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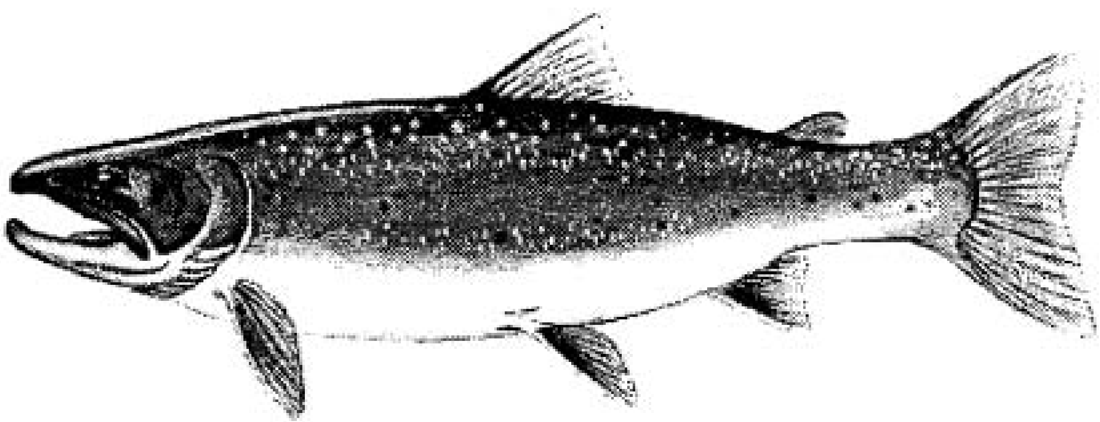
The Relationship Between Land Management Activities And Habitat Requirements Of Bull Trout



Prepared for
The Montana Bull Trout Restoration Team
*c/o Montana **Fish,** Wildlife and **Parks***
1420 E. 6th Ave.
Helena, Montana 59620

by
The Montana Bull Trout Scientific Group

Bonneville Power Administration

Confederated Salish & Kootenai Tribes

Department of State Lands

Montana Chapter American Fisheries Society

Montana Fish, Wildlife & Parks

National Wildlife Federation

Plum Creek Timber Co.

US Fish & Wildlife Service

US Forest Service

Montana Bull Trout Restoration Team

TO: Bull Trout Interested Parties

Please find attached a technical report prepared by the Montana Bull Trout Scientific Group for the Montana Bull Trout Restoration Team titled ***The Relationship Between Land Management Activities and Habitat Requirements of Bull Trout.*** The report consists of three main components: 1) a summary of the habitat requirements of bull trout, 2) a summary of effects of different land management activities on bull trout, and 3) a recommended monitoring-based strategy to maintain quality bull trout habitats in Montana, The document has been peer-reviewed by professional biologists, hydrologists, foresters, range scientists, and civil engineers.

This report, as well as other technical and status reports prepared for the Montana Bull Trout Restoration Team, are intended to be used in conjunction with the Montana Bull Trout Restoration Plan by local watershed groups, public resource management agencies, and private landowners as a reference to protect and restore bull trout habitat. This report, and its monitoring-based strategy, is not meant to replace existing approaches for protecting and/or conserving bull trout. The report, and its monitoring-based strategy, represents an important body of science that should be incorporated into public and private resource management planning processes. The selected approach should balance cost effectiveness and biological benefits to bull trout.

Sincerely,

Larry G. Peterman

Larry Peterman, Chair
Bull Trout Restoration Team

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Executive Summary

This report provides a summary of scientific information on habitat requirements of bull trout and the known relationship between effects of land management activities on their habitats. The report focuses on the effects of land management activities specifically identified as risks to bull trout in Montana. Where possible, we refer to specific studies on bull trout and bull trout habitats, especially in Montana. However, the limited scope and scale of such research required us to draw on other literature sources. Where necessary we use data for related species with similar ecological attributes, or processes documented in comparable ecosystems outside the range of the bull trout. Little information exists about some critical concerns, such as the effects of land management on exchange between surface waters and groundwater, or the cumulative effects of land management on lakes.

Habitat Requirements

The majority of migratory bull trout spawning in Montana occurs in a small percentage of the total stream habitat available. Spawning takes place between late August and early November, principally in third and fourth order streams. Spawning adults use low gradient areas (< 2%) of gravel/cobble substrate with water depths between 0.1 and 0.6 m and velocities from 0.1 to 0.6 m/s. Proximity of cover for the adult fish before and during spawning is an important habitat component. Spawning tends to be concentrated in reaches influenced by groundwater where temperature and flow conditions may be more stable. The relationship between groundwater exchange and migratory bull trout spawning requires more investigation. Spawning habitat requirements of resident bull trout are poorly documented.

Successful incubation of bull trout embryos requires water temperatures below 8° C, less than 35-40% of sediments smaller than 6.35 mm in diameter, and high gravel permeability. Eggs are deposited as deep as 25.0 cm below the streambed surface and the incubation period varies depending on water temperature. Spawning adults alter streambed characteristics during redd construction to improve survival of embryos, but conditions in redds often degrade during the incubation period. Mortality of eggs or fry can be caused by scouring during high flows, freezing during low flows, superimposition of redds, or deposition of fine sediments or organic materials. A significant inverse relationship exists between the percentage of fine sediment in the incubation environment and bull trout survival to emergence. Entombment appeared to be the largest mortality factor in incubation studies in the Flathead drainage. Groundwater influence plays a large role in embryo development and survival by mitigating mortality factors.

Rearing habitat requirements for juvenile bull trout include cold summer water temperatures (15° C) provided by sufficient surface and groundwater flows. Warmer temperatures are associated with lower bull trout densities and can increase the risk of invasion by other species that could displace, compete with, or prey on juvenile bull trout. Juvenile bull trout are generally benthic foragers, rarely stray from cover, and they prefer complex forms of cover. High sediment levels and embeddedness can result in decreased rearing densities. Unembedded cobble/rubble substrate is preferred for cover and feeding and also provides invertebrate production. Highly variable streamflow, reduction in large woody debris, bedload movement, and other forms of channel instability can limit the distribution and abundance of juvenile bull trout. Habitat characteristics that are important for juvenile bull trout of migratory populations are also important for stream resident subadults and adults. However, stream resident adults are more strongly associated with deep pool habitats than are migratory juveniles.

Both migratory and stream-resident bull trout move in response to developmental and seasonal habitat requirements. Migratory individuals can move great distances (up to 250 km) among lakes, rivers, and tributary streams in response to spawning, rearing, and adult habitat needs. Stream-resident bull trout migrate within tributary stream networks for spawning purposes, as well as in response to changes in seasonal habitat requirements and conditions. Open migratory corridors, both within and among tributary streams, larger rivers, and lake systems are critical for maintaining bull trout populations.

Lakes and reservoirs are critically important to adfluvial bull trout populations. In 6 of the 11 bull trout restoration/conservation areas (Flathead, Swan, South Fork Flathead, Upper Kootenai, Lower Kootenai, and lower Clark Fork), large standing bodies of water form the primary habitat for rearing of subadult bull trout and provide food and cover for fish to achieve rapid growth and maturation. Growth rates of juvenile bull trout increase substantially as they enter large river and lake environments and shift from a diet of insects to fish. Despite the importance of lakes and reservoirs, very limited information is available range-wide on habitat use by bull trout in lentic waters. In general, bull trout appear to use benthic areas in lakes but utilize predominantly shallow zones (< 40 m), provided water temperatures are < 15°C. During summer, bull trout appear to primarily occupy the upper hypolimnion of deep lakes, but forage opportunistically in shallower waters. River/lake transition zones appear to be particularly important habitats. Introduced species, especially lake trout and *Mysis relicta* in combination, have been implicated in cascading food web interactions that have led to declines or extinctions of bull trout in many lakes. Although poorly understood at this time, habitat conditions in lakes and reservoirs are critical to persistence of bull trout populations and require additional investigation.

Effects Of Land Use Activities

Residential and industrial development alter bull trout habitat by reducing habitat complexity through channelization, bank armoring, and removal of vegetation and large woody debris. Other impacts include chronic degradation of water quality, reduced substrate quality, modification of flow regimes (both groundwater and surface water), introduction of non-native fishes, disease from private fish ponds, and loss of floodplain capacity.

Mining operations affect bull trout and their habitat in several ways. Physical alteration of stream channels from mining operations reduces habitat complexity, pool quality, substrate quality and bank stability. Introduction of toxic wastes into surface and ground waters degrades water quality causing direct mortality, and can also have indirect effects that may extend for long distances downstream. These indirect effects include reduced growth due to altered food supply, bioaccumulation of metals, and loss of connectivity due to behavioral avoidance of areas with high metals concentrations. Connectivity may also be adversely affected due to physical blockage of stream channels. Construction of roads associated with mineral exploration and development can increase sediment delivery to stream channels. Groundwater inflows may be reduced or eliminated by interception of aquifers and channel alterations.

The effects of livestock grazing on bull trout and their habitat include elevated water temperatures caused by increased insolation resulting from removal of overhanging vegetation and increased channel width; increased sedimentation from bank and upland erosion; decreased pool volume and quality caused by increased channel width and loss of bank undercut; and decrease or absence of riparian vegetation caused by channel degradation, lowering of the water table, and soil compaction.

Cropland agriculture affects bull trout and their habitats through degradation of water quality by erosion and runoff of sediments, fertilizer, and pesticides. It can cause a reduction of habitat complexity, channel stability, and in-channel habitat quality due to direct alterations of channel and floodplain structure and processes. Agricultural land uses are associated with hydrologic alteration and contamination of aquifers and groundwater inflows to surface habitats and reduction of substrate quality by increased sediment delivery. Increases in summer maximum water temperature may also result from agricultural activities.

Diversion of surface waters for irrigation primarily affects bull trout and their habitats by reducing streamflows, increasing water temperature, and reducing or eliminating connectivity. Reduced streamflow lowers instream habitat complexity by reducing the area of available habitat and eliminating access to shoreline cover. Water withdrawals for irrigation reduce instream flows which increases water temperature. Water temperatures may be further increased via warmer irrigation return flows. Fine sediments and agricultural pesticides may be routed to stream channels in irrigation return flows. Reduced streamflows and irrigation diversion structures reduce and often eliminate connectivity among streams through physical blockages to fish movement. Direct mortality can occur to bull trout captured in irrigation water conveyance systems, and bull trout redds may be dewatered below irrigation storage facilities.

Dams can affect bull trout and their habitat in many ways. Storage of water and sediments during high runoff periods affects floodplain dynamics, channel substrates, channel capacity, migration of bull trout into tributaries, and habitat complexity. Storage of water during low flow periods reduces winter habitat quantity and quality, increases stream water temperatures, and alters migration patterns. Frequent fluctuation of dam discharges reduces streambed, shoreline, and bank stability; alters water temperatures and migration patterns; and may cause direct mortality through stranding of fish on stream margins and dewatering of bull trout redds. Occasional release of sediments and other pollutants stored in reservoir sediments affects channel substrate and impairs water quality.

The effects of upland timber management on bull trout and their habitat include reduced pool quality, habitat complexity, channel stability, and bank stability caused by increased peak flows. Increased sediment delivery reduces substrate quality. Alteration of natural streamflow regimes causes increased water temperatures and reduced groundwater inflows. Channel aggradation may reduce connection between stream systems by blocking migratory corridors. In riparian areas, the effects include increased summer and decreased winter water temperatures resulting from removal of shading and insulating vegetation; reduced large woody debris recruitment caused by removal of source vegetation; reduced pool quality, habitat complexity, channel stability, and bank stability arising from removal of vegetation and bank erosion; and reduced substrate quality caused by increased sediment delivery.

Secondary roads can affect bull trout and their habitat. Reduced substrate and pool quality can result from increased sediment delivery to stream channels through poor surface drainage or mass failure. Reduced habitat complexity, pool quality, bank and channel stability can be caused by removal of vegetation, alteration of runoff patterns, and channel alteration from road encroachment. Increased water temperatures and reduced groundwater inflows may result from vegetation removal, alteration of runoff patterns, and interception of subsurface flow.

Recreational development affects bull trout habitat in ways similar to other land management activities. Streamside vegetation removal for recreation facilities can reduce large woody debris and increase stream temperatures. Introductions of pesticides and human or other wastes degrades water quality. Increases in sediment delivery from recreational development reduces substrate quality, habitat complexity, and pool quality. Snowmaking operations for ski developments reduce winter stream flow and channel stability.

The most serious effects of major transportation systems on bull trout and their habitat include stream channelization, bank instability, and loss of riparian vegetation, which result in degraded pool quality, reduced habitat complexity, reduced large woody debris recruitment, increased bank instability, and increased water temperatures. Poorly designed culverts and stream crossings may block fish passage, reducing connectivity among systems. There is also the potential for degraded water quality ensuing from chemical spills and polluted runoff, and loss of coldwater refugia from interception of groundwater by deep cuts into hillslopes.

Wildfire impacts on bull trout habitat are variable and difficult to predict due to varying site conditions, fire behavior, and prior history. Intense fire can result in increased water temperature, accelerated nutrient and sediment loading, combustion of woody debris, and temporary declines in fish populations. However, these responses are partly compensated for by post fire increases in groundwater discharge and recruitment of large woody debris. As a consequence of heterogeneous fire behavior and effects, even large fires typically leave areas of high quality stream habitat that function as refugia from which bull trout and other aquatic taxa rapidly repopulate surrounding areas.

Many of the landscape level changes made within the range of bull trout in the past 150 years have been detrimental to the species. Many of these changes are irreversible and will affect bull trout survival and recovery for decades or centuries. Identifying the interactive and cumulative effects of these activities on bull trout is difficult and is not well addressed in our report. Bull trout are affected by the interactive effect of habitat change and introduction of non-native fish. Due to the bull trout's need for pristine habitats, many habitat alterations tend to favor other species of fish. Because of this, habitat protection for bull trout becomes more important.

Fragmentation, isolation, and widespread degradation of bull trout habitats increase a population's vulnerability to virtually all other environmental stressors. The lower elevation rivers and lakes that historically constituted the most important habitats for maturing fluvial and adfluvial bull trout have been especially degraded by human activities. The maintenance of habitat conditions that encourage movement and migration of large bull trout is critical to both biological and cultural goals.

Landscape level analysis of bull trout populations provides strong evidence that a cause and effect relationship exists between bull trout populations and land management activities. The evidence is circumstantial but compelling.

Recommended Monitoring Based Strategy

We also provide a recommended framework for a monitoring based strategy to maintain quality bull trout habitats in Montana through reducing adverse impacts from land management activities. Our goal in this effort is to provide for streams and lakes that are cold, clean, complex, and connected. The strategy relies heavily on establishing a baseline of existing conditions and monitoring to ensure those conditions are improved or maintained. To accomplish this we propose a set of criteria based standards against which proposed activities should be evaluated. Through this process, and adaptive management feedback, we hope to gain information that will subsequently allow us to determine which activities in particular areas will or will not adversely impact bull trout habitat. This information can subsequently be applied through adaptive management approaches to modify and improve land management activities to further reduce detrimental impacts to bull trout. In addition, the process will provide some impetus for improvements in areas that are currently contributing to a reduction in bull trout viability by identifying factors leading to degradation of habitat. This proposed strategy is not meant to replace existing mechanisms for protecting stream systems. Rather, it will complement existing mechanisms by increasing our understanding of the effects of land management activities on stream systems and bull trout populations.

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Introduction

The Governor of Montana established a Bull Trout Restoration Team (Restoration Team) in January 1994 to develop a restoration plan for bull trout, *Salvelinus confluentus,* in Montana. The Restoration Team appointed the Montana Bull Trout Scientific Group (MBTSG) to provide guidance on technical issues related to the restoration of bull trout populations in Montana.

The MBTSG reviewed the status of bull trout and the risks to the survival of the species in Montana. The MBTSG prepared reports on three of the most significant issues in bull trout restoration: (1) habitat requirements and land use impacts; (2) removal and suppression of introduced species (MBTSG 1996a); and (3) the use of hatcheries and transplants in restoration (MBTSG 1996b). Because the threats facing bull trout vary widely in western Montana, separate status reports were prepared for each of 11 restoration/conservation areas (MBTSG1995a-e; MBTSG 1996c-h). Delineation of these restoration/conservation areas was largely based on the physical fragmentation of historically connected systems resulting from the imposition of migration barriers or other habitat changes such as dams, altered thermal regimes, and stream dewatering. The status reports summarized known historic and current distribution, identified risks to bull trout populations, and identified core and nodal habitats for each of the restoration/conservation areas. Core areas were defined as drainages that currently contain the strongest remaining populations of bull trout within each restoration/conservation area. Nodal habitats provide migratory corridors, overwintering areas, and other critical habitat for core area populations.

This report provides a summary of scientific information on habitat requirements of bull trout and the known relationship between effects of land management activities on their habitats. The report focuses on the effects of land management activities specifically identified as risks to bull trout in Montana, as identified in the status reports. Where possible, we refer to specific studies on bull trout and bull trout habitats, especially in Montana. However, the limited scope and scale of such research required us to draw on other literature sources. Where necessary, we use data for related species with similar ecological attributes, or processes documented in comparable ecosystems outside the range of the bull trout. Little information exists about some critical concerns, such as the effects of land management on exchange between surface waters and groundwater, or the cumulative effects of land management on lakes.

