BULL TROUT
INTERIM CONSERVATION GUIDANCE

Prepared by
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The Bull Trout Interim Conservation Guidance (Guidance) was developed by the U.S. Fish and Wildlife Service (Service) as a tool to be used by Service biologists in bull trout conservation and recovery. It is not intended to provide site specific land management prescriptions, but to provide recommended actions that may be adapted and modified to benefit bull trout in a particular locale. This Guidance addresses land management activities; other activities affecting bull trout will be addressed through additions to the Guidance or the Recovery Plan.

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INTRODUCTION AND USER'S GUIDE

The purpose of the draft Bull Trout Interim Conservation Guidance (Guidance) is to provide Service biologists with a tool that will be useful in conducting Endangered Species Act (ESA) activities, including section 7 consultations, negotiating habitat conservation plans that culminate in the issuance of section 10(a)(1)(B)-incidental take permits, issuing recovery permits, and providing technical assistance in forest practice rule development and other interagency bull trout conservation and recovery efforts. This document is not intended to supersede any biological opinion that has been completed for federal agency interactions. Rather, it should b used as another tool to assist in consultation on those actions.

The focus of the Guidance is on the effects of land management on bull trout and their habitat. This Guidance is interim and intended to be used in the short term during the period of Recovery Plan development. However, by incorporating the best available information relative to bull trout life history needs, the Guidance is intended to be compatible, to the extent possible, with the primary components of a formally adopted Recovery Plan.

Watersheds can take many decades to respond to improvements in management actions (Scarlett and Cederholm 1996). Response of the fish to improved habitat conditions can take even longer. It is important that actions to conserve and protect habitat begin immediately as changes to the habitat can be detected earlier than changes to the population. This Guidance was developed in part because it is critical that we start now to reverse the declining trend in habitat conditions, so that we can do good things, avoid bad things, and not eliminate our options for recovery.

The Guidance is organized around a set of Habitat and Land Management issues that are based on the current status, threats, and biological needs of bull trout. Habitat issues that are addressed in this Guidance relate to the habitat characteristics identified by Rieman and McIntyre (1993) that are important for bull trout: temperature, habitat complexity (including cover), connectivity, and substrate composition and stability. Land Management issues are those that affect the important bull trout habitat characteristics identified above. The Management issues addressed in this Guidance are riparian and floodplain protection and roads. There is some overlap with the different issue papers, just as there is overlap in habitat functions. Our intent is to have each issue paper stand alone. This may create some redundancy.

There are other Habitat and Management issues that have the potential to affect bull trout (e.g., mining, dams, introduced species), and additional issue papers may be added to this Guidance in the future. The organization of each "Habitat and Management issue" is as follows:

- **Problem Assessment**--current habitat and management conditions relative to bull trout.

- **Biological Needs**--bull trout biological requirements relative to the issue.

- **Objectives**--desirable outcomes specific to the issue, but are not necessarily expected in all situations.

- **Caution Zone--**areas where land management activities have the greatest potential to adversely affect bull trout. This does not necessarily mean that all management activities need to be restricted in the caution zone, but that best protection options should be implemented within the caution zone wherever bull trout occur and in tributary streams that might affect bull trout. We have adopted the "caution zone" from the Montana Bull Trout Scientific Group's (MBTSG) report "The Relationship between Land Management Activities and Habitat Requirements of Bull Trout" (MBTSG 1998). While we acknowledge that a one size fits all caution zone fails to account for biophysical differences among stream and riparian systems, for this interim range-wide strategy we have identified caution zones for each issue, often using the 100-year floodplain plus one site-potential tree height distance on both sides of the stream. For some issues, such as roads, the entire watershed is identified as the caution zone. One site-potential tree is approximately 150' on the west side of the Cascade Mountains; 90' to 150' on the east side dependent on forest Potential Vegetation Type (PVG = cold, moist, or dry).

  > "The 100-year floodplain was chosen based on the need to fully incorporate the channel migration zone (CMZ) on low gradient alluvial streams. These stream channels provide critical spawning and rearing habitat for bull trout. An additional 150 feet on either side of the 100-year floodplain is required for the following reasons: 1) it encompasses one site-potential tree height at most locations; 2) provides sufficient width to filter most sediment from non-channeled surface runoff from most slope classes; 3) provides some microclimate and shallow groundwater thermal buffering to protect aquatic habitats inside the channel and the channel migration zone; and 4) provides an appropriate margin of error for unanticipated channel movement, hillslope and soil stability, blowdown, wildfire, operator error, disease, and certain other events that may be difficult or impossible to foresee on a site specific basis" (MBTSG 1998).

  The caution zone may also include non-fish bearing tributaries, seeps, springs, and wetlands in order to capture the linkages in a watershed critical to aquatic system function: stream, riparian, and sub-surface networks (Stanford and Ward 1992). In the caution zone the site-potential tree distance is measured horizontally from the edge of the floodplain. Although horizontal measurement may be slightly more cumbersome to measure than slope distance, horizontal distance for slope would better incorporate riparian management area dimensions.

- **Recommended Actions**--broad landscape-scale types of recommendations, <u>not</u> site prescriptions, requirements or standards. Not all recommended actions will apply to a specific situation or bioregion; they are intended to provide Service biologists direction in tailoring specific recommendations to the applicant or management agency.

- **Performance Indicators**--indices and variables to measure progress in implementing recommended actions. Sometimes a desired direction for progress is described with the indicator. The most important performance indicator for all actions is the response of the fish to environmental improvements (i.e., expanded distribution, increased abundance, unrestricted movement within and between populations, etc.). This will require a coordinated long-term population monitoring strategy, which will be developed in the Recovery Plan.

The following describe the overall objectives that guided development of these Habitat and Management issues:

1. Preserve or restore connectivity among bull trout subpopulations and their habitats through habitat restoration or protection.

2. Restore and conserve natural ecosystem processes to improve or protect habitat thereby expanding abundance, distribution, and diversity of life-history forms (i.e., fluvial or river dwelling, adfluvial or lake dwelling, resident, and anadromous).

The Guidance relies heavily on the Montana Bull Trout Scientific Group's 1998 report, "The Relationship between Land Management Activities and Habitat Requirements of Bull Trout." As emphasized in MBTSG (1998), the Service believes activities that occur within the caution zone may inherently pose some risk, and should not occur unless sufficient information is available to reliably demonstrate that the activity will not adversely affect habitat characteristics necessary to support bull trout. If information is not available, monitoring that allows us to detect the effects of an action needs to occur so that future actions may be adjusted or improved accordingly.

Another reason for caution is that much of the available literature on bull trout distribution, population structure, and habitat associations, is based on already disturbed bull trout populations; therefore, management actions should include monitoring activities that provide adaptive management options.

The Guidance does not provide site-specific prescriptions or standards. Responsibilities for bull trout conservation and recovery vary by land ownership (public and private) and effects of management activities vary by location; therefore we have used broadly defined recommended actions and performance indicators as the tools to provide some flexibility in application of this document.

The Guidance addresses large-scale, range-wide issues affecting bull trout. The Service has developed bull trout subpopulation maps and Table 2 of the Klamath and Columbia River Bull Trout Population Segments Status Summary (Service 1998), which identifies subpopulation-specific threats. These documents can be combined with this document to provide guidance for bull trout subpopulations in specific geographic areas.

We recommend that a data tracking form be developed in the future and used with this document. Data tracking would provide the Service with a tool to track changes in the bull trout subpopulations, habitat conditions, and watersheds. Other identified and important future additions to this Guidance include species population issue papers for bull trout in each watershed; refugia, non-native fish, agriculture, and mining issue papers; and a glossary.

DIFFERENCES BETWEEN BULL TROUT AND SALMON

Bull trout and Pacific salmon are both members of the family Salmonidae and in general require similar habitat components. Both require aquatic habitat that is "cold, clean, complex, and connected." However, bull trout tend to have more spatially restrictive biological requirements at the individual and population levels, and bull trout may require greater protection of these important habitat components. In the Pacific Northwest, salmonid habitat protections have focused primarily on measures to improve habitat for Pacific salmon rather than for freshwater salmonids such as bull trout. This section is intended to discuss some of the differences between salmon and bull trout.

- Bull trout are among the most cold water adapted fish and require very cold water for incubation, juvenile rearing and to initiate spawning (see chapter on Temperature). These temperatures are colder than for anadromous salmon and may in some cases be so cold as to exclude other fish, including certain salmon species, from utilizing the same habitat as bull trout, especially during spawning and egg incubation (Coombs and Burrows 1957 and Alderdice and Velsen 1978 both cited in Groot and Margolis 1991; Underwood et al. 1995). Cold water temperatures may reduce the likelihood of invasion by brook trout and other non-native fish into bull trout watersheds (Clancy 1993; Frissell et al. 1995).

- Spawning, incubation and juvenile rearing are the bull trout life history stages that require coldest water temperatures and lowest fine sediment levels. Juvenile rearing and spawning typically occur in the smaller tributaries and headwater streams that may be upstream of anadromous salmonids, and therefore they are more directly influenced by conditions in non-fish bearing streams (Underwood et al. 1995; Rieman et al. 1997; R. Leary, Univ. of Montana, pers. comm. 1998). Greatest riparian protection needs to be provided around bull trout spawning and rearing streams (often headwater streams and often the smaller fish-bearing streams), and the non-fish bearing streams above them that provide high quality water to downstream areas used by the fish.

- In many streams, bull trout may compete and hybridize with brook trout, an introduced char (Leary et al. 1993; Adams 1994). Although hybridization with non-native species is much less of a conservation factor for Pacific salmon, competition and interbreeding with hatchery salmon may pose similar risks for wild salmon (Reisenbichler and McIntyre 1977; NMFS 1991)

- Bull trout require a long period of time (220+ days) from egg deposition until emergence, making them especially vulnerable to effects of temperature, sediment deposition, and bedload movement during this period.

- Bull trout juveniles are strongly associated with cover including the interstitial spaces in the substrate, which makes them especially vulnerable to effects of sediment deposition, bedload movement, and changes in channel morphology (Weaver and Fraley 1991; Baxter and McPhail 1997).

- Historically, migratory life-history forms of bull trout were more prevalent, being either lake or river dwelling for part of their life history. This allowed access to a larger prey base for both sub-adults and post-spawners. "Open migratory corridors, both within and among tributary streams, large rivers, and lake systems are critical for maintaining bull trout populations" (MBTSG 1998).

- Bull trout may express either resident or migratory life-history forms. Migratory fish may be adfluvial (lake-dwelling), fluvial (river dwelling), or anadromous (ocean dwelling). There is little information on the relationship between migratory and non-migratory forms, although it is likely that historical populations may have consisted of resident and migratory forms. Many bull trout subpopulations that historically were migratory are now isolated and thought to consist of resident fish (Rieman and McIntyre 1993).

- In inter-mountain areas, lower elevation lakes and rivers historically constituted the most important habitats for maturing and overwintering fluvial and adfluvial bull trout. These habitats have been especially degraded by human activities, resulting in fragmented, isolated local bull trout populations (Rieman and McIntyre 1993; MBTSG 1998).

