washington Department of Fish and Wildlife Final Environmental Impact Statement.* Washington Department of Fish and Wildlife. Olympia, WA.

Washington Department of Fish and Wildlife. 1998. 1997 Washington Salmonid Stock Inventory. Appendix Bull Trout and Dolly Varden. Olympia, Washington.

Washington Office of Community Development (OCD). 2002. *Model Code Recommendations for Designating and Protecting Critical Areas, First Edition, 2nd Draft.* Prepared by Berryman & Henigar Inc., Adolfson Associates Inc., and GeoEngineers, Inc.

Washington State Pesticide/ESA Task Force. 2001. A Process for Evaluating Pesticides in Washington State Surface Waters for Potential Impacts to Salmonids. WSDA Publication No. 057, Olympia, WA.

Whitaker, D.M., and W.A. Montevecchi. 1999. Breeding Bird Assemblages Inhabiting Riparian Buffer Strips in Newfoundland, Canada. *Journal of Wildlife Management* 63:167-179.

Whitehead, D., and P.G. Jarvis. 1981. Coniferous Forests and Plantations. *In* Kozlowski, T.T., ed. Water Deficits and Plant Growth. Academic Press, New York.

Williams, R.D., and E.D. Lavey. 1986. Selected Buffer References. Water Quality and Watershed Research Laboratory, Durant, OK.

Wilson, L.G. 1967. Sediment Removal from Flood Water by Grass Filtration. *Transactions of the ASAE* pp. 35-37.

Wong, S.L., and R.H. McCuen. 1982. The Design of Vegetative Buffer Strips for Runoff and Sediment Control. A Technical Paper Developed as part of a Study of Stormwater Management in Coastal Areas Funded by Maryland Coastal Zone Management Program. 23 p.

Wray, W.K. 1986. Measuring Engineering Properties of Soil. Prentice Hall, Englewood Cliffs, NJ.

Wu, T.H. 1976. Investigation of Landslides on Prince of Wales Island, Alaska. *Geotechnical Engr. Report No. 5*, Dept. of Civil Engr., Ohio State Univ., Columbus, OH. 94 pp.

Wydoski, R.S. and R.R. Whitney. 1979. *Inland Fishes of Washington*. University of Washington Press. Seattle, Washington.

Xu, L., J.W. Gilliam, and R.B. Daniels. 1992. Nitrate Movement and Loss in Riparian Buffer Areas. *In* Agronomy Abstracts. ASA, Madison, WI.

Young, R.A., T. Huntrods, and W. Anderson. 1980. Effectiveness of Vegetated Buffer Strips in Controlling Pollution from Feedlot Runoff. *J Environ. Qual.* 9:483-497.

Zimmerman, R.C., J.C. Goodlett, and G.H. Comer. 1967. The Influence of Vegetation on Channel Form of Small Streams. Symposium on River Morphology. *Int. Assoc. Sci. Hydrol.* 75:255-275.

IX. GLOSSARY

Aggrade	The raising of a stream-channel bed with time due to the deposition of sediment that was eroded and transported from the upstream watershed or the channel.
Armoring	Formation of a layer of rocks on the surface of a streambed that resists erosion by water flows. The rocks can be naturally occurring, caused by the scour of smaller particles from high discharges, or placed by humans to stop channel erosion.
Base flow	The flow that a perennially flowing stream reduces to during the dry season. It is supported by ground-water seepage into the channel.
Bed	The bottom of a channel.
Bed load	Sediment particles up to rock, which slide and roll along the bottom of the streambed.
Daylight	In the restoration field, a verb that denotes the excavation and restoration of a stream channel from an underground culvert, covering, or pipe.
Discharge	The volume of water passing through a channel during a given time, usually measured in cubic feet per second.
Floodplain	The land adjacent to a channel at the elevation of the bankfull discharge, which is inundated on the average of about 2 out of 3 years. The floor of stream valleys, which can be inundated by small to very large floods. The one-in-100-year floodplain has a probability of .01 chance per year of being covered with water.
Floodway	A regulatory floodplain under the National Flood Insurance Program that includes the channel and that portion of the adjacent floodplain that is required to pass flood flows (normally the one-in-100-year flood) without increasing the water surface elevation more than a designated height (1 foot in most areas).
Incised Channel	A stream that has degraded and cut its bed into the valley bottom. Indicates accelerated and often destructive erosion.
Infiltration	That portion of rainfall or surface runoff that moves downward into the subsurface rock and soil.
Pool	A location in an active stream channel, usually located on the outside bends or meanders, where the water is deepest and has reduced current velocities.
Reach	A section of a stream's length.
Riffle	A shallow rapids, usually located at the crossover in a meander of the active channel.
Riparian	Referring to the riverside or riverine environment next to the stream channel, e.g., riparian, or streamside, vegetation.