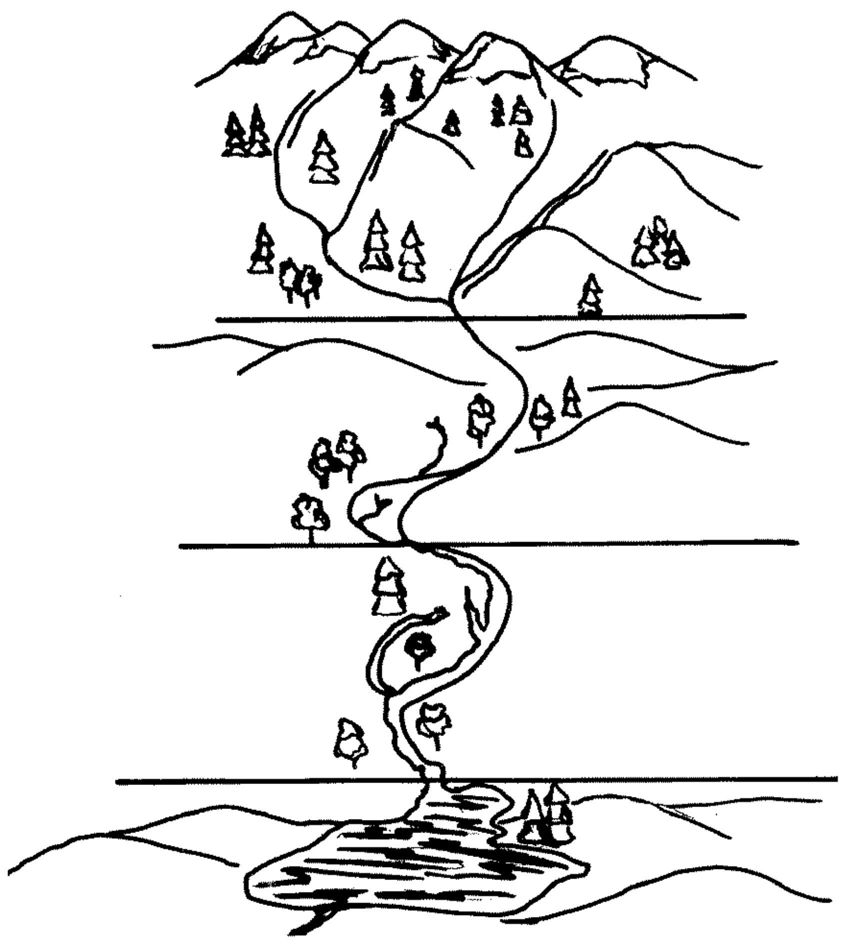
We also provide a recommended framework for a monitoring based strategy to maintain quality bull trout habitats in Montana through reducing adverse impacts from land management activities. In the first two sections of the report, we identify critical habitat components required by bull trout and describe how land management activities pervasive in western Montana can affect these habitat components. Our recommended strategy focuses on maintaining these critical habitat components.

There are critical issues that this report does not address. The issues of watershed analysis and cumulative-effects prediction are not discussed. The report does not consider the merits of various habitat restoration and improvement strategies, nor does it discuss establishing priorities for allocation of habitat conservation resources. These issues will need to be addressed in a scientifically informed, technically critical, and comprehensive way if conservation and recovery of the bull trout is to be successful.

Habitat Requirements Of Bull Trout

The conceptual approach used to organize this life history review follows the life cycle of the bull trout (Figure 1). We begin with spawning habitat, incubation of embryos in the substrate, fry emergence, and rearing habitat of juvenile bull trout in their natal tributary streams. We then examine habitat requirements of nonmigratory (resident) bull trout that remain in tributary streams to complete their life cycle. Subsequently, we describe what is known about the behavior and habitat requirements of migratory juvenile and subadult bull trout as they move downstream to large rivers and lakes. Finally, we summarize knowledge about habitat needs of subadult and adult bull trout that inhabit rivers or lakes for extended periods, before they mature and return to their natal tributary streams to spawn.

Figure 1. Typical downstream sequence of major aquatic habitat zones (delineated by horizontal bars) in the northern rocky Mountains and their role in shaping behavior and life history patterns of bull trout. Vertical bars depict the relative spatial extent of habitat use of the three major life history types of bull trout.



HABITAT ZONE	PRINCIPAL USE	LIFE HISTORY
Headwater tributaries Upland Zone	Spawning, juvenile rearing, resident adult rearing	
Major tributaries Foothills Zone	Juvenile rearing, subadult rearing, adult migration, seasonal adult use	Resident
River mainstems, Alluvial valleys and major canyons	Subadult and juvenile rearing, fluvial adult use, adult migration	
Lakes	Adfluvial juvenile, subadult and adult use	Fluvial (river migrant)
		Adfluvial (lake migrant)

Spawning

Bull trout spawn in streams. The species has narrow, specific spawning habitat requirements and therefore spawns in only a small percentage of the stream habitat available to it. In western Montana, Flathead Lake bull trout spawned in 28% of the 750 km of available stream habitat surveyed in 1978-1982 (Fraley and Shepard 1989). In the Swan River drainage, 75% of all bull trout spawning during 1983 and 1984 took place in 8.5% of the available habitat (Leathe and Enk 1985). About 70% of spawning in the Swan drainage during 1995 and 1996 occurred in portions of four streams, which amounted to less than 10% of available stream habitat (Montana Fish, Wildlife and Parks, Kalispell, unpublished data). Bull trout spawned in 13 of 37 streams surveyed in the South Fork of the Flathead River drainage upstream from Hungry Horse Dam during 1993. Portions of eight of these streams, totaling less than 10% of the total habitat, supported 80% of the spawning (MBTSG 1995c). Similar findings resulted from spawning site surveys in the Kootenai and Clark Fork River drainages (Montana Fish, Wildlife and Parks, Kalispell, unpublished data; MBTSG 1996c, 1996d). As a result of the specific spawning habitat requirements the majority of bull trout spawning is clustered in a small portion of available habitat, making such areas critical for bull trout production.

First-order streams (Strahler 1957) are not used for spawning by bull trout in western Montana. Generally, these headwater channels are too steep or lack sufficient flow for spawning. A small percentage of spawning can occur in second-order streams (formed by the confluence of two or more first-order channels), but this usually involves non-migratory bull trout. Several third-order streams in the Flathead drainage support migratory bull trout spawning (Shepard et al. 1984; Montana Fish, Wildlife and Parks, Kalispell, unpublished file data), but the vast majority of migratory bull trout spawning in Montana takes place in fourth-order streams. Limited bull trout spawning has been documented in fifth-order streams (Shepard et al. 1984). Similar relationships exist between stream order and bull trout spawning outside Montana (Platts 1979; Mullan et al. 1992; Ziller 1992).

Cover, substrate composition, water quality, and water quantity are important spawning habitat components for salmonids (Reiser and Bjornn 1979). The number of spawners that can be accommodated in a stream is largely a function of suitable habitat (gradient, substrate, groundwater influence, depth, velocity), area required for each redd, cover for adult fish, and the fishes behavior.

Cover for spawning bull trout can be provided by overhanging vegetation, undercut banks, submerged objects such as logs and rocks, water depth, and turbulence. Cover protects adult fish from disturbance or predation and provides security. Some migratory bull trout enter spawning streams and arrive at spawning areas weeks or months before they actually spawn (Leggett 1969; McPhail and Murray 1979; Fraley and Shepard 1989) and can be vulnerable to disturbance or predation if holding areas have little or no cover. Proximity to cover is critical to spawning site selection in some salmonid species (Reiser and Wesche 1977; Witzel and MacCrimmon 1983). Distance to cover appeared to be a major factor in spawning site selection by migratory bull trout in the Flathead drainage (Fraley and Shepard 1989).

The suitability of gravel substrates for spawning depends mostly on spawner size. Large fish can use larger substrate materials than small fish. Migratory bull trout in the Flathead drainage (450 - 900mm) spawn in areas of loosely compacted gravel/cobble with maximum particle sizes of 15.2 cm (Fraley and Shepard 1989).

Timing of salmonid spawning has likely evolved in response to seasonal changes in water temperature (Bjornn and Reiser 1991). Initiation of spawning by bull trout in the Flathead drainage appears to be strongly related to water temperature, although photoperiod and streamflow may also be factors (Shepard et al. 1984). Most bull trout spawn between late August and early November (McPhail and Murray 1979; Oliver 1979; Shepard et al. 1984; Pratt 1985; Brown 1992; Ratliff 1992). Spawning in the Flathead drainage (Fraley and Shepard 1989) and in MacKenzie Creek, British Columbia (McPhail and Murray 1979), began when daily maximum water temperatures declined to 9-10° C. Spawning takes place primarily at night (Heimer 1965; Weaver and White 1985), but also occurs during daylight hours (Needham and Vaughan 1952; T. Weaver, Montana Fish, Wildlife, and Parks, personal communication; Russ Thurow, USFS Intermountain Research Station, personal communication).

Bull trout spawning typically occurs in areas influenced by groundwater (Allan 1980; Shepard et al. 1984; Ratliff 1992; Fraley and Shepard 1989). Such areas tend to remain open in the Flathead drainage during harsh winter conditions, while adjacent stream sections ice over or contain extensive accumulations of anchor ice. Recent investigations in the Swan River drainage found that bull trout spawning site selection occurred primarily in stream reaches that were gaining water from the subsurface, or in reaches immediately downstream of upwelling reaches (Baxter 1997).

Habitats used by spawning adults typically have gradients less than 2% (Fraley and Shepard 1989). Water depths at the upstream edges of 80 redds of migratory bull trout in the Flathead drainage ranged from 0.1 to 0.6 m and averaged 0.3 m; water velocities (at 0.6 of the depth below the surface) ranged from 0.09 to 0.61 m/s and averaged 0.29 m/s (Fraley et al. 1981). Similar mean depths (0.3 m) and water velocities (0.31 m/s) at migratory bull trout redds were documented in the Swan River drainage (Kitano et al. 1994).

The large sizes of migratory bull trout redds can restrict spawning potential in specific locations. Migratory bull trout redds ranged from 1.0 to 3.1 m in length (mean 2.1 m) in tributaries of the North and Middle forks of the Flathead River (n = 465); width of these redds ranged from 0.8 to 1.5 m and averaged 1.1 m (Fraley et al. 1981). The largest redd observed in the Swan drainage was about 5.1 m long and 3.3 m wide (T. Weaver, Montana Fish, Wildlife, and Parks, personal observation).

Redds of fish species that spawn in autumn are particularly vulnerable to flooding and scour during runoff events (Wickett 1958; Elwood and Waters 1969; Seegrist and Gard 1972; Cross and Everest 1995), but low winter flows can result in dewatering and freezing of spawning substrates in the absence of groundwater influence (Weaver and White 1985). Extensive areas in the Flathead drainage visually appear suitable for bull trout spawning (i.e., proper gradient, depth, velocity, and substrate) but are not used by spawning adults (T. Weaver, Montana Fish, Wildlife, and Parks , personal communication). These areas may lack sufficient groundwater influence or suitable water temperature.

In summary, the majority of migratory bull trout spawning in Montana occurs in a small percentage of the total stream habitat available. Spawning takes place between late August and early November, principally in third and fourth order streams. Spawning adults use low gradient areas (< 2%) of gravel/cobble substrate with water depths between 0.1 and 0.6 m and velocities from 0.1 to 0.6 m/s. Proximity of cover for the adult fish before and during spawning is an important habitat component. Spawning tends to be concentrated in reaches influenced by groundwater where temperature and flow conditions may be more stable. The relationship between groundwater exchange and migratory bull trout spawning requires more investigation. Spawning habitat requirements of resident bull trout are poorly documented.

Incubation

Successful incubation and fry emergence are dependent on gravel composition, gravel permeability, water temperature, and surface flow conditions. The female bull trout begins redd construction by digging an initial pit or depression in the streambed gravel with her tail. After the spawning pair deposits eggs and sperm into this area, the female moves upstream a short distance and continues the excavation, covering the deposited eggs. The process is then repeated several more times, resulting in a series of egg pockets formed by the upstream progression of excavations. The displaced gravel mounds up, covering egg pockets already in place. After egg laying is complete the female creates a large depression at the upstream edge of the redd, which enhances intragravel flow and displaces more gravel back over the entire spawning area. Excavation of the redd causes fine sediments and organic particles to be washed downstream, leaving the redd environment with less fine material than the surrounding substrate. Weather, streamflow, and transport of fine sediment and organic material in the stream can change conditions in redds during the incubation period. Redds can be disturbed by other spawning fish, animals, human activities, or by high flows that displace streambed materials (Chapman 1988).

Redd construction by migratory bull trout in the Flathead drainage disturbs the streambed to a depth of at least 18.0 - 25.0 cm (Weaver and Fraley 1991). Egg pockets of smaller fish tend to be shallower. The maximum depth of gravel displacement is indicative of egg deposition depth (Everest et al. 1987). Freeze coring documented larger substrate particles (up to 15.2 cm) at the base of egg pockets than in overlying substrates (Weaver and Fraley 1991). These particles are likely too large for the female to dislodge during redd construction. Eggs are deposited and settle around these larger particles (Chapman 1988). Continued displacement of streambed materials by the female then covers the eggs.

Redds become less suitable for incubating embryos if fine sediments and organic materials are deposited in interstitial spaces of the gravel during the incubation period. Fine particles impede movement of water through the gravel, thereby reducing delivery of dissolved oxygen to, and flushing of metabolic wastes away from, incubating embryos. This results in lower survival (Wickett 1958; McNeil and Ahnell 1964; Reiser and Wesche 1979). For successful emergence to occur, fry need to be able to move within the redd, but high levels of fine sediment can restrict their movements (Koski 1966; Bjornn 1969; Phillips et al. 1975). In some instances, embryos that incubate and develop successfully can become entombed (trapped by fine sediments). Sediment levels can alter timing of emergence (Alderdice et al. 1958; Shumway et al. 1964) and affect fry condition at emergence (Silver et al. 1963; Koski 1975).

A significant inverse relationship exists between the percentage of fine sediment in substrates and survival to emergence of bull trout embryos (Weaver and White 1985; Weaver and Fraley 1991). In incubation tests mean adjusted emergence success ranged from about 80% when no fine material was present to less than 5% when half of the incubation gravel was smaller than 6.35 mm; about 30% survival occurs at 35% fines. Entombment was the major mortality factor. Median percentages of streambed materials smaller than 6.35 mm at fry emergence ranged from 24.8 to 50.3% in 29 separate bull trout spawning areas sampled during the Flathead Basin Forest Practice Water Quality and Fisheries Study (Weaver and Fraley 1991).

Survival of bull trout eggs incubated at 2, 4, 6, 8 and 10° C was highest at 2 and 4° C (McPhail and Murray 1979). Mortality increased markedly above 8° C (McPhail and Murray 1979; Weaver and White 1985). Interstitial temperatures ranged from 1.2 to 5.4° C during the incubation period under natural conditions in the Flathead drainage (Weaver and White 1985).

Although largely unquantified, upwelling of groundwater affects incubation temperatures, which in turn affect survival, development, and timing of emergence. Embryos incubated in areas with strong groundwater influence often develop at an accelerated rate due to higher water temperature, resulting in earlier emergence. Bull trout fry emergence in Flathead Lake nursery streams coincides with spring runoff in late April and early May. In nearby Swan Lake nursery streams, fry emerge up to one month earlier because of greater groundwater influence (Weaver and White 1985; Weaver and Fraley 1991). Upwelling of groundwater reduces the probability that embryos will become dewatered and/or freeze (Reiser and Wesche 1979) and increases the water exchange rate, thereby enhancing oxygen replenishment (Coble 1961; Phillips and Campbell 1961) and waste removal (Vining et al. 1985).

In summary, successful incubation of bull trout embryos requires water temperatures below 8° C, less than 35-40% of sediments smaller than 6.35 mm in diameter, and high gravel permeability. Eggs are deposited as deep as 25.0 cm below the streambed surface, and the incubation period varies depending on water temperature. Spawning adults alter streambed characteristics during redd construction to improve survival of embryos, but conditions in redds often degrade during the incubation period. Mortality of eggs or fry can be caused by scouring during high flows, freezing during low flows, superimposition of redds, or deposition of fine sediments or organic materials. A significant inverse relationship exists between the percentage of fine sediment in the incubation environment and bull trout survival to emergence. Entombment appeared to be the largest mortality factor in incubation studies in the Flathead drainage. Groundwater influence plays a large role in embryo development and survival by mitigating mortality factors.

Juvenile Rearing In Tributary Streams

Environmental factors influence distribution and abundance of juvenile bull trout within drainages throughout the range of the species, as well as within specific stream segments (Oliver 1979; Allan 1980; Leathe and Enk 1985; Pratt 1985; Fraley and Shepard 1989; Ziller 1992). Temperature, cover, and water quality regulate general distribution and abundance of juvenile salmonids within drainages, and juvenile presence at specific locations in a stream is affected by depth, velocity, substrate, cover, predators, and competitors. Although spawning occurs in limited portions of a drainage, juvenile salmonids disperse to occupy most of the areas within the drainage that are suitable and accessible (Everest 1973; Leider et al. 1986).

Juvenile bull trout distribution is strongly influenced by water temperature (Oliver 1979; Allan 1980; Brown 1992; Ratliff 1992; Lee at al. 1996). Juvenile bull trout occupied about half the stream reaches surveyed in the Flathead Basin and were rarely found in streams with summer maximum water temperatures exceeding 15° C (Fraley and Shepard 1989). The influence of groundwater on stream temperatures likely represents a critical habitat characteristic for juvenile bull trout during both summer and winter. Stream reaches influenced by groundwater have more stable temperature regimes and are cooler in the summer and warmer in winter. In the Pend Oreille drainage, highest densities of bull trout were found in streams with cold groundwater influence during summer and closed forest canopies that limited solar heating (Pratt 1985). Water temperatures in winter rearing habitats may also limit juvenile bull trout in the Flathead drainage (Weaver and Fraley 1991). Limited channel areas that remain open during winter because they are influenced by groundwater may be critical because other stream sections not influenced by groundwater are completely iced over or contain extensive anchor ice.

