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4.2.3 Description of the riparian ecosystem and a comparison of the HCP alternatives for protection of riparian ecosystem components

Summary

Protection of riparian ecosystems for the benefit of salmon habitat is necessary throughout the landscape of western Washington if these fish are to survive and prosper in the future. Because rivers and streams are a continuum, this will require cooperation from all state, federal, tribal, and private landowners that reside in the watersheds. The importance of several riparian ecosystem components (i.e., detrital inputs, large woody debris (LWD), windthrow, water temperature, sediment, stream bank stability, stream flow, and wetlands protection) as they relate to salmon protection were used in analyzing the riparian protection strategies for DNR-managed lands in western Washington. Three alternative approaches to riparian protection were developed and analyzed: Alternative A, the No Action alternative; Alternative B, the proposed HCP; and, Alternative C. The overall conclusion regarding the riparian protection provided by these three alternatives is that Alternative A is inadequate, Alternative B likely provides adequate protection, and Alternative C is the most protective.

Under Alternative A, the lack of specified minimum widths of riparian management zones on Type 4 Waters, the allowance of logging within 25 feet of streams, and the absence of wind buffers could result in damage to the riparian ecosystem components.

Riparian management zone widths under Alternative A would not always ensure protection of the riparian components because the minimum widths, as specified by the Washington Forest Practices Rules, are insufficient to fully protect riparian ecosystems. Current practices result in a wide range of application of riparian protection measures that in some cases are not sufficient to address salmon habitat needs (i.e., detrital inputs, water temperature, stream bank stability, LWD recruitment). Although not guaranteed, Alternative A would often result in sufficiently wide riparian management zones on Type 1 and 2 Waters, but may not be sufficiently protective of Type 3 and 4 Waters. Alternatives B and C both address the need for guaranteed riparian management zones on Type 1 through 4 Waters.

Logging within the riparian ecosystem is allowed under Alternative A. Under Alternatives B and C, logging is excluded from the 25 feet closest to the stream unless a part of restoration activities and minimized in the remainder of the riparian management zone. Alternatives B and C allow riparian restoration work to occur in the riparian management zones. These requirements recognize that many of the existing riparian areas are in need of enhancement if they are to be returned to a productive condition in the relatively near future. The measures specified under Alternatives B and C will ensure that stream bank integrity and riparian ecosystem productivity will be protected and potentially enhanced, which will benefit salmon.

Alternative A does not require a wind buffer on riparian management zones in wind-prone areas. The failure to address wind damage vulnerability of riparian management

zones in the past has resulted in frequent loss of riparian integrity and salmon habitat values. Alternatives B and C both specify that a wind buffer be added to riparian management zones in wind prone areas. 4.2.3 (1) "Alternative B requires the wind buffer to be added to the windward side of streams in areas prone to wind damage. Alternative C requires the wind buffer be added to both sides of streams."

Logging roads are a significant cause of sedimentation in salmon streams. Under Alternative A, DNR would continue to implement Forest Resource Plan direction to develop and maintain a road system that controls adverse environmental impacts. Alternatives B and C go even further by attempting to minimize the active road density based on a comprehensive road network management plan.

Matrix 4.2.3: Management Strategies for HCP (excluding OESF)

	Alternative A No Action	Alternative B Proposed HCP	Alternative C
Riparian			
Riparian Protection Area (west-side planning units)	Continued implementation of Forest Resource Plan; conservation strategies range from Forest Practices Rules minimums to substantial buffers applied on a site-specific basis. Review of 129 sales since implementation of FRP began shows no harvest in riparian management zones of following size on each side of stream: (1) Types 1 and 2 Waters, average riparian management zone width = approx. 196 feet, range = 0-350 feet. (2) Type 3 Waters, average riparian management zone width = approx. 85 feet, range = 0-300 feet. (3) Type 4 Waters, average riparian management zone width = approx. 55 feet, range = 0-300 feet. (continued)	Riparian management zones (each side of stream) defined as: (a) Type 1, 2, and 3 Waters: width = height of site tree at age 100 years or 100 feet, whichever is greater, (b) Type 4 Waters: width = 100 feet; and, (c) Type 5 Waters are protected "where necessary" according to FRP. Wind buffers added on windward side of riparian management zone where there is at least a moderate potential for windthrow: (a) Type 1 and 2 Waters, wind buffer width = 100 feet; (b) Type 3 Waters that are greater than 5 feet wide, wind buffer width = 50 feet. Riparian management zone activities: (a) no harvest except for restoration within first 25 feet, (b) minimal harvest between 25 and 100 feet, (c) low harvest beyond 100 feet.	Riparian management zone defined as: (1) riparian buffers on each side of Type 1 through 5 Waters - width = height of site tree at age 100 years or 100 feet, whichever is greater, (2) wind buffers added on both sides of riparian buffer: (a) Type 1 and 2 Waters, wind buffer width = 100 feet; (b) Type 3 Waters that are greater than 5 feet wide, wind buffer width = 50 feet, and (3) riparian buffer management activities: (a) no harvest within first 25 feet, (b) restoration activities allowed beyond 25 feet.

	Alternative A No Action	Alternative B Proposed HCP	Alternative C
Riparian (continued)			
Riparian Protection Area (west-side planning units) (continued)	(4) Type 5 Waters, riparian management zones on 47% of streams, average riparian management zone width for those streams = 40 feet. Remaining 53% receive no riparian management zones. Range on all = 0-150 feet.		
Unstable Hill slopes and Mass Wasting	No timber harvest on unstable slopes unless and until it can be done with no increase in failure rate or severity.	Same as Alternative A.	Same as Alternative A.
Road Network Management	Implement Forest Resource Plan direction to develop and maintain a road system that integrates management needs and controls adverse environmental impacts on the forest environment.	Implement Forest Resource Plan direction to develop and maintain a road system that integrates management needs and controls adverse environmental impacts on the forest environment. Minimize active road density based on comprehensive road network management plan.	Same as Alternative B.
Hydrologic Maturity	Hydrologic maturity addressed as part of Forest Practices watershed analysis. This process completed for only a small percentage of DNR- managed land. (continued)	Two-thirds of DNR-managed lands in the rain-on-snow zone, with some exceptions, to be hydrologically mature.	Same as Alternative B.

	Alternative A No Action	Alternative B Proposed HCP	Alternative C
Riparian (continued)			
Hydrologic Maturity (continued)	While not a specific requirement, hydrologic maturity is often considered when laying out harvest units, is included on the timber sale environmental checklist, and is part of the landscape planning process.		
Wetlands Protection	Wetlands protected in the future through full implementation of FRP Policy No. 21- "no net loss of acreage or function." Could change if policy is replaced or modified. Buffers provided based on size of wetland: (1) .25-1 acre wetlands, buffer width = 100 feet; and, (2) wetlands larger than 1 acre, buffer width = height of site tree at age 100 or 100 feet whichever is greater. Buffer and forested wetland management activities: (1) maintain at least 120 feet^2 of basal area in wind-firm trees with large root systems; (2) no roading without on-site mitigation; (continued)	Same as Alternative A. and guaranteed for length of HCP.	Same wetland buffers as in Alternatives A and B plus: (1) bogs 0.1-0.25 acres receive 100-foot buffers; (2) small wetlands that are interconnected or connected to a typed water are buffered; and, (3) wetlands within 200 feet upslope of unstable hill slopes have the buffer width increased by 50% on the half of the wetland closest to the unstable area. Management of forested wetlands and buffers around forested wetlands same as Alternative A plus: (1) the required 120 feet^2 of basal area consists of the most wind-firm dominant and co-dominant trees; (2) maintain a minimum of at least 75 trees per acre; and, (3) no ground-based equipment operation (continued)

	Alternative A No Action	Alternative B Proposed HCP	Alternative C
Riparian (continued)			
Wetlands Protection (continued)	(3) natural surface and subsurface drainage conditions must be maintained or restored; and, (4) ground-based equipment generally precluded.		within wetland or 50 feet of wetland edge. Management of buffers around nonforested wetlands same as forested wetlands plus: (1) no harvest within 50 feet of wetland edge; and, (2) no ground-based equipment within 100 feet of bogs.

Affected Environment

This section describes the riparian ecosystem and its various components, including: detrital input, large woody debris (LWD) recruitment, windthrow, water temperature, sediment, stream bank stability, stream flow, and wetlands; evaluates the way in which each HCP alternative would protect the components, and compares Alternatives B and C to Alternative A, the No Action alternative. All references to riparian management zone widths apply to both sides of the streams, unless otherwise noted.

Riparian Ecosystem

The riparian ecosystem includes, in addition to rivers, streams, lakes, ponds, wetlands, and other bodies of water, the land and corresponding flora and fauna occurring along the water bodies themselves. Within this area are found the physical and biological processes that function together as an extremely important water-driven habitat within the landscape (WFPB Riparian Habitat Technical Committee 1985; Cederholm 1994). The riparian discussion contained within this DEIS focuses on salmonid habitat in rivers and streams, with some reference to wetlands. Maintaining the various components of the riparian ecosystem within some level of natural background variability is critical to maintaining beneficial conditions for salmonids. It is important to realize that plant and wildlife species and communities within the riparian ecosystem are also dependent on good habitat quality (Raedeke 1988; Bilby 1988). The potential impacts on many of these species are discussed in Section 4.5.

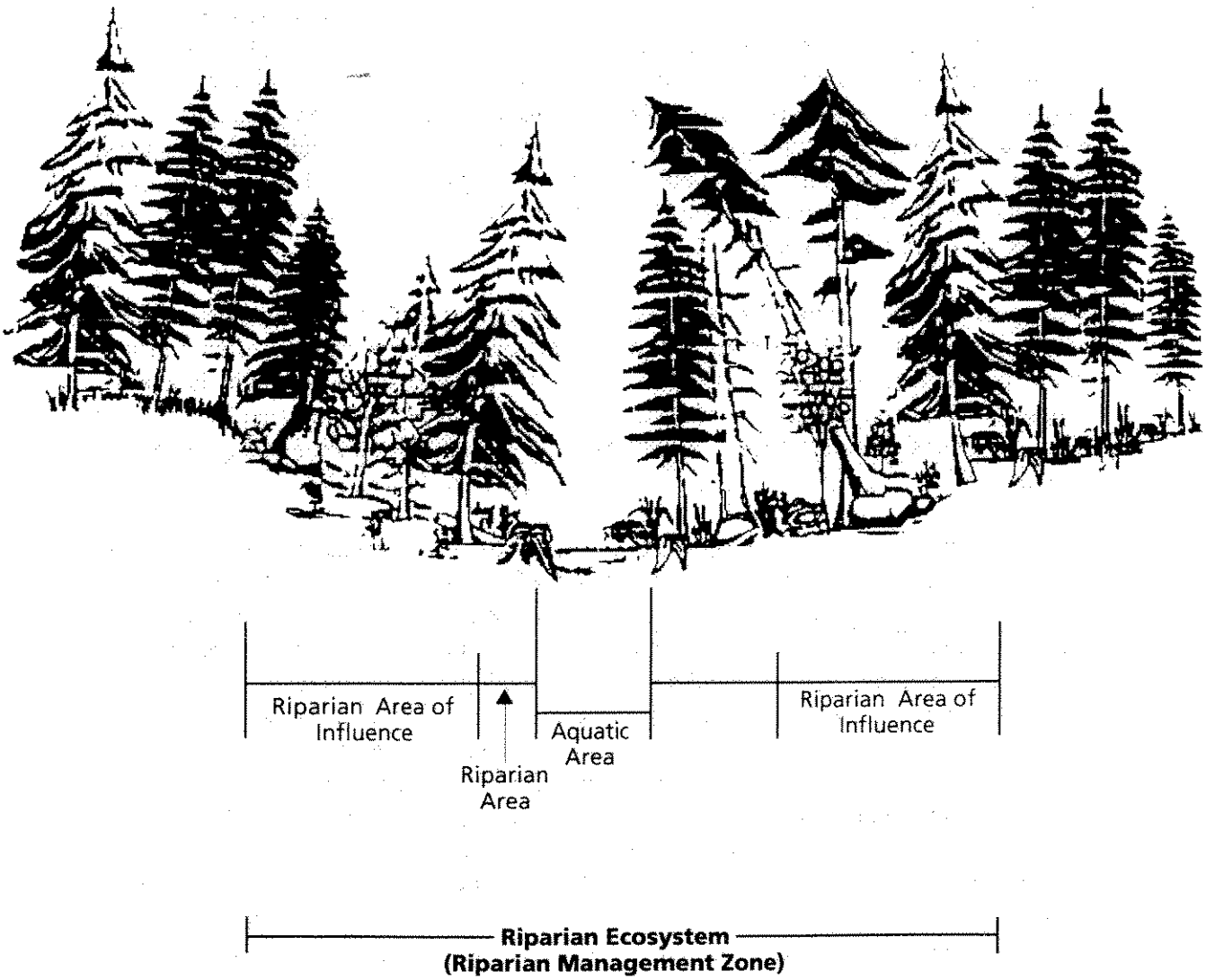
Riparian ecosystems encompass the aquatic environment and both the riparian and upland vegetation communities. Riparian ecosystems are comprised of mosaics of land forms, plant communities, and environments that vary in width and shape within the larger landscape. As such, their boundaries do not stop at an arbitrary, uniform distance from the stream but are delineated primarily by how the ecosystem functions (Castelle et al. 1992).