Riprap	Heavy stones used to protect soil from the action of fast-moving water.
Roughness	A term used by hydraulic engineers and hydrologists designating a measurement or estimate of the resistance that streambed materials, vegetation, and other physical components contribute to the flow of water in the stream channel and floodplain. It is commonly measured as the Mannings' roughness coefficient.
Scour	The erosive action of flowing water in streams that removes and carries away material from the bed and banks.
Sediment	Soil particles that have been transported from their natural location by wind or water action.
Sediment deposition	The accumulation of soil particles on the channel bed and banks.
Sediment load	The soil particles transported through a channel by stream flow.
Sloughing (or sloughing off)	Movement of a mass of soil down a bank into the channel (also called slumping). Sloughing is similar to a landslide.
Stream bank	The side slopes of an active channel between which the streamflow is normally confined.
Watershed	An area confined by topographic divides that drains a given stream or river.

APPENDIX BAS-S-1: LITERATURE FINDINGS, RIPAIRAN BUFFERS BY FUNCTION

Table 1. Riparian Buffers by Function

Buffer Functions	Riparian Buffer Width Studied (feet)	Reference	Notes
Sediment Removal	100	Terrell & Perfetti, 1989	Nutrient pollution in forested riparian areas
	100	Castelle & Johnson, 2000	Approaches 100% particulate organic matter production
	100	Lynch et al., 1985	75-80% removal
	100 - 125	Karr & Schlosser, 1977	75% removal
	100	Wong & McCuen, 1982	90% removal
	200	Wong & McCuen, 1982	95% removal
	200	Horner & Mar, 1982	80% removal in grassy swale
	200	Broderson, 1973	Removal of most sediment on slopes > 50%
	200	Terrell & Perfetti, 1989	Pesticides & animal waste
	290	Gilliam & Skaggs, 1986	50% deposition
	295 - 400	Wilson, 1967	Clay
Pollutant Removal	13	Doyle et al., 1975	Grass buffers
	15	Madison et al., 1992	90% removal of NH4-N, NO3-N, and PO4-P
	33	Petersen et al., 1992	Minimum for nutrient reduction
	50	Castelle et al., 1992	80% pollutant removal
	53	Jacobs & Gilliam, 1985	Most sediment removal
	65	Schultz et al., 1995	N/A **PLEASE PROVIDE**
	100	Lynch et al., 1985	75-80% pollutant removal
	100	Grismer, 1981	Reduced fecal coliforms by 60%
	100 - 140	Jones et al., 1988	Nutrient reduction
	120	Young et al., 1980	Minimum for nutrient reduction
	300	Vanderholm & Dickey, 1978	80% removal on a 0.5% slope
	860	Vanderholm & Dickey, 1978	80% removal on a 4% slope
Large Woody Debris Recruitment	16 - 33	Castelle & Johnson, 2000	40-60% LOD input
	33	McDade et al., 1990	<50% of naturally occurring LOD
	50	McDade et al., 1990	60-90% of all LOD
	55	Thomas et al., 1993	Minimum for 80% LOD input
	65 - 100	Castelle & Johnson, 2000	80-100% LOD input
	65	Murphy & Koski, 1989	95% of LOD
	100	McDade et al., 1990	85% of nat. occurring LOD