- Bull trout movement in response to developmental and seasonal habitat requirements make their movements difficult to predict both temporally and spatially (MBTSG 1998; D. Ratliff, Portland General Electric, pers. comm. 1998). Juveniles can outmigrate from natal tributaries at any time of the year; their movement can be downstream, followed by upstream movement beyond reaches used by spawning adults; and they are almost always found in close association with the substrate during the day, making them difficult to detect. Adults tend to overwinter in the same area, but can move in response to prey base changes or ice formation (Jakober et al. 1997; D. Ratliff, Portland General Electric, pers. comm. 1998)**;** can be consecutive or alternative year spawners; can be resident or migratory; and can change from adfluvial to fluvial life-history strategies. Bull trout exhibit a patchy distribution, move throughout the system, and do not simultaneously occupy all available habitats.

- Most bull trout spend their entire lives in freshwater environments and are vulnerable to land management activities affecting streams, rivers and lakes (Rieman and McIntyre 1993; MBTSG 1998). The salmon ocean cycle reduces the salmon's dependence on the freshwater habitat for fulfilling all life-history stages, although the freshwater environment is critical to the functions of spawning, incubation, and juvenile rearing.

- The Columbia River basin, historically may have been one or a few large bull trout metapopulations, containing some unique, naturally isolated, genetically distinct populations (M. Gilpin *in litt*. 1996). The Columbia River basin now contains 141 bull trout sub-populations (U.S. Department of the Interior 1998). Many bull trout local populations are isolated and fragmented in headwater areas, creating a patchwork of remnant populations. This patchwork of remnant populations has become progressively more isolated as distance between patches has increased. Remnant or regional populations that lack the connectivity to refound or support local populations lend these populations to greater likelihood of extinction (Rieman and McIntyre 1993; Rieman et al. 1997).

- Based on population genetics, there is more divergence among bull trout than among salmon (Leary and Allendorf 1997), indicating less genetic exchange among bull trout population. The recolonization rate for bull trout is very low and recolonization may require a very long time, especially in light of the man-made isolation of various bull trout populations.

- The salmon life cycle has a saltwater or ocean component with a very large prey base available for sub-adult and adult fish. Adult salmon are not freshwater piscivores (Groot and Margolis 1991). Adult migratory bull trout are a freshwater piscivore, an apex predator, and an opportunistic feeder. At all life history stages they need access to an adequate prey base, which for adults necessitates habitats accessible through migratory corridors with suitable temperature, habitat complexity, and passage.

- Top carnivores, such as bull trout, are more extinction prone than species lower down on the food chain. They have lower total populations sizes and environmental disturbances tend to affect species more at the top of the food web than at lower trophic levels (M. Gilpin *in litt*. 1996).

- All North American salmon species die after spawning (Groot and Margolis 1991). Bull trout are consecutive or alternate year spawners and where there is an adequate prey base, they may gain weight during the winter (Elle 1995; D. Ratliff, Portland General Electric, pers. comm. 1998). When the kokanee population in Lake Billy Chinook experienced significant declines, the bull trout redds in tributary systems also declined. This indicates a possible relationship between prey base and consecutive or alternate year spawning strategy where the prey base may not be adequate for post-spawners to rebuild their gametes (S. Thiesfeld, Oregon Dept. of Fish and Wildlife, pers. comm. 1998).

- Bull trout have delayed sexual maturity (5-7 years) (Rieman and McIntyre 1993). Late age at maturity and slow growth likely will result in prolonged recovery time for bull trout.

- Bull trout can live 20+ years (G. Haas, University of British Columbia, pers comm. 1998). Because larger fish are more fecund than smaller fish, their contribution to a population may be disproportionate to their abundance. Elimination of the larger, older fish, whether from poaching, harvest or loss of suitable over-wintering habitat, lowers the potential growth rate of a population and makes it more vulnerable to other factors (M. Gilpin *in litt*. 1996).

TEMPERATURE

Problem Assessment

Bull trout distribution is strongly influenced by water temperature (Ratliff 1992; Rieman and McIntyre 1993, 1995; Bonneau and Scarnechia 1996; Buchanan and Gregory 1997; Lee et al. 1997), and they are found to be associated with the coldest stream reaches in basins (Lee et al. 1997). Researchers recognize temperature more consistently than any other factor influencing bull trout distribution (Rieman and McIntyre 1993). Thermal barriers have contributed to the disruption and fragmentation of bull trout habitat (Buchanan et al. 1997; EPA 1997; WDFW 1997; MBTSG 1998). Increases in stream temperatures can cause direct mortality, displacement by avoidance (Bonneau and Scarnechia 1996), or increased competition with species more tolerant of warm stream temperatures (Rieman and McIntyre 1993; Craig and Wissmar 1993 cited in 62 FR114 Proposed Rule; MBTSG 1998). Brook trout, which can hybridize with bull trout, may be more competitive than bull trout and displace them, especially in degraded drainages containing fine sediment and higher water temperatures (Clancy 1993; Leary et al. 1993).

Many areas within the species range have temperature standards that exceed levels identified as necessary to support various life stages of bull trout (Montana Dept. of Health and Environmental Sciences 1994; Oregon Dept. of Environmental Quality 1996; EPA 1997; Washington Dept. of Ecology 1998). For example, in Washington, the current State temperature criteria are inadequate to protect bull trout (WDOE 1998); in 1996, EPA disapproved Idaho's standards after concluding they were inconsistent with the Clean Water Act (EPA 1997); and in Oregon, as recently as 1995, bull trout and other cold water species were not protected by Oregon's threshold temperature standards (Buchanan and Gregory 1997). Oregon is currently in the process of adopting specific temperature standards for bull trout streams. These temperature standards developed for Idaho and Oregon only address spawning and rearing areas of bull trout streams, standards have not yet been developed for migratory corridors, over-wintering, or sub-adult rearing.

Biological Needs

Bull trout and other char often thrive in waters too cold for other salmonid species (Balon 1980). Although preferred water temperatures vary by life history stage, consistently cold water is required at all critical life history stages (spawning, incubation, rearing, overwintering).

- Spawning is initiated in the fall as water temperatures drop to 9-10°C (48-50°F) (McPhail and Murray 1979; Fraley and Shepard 1989), although the threshold for char spawning in north Puget Sound is believed to be 8°C (46.5°F) (Kraemer 1994).

- Survival of incubating eggs has been found to be optimal at constant exposure to 2-4°C (35.5-39°F) water, with mortality increasing markedly above 8°C (46.5°F) (McPhail and Murray 1979; Weaver and White 1985). From egg deposition to emergence, juvenile bull trout may reside 220 or more days in the gravel.

- Optimal juvenile rearing temperatures range between 4-10°C (39-50°F) (Buchanan and

Gregory 1997).

- For migratory corridors, bull trout typically prefer water temperatures ranging between 10-12°C (50-53.5°F) (McPhail and Murray 1979; Buchanan and Gregory 1997). However, bull trout will migrate in stream segments with higher water temperatures and are found in areas offering thermal refuge, such as confluences with cold tributaries (Swanberg 1997).

Temperature criteria are based on the consecutive 7-day average daily maximum temperature standards consistent with EPA water quality standards for Idaho (EPA 1997).

Objectives

- Maintain or restore temperature regimes that support bull trout at all life-history stages, including historic migratory corridors that will be necessary for reconnecting fragmented subpopulations. The overall objective is to reestablish or maintain the natural patterns and ranges of temperature within individual bull trout basins.

- Maintain or restore cold water temperature contributions of intermittent and non-fish bearing tributaries to bull trout streams.

- Decrease the risk of invasion and displacement by introduced species by preventing increases in water temperature.

- Provide or maintain sufficient thermal refugia (deep pools, tributary confluences, groundwater influences) to support residence throughout summer months.

- Protect all ground water sources (seeps, springs, wetlands, hyporheic zone) that may influence stream temperatures.

- Maintain or restore water quality within a range that maintains the biological, physical, and chemical integrity of bull trout watersheds.

Caution Zone

Until more information is available for microclimate and hyporheic zone contributions to stream temperature, the caution zone is the 100-year floodplain plus one site potential tree height distance, including tributaries that provide or have potential to provide thermal refugia, wetlands, and groundwater (seeps and springs) sources that provide cool water (USDA et al. 1993).

In the last decade, a previously unrecognized habitat, the hyporheic zone, has been identified as a critical component of many streams and rivers, influencing both water temperature and nutrients (Edwards 1998; C. Frissell, University of Montana, pers. com. 1998). Defining caution zones to include the extent of hyporheic zone disturbances would ensure that this critical ecosystem process is included in management decisions. However, it is currently difficult to delineate hyporheic zone boundaries as well as to measure the effects of land management activities on these important groundwater/surface water interaction zones.

USDA et al. (1993) indicated that stream buffers may need to be wider for maintaining microclimate than for other riparian functions. The contribution of microclimate to stream temperature is another area needing further research.

Recommended Actions

Because bull trout are very sensitive to water temperature, recommended actions need to be conservative to protect this critical habitat element. Factors that may be useful in modifying these recommendations to account for site specific conditions include elevation, aspect, geomorphology, groundwater and hyporheic influence, size of contributing non-fish bearing and intermittent streams, and baseline watershed conditions.

- Sediment: Because sedimentation can increase water temperature of streams (i.e., by filling pools and reducing channel depth, increasing riffle area and channel width, which results in increased solar insolation [MBTSG 1998]), land management activities (upland and riparian) that contribute sediment to streams should be identified and modified to eliminate increased levels of sedimentation.

- Shade: Maintain or restore optimal and preferred water temperatures by retaining adequate canopy and streamside vegetation through restricting harvest or management activities that reduce shade below 100% or below the level of shade necessary for maintaining cold water in both fish bearing and non-fish bearing streams, including headwaters.

- Groundwater: Protect sources and prevent alteration of groundwater flow by limiting new withdrawals and maintaining or restoring historic groundwater flows in both the floodplain and deep aquifer. Avoid all management activities that may alter groundwater input to spawning and rearing streams, such as draining or filling wetlands, placing roads in sensitive sites such as seeps and springs, etc.

- Hydro System Operation: Use selective withdrawals to provide optimal or preferred temperatures for appropriate bull trout life history stages. Provide instream flow to maintain optimal temperature regimes throughout the year in occupiable habitat and historic migratory corridors that will be necessary for reconnecting fragmented subpopulations.

- Diversions: Discontinue or modify water diversions that result in thermal barriers to passage or increased water temperatures above optimal or preferred levels.

- Point Source Discharges: Avoid or modify discharges that elevate water temperatures in current and occupiable bull trout habitat (need to determine reasonable mixing zone).

- Non-point Source Returns: Control returns so that they do not limit the distribution of bull trout by altering temperature regimes (i.e., develop and implement Best Management Practices (BMPs)).

- Altered Hydrography: Modify activities in both riparian and upland areas that alter flow regimes and may indirectly cause water temperature to exceed optimal or preferred temperatures of bull trout.

- Microclimate: Because air temperature and relative humidity can influence stream temperature, seek to maintain or restore riparian conditions at a level that approaches the natural microclimate of undisturbed systems.