A properly functioning riparian ecosystem includes the maintenance of cool clean water, stable stream banks, and short- and long-term LWD recruitment to the aquatic environment. Salmonid fish live within the aquatic environment from which they obtain the food and living space necessary for growth, reproduction, and survival. Each part of the aquatic environment has unique physical and biological characteristics and corresponding riparian components that are also unique. Riparian ecosystems directly and indirectly influence the quality of salmonid habitat. In areas of high wind intensity it is necessary to protect the riparian ecosystem from blowdown by providing additional width (i.e., a wind buffer) beyond the site potential tree height. Salmonids have evolved with specialized and unique habitat requirements that are met in part by healthy, functioning riparian ecosystems (Bisson et al. 1987; Hicks et al. 1991; Cederholm 1994). Some of the most important habitat requirements that salmonids derive from riparian ecosystems are clean well-oxygenated water, spawning gravel that is relatively low in fine sediment, an abundant food supply, a moderate hydrologic regime, cover provided by LWD, and other forms of aquatic diversity provided by wood.

The riparian ecosystem discussed in this DEIS includes the aquatic zone, riparian zone, and the zone of direct influence (Figure 4.2.11), all of which fall within the riparian

ecosystem as described by the Washington Department of Ecology (WFPB Riparian Habitat Technical Committee 1985). While salmonids live in the aquatic environment, their welfare is directly dependent on how well the entire riparian ecosystem is functioning. When a watershed's uplands are logged, it is important to realize the potential impacts that can occur to the riparian ecosystem. Consideration of maintenance of the various components of salmonid habitat is important when logging and associated activities are carried out within watersheds.

Figure 4.2.11: The relationship between the riparian ecosystem and DNR's riparian management zone



When establishing the width of the riparian ecosystem, it is important to realize that measurements should start at the outer margin of the channel migration zone (flood plain). This is important because over the course of a timber rotation, streams naturally move laterally due to stream bank erosion. If riparian ecosystem widths are measured from the low flow wetted perimeter and not the outer margin of the flood plain, then the stream has less room to move through, and may eventually migrate outside the riparian ecosystem into the logged areas behind.

The input of detritus and large woody debris (LWD) to water bodies is of major importance as both a food base and a structural component of salmonid habitat. Detritus is the primary food base of many aquatic insects that are important in the juvenile salmonid diet (Mundie 1969; Waters 1969; Friesen 1990). Large woody debris provides both biological and physical structuring of stream channels that benefit salmonids (Bisson et al. 1987; Hicks et al. 1991; Naiman et al. 1992). Large woody debris input needs to include sufficient numbers, species, and sizes of wood to result in a productive aquatic environment for salmonids (Bisson et al. 1987; Naiman et al. 1992; FEMAT 1993).

The necessary width of riparian management zones, and the management activities that would be allowed within them, depends on the situation. If the riparian management zone is wide enough to provide LWD input at a natural background composition and rate, then it most likely will provide most of the required salmonid habitat protection (WFPB Riparian Habitat Technical Committee 1985; FEMAT 1993; Cederholm 1994). The Washington Forest Practices Board Riparian Habitat Technical Committee (1985) recommends a buffer of 200 feet on each side of the stream if the total riparian ecosystem is to be protected. For fishbearing waters, FEMAT (1993) suggests that protection of riparian ecosystem values may require a buffer equal in width to two site potential tree heights or about a 300-foot slope distance, the 100-year flood plain, or to the top of the inner gorge in order to protect the full range of riparian functions. Most riparian ecosystem functions (shade, bank stability, sediment filtering, and detritus input), and up to 80-90 percent of the LWD recruitment, will be met on these streams by a buffer width of 100 feet (McDade et al. 1990; FEMAT 1993 Figure V-12). The additional 10-20 percent of the LWD input is provided from beyond this distance. However, as riparian stands develop more late-successional characteristics, including a higher component of conifer and taller trees, proportionately more input will occur from distances beyond 30 meters (100 feet)(Van Sickle and Gregory 1990).

Other studies call for narrower buffer widths; however, the recommendations from these studies are often based on protection of individual riparian components (Castelle et al. 1992; Johnson and Ryba 1992) rather than the entire riparian ecosystem.

The riparian management zone that is left after harvest activity should be of sufficient width and condition to maintain the integrity of the riparian ecosystem. Whenever possible, the riparian management zone should at least encompass the riparian ecosystem and have a sufficient buffer width to allow for channel movement and external impacts (i.e., windthrow, landslides, etc.). For example, logging in the uplands can potentially change the conditions along the outer boundary of the riparian management zone, making it far more vulnerable to wind damage and sedimentation from upslope logging-

associated activities. Therefore, the riparian management zone may have to be wider in areas of high wind vulnerability. Following harvest of the uplands, wind becomes more problematic for riparian management zones, because the removal of adjacent timber allows the wind to accelerate along the ground, resulting in a greater blowdown effect on the trees left standing. Sediment from unchannelled upslope land failures can usually be filtered out by riparian ecosystems if the riparian management zone is of sufficient width and composition. However, if protection of the riparian ecosystem is insufficient (i.e., too narrow or of low quality) sediment could reach the aquatic habitat (Castelle et al. 1992; Johnson and Ryba 1992). The preference would be that upslope stability would be maintained within some natural level of landslide occurrence, using comprehensive road construction and maintenance planning, avoidance of logging on unstable slopes, and maintenance of hydrologic maturity in the rain-on-snow zone.

Comparison of the HCP Alternatives for Protection of the Riparian Ecosystem Components

Detrital Inputs

Stream benthic communities (aquatic macroinvertebrates that live in the streambed) are highly dependent on detritus. Detritus is defined as all "dead" organic carbon as distinguished from "living" organic or inorganic carbon (Hicks et al. 1991). With respect to stream systems, detritus has two forms: (1) detritus originating within the stream (autochthonous); and, (2) detritus originating from outside of the stream (allochthonous). The primary form of autochthonous detritus is dead algae and other aquatic plant material. In small, forested mountain streams autochthonous detritus accounts for only a small portion of the total detrital input within the system. Allochthonous detritus is the primary source of detrital input into small- and medium-sized streams through the annual contribution of large amounts of leaves, cones, wood, and dissolved organic matter (Anderson and Sedell 1979; Gregory et al. 1987; Richardson 1992).

The types of aquatic insects that consume the detrital material differ as one progresses downstream in the river continuum (Vannote et al. 1980). In the small headwater streams (high in the river continuum) the aquatic insects classified as "shredders" dominate the population and these organisms actually shred and digest wood fiber. Downstream, in the larger, more exposed streams, the "collectors" dominate and these aquatic insects mainly graze the algae from the surface of stream gravels (Vannote et al. 1980).

The importance of this type of detrital input varies among streams but can provide up to 60 percent of the total energy of stream community metabolism (Richardson 1992). In deciduous riparian forests, 80 percent of the allochthonous input to streams is derived from leaf litter. Most of this input occurs within a 6-8 week period in the autumn (Naiman et al. 1992). In coniferous riparian forests, needles contribute a major portion of the allochthonous input to streams (Bilby and Bisson 1992), and fallen cones or wood may account for 40-50 percent of the total allochthonous detrital input (Naiman et al. 1992). Up to 90 percent of the detritus that ultimately remains in small coniferous forest streams is comprised of woody material (Naiman and Sedell 1979; Triska and Cromack 1980). The complete decay process takes about 1 year for most high quality materials

such as leaves and herbaceous plants and may take several years or decades for low quality materials such as cones and wood (Gregory et al. 1991).

Stand age significantly influences detrital input to a stream system. Total input of allochthonous detritus to streams within old-growth forests is known to be approximately five times higher than in streams within clearcut forests (Bilby and Bisson 1992). Furthermore, Richardson (1992) found that allochthonous detrital input was approximately twice as high in old-growth forests as compared to either 30- or 60-year-old forests. However, reduced levels of allochthonous detrital input into streams due to streamside timber harvest is somewhat offset by concomitant increases in autochthonous detrital production. It isn't known what the effect of a change in type of detritus (allocthonous versus autochthonous) would have on the community structure in streams, however, several studies have documented increases in aquatic insect production and fish production after canopy removal (Murphy and Hall 1981; Bisson and Sedell 1984; Gregory et al. 1987; Hicks et al. 1991). Reduced forest canopy in the riparian zone leads to increased light levels in the aquatic zone, thereby increasing algae production in streams (Sedell and Swanson 1984; Bilby and Bisson 1992).

Some detrital input into streams also originates from beyond the immediate streamside. Detrital input to streams can originate from upstream areas. Richardson (1992) estimated that 70-94 percent of all leaves that enter a stream segment are transported downstream, until likely stored in a large pool or lake. Gregory et al. (1987) indicated that the greater the roughness elements of a stream, the greater the retention of detrital input. Thus, areas having large amounts of existing debris tend to retain more of the additional detrital input. This finding suggests that some detrital input from upper headwater areas that may not have fish likely contributes to lower downstream segments that support fish. The overall importance and magnitude of this upstream contribution to detrital input is not known.

No studies have been conducted to specifically determine the horizontal distance within which allochthonous detritus is input to streams (FEMAT 1993), but it has been estimated that 14-25 percent of the total litter input to a stream can originate from along the banks due to wind action alone (Richardson 1992). Newbold et al. (1980) found that diversity, a measure of aquatic insect community health, was high in streams with buffer strips at least 30 meters (100 feet) wide. According to Figure V-12 in FEMAT (1993), approximately 90 percent of the litter fall to streams occurs within half a site potential tree height from the stream, or about 33 meters.

ALTERNATIVE A

Under Alternative A the majority of Type 1 and 2 Waters would receive sufficient buffering to protect detrital production. Type 3, 4, and 5 Waters, however, would receive, on average, less than the 100 feet suggested by the literature (FEMAT 1993 Figure 12) for total protection of detritus input. In some cases where no minimum zone width is specified, such as in Type 4 and 5 Waters, buffers may not provide sufficient detrital production protection for many years. Without sufficiently wide riparian management zones, the detritus materials that come from the adjacent forest canopy would no longer

supply the stream with an energy base. This could be an important impact during the initial years after logging, at least until the riparian canopy could regrow.

The natural mix of deciduous and coniferous detritus is a vital part of the energy cycle in small forested streams. The deciduous material provides short-term energy and the coniferous material provides long-term energy. The riparian forest is an important regulator of stream productivity through the amounts and qualities of material directly contributed to the stream. In some cases, the source of woody material to stream channels is lost for decades, until a new forest can regrow. During the interim period, the composition of woody inputs shifts from coniferous material, which is relatively decay-resistant, to deciduous material, which is more rapidly decomposed.

ALTERNATIVE B

Riparian management zones provided on Type 1 through 4 Waters under Alternative B meet the widths recommended by the literature (100 feet) for detritus production protection. These widths would provide continuous inputs of detritus to the streams, and would allow the maintenance of stream productivity in both the short and long term. The amount of detrital production that comes from Type 4 and 5 Waters is not well documented, however, it is probably an important portion of the overall productivity. Under Alternative B the protection provided on Type 5 Waters in unstable areas will meet most recommended detrital input needs; but this may not be the case for Type 5 Waters on stable ground because they will not receive riparian management zone protection. Because of the lack of riparian management zone protection along these streams, it is possible that there will be an interruption of detritus input until the riparian forest regrows to the point of canopy closure.

Because the riparian management zone closest to the stream would be a no-harvest area, except for ecosystem restoration, maintenance of detrital inputs will occur because the riparian management zone will remain in a relatively productive condition. Ecosystem restoration activities in the minimal-harvest area, occurring 25-100 feet from the active channel, would not appreciably reduce the ability of the riparian management zones to contribute detrital nutrients. The remaining portion of the riparian management zone (more than 100 feet from the active channel margin) is beyond the width necessary to protect detrital inputs.

The provision of a 100-foot-wide wind buffer on the windward side of Type 1, 2, and the larger Type 3 Waters will provide additional protection for the riparian management zone, ensuring that detrital inputs would be maintained.