Buffer Functions	Riparian Buffer Width Studied (feet)	Reference	Notes
Large Woody Debris Recruitment (cont'd)	100	May et al., 1997	Recommended minimum
	100	Bottom et al., 1983	Minimum to supply LOD
	150	Harmon et al., 1986	Supply most LOD
	150	Robison & Beschta, 1990	Supply most LOD
	165	Van Sickle & Gregory, 1990	Minimum for LOD input
	330	May et al., 1997	Sensitive streams
Stream Water Temp. Moderation	35 - 80	Brazier & Brown, 1973	60-80% shade
	40	Corbett & Lynch, 1985	Control stream temperature fluctuations
	50 - 100	Hewlett & Fortson, 1982	N/A **PLEASE PROVIDE**
	50	Broderson, 1973	Buffer widths decrease as tree heights increase
	55	Steinblums et al., 1984	Maximum angular canopy density
	55	Moring, 1975	Maintain stream temperature if forested conditions
	75 - 90	Steinblums et al., 1984	60-80% shade
	100	Beschta et al., 1987	Minimum shade to level of old growth forest
	100	Lynch et al., 1985	Maintain stream temperatures that are within 1C of areas that are fully forested
	100 - 150	Jones et al., 1988	Maintain temperatures similar to fully forested areas
Maintenance of Benthic Communities	33	Culp and Davies, 1983	Minimum for healthy communities
	100	Roby et al., 1977	Maintain benthic communities similar to streams in fully forested areas
	100	Newbold et al., 1980	Maintain healthy benthic communities
	100	Castelle & Johnson, 2000	Minimum for healthy benthic communities
	100	Erman et al., 1977	Maintain macroinvert diversity
	>100	May et al., 1997	Benthic integrity or B-IBI - high in stream with >70% upstream buffer intact
	>100 33	Erman et al., 1977 Petersen et al., 1992	Macroinverts similar to prelogged condition Minimum for wildlife species
	75	Mudd, 1975	Pheasant, quail, and deer use

Buffer Functions	Riparian Buffer Width Studied (feet)	Reference	Notes
Wildlife Habitat	100	Gregory et al., 1987	Macroinvertebrate diversity
	100 - 165	Dickson, 1989	Range for amphibian, reptile needs
	100-300	Castelle et al., 1992	Range for most wildlife species
	100 - 310	Rudolph & Dickson, 1990	Reptiles & amphibians
	100 - 330	Allen, 1983	Beaver
	105	Groffman et al., 1990	Forested buffer for minimizing noise impacts to wildlife
	220 - 305	Jones et al., 1988	Small mammals

APPENDIX BAS-S-2: RIPARIAN HABITAT AREA BUFFER RECOMMENDATIONS: WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

Table 1. Recommended Riparian Width

Stream Type	Recommended Riparian Width
Type 1 & 2, shorelines of statewide significance	250 feet
Type 3 or other perennial or fish bearing streams, 5-20 feet wide	200 feet
Type 3 or other perennial or fish bearing streams, less than 5 feet wide	150 feet
Type 4 and 5 (low mass wasting potential)	150 feet
Type 4 and 5 (high mass wasting potential)	225 feet

Source: OCD, 2002

For definitions of the stream types see the Washington Administrative Code Sections 222-16-030 and 031.

APPENDIX BAS-S-3: EFFECTS OF ECOSYSTEM ALTERATIONS ON SALMONIDS

Table 1. Effects of EcoSystem Alterations

Ecosystem Feature	Altered Component	Effects on Salmonid Fishes and Their Ecosystems
Water Quality	Increased Temperature	Altered adult migration patterns, accelerated development of eggs and alevins, earlier fry emergence, increased metabolism, behavioral avoidance at high temperatures, increased primary and secondary production, increased susceptibility of both juveniles and adults to certain parasites and diseases, altered competitive interactions between species, mortality at sustained temperatures of >73-84? F, reduced biodiversity.
	Decreased Temperature	Cessation of spawning, increased egg mortalities, susceptibility to disease.
	Dissolved Oxygen	Reduced survival of eggs and alevins, smaller size at emergence, increased physiological stress, reduced growth.
	Gas Supersaturation	Increased mortality of migrating salmon.
	Nutrient Loading	Increased primary and secondary production, p ossible oxygen depletion during extreme algal blooms, lower survival and productivity, increased eutrophication rate of standing waters, certain nutrients (e.g., nonionized ammonia, some metals) possibly toxic to eggs and juveniles at high concentrations.
Sediment/Substrate	Surface Erosion	Reduced survival of eggs and alevins, reduced primary and secondary productivity, interference with feedings, behavioral avoidance and breakdown of social organization, pool filling.
	Mass Failures and Landslides	Reduced survival of eggs and alevins, reduced primary and secondary productivity, behavioral avoidance, formation of upstream migration barriers, pool filling, addition of new large structure to channels.
Habitat Access	Physical Barriers	Loss of spawning habitat for adults; inability of juveniles to reach overwintering sites or thermal refugia, loss of summer rearing habitat, increased vulnerability to predation.
Channel Structure	Flood Plains	Loss of overwintering habitat, loss of refuge from high flows, loss of inputs of organic matter and large wood, loss of sediment removal capacity.
Channel Structure (contd.)	Side-Channels	Loss of overwintering habitat, loss of refuge from high flows.
	Pools and Riffles	Shift in the balance of species, loss of deep water cover and adult holding areas, reduced rearing sites for yearling and older juveniles.
	Large Wood	Loss of cover from predators and high flows, reduced sediment and organic matter storage, reduced pool-forming structures, reduced organic substrate for macroinvertebrates, formation of new migration barriers, reduced capacity to trap salmon carcasses.
	Substrate	Reduced survival of eggs and alevins, loss of inter-gravel spaces used for refuge by fry, reduced macroinvertebrate production, reduced biodiversity.
	Hyporheic Zone (biologically active groundwater area)	Reduced exchange of nutrients between surface and subsurface waters and between aquatic and terrestrial ecosystems, reduced potential for recolonizing disturbed substrates.