Performance Indicators

- Net increase in number of stream miles with optimal water temperatures supporting various life stages of bull trout.

- Land use changes and BMPs implemented to address thermal barriers, and results of the evaluation of the efficacy of the activities.

- Percent stream network containing a continuous riparian buffer of mature forest.

- Measured increase in effective canopy cover.

- Measured decrease in seasonal and daily variation of water temperature.

- Measured decrease in 7-day average daily maximum temperature toward optimal or preferred temperature range for bull trout.

- No increase or measurable decrease in wetted stream area as a consequence of sedimentation.

- Implementation of instream flow agreements that adequately support all life stages of bull trout.

- Net increase in stream miles below hydroelectric and other storage facilities with seasonally optimal or preferred temperatures.

- Net increase in stream miles below water diversion structures with seasonally optimal or preferred temperatures.

- Optimal or preferred temperatures below <u>point source</u> discharges.
- Optimal or preferred temperatures below <u>non-point source</u> discharges.

- Development of performance indicators for microclimate through research and monitoring of changes in soil and air temperature, soil moisture, relative humidity, wind speed, and radiation (Chen 1991 cited in USDA et al. 1993).

- Development of performance indicators for groundwater through research and monitoring of the influence of riparian vegetation, roads, and water withdrawals.

- No net increase in channel width to depth ratio, a measure of channel widening that can affect stream temperatures.

- No net decrease in pool frequency or maximum depth.

- Decrease in negative effects of roads as indicated by: number of miles of road removed in a bull trout watershed expressed in miles per square miles (mi/mi^2); number of miles of roads that are storm proofed or resurfaced; miles of roads removed or relocated to aid recovery of riparian processes.

HABITAT COMPLEXITY

Problem Assessment

Habitat Complexity is one of the five characteristics that Rieman and McIntyre (1993) discuss as important for bull trout, although it is difficult to provide a definition of habitat complexity that is specific and quantifiable. As a result of human activities, habitats have been simplified. There is a need for research to develop performance indicators that identify success in reducing habitat homogeneity. Land management activities can alter processes that create and maintain riparian and aquatic habitats, often resulting in reductions of habitat complexity and the diversity of aquatic species (Elmore and Beschta 1987; USDA et al. 1993). In watersheds containing bull trout, changes in habitat features associated with reductions in habitat complexity include decreases in: large woody debris (LWD), pool quality, channel stability, substrate quality, groundwater inflows, and suitable habitat serving as corridors between habitat patches (e.g., resulting from increases in water temperature [MBTSG 1998]). In addition, habitat changes can alter species abundances and compositions. Where non-native species such as eastern brook trout, lake trout, rainbow trout, and brown trout occupy bull trout watersheds, bull trout populations have declined.

Large pools, consisting of a wide range of water depths, velocities, substrates, and cover, are characteristic of high quality aquatic habitat and an important component of channel complexity. Moreover, bull trout are associated with large, deep pools (Watson and Hillman 1997). Large pools have been lost in many tributaries of the Columbia River in the past 50 years (Sedell and Everest 1991; McIntosh et al. 1994; USFS 1996). Overall, there has been a 58 percent reduction in the number of large, deep pools in resurveyed streams in National Forests within the range of the northern spotted owl in western and eastern Washington (USDA et al. 1993). A similar trend is apparent on private lands in coastal Oregon where large, deep pools decreased by 80 percent (USDA et al. 1993). In western Washington, Bisson and Sedell (1984), reported a similar loss of pools in basins with moderate to intensive levels of timber harvest. Historical grazing practices in eastern Oregon have contributed to degraded riparian zones with reduced summer flows in streams, unstable and eroding stream banks, and reduced productivity of fish and wildlife (Elmore and Beschta 1987). Reduction of wood in stream channels, either from present or past activities, generally reduces pool frequency, quality, and channel complexity (Bisson et al. 1987; House and Boehne 1987; Spence et al. 1996). Road construction and timber harvest on unstable slopes can result in the loss of pools due to mass wasting and sedimentation (Janda et al. 1975; Morrison 1975; Swanson and Dyrness 1975; Ziemer and Swanston 1977; Betcha 1978; Ketcheson and Froehlich 1978; Marion 1981; Swanson et al.1981; Coats 1987; Kelsey et al. 1981; Madej 1984; Nolan and Marron 1985; Grant and Wolff 1991).

Large woody debris in streams enhances the quality of habitat for salmonids and contributes to channel stability (Bisson et al. 1987). It creates pools and undercut banks, deflects streamflow, retains sediment, stabilizes the stream channel, increases hydraulic complexity, and improves feeding opportunities (Murphy 1995). By forming pools and retaining sediment, LWD also helps maintain water levels in small streams during periods of low stream flow (Lisle 1986 cited in Murphy 1995).

Cover is another important component of habitat complexity that is used by bull trout at all life-history stages. Cover can include woody debris, overhanging vegetation, undercut banks, cobble and boulder substrate, water depth and turbulence, and aquatic vegetation (Graham et al. 1981; Pratt 1984; Hoelscher and Bjornn 1989; Goetz 1991; Pratt 1992; Murphy 1995). Past land management activities have reduced cover through reductions in riparian vegetation and associated decreases in woody debris recruitment, declines in pool size and frequency, stream clean-up activities that removed woody debris, splash dams, and declines in shrub lands (Narver 1971; Sedell and Luchessa 1982; Bisson and Sedell 1984; NMFS 1991; Sedell et al. 1991; Lee et al. 1997).

Other factors relevant to bull trout habitat complexity are the hydroelectric dams on the Columbia River and its tributaries and agricultural, hatchery, and public water impoundments such as ditches and diversions.

Biological Needs
Complex aquatic habitats are necessary to accommodate the diverse needs of various salmonid species (Murphy 1995; Spence et al. 1996). Complex habitats not only provide salmonids with critical habitat for all life-history stages in freshwater, but provide refuges from environmental variability (e.g., extreme flows) and stochastic events (e.g., catastrophic fires), buffering populations from the effects of environmental perturbations (Sedell et al. 1990; Rieman and McIntyre 1993). Because most bull trout spend their entire life in freshwater, they are more sensitive to habitat disturbance than anadromous salmonids (Balon 1980; Rieman and McIntyre 1993). Bull trout are strongly associated with various components of habitat complexity, including cover, LWD, side channels, undercut banks, boulders, pools, and interstitial spaces in coarse substrate (Rieman and McIntyre 1993; Jakober 1995; MBTSG 1998). Anadromous bull trout spend part of their life in fresh water, but may be sensitive to a set of other variables while occupying the ocean and estuaries. More information is needed about these variables. Water quality indicators such as temperature and turbidity, and water quantity are variables that may be important for bull trout returning to their natal streams.

Several life history features of bull trout make them particularly sensitive to activities directly or indirectly affecting stream channel integrity and natural flow patterns (MBTSG 1998). Examples of these life history features and their association with habitat complexity are:

- An extremely long period from egg deposition to fry emergence from the gravel (220 days or more during winter and early spring);
- Strong association of juvenile bull trout with streambed cobble and substrates low in fine sediments;
- Extensive spawning and overwintering migrations of adult bull trout, which require a large network of suitable freshwater habitat with migratory corridors;
- Use of deep pools by both adults and juveniles for cover and thermal refuge;
- Selection of redd sites by adults in low gradient reaches and in areas of groundwater influence (C. Baxter, University of Montana, pers. comm. 1998). The lower gradient sites are sometimes located adjacent to channel roughness elements (LWD and boulders) within stream reaches having overall moderate to steep grades;
- Use by both adults and juveniles of areas with reduced water velocity, such as side

channels, stream margins, and pools (Watson and Hillman 1997; MBTSG 1998).

Objective

- Maintain and restore floodplain, riparian, and channel processes, including hydrologic regime, sediment inputs and transport, channel configurations, and bank characteristics, to resemble watershed-specific historic or expected conditions to the greatest extent possible.

Caution Zone

In streams, channel morphology is largely influenced by geomorphic setting and riparian vegetation (Sullivan et al. 1987 cited in Murphy 1995), and by climate (Leopold 1994) such as the frequency of rain and snow. Other factors influencing channel morphology are discharge, sediment load, bank characteristics, and solid structures, such as LWD, bedrock, and boulders (Murphy 1995). The upstream head of steep channels and other steep hill slope areas are common initiation sites of debris slides and debris flows (Dietrich and Dunne 1978; Grant et al. 1990; Selby 1993). Headwater riparian areas need to be protected, so that adequate materials contributing to complex habitat downstream would be available when debris slides and flows occur (USDA et al. 1993).

Because the natural processes (erosion, fire, flood, mass wasting, wind, avalanches) in a watershed produce the components that maintain complex aquatic habitat, the whole watershed may be the caution zone. At the very least, the caution zone is the 100-year floodplain plus 150 feet and all unstable or potentially unstable slopes. This applies to all streams, fish bearing, non-fish bearing, and intermittent in bull trout watersheds.

Recommended Actions

- Identify areas minimally affected by land management activities, and evaluate riparian and channel processes and structure to serve as a reference for similar geomorphic areas altered by land management activities.

- Identify channel reaches in bull trout watersheds that are at risk of degradation or that are not appropriately functioning for water and sediment discharge (at all levels of flow). For example, use scientifially sound survey techniques to identify where streambanks are actively eroding and stream channels are braiding, aggrading, downcutting, or are channelized; or identify and locate water diversions, withdrawal sites, and ditches to determine adequate flows or other activities to prevent habitat degradation, especially at low flow and in late summer.

- Identify and relocate recreational activities (i.e., camping, rafting, etc.) that affect bull trout by causing changes in bank characteristics and removing or altering instream woody debris.

- Identify bank characteristics, instream channel characteristics, and solid structures needed to maintain channel complexity and habitat features important for bull trout. This may include an analysis of geologic land forms and forest stand types to help develop baseline data and goals for habitat characters such as LWD or pools per mile. This data is currently lacking in most areas.

- Maintain or restore natural bank characteristics (riparian vegetation, woody debris, sinuosity), solid structures (boulders, large wood), and instream channel characteristics (large pools, side channels) that are needed for floodplain and channel function across all land ownerships. This may include an analysis of grazing allotments, roads, culverts, past timber harvest areas, or dispersed and developed recreation.

- Identify areas where roads, railroads, utility corridors, bridges, or culverts restrict floodplain and channel functions, and habitat complexity; and develop a watershed transportation plan using recommendations above.

- Identify hydropower and water diversion projects where daily fluctuations in flows results in the periodic dessication of the wetted perimeter of stream channel. Daily fluctuations in flows could result in the dessication of redds, stranding of bull trout and other species of fish that may serve as the prey base for bull trout, and the reduction in stream productivity, including all trophic levels.

- Identify and repair, relocate, or remove roads that contribute signigicantly to sediment input. Priorities may be designed around sections of roads that are particularly damaging to riparian areas, stream channels, and water quality.

- Monitor watersheds, stream reaches, and project areas to determine if restoration of floodplain and channel function is occurring.