Alternative B provides more consistent protection of detrital inputs than Alternative A, because of the wider riparian management zones left on all water types, and the limited harvest activity allowed within the riparian management zones. The provision of additional wind buffers on the windward side of the riparian management zones would further decrease the risk of blowdown, and thus increase the ability of the riparian management zones to provide detritus production protection.

ALTERNATIVE C

The riparian management zones provided along all water types will be sufficient to maintain the detrital inputs on all streams at or near natural conditions. The provision of wind buffers on Type 1, 2, and larger Type 3 Waters will further protect the integrity of the riparian management zones. The 25-foot-wide no-harvest area immediately adjacent to all stream types, and the limited activity area in the rest of the riparian management zone, will ensure full protection of detrital inputs.

Alternative C would provide more protection of detrital input rates than Alternative A on all water types. Unlike Alternative A, Alternative C would provide a wind buffer on both sides of the riparian management zones on Type 1, 2, and larger Type 3 Waters. Under Alternative C, Type 3 Waters less than 5 feet wide, Type 4 Waters, and most Type 5 Waters would receive more detritus protection than is provided under Alternative A; however, some Type 5 Waters in stable areas would not receive protection.

Large Woody Debris (LWD)

Numerous studies have shown that large woody debris (LWD) is an important component of fish habitat (Swanson et al. 1976; Bisson et al. 1987; Hicks et al. 1991; Naiman et al. 1992). Trees and other large pieces of wood that fall into streams provide critical physical and biological functions in streams (Swanson and Leinkaemper 1978, 1982; Bisson et al. 1987; Sedell et al. 1988; Maser and Sedell 1994). These functions relate to sediment retention (Keller and Swanson 1979), gradient modification (Bilby 1979), channel structural diversity (Ralph et al. 1994), stream nutrient production (Cummins 1974), and escape cover (Bisson et al. 1987; Bilby and Ward 1989). Large woody debris also plays an important role in retaining salmon carcasses in streams, where they are consumed by a variety of wildlife scavengers and contribute to aquatic productivity (Cederholm and Peterson 1985; Cederholm et al. 1989; Bilby et al. in press).

Buffer zones are critical in maintaining LWD input to streams in areas intensively managed for timber harvest. Post-harvest LWD recruitment levels have relatively long recovery rates of up to 250 years (Murphy and Koski 1989; Grette 1985). Based on a study by Murphy and Koski (1989), the buffer zone width recommended to maintain adequate LWD is approximately 30 meters (100 feet). However, this study was carried out in Alaska where the tallest trees are not as large as those found in Washington. McDade et al. (1990) estimated that for old-growth conifer forests in Oregon, 50 percent of debris originates within 10 meters (33 feet) of the stream, 85 percent within 30 meters (100 feet), and 100 percent within 50-55 meters (165-182 feet). For mature hardwoods, they estimated that 100 percent of LWD originates within 25 meters (83 feet) of the stream. Van Sickle and Gregory (1990) presented a general model of LWD input to streams that shows that the majority of LWD originates within relatively short distances from the stream. Maintaining 100 percent of available LWD input into streams requires buffer widths approaching total tree height, and the rate of LWD input for streams changes with increasing distance away from the stream (FEMAT 1993 Figure V-12; McDade et al. 1990). Based on this figure, approximately 90 percent of the LWD input occurs within a distance of 80 percent of a site potential tree height from the stream, or about 50 meters (155 feet). Cederholm (1994) reviewed the literature on maintenance of

LWD input for salmon streams and found that the distance needed for 100 percent recruitment potential averaged 47 meters (155 feet).

In addition to the amount of LWD input, the species of LWD contributed is also important. Coniferous LWD significantly outlasts deciduous LWD in the stream system (Harmon et al. 1986; Bisson et al. 1987) and can remain in stream channels for 200 years or longer (Swanson et al. 1976; Keller and Tally 1979; Grette 1985). Thus, simply setting aside buffers of second-growth hardwoods (which comprise a large proportion of the streamside vegetation on DNR-managed lands) does not provide optimal LWD input over the short term because unassisted recovery of these areas to pre-logging coniferous LWD recruitment levels may take hundreds of years.

Although the specific role of Type 4 and 5 Waters in LWD input to downstream areas is not completely understood, these streams are known to supply some LWD to the larger downstream salmon-bearing waters (Potts and Anderson 1990). The role of LWD in Type 4 and 5 Waters is partly one of stabilizing existing debris and sediment to maintain rates of sediment routing at near natural levels.

Regional differences in LWD loading in unmanaged forests apparently exist. However, due to lack of site-specific stream survey information and the wide variability of data within regions, limited comparison of LWD loading could be evaluated at this gross level of analysis. A systematic study to determine regional differences in LWD loading has not been conducted. Although not well documented, some differences in LWD loading between geographic regions can be found in the literature. Bilby and Ward (1991) found approximately 200 pieces of LWD per 500 meters (1,650 feet) of stream in unmanaged stands in southwestern Washington. This contrasts with an average of 300 pieces (95 percent confidence interval = 200-400) per 500 meters (1,650 feet) of stream in old-growth forests of the Olympic Peninsula (Grette 1985), and an average of 313 pieces per 500 meters (1,650 feet) of recently managed tributaries of the Hoh River (C. J. Cederholm, DNR, Olympia, WA, unpubl. data, 1996). It is important to realize that LWD loading rates can vary widely between and within drainages of similar size, gradient, and logging history.

ALTERNATIVE A

The riparian management zones left on Type 1 and 2 Waters could provide a high degree of protection of future LWD loading, because they average 196 feet wide. However, some riparian management zones could end up being much smaller than average, due to the minimum 40 foot widths provided under this alternative. Riparian management zone widths on Type 3 Waters would only provide a portion of the LWD needs, because the zone widths average 85 feet wide. This alternative would allow timber harvest for commercial purposes in the riparian management zones and this removal might result in decreased LWD input rates over the short and long term. This could have a cumulative effect on future LWD loadings because of an eventual slowdown in LWD inputs in future years. Because there is no minimum riparian management zone width designation on Type 4 and 5 Waters under this alternative, some streams could receive no riparian management zone protection.

The lack of specifically applied wind buffers under Alternative A increases the risk that riparian management zones may blow down. This would result in a short-term input of LWD, but in the long term the LWD input would reduce to a low level until the forest regrows.

ALTERNATIVE B

Alternative B specifies a minimum riparian management zone width of 100 feet on Type 1 and 2 Waters. This alternative would exceed the LWD protection provided under Alternative A in many cases. When compared to Alternative A, it is anticipated that Alternative B would allow very limited timber removal from the riparian management zone and therefore more trees would be available as LWD trees. The reason for this limited removal is to maintain or restore the quality of salmon habitat. In areas prone to blowdown, riparian management zones left along Type 1 and 2 Waters would receive additional 100-foot wind buffers on the windward side of streams. These riparian management zones would therefore have a high probability of maintaining the short- and long-term LWD inputs because they would be protected from blowdown.

Type 3 Waters would receive more, and consistently wider, riparian management zones than under Alternative A. Type 3 Waters wider than 5 feet would receive 50-foot wind buffers on their windward sides, and these wind buffers would protect the riparian management zones from damage, thus ensuring that they would provide LWD inputs over time. Type 4 Waters would receive 100-foot riparian management zones, which are less than the one site potential tree height recommended by the literature; but, because this is a minimum width, all streams would receive at least this much protection. This size of riparian management zones on Type 4 Waters is sufficiently wide to provide most LWD inputs over time. Type 5 Waters would receive riparian protection where necessary, according to the Forest Resource Plan Policy No. 20 (DNR 1992b).

The 25 feet of the riparian management zone closest to the stream would be a no-harvest area. Any ecosystem restoration or single-tree selective harvest activities occurring between 25 and 100 feet from the active channel would not appreciably reduce the ability of the zone to contribute LWD. The remaining portion of the riparian management zone in the case of Type 1, 2, and 3 Waters is a low-harvest area, and additional LWD contributions would be provided from this area.

Alternative B provides for more LWD inputs than Alternative A because it provides wider riparian management zones on the smaller Type 3 and 4, Waters. This alternative also provides a wind buffer on the windward side of Type 1, 2, and larger Type 3 Waters in blowdown-prone areas, and allows less harvest activity within the riparian management zones. The provision of additional wind buffers in Alternative B decreases the risk that the riparian management zones may blow down, and thus increases their ability to provide LWD input over time.

ALTERNATIVE C

The riparian management zones on Type 1 through 5 Waters would ensure most LWD recruitment is maintained on all streams. The provision of 100-foot wind buffers on both sides of the riparian management zones on the Type 1, 2, and larger Type 3 Waters would

decrease the risk that riparian management zones may blow down and lower the LWD protection.

A 25-foot-wide area immediately adjacent to the stream would be a no-harvest area, and from there to the outer edge of the protected zone, activities would be allowed only if serving to restore and/or enhance the function of the riparian management zone. This will provide protection of LWD recruitment potential in almost all cases.

Alternative C is more protective of LWD inputs than Alternative A because it leaves sufficiently wide riparian management zones on all water types, allows very limited harvest activity within the riparian management zones, and provides a wind buffer on both sides of Type 1, 2, and larger Type 3 Waters.

Windthrow

Windthrow of entire trees occurs when wind forces overcome the rooting strength in the soil, tipping over the tree, its root ball, and some amount of root-attached soil (Coutts 1986). Windbreak, a type of windthrow, occurs when applied wind forces overcome stem strength somewhere above the root ball, breaking the stem and tipping over some percentage of the total tree height. Wind force is transferred to trees by the resistance they provide to wind flow (i.e., drag). Windthrow is a normal occurrence in forests but is known to increase after timber harvest opens formerly interior forest trees to the more direct effects of the wind (Harris 1989). Buffer strips along streams are subject to similar increases in windthrow. Though windthrow and buffer strip stability have not been studied extensively, several pertinent studies exist for the Pacific Northwest (Steinblums 1977; Steinblums et al. 1984; Andrus and Froehlich 1986; Rot 1993; Mobbs and Jones 1995).

In the Pacific Northwest, the strongest and most damaging winds are associated with fall and winter windstorms approaching the coast from the southwest (Canada. Environment Canada 1992). These high wind storms are commonly associated with heavy precipitation. The combination of high winds and wet soil conditions increases the potential for windthrow (Harris 1989). The strongest wind systems, known as superstorms, also originate from the southwest, usually between October and February (Renner 1993). These storms can produce gusts of greater than 100 miles per hour. The three best known superstorm occurrences are the Great Olympic Blowdown of January 1921, the Columbus Day storm of 1962, and the Inauguration Day storm of 1993 (Kruckeberg 1991; Renner 1993). The Great Olympic Blowdown storm had winds of 113 miles per hour with gusts apparently reaching 150 miles per hour (Kruckeberg 1991). Winds exceeding 80 miles per hour occurred in Puget Sound during the two later storms (Renner 1993). In the Columbus Day storm, almost 10 billion board feet of timber were blown down (Kruckeberg 1991).

A combination of high winds and heavy snowfall can also influence windthrow. This combination of factors can occur with southwest storms, but is primarily associated with cold winter storms or arctic outbreaks that originate from the interior of British Columbia (Canada. Environment Canada 1992; Renner 1993). These arctic outbreaks are often

associated with strong wind systems found in the valleys of the Fraser and Squamish Rivers in British Columbia (Canada. Environment Canada 1992). Such storms would most likely influence the east Olympic Peninsula and north Cascade regions, though their effect can reach as far as the Willamette Valley in Oregon. These storms are short-lived, generally lasting only a day or two (Renner 1993). With cold storms of longer duration, the soil is more likely to be frozen, which may increase soil resistance and reduce windthrow (Moore 1977).

Topographic channeling or directing of winds is also an important influence on wind direction and windthrow. On a broad scale, wind channeling is evident in the Columbia River valley, the Chehalis River valley (E-W winds), central Puget Sound (N-S winds) and along the Strait of Juan de Fuca (E-W winds) (Phillips and Donaldson 1972; Canada. Environment Canada 1992; Renner 1993). On a local scale, wind channeling is evident in individual valleys based on observed windthrow directions (Andrus and Froehlich 1986; Rot 1993). Winds may also be constricted as they move through a valley in a process called funneling (Canada. Environment Canada 1992; Renner 1993). Such constriction causes a Bernouli effect and the winds accelerate, perhaps to twice their initial speed (Renner 1993).

On a very local scale, down-valley winds may occur. These winds usually occur when air near the ground cools at night, becomes more dense than the air above it, and then drains down the valley (Renner 1993). Such winds are documented at Mt. Rainier (Buettner and Thyer 1962) but are not known to produce significant amounts of windthrow.