Ecosystem Feature	Altered Component	Effects on Salmonid Fishes and Their Ecosystems
Hydrology	Discharge	Altered timing of discharge related life cycle cue (e.g., migrations), changes in availability of food organisms related to timing of emergence and recovery after disturbance, altered transport of sediment and fine particulate organic matter, reduced prey diversity.
	Peak Flows	Scour-related mortality of eggs and alevins, reduced primary and secondary productivity, long-term depletion of large wood and organic matter, involuntary downstream movement of juveniles during high water flows, accelerated erosion of streambanks.
	Low Flows	Crowding and increased competition for foraging sites, reduced primary and secondary productivity, increased vulnerability to predation, increased fine sediment deposition.
	Rapid Fluctuations	Altered timing of discharge-related life cycle events (e.g., migrations), stranding, redd dewatering, intermittent connections between mainstream and floodplain rearing habitats, reduced primary and secondary productivity.
Riparian Forest	Production of Large Wood	Loss of cover from predators and high flows, reduced sediment and organic matter storage, reduced pool-forming structures, reduced organic substrate for macroinvertebrates.
	Production of Food Organisms and Organic Matter	Reduced production and abundance of certain macroinvertebrates, reduced surface-drifting food items, reduced growth in some seasons.
	Shading	Increased water temperature, increased primary and secondary production, reduced overhead cover, altered foraging efficiency.
	Vegetative Rooting Systems and Streambank Integrity	Loss of cover along channel margins, decreased channel stability, increased streambank erosion, increased landslides.
	Nutrient Modification	Altered nutrient inputs from terrestrial ecosystems, altered primary and secondary production.
Exogenous Material	Chemicals	Reduced survival of eggs and alevins, toxicity to juveniles and adults, increased physiological stress, altered primary and secondary production, reduced biodiversity.
	Exotic Organisms/Plants	Increased mortality through predation, increased interspecific competition, introduction of diseases, habitat structure alteration.