- Provide for recruitment of woody debris from both occupied and upstream areas (including non-fish bearing and intermittent streams). According to USDA et al. (1993), LWD recruitment in an old growth forest is provided by a riparian buffer of 2/3 to one site potential tree height. Geology, landforms, and natural processes play an important role in the contribution of LWD in many locations along the riparian corridor.

Performance Indicators

- Number of primary pools (>3 feet deep) per mile expected, based on specific watershed conditions. For example, the number of primary pools for a specific watershed can be developed by comparisons with an unmanaged watershed with similar features and of similar size.
- Number and size of pieces of woody debris expected, based on specific watershed and reference reach conditions. For example, the amount of LWD for a specific watershed can be determined by comparisons with an unmanaged watershed with similar features and of similar size.

- Width/depth ratios expected for the channel type, so that the channel has an appropriate sinuosity with stable stream banks (e.g., armoring by vegetation, wood, bedrock, or other substrates), and is not aggrading (causing a wider, braided, and shallower channel) or down cutting (causing loss of floodplain features) at accelerated rates or outside of its natural capacity.

- Pool/riffle ratio appropriate for the channel type. For example, this can be determined using Rosgen's Channel typing systems, or other hydrologic models that incorporate natural sinuosity, geology, gradients, etc.; or extrapolated from other similar watersheds with similar characteristics.

- Floodplains functioning well to distribute high flows, retain sediment, and maintain water tables.

- Length of miles of channel restored (track over time). Some analysis of past projects needs to occur to determine effectiveness for bull trout.

- Area of floodplain restored (track over time).

- Number of barriers to floodplain and channel connectivity (including but not limited to: roads, culverts, bridges, railroads, dams, diversions, manmade ponds) that are removed, relocated, or modified to not disrupt floodplain or channel complexity.

- Acres of riparian forests vegetation restored to allow for bank stability, LWD, and floodplain functions.

- Area or number of beaver ponds present that resembles natural levels. If unknown, try to determine if beavers are or historically were part of the watershed ecosystem and estimate their contribution to off channel areas before reintroduction occurs.

CONNECTIVITY

Problem Assessment
The Service's bull trout listing team identified 141 isolated bull trout subpopulations in the Columbia River distinct population segment (DPS) and 7 subpopulations in the Klamath River DPS (Service 1998). Overall, there is a lack of connectivity among subpopulations. Isolating mechanisms that have resulted in the loss of migratory bull trout (Rieman and McIntyre 1993) include, physical passage blockages at mainstem impoundments that have isolated whole subbasins (Brown 1992; Pratt and Huston 1993; Rieman and McIntyre 1995), water diversions preventing spawners access to formerly suitable habitat, and thermal passage barriers at both tributary and mainstem scales.

Currently, fish passage research, management, and facility modification efforts at mainstem projects are focused on salmon and steelhead. Most projects provide upstream adult passage facilities (designed to pass steelhead and salmon), but the development of downstream passage of migrating steelhead kelts (or adult bull trout) have not been developed, and efficiency of passing these individuals through juvenile passage facilities or via spill has not been thoroughly examined (NMFS 1998). Other natural and artificial barriers may prevent upstream or downstream movement of juveniles or adults at some locations or at certain times of the year. Intervening areas of poor habitat quality may also limit dispersal of resident forms. Conversely, some man-made barriers may have unintentionally benefitted bull trout by preventing invasion of non-native species such as introduced brook trout or lake trout. Habitat fragmentation and the subsequent isolation of bull trout subpopulations is a key factor in the current threatened status of bull trout in the Klamath River and Columbia River basins (Lee et al. 1997; Rieman et al. 1997). Historically current bull trout subpopulations were well connected throughout the basins (Lee et al. 1997). Many bull trout subpopulations are currently confined to smaller headwater streams that have been minimally affected by human caused habitat alterations.

Small, isolated subpopulations are more likely than larger subpopulations to go extinct over long time scales due to stochastic events (e.g., landslides, catastrophic fires, and floods). Further isolation of subpopulations in shrinking habitat will probably lead to increasing rates of extirpation not proportional to the simple loss of habitat area (Lee et al. 1997). Even with no further habitat loss, extirpation may be likely for many remaining isolated subpopulations (Lee et al. 1997; Rieman et al. 1997). As subpopulations become fragmented and isolated, local extinctions become permanent, making the extirpation of other subpopulations more likely (Rieman and McIntyre 1993). Meffe and Carrol (1994) cautioned against managing for unnaturally small populations, and urge that gene flow among historically connected populations should continue at historical rates.

Irrigation diversions, culverts, and degraded mainstem habitats have eliminated or seriously depressed migratory bull trout, effectively isolating resident subpopulations in headwater tributaries (Brown 1992; Ratliff and Howell 1992; Rieman and McIntyre 1993; Thurow et al. 1997). Loss of suitable habitat through watershed disturbance may also increase the distance between suitable or refuge habitats and strong subpopulations, thus reducing the likelihood of effective dispersal (Frissell et al. 1993).

Biological Needs
Bull trout is a wide-ranging species with different habitat requirements at specific life history stages (MBTSG 1998). Migratory corridors provide the necessary connection between bull trout spawning, juvenile rearing, sub-adult rearing, and adult over-wintering and foraging areas (Rieman and McIntyre 1993). Disruption of migratory corridors can increase stress, reduce growth and survival, and potentially lead to the loss of the migratory life-history types (Rieman and McIntyre 1993). In general, it is necessary to provide bull trout access to a large, connected, high quality, freshwater habitat that includes cool temperature, deep pools, large wood, low substrate embeddedness, unimpaired flow regime and channel floodplain interactions.

Movement is also believed to be important to the persistence and interaction of local populations within the larger subpopulations (Rieman and McIntyre 1993). Movement of individuals allows for the full expression of life history forms and survival strategies (Rieman and Clayton 1997). Furthermore, within the Columbia River basin, bull trout persistence will require improved connectivity among the 141 subpopulations that are not historically isolated by natural barriers or that are not currently at risk of invasion by non-native species. Enhanced connectivity for migratory life forms within bull trout subpopulations is needed to encourage population refounding and to allow gene transfer at historical rates.

Objectives

- Protect current bull trout refugia. Avoid activities or their negative effects that would further fragment habitat, reduce habitat patch size, or further isolate remaining bull trout subpopulations.

- Maintain or improve connectivity among occupied habitats and refugia by removing human-caused physical, thermal, and chemical barriers within and among isolated subpopulations in areas not at risk of invasion by non-native species (e.g., introduced brook trout, lake trout).

- Improve connectivity among occupied habitats and refugia by providing both upstream and downstream passage of bull trout migrants at mainstem hydroelectric and flood control projects.

- Restore occupiable habitat, particularly in low gradient unconstrained channels that often serve as migratory corridors or seasonal habitats for specific life-history stages of bull trout. Historically, alluvial floodplain reaches were highly productive for salmonids, and bull trout occur significantly more often in streams of alluviated lowlands and valleys than in other areas (Watson and Hilman 1997).

Caution Zone
The area of concern for improved connectivity is the watershed, basin, or largest hydrologic unit that matches bull trout distribution within a DPS or historical subpopulation. Further research into interactions among bull trout subpopulations may help refine the appropriate scale for understanding connectivity issues.

Recommended Actions

- Avoid activities that would fragment bull trout habitat, reduce habitat patch size, or further isolate remaining bull trout subpopulations, unless the activity can be modified to prevent such effects.

- Identify, determine the cause of, and correct or prevent, water quality related passage problems in bull trout watersheds.

- Identify and correct locations of heated effluent discharges in basins that may prevent or hinder migration.

- Restore streams or portions of watersheds with degraded instream and riparian habitats that may be limiting movement or dispersal of bull trout between isolated spawning and rearing areas (emphasize passive approaches to restoration).

- Identify specific locations of complete and partial physical passage barriers in occupied and occupiable bull trout habitats (e.g., undersized or improperly placed culverts) and modify human-caused barriers to facilitate year round passage.

- Identify the subset of human-caused barriers that are removable without risk of non-native introductions, then remove or modify those barriers to allow for juvenile and adult fish passage.

- Determine upstream and downstream bull trout passage requirements at mainstem hydroelectric and flood control projects.

- Coordinate conservation planning efforts in and between bull trout watersheds in order to maximize basin level connectivity.

- Prioritize inventories and restoration opportunities to provide for conservation of bull trout and their habitat.

Performance Indicators

- Number and type of human-caused physical barriers removed or upgraded to allow two-way passage of bull trout (relate to total number of identified barriers of each type within a watershed and prioritize the removal of the most detrimental barriers).

- Appropriate precautions and actions taken in instances where the threat of introduced species effectively limits passage remediation opportunities (in some cases this may mean no action).

- Number of thermal or chemical barriers identified and corrected.

- Riparian and upslope land use changes instituted to address thermal, chemical, or other types of passage barriers to bull trout.

- Number of priority sites identified for passive restoration (large wood, pools, temperature, etc.).

- Number and type of passive restoration projects specifically designed to improve bull trout habitat.

- Percentage of active restoration and barrier modification or removal projects monitored for effectiveness (and efficacy of specific projects evaluated).

SUBSTRATE COMPOSITION AND STABILITY

Problem Assessment
Bull trout show strong affinity for stream bottoms and a preference for deep pools of cold water streams, lakes and reservoirs (Goetz 1989). Because of this strong association with the stream bottom throughout their life history, they can be adversely affected by human activities that directly or indirectly change substrate composition and stability.

Sedimentation reduces pool depth, alters substrate composition, reduces interstitial space, and causes channels to braid (Rieman and McIntyre 1993 citing others). For example, in National Forests within the range of the northern spotted owl in western and eastern Washington, there has been a 58 percent reduction in large, deep pools as a result of sedimentation and loss of pool-forming structures such as boulders and large wood (USDA et al. 1993). In the Oregon and Washington portions of the Columbia Basin outside the range of the northern spotted owl, the frequency of large pools within managed watersheds have decreased by 28 percent over the past 50 years (McIntosh et al. 1994). Sedimentation from extensive and intensive land use activities (timber harvest, road building, livestock grazing, agriculture, and urbanization) is recognized as a primary cause of habitat degradation in the range of west coast steelhead and west coast chinook salmon (NMFS proposed rules: 62FR43937, 63FR11798, and 63FR11482). Impoundments and diversions have altered natural sediment transport processes, causing deposition of fine sediments in slackwater areas, reducing flushing of sediments through moderation of extreme flows, and decreasing recruitment of coarse material (including spawning gravels) downstream of the obstruction (Spence et al. 1996).

According to Rieman and McIntyre (1993), "Some substrates are more likely to accumulate fine sediments than others, and some bull trout populations probably are more sensitive than others. In the absence of detailed local information on population and habitat dynamics, any increase in the proportion of fines in substrates should be considered a risk to productivity of an environment and to the persistence of associated bull trout populations." Bull trout tend to spawn and rear in headwater streams within mountainous terrain that are influenced by inputs and transport of sediment via a range of natural sources, so any additional inputs of sediment from land management actions are cause for concern.