Steinblums (1977) and Steinblums et al. (1984) evaluated 40 streamside buffer strips in old-growth forest in the Cascade mountains of western Oregon. Logging had occurred at these sites between 1 and 15 years prior to data collection. Stability in these buffer strips ranged from 22-100 percent of initial gross volume. Windbreak was minor. Steinblums et al. (1984) established a relationship between site parameters and the timber volume remaining in buffer strips. The important parameters were slope distance from the outer edge to uncut timber in the direction of damaging wind, change in the elevation from the midpoint of the buffer to the top of the nearest major ridge in the direction of the wind, the horizontal distance from the outer buffer edge to the top of nearest major ridge in the direction of the wind, the direction of stream flow in relationship to damaging winds, the elevation of the buffer strip at its midpoint, a visual estimate of stability, and a measure of the site's soil moisture.

Andrus and Froehlich (1986) evaluated 30 streamside buffers in second-growth forests in the western part of the Oregon Coast Range. Logging had occurred at these sites between 1 and 6 years prior to data collection. Thirteen buffers (43 percent) were in stands between 50 and 75 years old, and 17 buffers (57 percent) were in stands between 80 and 140 years old. The basal area of snapped and uprooted trees ranged from 0-72 percent of the total original basal area of the buffer strips. Damage was greater than 20 percent at 13 sites (43 percent of total sites). At nine sites greater than one-third of the trees were damaged by windbreak. The damaging wind direction was from the southwest. The direction of windthrow was northeast on the windward side of the buffers, but on their leeward side the direction of windthrow ranged between northwest and northeast. The

wider range on the leeward side indicates that variable winds due to turbulence were more of a factor at these locations. Additionally, when the sites were examined individually the direction of damaging winds was wider, ranging from S75E to N60W. At only 14 of 26 sites (54 percent) did the most common direction of tree fall indicate that the most damaging winds were from the southwest. This observation indicates that topographic funneling of winds can be an important factor in windthrow.

Andrus and Froehlich (1986) found that four site characteristics accounted for 57 percent of the variability in windthrow. These site characteristics were: (1) percentage of live trees in the initial buffer stand that grow on boggy terraces; (2) percentage of basal area in the initial stand that is conifer; (3) general orientation of the stream segment with respect to southwesterly winds (S45W); and, (4) the shape of the hillslope in the direction S30W or S60W from the midpoint of the stream segment.

Andrus and Froelich (1986) also noted that only 12 percent of windthrown trees were sources of accelerated sedimentation to the adjacent stream. The sediment source was the upturned root wad. Compared to estimated natural sediment yields in these basins, the additional sediment influx ranged from 1-21 percent. Only seven sites had sediment yield increases greater than 1 percent. Additionally, Andrus and Froelich (1986) did not find any accelerated mass wasting associated with these windthrown trees or their associated upturned root wads.

Rot (1993) analyzed 14 stream buffers along Type 1 and 3 Waters on the southwestern Olympic Peninsula north of Hoquiam in Grays Harbor County, Washington. Logging at these sites had occurred less than 5 years prior to data collection. These stands were second growth between 53 and 143 years old. Five Type 1 and nine Type 3 stream buffers were evaluated with 6 percent and 35 percent windthrow found in the buffers for Type 1 and 3 Waters, respectively. These values are percentages of trees left following harvest. Windbreak was not measured separately but was included in the windthrow total.

Rot (1993) found that the strongest winds were from the southwest (between S and S60W) and accounted for 51 percent of the windthrow. Winds originating from the south to west (S30E to W) accounted for 75 percent of the windthrow. He defined three types of riparian topography: Type A - narrow alluvial flats (50-200 feet wide) with upland slopes greater than one tree height high and less than two tree heights wide, Type B - steep sideslopes greater than 15 feet high with a 5- to 20-foot-wide stream in the valley bottom, and Type C - flat riparian and upland topography. Buffers in Type B riparian topography were the most windfirm with 20 percent windthrow compared to approximately 50 percent windthrow in Types A and C. He found that the most windfirm buffers had upwind topography that was at least one tree height higher than the buffer and less than two tree lengths in distance from the buffer to the slope crest.

Soil moisture is another important variable affecting windfirmness (Rot 1993). Windthrow was higher for conifers rooted near the stream in wetter areas than for those rooted well above the stream, either on higher terraces or on the hillside. The higher terraces seem to be above the ground water table. Trees near the bottom of steep valley

sides appeared to be rooted in wetter sites caused by ground water concentration at the base of slopes. Rot (1993) noted that the windfirmness of Type 1 Waters was partially due to their southwesterly flow direction, i.e., they flowed into the prevailing wind. Similarly, Type 3 Waters with their buffers aligned parallel to the southwesterly winds had a lower percentage of windthrow than Type 3 Waters with their buffers aligned perpendicular to the southwesterly winds.

Mobbs and Jones (1995) analyzed 90 riparian management zones on Type 1 through 4 Waters in coastal western Washington from the Queets River basin south to the Chehalis River basin. The area included three DNR administrative regions and six counties. The sites were sampled within 1 year of harvest. Windthrow was totaled as a percent of total live trees. Total windthrow as a percent of total leave trees by water type was: (1) Type 1 Water - 3.3 percent; (2) Type 2 Water - 3.2 percent; (3) Type 3 Water - 6.2 percent; and, (4) Type 4 Water - 8 percent. They found that windthrow as a percent of total leave trees by riparian management zone orientation was: (1) 2.4 percent for north-to-south riparian management zone orientation; (2) 4.5 percent for east-to-west riparian management zone orientation; (3) 4.9 percent for northeast-to-southwest riparian management zone orientation; and, (4) 7.0 percent for northwest-to-southeast riparian management zone orientation. Windthrow was significantly higher on Type 4 Waters than for all other water types.

Steinblums et al. (1984) and Andrus and Froehlich (1986) found no significant correlation between buffer width and the amount of windthrow. Rot (1993) found a very weak relationship between buffer width and windthrow (correlation coefficient of 0.33 for standing live trees and 0.31 for windthrow). Mobbs and Jones (1995) present plots of percent windthrow versus average buffer width that suggest there is less total windthrow in wider buffers, though this relationship was not quantified. This relationship is weak to moderate because windthrow is generally concentrated at the buffer edge no matter how wide the buffer actually is. Andrus and Froehlich (1986) cite that Gratowski (1956) found windthrow concentrated in the first 50 feet of a harvest unit edge, and that in each successive 50-foot segment windthrow diminished by approximately one-half. Rot (1993) cites that Gratowski (1956) found windthrow extended up to approximately 200 feet from the old-growth harvest unit boundaries.

Fall and winter winds approaching from the southwest are the dominant cause of significant windthrow. Topographic channeling and funneling may also produce localized winds capable of windthrow. No study documents regional variability in windthrow, however, it is likely that local windthrow variability is greater than regional variability in western Washington. Therefore, all regions were considered to have an equal windthrow potential.

Adding wind buffers to the outside of riparian management zones is as yet an untested idea; however, it is felt that the additional width of some blowdown-prone riparian management zones would help protect the interior riparian habitat components.

ALTERNATIVE A

There would be no provision for wind buffers along any water types. As a result, there is a high risk that the integrity of the riparian management zones will be lost due to blowdown in some areas.

ALTERNATIVE B

Alternative B provides wind buffering on the windward side of the Type 1, 2, and larger Type 3 Waters in areas of high blowdown potential. This would increase the likelihood of the riparian management zone functioning to provide salmonid habitat protection over the long term. Harvest activity in the wind buffers would have the objective of increasing the windfirmness of the interior riparian management zone.

The unpredictability of choosing where and when to leave a wind buffer may be a problem in this alternative. It would, however, protect the interior riparian management zone from blowdown in many cases and thus provide increased protection when compared to Alternative A.

ALTERNATIVE C

The application of wind buffers on both sides of Type 1, 2, and larger Type 3 Waters would reduce error in the placement of wind buffers that might occur based on the misinterpretation of local wind direction. Wind buffers applied to both sides of streams would also tend to displace windthrow further from the stream, protecting the riparian management zone from both the direct impacts of wind on the windward side, and indirect effects of wind from turbulence on the lee side of buffers. This should result in more consistent protection of the integrity of the riparian management zone.

Alternative C gives more protection to salmon habitat than Alternative A because it leaves a wind buffer on both sides of the riparian management zone on the Type 1, 2, and larger Type 3 Waters and this buffer will further ensure that the riparian management zones are functioning as intended over time.

Water Temperature

Changes in water temperature and light regime have both positive and negative consequences for salmonid production and are often difficult to predict. Removal of streamside vegetation allows more solar radiation to reach the stream surface, increasing water temperature and light availability (Brown and Krygier 1970; Meehan 1970; Beschta et al. 1987; Bisson et al. 1988a). The interpretation of much of the early research on water temperature changes induced by logging was that these alterations were predominantly harmful to salmonids (Lantz 1970).

Water temperature increases can be expected to influence embryonic, juvenile, and adult salmonids in small streams (Hicks et al. 1991). It is likely that effects during the time that juveniles are rearing in freshwater are the most significant. Temperature increases can also affect fish survival by increasing the virulence of many diseases, modifying the effects of toxic materials (Lantz 1970), and lowering the amounts of oxygen available to salmonids.

The upper and lower limits of temperature tolerance in fish can be extended through both adaptation and resistance (Fry 1947). Brett (1952) reported that more time was needed for acclimation to low temperatures than to high temperatures. He also determined the lethal limits for high and low water temperatures for the young of all species of Pacific salmon using a range of acclimation temperatures. Coho and chinook salmon were the most tolerant of high temperatures although no species could tolerate temperatures exceeding 25.1 degrees C (77.2 degrees F) for exposure times of 1 week. Work by Bisson et al. (1988a) under highly unusual conditions in tributaries of the Toutle River (within the blast zone of the volcano at Mt. St. Helens, Washington) documented juvenile coho salmon rearing in summer water temperatures up to 29.5 degrees C (85.1 degrees F). This was a situation of planted hatchery coho in a stream with no other fish community present. These were determined to be the highest water temperatures ever recorded with coho salmon-rearing populations in Washington streams.

Forest canopy removal has resulted in increased winter temperatures in some coastal drainages of the Pacific Northwest (Beschta et al. 1987). Slight post-logging increases in late-winter water temperatures were found in Carnation Creek, a coastal stream on Vancouver Island, British Columbia (Hartman et al. 1987; Holtby 1988). These temperature increases led to accelerated development of coho salmon embryos in the gravel and earlier emergence of juveniles in the spring. Earlier emergence resulted in a prolonged growing season for the young salmon but also increased the risk of downstream fry displacement during late-winter freshets. The increased fry displacement resulted in underseeded conditions during some years. The juveniles that were able to survive to the rearing stage had a higher proportion of 1-year old smolts rather than the normal high proportion of 2-year olds. Using a marine survival model developed by Bilton et al. (1982), marine survival is expected to decline sharply as the fish are still smaller than the normal 2-year olds.

Adult salmon and trout respond to stream temperatures during their upstream migrations (Bjornn and Reiser 1991). Delays in upstream migration due to excessively warm natal streams have been observed for sockeye salmon (Major and Mighell 1966), chinook salmon (Hallock et al. 1970), and steelhead (Monan et al. 1975). Bell (1986) reported that Pacific salmon and steelhead have migrated upstream at temperatures between 3 and 20 degrees C (37.4 to 68 degrees F).

Salmonids are most metabolically efficient within the range of 12-14 degrees C (53.6-57.2 degrees F); 10-13 for steelhead (50-55.4 degrees F), and growth is reduced at higher and lower temperatures (Bjornn and Reiser 1991). Growth ceases for coho when temperatures exceed 20.3 degrees C (68.5 degrees F) (Reiser and Bjornn 1979; Brett 1952). At temperature extremes, fish not only do not have the energy to acquire food, but they also cannot digest it. The capacity for work, including swimming, declines and fish will eventually starve to death if they do not succumb to some other cause first (Beschta et al. 1987).

Competitive interactions will be affected by temperatures in several ways: Elevated temperatures may increase competition as fish "pack" into cooler areas to avoid high temperatures. In cohabiting situations, Reeves et al. (1987) found that steelhead were

dominant in cooler temperatures, while redsided shiners (a highly competitive non-salmonid fish) were dominant at temperatures above 19 degrees C (66.2 degrees F).

Streams can be too cold as well as too warm for upstream-migrating salmonids (Bjornn and Reiser 1991). Cutthroat and rainbow trout have been observed waiting for tributaries to warm in spring before entering them to spawn. Adult steelhead that return from the sea in summer and spend the winter in inland rivers before spawning in spring, overwinter in large rivers downstream from their natal streams because the smaller headwater streams are often ice-choked during winter. It is believed that steelhead overwinter in the larger rivers because survival rates are higher there and the slightly higher temperatures in the rivers enable timely maturation (Reingold 1968).