Source: http://www.psmfc.org/efh/Jan99-sec3-2.htm

Matrix of Pathways and Indicators

PATHWAY	INDICATORS	PROPERLY FUNCTIONING	AT RISK	NOT PROPERLY FUNCTIONING
Water Quality:	Temperature	50-75°F[1]	57-60° (spawning) 57-64° (migration & rearing)[2]	>60° (spawning) >64° (migration & rearing)[2]
	Sediment/Turbidity	<12% fines (<0.85 mm) in gravel, turbidity low	12-17% (westside)[3] 12-20% (eastside)[2] turbidity moderate	>17% (westside)[3] >20% (eastside)[2] fines at surface or depth in spawning habitat[2], turbidity high
	Chemical Contamination/Nutrients	Low levels of chemical contamination from agricultural, industrial and other sources, no excess nutrients, no CWA 303d designated reaches [5]	Moderate levels of chemical contamination from agricultural, industrial and other sources, some excess nutrients, one CWA 303d designated reach[5]	high levels of chemical contamination from agricultural, industrial and other sources, high levels of excess nutrients, more than one CWA 303d designated reach[5]
Habitat Access:	Physical Barriers	Any man-made barriers present in watershed allow upstream and downstream fish passage at all flows	Any man-made barriers present in watershed do not allow upstream and/or downstream fish passage at base/low flows	Any man-made barriers present in watershed do not allow upstream and/or downstream fish passage at a range of flows
Habit Elements:	Substrate	Dominant substrate is gravel or cobble (interstitial spaces clear), or embeddedness <20%[3]	Gravel and cobble is subdominant, or if dominant, embeddedness 20-30%[3]	Bedrock, sand, silt or small gravel dominant, or if gravel and cobble dominant embeddedness >30%[2]
	Large Woody Debris	>80 pieces/mile >24" diameter >50 ft. length[4]; >20 pieces/mile >12" diameter >35 ft. length[2]; and adequate sources of woody debris recruitment in riparian areas	Currently meets standards for properly functioning, but lacks potential sources from riparian areas of woody debris recruitment to maintain that standard	Does not meet standards for properly functioning and lacks potential large woody debris recruitment

Matrix of Pathways and Indicators (cont.)

PATHWAY	INDICATORS	PROPERLY FUNCTIONING	AT RISK	NOT PROPERLY FUNCTIONING
Habit Elements (cont.):	Pool Frequency Channel width — # pools/mile[6] 5 feet — 184 10 feet — 96 15 feet — 70 20 feet — 56 25 feet — 47 50 feet — 26 75 feet — 23 100 feet — 18	Meets pool frequency standards (left) and large woody debris recruitment standards for properly functioning habitat (above)	Meets pool frequency standards but large woody debris recruitment inadequate to maintain pools over time	Does not meet pool frequency standards
	Pool Quality	Pools >1 meter deep (holding pools) with good cover and cool water[3], minor reduction of pool volume by fine sediment	Few deeper pools (>1 meter) present or inadequate cover/temperature[3], moderate reduction of pool volume by fine sediment	No deep pools (>1 meter) and inadequate cover/temperature[3], major reduction of pool volume by fine sediment
	Off-channel Habitat	Backwaters with cover, and low energy off-channel areas (ponds, oxbows, etc.)[3]	Some backwaters and high energy side channels[3]	Few or no backwaters, no off-channel ponds[3]
	Refugia (important remnant habitat for sensitive aquatic species)	Habitat refugia exist and are adequately buffered (e.g., by intact riparian reserves); existing refugia are sufficient in size, number and connectivity to maintain viable populations or sub-populations[7]	Habitat refugia exist but are not adequately buffered (e.g., by intact riparian reserves); existing refugia are insufficient in size, number and connectivity to maintain viable populations or sub-populations[7]	Adequate habitat refugia do not exist[7]
Channel Condition & Dynamics:	Width/Depth Ratio	<10[2,4]	**10-12 (we are unaware of any criteria to reference)**	>12 (we are unaware of any criteria to reference

COB_SMP009467

Matrix of Pathways and Indicators (cont.)

PATHWAY	INDICATORS	PROPERLY FUNCTIONING	AT RISK	NOT PROPERLY FUNCTIONING
Channel Condition & Dynamics: (cont.)	Streambank Condition	>90% stable; i.e. on average, less than 10% of banks are actively eroding[2]	80-90% stable	<80% stable
Channel Condition & Dynamics (cont.):	Floodplain Connectivity	Off-channel areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession	Reduced linkage of wetland, floodplains and riparian areas to main channel; overbank flows are reduced relative to historic frequency, as evidenced by moderate degradation of wetland function, riparian vegetation/succession	Severe reduction in hydrologic connectivity between off-channel, wetland, floodplain and riparian areas; wetland extent drastically reduced and riparian vegetation/succession altered significantly
Flow/Hydrology:	Change in Peak/Base Flows	Watershed hydrograph indicates peak flow, base flow and how timing characteristics comparable to any undisturbed watershed of similar size, geology and geography	Some evidence of altered peak flow, baseflow and/or flow timing relative to an undisturbed watershed of similar size, geology and geography	Pronounced changes in peak flow, baseflow and/or flow timing relative to an undisturbed watershed of similar size, geology and geography
	Increase in Drainage Network	Zero or minimum increases in drainage network density due to roads [8,9]	Moderate increases in drainage network density due to roads (e.g., ~5%)[8,9]	Significant increases in drainage network density due to roads (e.g., ~20-25%)[8,9]
Watershed Conditions:	Road Density & Location	<2 ml/ml[2,11], no valley bottom roads	2-3 ml/ml[2], some valley bottom roads	>3 ml/ml2, many valley bottom roads
	Disturbance History	<15% ECA (entire watershed) with no concentration of disturbance in unstable or potentially unstable areas, and/or refugia, and/or riparian area; and for NWFP area (except AMAs), ≥15% retention of LSOG in watershed[10]	<15% ECA (entire watershed) but disturbance concentrated in unstable or potentially unstable areas, and/or refugia, and/or riparian area; and for NWFP area (except AMAs), ≥15% retention of LSOG in watershed[10]	<15% ECA (entire watershed) and disturbance concentrated in unstable or potentially unstable areas, and/or refugia, and/or riparian area; does not meet NWFP standard for LSOG retention