Biological Needs
For spawning, bull trout prefer loose, clean, gravel (McPhail and Murrey 1979; Fraley and Shepard 1989). Spawning occurs primarily in gravels and cobbles (Baxter and McPhail 1996). Due to the bull trout's extended residency in the gravel (220+ days from egg deposition to emergence), eggs, alevins, and fry are highly vulnerable to bedload movements and deposition of fine sediments. Unembedded substrate provides an important cover element for juvenile bull trout, especially in areas lacking other forms of cover (Goetz 1989; Pratt 1992; Baxter and McPhail 1996; Thurow 1997). Juvenile bull trout densities decrease with increasing embeddedness of substrate (Shepard et al. 1984; Enk 1985; Pratt 1992).

Objectives
- To the degree possible, maintain or restore the pre-exploitation sediment regimes of

aquatic ecosystems.

- Reduce the effects of management activities on sediment delivery to stream channels in sensitive reaches (spawning and rearing areas, less than 3% gradient) including percent inter-gravel fine sediment in spawning areas.

- Maintain or restore channel stability (MBTSG 1998).

- Maintain or restore pocket water and pools.

Caution Zone
Because coarse and fine substrate may come from any part of the watershed, and its delivery is influenced by basin hydrology, the entire watershed is the caution zone.

Recommended actions

- Identify and modify land management activities (upland and riparian) that have the potential to contribute sediment to spawning and rearing areas above natural levels to prevent elevated levels of sedimentation.

- Identify and modify land management activities (upland and riparian) that have the potential to reduce pocket waters and pools in rearing habitat should be identified and modified to prevent negative effects.

- Maintain or provide adequate peak flows below hydropower projects to adequately flush fine sediments.

- Provide greater protection for spring-fed systems than surface-water fed systems, because these systems often lack flushing flows and effects of sedimentation will be long lasting.

- Maintain or restore natural surface flows and local runoff patterns in order to avoid unnatural bedload movements as a result of extreme peak flows or formation of anchor ice.

- Avoid new road construction in areas vulnerable to mass wasting and in areas that may initiate or exacerbate stream bank erosion.

- Identify, repair, remove, or relocate roads that are in areas susceptible to mass wasting and are likely to cause bank failures.

- Identify, repair, remove, or relocate roads and culverts that negatively affect hydraulic processes, contribute elevated sediment levels, or are subject to failure. This includes periodic inspection and maintenance of culverts to remove debris and prevent erosion of fill around the culverts.

- Avoid activities that directly alter the streambed in spawning areas.

- Provide adequate riparian buffers to capture sediments that result from land management activities.

- Provide adequate amounts of woody debris to capture instream sediment and trap spawning gravels.

- Modify surface disturbing land management practices to prevent or reduce sediment delivery to sensitive bull trout habitats, especially spawning and juvenile rearing areas.

- Conduct further research on how sediment affects juvenile rearing capacity (summer rearing habitat, food production habitat, overwintering habitat).

- Conduct further research on the influence of groundwater upwellings on sediment levels in bull trout redds during incubation.

- Conduct further research on the effects of bed scouring on habitat suitability.

- Coordinate public and private land owner development of access and travel management plans that will minimize effects of roads in bull trout watersheds.

Performance Indicators

- Percentage of roads storm-proofed, or removed in a bull trout watershed, especially in those areas susceptible to mass wasting and areas within the riparian zone.

- Monitoring of bedload movement in sensitive areas (spawning and rearing).

- Percent decrease in eroding stream banks.

- Decrease or no net increase in percent fines (substrate score, core samples).

- Substrate composition and embeddedness.

- Pool:riffle ratio maintained or increased.

- Amounts of LWD.

- Sediment budget results.

- Number or percentage of poorly installed or sized culverts removed or replaced.

- Implementation of instream flow agreements that adequately protect bull trout habitat.

- Implementation of ecoregion or ecotype specific riparian conservation strategies.

- Decrease or no net increase in soil loss from surface disturbing land management activities.

- Indices of channel stability (e.g., changes in channel form, scour depth as indicated by scour chains, substrate transport relative to reference stream reaches).

- Maintenance of adequate peak flow events, reflected in hydrograph, to mimic natural rates of deposition of coarse sediments and flushing of fine sediments in stream channels.

- Proportion of stream miles (streambanks and riparian areas) that are protected from the effects of livestock (e.g., fenced or enclosed).

ROADS

Problem Assessment

Roads are a prevalent feature on managed forested and rangeland landscapes, and can have numerous negative effects to bull trout. The aquatic assessment portion of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) provides a detailed analysis of the relationship between road densities and bull trout status and distribution (Quigley et al. 1997). The following problem assessment draws on information contained in that report. Bull trout are less likely to use streams in highly roaded areas for spawning and rearing, and where found in highly roaded areas are less likely to be at strong population levels. Bull trout strongholds in the Interior Columbia River Basin showed a very strong (P=0.0001) negative correlation with road densities. The average road density in bull trout strongholds was 0.45 mi/mi^2, which is considerably less than the standard of 2-3 mi/mi^2 reported as adequate for populations of anadromous salmonids. Bull trout populations classified as "depressed" had an average watershed road density of 1.4 mi/mi^2 and bull trout typically were absent at an average road density of 1.7 mi/mi^2. Although some variability in these patterns was apparent the association was strong, suggesting that bull trout are exceptionally sensitive to the direct, indirect, or cumulative effects of roads.

Quigley et al. (1997) state that,

> "The effects associated with roads reach beyond their direct contribution to disruption of hydrologic function and increased sediment delivery to streams. Roads provide access, and the activities which accompany access magnify the negative effects on aquatic systems beyond those due solely to roads themselves. Activities associated with roads include, but are not limited to, fishing, recreation, timber harvest, livestock grazing, and agriculture. Roads also provide avenues for stocking non-native fishes. Unfortunately, we do not have adequate broad-scale information on many of these attendant effects to identify their component contributions accurately. Thus we are forced to use roads as a catch-all indicator of human disturbance."

Reeves and Sedell (1992) state that,

> "Reduction of total miles of forest roads is an important component of watershed restoration. This is because there is a legacy of roads built without adequate consideration of requirements for drainage or placement necessary to maintain fisheries and other aquatic values. High road densities may result in increased frequency of debris avalanches, which can cause massive sediment entry into fish bearing streams. Many miles of roads must be "put to bed", by pulling culverts, resloping road beds, pulling fill and replanting. Roads should be relocated out of floodplains where feasible. Road mileage for new harvest units should be minimized; roadless areas should remain roadless and should be harvested by other means where possible."

Biological Needs

Bull trout need streams and lakes that are cold, clean, complex and connected (MBTSG 1998). Roads have the potential to adversely affect all of the habitat components discussed in this

Guidance: water temperature, substrate composition and stability, habitat complexity, and connectivity. Roads may also isolate streams from riparian areas, causing a loss in floodplain and riparian function. Furniss et al. (1991) state that,

> "Roads may have unavoidable harmful effects on streams, no matter how well they are located, designed or maintained...Roads modify natural hillslope networks and accelerate erosion processes. These changes can alter physical processes in streams, leading to changes in stream flow regimes, sediment transport and storage, channel bank and bed configurations, substrate composition, and stability of slopes adjacent to streams. These changes can have significant biological consequences that affect virtually all components of stream ecosystems."

Increased sediment transport to streams is one of the most frequently cited effects of roads (Gibbons and Salo 1973; Reid and Dunne 1984; Everest et al. 1987; Swanston 1991). Increased levels of sedimentation often have adverse effects on fish habitats and riparian ecosystems, and fine sediment deposited in spawning gravels of bull trout can reduce survival of eggs and developing alevins (Weaver and White, 1985; Weaver and Fraley 1991; Cross and Everest 1995). Important habitat components for juvenile bull trout such as benthic invertebrate abundance, food availability, interstitial spaces in the substrate, and pools may be reduced or lost due to increased levels of sediment (Megahan et al. 1980; Shepard et al. 1984; Everest et al. 1987; USDA and USDI 1994). Runoff from road surfaces can degrade water quality not only by increasing fine sediment, but also total dissolved solids (TDS) and nutrient concentrations.

Various effects of roads may combine to alter the hydrologic response characteristics of streams. Roads and roadside ditches may substantially increase the stream drainage network. Roads also intercept groundwater and significantly compact forest soils, resulting in increased surface runoff. Any of these changes may contribute to increased stream peak flows. During normal high flow events, the added stream power may help mobilize coarse bedload (boulders, cobble, gravel) (Furniss et al. 1991). Depending on magnitude and timing, this has the potential to cause physical displacement and direct mortality of bull trout eggs and juveniles.

Although some mechanisms of increased road surface erosion and hydrologic change can be minimized by BMPs, some mechanisms are inherent to watershed and site conditions (e.g., slope steepness, stream network density, geologic instability) and are not readily controllable by BMPs or improved road design (Packer 1967; Furniss et al. 1991; USDA et al. 1993).

The effects of roads to bull trout are not limited to those associated with increases in fine sediment delivery to streams, but can include barriers to migration and changes in water temperature. Road crossings are a common migration barrier to fish (Evans and Johnston 1980; Clancy and Reichmuth 1990; Furniss et al. 1991), since improper culvert placement at road-stream crossings can reduce or eliminate fish passage (Belford and Gould 1989).
Bull trout are highly vulnerable to extinction when they exist as small, isolated subpopulations above man-made barriers. Widespread degradation of bull trout habitats resulting from direct and indirect effects of roads provide barriers to bull trout movement. Barriers to movement can result in fragmentation and isolation, resulting in subpopulations being more vulnerable to all

other stressors. Other stressors include hybridization with brook trout, angling and poaching, as well as degradation of spawning and rearing habitats (MBTSG 1998).

Objectives

- Manage or reduce negative effects of roads to habitat in bull trout watersheds by repairing and relocating roads, and by decreasing current road densities.

- Restore floodplain and habitat connectivity by removing physical barriers to migration caused by roads, culverts, fords and crossings, and maintain or restore hydrologic processes and floodplain functions. However, in specific cases where barriers block non-native species access to bull trout habitat, retaining the barrier may be more desirable than removing it.

- Implement integrated road management strategies across public and private lands for bull trout.

- Control road access, avoid road placement, and prioritize road removal to eliminate access for non-native species introductions in areas of high native species integrity.

- Control road access, avoid road placement, and prioritize road removal to eliminate access for poaching in bull trout staging and spawning areas.

- Avoid road placement and prioritize road removal to eliminate impacts that increase peak flows and physical disturbance causing mortality of eggs or displacement of juveniles using the substrate for cover.

Caution Zone

Because negative effects from roads in both upland and riparian forests potentially affect bull trout habitat, the entire watershed is the caution zone. Although findings from ICBEMP have not been analyzed for watersheds west of the Cascades (i.e., where the Northwest Forest Plan applies), it is very likely that these patterns will apply equally to those steeper, wetter coastal forests.

Recommended Actions

- Develop a road management strategy to enhance bull trout connectivity and restore habitat.

- Maintain unroaded portions of bull trout watersheds in current roadless condition.

- Identify and repair, remove, or relocate roads that are susceptible to mass wasting and bank failures in all bull trout watersheds.