The Washington Department of Ecology maximum temperature standards for waters impacted by human activities are 16.3 degrees C (61.3 degrees F) for Class AA waters and 18.3 degrees C (64.94 degrees F) for Class A waters. Class AA and A waters encompass nearly all forested streams in the state.

The forest canopy is typically evaluated by considering the angular canopy density (ACD). In contrast to canopy closure, which measures canopy density projected to a horizontal surface, ACD is the projection of canopy closure at the angle at which solar energy passes through the canopy to the stream. In areas intensively managed for timber harvest, maintaining vegetation buffers along the stream banks is an effective way to maintain stream temperatures at levels appropriate for fish and other aquatic organisms.

Specific approaches for managing riparian vegetation to protect water temperature in western Washington are provided by Sullivan et al. (Timber/Fish/Wildlife Temperature Work Group 1990) and Caldwell et al. (1991) and are summarized in the watershed analysis training manual (WFPB 1995b). These sources identified a number of important considerations relative to protection of stream temperature, including: (1) non-fishbearing waters that contribute 20 percent or more of the volume of fishbearing Type 1, 2, or 3 Waters significantly influence water temperature; (2) water temperature reaches equilibrium with local conditions once streams have traveled for approximately 1,000 feet (305 meters) through a zone of uniform canopy closure; (3) in western Washington, at elevations greater than 3,600 feet (1,098 meters), stream temperature is unlikely to exceed temperature standards, even when timber harvest activities occur; (4) target shade requirements vary with water type and elevation; and, (5) for Type 1, 2, and 3 Waters, total stream shading of 50-75 percent is generally required to maintain streams within water quality standards.

Water temperatures in Type 4 and 5 Waters are more sensitive to changes in streamside shading than Type 1, 2, and 3 Waters downstream (Timber/Fish/Wildlife Temperature Work Group 1990). Cumulative downstream effects of increased temperatures in headwater tributaries have not been documented. It would be expected that, assuming similar amounts of ground water inflow into lower streams, the proportion of Type 4 and 5 Waters in a watershed may affect overall downstream water temperature sensitivity in that planning unit.

Rashin and Graber (1992) evaluated the effectiveness of best management practices (BMPs) for protecting water temperatures in streams in western Washington. The riparian management zones studied were narrow and included some partial cutting. The riparian management zone buffers were considered ineffective on many of the streams that were studied, particularly those with losing reaches (i.e., stream discharge loss to ground water) and beaver ponds. Rashin and Graber (1992) also evaluated the methods of Sullivan et al. (Timber/Fish/Wildlife Temperature Work Group 1990) and considered their methods to offer major advantages because the methods included parameters such as site elevation and riparian shade. If watershed analysis procedures and requirements (WFPB 1995b) alone are implemented, a low to moderate level of protection for water temperature is anticipated.

Buffer strips approximately 30 meters (100 feet) wide are believed to shade the stream to the same extent as old-growth forests which typically have ACDs of 80-90 percent (Beschta et al. 1987). Other studies, summarized in Johnson and Ryba (1992), generally recommend a similar buffer width of approximately 29 meters (96 feet) to protect stream temperature. If the buffer is less than 30 meters (100 feet), or if the buffer is selectively logged, considerations such as species composition, stand age, and vegetation density become important (Beschta et al. 1987).

The sensitivity of streams to changes in water temperature may vary regionally. Such regional differences in temperature sensitivity are due to a number of factors including elevation (Rashin and Graber 1992), proportion of Type 4 and 5 Waters and proximity to the coast (Timber/Fish/Wildlife Temperature Work Group 1990). Because stream temperature decreases with increased elevation, streams at higher elevations are expected to be cooler and less influenced by shade levels than downstream areas. Proximity to the coast may also influence geographic variation in stream temperature although relationships are poorly defined. Data in Sullivan et al. (Timber/Fish/Wildlife Temperature Work Group 1990) suggest that coastal streams tend to have higher summer temperatures than streams on the west slope of the Cascades. However, since data on streams with equivalent shading, elevation, and flow are limited, this trend should be considered weakly supported.

The number and type of wetlands in a watershed may also influence stream temperature, particularly during low-flow periods, by augmenting stream flow with cool ground water or well-shaded surface water from wetland outlets and subsurface flow.

ALTERNATIVE A

Type 4 and 5 Waters would not always receive adequate protection because the lower end of the range of buffer widths would be zero. Roughly 50 percent of Type 5 Waters would receive riparian management zones averaging 40 feet (range 0-150 feet) in width and the other half would not receive a riparian management zone. The lack of specifically applied buffers to protect them from windthrow would increase the risk that riparian management zones would blow down, reducing their ability to provide shade protection.

ALTERNATIVE B

Riparian management zones on Type 1, 2, and 3 Waters would equal the height of one site potential tree, wider than the widths recommended in the literature to protect stream shading. Type 4 Waters would receive riparian management zone widths of at least 100 feet on each side of the streams, well within the range recommended by the literature. Type 1, 2, and larger Type 3 Waters would also receive a wind buffer on the windward side of the stream, further protecting the riparian management zone in blowdown-prone areas.

All Type 5 Waters in areas of unstable slopes would receive riparian management zone protection; those in stable terrain would not.

The 25 feet of the riparian management zone closest to the stream is a no-harvest area, and this zone will contribute to water temperature protection. It is anticipated that only ecosystem restoration activities would occur in this area. Activities occurring between 25 and 100 feet from the active channel would not appreciably reduce stream shading. It is anticipated that only two types of silvicultural activities will occur in this area: ecosystem restoration and single-tree selective harvest. The remaining portion of the riparian management zone (more than 100 feet from the active channel margin) would be a low-harvest area, and the low harvest activity in this area will further ensure water temperature protection.

Because Alternative B states riparian management zone width of one site potential tree height and a 100-foot minimum width riparian management zone on Type 1, 2, and 3 Waters, these waters would receive consistently greater shade protection than under Alternative A. Alternative B does a better job of protecting the shading of Type 4 Waters, because it designates a minimum width 100-foot riparian management zone, while Alternative A riparian management zones specify an average and do not designate a minimum width. Additionally, in blowdown-prone areas, Alternative B adds a 100-foot wind buffer on the windward side of Type 1 and 2 Waters and a 50-foot wind buffer on the windward side of the larger Type 3 Waters, and this further ensures that the riparian management zones along these streams will provide shade protection.

ALTERNATIVE C

The riparian management zones on each side of Type 1 through 5 Waters would be consistently wider than the widths recommended in the literature for water temperature protection. The 100-foot wind buffers would be provided on either side of Type 1 and 2 Waters and 50-foot wind buffers on either side of Type 3 Waters greater than 5 feet wide, further ensuring water temperature protection.

The 25-foot wide area immediately adjacent to the stream would be a no-harvest area. From there to the outer edge of the protected area, activities would be allowed only if the activity serves to restore and/or enhance the water temperature protection function.

All water types would receive significantly greater shade protection under Alternative C than under Alternative A, because Alternative C designates riparian management zone widths that are well within the acceptable range of literature recommendations and allows relatively little harvest in the riparian management zones. Alternative C also adds a 100-

foot wind buffer on each side of Type 1 and 2 Waters and a 50-foot wind buffer on each side of the larger Type 3 Waters, which further ensures the water temperature protection function.

Sediment

Timber harvest activities often alter watershed conditions by changing the quantity and size of sediment supplied to streams. Such activities can lead to stream channel instability, pool filling by coarse sediment, or the introduction of fine sediment to spawning gravel. Factors influencing the excessive delivery of sediment to a stream include the intensity and location of erosion and mass-wasting events and the presence of adequate vegetated buffers to filter fine sediment derived from hillslope and road erosion (Hicks et al. 1991; Everest et al. 1987).

Though increased sediment yields can originate from either the banks or beds of destabilized streams (Megahan 1982; Scrivener 1988), the major upland source of coarse and fine sediments is landslides from road prisms and steep harvested hillsides (Reid 1981; Schlichte et al. 1991; Chamberlin et al. 1991). Coarse sediment derived from hillslope and road prism failures can enter high-gradient Type 4 and 5 Waters and be transported directly downstream to Type 1, 2, or 3 Waters. Erosion from road surfaces can also be a major source of fine sediment (Reid 1981; Cederholm and Reid 1987; Beschta 1978; Furniss et al. 1991). A clearcut on an unstable slope increases the likelihood of landslides (Swanson and Dyrness 1975; Swanson et al. 1987). Landslides resulting from timber harvest are considered a significant source of sediment input into streams (Wu and Swanson 1980; Chesney 1982; Everest et al. 1987; Sidle 1985). In the Pacific Northwest, roads appear to cause more landslides than clearcutting; however, this pattern varies substantially among areas (Sidle et al. 1985), and seems to be highly dependent on watershed characteristics (Duncan and Ward 1985).

Typically, landslides occur when local changes in the soil pore water pressure increase to a degree that the friction between soil particles is inadequate to bind them together and the soil slides downslope under the force of gravity. Timber harvest affects the local soil pore water pressure in at least two ways. First, transpiration is decreased with tree removal. Decreased transpiration increases soil moisture, thus increasing the risk of slope failure. Second, since the forest canopy intercepts precipitation, the amount of precipitation reaching the forest floor per unit time increases after harvest, and this too causes an increase in soil moisture. Also, tree harvest ultimately results in the decay of tree roots. Living tree roots add strength to the soil, but as roots decay this strength is lost and the likelihood of landsliding increases until new root systems are established.

Road-caused erosion in upland areas can have significant detrimental impacts to salmonid habitat in downstream areas (Hicks et al. 1991). Only rarely can roads be built that have no negative effects on streams (Furniss et al. 1991). Roads are a major source of management-related sedimentation in streams (Cederholm and Reid 1987). The contribution of sediment per unit area from roads is often greater than that from all land management activities combined (Furniss et al. 1991). In northern coastal California, haul roads and tractor skids were found to alter the drainage network and sediment yield

of water basins (Swanson et al. 1987). Cederholm et al. (1981b) reported a significant positive correlation between fine sediment in spawning gravels and the percentage of basin area with roads. Forest roads can increase the incidence of mass soil movements (i.e., landslides) by 30-300 times as compared to undisturbed forests (Furniss et al. 1991).

Sediment that settles in streams or moves in suspension can reduce salmonid viability (Hicks et al. 1991). Fine sediment deposited in spawning gravel can reduce interstitial water flow, leading to depressed dissolved oxygen concentrations, and can physically trap emerging fry in the gravel (Koski 1966; Meehan and Swanston 1977; Everest et al. 1987). Survival of coho salmon in natural and simulated redds (spawning nests) is related to the proportion of fine particles in the gravel (Koski 1966, 1975; Tagart 1976).

Studies in coastal drainages on the Olympic Peninsula of Washington have addressed the effects of sediment on coho salmon spawning gravel (Tagart 1976; Cederholm and Reid 1987). These studies concluded that sediment can lower the smolt yield in some years of low spawner abundance. The concentration of intragravel fine sediment in spawning riffles was positively correlated with the extent of logging road mileage in the watersheds. The negative effects of sedimentation on coho salmon spawning success was estimated by monitoring the survival of embryos and fry in natural redds (Tagart 1976).

In addition to directly affecting salmonid survival, fine sediment in deposits or in suspension can reduce primary production and invertebrate abundance (Hicks et al. 1991). These effects can reduce the availability of aquatic food sources important for fish (Cordone and Kelley 1960; Lloyd et al. 1987). In northern California, diversity of aquatic invertebrates was lower in streams passing through clearcut areas with no buffers or narrow buffers than it was in streams in unlogged watersheds. However, the densities of invertebrates in the clearcut areas was higher than those in unlogged watersheds (Newbold et al. 1980; Erman and Mahoney 1983). The detrimental effects of large amounts of fine sediment are generally accepted but precise thresholds of fine sediment concentrations that result in damage to benthic invertebrates are difficult to establish (Chapman and McLeod 1987; Wasserman et al. 1984).

Fine sediment in suspension can cause damage to juvenile salmonid gills and outright mortality when concentrations are excessively high (Noggle 1978). It was also found that low levels of suspended sediment were less damaging and to a certain degree beneficial as cover from predators (Noggle 1978).

Fine sediment that is transported over land can be filtered out by streamside buffer strips. The ability of streamside buffer strips to capture fine sediment is largely dependent on their width. Thus, buffer strip width is an important parameter for evaluating the ability of a management option to avoid excessive fine sediment delivery to streams. Recommended buffer widths for sediment removal vary widely (Johnson and Ryba 1992) and range from 3 meters (10 feet) for the coarse fraction to 122 meters (403 feet) for the fine fraction. Studies of forested watersheds recommend buffers of approximately 30 meters (100 feet) for this purpose (Johnson and Ryba 1992).