Substrate composition influences distribution of juvenile bull trout and rearing capacities of nursery streams (Baxter and McPhail 1997). Sediment accumulations reduce pool depth, cause channel braiding or dewatering, and reduce interstitial spaces among larger streambed particles (Megahan et al. 1980; Shepard et al. 1984; Everest et al. 1987). Juvenile bull trout are almost always found in close association with the substrate (McPhail and Murray 1979; Shepard et al. 1984; Weaver and Fraley 1991; Baxter and McPhail 1997). A significant positive relationship existed between substrate score and juvenile bull trout densities in Swan River tributaries (Leathe and Enk 1985) and Flathead River tributaries (Weaver and Fraley 1991). A high substrate score is indicative of large particle sizes and low embeddedness (Crouse et al. 1981). This relationship is thought to reflect substrate types favoring overwinter survival (Pratt 1984; Weaver and Fraley 1991).

Juvenile bull trout are opportunistic feeders, eating mainly aquatic invertebrates (Fraley et al. 1981). Juvenile bull trout longer than 110 mm in Flathead River tributaries also eat small fish (Fraley and Shepard 1989). Fish identified in bull trout stomachs in Idaho included sculpins, *Cottus* spp., salmon fry, *Oncorhynchus* spp., and other bull trout (Pratt 1992). Nearly 70% of juvenile bull trout in Red Meadow Creek, a tributary to the North Fork of the Flathead River, were categorized as benthic foragers that moved constantly and captured prey from the streambed (Nakano et al. 1992).

Young-of-the-year bull trout are generally found in microhabitats characterized by low current velocities, such as side channels or along stream margins (McPhail and Murray 1979; Fraley and Shepard 1989). Juvenile bull trout in the Flathead drainage usually remained near the streambed, close to substrate and submerged debris (Pratt 1984). As the fish grew, they became less associated with the streambed and used larger cover. In an artificial stream, juvenile bull trout concealed themselves in low velocity areas amongst coarse rock substrate during the day and moved to deeper and faster areas at night (Baxter and McPhail 1997). However, at all times juvenile bull trout were observed close to the substrate.

In summary, basic rearing habitat requirements for juvenile bull trout include cold summer water temperatures (≤ 15° C) provided by sufficient surface and groundwater flows. Warmer temperatures are associated with lower bull trout densities and can increase the risk of invasion by other species that could displace, compete with, or prey on juvenile bull trout. Juvenile bull trout are generally benthic foragers and rarely stray from cover. They prefer complex forms of cover. High sediment levels and embeddedness can result in decreased rearing densities. Unembedded cobble/rubble substrate is preferred for cover and feeding and provides invertebrate production. Highly variable streamflow, reduction in large woody debris, bedload movement, and other forms of channel instability can limit the distribution and abundance of juvenile bull trout.

Subadults And Adults In Tributary Streams

The majority of available information on habitat requirements of bull trout in streams concerns spawning and incubation requirements and habitat use by early life stages (young-of-the-year and juveniles less than 3-4 years old). Habitat preferences and requirements of adult resident bull trout are poorly known by comparison. Five habitat characteristics considered particularly important for bull trout are channel stability, substrate composition, cover, water temperature, and migratory corridors (Rieman and McIntyre 1993). Our review of available literature and unpublished data from Montana supports the importance of these habitat characteristics (with the exception of migratory corridors) for adult resident bull trout.

Water temperature is a critical habitat characteristic that can limit bull trout distribution and exacerbate habitat fragmentation (Rieman and McIntyre 1993). Resident bull trout were found only in streams with maximum daily water temperatures below 15°C in the upper Klamath Basin, Oregon (Goetz 1989). Stream resident bull trout preferred summer water temperatures of 9 to 13 °C in the John Day River, Oregon (Goetz 1989). Water temperatures never exceeded 10°C in upper sections of the John Day River occupied by adult bull trout. Juvenile non-migratory bull trout occupied the coldest water available when a temperature range (8 to 15°C) was present (Bonneau 1994). Age 0, juvenile and adult non-migratory bull trout were found in one stream in the Weiser River drainage, Idaho, where water temperatures exceeded 20.5°C during midsummer (Adams 1994). The lack of other fish species and cool water available at night may have allowed them to persist in this stream.

Adult bull trout have been collected at water temperatures up to 20.5°C, but highest densities occur at temperatures < 12°C (Adams 1994; Buchanan and Gregory 1995; Clancy

1996). Bull trout were found at sites having maximum daily water temperatures of 10.5 and 11.1°C in tributaries of the Malheur River, Oregon (Buckman et al. 1992). In the North Fork Malheur Riverm, temperatures exceeded 21°C, but adult bull trout were found only near the mouths of coldwater tributaries, indicating they were seeking thermal refuge (Buckman et al. 1992). The highest temperature at which bull trout were captured in southeast Washington streams was 16°C (Martin et al. 1992; Underwood et al. 1995).

Deep pools with abundant cover provide important habitat for stream resident bull trout. Bull trout occupied deep pools with boulder-rubble substrate, abundant large woody debris, or overhanging banks in the John Day River, Oregon (Goetz 1989). Stream resident bull trout preferred pools over other habitats in upper reaches of Sun Creek, Oregon; abundances were reduced where pool habitats were limited in availability (Dambacher et al. 1992). Bull trout preferred pools in southeast Washington streams (Martin et al. 1992; Underwood et al. 1995). Few bull trout were found in the Middle Fork Malheur River where pool habitat was lacking (Buckman et al. 1992). Resident bull trout preferred deep pool habitats that provided complex cover and low current velocities throughout autumn and winter in two streams on the Bitterroot National Forest, Montana (Jakober 1995). Pool habitats and unembedded substrate were important for bull trout in Idaho streams (Bonneau 1994, Thurow 1996). Cover used by stream resident bull trout includes large woody debris, boulder and cobble substrates, and undercut or overhanging banks (Goetz 1989; Buckman et al. 1992; Dambacher et al. 1992; Jakober 1995). Although the type of cover used by bull trout can vary by stream and season (Jakober 1995), availability of abundant cover appears to be important for site occupancy. Bull trout in southeast Washington streams occupied low velocity areas associated with boulders and large woody debris (Underwood et al. 1995); use of specific cover types was related more to availability than to a discernible preference.

Stream resident bull trout exhibit diel shifts in habitat use. They conceal themselves in cover (substrate and large woody debris) during the daytime, likely to reduce their vulnerability to predation, and they move into more exposed positions at night (Pratt 1984; Goetz 1991; Jakober 1995; Baxter and McPhail 1997; Thurow 1997). Nocturnal activity by bull trout has been observed in a large spring brook along the Middle Fork Flathead River (C. Frissell and B. Cavallo, Flathead Lake Biological Station, personal communication). Densities of bull trout observed by snorkeling are sometimes greater at night than during the day (Bonneau 1994; Jakober 1995). However, Thurow and Schill (1996) found no difference between day and night snorkeling counts of bull trout. The pattern of daytime concealment followed by nocturnal emergence is more pronounced at water temperatures < 7°C (Schill 1991; Jakober 1995; Thurow 1996). Bull trout exhibited no preferences among cover types during the daytime, but significantly preferred large woody debris at night (Jakober 1995).

Stream resident bull trout undergo seasonal habitat shifts. During winter, when water temperatures decline to < 6°C, they move closer to the substrate and occupy reduced current velocities. Large pools that provide complex cover (large woody debris, boulders, or overhanging banks), low velocities, and depths > 50 cm are preferred throughout autumn and winter. These pools are unaffected by anchor ice and usually offer adequate protection from accumulations of frazil ice (Jakober 1995). Channel morphology strongly influences the type of pool occupied in winter (Jakober 1995). In large, high gradient streams, preferred pools contain a combination of abundant boulders and moderate amounts of large woody debris. In smaller, lower gradient streams, beaver ponds can provide critical winter habitat (Jakober 1995).

In summary, habitat characteristics that are important for juvenile bull trout of migratory populations (low water temperatures, clean cobble-boulder substrates, and abundant cover) are also important for stream resident subadults and adults. However, stream resident adults are more strongly associated with deep pool habitats than are migratory juveniles.

Movement And Migration In Tributary Streams

Adfluvial Flathead Lake bull trout begin their upstream spawning migration as early as April (Fraley and Shepard 1989). The migrating adults move slowly upstream, staging in the North and Middle forks of the Flathead River during late June and July. They enter spawning tributaries from July through September, with a majority entering in August. They are believed to move back downstream to Flathead Lake shortly after spawning (Fraley and Shepard 1989).

Adult bull trout migrate upstream from June through August in the Tucannon River in southeast Washington and move into tributary streams in August (Martin et al. 1992). Individual fish begin their spawning migrations from June to August in the Swift Reservoir/North Fork Lewis River system in Washington (Faler and Bair 1992). Timing of pre-spawning movements is similar in British Columbia, and peak movement coincides with maximum water temperatures of 10-12°C (McPhail and Murray 1979). Adult bull trout begin arriving at spawning tributaries in the Metolius River system, Oregon, in late July and continue through the first week in October (Ratliff et al. 1994). These fish enter spawning tributaries during the first part of August, complete spawning by mid-September, and migrate downstream during October. Migratory bull trout move into Rapid River, Idaho, during June and July, spawn in September and early October, and rapidly outmigrate following spawning (Elle and Thurow 1994; Elle 1995). Before spawning, migratory fish may spend 1 - 3 months in staging areas within spawning tributaries (R. Thurow, USFS Intermountain Research Station, personal communication).

Adult adfluvial bull trout were observed in a perennial stream segment upstream of an intermittent reach in the Pend Oreille system (Pratt 1992). These fish apparently migrated into spawning areas during early summer when a water corridor was still present. Intermittent summer flows or low-water barriers preclude emigration of juveniles and immigration of adults, except during the short spring runoff period or other high flow conditions in some Montana streams (e.g., Lost Creek in the Swan drainage, Ole and Park Creeks in the Flathead drainage; T. Weaver, Montana Fish, Wildlife and Parks, personal communication).

Juvenile bull trout outmigrate from natal tributaries from June through August in the Flathead River system (Fraley and Shepard 1989), but movements in other months have not been monitored. Similar timing of outmigration occurred in British Columbia (Pratt 1992) and in the Tucannon River system in Washington (Martin et al. 1992). In the Rapid River, Idaho, peak downstream migration of juvenile bull trout occurred during September and October, but sampling did not include the spring runoff period. (Elle 1995; Elle and Thurow 1994). Outmigration of juveniles occurred during all months in the Metolius River - Lake Billy Chinook system in Oregon, but the majority outmigrated during May and June (Ratliff et al. 1994). Most juveniles outmigrate at age 2 in the Flathead River system, with smaller percentages moving at ages 1 and 3 (Fraley and Shepard 1989). Outmigration of bull trout fry (i.e., young-of-the-year) has been observed in the McKenzie River system, Oregon (Jeff Ziller, Oregon Department of Fish and Wildlife, Springfield, unpublished data), and in the Arrow Lake system in British Columbia (McPhail and Murray 1979).

Downstream migration affords access to denser forage, better protection from avian and terrestrial predators, and alleviates potential intraspecific competition or cannibalism in rearing areas (Schlosser 1991). Benefits of migration from tributary rearing areas to larger rivers may be realized in increased growth potential (Elle 1995). Migratory juvenile bull trout face an array of natural and human-caused threats to their survival after they leave their natal tributaries. Migration exposes fish to many new hazards, including passage of sometimes difficult and unpredictable physical barriers, increased vulnerability to predators (including anglers), exposure to introduced species, exposure to pathogens, and the challenges of new and unfamiliar habitats.

Available genetic data indicate very restricted exchange among local populations of bull trout, suggesting that bull trout exhibit strong homing tendencies to natal areas (Kanda et al. 1997). Homing ability is thought to be controlled by olfactory imprinting. The critical period for olfactory imprinting in several species of salmonids is induced by thyroid hormone (thyroxine) surges (see Galloway et al. 1994). Investigations were initiated at Creston National Fish Hatchery, Kalispell, Montana, in 1993 to measure thyroxine concentrations in bull trout eggs, alevins, fry, and juveniles reared from eggs collected from wild fish in the Swan River drainage. A pronounced thyroxine spike occurred with, and following, swimup (during April and early May). A second thyroxine spike occurred in May and early June in age-1 fish (Galloway et al. 1994) and age-2 fish (W. Fredenberg, U.S. Fish and Wildlife Service, personal communication). These spikes coincide with observed periods of outmigration in many wild populations of bull trout.

Juvenile bull trout move within natal tributaries, possibly in response to changing habitat and foraging requirements. In the Flathead River Basin, juveniles moved upstream into stream reaches not used by adults for spawning, presumably to occupy rearing habitats (Fraley and Shepard 1989). Young bull trout dispersed from natal areas in the Metolius River system, apparently to forage in other accessible waters (Ratliff 1992).

Stream resident bull trout move from summer and autumn habitats into winter habitats in response to changing environmental conditions. Stream resident bull trout exhibited two movements in the Bitterroot River drainage, Montana (Jakober 1995). Initially, declining water temperatures in autumn triggered substantial (0.5-12.0 km) nocturnal downstream movements into winter habitat. These initial movements were generally completed prior to the formation of sub-surface ice. Secondary movements to better overwintering sites were dependent on changing ice conditions (Jakober 1995).

In summary, both migratory and stream-resident bull trout move in response to developmental and seasonal habitat requirements. Migratory individuals can move great distances (up to 250 km) among lakes, rivers, and tributary streams in response to spawning, rearing, and adult habitat needs. Stream-resident bull trout migrate within

tributary stream networks for spawning purposes, as well as in response to changes in seasonal habitat requirements and conditions. Open migratory corridors, both within and among tributary streams, larger rivers, and lake systems are critical for maintaining bull trout populations.

Subadults And Adults In Large Rivers

Ecological integrity of river corridors is critical for the maintenance (or recovery) of migratory populations of bull trout. Declines of fluvial populations in western Montana are the result of cumulative impacts, including obstruction of migration by dams, alteration of riverine thermal and flow regimes, loss of access to vital tributaries, and disruption and simplification of habitats within and along mainstem river channels in alluvial valleys. Fish assemblages of many large rivers have been altered by the proliferation of introduced species, with largely unknown consequences for bull trout (MBTSG 1996a) Sorting out the relative contributions of these factors is presently impossible for most populations in Montana because of the scarcity of relevant research and documentation and the difficulty of separating overlapping cumulative effects.

Fluvial and most adfluvial bull trout use large river habitats. Large dams and diversions have fragmented the migratory corridors of major rivers in western Montana, thereby isolating formerly connected bull trout populations (Thomas 1992; Pratt and Huston 1993; Rieman and McIntyre 1993; USDI Fish and Wildlife Service 1994). For example, migratory bull trout originating in the Bitterroot and other Clark Fork tributaries historically could have run downstream to the lower Clark Fork River and Lake Pend Oreille in Idaho (Thomas 1992; Pratt and Huston 1993), but such migratory patterns no longer exist. If the migratory tendency persists in some individuals, only downstream migration can occur because dams on the Clark Fork block them from returning to their natal tributaries. Similar conditions exist on most major river systems throughout the range of bull trout. A dilemma exists in certain cases where dams have blocked migratory corridors. Existing dams block upstream invasion of non-native competitors as is the case of Hungry Horse and Bigfork Dams, which prevent the upstream movement of lake trout into Hungry Horse Reservoir and Swan Lake, respectively.

Several kinds of riverine habitats are used by bull trout in the Flathead Basin during the course of a year. In the Flathead River upstream from Flathead Lake, subadult and adult bull trout ranging in length from 195 mm to 645 mm were captured during all seasons in large oxbow lakes (sloughs) adjacent to the main river channel (T. Weaver, Montana Fish, Wildlife and Parks, personal communication). Subadult bull trout were commonly captured during macroinvertebrate sampling of the substrate in the Flathead River above Flathead Lake during the 1970s (J. Stanford, Flathead Lake Biological Station, University of Montana, personal communication).

Habitats influenced by groundwater and tributary inflows can be critical thermal refugia for riverine bull trout in both summer and winter. Adult bull trout use cold tributary plumes as thermal refuges during warm summer days (Buckman et al. 1992; Swanberg 1997). Some subadult (120-275 mm total length) bull trout in the basin of the Middle Fork Flathead River apparently migrate out of natal tributaries and reside in groundwater-influenced floodplain ponds and spring brooks along the main river. (Cavallo 1997; C.A. Frissell and B.J. Cavallo, Flathead Lake Biological Station, unpublished data).

Fluvial bull trout move seasonally within large rivers. Bull trout in the Rapid River, Idaho, migrated downstream more than 100 km to winter in deep pools and runs in canyon segments of the Salmon River mainstem (Elle and Thurow 1994). Most individuals remained within a single pool or run during the entire winter. The extent to which Montana bull trout follow a similar pattern is uncertain, but anecdotal evidence suggests that this is probably a common pattern for fluvial fish where such habitat is available.

Lake-rearing bull trout populations, including several in Glacier National Park, Montana, move directly from natal streams into near-headwater lakes, never passing through large river habitats. Most other adfluvial populations require at least seasonal continuity among tributary, riverine, and lacustrine habitats to complete their life cycle. Investigation of riverine life stages of adfluvial bull trout has been cursory, even in the Flathead Basin where a large body of bull trout research has been conducted since the 1970s.