- Identify and repair, remove, or relocate specific roads that intercept ground water and surface water, and detrimentally affect floodplain function.

- Identify and repair, remove, or relocate roads and culverts that are barriers for fish migration[1], restrict subpopulation connectivity, or inhibit downstream transport of substrate and woody debris.

- Identify and repair, remove or relocate roads that negatively affect riparian processes (vegetative cover, LWD, particulate organic matter input, hydraulic processes).

- Avoid placement of new roads in riparian areas unless the alternative would result in greater harm to the aquatic system.

- Identify and close or provide law enforcement for roads that increase risk of poaching and fishing pressure, especially in bull trout spawning and staging areas.

- If new road construction is planned within a bull trout watershed, strive to attain a road restoration/construction ratio that will reduce road densities. For example, strive to attain a 2:1 or 3:1 mitigation ratio, i.e. 2-3 miles of roads restored (obliterated) to 1 mile built or left within valley bottoms, and mid-slope portions of drainages (i.e., on unstable slopes or landslide prone areas that may fail). A minimum ratio of 1:1 for mitigation may suffice in some situations (e.g., for roads that are not contributing excess sediment to streams, interacting with the floodplain, or causing passage problems). Note that the 2:1 or 3:1 mitigation ratios above are only an approximation of what may be necessary, given the high current road densities in many bull trout watersheds.

  Overall, a 1:1 mitigation ratio may not be enough to achieve the broad objective of maintaining road related effects at a constant or decreased level. This is due primarily to the excess sediment production caused by road removal (especially within the first year after road obliteration), which adds to the sediment effects of the newer roads. A 1:1 mitigation ratio may also fail to meet overall objectives in cases where riparian and floodplain road densities are high, or where there is a high percentage of older roads on the landscape that may still fail. It is extremely important to identify and obliterate (or at least stabilize) old, poorly located roads. One must consider the current condition of roads that are proposed for "putting to bed". In some situations, it may be preferable to eliminate access to roads that are in stable condition, rather than to "put them to bed".

Performance Indicators

- Implementation of an integrated road management strategy among all land owners and managers in a bull trout watershed.

- Mitigation ratio achieved through restoration (e.g. 1:1, 2:1, 3:1).

- Number of miles of road in the various "identify and remove, repair, or relocate" categories described under "Recommended Actions."

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1 In areas of high native species integrity, identify barriers for which removal will not increase risk of non-native species introductions.

- Number of miles of roads that are storm proofed or resurfaced.
- Percentage of active road obliteration projects with monitoring plans.
- Number of human-caused barriers removed or upgraded to allow two way passage of bull trout with appropriate precautions taken to limit non-native species introduction.
- Miles of roads removed or relocated to aid recovery of riparian processes.
- Road segments or culverts identified and removed that promote access of bull trout or reduce access of people and livestock to bull trout streams.

FLOODPLAIN AND RIPARIAN PROTECTION

Problem Assessment
Both east and west of the Cascades, current riparian vegetation patterns are fragmented and early seral vegetation has frequently replaced mature riparian forests. For example, basinwide analysis of the Interior Columbia Basin indicates that riparian tree composition and age and size class have changed largely as a result of land management activities, while riparian stand density has increased (Quigley and Arbelbide 1997). Elmore and Beschta (1987) found that livestock grazing in eastern Oregon has resulted in the degradation of riparian areas to the extent that productive habitat for fish and wildlife has been compromised, a phenomenon that has likely occurred throughout the range of bull trout. In many areas, including eastern Washington, fire control in addition to other land management practices has contributed to shifts in species composition away from native, shade intolerant species (e.g., ponderosa pine) towards higher stand densities of native and non-native shade tolerant species.

Similarly, riparian habitat conditions on federal lands within the range of the northern spotted owl have been degraded by road construction and land management activities (USDA and USDI 1994). This has resulted in many riparian areas being currently dominated by red alder or bigleaf maple and containing fewer conifers than the historic condition (USDA et al. 1993). These changes in species composition and size of riparian conifers can affect the potential LWD component needed to maintain channel complexity, as well as other riparian and floodplain functions. The overall goal of riparian management should be to reestablish historical vegetative patterns, disturbance regime, species composition, and successional stages.

Biological Needs
Floodplain and riparian forest functions important to bull trout include: storing and slowing floodwaters; absorbing pollutants from runoff; reducing sediment delivery to streams; providing a forage base to fish and habitat to aquatic invertebrates; maintaining habitat and channel complexity; supplying shade, nutrients, and LWD; providing hydrologic connectivity for seeps, springs, and groundwater upwellings; and providing connectivity to off-channel habitats.

Caution Zone
Each specific riparian function primarily operates within an area of variable size relative to the stream channel and is important for both fish bearing and non-fish bearing streams. For example, the USDA et al. (1993) and Montana Bull Trout Scientific Group (1998), as well as other authors, identified the following functions of riparian zones and widths of riparian area associated with maintaining each function:

- Root strength and bank stability: Root systems are important in providing slope stability, maintaining bank integrity, reducing erosion and sediment delivery rates, providing cover (undercut banks and deep pools) (Swanson et al. 1987). In order to account for the dynamics of channel migration, the caution zone for root strength is approximately 30 feet or ½ crown diameter beyond the 100-year floodplain.

- Large wood delivery to streams: LWD functions to form pools, regulate sediments, disperse stream energy, create channel complexity, stabilizes channels, and provides a major component of instream organic matter (Bisson et al. 1987; Bilby and Ward 1989; Pearsons et al. 1992). The effects of LWD are relatively more important to the functions of small channels in comparison to large channels (Kondolf et al. 1996). Caution zone for this function is the 100-year floodplain plus one site-potential tree height distance.

- Sediment storage: Small headwater streams serve as temporary storage sites for both sediment and fine particulate organic matter (FPOM) from the surrounding forest. Loss of sediment and FPOM storage capacity in small streams results in lower biological productivity and reduced diversity of species requiring clean gravel substrate (Harmon et al. 1986, Keller and Swanson 1979, Triska and Cromack 1980, Triska et al. 1982, Gregory et al. 1987, Naiman and Sedell 1980, Sedell and Beschta 1991, Meghan and Nowlin 1976, Platts and Meghan 1976, Berkman and Rabeni 1987, and Bisson et al. 1992 cited in Naiman 1992). Small streams tend to be more affected by hillslope activities than are larger streams and since adjacent slopes are often steeper, the likelihood of disturbance with in-stream impacts increases (Lee et al. 1997).

- Stream shade, groundwater, and temperature: Canopy cover provided by riparian vegetation is an important factor influencing the effects of solar radiation on increasing stream water temperatures (Beschta et al. 1987; Kondolf et al. 1996). Elevated water temperatures will remain relatively unchanged in a shaded reach unless there is mixing of cooler hyporheic, subsurface, or tributary waters with the stream water (Beschta 1987). Buffer widths of approximately one site potential tree height correlate well with shade provided for maintenance of water temperatures. Defining buffer widths required to protect the hyporheic or groundwater interaction zones is more difficult and is a topic of current research. At this time the recommended caution zone is the 100-year floodplain plus one site potential tree height. If there are springs, seeps, or wetlands present immediately outside of this caution zone, the width of the caution zone would be expanded to include and protect these features, which provide important sources of cool water to streams..

- Microclimate: Brosofske et al. (1997) and USDA et al. (1993) indicate that stream buffers may need to be wider for maintaining microclimate than for other riparian functions. The appropriate zone of concern for small streams (1^{st} - 4^{th} order) that are temperature sensitive, have discontinuous or inadequate riparian vegetation along much of their length, and are already listed under section 303 (d) of the Clean Water Act due to thermal impairment, may be the 100-year floodplain plus two site potential tree height distances (approx. 300'). However, the contribution of microclimate to stream temperature is an area needing further research.

- Nutrients: Leaf and organic litter inputs may originate from varying distances from streams, depending on numerous site-specific conditions. However, most litter inputs to streams decline at distances greater than approximately one-half of a site potential tree height (Erman et al. 1977; USDA et al. 1993). Extensive networks of small first to third order streams comprise about 85 percent of the total length of running waters. These headwater streams are maximally influenced by riparian vegetation, both through shading and as the source of organic matter inputs (Meehan et al. 1997).

Objectives

- Conduct activities that allow for and enhance the various functions of riparian areas and that consider the various caution zones above.

- Modify or avoid land management activities that do not promote the full array and expression of riparian functions over time (e.g., shade, LWD, litter inputs, root strength and bank stability, microclimate, etc.).

- Avoid concentrating known or potentially harmful activities (e.g., livestock grazing, timber harvest and salvage, gravel mining, motorized travel, recreational development) in riparian areas.

- Use appropriate measurements, and common sense, when describing and delineating riparian areas and their functional zones of influence.

Recommended Actions

Adequate protection of bull trout habitat will require protection and restoration of riparian habitat functions for both fish bearing and non-fish bearing streams. It is widely accepted that riparian buffer strips along streams are one of the most effective ways of protecting stream habitats from the effects of land management activities (Cummins et al. 1994).

- Limit activities within the channel migration zone or 100-year floodplain to those that have either a neutral or beneficial effect on floodplain functions. This is a high natural disturbance zone that, if allowed to recover, will develop appropriate functions. Areas of active channel migration typically occur in low gradient, unconfined channel types although they may occur in much steeper gradient streams where the channel slope within a reach declines relative to areas upstream. These zones historically were extremely important for bull trout and other salmonids through providing for instream off-channel habitat and refugia at high flows as well as contributing to habitat complexity. Protection of the CMZ will also provide protection to hyporheic and important groundwater interaction areas.

- Measure riparian buffer strips beginning at the outer edge of the channel migration zone or 100-year floodplain, whichever is greater, and use horizontal distance measurements (not slope distance). Include potentially unstable areas that provide wood, substrates, and nutrients to bull trout streams.

- In watersheds containing bull trout, provide continuous buffers strips on all streams including intermittent and non-fish bearing headwater streams.

- Outside of the bank stability caution zone and within the stream shade and large wood delivery caution zones, manage for increased potential recruitment of coniferous LWD.

- Within the bank stability zone, where available conifers for LWD recruitment are lacking, and where stream temperatures for bull trout are not impaired, consider a variety of ways to promote conifer regeneration and plant conifer seedlings. Treat as experimental and monitor for effectiveness.

Performance Indicators

- Number of actions in riparian areas that apply information or recommendations from basin-wide or watershed scale assessments.

- Proper identification of caution zones for different riparian functions preceding activities within these zones.

- Monitoring of activities that occur within caution zones that show no net detrimental change or an improvement in riparian functions.

- Number and size of riparian buffer strips using correct horizontal measurement starting at the outer CMZ or 100-year floodplain.

- Percent stream network containing continuous mature forest buffer strips.

- Level of potential coniferous LWD located within the root strength, stream shade, and large wood delivery caution zones.

- Percent of conifer regeneration patches being monitored and the results of evaluations of regeneration.

Appendix 1:

References Cited

Adams, S.B. 1994. Bull trout distribution and habitat use in the Weiser River drainage, Idaho. M.S. thesis, University of Idaho, Moscow, Idaho.