Wetlands are important sediment filters in many watersheds. Forested wetlands in particular have a high capacity to collect sediments (Hupp et al. 1993). Wetlands slow surface waters, allowing sediments to settle out of the water or adhere to vegetation. Oberts (1981) found that watersheds with less than 10 percent wetlands had sediment loading rates per unit area that were as much as 100 times greater than sediment loading rates of watersheds with more than 10 percent wetlands.

ALTERNATIVE A

Type 1 and 2 Waters would receive an average riparian management zone width which is well within the range of buffer widths for sediment filtering recommended in the literature. The riparian management zone widths on Type 4 and 5 Waters do not specify a minimum width and therefore do not always ensure that adequate sediment filtering would occur.

Under Alternative A, unstable slopes receive protection based on the Shaw and Johnson (in press) model. Because unstable slopes would often extend well beyond the riparian management zone in steep Type 4 and 5 Waters, the zones are likely too narrow to protect against upslope sediment sources. Only about half of Type 5 Waters would receive riparian management zones.

The lack of a comprehensive road management plan under Alternative A could further result in high road densities and consequent sediment runoff. Studies of existing logging roads in both the Clearwater (Cederholm and Reid 1987) and Hoh River (Schlichte et al. 1991) drainages on DNR-managed lands indicate that roads are a significant source of sediment that reaches streams.

The wetland buffers required in Alternative A will provide some protection to the sediment-catching function of wetlands. However, ground-based equipment within forested wetlands and wetland buffers could contribute to channelization and erosion of wetland soils, adding to sediment problems downstream.

ALTERNATIVE B

Riparian management zones on Type 1, 2, and 3 Waters would average in the middle to upper end of values recommended in the literature for protection from sediment runoff. A minimum riparian management zone width of 100 feet would be specified, so there would be no situations where no riparian management zones would be provided on these water types. An additional 100-foot-wide wind buffer would be provided along the Type 1 and 2 Waters and a 50-foot wind buffer would be provided along Type 3 Waters greater than 5 feet wide. This would further ensure that these riparian management zones were functioning to provide the sediment-filtering function. Type 4 Waters would receive 100-foot wide riparian management zones and Type 5 Waters in unstable slopes would receive protection based on the area of unstable area. Type 5 Waters in stable terrain would be protected by the Forest Resource Plan Policy No. 20.

The 25 feet of the riparian management zone closest to the stream would be a no-harvest area, and the area of the riparian management zone from 25-100 feet would be a minimal-harvest area; these zones would provide sufficient width to intercept sediments. Because

the remaining portion of the riparian management zone (more than 100 feet from the active channel margin) would be a low-harvest area, then this zone should provide sufficient sediment filtering.

Under Alternative B, there would be a comprehensive landscape-based road management plan developed and instituted, which would have an objective of minimizing sediment runoff from roads reaching the streams. This would contribute to a road system with a low road density and high maintenance standard. Low road density and continuing road maintenance is expected to substantially reduce the risk of excessive sediment delivery to streams.

Hydrologic maturity of the forest is a major consideration under Alternative B and this would minimize adverse impacts of sedimentation and other channel destabilizations that can occur during rain-on-snow floods. Under Alternative A, consideration of hydrologically mature forest is not a specific requirement of timber sale layout, however, WAC 222-22-100 gives interim regulatory measures prior to watershed analysis in a WAU. Under this rule, DNR shall condition the size of clearcut harvests in the significant rain-on-snow zone where local evidence indicates that material damage to public resources has occurred during peak flows. Because this rule only affects harvests in watersheds where material damage to public resources has already occurred, some sedimentation and channel destabilization could occur.
Alternative B would protect against sedimentation of salmonid habitats better than Alternative A because of the wider riparian management zones and wind buffers on the headwater streams, the minimum riparian management zone width designation on Type 1 through 4 Waters, the allowance for hydrologic maturity in the rain-on-snow zone, and the comprehensive road management plan. Wetlands may help to keep sediments from entering streams if ground-based equipment is kept out of forested wetlands and wetland buffers. However, the use of ground-based equipment in and around wetlands is allowed under Alternative B.

ALTERNATIVE C

Riparian management zones for all Type 1 through 5 Waters would average one site potential tree height in width, which is at the upper end of the range of literature recommendations for protection from sediment runoff. A 100-foot wind buffer provided on both sides of the riparian management zone on Type 1 and 2 Waters and the 50-foot wind buffer on both sides of the larger Type 3 Waters will further minimize sedimentation of salmon streams.

There would be a 25-foot-wide area immediately adjacent to the stream that would be a no-harvest area. Stream bank stability would be the primary concern and a wider zone should be used where necessary to protect salmonid habitat from sedimentation.

The comprehensive, landscape-based road management plan will result in an improved situation for salmon habitat because it will result in fewer and better maintained roads. This should lower the probability of landslide failures and sediment runoff reaching salmon streams.

Under Alternative C, hydrologic maturity is a major consideration to minimize sedimentation of salmonid habitats and channel destabilization caused by rain-on-snow floods.

Alternative C provides more protection from sediment runoff than Alternative A, because of the wider and more consistent riparian management zones on all water types, limited harvest activity allowed in the riparian management zones, the wind buffers, allowance for hydrologic maturity in the rain-on-snow zone, and the comprehensive road management plan. Alternative C also provides good protection of wetlands through the use of buffers and the preclusion of ground-based equipment in forested wetlands and wetland buffers. These factors would allow wetlands to intercept sediment at natural or near natural rates.

Stream Bank Stability

Stream bank erosion is a natural process that occurs sporadically in forested and nonforested watersheds (Richards 1982; Thorne 1982). Under natural conditions, this process is part of the normal equilibrium of streams. The forces of erosion, resistance and sediment transport maintain natural conditions. Stream bank erosion can be accelerated by human activity. Important alterations that typically result from timber harvest activities include removal of trees from or near the stream bank, change in the hydrology of the watershed and increasing the sediment load which fills pools, and contributes to lateral scour by forcing erosive stream flow against the stream bank (Pfankuch 1975; Cederholm et al. 1978; Madej 1982; Roberts and Church 1986; Chamberlin et al. 1991).

Coarse sediment influx occurs primarily due to slope failures along Type 4 and 5 Waters, accelerated erosion of stream banks in larger streams, and failure of road prisms resulting in delivery of heavy loads of sediment to downstream channels. Consequently, the value of riparian management options for protecting stream bank stability is based on the widths of the respective buffer zones, activities allowed within the buffer zone, changes in watershed hydrology, and the potential for increased influx of sediment.

Peak flows may not be as important in affecting stream bank stability factors as buffer width and management activities allowed within the buffer. These factors affect root strength and sediment supply, the main variables affecting bank stability. Increased peak flows contribute incrementally more erosive power to streams. If stream banks are cut over, they will not have the resistive strengths to prevent erosion during peak flows (Hicks et al. 1991).

Channel morphology changes when timber harvesting increases the rate at which coarse sediment is delivered to streams (Hicks et al. 1991). Increased frequencies of landslides and other mass-wasting events can cause channels to aggrade where the gradient and other aspects of valley topography permit gravel deposition. Stream reaches that are aggraded with coarse sediments typically become wider, shallower, and more prone to lateral movement and bank erosion (Sullivan et al. 1987). Water passes through deposited gravels, reducing surface flow of summer rearing habitat (Cederholm and Reid

1987). Under these conditions the total riffle area may increase while pool area decreases and habitat may be lost (Everest et al. 1987).

Regional differences in the processes affecting stream bank stability are minimal to nonexistent with the exception of rain-on-snow and snow-dominated categories in the North Cascades. The physics of root strength, while not well understood in all situations, is not expected to vary significantly across western Washington. Therefore, response of stream banks to DNR timber management activities is expected to be similar across administrative regions.

ALTERNATIVE A

The width of the riparian management zones on Type 1, 2, and 3 Waters should be sufficient to protect stream bank stability, however, the lack of a minimum width of riparian management zones on the smaller streams would indicate that some Type 4 and 5 Waters would receive no protection. Most riparian management zones are currently treated as no-harvest areas, however, such treatment is not required under Alternative A and cannot be ensured in the future. Given these conditions, stream bank stability can be expected to be adversely impacted in at least some instances.

Roughly half of Type 5 Waters would receive riparian management zones averaging 40 feet in width (range 0-150 feet). The streams not receiving protection have potential to deliver sediment to downstream channels, which could further result in high rates of stream bank erosion and resulting stream bank instability in downstream areas.

The possibility of harvest activity within the riparian management zones under Alternative A leaves the possibility that some stream banks may be damaged. The lack of specifically applied wind buffers increases the risk that riparian management zones may blow down. Such blowdown would reduce stream bank stability in some areas, and perhaps result in direct and indirect stream bank damage.

Under Alternative A, consideration of hydrologically mature forest is not a specific requirement of timber sale layout, however, WAC 222-22-100 gives interim regulatory measures prior to watershed analysis in a WAU. Under this rule, DNR shall condition the size of clearcut harvests in the significant rain-on-snow zone where local evidence indicates that material damage to public resources has occurred during peak flows. Because this rule only affects harvests in watersheds where material damage to public resources has already occurred, some sedimentation and channel destabilization could occur.

There is no comprehensive road management plan under Alternative A and, therefore, stream bank erosion caused by high sediment runoff into channels may occur.

ALTERNATIVE B

Riparian management zone widths on Type 1 through 4 Waters under Alternative B are sufficiently wide to protect stream bank stability. Stream banks along Type 5 Waters in areas of unstable slopes would be protected. Type 5 Waters in stable areas, however, would be covered by Policy No. 20 of the Forest Resource Plan and this would not always ensure stream bank protection.

100-foot wind buffers would be applied to the windward side of Type 1 and 2 Waters and 50-foot wind buffers to the windward side of Type 3 Waters greater than 5 feet wide, in areas that are blowdown-prone. This would reduce stream bank damage caused by tree blowdown along the stream banks of these streams and further ensure that these streams would be protected from stream bank damage.

The 25 feet of the riparian management zone closest to the streams would be a no-harvest area, and this would lend considerable protection to stream bank stability.

Under Alternative B, hydrologic maturity is a major consideration to minimize adverse impacts caused during peak flow, such as during rain-on-snow floods. Because wider riparian management zones would be left on smaller headwater Type 4 and 5 Waters, increased peak flows are expected to diminish resulting in decreased annual erosion of stream banks. Decreased downstream delivery of sediment from Type 4 and 5 Waters would reduce the chance of stream bank erosion and lateral migration of the channel in downstream areas.

The comprehensive road management plan under Alternative B will further ensure that road densities and sediment runoff will be kept to a minimum.

Alternative B would provide more protection for stream bank stability than Alternative A, particularly on Type 3, 4, and 5 Waters, because it would provide wider riparian management zones and increased surety that management activities within these areas would not cause stream bank instability. Consideration of hydrologic maturity would reduce stream bank damage caused by peak flood events. The provision of additional 100-foot wind buffers in Alternative B on the windward side of Type 1 and 2 Waters and 50-foot wind buffers on the windward side of the larger Type 3 Waters would further increase the likelihood that the riparian management zones would protect stream bank stability.

ALTERNATIVE C

Riparian management zones of one site potential tree height in width would be provided on both sides of Type 1 through 5 Waters, and this should be sufficient to protect against direct damage to stream banks. Additional 100-foot wind buffers on both sides of Type 1 and 2 Waters and a 50-foot wind buffer on both sides of the larger Type 3 Waters would also ensure stream bank protection.

There would be a 25-foot-wide area immediately adjacent to the stream that would be a no-harvest area, and this would go a long way in ensuring stream bank stability. Stream bank stability would be the primary concern and a wider zone would be used where necessary.

Stream bank erosion would diminish because of the riparian management zones, which should decrease the annual delivery of sediment to downstream channels. Decreased downstream delivery of sediment from Type 4 and 5 Waters would reduce the chance of

lateral migration of streams in downstream segments. Areas of instability along Type 4 and 5 Waters would be protected.

Under Alternative C, hydrologic maturity within the watersheds is a major consideration to minimize adverse impact to salmonid resources due to rain-on-snow floods.

Alternative C provides increased protection for stream bank stability compared to Alternative A by providing more consistent and wider riparian management zones on all water types, restriction of management activities in the riparian management zones that adversely impact stream bank stability, reduced peak flows in small headwater streams, and substantial windthrow buffering.