The timing of adult movement from rivers into spawning tributaries varies among streams, aparently in response to local hydrologic and thermal patterns in the tributary and river itself. Swanberg (1997) found that after maintaining near-stationary locations during winter and early spring, adult bull trout began upstream movements within the Blackfoot River in June. They ascended spawning tributaries from late June until early July, 2-3 months prior to fall spawning. Most movements occurred at night. While in spawning tributaries bull trout were associated with deep pools that also held high densities of mountain whitefish, *Prosopium williamsoni*, a common prey species, but were not clearly associated with large woody debris. After spawning, adult bull trout returned downstream to locations in the mainstem very close to those they had occupied the previous winter. Some subadult bull trout originally tagged in the Blackfoot River made similar summer movements upstream into tributaries, but returned to the mainstem river only a few weeks later, prior to the time of spawning activity in those tributaries (Swanberg 1997). Subadult movements could have been related to avoidance of high water temperatures in the main river, as other bull trout that remained all summer in the Blackfoot River without migrating were closely associated with cold water plumes at tributary outfalls (Swanberg 1997).

In summary, small numbers of migratory fish apparently move into large rivers within their first year of life, but most remain in tributaries for 1 year or more before moving downstream. After they reach large river habitats, bull trout can remain there for brief periods, or for as long as several years, before either moving into lakes or returning to tributary streams to spawn. During their river residency, bull trout commonly make long-distance annual or seasonal movements among various riverine habitats, apparently in search of foraging opportunities and refuge from warm, low-water conditions in mid-summer and ice in winter. We know little about how these patterns vary among basins, but it is likely that river residency and migratory behavior in each bull trout stock largely reflects local adaptation to the specific array of suitable habitats historically available in the basin. The degree of genetic control of migratory behavior in bull trout is unknown.

Migratory behavior in bull trout is frequently categorized (fluvial, adfluvial, resident), but in reality there is a continuum, and these categories are not mutually exclusive.

Subadults And Adults In Lakes

Bull trout habitat associations in natural lakes are poorly known. Most research on habitats of adfluvial populations has focused on adults migrating upstream and on juveniles reared in natal tributaries. A substantial gap exists in our knowledge of habitat requirements of subadult and adult fish in lakes, which must be filled if we are to effectively protect and manage these habitats to restore bull trout populations.

The timing and pattern of movements of bull trout from stream habitats into lakes are poorly understood. This transition involves significant shifts in foraging behavior, and the large-river migratory corridor and lake environments expose downstream migrants to a suite of unfamiliar habitats and piscivorous native and introduced fishes.

The transition zones where rivers enter lakes are often modified for navigation, drainage, homesite or marina development, and other uses. These alterations can reduce the structural complexity of shoreline habitats. For example, the confluence of the Flathead River with Flathead Lake has been altered by accelerated shoreline erosion resulting from lake level regulation, loss of woody vegetation, and revetment. These transition zones appear to be disproportionately important to adfluvial bull trout. Modification of them can increase exposure of migrating bull trout to aquatic predators and reduce bull trout foraging habitat. The effects of these modifications on bull trout and sympatric species have not been examined sufficiently.

Habitat requirements of adult and subadult bull trout in lakes are not well documented. Bull trout captured in gill nets were evenly distributed among depths from the surface to 35 m in Flathead Lake during isothermal conditions in spring and autumn when lake temperatures were 15°C or colder (Leathe and Graham 1982). After thermal stratification developed in early or mid-summer, bull trout were common in the hypolimnion and metalimnion (typically at water temperatures < 10°C and depths > 14 m) and captured less frequently in surface waters, where temperatures often approached 17-20°C. Whereas little is known about bull trout use of deeper parts of the hypolimnion, bull trout were rarely captured by nets or deep-trolling anglers at depths > 34 m in Flathead Lake during the early 1980s (W. Fredenberg, U.S. Fish and Wildlife Service, personal communication); lake trout, *Salvelinus namaycush,* commonly frequent depths > 34 m in Flathead Lake.

Bull trout were more commonly captured in sinking gill nets than in surface gill nets in Flathead Lake (Leathe and Graham 1982) and Hungry Horse Reservoir (Huston 1975), indicating a tendency to be associated with the bottom at depths less than 34 meters. Bull trout made up 10.3% of the fish caught in 137 sinking gill-net sets and 3.4% of the catch in 156 floating sets in Flathead Lake during 1980 and 1981 (Leathe and Graham 1982). Catches in sinking gill-nets were seasonally constant (2.2 to 2.9 fish per net), but catch rates in floating nets were higher in spring (0.8 per net) and autumn (0.5 per net) than in summer and winter (0.1 per net). We infer from these collection records that bull trout in Flathead Lake prefer areas of moderate depth, with access to shallower areas for feeding, throughout the year.

Gill-net catch rates of bull trout in Flathead Lake were higher in the north end of the lake (near the mouth of the Flathead River) than elsewhere during autumn, winter, and spring, whereas they were higher in the mid-lake area than elsewhere during summer (Leathe and Graham 1982; Hanzel 1970). Water depths in much of the north end and mid-lake are typically less than 40 meters. Flathead Lake bull trout migrate 88-250 km upstream over a period of up to 6 months to spawn (Fraley and Shepard 1989). An estimated 38-69% (mean = 57%) of adult bull trout left the lake each year to spawn. Therefore, the lower river and upstream end of the lake (the migratory corridor) may be critical habitat in a large system such as the Flathead.

Bull trout residing in lakes are largely piscivorous. Fish made up over 99% of stomach contents by volume of Flathead Lake bull trout between 177 and 740 mm (Leathe and Graham 1982). Lake whitefish, *Coregonus clupeaformis,* and mountain whitefish were the most important forage items throughout the year. Yellow perch, *Perca flavescens,* were the third most important food item and were consumed by bull trout during all seasons, but especially in winter (Leathe and Graham 1982). The presence of cyprinids and yellow perch in the diets of bull trout in summer indicates that bull trout make occasional forays into near-surface waters to feed (Flathead River Basin Environmental Impact Study 1983). Lake trout exhibit similar behavior (Snucins and Gunn 1995). Habitat or forage partitioning by different sizes of bull trout can occur, as small bull trout (< 300 mm) fed extensively on slimy sculpins, *Cottus cognatus*, in Flathead Lake whereas larger fish did not (Leathe and Graham 1982). Kokanee, *Onchorynchus nerka*, an introduced species, was the fourth most important prey species, overall, in Flathead Lake (Leathe and Graham 1982), but was the primary forage of bull trout in Lake Pend Oreille, Idaho (Jeppson and Platts 1959), and in Priest Lake, Idaho (Bjornn 1957). Bull trout ate more whitefish than kokanee in Upper Priest Lake, presumably because kokanee were less abundant than whitefish (Bjornn 1957). Following its introduction, *Mysis relicta* (opossum shrimp) became the most important forage of bull trout in Priest Lake (Rieman and Lukens 1979).

Fish made up about 99% by weight of food in 359 bull trout stomachs collected in Hungry Horse Reservoir (May et al. 1988), where a largely native fish assemblage persists. Collections were made during all four seasons. During 1984, juvenile bull trout fed primarily (60% by volume) on northern squawfish, *Ptychocheilus oregonensis*, whereas in 1985 the diet was more evenly split among westslope cutthroat trout, *Oncorhynchus clarki lewisi* (25.8%), suckers, Catostomidae, (20.6%), and northern squawfish (19.6%). Adult bull trout consumed suckers (43-54%) and northern squawfish (12-23%) during both years (May et al. 1988). The high relative abundance of cyprinids and catostomids in the diets of bull trout in Hungry Horse Reservoir may reflect the artificially high abundance of these native taxa in the reservoir environment. Bull trout habitat use and foraging behavior in this reservoir are probably not restricted by temperature because water temperatures exceed 16 °C only from July to September and typically only in the upper few meters of the water column.

Bull trout in lakes appear to be largely opportunistic feeders. Therefore, bull trout habitat use in lakes can be variable depending upon foraging opportunities. Bull trout apparently aggregated near seasonally concentrated forage fishes in Flathead Lake in the past. For example, kokanee were an important food during spring months, whereas in the autumn, bull trout concentrated near the mouth of the Flathead River, reportedly to exploit a pygmy whitefish, *Prosopium coulteri,* spawning run (Leathe and Graham 1982). Eight bull trout collected during summer had eaten severed kokanee heads and viscera discarded by anglers (Leathe and Graham 1982). Bull trout are the only fish species present in some small isolated mountain lakes such as Pinto Lake, Alberta (Carl et al. 1989), and Upper Kintla Lake in Glacier National Park (L. Marnell, Glacier National Park, personal communication). They have largely nonpiscivorous diets in these waters, grow more slowly, and mature at smaller sizes than is typical of adfluvial fish.

Habitat conditions in lakes can determine the relative availability of bull trout forage and may mediate interactions of bull trout with potential competitors or predators in complicated and lake-specific ways. For example, bull trout in relatively shallow Swan Lake (maximum depth = 43 m) feed extensively on introduced *Mysis* (S. Rumsey, Montana Fish, Wildlife and Parks, personal communication) and have increased in abundance since *Mysis* were introduced in 1975. In deeper Flathead Lake (maximum depth = 118 m), lake trout are now abundant, and bull trout have declined despite the presence of *Mysis* since the early 1980s. *Mysis* may occupy depths in Flathead Lake where they are susceptible to predation by lake trout, but not by bull trout. Relationships between depth distributions of potential forage and habitat use by bull trout have not been investigated, but such mechanisms may be important in determining the outcome of interactions between sympatric lake trout and bull trout (Donald and Alger 1993).

Some populations of migratory bull trout now use manmade reservoirs in place of natural lakes and rivers to complete their life cycles (Pratt and Huston 1993). Reservoirs vary in their suitability as substitute habitats for bull trout, likely as a function of their size, basin characteristics, watershed quality, dam operations, and other factors. Reservoirs that closely resemble natural lakes are more likely to provide suitable habitat for bull trout than reservoirs that provide unnatural conditions. In extreme cases, reservoirs can be largely unproductive, turbid, warm, oxygen-depleted, and dominated by introduced species. Some of these problems occur on mainstem reservoirs of the Clark Fork (e.g., Noxon and Cabinet Gorge) that likely offer poor foraging and growth opportunities for bull trout compared to historic riverine habitats. In other cases, reservoirs appear to allow bull trout populations to exist at near-natural abundance. The Lake Koocanusa (Libby Dam) bull trout population increased in the first few years after impoundment in 1972 because of enhanced juvenile survival in the relatively productive reservoir environment (Huston et al. 1984), but it is unknown how long these favorable conditions and adequate recruitment may persist.

Although dams have inundated or fragmented what historically may have served as the primary habitat for growth and maturation of migratory bull trout, in some circumstances reservoirs may constitute the only suitable remaining habitat. Appropriate reservoir water-level management can, therefore, be important for maintenance of these fragmented populations. The amount and quality of riverine and tributary habitat that remain connected to reservoirs probably dictate their suitability for bull trout populations. Studies of the ecology of bull trout in specific reservoirs and connecting rivers will be necessary to determine the full implications of reservoirs and their management on bull trout populations.

In summary, lakes and reservoirs are critically important to adfluvial bull trout populations. In 6 of the 11 bull trout restoration/conservation areas (Flathead , Swan, South Fork Flathead, Upper Kootenai, Lower Kootenai, and Lower Clark Fork), large standing

bodies of water form the primary habitat for rearing of subadult bull trout and provide food and cover for fish to achieve rapid growth and maturation. Growth rates of juvenile bull trout increase substantially as they enter large river and lake environments and shift from a diet of insects to fish. Despite the importance of lakes and reservoirs, very limited information is available range-wide on habitat use by bull trout in lentic waters. In general, bull trout appear to use benthic areas in lakes but use predominantly shallow zones (< 40 m), provided water temperatures are < 15°C. During summer, bull trout appear to primarily occupy the upper hypolimnion of deep lakes, but forage opportunistically in shallower waters. River/lake transition zones appear to be particularly important habitats. Introduced species, especially lake trout and *Mysis relicta* in combination, have been implicated in cascading food web interactions that have led to declines or extinctions of bull trout in many lakes. Although poorly understood at this time, habitat conditions in lakes and reservoirs are critical to persistence of bull trout populations and require additional investigation.

Effects Of Land Use Activities

Bull trout require a variety of habitats for completion of their life cycle. Although we do not have a complete understanding of all of these habitat requirements, we do know that land management activities can affect bull trout habitats in many direct and indirect ways. Direct effects involve physical alterations of stream channels and adjacent riparian habitats; indirect effects occur away from the stream channel, but initiate responses that are ultimately realized through changes in instream conditions. Because the physical and chemical characteristics of streams are controlled by conditions in the watersheds they drain, activities affecting watersheds can affect instream conditions. Any ground-disturbing activity has the potential to affect downstream water quality, water quantity, or physical stream habitat. Specific effects on fish habitat and populations can vary depending upon the location, extent, and timing of the activity.

We have identified the habitat components that we believe are necessary to meet the requirements of all bull trout life stages (Table 1), as well as the major land management activities pervasive in western Montana and how these may affect specific habitat requirements. We have also identified which of these land management activities have affected bull trout habitats and pose a risk to restoration in each of 11 restoration/conservation areas (MBTSG 1995a-e; MBTSG 1996c-h) in western Montana (Table 2). The description of these effects and risks are based on the best judgment of the MBTSG and local resource professionals. In the following sections, we describe how these individual activities affect specific bull trout habitat components. We also discuss how they interact and cumulatively affect bull trout habitats and how population connectivity and habitat fragmentation affect the persistence of bull trout.

Table 1. Potential effects of land management activities on important bull trout habitat components in Montana.

Activity	Habitat component: Cold water, thermal refuges	High quality pools	Habitat complexity	Clean substrate	Stable substrate	Ground-water inflow	Connect between systems	Large woody debris	Adequate stream-flow	Chemical water quality	Stable vegetated banks
Residential & Industrial Development	*	*	**	**		**	*	*	*	**	**
Mining		**	**	**	**	**	*	*	*	**	*
Livestock Grazing	*	**	**	**				*	*	*	**
Agriculture	*	*	**	**	*	**	*	*	*	**	*
Irrigation Diversion	**		*	*	*	**	**		**	*	*
Dams	**	**	**	**	**	*	**	*	**		**
Timber harvest: upland	*	**	*	**	*	*		*			*
Timber harvest: riparian	**	**	**	**	*	*		**			**
Secondary roads	*	**	**	**	*	*	**	*	*		*
Recreation	*	*	*	*				*		*	*
Transportation systems	*	**	**	**	*	*	**	*		*	**
Fire	*	*	*	*	*	*	*	*		*	*

* = potentially affected or indirect effect   ** = high magnitude effect or direct effect

Table 2. Activities posing risk to restoration of bull trout populations within identified bull trout restoration/conservation areas in Montana (summarized from individual restoration/conservation area status reports).

	Restoration/Conservation Area										
	Lower Kootenai[1]	Middle Kootenai[2]	Upper Kootenai[3]	Lower Clark Fork[4]	Middle Clark Fork[5]	Upper Clark Fork[6]	Blackfoot[7]	Bitterroot[8]	Flathead[9]	South Fork Flathead[10]	Swan[11]
Rural and Industrial Development			*				*	**	*		*
Mining	*	*		**	*	**	**				
Grazing						**	**	**			
Agriculture	**		*		**	**	*	**			
Irrigation Diversion			*		*	*	**	**			
Dams	*	**	*		*					**	
Forestry (Timber Harvest and Secondary Roads)	**	**	**	**	**	**	**	**	**	**	**
Recreation											
Transportation Systems	*	*			*						
Fire		*				*		*			

* High risk, ** Very high risk

([1] MBTSG 1996d, [2] MBTSG 1996f, [3] MBTSG 1996h, [4] MBTSG 1996c, [5] MBTSG 1996e, [6] MBTSG 1995d, [7] MBTSG 1995a, [8] MBTSG 1995e, [9] MBTSG 1995b, [10] MBTSG 1995c, [11] MBTSG 1996g)

Residential And Industrial Development

Residential development is occurring at a rapid rate throughout western Montana and tends to be concentrated in, or immediately adjacent to, floodplains of rivers and higher-order streams. For example, road mileage has increased more than 3-fold, and the number of residential dwellings has increased more than 10-fold, in the floodplain of the Bitterroot River from 1936 to 1990 (Javorsky 1994). The rate of increase in the number of new dwellings on a portion of the Bitterroot floodplain accelerated more than 5-fold over time (Javorsky 1994). Fish habitat in virtually every major watershed containing bull trout in Montana is likely to be affected by accelerated rates of development. Residential development has been designated a high risk to bull trout in 5 of the 11 bull trout restoration/conservation areas in Montana; Bitterroot, Blackfoot, Flathead, Swan, Upper Kootenai (Table 2).

Residential and industrial development can potentially affect fish habitat in various ways. These include simplification or loss of habitat through direct and indirect channel and floodplain modifications (Booth 1990), alteration of flow regimes (Moscrip and Montgomery 1997), removal of riparian vegetation and prevention of its regrowth, and degradation of water quality (Booth and Jackson 1997). Development can also affect fish populations through increased angling pressure as well as enhanced predation, competition, and disease transmission associated with introduced species that escape from private ponds. Particular attention should be paid to this range of effects because residential and industrial development commonly occurs in or near the floodplains of larger streams that provide some of the most productive and diverse fish habitats in western Montana.