Balon, E.K., editor. 1980. Charrs, salmonid fishes of the genus Salvelinus. W. Junk Publishers, the Hague, Netherlands.

Baxter, J.S., and J.D. McPhail. 1996. Bull trout spawning and rearing habitat requirements: summary of the literature. Fisheries technical circular no. 98. Fisheries Branch, British Columbia Ministry of Environment, Lands and Parks, Vancouver.

Baxter, J.S., and J.D. McPhail. 1997. Diel microhabitat preferences of juvenile bull trout in an artificial stream channel. North American Journal of Fisheries Management 17:975-980.

Belford, D.A., and W.R. Gould. 1989. An evaluation of trout passage through six highway culverts in Montana. North American Journal of Fisheries Management 9:437-445.

Beschta, R.L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. Water Resources Research 14:1011-1016.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. Pages 191-232 *in*: E.O. Salo and T.W. Cundy, editors. Streamside management: forestry and fishery Interactions. University of Washington, Institute of Forest Resources Contribution 57, Seattle.

Bilby, R.E., and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society 118:368-378.

Bisson, P.A., R.E. Bilby, M.D. Bryant, C.A. Dolloff, G.B. Grette, R.A. House, M.L. Murphy, K.V. Koski, and J.R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. Pages 143-190 *in*: E.O. Salo and T.W. Cundy, editors. Streamside management: forestry and fishery Interactions. University of Washington, Institute of Forest Resources Contribution 57, Seattle.

Bisson, P.A., and J.R. Sedell. 1984. Salmonid populations in streams in clearcut vs. old-growth forests of western Washington. Pages 121-129 in Meehan, W.R., T.R. Merrell, Jr., and T.A. Hanley, editors. Proceedings, fish and wildlife relationships in old-growth forests symposium. American Institute of Fishery Research Biologists, Asheville, North Carolina.

Bonneau, J.L., and D.L. Scarnecchia. 1996. Distribution of juvenile bull trout in a thermal gradient of a plunge pool in Granite Creek, Idaho. Transactions of the American Fisheries Society 125:628-630.

Brown, L.G. 1992. On the zoogeography and life history of Washington native charr Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*). Washington Department of Wildlife, Fisheries Management Division Report. Olympia, Washington.

Brosofske, K.D., J. Chen, R.J. Naiman, and J.F. Franklin. 1997. Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. Ecological Applications, 7(4):1188-1200.

Buchanan, D.V., and S.V. Gregory. 1997. Development of water temperature standards to protect and restore habitat for bull trout and other cold water species in Oregon. Pages 119-126 *in* Mackay, W.C., M.K. Brewin, and M. Monita, editors. Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Buchanan, D.V., M. Hanson, and R. M. Hooten. 1997. Status of Oregon's Bull Trout, distribution, life history, limiting factors, management considerations and status. Oregon Department of Fish and Wildlife, Portland, Oregon.

Clancy, C.G. 1993. Statewide fisheries investigations, Bitterroot Forest Inventory. July 1, 1991-June 30, 1992. Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Clancy, C.G., and D.R. Reichmuth. 1990. A detachable fishway for steep culverts. North American Journal of Fisheries Management 10:244-246.

Coats, R. 1987. Cumulative watershed effects: a historical perspective. In: Callahm, R.Z.; DeVries, J.J., tech, coords. California watershed management: Proceedings of the symposium; 18-20 November 1986; Sacramento, CA. Wildlands Resources Center

Report Number 11. Berkeley, CA; University of California. 107-111.

Cross, D., and L. Everest. 1995. Fish habitat attributes of reference and managed watersheds with special reference to the location of bull charr (*Salvelinus confluentus*) spawning sites in the upper Spokane River system, northern Idaho. FHR Currents, Fish Habitat Relationships Technical Bulletin 17, USDA, Forest Service.

Cummins, K., D. Botkin, H. Regier, M. Sobel, and L. Talbot. 1994. Status and future of salmon of western Oregon and northern California: management of the riparian zone for the conservation and production of salmon. Draft Research Repot. The Center for the Study of the Environment, Santa Barbara, California.

Dietrich, W.E., and T. Dunne. 1978. Sediment budget for a small catchment in mountainous terrain. Zeitschrift für Geomorphologie, Supplementband 29:191-206.

Edwards, R.T. 1998. The hyporheic zone. Pages 399-429 *in* R.J. Naiman and R.E. Bilby, editors. River ecology. Springer-Verlag, New York.

Elle, S. 1995. Rapid River bull trout movement and mortality studies. Bull trout investigations. Annual Performance Report F-73-R-17. Idaho Fish and Game, Boise, Idaho.

Elmore, W., and R.L. Beschta. 1987. Riparian areas: perceptions in management. Rangelands 9(6):260-265.

Enk, M. 1985. Modeling the effects of forest sediment on bull trout. Page 5 *in* D.D. MacDonald, editor. Proceedings of the Flathead River basin bull trout biology and population dynamics modeling exchange. British Columbia Ministry of the Environment, Fisheries Branch, Cranbrook, British Columbia.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. Evaluation of streamside bufferstrips for protecting aquatic organisms. Contribution 165. University of California, Water Resources Center, Davis, California.

Evans, W.A., and B. Johnston. 1980. Fish migration and fish passage: a practical guide to solving fish passage problems. Washington D.C.: U.S. Department of Agriculture, Forest Service. EM-7100-2.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cederholm. 1987. Fine sediment and salmonid production: a paradox. Pages 98-142 *in*: E.O. Salo and T.W. Cundy, eds., Streamside management: forestry and fishery Interactions. University of Washington, Institute of Forest Resources Contribution 57, Seattle.

Fraley, J.J., and B.B. Shepard. 1989. Life history, ecology and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and River System, Montana. Northwest Science 63(4):133-143.

Frissell, C.A., J. Doskocil, J.T. Gangemi, and J.A. Stanford. 1995. Identifying priority areas for protection and restoration of aquatic biodiversity: a case study in the Swan River basin, Montana, USA. Open File Report Number 136-95. Flathead Lake Biological Station, The University of Montana, Polson, Montana.

Frissell, C.A., W.J. Liss, and D. Bayles. 1993. An integrated, biophysical strategy for ecological restoration of large watersheds. Pages 449-456 *in* D.F. Potts, editor. Proceedings of the symposium on: changing roles in water resources management and policy. American Water Resources Association, Bellevue, Washington.

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. Road construction and maintenance. American Fisheries Society Special Publication 19: 297-323.

Gibbons, D.R., and E.O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. USDA Forest Service General Technical Report PNW-10. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Gilpin, M. 1996. Analysis towards a PVA for the bull trout in western Montana: a progress report for the Montana Bull Trout Science Group. Draft. Bozeman, MT.

Goetz, F. 1989. Biology of the bull trout, *Salvelinus confluentus*, a literature review. Willamette National Forest. Eugene, Oregon.

Goetz, F. 1991. Bull trout life history and habitat study. Final Report to the Deschutes National Forest. Contract No. 43-04GG-9-1371. Deschutes National Forest, Bend, Oregon.

Graham, P.J., B.B. Shepard, and J.J. Fraley. 1981. Use of stream habitat classifications to identify bull trout spawning areas in streams. Pages 186-192 *in* N.B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. 1982. Western Division of the American Fisheries Society, Bethesda, Maryland.

Grant, G.E., F. J. Swanson, and M.G. Wolman. 1990. Pattern and origin of stepped-bed morphology in high gradient streams. Geol. Soc. Am. Bull. 102:340-352.

Grant, G.E., and A.L Wolff. 1991. Long-term patterns of sediment transport after timber harvest, western Cascade Mountains, Oregon, USA. In: Sediment and stream water quality in a changing environment: trends and explanation: Proceedings of the symposium; 1991 August 11-24; Vienna, Austria. IAHS Publication 203. 31-40.

Groot, C., and L Margolis. 1991. Pacific Salmon Life Histories. University of British Columbia Press.

Hoelscher, B., and T.C. Bjorn. 1989. Habitat, density and potential production of trout and char in Pend Oreille Lake tributaries. Project F-71-R-10, Subproject III, Job No. 8.Idaho Department of Fish and Game, Boise, ID.

House, R.A., and P.L. Boehne. 1987. The effect of stream cleaning on salmonid habitat and populations in a coastal Oregon drainage. Western Journal of Applied Forestry 2:84-87

Jakober, M.J. 1995. Influence of stream size and morphology on the seasonal distribution and habitat use of resident bull trout and westslope cutthroat trout in Montana. Master's thesis. Montana State University, Bozeman.

Jakober, M.J., T.E. McMahon, R.F. Thurow, and C.G. Clancy. 1997. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127:223-235.

Janda, R.J., K.M. Nolan, D.R. Harden, and S.M. Colman. 1975. Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California as of 1973. U.S. Geological Survey Open-File Report 75-568. 266 p.

Kelsey, H., M.A. Madej, J. Pitlick, et al. 1981. Sediment budget and an analysis of geomorphic process in the Redwood Creek Basin: A progress report. Technical Report 3. Redwood National Park, Arcata, California.

Ketcheson, G.L., and H.A. Froehlich. 1978. Hydrology factors and environmental impacts of mass soil movements in the Oregon Coast Range. Report by the Water Resources Research Institute, Oregon State University, Corvallis.

Kondolf, G.M., R. Kattleman, M. Embury and D.C. Erman. 1996. Status of riparian habitat, chapter 36, pp. 1009-1030 *in*: Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, 1997, Davis, CA.

Kraemer, C. 1994. Some observations on the life history and behavior of the native char, Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*) of the North Puget Sound Region. WDW. (Draft).

Leary, R.F., and F.W. Allendorf. 1997. Genetic confirmation of sympatric bull trout and Dolly Varden in Western Washington. Transactions of the American Fisheries Society 126:715-720.

Leary, R.F., F.W. Allendorf, and S.H. Forbes. 1993. Conservation genetics of bull trout in the Columbia and Klamath River drainages. Conservation Biology 7:856-865.

Lee, D.C., J.R. Sedell, B.E. Rieman, R.F. Thurow J.E. Williams and others. 1997. Chapter 4: Broadscale Assessment of Aquatic Species and Habitats. *In* T.M. Quigley and S.J. Arbelbide eds. " An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins Volume III". U.S. Department of Agriculture, Forest Service, and U.S. Department of Interior, Bureau of Land Management, General Technical Report PNW- GTR-405.

Leopold, L.B. 1994. A view of the River. Harvard University Press, Cambridge, Mass. 298 P.

Madej, M.A. 1984. Recent changes in channel-stored sediment Redwood Creek, California. Redwood National Park Research and Development Technical Report 11. National Park Service. 54 p.

Marion, D.A. 1981. Landslide occurrence in the Blue River drainage, Oregon. Master's thesis. Oregon State University, Corvallis.

McIntosh, B.A., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves and L.A. Brown. 1994. Management History of Eastside Ecosystems: Changes in Fish Habitat Over 50 Years, 1935 to 1992. US Forest Service. PNW-GTR-321.