Stream flow

Timber harvest can alter drainage-basin hydrology through its effects on a number of forest stand properties including transpiration, interception, evaporation of rainfall, fog, snow, soil structure, and resultant water infiltration and transmission rates (Chamberlin et al. 1991). Increases in the length of the drainage network through added road mileage can also significantly influence stream flow (Grant 1994). Though changes in stream flow are expected from timber harvest activities, the direction and magnitude of these changes vary and specific effects cannot be easily predicted.

Timber harvest can influence stream flow by altering the amount of snow accumulation and the rate of the associated melt. In general, loss of vegetation from timber harvest decreases the snow-interception and evapotranspiration properties of the forest, thereby increasing water yields (Bosch and Hewlett 1982). An intact coniferous forest canopy normally captures snow which then evaporates or melts rather than accumulating on the ground. However, in clearcut and thinned stands, the forest floor accumulates considerable quantities of snow due to the decrease in the snow-interception properties of the forest canopy. Snow accumulated in canopy openings also melts more rapidly than snow in the surrounding forest due to direct exposure to atmospheric heat. Resultant increased water yields can be expressed in either increased summer base flows or increased peak flows (Bosch and Hewlett 1982). Increased peak flows are generally more detectable in streams at lower discharges as compared to higher discharges (Rothacher 1973; Lyons and Beschta 1983). Similarly, such changes in peak flow are more detectable in smaller rather than in larger drainage basins.

The elevational range over which snow might accumulate and melt, perhaps several times in one season, is called the rain-on-snow zone. In western Washington, this zone occurs between approximately 1,200 and 4,000 feet (366 to 1220 meters) above sea level (WFPB 1995b). Melting of snowpacks accumulated in harvested areas can be further accelerated during rainstorm events, resulting in even higher rates of water input to soil and streams than would occur otherwise (Harr 1986; Berris and Harr 1987; Harr et al. 1989). These peak flows are known as rain-on-snow events. Hydrologic maturity refers to the percentage of a watershed that is comprised of forest with a predominantly closed canopy within the rain-on-snow zone. A forest is said to be hydrologically mature when it has the structure and composition that causes it to behave hydrologically in a manner similar

to mature forest. Hydrologic maturity is important because of its effects on the amount of snow accumulation and associated rain-on-snow events. The greater the canopy openings and the younger the stands within an area, the greater the potential snow accumulation, and thus the greater the available water to contribute to peak flows during a rain-on-snow event.

Significant recovery from hydrologic changes in a forest tends to be gradual. Grant (1994) observed little recovery after 30 years. Harr reported 50 percent recovery was achieved in 25 years (Harr et al. 1989). The effects of an extended drainage network via roads will last as long as the road system is maintained. The potential for increased snow accumulation continues within a harvested stand until the second-growth canopy closes. The age at which closure occurs depends on site quality, species composition, and the number of trees left after harvest, but occurs at an age of approximately 25-35 years for clearcuts in western Washington (WFPB 1995b).

The percentage of a watershed harvested is generally correlated positively with stream flow. Several studies have shown that harvest of at least 25-40 percent of basin area is required within a period of 5-15 years before effects on mainstem flow are detectable (Rothacher 1970, 1973; Harr et al. 1979; Duncan 1986). Rothacher (1970) investigated a 237-acre (96-hectare) watershed in Oregon that was 100 percent clearcut and was able to detect stream flow increases after about 40 percent of the basin had been harvested. In another study (Hetherington 1987), a 90 percent clearcut harvest in 1 year on a 2,964-acre (1,200 hectare) tributary on Vancouver Island resulted in a 14 percent increase in annual water yield, a 78 percent increase in summer low flow, and a 20 percent increase in peak flows. Some ongoing investigations also document increases in peak flows in mainstem channels due to timber harvest (Grant 1994).

In contrast, Hicks et al. (1991) presented long-term data from the same 237-acre (96 hectare) watershed investigated by Rothacher (1970, 1973) and documented decreases in summer low flow. They found that water yield increased above that of the control watershed for approximately 8 years. However, for the next 19 years of record late summer water yield decreased below that of the control watershed. This decrease in flow may have been related to increased transpiration by second-growth alder. Harr (1982) has shown that logging may also decrease summer low flows by reducing fog-drip in fog-influenced forests.

In forested environments, most water is delivered to streams by subsurface flow through the soil. Logging operations that compact soil may increase surface runoff which could either increase or decrease peak flows. Generally, overland flow is faster than subsurface flow, thus increases in peak flow may occur through inhibition of subsurface flow due to soil compaction (Jones 1987). Cheng (1988) indicated the opposite effect in southern British Columbia. In that case, logging had compacted the soil, delayed water infiltration, slowed water transmission through soil macropores and reduced peak flows.

Roads constructed in conjunction with timber harvest can also gather and transmit water faster than the natural landscape, thereby altering basin hydrology (Harr et al. 1975; Harr 1979). Roads, and their associated ditches, can intercept both surface and subsurface

flow and redirect this water toward stream channels, potentially changing the timing and magnitude of peak flows. Poorly designed roadside ditches can essentially become extensions of the stream system (Wemple 1994). In one study, roads caused the winter stream drainage density to increase 38 percent over the pre-road conditions (Grant 1994).

A sub-basin in western Washington which is completely within the significant rain-on-snow zone is estimated to yield an additional inch of water during a 10-year 24-hour rain-on-snow event if one-third of the sub-basin is in a hydrologically immature condition. The implicit assumption used to develop WAC 222-16-046 is that peak flows caused by the addition of 1 inch of water onto a 10-year 24-hour storm, a storm of moderate intensity, present an acceptable level of risk to public resources.

The appropriate size of the drainage basin for the hydrologically-mature forest prescription was based on guidelines in the hydrology module of watershed analysis (WFPB 1995b) and their current application by hydrologic analysis. In watershed analysis, increases of peak flow greater than 10 percent are considered to offer the possibility of adverse effects to public resources. It is generally recognized that the precision of flow measurements is on the order of 10 cubic feet per second. Therefore, 100 cubic feet per second (a 10 percent change of 100 cubic feet per second equals 10 cubic feet per second) seems to be a reasonable level of peak flow from which to derive the appropriate drainage basin size.

Bankfull channel discharge is a geomorphologically effective discharge that causes long-term channel erosion and sediment transport (especially bedload movement). A regression equation relating bankfull discharge to drainage basin area for the Puget Lowland and western Cascades (Frederick and Pitlick 1975; Parsons 1976; Dunne and Leopold 1978
p. 616-617) shows that approximately 100 cubic feet per second of bankfull flow can be generated by a drainage basin having an area of approximately 1220 acres.

In addition, a review of watershed analysis reports shows that most hydrologic analysis units (HAUs) are greater than 900 acres. In a few instances, HAUs are as small as 350 acres, but these are fragmented areas between basins of significant creeks. Most hydrologic analysts involved in watershed analysis delineate HAUs that are 1,000 acres or more.

In some 100-acre drainage basins there will be little risk of material damage to salmonid habitat during rain-on-snow floods. For instance, in basins with less than one-third of their area in the significant rain-on-snow zone, the estimated additional yield due to rain-on-snow during a 10-year 24-hour storm is less than 1 inch. In basins with at least two-thirds of their area in the significant rain-on-snow zone, covered by hydrologically-mature forests and reasonable assurance that it will remain in that condition (e.g., forests in national parks or national forest Late-Successional Reserves), there is little risk of material damage to salmonid habitat. In some basins, due to ownership patterns, DNR management will not significantly decrease the risk of material damage. Consider a basin with exactly half of its area in the significant rain-on-snow zone under DNR management. If other owners did not manage for hydrologically-mature forest and DNR

maintained two-thirds of its forest lands in a hydrologically mature condition, only one-third of the area in the significant rain-on-snow zone would be hydrologically-mature forest. During a 10-year 24-hour rain-on-snow event, the estimated additional yield of water due to a hydrologically immature area is 2 inches. DNR management, in this case, would not significantly decrease the risk of material damage because a 2-inch additional yield is expected to cause material damage to salmonid habitat.

Wetlands can augment stream flows during low-flow periods through their storage of water and subsequent discharge to subsurface flow or direct input to streams. Wetlands can also be quite important in attenuating flood peaks during storm events by absorbing storm water and releasing it slowly (Richardson 1994). Flood peaks have been linked with declines in coho smolt yield during the most extreme discharges (Seiler 1994; Cederholm et al. in prep.).

ALTERNATIVE A

Under the existing Forest Resource Plan (DNR 1992b), the mechanism by which hydrologic maturity is to be addressed is watershed analysis (WFPB 1995b). At this time, not all watersheds have had an analysis, and the analysis of all watersheds may require decades to be completed. Where watershed analysis is complete, the hydrology module is designed specifically to address and minimize increases in peak flows during rain-on-snow events by evaluating all Type 3 Water sub-basins individually. Under Alternative A, consideration of hydrologically mature forest is not a specific requirement of timber sale layout, however, WAC 222-22-100 gives interim regulatory measures prior to watershed analysis in a WAU. Under this rule, DNR shall condition the size of clearcut harvests in the significant rain-on-snow zone where local evidence indicates that material damage to public resources has occurred during peak flows. Because this rule only affects harvests in watersheds where material damage to public resources has already occurred, some sedimentation and channel destabilization could occur. The contribution of roads to peak flows and decreases in summer low flow caused by timber removal are not presently addressed in the watershed analysis.

The hydrology module assumes that peak flows that are 10 percent higher than background conditions may have significant adverse effects. This threshold was selected based on the resolution of stream-gauge data, which is generally plus or minus 10 percent. The methodology presented to evaluate the percentage of peak flow change uses a variety of regional discharge estimates and available stream-gauge data. Whether this methodology provides sufficient resolution to determine a realistic 10 percent flow change or whether the 10 percent threshold adequately protects against significant rain-on-snow events is uncertain.

Wetlands would be protected to ensure no net loss of acreage or function.

ALTERNATIVE B

Alternative B would minimize the amount of hydrologic change within a basin by requiring that rain-on-snow considerations be applied, thus increasing the amount of forest cover. Two-thirds of the rain-on-snow and snow-dominated zones on DNR-managed land within each Type 3 sub-basin would be maintained in a hydrologically mature state. With much of the area maintained in a hydrologically mature state,

increases in peak flow due to timber harvest are expected to be minimal. Additionally, the Shaw and Johnson (in press) slope stability model would be applied to identify areas of slope instability.

There are substantial riparian management zones left along Type 1 through 4 Waters and protection of Type 5 Waters in areas of unstable slopes, which contributes to additional hydrologically-mature forest within a drainage basin. There is a 100-foot-wide wind buffer left on the windward side of blowdown-prone Type 1 and 2 Waters, and a 50-foot buffer left on larger Type 3 Waters that are in similarly blowdown-prone areas.

The 25 feet of the riparian management zone closest to the stream would be a no-harvest area, and a wider zone would be established where necessary. It is anticipated that only ecosystem restoration would occur in this area. Activities occurring between 25 and 100 feet from the active channel must not appreciably increase stream flow. It is anticipated that only two types of silvicultural activities will occur in this area: ecosystem restoration and single-tree selective harvest. The remaining portion of the riparian management zone (more than 100 feet from the active channel margin) will be a low-harvest area. It is anticipated that single-tree selective harvest thinning operations, salvage operations, and partial harvest will occur in this area.

The comprehensive road management plan under Alternative B will minimize active road density and thus reduce the negative effects of high road density on peak flows.

Alternative B would provide similar wetlands protection compared with Alternative A.

Alternative B provides more protection than Alternative A for hydrologic impacts on stream flow with greater protection of Type 3 sub-basins within the rain-on-snow zone, wider riparian management zones on Type 4 Waters, wind buffers, a comprehensive road management plan, and the provision of additional leave areas along Type 5 Waters in unstable slopes.

ALTERNATIVE C

Alternative C provides significant protection of salmonid habitats by ensuring that two-thirds of DNR-managed lands within the significant rain-on-snow zone in Type 3 sub-basins be maintained in a hydrologically mature condition.

Riparian management zones equal in width to one site potential tree height would be provided on all water types. There would be an additional 100-foot wind buffer on both sides of Type 1 and 2 Waters and a 50-foot wind buffer on both sides of the larger Type 3 Waters. The addition of wind buffers on both sides of streams reduces the amount of timber harvested at any given time, thereby slightly reducing hydrologic changes. This would minimize hydrologic changes to streams that are direct tributaries to Type 3 basins.

A 25-foot-wide area immediately adjacent to the stream would be a no-harvest area. From there to the outer edge of the protected area, activities would be allowed only if the activity serves to restore and/or enhance the function of the riparian ecosystem and/or the

buffer. However, even after the stands reach a mature state, the only activities allowed would be those restoring/enhancing ecosystem or riparian management zone function.