Matrix of Pathways and Indicators (cont.)

PATHWAY	INDICATORS	PROPERLY FUNCTIONING	AT RISK	NOT PROPERLY FUNCTIONING
Watershed Conditions (cont.):	Riparian Reserves	The riparian reserve system provides adequate shade, large woody debris recruitment, and habitat protection and connectivity in all subwatershed, and buffers or includes known refugia for sensitive aquatic species (>80% intact), and/or for grazing impacts: percent similarity of riparian vegetation to the potential natural community/composition >50%[12]	Moderate loss of connectivity or function (shade, LWD recruitment, etc.) of riparian reserve system, or incomplete protection of habitats and refugia for sensitive aquatic species (~70-80% intact), and/or for grazing impacts: percent similarity of riparian vegetation to the potential natural community/composition 25-50% or better[12]	Riparian reserve system is fragmented, poorly connected, or provides inadequate protection of habitats and refugia for sensitive aquatic species (<70% intact), and/or for grazing impacts: percent similarity of riparian vegetation to the potential natural community/composition <25%[12]

1 Bjornn, T.C. and D.W. Reiser, 1991. Habitat Requirements of Salmonids in Streams. American Fisheries Society Special Publication 19:83-138. Meehan, W.R., ed.

2 Biological Opinion on Land and Resource Management Plans for the: Boise, Challis, Nez Perce, Payette, Salmon, Sawtooth, Umatilla, and Wallowa-Whitman National Forests. March 1, 1995

3 Washington Timber/Fish Wildlife Cooperative Monitoring Evaluation and Research Committee, 1993. Watershed Analysis Manual (Version 2.0). Washington Department of Natural Resources.

4 Biological Opinion on Implementation of Interim Strategies for Managing Anadromous Fish-producing Watersheds in Eastern Oregon and Washington, Idaho, and Portions of California (PACFISH). National Marine Fisheries Service, Northwest Region, January 23, 1995.

5 A Federal Agency Guide for Pilot Watershed Analysis (Version 1.2), 1994.

6 USDA Forest Service. 1994. Section 7 Fish Habitat Monitoring Protocol for the Upper Columbia River Basin.

7 Frissell, C.A., Liss, W.J., and David Bayles. 1993. An Integrated Biophysical Strategy for Ecological Restoration of Large Watersheds. Proceedings from the Symposium on changing roles in Water Resources Management and Policy, June 27-30, 1993 (American Water Resources Association), p. 449-456.

8 Wemple, B.C. 1994. Hydrologic Integration of Forest Roads with Stream Networks in Two Basins, Western Cascades, Oregon. M.S. Thesis, Geosciences Department, Oregon State University.

9 E.g., see Elk River Watershed Analysis Report, 1995. Siskiyou National Forest, Oregon.

10 Northwest forest Plan. 1994. Standards and Guidelines for Management of Habitat for Late-Successional and Old-Growth Forest Related Species Within the Range of the Northern spotted Owl. USDA Forest Service and USDI Bureau of land Management.

11 USDA Forest Service. 1993. Determining the Risk of Cumulative Watershed Effects Resulting from Multiple Activities.

12 Winward, A.H. 1989. Ecology Status of Vegetation as a base for Multiple Produce Management. Abstracts 42nd annual meeting, society for Range Management, Billings MT, Denver Co; Society for Range Management, p. 277.