Residential and industrial development commonly results in the clearing and permanent removal of some, if not all, native riparian vegetation for the construction of buildings, drives, parking areas, and lawns. Riparian vegetation is important in the maintenance of fish habitat through recruitment of large organic woody debris, stream-bank stabilization, stream shading, nutrient supply through litter fall, and buffering of stream channels from overland sediment delivery. Removal of this vegetation can potentially disrupt all of these processes (Lucchetti and Fuerstenberg 1993). Residential and industrial development often occurs near unconfined stream channels in wide floodplains that provide the most productive habitats. If undisturbed, low-gradient channels tend to have a high degree of habitat diversity and productivity; these areas are capable of supporting relatively high densities of a variety of fish species and sizes. A common practice by landowners is the removal and prevention of regrowth of riparian vegetation in these areas, generally resulting in increased channel instability with significant reductions in habitat diversity (Lucchetti and Fuerstenberg 1993). Channels tend to become wider and shallower with subsequent reductions in pool habitat. Bank erosion increases and causes enhanced delivery of fine sediments and loss of complex marginal habitats (Klein 1979). These effects, combined with elevated water temperatures resulting from loss of shading, result in decreased survival and carrying capacity of bull trout.

Direct physical modification of stream channels to reduce flooding and channel migration is commonly associated with residential and industrial development. Examples include channel dredging and straightening, bank hardening using riprap and pilings, and levee construction. These practices result in permanent losses of stream channel complexity, especially of slow-water habitats. Channelization and bank hardening also cause increased bed scouring, resulting in elevated transport of bedload downstream (Bryan 1972). Where bedload deposits reach extreme levels, all streamflows may percolate through them below the surface during late summer and early autumn, creating a passage barrier to migrating bull trout. This has occurred in Libby Creek, preventing migratory bull trout from the Kootenai River entering Libby Creek (MBTSG 1996e).

Indirect effects of development within or adjacent to floodplains are soil disturbance, soil compaction, and water withdrawals (Wolman and Schick 1967). Soil disturbance resulting from land clearing, road construction, and landscaping exposes unconsolidated soil to weather action. Depending on the extent, locale, and timing of the disturbance, significant pulses of fine sediment can be delivered to stream channels (Klein 1979). Soil compaction results from the construction of structures, roads, and parking areas. Water that would normally infiltrate into the soil and enter stream channels as groundwater recharge is artificially captured, concentrated, and routed directly to stream channels through drainage systems (Booth 1991). Artificially high instantaneous discharges can result in localized areas. Stream channel stability is compromised by the increased magnitude and frequency of high discharge events, resulting in elevated bed and bank erosion rates (Scott et al. 1986). Water withdrawals from shallow, alluviated aquifers are commonly associated with residential and industrial development. It is probable that these withdrawals influence water table elevation in some areas to the extent that groundwater recharge to streams is diminished during the low-flow season. This can reduce flows and elevate stream temperatures.

Effects on water quality are major concerns associated with residential and industrial development. Pesticides, fertilizers, human and animal wastes, petroleum products, and industrial/chemical wastes (both organic and inorganic) can potentially be delivered to streams and groundwater from residential and industrial sources (Wanielista 1978). Mechanisms of delivery include surface runoff or percolation during and after precipitation events, deliberate discharges into drains or stream channels, failure of sewage systems, drain fields, filtration systems, or storage tanks, runoff from roads or drives, and floods (Booth and Jackson 1997). Settling or storage ponds associated with industrial facilities, sewage treatment plants, and stock farms are usually located in riverine floodplains and are vulnerable to overflow, leaching into shallow aquifers, and breaching by floodwaters. Effects of pollutant discharges on water quality and bull trout populations range from benign to extreme, depending upon the type and concentration of material delivered.

Non-native fish in private ponds pose a significant risk to native fish populations. For example, Montana Fish, Wildlife and Parks granted over 100 permits for private pond development in western Montana over the last 3 years (C. Clancy and T. Weaver, Montana Fish, Wildlife and Parks, personal communication). Private ponds are usually developed in floodplains, use surface waters or shallow groundwater for water supply, and commonly have outlets connected to public waters. These ponds are frequently stocked with non-native fish species from private hatcheries. The risks of introducing non-native fish or diseases into state waters is generally high because of where the ponds are located and because they lack adequate containment to prevent escape of stocked fish and pathogens. Even if nominal containment is maintained, the risk exists of pond capture by flowing waters resulting from channel migration or flooding. Introduced fish species represent a significant threat to bull trout populations (MBTSG 1996a).

In summary, the most serious effects of residential and industrial development on bull trout habitat include: reductions in habitat complexity caused by channelization, bank armoring, and removal of vegetation and large woody debris; chronic degradation of water quality resulting from frequent releases of pollutants; reduced substrate quality resulting from increased sediment delivery to stream channels; modification of flow regimes (both groundwater and surface water); introduction of non-native fishes or disease from private fish ponds; and losses of floodplain and riparian vegetation.

Mining

The effects of mining on aquatic habitats and salmonid fishes include direct physical alteration of these habitats and introduction of pollutants. Extraction of hard-rock minerals, coal, oil, gas, or non-mineral materials can potentially affect aquatic systems within the range of bull trout in Montana. In addition, a large coal deposit in the Canadian portion of the North Fork of the Flathead drainage has potential for development. Mining is considered a high risk to bull trout populations in 6 of the 11 bull trout restoration/conservation areas in Montana: Blackfoot, Lower Clark Fork, Middle Clark Fork, Upper Clark Fork, Lower Kootenai, and Middle Kootenai (Table 2).

Direct physical effects of mining to aquatic systems are largely associated with extraction of alluvial mineral deposits because these deposits are highly associated with stream courses. Extraction techniques include placer dredging and hydraulic mining. Hydraulic extraction techniques have been nearly eliminated because of environmental concerns, but vestiges of former operations continue to affect aquatic systems.

Dredging of alluvial deposits usually disturbs the streambed and adjacent terraces, and spoils are spread over the surrounding land surface (Nelson et al. 1991). These waste materials can occupy as much as 20% more volume after dredging than they occupied in their natural configuration (USDA Forest Service 1977). Dredging completely removes riparian vegetation, eliminating potential for large woody debris recruitment. Dredging often involves routing of streams away from their natural channels, creating potential barriers to fish movement. Deposition of spoils results in channelized stream systems with highly unstable banks made up of materials that are too coarse-textured and dry to support riparian vegetation. Residual mercury and other toxic materials used to capture and extract precious metals from placer deposits can persist in some spoils. Placer dredging introduces significant amounts of bedload and suspended sediments into stream systems. Dredging displaces, removes, or directly affects aquatic flora and fauna by increased sediment transport, removal of riparian vegetation, and removal or alteration of all habitat components (Levell et al. 1987). Fine sediment transported from mined deposits affect streambed conditions downstream, including impairment of exchange between surface and subsurface water (Bjerklie and LaPerrier 1985).

Settling ponds are used in placer operations and at ore processing sites. Tailings impoundments store mine wastes and ore tailings. These are normally constructed in floodplains and are subject to disturbance or failure from high flow events. Failure of settling ponds can result in the release of large quantities of contaminants. The major decline in the westslope cutthroat trout population in the upper Blackfoot River was attributed to failure of the tailings impoundment at the Mikehorse Mine (Peters 1990). Effects of the impoundment failure extended at least 15 miles downstream. Liver tissues of all fish species in this river reach exhibited elevated levels of metals (Morre et al. 1991).

Acid mine drainage is associated with coal mining and hard-rock mineral extraction from granitic deposits. It is generally considered to be the most serious water pollution problem associated with mining (Nelson et al. 1991). Sources of acidic effluent include discharge from underground mining, surface runoff over tailings and waste rock piles, and leakage from settling ponds. Acidic effluent is directly toxic to most forms of aquatic life and often promotes mobilization of toxic metals causing concentrations that exceed background levels (Nelson et al. 1991). Dissolved metals can be toxic to fish individually or in combination and may be additive, synergistic, or antagonistic. Effects on salmonid fishes include direct mortality from exposure to high concentrations or chronic effects such as reduced growth rates, reproductive failure, and behavioral changes from exposure to sublethal levels. Mining-generated metals can bioaccumulate in food webs of aquatic systems and reduce abundances of benthic invertebrates and fish, as was documented in the Blackfoot River (Moore et al. 1991), reducing the prey base for bull trout.

Road construction for access and exploration releases sediments that can enter stream channels. A major source of sediment delivery to stream channels is the extensive network of exploration roads needed to efficiently locate extractable precious metal ores (Sidle and Sharma 1996). Drill pads, exploration pits, open pit mines, and strip mines disturb upland sites and release sediments, alter surface and subsurface hydrologic conditions, and can cause mass soil movements (Nelson et al. 1991). Toxic drilling fluids, lubricants, and fuels associated with mineral extraction have the potential to enter streams through accidental spills either onsite or during transportation. Toxic chemicals, such as sodium cyanide, used in the processing and recovery of hard rock minerals may also enter stream systems through surface or groundwater pathways.

Physical alterations of stream habitats and deposits of mine wastes in stream floodplains frequently continue to affect aquatic systems long after mining has ceased. Eleven fish kills have occurred in the Clark Fork River between the Warm Springs ponds and Rock Creek since 1959. Most of the kills occurred after summer thunderstorms, when runoff released pulses of toxins from floodplain mine tailing deposits (RCG/Hagler Bailey 1995).

Deposits of metals from mine wastes and effects on stream biota can occur for long distances downstream from mining activities. Significant deposition of copper, zinc, cadmium, lead, and silver has occured as far as 381 km downstream of mine and smelting sites in the Clark Fork River (Axtmann and Luoma 1991). Elevated concentrations of trace metals occur in bodies of six taxa of benthic invertebrates collected along a 381km reach of the Clark Fork below mine sites (Cain et al. 1992).

Sub-lethal effects to fish include health impairment, reduced growth rates, and behavioral avoidance of areas with high metals concentrations. Behavioral avoidance can preclude downstream migration of fish from tributaries into the Clark Fork River, or force fish out of the mainstem into tributaries at inappropriate times (RCG/Hagler Bailey 1995). In the Coeur d'Alene basin, Idaho, a relationship was observed between elevated metals below mined areas and a reduction in natural fish populations by behavioral avoidance of high metals concentration (Woodward et al. 1997). Other impacts from high metals concentrations include indirect mortality through reduced growth, limiting macroinvertbrate food supply, and increasing the effects of competition from more tolerant fish species.

Small-scale suction dredging is becoming increasingly popular. Small-scale suction dredging disrupts trophic relationships, results in temporary losses of diversity and shifts in abundances of aquatic insects, causes some losses of small fish such as sculpins and pre-emergent salmonid fry, and locally alters habitat (Thomas 1985; Harvey 1986; Somer and Hassler 1992). Off-site effects are usually minimal. The negative effects are probably minor and localized if (1) the extent of the dredging is small; (2) operations are timed to avoid direct excavation of salmonid eggs and fry; (3) operators do not disturb or destabilize streambanks, vegetation, large woody debris, or boulders; and (4) the reconfigured streambed does not reduce the stability of interstitial spawning and rearing habitats during subsequent peak flow events. Delayed instability of substrate altered by suction dredging is a potentially serious problem, but has been the subject of little research or environmental analysis. Effects of suction dredging are proportional to the size of equipment used and length of stream dredged (Perkinson 1993).

In summary, mining operations affect bull trout and their habitat in several ways. Physical alteration of stream channels from mining operations reduces habitat complexity, pool quality, substrate quality and bank stability. Introduction of toxic wastes into surface and ground waters degrades water quality causing direct mortality and can also have indirect effects which may extend for long distances downstream. These indirect effects include reduced growth due to altered food supply, bioaccumulation of metals, and loss of connectivity due to behavioral avoidance of areas with high metals concentrations. Connectivity may also be adversely affected due to physical blockage of stream channels. Construction of roads associated with mineral exploration and development increases sediment delivery to stream channels. Groundwater inflows may be reduced or eliminated by interception of aquifers and channel alterations.

Livestock Grazing

Grazing by livestock alters water quality, riparian zones, and stream channels in ways that can be detrimental to bull trout (Meehan and Platts 1978; Kauffman and Krueger 1984; Platts 1990, 1991). Livestock grazing is an important concern in 3 of the 11 bull trout restoration/conservation areas in Montana: Upper Clark Fork, Blackfoot, and Bitterroot (Table 2).

Reductions in overhanging vegetation and increases in stream channel widths by grazing livestock can result in significantly elevated summer water temperatures by increasing direct solar radiation. Reduced riparian canopy cover can also reduce water temperatures in winter, thereby accelerating formation of anchor ice.

Grazing affects channel stability by trampling of streambanks and removal or alteration of streambank vegetation. Trampling causes streambanks to slough, reduces undercut bank cover, increases sediment input, and accelerates bank erosion. Soil compaction in uplands can alter runoff patterns, thereby contributing to stream channel instability and reduced late-season streamflows. Vegetation provides soil-binding root masses and protects streambanks from the erosive energy of water and damage from ice and debris flows. Native riparian vegetation may be reduced by soil compaction and/or replaced by non-native plant species. Removal of the riparian conifer overstory by timber harvest or fire creates transitory range that increases accessibility and attraction to livestock. Changes in species composition of streambank vegetation, reductions in vegetative vigor, and elimination of vegetation increase erosive potential and cause channel widening and downcutting. Channel downcutting can result in lowering of the water table, thereby reducing groundwater recharge to streams. Livestock crossings are often located in stream reaches used for spawning by salmonids, thereby exposing bull trout eggs to direct mortality by trampling.

Effects of livestock grazing on aquatic systems have been well documented (Meehan and Platts 1978; Kauffman and Krueger 1984; Platts 1990, 1991), but studies specifically addressing effects of grazing on bull trout are lacking. Channelization and intense grazing by cattle degraded lower Sun Creek and adjoining streams in the Klamath Basin, Oregon, and may have contributed to the extinction of migratory bull trout (Dambacher et al. 1992). Few bull trout were found in sections of the Middle Fork Malheur River, Oregon, where pool habitat was lacking and water quality was affected by livestock in adjacent irrigated meadows (Buckman et al. 1992). Bull trout habitat in the Malheur drainage was adversely affected by livestock grazing and irrigation diversions (Buckman et al. 1992).

In summary, livestock grazing effects to bull trout and their habitat include elevated water temperatures caused by increased insolation resulting from removal of overhanging vegetation and increased channel width; increased sedimentation from bank and upland erosion; decreased pool volume and quality caused by increased channel width and loss of bank undercut; and decrease or absence of riparian vegetation caused by channel degradation, lowering of the water table, and soil compaction.

Agriculture

Cropland agriculture is a high risk factor in 7 bull trout restoration/conservation areas in Montana: Lower Kootenai, Upper Kootenai, Middle Clark Fork, Bitterroot, Upper Clark Fork, and Blackfoot (Table 2). It has the potential to affect all important bull trout habitat components (Table 1), but its effects have been manifested primarily in the formerly broad, timbered or partly timbered, and densely vegetated valley floors along Montana's major river corridors. Timber and other riparian vegetation were removed long ago, affecting interchange of groundwater and surface waters, stream shading, bank stability, and the sediment filtering effects of floodplain vegetation. Over the expanse of western Montana, cropland agriculture is relatively limited in spatial extent, but it is concentrated in some key corridors for bull trout, and its ecological effects can propagate downstream.

Through a variety of mechanisms, agricultural practices can directly modify stream channels, riparian areas, stream discharge rates, and water quality (Lowrance et al. 1985; Maas et al. 1985; Roth et al. 1996). Use of riparian areas and floodplains for cropland results in loss of stabilizing vegetation. Subsequent stream instability and lateral migration of stream channels into the cropland creates incentive for streambank stabilization or channelization (Lowrance et al. 1985). Channelization, in turn, leads to loss of spawning areas, habitat complexity, high quality pools, stable vegetated banks, and woody debris recruitment. Effects of streambank stabilization and channelization are further discussed in the sections on Transportation Systems and Timber Harvest-Riparian.

Erosion of tilled croplands increases rates of sediment delivery to stream systems (Lowrance et al. 1985; Geleta et al. 1994; Daniels and Gilliam 1996; Wood and Armitage 1997) and these processes and consequences are covered in the section on Effects of Secondary Roads. Streamflows and groundwater inflow can be affected in agricultural areas by water withdrawals from shallow, alluvial aquifers which should be considered tributary waters to the surface streams. See the section on Irrigation Diversion for a discussion of the effects of water withdrawals. Summer groundwater temperatures can increase with the removal of natural vegetation cover (Pluhowski 1970), and warming of groundwater under croplands or fallow fields could result in increased maximum and diurnal variation of temperature of associated streams.

Polluted runoff and contaminated groundwater are serious water quality concerns associated with cropland agriculture. Although the Conservation Reserve Program and other federally supported programs have begun to address polluted runoff, contaminants in surface and subsurface water from agricultural lands remains a major risk factor for bull trout in hundreds of miles of streams in western Montana (MDHES 1994). Polluted runoff includes pesticides, fertilizer, sediment, and human and animal wastes.

Bull trout come into direct contact with pesticides in water, stream sediments, or food. Stream sediments can be contaminated with agricultural chemicals through deposition of soils carrying adsorbed chemicals from the land or by adsorption of chemicals from the water (Norris et al. 1991; Kimbrough and Litke 1996). Forage of bull trout can become contaminated if it is sprayed directly or by adsorption or bioaccumulation of the chemical from the water. The bioaccumulative properties of chemicals vary depending on the physiochemical properties of the specific compounds involved (Norris et al. 1991). Chronic application of pesticides, even at low levels, can result in bioaccumulation within the aquatic ecosystem over time (Norris et al. 1991). As contaminated forage is ingested, these contaminates will be further bioaccumalated in bull trout. Pesticide application can also modify bull trout habitat indirectly. For example, insecticides can decrease biomass or alter the species composition and availability of terrestrial or aquatic insects or fishes (Gammon et al. 1983; Lenat 1984; Roth et al. 1996). This could change food availability for bull trout. Herbicide applications in streamside zones alters vegetation in riparian areas (Norris et al. 1991).