Alternative C would benefit stream flow moderation and augmentation more than Alternative A through a more protective wetland strategy. Restriction of ground-based equipment within the wetland and wetland management zone (WMZ) would prevent channelization of the wetland and help to maintain wetland hydrologic function.

The comprehensive road management plan under Alternative C will help minimize active road density and its negative effects on hydrology.

Alternative C is more protective than Alternative A because of the protection of the rain-on-snow dominated zone, the maintenance of hydrologic maturity, comprehensive road management plan, the provision of wide riparian management zones on all water types, and the provision of wind buffers on both sides of the larger streams.

Wetlands

Although the evaluation of alternatives in relation to the preceding components focused on salmonid habitat, a broader perspective is applied to evaluating the alternatives in relation to wetlands. This evaluation addresses hydrology (low-flow augmentation and flood-peak attenuation), stream flow and salmon habitat, water quality, wildlife, and wetland vegetation.

Wetlands have tremendous value in forested watersheds for several reasons. An important component in forest hydrology, wetlands help to moderate the stream flow and regulate water quality, directly influencing riparian habitats downstream. Unique habitats in themselves, wetlands provide forage, shelter, breeding and resting areas for many wildlife species, and habitat for unique and sometimes rare plant species. The wetland alternatives presented in the HCP are designed with the primary intention of maintaining wetland hydrologic function for the benefit of downstream salmon habitat. Wetland hydrology and wetland habitats are of importance to a broad range of other species as well, throughout the riparian ecosystem.

The following is a brief discussion of the various functions that wetlands serve. It should be recognized that wetland functions can vary considerably by wetland type, and thus the functions outlined below may not necessarily be performed in every wetland. Also, Brinson (1993) states that the "...less frequently flooded portions of wetlands are no less functionally active than wetter portions; the functions are simply different." It is important to be cautious about value judgements placed on any particular wetland.

Wetlands - Hydrology: Low-flow augmentation, flood-peak attenuation. Our understanding of wetland hydrology specific to the Pacific Northwest is rudimentary. However, based on what we do know, a cautious approach to wetlands management is warranted. Because most studies have been done in the southeastern or lake states, extrapolation of any conclusions needs to be done carefully.

Wetlands are a primary part of the permanent soil and ground water hydrology of forests on many watersheds. Their influence on stream hydrology has been repeatedly demonstrated (Winter 1988; Waddington et. al. 1993). Specifically, wetlands can augment stream flow during low flow periods through discharge of ground water, storage of water and subsequent discharge through soil interflow, or direct contribution to streams.

Wetlands also play an important role in moderating flows during storm events, dampening stormflow and storing the water for future discharge (Richardson 1994). Empirically derived equations predicting stream flow (Jacques and Lorenz 1988) show that storm floodflows are proportional to the negative exponent of the proportion of the watershed area that is in wetlands and lakes. That is to say, wetlands in watersheds with few wetlands have a disproportionately large impact on reducing floodflows. The equations predict that a watershed containing as little as 5 percent wetlands would have a storm floodflow that is 50 percent lower than if there were no wetlands. Johnston et al. (1990) applied the same equation and found that a watershed with 1.6 percent lakes and wetlands had a flow-per-unit watershed area that was 10 times greater than the flow predicted for a watershed where 10 percent of the area was lakes or wetlands. The conclusions of these studies strongly suggest that the loss of any wetlands in watersheds where there is less than 10 percent wetlands would be significant.

ALTERNATIVES A AND B

Alternatives A and B are designed to help maintain the natural hydrology of wetlands through protecting wetland soils from compaction and channelization, and maintaining wetland vegetation to the extent that it can continue near-natural rates of evapotranspiration.

This is accomplished through maintaining managed buffers around both forested and nonforested wetlands, and imposing restrictions on the amount of timber volume that can be removed. These restrictions should in most cases protect the wetland's ability to store, release and exchange surface and ground water at natural or near-natural capacity, and to recover from management activities without impairing hydrologic function significantly.

ALTERNATIVE C

Alternative C provides more protection to wetland hydrologic function by buffering small wetlands that function together as a larger wetland, by increased protection of the wetland edge (which will in turn provide more protection to wetland inflows and outflows, hopefully preventing channelization and conversion of subsurface flow to surface flow), and by ensuring that the trees left in buffers and forested wetlands are the most windfirm trees available, to avoid losses by blowdown.

Wetlands - Stream flow and salmon habitat. Low summer flows have been regarded as a primary determinant of natural coho production in western Washington since the mid-1950s when Smoker (1955) reported on a significant relationship between salmon catch and stream flow during the year those fish were reared. Seiler (1995) found a correlation between summer low flows and poor coho smolt survival. The working

hypothesis is that summer low flows limit the amount of habitat during summer rearing, thereby setting the stream's capacity for a given brood.

Summer stream flows have direct influence on habitat size, have often been assumed to be the limiting factor to smolt yield, and have been used in forecasting adult natural coho run sizes for Puget Sound (Zillges 1977). Lestelle et al. (1993) recently found coho smolt yield to be correlated with summer stream flows of the previous year in five of thirteen streams analyzed in western Washington.

The potential effects of stream flow on coho production are not limited to summer flows. Benefits that fall and winter high stream flows provide are likely negated by streambed scour and mortality to incubating eggs. Seiler (1995) found a significant negative correlation between winter flow during the incubation period and smolt yield 2 years later. Storm flow can also impact salmon populations by catalyzing debris flows and slope failures into streams, directly killing salmon eggs (Seiler 1995).

Variable stream flow can also affect salmon survival. High flows can reduce fry survival during dispersal following emergence (Holtby 1988). During fall high flow periods, juvenile coho salmon have been found to seek refuge in small spring and pond feed tributaries of the Clearwater River (Peterson 1982b; Cederholm and Scarlett 1982).

ALTERNATIVES A AND B

Soil disturbance and over-cutting in wetlands and their buffers are the main threats to the wetland functions that moderate stream flows and benefit salmon habitat. If fully implemented, Alternatives A and B should provide some protection to wetland recharge and discharge areas through buffers, particularly if ground-based equipment is used judiciously in the buffer and kept out of the wetland entirely. Such restrictions on equipment are not mandatory under these alternatives, however. The maintenance of the required basal area will also help to keep the wetland hydrology within natural parameters. However, if the basal area that is left does not contain large windfirm trees, the evapotranspiration rates could be lower, the water table could rise and the risk of loss through blowdown would increase.

ALTERNATIVE C

Several factors make Alternative C substantially more protective than Alternatives A and B. First, the restrictions on ground-based equipment in forested wetlands and within 50 feet of the wetland's edge will improve chances that wetland inflow and outflow will retain their natural character. The mandatory selection of large dominant and co-dominant windfirm leave trees will help to maintain the integrity of the buffer and near natural evapotranspiration rates, both of which should help the wetland moderate stream flows. The buffering of small, interconnected wetlands could have a sizable impact on both flood-peak attenuation and low flow stream augmentation in some watersheds. Finally, the added protection of small bogs may contribute to stream flow moderation. Bogs are hydrologically isolated "donor" wetlands that receive water almost exclusively through precipitation, and for this reason do not have inflows. They do have outflows however, and may be important in some watersheds for low flow stream augmentation.

Wetlands - Water quality. Wetlands can play a critical role in maintaining water quality. Wetlands slow surface water flow, allowing water-borne sediments to precipitate or adhere to vegetation. Oberts (1981) found that watersheds with less than 10 percent wetlands had sediment loading rates per unit area that were as much as 100 times greater than suspended solid loading rates of watersheds with more than 10 percent wetlands. Forested wetlands in particular appear to have a disproportionately high capacity for sediment trapping (Hupp et al. 1993). This sediment trapping function can be of great benefit to salmon habitat downstream. Cederholm and Reid (1987) found that salmon survival to emergence was reduced 50 percent as a consequence of increased sedimentation in two heavily roaded sub-basins of the Clearwater River.

Wetlands can also positively influence water temperature in streams during warm summer months by contributing cool ground water or surface and subsurface flow that has been shaded.

As water temperature and sedimentation are the two most limiting factors to water quality in most forested watersheds, these wetland functions are particularly important. In addition to sediment trapping, wetlands have the capacity to remove various pollutants from water, because such pollutants tend to bond to suspended sediments and become entrapped in wetland soils and vegetation.

Prior to the Forest Resource Plan (DNR 1992b), DNR did not have explicit direction to fully protect wetlands. Consequently, past forest practices on DNR-managed land often resulted in the loss of wetlands or a degradation of wetland function. Forest Resource Plan Policy No. 21 directed "DNR to allow no overall net loss of wetland acreage and function." This policy has yet to be completely implemented, and so some loss of wetland acreage or function may have occurred since the formal adoption of the Forest Resource Plan. The No Action alternative represents the forest management prescriptions that are thought to be the most effective implementation of Policy No. 21.

ALTERNATIVES A AND B

As with other aspects of wetland hydrology, the primary threats to water quality in wetlands and the water that they contribute to downstream systems are from soil and vegetation disturbance. If fully implemented, the buffers required for Alternatives A and B will act to prevent erosion and maintain the wetland's ability to filter sediments and pollutants. The maintenance of some trees and other wetland vegetation in forested wetlands and buffers should help keep water temperatures cool. This could be of benefit to salmon habitat downstream during warm, low flow periods.

ALTERNATIVE C

Protection of water quality under Alternative C may be increased due to more restrictive cutting requirements, better protection of wetland soils due to restrictions on ground-based equipment, and increased protection of small, interconnected wetlands and bogs. The benefits of these measures are similar to those described for Alternatives A and B.

Wetlands - Wildlife. Wetlands receive a disproportionately high amount of use by wildlife compared to upland areas. It has been estimated that of 414 wildlife species in western Washington and Oregon, 359 rely on the use of wetland or riparian areas for

some seasons or some part of their lives (Brown 1985). Some species such as beavers and some species of amphibians are completely dependent on wetlands for their entire life cycle, while others such as raccoons and myotis bats may use wetlands for only part of their needs.

Wetlands have very high levels of net primary productivity, and also provide rearing habitat for many insect species that are a very important part of many food webs. For this reason, many wildlife species such as raptors and coyotes are indirectly supported by wetland environments because their prey base comes from wetlands. Because wetlands tend to support higher concentrations of prey species than surrounding uplands, they can improve the habitat quality of adjacent uplands by proximity.

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ALTERNATIVES A AND B

The partially forested buffer areas left around wetlands under these alternatives would provide some habitat features important to a wide variety of wildlife species. Trees left in forested wetlands and buffer areas should provide roosting, nesting, foraging, and shelter areas. Over time, snags might be available for nesting and foraging sites. The benefits of these buffers would be reduced for some species if blowdown due to rising water levels or non-windfirm trees were to reduce stand density in the buffer. Other species might benefit from increased edge habitat. The hydrology and water quality protection offered by these alternatives would benefit any aquatic species, both within and downstream of the wetland.

ALTERNATIVE C

The potentially more stable buffer areas and undisturbed portions of nonforested wetland buffers should increase wildlife habitat values over those provided by Alternatives A and B. Protection of small bogs would benefit some bog-dependent species. Perhaps one of the most important differences between Alternative C and Alternatives A and B is the protection offered to small interconnected wetlands. Small wetlands are believed to be very important in supporting wetland-associated taxa. Gibbs (1993) found through modeling the disturbance of the smallest wetlands (0.1-4.5 hectares) (0.25-11 acres) on a landscape, that small wetlands play a disproportionately large role in the maintenance of associated animals. Using a spatially-structured demographic model, Gibbs found that stable populations of turtles, small birds and small mammals faced a significant risk of extinction after loss of the smallest wetlands representing 14 percent of the total wetland area on the watershed.

Wetland vegetation

Wetlands provide habitat for many plant species that are otherwise rare in the forest. Some of these species are highly specialized for specific hydrologic and nutrient regimes, while others have broader ecological amplitudes (can survive a broader range of environmental conditions). Due to historic losses of wetland habitats, many federally and state-listed rare plant species are wetland-dependent species.

ALTERNATIVES A AND B

Protection for rare plants under Alternatives A and B is provided chiefly through buffers and provisions that support natural wetland hydrology. If ground-based equipment were to be kept out of wetland buffers, wetland plants would benefit from less soil disturbance. Also, the seeds of invasive exotic species can often be brought into wetland areas by heavy machinery, which also prepares a suitable seed bed. These species can sometimes outcompete native species and constitute a threat to some of the federally and state-listed wetland species.

ALTERNATIVE C

More restrictive harvest and ground-based equipment requirements through Alternative C would benefit wetland vegetation by reducing disturbance and improving the protection to wetland hydrologic functions. In addition, added protection for small bogs and interconnected wetlands will increase the amount of protected habitat substantially in some watersheds.