McPhail, J.D., and C.B. Murray. 1979. The early life-history and ecology of Dolly Varden (*Salvelinus malma*) in the upper Arrow Lakes. Report to B.C. Hydro and Power

Authority and Kootenay Region Fish and Wildlife. Nelson, British Columbia. 113 pp.

Meffe, G.K., and C.R. Carrol. 1994. Principles of conservation biology. Principles of conservation biology. Sinauer Associates, Inc. Sunderland, MA.

Megahan, W., W.S. Platts, and B. Kulesza. 1980. Riverbed improves over time: South Fork Salmon. *In*: Symposium on watershed management. American Society of Civil Engineers, New York.

Meehan, W., F. Swanson, and J. Sedell. 1997. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. *In* Symposium on the Importance, Preservation, and Management of Riparian Habitat, July 9, 1997, Tuscon Arizona (U.S.D.A. Forest Service Gen. Tech. Rpt. RM-43).

MBTSG (Montana Bull Trout Scientific Group). 1998. The relationship between land management activities and habitat requirements of bull trout. Report prepared for the Montana Bull Trout Restoration Team, Helena, Montana.

MDHES (Montana Department Health Environmental Sciences). 1994. Montana Water Quality 1994. The Montana 305(b) Report. Water Quality Division, Helena, MT.

Morrison, P.H. 1975. Ecological and geomorphological consequences of mass movements in the Alder Creek watershed and implications for forest land management. Bachelor's thesis. University of Oregon, Eugene.

Mullan, J.W., K.R. Williams, G. Rhodus, T.W. Hillman, and J.D. McIntyre. 1992. Production and habitat of salmonids in mid-Columbia River tributary streams. U.S. Fish and Wildlife Service Monograph I. 187pp. + appendix.

Murphy, M.L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska--Requirements for protection and restoration. Decision Analysis Series Number 1. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Coastal Ocean Program, Juneau, Alaska.

Naiman, R.J. 1992. Watershed management. Balancing sustainability and environmental change. Springer-Verlag, New York.

NMFS (National Marine Fisheries Service). 1991. Factors for decline; a supplement to the notice of determination for Snake River spring/summer chinook salmon under the endangered species act. NMFS, ETSD, Portland, Oregon.

NMFS (National Marine Fisheries Service). 1998. Supplementation Biological Opinion on the operation of the Federal Columbia River power system including the smolt monitoring program and juvenile fish transportation program.

Narver, D.W. 1971. Effects of logging debris on fish production. Pages 100-111 *in* Krygier and Hall, directors. Proceedings, forest land uses and stream environment symposium. Continuing Education Publications, Oregon State University, Corvallis.

Nolan, K.M., and D.C. Marron. 1985. Contrast in stream-channel response to major storms in two mountainous areas of California. Geology. 13:135-138.

Oregon Department of Environmental Quality. 1996. DEQ's 1994/1996 303 (d) List of Water Quality Limited Water bodies and Oregon's Criteria Used for Listing Water bodies.

Packer, P. 1967. Criteria for designing and locating logging roads to control sediment. Forest Science. Volume 13, no. 67.

Pearsons, T.D., H.W. Li, and G.A. Lamberti.

1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Transactions of the American Fisheries Society 121:427-436.

Pratt, K.L. 1984. Pend Oreille trout and char life history study. Idaho Department of Fish and Game, Boise, Idaho.

Pratt, K.L. 1992. A review of bull trout life history. Pages 5-9 *in* Howell, P.J. and D.V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, OR.

Pratt, K.L., and J.E. Huston. 1993. Status of bull trout (*Salvelinus confluentus*) in Lake Pend Oreille and the lower Clark Fork River: Draft. The Washington Power Company, Spokane, Washington.

Quigley, T.M., and S.J. Arbelbide, technical editors. 1997. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great Basins: Volume III. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon.

Quigley, T.M., R.W. Haynes, and R.T. Graham, technical editors. 1996. Integrated scientific assessment for ecosystem management in the interior Columbia Basin and portions of the Klamath and Great Basins: Volume III. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon.

Ratliff, D.E. 1992. Bull trout investigations in the Metolius River-Lake Billy Chinook system. Pages 37-44 *in* P.J. Howell and D.V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. Oregon chapter of the American Fisheries Society, Corvallis.

Ratliff, D.E., and P.J. Howell. 1992. The status of bull trout populations in Oregon. Pages 10-17 *in* Howell, P.J. and D.V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, OR.

Reeves, G., and J. Sedell. 1992. An ecosystem approach to the conservation and management of freshwater habitat for anadromous salmonids in the Pacific Northwest. Proceedings of the 57th North American Wildlife and Natural Resources Conference: 408-415.

Reid, L.M., and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20:1753-1761.

Reisenbichler, R.R., and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, *Salmo gairdneri.* J. Fish.Res. Board Can. 34(1): 123-128.

Rieman, B., and J. Clayton. 1997. Wildfire and native fish: issues of forest health and conservation of sensitive species. Fisheries 22(11):6-15.

Rieman, B.E., and J.D. McIntyre. 1993. Demographic and habitat requirements of bull trout *Salvelinus confluentus*. General Technical Report INT-GTR-302. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Rieman, B.E., and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124:285-296.

Rieman, B.E., D.C. Lee, and R.F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River basins. North American Journal of Fisheries Management 17:1111-1125.

Scarlett, W., and J. Cederholm. 1996. The response of a cutthroat trout population to a logging road caused debris torrent event in Octopus-B Creek. Paper presented to a workshop on Type 4 and 5 Waters, National Oceanographic Atmospheric Administration, Sand Point, Seattle, WA.

Sedell, J.R., and F.H. Everest. 1991. Historic changes in pool habitat for Columbia River Basin salmon under study for TES listing. Draft USDA Report. Pacific Northwest Research Station. Corvallis, OR.

Sedell, J.R., F.N. Leone, and W.S. Duval. 1991. Water transportation of logs. American Fisheries Society Special Publication. 19:325-368.

Sedell, J.R., and K.J. Luchessa. 1982. Using the historical record as an aid to salmonid habitat enhancement. Pages 210-223 in N.B. Armantrout, editor. Acquisition and Utilization of Aquatic Habitat Inventory Information, symposium held 23-28 October 1981, Portland, Oregon. American Fisheries Society, Western division, Bethesda, Maryland.

Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford, and C.P. Hawkins. 1990. Role of refugia in recovery from disturbance: modern fragmented and disconnected river systems. Environmental Management. 14:711-724.

Selby, M.J. 1993. Hillslope materials and processes. Oxford University Press, New York.

Shepard, B.B., S.A. Leathe, T.M. Weaver, and M.D. Enk. 1984. Monitoring levels of fine sediment within tributaries of Flathead Lake and impacts of fine sediment on bull trout recruitment. Proceedings of the Wild Trout III Symposium, Yellowstone National Park, WY.

Spence, B.C., G.A. Lomnicky, R.M. Hughs, and R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.

Stanford, J. A., and J. V. Ward. 1992. Management of aquatic resources in large catchments: recognizing interactions between ecosystem connectivity and environmental disturbance. Pages 91-124 *in* R. J. Naiman, editor. Watershed management: balancing sustainability and environmental change. Springer-Verlag, New York.

Swanberg, T.R. 1997. Movements of and Habitat use by fluvial bull trout in the Blackfoot River, Montana. Transactions of the American Fisheries Society 126:735-746.

Swanson, F.J., L.E. Benda, S.H. Duncan, G.E. Grant, W.F. Megahan, L.M. Reid, and R.R. Ziemer. 1987. Mass failures and other processes of sediment production in Pacific Northwest forest landscapes. Pages 9-38 *in*: E.O. Salo and T.W. Cundy, eds., Streamside management: forestry and fishery Interactions. University of Washington, Institute of Forest Resources Contribution 57, Seattle.

Swanson, F.J., and C.T. Dyrness. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3:393-396.

Swanson, F.J., M.M. Swanson, and C. Woods. 1981. Analysis of debris-avalanche erosion in steep forest lands: an example from Mapleton, Oregon, USA. In: Davies, T.R.H; Pearce, A.J.; eds.. Erosion and sediment transport in Pacific rim steeplands symposium. International Association of Hydrological Sciences. Washington, DC. 67-75.

Swanston, D.N. 1991. Natural processes. Pages 139-179 in W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishers and their habitat. Special Publication 19. American Fisheries Society, Bethesda, Maryland.

Thurow, R.F., D.C. Lee, and B.E. Rieman. 1997. Distribution and status of seven native salmonids in the interior Columbia River basin and portions of the Klamath river and Great Basins. North American Journal of Fisheries Management 17:1094-1110.

Underwood, K.D., S.W. Martin, M.L. Schuck, and A.T. Scholz. 1995. Investigations of bull trout (*Salvelinus confluentus)*, steelehead (*Oncorhynchus mykiss)*, and spring chinook (*O. tshawytscha)* interactions in southeast Washington streams. 1992 final report prepared for Bonnieville Power Administration, Portland, Or.

USDA (U.S. Department of Agriculture) and USDI (U.S. Department of Interior). 1994. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. Interagency SEIS Team, Portland, OR.

USDA (U.S. Department of Agriculture), U.S. Department of Interior (USDI), U.S. Department of Commerce (USDC), and the Environmental Protection Agency (USEPA). 1993. Forest ecosystem management: An ecological, economic, and social assessment. Report of the Forest Ecosystem Assessment Team. Forest Service, Fish and Wildlife Service, National Park Service, Bureau of Land Management, National Marine Fisheries Service, Environmental Protection Agency.

U.S. Department of the Interior. 1998. Determination of threatened status for the Klamath River and Columbia River distinct population segments of bull trout (63 FR 31647).

U.S. Environmental Protection Agency. (EPA). 1997. Water quality standards for Idaho (62 FR 41162 - 41188).

U.S. Fish and Wildlife Service (Service). 1998. Klamath River and Columbia River bull trout population segments: status summary. Prepared by the Service's bull trout listing team.

Washington Department of Ecology (WDOE). 1997. 1998 proposed list of water quality limited streams in Washington State [Section 303(d) of the Federal Clean Water Act]. Washington Department of Ecology, Water Quality Program, Olympia.

Washington Department of Fish and Wildlife (WDFW). 1997. 1997 Washington salmonid stock inventory: bull trout/Dolly Varden. Olympia, Washington. 437 pp.

Watson, G., and T.W. Hillman. 1997. Factors affecting the distribution and abundance of bull trout: an investigation at hierarchical scales. North Amer. J. Fisheries Manage. 17:237-252.

Weaver, T.M., and J.J. Fraley. 1991. Fisheries habitat and fish populations. Flathead basin forest practices, water quality, and fisheries cooperative program. Flathead Basin Commission, Kalispell, Montana.

Weaver, T.M., and R.G. White. 1985. Coal Creek fisheries monitoring study No. III. Quarterly progress report. Montana State Cooperative Fisheries Research Unit, Bozeman.

Ziemer, R.R., and D.N. Swanston. 1977. Root strength changes after logging in southeast Alaska. Research Note PNW-306. USDA Forest Service.