Pathways for delivery of fertilizers and human and animal wastes are similar to those for pesticides (Naylor and Busch 1973; Maas et al. 1985; Geleta et al. 1994; Owens 1994; Kirchmann 1994). In stream ecosystems where nitrogen availability often limits productivity, nitrogen-based fertilizers (the most common type used) can enhance primary production and elevate invertebrate and fish production rates. Conversely, excessive delivery of fertilizers can result in concentrations toxic to aquatic life or eutrophication of aquatic ecosystems. Unfiltered runoff from feedlots is a major source of contamination from animal wastes and can contribute to eutrophication (Gammon et al. 1983; Kirchmann 1994). Eutrophication commonly depresses concentrations of dissolved oxygen in stream and lake ecosystems by artificially increasing rates of decomposition (Butler et al. 1995).

In summary, cropland agriculture affects bull trout and their habitats through degradation of water quality by erosion and runoff of sediments, fertilizer, and pesticides. It also can cause the reduction of habitat complexity, channel stability, and in-channel habitat quality due to direct alterations of channel and floodplain structure and processes. Agricultural land uses are associated with hydrologic alteration and contamination of aquifers and groundwater inflows to surface habitats and reduction of substrate quality by increased sediment delivery. Summer maximum water temperature increases may also result from agricultural activities.

Irrigation Diversion

Direct effects of irrigation withdrawals and return flows on bull trout and habitats include water quality degradation (increases in water temperatures, suspended sediment loads, and nutrient and pesticide concentrations), reduced stream flows, blockage of migration corridors by flow depletion and diversion structures, and direct losses of bull trout into water conveyance facilities. Other effects include physical habitat alterations such as channelization, bank stabilization, channel narrowing, and aggradation. Irrigation operations and their effects are highly variable and unpredictable, but they must be carefully examined when evaluating overall status of bull trout habitat and restoration needs in a particular basin or watershed. Irrigation diversion was identified as a risk to bull trout in the Upper Kootenai, Middle Clark Fork, Upper Clark Fork, Bitterroot, and Blackfoot bull trout restoration/conservation areas (Table 2).

Irrigation increases water temperatures when irrigation water is exposed to elevated ambient air temperatures and solar insolation before returning to streams via surface drainage (Boone 1976). Simulation modeling of stream temperatures in the Yakima River basin showed that elimination of irrigation diversions and return flows could increase stream flows and decrease water temperatures during the irrigation season, thereby improving conditions for anadromous salmonids (Vaccaro 1988). Irrigation increases net evaporative loss of water from a river basin because more surface area of water is exposed in ditches and irrigation systems than in natural stream channels. Irrigation withdrawals also increase surface area-to-volume ratios below irrigation diversions in natural stream channels, thereby promoting solar heating of water remaining in the natural channels. Thermal effects are compounded because the primary irrigation season coincides with low stream flows and high water and air temperatures. Because bull trout require cold water temperatures, even slight increases in stream temperatures can cause direct mortality, displacement by avoidance, or increased competion with species more tolerant of warm stream temperatures.

Irrigation return-flows can be laden with elevated levels of suspended and dissolved solids, nutrients, and pesticides (Boone 1976). Drainage ditches collecting water from agricultural lands tend to act as sinks for non-point-source pollutants that are then delivered directly to the stream. Increases in concentrations of nutrients (especially nitrogen) from irrigation return-flows can stimulate nuisance aquatic vegetation growth and depress dissolved oxygen concentrations. Sediments eroded from fields, canals, and drains are delivered to stream channels via return flows.

Deleterious effects of nutrients and pesticides in return flows may not be as prominent in western Montana as elsewhere because the major crops grown here (grass hay, alfalfa, and some grains) usually require less application of chemicals than some other commercial crops (MDNRC 1988). However, intensified chemical weed control in the future could increase pesticide loadings in return flows. Herbicides such as acrolein are often used to kill vegetation within ditches to maintain ditch capacity and are extremely toxic to fish. Additional herbicides may be applied to control vegetation along ditch banks. These chemicals can kill fish in irrigation ditches or can be transported by return flows to natural stream channels in solution or adsorbed on dislodged vegetation, organic matter, or flushed sediments.

Reductions in flow below irrigation diversions creates seasonal fish passage barriers in tributary streams. Adult bull trout enter spawning tributaries during late summer (described in the section on Movement and Migration in Tributary Streams) when irrigation demand is likely to be greatest. Elimination of stream flows at this time artificially renders these tributaries inaccessible to migratory adult bull trout. Reductions in stream discharge rates can, by increasing stream temperatures, create thermal barriers to migration that are equally disruptive. Migratory bull trout are dependent on a limited number of stream reaches for spawning in a given river system. Elimination of access to a single stream can reduce recruitment greatly and jeopardize viability of a population.

Irrigation diversion structures themselves create impediments to fish passage. Diversion structures on tributary streams often span the entire channel and create vertical drops that may be impassable to fish migrating upstream. Some diversion structures can be surmounted during high flows, but not during low-flow periods. General requirements for upstream fish-passage over obstacles include resting areas and sufficient pool depths below the obstacles, jumps of minimal size, suitable water depths and velocities, resting pools en route, and resting pools above the obstacles (Evans and Johnston 1980). Because diversion structures are designed to pass annual-high flows, vertical drops below them are often too great during low-flow periods to allow upstream passage. Insufficient depths of water flowing over the structures and shallow downstream plunge pools compound the effect.

When all, or most streamflow is diverted, fish are entrained into ditch systems by following the majority of flow. Downstream migrating juveniles tend to follow stream margins, and because diversion head gates are located along these margins, the juveniles are commonly entrained. Ditch heads often closely resemble off-channel habitats, which can be important seasonal habitats for bull trout fry and juveniles, thereby luring the young fish into unfavorable and eventually lethal habitats. Emigrating juveniles and upstream migrating adults entered unscreened irrigation diversions in the Malheur River basin (Buckman et al. 1992). The extent of the losses were unknown, but may have been significant, especially where a majority of water was diverted. Loss of juvenile bull trout to irrigation ditches occurred in the Blackfoot River basin in Montana (Pierce et al. 1997). Juvenile bull trout were more abundant than other fish species in samples from irrigation ditches there.

Large acreages are irrigated in the Upper Clark Fork (100,000 acres), Bitterroot (110,000 acres), and Blackfoot (20,000 acres) drainages in Montana (USGS 1993). Irrigation appropriates about 50% of July-through-September runoff in the Clark Fork River above Missoula, including the Blackfoot and Bitterroot rivers (Boettcher and Gosling 1977). Most irrigation occurs through the diversion of surface flows, with very small volumes resulting from groundwater pumping. Groundwater pumping has the potential to adversely affect stream systems because subsurface water provides most of the baseflow (the consistent low flow that maintains aquatic life in streams from August through March) in snowmelt-dominated areas such as western Montana. Excessive groundwater withdrawal lowers the water table, which in turn can reduce late-season base flows and increase water temperatures, and disrupt underwater springs and hyporheic exchange with surface systems. The hyporheic zone is that area of alluvium beneath the riverbed and floodplain where surface and subsurface waters are exchanged (Stanford and Ward 1988). Underwater springs commonly emerge where mountain valleys are compressed vertically by bedrock or pinched by valley walls. These spring fed reaches provide important bull trout habitat (Allan 1980; Shepard et al. 1984; Fraley and Shepard 1989; Ratliff 1992). Future shifts to groundwater pumping in bull trout drainages need to be evaluated for their potential effects on bull trout populations.

Water for 24% of the irrigated area in the Bitterroot River drainage is diverted from the Bitterroot River mainstem; the remainder is diverted from its tributaries (McMurtrey et al. 1972). Most of the tributaries have permanent flow in their upper reaches, but diversions and subsurface flows leave stream channels dry in their lower reaches during summer and autumn. Some of the streams, especially on the east side of the valley, have been diverted and have had their original courses cultivated, such that their channels are no longer recognizable (McMurtrey et al. 1972).

Irrigated croplands on the floodplains and terraces of the Clark Fork River and its tributaries receive little water directly from the Clark Fork River (MDNRC 1988). Most irrigated terraces or benches receive water from tributary streams that have been diverted at higher elevations. These diversions reduce flows in the tributaries and mainstem of the Clark Fork River substantially in summer. Summer flows in Warm Springs Creek, a bull trout core watershed, can be very low because of a diversion at Meyers Dam (for industrial water) and an irrigation diversion 2.5 miles below Anaconda (MDNRC 1988); sometimes lower reaches are almost completely dry. Irrigation withdrawal nearly dewaters the Clark Fork near Deer Lodge during dry years. Factors contributing to depressed bull trout abundances in the upper Clark Fork River drainage include severe reductions in flow, elevated water temperatures, and low dissolved oxygen concentrations during the irrigation season (MDNRC 1988). Median daily temperatures exceeded 19°C in the Clark Fork drainage 6 to 29% of the time from June through August, 1977-1982, depending on location. Maximum daily water temperatures exceeded 16°C for 81 to 89 days, and 20°C for 35 to 61 days, from June through September in 1992, depending on location (USGS 1993). Bull trout require water temperatures below 16°C.

Irrigation water storage systems were created on many tributary streams in the Bitterroot and Clark Fork drainages by increasing the storage capacities of natural lakes or creation of irrigation reservoirs. Operation of these systems changes natural hydrographs by reducing or eliminating winter flows, reducing peak discharges, and increasing flows during the irrigation season. Reductions in winter flows reduce winter habitat and can dewater bull trout redds. Increased streamflow during the irrigation season can benefit some stream sections, but this added water is eventually diverted from the channel, thereby providing no benefit to stream sections below the diversion.

In summary, diversion of surface waters for irrigation primarily affects bull trout and their habitats by reducing streamflows, increasing water temperature, and reducing or eliminating connectivity. Reduced streamflow lowers instream habitat complexity by reducing area of habitat available and eliminating access to shoreline cover. Water withdrawals for irrigation reduce instream flows, which increases water temperature. Water temperatures may be further increased via warmer irrigation return flows. Fine sediments and agricultural pesticides may be routed to stream channels in irrigation return flows. Reduced streamflows and irrigation diversion structures reduce and often eliminate connectivity among streams through physical blockages to fish movement. Direct mortality can occur to bull trout captured in irrigation water conveyance systems, and bull trout redds may be dewatered below irrigation storage facilities.

Dams

Dams have considerable effects on habitat within impounded reservoirs and in downstream river systems (Park 1977; USDI Fish and Wildlife Service 1981; Lisle 1982; Williams and Wolman 1984; Wesche et al. 1985; Andrews 1986; Marotz et al. 1996). Dams have been identified as a high risk to bull trout in the Middle Clark Fork, South Fork Flathead, and the Lower, Middle, Upper, and Kootenai (Table 2).

Reservoirs alter most or all natural riverine physical, biological, and ecological processes by changing streamflow regimes, sediment and nutrient loads, energetics, and biota (Ligon et al. 1995; Collier et al. 1997). Reservoirs typically store water during runoff, thereby reducing downstream flooding, disconnecting the river from its alluvial floodplain, and disrupting maintenance of natural habitats, floodplain productivity, and species diversity (Ward and Stanford 1995). Less frequent flooding and lower peak flows can change insect species composition, floodplain vegetation, reduce moisture storage and stability of soils, and reduce downstream channel widths. These effects can reach far beyond the immediate vicinity of the dam, sometimes extending downstream for more than 100 miles (Andrews 1986).

Downstream fish habitat is degraded below remote headwater reservoirs at which storage patterns are set in autumn and remain unaltered through winter because of their inaccessibility. Winter streamflows are often reduced significantly below these reservoirs during the time when streamflows are already at their annual minimum, thereby reducing availability of winter habitat, altering ice formation processes, and potentially modifying normal migration patterns.

Rapid fluctuations in dam releases, especially during low-flow periods, are common below hydropower dams. Resulting rapid fluctuations of downstream water levels tend to destabilize streambanks and can lead to increased bank erosion and lateral migration of the channel (Collier et al. 1997). The water pore pressure of the banks may exceed the cohesiveness of the bank materials when water levels fall rapidly, causing banks to fail. Accelerated bank erosion and lateral channel migration lead to channel widening and pool filling, homogenization of the instream habitat, loss of riparian vegetation, and possibly downcutting. Rapid and frequent discharge fluctuations also displace and strand fish and invertebrates on the dewatered stream margins, dewater cover associated with shoreline areas, and curtail biological productivity in the fluctuation zone (Marotz et al. 1996). During non-generation periods, bull trout redds may be dewatered. Unlike natural runoff events where streams stabilize in the interval between infrequent floods, peaking hydropower discharges are too irregular and brief to allow equilibrium conditions to develop.

Releases of sediment-free water from reservoirs generally scours or removes fine or poorly armored downstream bed materials, thereby coarsening the bed material and producing homogenous riffle habitats with few pools. Suitable spawning gravels may disappear. In extreme cases, releases of sediment-free water downcuts channels, increases bank erosion, and lowers water table levels in adjacent floodplains, thereby changing vegetative assemblages (Galay 1983). Recent flood flow releases from Glen Canyon Dam have been touted as a solution to bank erosion below the dam (USEPA 1997), and in some situations it may be. In the Glen Canyon case, there are two major tributaries to the Colorado River just below Glen Canyon Dam. When major flood flows are released, they act to redistribute some of the sediment load of these tributaries onto higher banks and floodplains. Below most dams, however, there are no such sediment laden tributaries, and the release of high flows would further erode the bed and banks with no benefit to either aesthetics or fish (Randy Peterson, USDI Bureau of Reclamation, personal communication).

Reservoirs are occasionally drawn down to levels that allow releases of stored sediments and other pollutants. Two recent examples illustrate the seriousness of these effects on downstream fish and habitats. Draw-down of Ruby Reservoir by irrigators in late summer of 1994 released long-stored sediments downstream into the Ruby River near Sheridan, Montana (Gary Fritz, Montana Department of Natural Resources and Conservation, personal communication). An estimated 8,000 to 10,000 fish (mostly of reservoir origin) were killed and fine sediments up to 1 ft deep were deposited in the river. Agreements with water users were negotiated subsequently to minimize the potential of a recurrence. A more recent example occurred when the water level in Milltown Dam Reservoir near Bonner, Montana, was lowered by about 8 ft to prepare for excessive ice flows in February, 1996 (Dennis Workman, Montana Fish, Wildlife and Parks, personal communication). Downcutting through reservoir sediments containing high levels of copper, zinc and cadmium caused downstream concentrations of these metals that exceeded recognized standards for chronic fish toxicity.

Reservoir water level fluctuations sometimes create migration barriers at the confluence of tributaries entering the reservoir. Sediments discharged from tributaries form alluvial fans (Kuiper 1965) that are left perched above the water level when reservoir elevations are drawn down. If the deposits are made up of coarse materials, all tributary inflows may percolate through them below the surface, creating a migration barrier for bull trout. A similar phenomenon can occur at the confluence of tributaries downstream from reservoirs. Elimination of flushing discharges allows alluvial fans to form at the mouths of these tributaries as well (MBTSG 1996f).

Reservoir water level manipulations degrade littoral rearing habitats by either exaggerating or eliminating natural water level fluctuations. Excessive fluctuations directly increase shoreline erosion or enhance it indirectly by eliminating shoreline vegetation. Habitat alterations in reservoirs are documented in Status Reports for the Middle Kootenai (MBTSG 1996f), Lower Clark Fork (MBTSG 1996c) and Flathead Rivers (MBTSG 1995b). Manipulation of Flathead Lake levels in summer and autumn by Kerr Dam has caused accelerated erosion of shorelines during windstorms (Lorang and Stanford 1993). Before the dam was in place, lake levels typically receded before mid-summer and autumn wind storms began, and wave energy associated with the storms was dissipated on lower beaches rather than on the upper shoreline. Where present, drift logs and forest vegetation on the shoreline of the delta of the Flathead River reduced the effects of wave erosion locally (Lorang and Stanford 1993).

Water temperature regimes below reservoirs usually do not correspond to pre-impoundment conditions, but they can be either higher or lower than normal depending on the season, depth, and volume of the reservoir, and the depth(s) of water intakes. The altered discharge temperatures change ice formation patterns, timing and duration of seasonal biological events (e.g., migration, spawning, emergence, growth rates) aquatic biodiversity, food web interactions, and riparian habitat as described in the section on Irrigation.

In summary, dams can affect bull trout and their habitat in many ways. Storage of water and sediments during high runoff periods affects floodplain dynamics, channel substrates, channel capacity, migration of bull trout into tributaries, and habitat complexity. Storage of water during low flow periods reduces winter habitat quantity and quality, increases stream water temperatures, and alters migration patterns. Frequent fluctuation of dam discharges reduces streambed, shoreline, and bank stability; alters water temperatures and migration patterns; and may cause direct mortality through stranding of fish on stream margins and dewatering of bull trout redds. Occasional release of sediments and other pollutants stored in reservoir sediments affects channel substrate and impairs water quality.

Timber Harvest - Upland

Forestry practices have been identified as a high risk factor in all bull trout restoration/conservation areas in Montana (Table 2). Timber management includes felling, yarding, fire hazard reduction, brush removal, thinning, site preparation, revegetation, chemical treatments, and road construction and maintenance. These types of activities occur in both riparian zones and upland areas. Because of the potential for riparian timber harvest to directly influence stream habitats, it is addressed separately in the following section of this report. Similarly, the effects of forest road construction and maintenance are considered separately (see Secondary Roads), although they are usually closely tied to timber management. This section addresses the effects of timber harvest in upland areas on stream habitat.

Upland timber harvest is the predominant land management activity in most bull trout restoration/conservation areas. It is often conducted in close proximity to critical core areas and nodal habitats, especially the second through fourth order channels where most bull trout spawning and rearing takes place. These streams account for the majority of the total stream length available in most western Montana watersheds. Where these streams are not directly used by bull trout, they are nevertheless important to habitat quality in downstream areas.

Vegetative crown cover is often extensive in drainages of second through fourth order streams. Manipulation of this canopy can influence a stream's energy supply, local runoff patterns, erosion, and sedimentation; effects may be more obvious on smaller streams than on larger ones. Bull trout spawning, incubation, and rearing occur in areas most susceptible to effects resulting from canopy manipulation.

Increased water and sediment yields can accelerate bank erosion of alluvial channels occupied by bull trout and cause mass wasting, bedload deposition, channel braiding, and overall channel instability. Channels thereby become wider, shallower, and warmer and have fewer pools, more riffles, and greater solar insolation. Higher water temperatures limit bull trout distribution (see Habitat Requirements of Bull Trout). In some situations, excess sediment aggradation blocks fish migrations if all surface flows percolate into the coarse deposits.

Upland timber management has the potential to significantly affect bull trout habitat by altering runoff patterns. Regional differences make it difficult to predict specific hydrologic effects (Swanston 1991), but forest management activities can affect bull trout habitats by altering normal frequencies of high or low streamflows. Timber harvest activities can influence snow accumulation and melt rates (Berris and Harr 1987; Troendle and King 1985), evapotranspiration rates (Harr et al. 1979), and soil infiltration and transmission routes (Cheng et al. 1975; deVries and Chow 1978). Timber harvest and related watershed disruptions, most notably clearcutting, have been linked to increased water yields, bedload movements, and more frequent flooding or scour events (Sullivan et al. 1987; King 1989; Chamberlain et al. 1991). Intensity of ground disturbing activity is positively related to water yields, and quality of bull trout spawning/incubation and juvenile rearing habitats is inversely associated with ground disturbance and water yields (Weaver and Fraley 1991). Most bull trout populations remaining in the Bitterroot River drainage occur in the least disturbed watersheds (Clancy 1993) and absence of bull trout in the Coeur d'Alene drainage may be related to increased water yields and channel instability related to timber harvest activities (Cross and Everest 1995).

Upland timber harvest and associated activities significantly influence the availability of sediment to streams (Ice 1979; Brown 1983; Chamberlin et al. 1991), and fine sediments adversely affect salmonids (Cordone and Kelley 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). Forest management activities have been shown to directly affect bull trout spawning, incubation and juvenile rearing habitat quality in the Flathead drainage (Shepard et al. 1984;

Weaver and Fraley 1991). Correlations exist between substrate composition and management activities and estimates of bull trout survival, distribution, and abundance (Shepard et al. 1984; Leathe and Enk 1985; Thurow 1987; Weaver and Fraley 1991).

Burning associated with some silvicultural activities can increase water yield and sediment production by exposing mineral soils. Intense burns that expose mineral soil can cause formation of a water repellent layer that reduces infiltration and increases runoff. The use of forestry chemicals (pesticides, fertilizers, and fire retardants) can result in both acute direct (mortality) and chronic or delayed indirect effects (reduced growth, reduced survival, reduced forage base) on salmonids and their habitat.

Concern over forest management practices prompted the 1987 Montana Legislature to pass House Joint Resolution 49, calling for assessment of effects of forest management practices on watersheds in Montana. A technical committee was formed, which in 1989 produced a revised list of best management practices (BMPs) designed to provide guidance for minimum water quality standards for forest operations in Montana (Frank 1994). A team audit process is used to evaluate application and effectiveness of the BMPs. Application of BMPs that met or exceeded requirements increased from 78% in 1990 audits, to 87% in 1992, to 91% in 1994 (Frank 1994), and to 92% in 1996 (Mathieus 1996). However, a subset of the practices considered to be of highest risk to the stream met BMP requirements in only 81% of the cases during 1996. Of the 44 timber sale areas audited during 1996, 15 (34%) had at least one major/temporary or one minor/prolonged deleterious effect. A mean of three deleterious effects per site was found (Mathieus 1996). It is not possible to ensure that a recently applied BMP will protect water quality and aquatic habitat adequately based solely on qualitative assessments or site visits. Quantitative monitoring and targeted research are necessary to evaluate effectiveness of BMPs. The 1996 audit teams also evaluated application and implementation of the Montana Streamside Management Act. There were 29 infractions noted during the audits (Mathieus 1996).

In summary, the most serious effects of upland timber management on bull trout and their habitat include : reduced pool quality, habitat complexity, channel stability, and bank stability caused by increased peak flows; reduced substrate quality resulting from increased sediment delivery; increased water temperatures and reduced groundwater inflows produced through alteration of natural flow regimes; and reduced connection between stream systems and blockage of migratory corridors caused by channel aggradation

Timber Harvest - Riparian

Removal of riparian vegetation affects fish habitat by leading to decreases in large woody debris recruitment, stream shading, litterfall, streambank stability, and protection from erosion (Hicks et al. 1991). The magnitude and intensity of these effects on bull trout habitat are influenced by multiple factors, including type and degree of timber management, existing structure of the riparian area, local geomorphology, and condition of the stream/riparian complex as a result of past natural events and anthropogenic activities. All of these factors must be considered when evaluating potential effects of timber harvest in riparian areas on bull trout populations. Forestry practices have been identified as a high risk factor in all bull trout restoration/conservation areas in Montana (Table 2).

Removal of riparian vegetation reduces stream habitat complexity by decreasing the amount of large woody debris available for recruitment into the stream. Large woody debris helps form pools, regulate sediments, and create complex fish habitat (Bisson et al. 1987; Bilby and Ward 1989). Reductions in large woody debris can diminish channel stability. Input of large woody debris to stream channels generally occurs within one tree height from the channel edge (FEMAT 1993). Removal of trees from this area results in a reduction of large woody debris recruitment to the stream channel. The probability of a tree falling into a stream in order to provide large woody debris is a function of the tree's height and distance from the stream (Robison and Beschta 1990). Studies suggest that approximately one-third of the trees within one tree height will ultimately be recruited as large woody debris and that 80% of large woody debris originates within 0.62 tree heights of the stream channel (McDade et al. 1990; Van Sickel and Gregory 1990). The size and density of large woody debris needed to remain in place and function properly varies according to stream size and morphology. Generally, as stream size increases, the size of large woody debris available from adjacent stands must increase proportionately (Bilby 1985).

Stream shading by canopy cover is one of several factors influencing stream water temperatures. Other factors include elevation, aspect, season, and groundwater (Sullivan et al. 1990; Beschta et al. 1987; Adams and Sullivan 1990). If canopy cover is removed, water temperatures exceeding the tolerance of bull trout may result, especially in low elevation streams during mid-summer (Sullivan et al. 1990). Loss of overhanging insulation, coupled with increased radiative cooling, also reduces stream water temperatures in winter (Hicks et al. 1991) leading to more rapid ice formation and increased likelihood of freeze-up. Resident bull trout avoid habitats with extensive amounts of anchor ice (Jakober 1995).

Root systems of riparian vegetation are important in maintaining bank integrity and stability of some stream channel types (Swanson et al. 1982). Decomposition of root masses after harvest of riparian trees can lead to decreased channel stability, accelerated erosion and sediment delivery rates, lateral channel migration during flood events, and reductions in the quantity and quality of bull trout cover (undercut banks and deep pools).

Riparian areas buffer sediment delivery to streams from upslope areas (Burroughs and King 1989; Ketcheson and Megahan 1990), but timber harvest there may limit this capability. Slope, soil type, and distances of sediment sources (e.g., roads, skid trials, cross drains) from the stream contribute to the probability of sediment from upland sources reaching stream channels. Yarding and skidding within riparian areas can result in soil disturbance and compaction, potentially increasing fine sediment delivery. Understory vegetation and coarse woody debris on the ground (either naturally occurring or placed in slash filter windrows) may decrease sediment delivery.

In summary, the most serious effects of timber harvest in riparian areas on bull trout and their habitat include increased summer and decreased winter water temperatures resulting from removal of shading and insulating vegetation; reduced large woody debris

recruitment caused by removal of source vegetation; reduced pool quality, habitat complexity, channel stability, and bank stability arising from removal of vegetation and bank erosion; and reduced substrate quality caused by increased sediment delivery.

Secondary Roads

Secondary roads are typically single-lane, unpaved roads used by passenger vehicles, logging trucks, and heavy equipment. Forestry, and road systems related to it, were identified as a high risk to bull trout in all bull trout restoration/conservation areas. Secondary roads are not limited to forest uses, but also include access to ranches, residences, mining operations, and recreation sites.

Forest roads can cause serious degradation of salmonid habitats in streams. Numerous studies during the past 25 years have documented the changes caused by roads and related activities. Roads modify natural drainage networks and accelerate erosion, thereby affecting streams through sediment loading and alteration of runoff characteristics and channel morphology. Roads cause direct and indirect changes in streams that affect critical bull trout habitat components.

Construction of a road network can lead to significant and long-lasting increases in erosion rates in a watershed (Reid and Dunne 1984; Everest et al. 1987). The contribution of sediment per unit area from roads is often much greater than that from all other land management activities combined (Gibbons and Salo 1973). Sediment delivery generally occurs through mass movements or surface erosion (Swanston 1991). Failures of stream crossings, diversions, fill washout, and scour at culverts also contribute sediments as a direct result of roads.

On steep terrain, mass movement is often the primary means of sediment delivery from roads. The most common causes are poor road location, improper placement and construction of road fills, inadequate or improper road maintenance, insufficient culvert size, and interception and concentration of surface or sub-surface waters. Forest roads can substantially increase the frequency of mass soil movements (Everest et al. 1987). Even though only a small percentage of the land base is affected by road-related failures, a large proportion of a stream can be affected by direct sediment input and transport downstream.

Surface erosion from roadbeds, drainage ditches, and cut-and-fill slopes can be the primary source of sedimentation to streams, especially in areas with sensitive soils (Burns 1970; Gibbons and Salo 1993). Sediment yields from roads increase with the amount of traffic (Reid and Dunne 1984). The percentage of fine sediment in spawning gravels increased above natural levels in the Clearwater River drainage, Washington, where roads made up more than 2.5% of basin area (Cederholm et al. 1981). Application of BMPs can reduce sediment delivery from roads to stream channels, but 1994 forest BMP audits in Montana showed that lack of adequate drainage on new and existing roads (BMPs improperly applied or not applied) continued to be the primary effect on water quality (Frank 1994).

Road systems can change relations between precipitation and runoff, and resulting changes in storm hydrographs can affect sediment deposition and channel stability. An increase in peak flows followed road construction in Oregon coast range drainages (Harr et al. 1975). Surveyors report that old road systems in some Flathead drainage watersheds act as first-order stream channels. Most of these developed when intercepted groundwater was concentrated in channels formed by equipment use and soil compaction. Some of these channels flow perennially, whereas others are intermittent or ephemeral. These channels increased the drainage density in these watersheds (the amount of stream channel in an area) and enhanced efficiency of water delivery during runoff events. The resulting increases in water yields cause channel instability downstream in bull trout spawning and rearing areas (Weaver 1988, 1992).

Many secondary roads are located adjacent to stream channels. Roads encroaching on stream channels cause channelization, losses of channel morphology and dynamics, and chemical runoff. These effects are discussed in the Transportation Systems section.

Roads can adversely affect bull trout migrations, spawning, incubation, and rearing through physical alterations to sediment loading rates, channel morphology, and riparian conditions. Improperly designed crossings, especially culverts, interfere with migrations of adults and juveniles. Extreme sediment deposits can reduce or eliminate surface flows, thereby blocking fish movements. Sedimentation reduces abundance and quality of spawning gravels and habitats by causing channel braiding, increased width:depth ratios, increased bank erosion, and reduced pool volume. Successful incubation depends on interstitial flow within the gravel to provide oxygen and remove metabolic wastes. If gravel interstices are filled with fine sediments, flows are reduced and embryo mortality can occur. Fry emergence is also hampered by excess fine materials. Developing embryos can be destroyed by scour resulting from high flows. Reduced streambed particle sizes and increased embeddedness decrease physical space available for juvenile rearing. This factor is especially important during winter. Riparian vegetation and large woody debris provide important components of juvenile rearing habitat including shade, food production, channel stability, and channel structure. Road construction near streams often results in direct removal of riparian vegetation. Roads also allow easier human access to streams.

In summary, the most serious effects of secondary roads on bull trout and their habitat include reduced substrate and pool quality resulting from increased sediment delivery to stream channels through poor surface drainage or mass failure; reduced habitat complexity, pool quality, bank stability, and channel stability caused by removal of vegetation, alteration of runoff patterns, and channel alteration from road encroachment; and increased water temperatures and reduced groundwater inflows associated with removal of vegetation, alteration of runoff patterns, and interception of subsurface flow.

Recreation

The effects of recreational use and development of recreation facilities on fish habitat have received little study, but generally appear to be similar in type, but not necessarily magnitude, to the effects of other management activities (Clark and Gibbons 1991). Effects of recreational use can be similar to those associated with riparian and upland timber harvest, livestock grazing, and road construction. The effects of recreational developments (e.g., golf courses, developed parks) along larger river corridors are similar to those discussed in the

Residential and Industrial Development section of this report. Impacts to bull trout habitat from recreational development have been identified in Montana. However, these are not considered to pose a high risk to bull trout in any of the 11 restoration/conservation areas (Table 2).

Recreationists are often drawn to water, and as a consequence frequently affect stream habitats. Developed recreation sites, such as campgrounds and trailheads, are usually located adjacent to streams and lakes. Effects of developed sites on riparian vegetation are similar to effects of riparian timber harvest, and include removal of both overstory and understory layers, mortality of overstory, loss of tree vigor, mechanical injury, root kill, and loss of ground cover (Settergren 1977). These effects can reduce stream shading, streambank cover, recruitment of large woody debris, and bank stability. Localized effects to riparian soils increase sediment delivery to stream channels and indirectly influence site vegetation. Human waste facilities and applications of pesticides to control vegetation and insects can affect water quality. However, these effects can be greatly reduced through proper planning and location (Clark and Gibbons 1991). To a lesser extent, effects also occur at dispersed recreation sites (remote campsites, off-highway vehicle and hiking trails). Lake-based recreation can affect water quality through contamination from human waste facilities and introduction of petroleum pollutants from powerboats.

Roads and trails (foot, horse, and off-highway-vehicle) used for recreation or access to recreation affect bull trout habitats similarly to secondary roads constructed for other purposes. Trails can cause erosion, but usually not as severely as roads, unless they are poorly maintained or located. Roads constructed for other activities (e.g., timber harvest) are often overlooked in considering recreational effects. Instead of being reclaimed, these are often left open to provide recreational access and allow continued degradation of bull trout habitats.

Developed downhill ski areas can affect stream habitats through vegetation removal, access road construction, and snowmaking. Although developed ski areas are not widespread across western Montana, their effects on bull trout habitat can be locally significant (USDA Forest Service 1995). Initial vegetation removal over large areas is similar to upland timber harvest. However, revegetation is mostly limited to grasses and shrubs, precluding recovery of these areas in relation to water yield. Contouring of ski runs and construction of lift-base areas can deposit large volumes of cut-and-fill material close to stream channels. Snowmaking can potentially affect the hydrologic regime of the affected watershed and associated aquatic habitats in unique ways. These effects can be similar to some reservoir operations, but on a smaller scale. Water is sometimes diverted near the bottom of a drainage, pumped to the upper end of the drainage, and released there as artificial snow. The potential effects of increased sedimentation are similar to those described for secondary roads, but greater in magnitude. Snowmaking occurs during winter when streamflows are at their lowest point. Additional water depletion at this time can seriously affect winter habitat and ice formation. Snowmaking adds to the existing snowpack and can increase peak flows from a drainage during snowmelt, thereby increasing erosion and channel scour.

Any recreational use of upland and riparian areas will have some effects on stream habitats, but these are likely to be minor compared to those of roads, timber harvest, livestock grazing, and other human developments. As recreation increases, the potential for adverse effects to stream habitats also increases.

In summary, effects to bull trout and their habitat from recreation are similar to impacts from other land management activities. Streamside vegetation removal for recreation facilities can reduce large woody debris and increase stream temperatures. Introductions of pesticides and human or other wastes degrades water quality. Increases in sediment delivery from recreational development reduces substrate quality, habitat complexity and pool quality. Snowmaking operations for ski developments reduce winter stream flow and channel stability.

Transportation Systems

Major transportation systems are multi-lane, paved highways (as opposed to the smaller, unpaved secondary roads) and railroad corridors. They can potentially affect bull trout habitat and they often follow river or stream corridors. For example, portions of the Upper Clark Fork River upstream from Bonner are confined between two highways and two railroad corridors (MBTSG 1995d). Transportation systems have been identified as a high risk in three bull trout restoration/conservation areas: Middle Clark Fork, Middle Kootenai, and Lower Kootenai (Table 2). In addition to these recovery areas, most of the larger river systems in Montana have major transportation systems running along their corridors. Because these rivers are also the nodal habitats of bull trout, the effects of transportation systems are direct and continuous, both temporally and spatially. Our review of the effects of transportation systems on bull trout habitats is general in nature because responses of individual stream systems to them are highly variable. Our review draws on material found in Dunne and Leopold (1978), Meehan (1991), and MacDonald et al. (1991).

Little specific information exists on the effects of transportation system construction on bull trout habitat, primarily because most of these systems were constructed long before bull trout were a concern. However, a direct, positive correlation exists between the construction of major transportation systems and rates of deep lake sediment accumulation in lakes in the Flathead basin (Spencer 1991). Sediment deposition increased about 3 to 10 fold over background levels during periods of road and railroad construction. Because sediments reach these lakes via major rivers in the basin, we presume that these rivers also experienced increased sedimentation, and associated deleterious effects, during periods of major road and railroad construction.

Effects of transportation systems on aquatic habitats are highly variable, depending on the type of stream and valley involved. Effects can be very different on rivers naturally confined within canyons compared to those traversing broad alluvial valleys. All effects discussed in the section on Secondary Roads also apply to major transportation systems, but differ in scale and location. Most major highways and railways parallel large rivers and therefore directly affect them, their riparian zones, and nodal habitats over long distances.

Transportation systems usually involve extensive channel modifications including bank hardening, constriction, channelization, and relocation. Although the effects of channel modifications are highly variable, stream instability, bank erosion, sediment deposition, and lateral stream migration often result. Direct effects include loss of total stream length and loss of pools. Straightening tends to homogenize habitat, transforming entire reaches into higher gradient riffle with unsorted channel materials, consistently high stream velocities, and insufficient depth during low flow periods to support a diverse aquatic community (Corning 1975). Where the stream has downcut or is placed within hardened banks, riparian and wetland vegetation is lost, reducing overhead cover, shading, and food sources. Numerous studies have demonstrated the detrimental effects of stream channelization on macroinvertebrates and fish (Brookes 1988).

Maintenance of roads and highways can result in the delivery of fine sediments, salts, and organic compounds directly to stream channels. A positive correlation existed between maintenance sanding of Highway 12 and erosion along Lolo Creek on the Lolo National Forest, Montana (Riggers and Furrow 1994). Maintenance sanding caused an increase in fine sediments in the substrate of this stream. Effects of fine sediment loading are described in the section on Secondary Roads. Sporadic delivery of road salts can depress system productivity as well as cause direct mortality of aquatic life at high concentrations. Organic materials used for dust abatement, such as oils or lignin, can be toxic (oils) or depress dissolved oxygen concentrations in streams (lignins). Chemical and petroleum spills are a serious concern because these products are frequently conveyed along major transportation systems. Two recent examples are the 2000-gallon diesel fuel spill into Parmenter Creek (Kootenai River drainage) and the illegal disposal of up to 100 gallons of petroleum in the Little Bitterroot River (T. Weaver, Montana Fish, Wildlife, and Parks, personal communication).

During runoff events, contaminated runoff from highways can deliver toxins to stream ecosystems. High effluent concentrations delivered to stream channels can be toxic to aquatic life and cause eutrophication (see the section on Agriculture).

In summary, the most serious effects of major transportation systems on bull trout and their habitat include channelization, bank instability, and loss of riparian vegetation, which result in degraded pool quality, reduced habitat complexity, reduced large woody debris recruitment, increased bank instability, and increased water temperatures. Poorly designed culverts and stream crossings may block fish passage, reducing connectivity among systems. There is also the potential for degraded water quality ensuing from chemical spills and polluted runoff and loss of coldwater refugia from interception of groundwater by deep cuts into hillslopes.

Fire Management

Recent emphasis has been placed on the role of fire as a disturbance regime on western landscapes, and on how fire suppression has altered vegetation patterns in forested communities in these areas (Agee 1990). Fire suppression has led to increased fuel loading in low elevation forests in the interior western states and increased the potential for large catastrophic fires. Past timber harvest has likely compounded the problem by altering forest composition and promoting large even-aged timber stands (Lee et al. 1996). The potential for catastrophic wildfire was identified as a risk to bull trout in three bull trout restoration/conservation areas in Montana: Bitterroot, Middle Kootenai, and Upper Clark Fork (Table 2).

Fire has both direct and indirect effects on aquatic systems. Direct effects include increased water temperature and short term changes in water chemistry (Minshall et al. 1989; Minshall and Brock 1991). Indirect effects include changes in hydrologic regime, debris loading, sediment input, and riparian cover (Minshall et al. 1989; Minshall and Robinson 1993; Bozek and Young 1994; Young 1994), which occur over extended periods. Catastrophic fires have caused direct mortality of fish (Minshall and Brock 1993; Bozek and Young 1994; Rieman et al. 1995); however, fish mortality was not uniform in these streams. Effects of fire on aquatic systems tend to be most pronounced in small watersheds (Minshall et al. 1989). Monitoring of larger streams (> fourth order) in Yellowstone National Park showed few definitive relationships between fire intensity and post-fire variation in hydrologic regime, stream habitat, and water chemistry (Jones et al. 1993). These authors concluded that the changes observed did not negatively affect fish populations in the monitored streams.

Effects of fire on streams is also related to intensity of the fire and extent of burned areas in the watershed (Minshall et al. 1989). Small watersheds tend to burn extensively or not at all, while larger watersheds tend to burn only partially (Minshall and Brock 1993). As the size of the watershed increases, larger percentages remain unburned, leaving larger percentages of the catchment to dissipate effects of the fire (Minshall and Brock 1993). High gradient stream reaches are more affected by fire caused changes in hydrologic regime and erosion processes than are low gradient streams. In Yellowstone National Park, high gradient streams in burned watersheds showed major changes in cross section morphology, while low gradient streams in burned watersheds remained relatively unchanged (Minshall and Robinson 1993).

Historically, fires were a natural component of the disturbance regime for aquatic systems. Large fires provided woody debris, magnified hydrologic events, and provided additional sources of coarse substrate, which maintained productive stream habitats (Reeves et al. 1995). Some effects of large fires can be detrimental to stream systems over the short term; however, these effects occur as acute inputs (as opposed to chronic inputs often associated with land management activities) and contribute to maintenance of productive stream habitats over time (Reeves et al. 1995). This disturbance regime likely maintained heterogeneity of stream habitats over large areas.

Although fish populations may be altered by immediate effects of intense wildfire through mortality or displacement, recovery of populations occurs rapidly (Lee et al. 1996). Rieman et al. (1995) found that both bull trout and redband trout, *Onchorynchus gairdneri,* numbers were greatly reduced or eliminated from some intensively burned stream reaches on the Boise National Forest, Idaho, immediately following intense wildfires. However, recovery of these populations occurred rapidly. Fish were present in the defaunated reaches within 1 year, and numbers approached those in unaffected stream reaches within 1 to 3 years. In some stream reaches, high juvenile densities suggested that recruitment may have benefited from the effects of the fires.

Two mechanisms are important for rapid recovery of fish populations following intense wildfire (Rieman et al. 1995). Local refuges provided by unburned or lightly burned stream reaches and tributaries provide refugia for fish and also provide a local source of fish for recolonization. Where refuges exist in close proximity to defaunated areas, recolonization occurs rapidly. The other mechanism for recovery is provided by complex life history patterns. Migratory life histories ensure portions of a population are distributed across larger areas both spatially and temporally. Recovery of bull trout in defaunated stream reaches was likely due to a portion of the population which occupied areas outside the burned watersheds and returned to spawn following the wildfires. Similar recovery of a rainbow trout population following intense wildfire was observed in Beaver Creek, Montana (Novak and White 1990). The two mechanisms for short term recovery of fish populations affected by wildfire reinforce the importance of well connected, complex habitats and also the importance of maintaining migratory life history strategies (Lee et al. 1996).

Increased emphasis has recently been placed on the use of intensive forest management to reestablish historic vegetative patterns and disturbance regimes such as wildfire. Use of timber harvest and other activities has been proposed to simulate historical fire patterns and to reduce the risk of catastrophic fires, sometimes being justified to reduce risk to sensitive aquatic species (Lee et al. 1996). Increasing timber harvest to minimize the risk of large fires will likely increase the well established negative effects on streams and fish populations (Rieman et al. 1995). The risk of this active management may outweigh the risks associated with large wildfires (Lee et al. 1996).

In summary, the local effects of wildfire on bull trout habitat are variable and difficult to predict, as they vary depending on site conditions, fire behavior, and prior history. Intense fire can result in increased water temperature, accelerated nutrient and sediment loading, combustion of woody debris, and temporary declines in fish populations. However, these responses are partly compensated by post fire increases in groundwater discharge and recruitment of large woody debris. Moreover, as a consequence of heterogeneous behavior and effects, even large fires typically leave areas of high quality stream habitat that function as refugia from which bull trout and other aquatic taxa rapidly repopulate surrounding areas.

Cumulative And Interactive Effects Of Habitat Alteration

The preceding review of the effects of various land management activities does not address the many ways that such effects interact and accumulate in the environment. Bull trout habitats and populations are subject to a wide array of natural and human processes (Fraley et al. 1989). These processes and their primary and secondary effects interact in complex ways that are difficult or impossible to predict or quantify on a case by case or regional basis. However, it is often possible to discern general patterns, or syndromes of response, that tend to result from typical human alterations of ecosystems (Karr 1991; Schlosser 1991; Richards et al. 1996; Roth et al. 1996). In general, it is evident that many of the landscape level changes made in the range of the bull trout since the arrival of Europeans have been detrimental to the species. Many of these changes are irreversible and have long-term legacies that will affect bull trout survival and recovery for many decades or centuries, or that will continue as human activities spread to new areas and human population increases in the region (Steedman and Regier 1987; Frissell 1993a, Frissell and Bayles 1996).

In the individual basin status reports, the MBTSG attempted to assess the relative significance of various land and water management activities to specific bull trout populations. We did not, however, directly evaluate the interactive and cumulative effects of these activites. As important as this task is, it represents a formidable and time-consuming scientific problem (Rhodes et al. 1994; Montgomery et al. 1995; Frissell and Bayles 1996). No cookbook exists to accomplish such an analysis, and potentially useful techniques require considerably more resources than those that we have available.

Interactive Effects Of Habitat Change And Introduced Species

Interaction with introduced species is a principal way in which the adverse effects of habitat alteration on bull trout can be compounded (MBTSG 1996a). In general, artificial habitat disruption increases the vulnerability of freshwater fish assemblages to successful invasion by introduced fishes (Baltz and Moyle 1993; Moyle and Sato 1991). This is especially true for coldwater, salmonid-dominated assemblages if the potential invading species evolved in ecosystems with warmer thermal regimes and if the effect of human disturbance is to increase water temperatures. For example, brook trout, *Salvelinus confluentus,* may be favored over sympatric bull trout in habitats where summer water temperatures or fine sediment levels are elevated above historical levels (Clancy 1993). Generally, brook trout distributions are more extensive, and bull trout are less abundant, in drainages with more extensive human disturbance (Clancy 1993; Frissell et al. 1995; Huntington 1995). Alteration or artificial stabilization of stream flows for power generation, flood control, water storage, or flow diversion can make stream habitat more vulnerable to successful colonization by invading or stocked non-native species (Baltz and Moyle 1993; Ward and Stanford 1995). Similar interactive effects of habitat alteration and invasion can occur when seasonal hydrologic regimes of lakes and reservoirs are changed by flow regulation and dam operations.

Land management activities often directly increase the likelihood of introduction of non-native species by humans. For example, the present distribution of brook trout in the Bitterroot drainage appears to be related to the locations of road crossings over streams during the period that brook trout were widely stocked (Clancy 1993). It can, therefore, be difficult to distinguish the direct effects of historical stocking from the indirect effects of habitat alterations in explaining the present distributions of introduced fishes (MBTSG 1996a). Historical stocking records are incomplete, and much illegal stocking has occurred, especially where roads provide easy access to streams and lakes. Roads also provide access for poachers who harass or deliberately kill adult bull trout and for recreationists who unintentionally disturb or stress fish.

In some cases, including Flathead Lake, introduction of non-native fishes and other organisms (e.g., *Mysis*), has triggered radical changes in food webs, resulting in severe and rapid declines of previously abundant fishes (Fraley et al. 1989; Beattie and Clancey 1991; Spencer et al. 1991). A recent example in Flathead Lake is the decline of adfluvial bull trout (Weaver 1994). Similar ecological and food web changes associated with introduced species may have affected migratory populations of bull trout in rivers, but these interactions have not been studied.

The presence of introduced species in an ecosystem increases the need for habitat protection and restoration. When brook trout, brown trout (*Salmo trutta)*, lake trout, or any other potentially dominant species is present or has access to a particular stream, river, or lake, the ability of bull trout and other native species to survive and recover from habitat alterations can be irreversibly compromised. Any change in the habitat or ecosystem that temporarily favors establishment or proliferation of a non-native species can prevent or delay recovery of native species or increase the probability of their extinction. A minor habitat alteration that may not have directly threatened a native species under otherwise natural conditions can be the catalyst that allows undesireable introduced species to expand, diversify, and permanently colonize new habitat. A habitat change that alters the structure of a bull trout population or decreases its abundance can reduce predation on introduced fishes or open up ecological niches for introduced fishes that were previously occupied by bull trout.

Elimination of non-native fishes from most bull trout ecosystems is not likely to be feasible (MBTSG 1996a). Accordingly, management of watersheds and aquatic habitats to discourage the proliferation of introduced species and encourage the persistence or recovery of native bull trout populations becomes even more critical. In general, this means maintaining and restoring conditions and processes that minimize artificial summer warming of surface and ground waters, fostering groundwater to surface water exchange, maintaining and restoring natural floodplain integrity and channel complexity and stability, and minimizing artificial infusion of sediments and nutrients to streams and lakes. In other words, maintaining the best attainable water quality and habitat conditions and least-altered flow regimes is required, given the natural potential of the stream.

Population Connectivity And Habitat Fragmentation

Well-distributed and interconnected populations of bull trout and other salmonid fishes across the landscape are needed to maintain their long-term productivity and viability (Rieman and McIntyre 1993; Rieman et al. 1993). Metapopulation structure, in which natural movement and interbreeding of a few individuals among spatially discontinuous populations confers demographic and genetic advantages to the entire network of population patches, appears to be important for long term survival of the bull trout (Rieman and McIntyre 1993). This population pattern is likely common among many species of stream fishes and other organisms. It allows a species to persist in an environment where occasional extirpation of local subpopulations can occur from natural disturbances because individuals can move from the remaining subpopulations to recolonize the habitat as it recovers. This strategy appears to be highly successful where natural disturbance events occur in localized patches across the landscape, but where some habitats always remain undisturbed to act as local refuges to recolonize nearby areas (Rieman and McIntyre 1993; Frissell 1993b). However, species exhibiting this strategy can be highly vulnerable to regional extinction under three distinct kinds of pressures, and there is evidence that bull trout metapopulations suffer from all three of these effects.

First, rapid extirpation or regional collapse of a species can occur when widespread and persistent or synchronous habitat deterioration or other source of mortality occurs. In these instances, all populations are depleted simultaneously, and none can function as source areas to recolonize nearby areas. Second, such metapopulation systems can be highly vulnerable to processes that selectively depress or destroy the most productive, stable, or centrally located source populations in the network. Loss of these core populations results in greater rates of extinction among outlying "satellite" populations that are dependent on core populations for their persistence. This can lead to a relatively sudden collapse of the species across its range. Productive core populations can be associated with watersheds or habitats that, in their natural state, are resistant to the stresses of floods or droughts (e.g., spring-fed streams on the floodplains of major rivers). Loss of core populations by direct human alterations of these habitats (e.g., by depletion of groundwater sources, sedimentation of spawning habitats, or perhaps introduction of brook trout) can render remaining populations highly vulnerable to natural environmental fluctuations. Third, metapopulation systems can be jeopardized by fragmentation of formerly connected networks into smaller, more isolated units. Fragmentation can result from habitat changes that limit numbers of emigrant individuals (e.g., by reducing survival and density within source populations) or reduce survival rates of emigrants as they traverse corridors between population patches. Dams, diversions, and dewatered reaches directly fragment bull trout populations. Such barriers often create "sinks" that allow migrating fish to move through them seasonally (usually downstream during high water) but prevent their return to natal tributaries to reproduce. Less obvious barriers, such as hostile habitat conditions or increased exposure to predators, can also reduce effective movement of bull trout among habitat patches in a basin. These barriers increase the likelihood of local extirpations of bull trout populations and reduce the probability of subsequent re-establishment by recolonization.

Many small, headwater habitats are now too fragmented and isolated from neighboring habitats to sustain viable bull trout populations for long periods of time (Rieman and McIntyre

1995). Bull trout appear to be highly vulnerable to extinction when they exist as small, isolated populations above barriers (natural or artificial) or in small or poor quality habitat patches that can sustain only small populations. Fragmentation, isolation, and widespread degradation of bull trout habitats render populations more vulnerable to virtually all other environmental stressors, ranging from hybridization with brook trout to angling to degradation of spawning and rearing habitats.

Unfortunately, the degree to which human alterations of ecosystems in western Montana have affected the survival of bull trout during their migratory life stages is very poorly known. The ecological details of movement and migration of freshwater fishes have received little emphasis in past fisheries research (Gowan et al.1994). River-migrant life histories were known historically or suspected for many populations of bull trout in Montana. Populations exhibiting migratory life histories have been reduced or eliminated by blockages from dams, diversions of river flows, or from chemical or thermal barriers resulting from toxins, alterations of riparian vegetation and river channels, and flow regulation by reservoirs (Thomas 1992; Rieman and McIntyre 1993; Clancy 1993; MBTSG 1995d, 1995e). More subtly, channelization of rivers, filling or revetment of riverine ponds and wetlands, and deforestation of floodplains can largely disconnect rivers from their floodplain aquifers, thereby severing the geomorphic processes that create and maintain lateral complexity and habitat refuges along river margins (Stanford and Ward 1992; Sparks 1995). Human alterations of ecosystems and aquatic habitats directly and indirectly increase all of these threats and challenge the survival of migratory bull trout. The lower elevation rivers and lakes that historically constituted the most important habitats for maturing adfluvial and fluvial bull trout have been especially degraded by human activities.

Environmental perturbations that reduce survival rates and connectivity of bull trout metapopulations not only increase the likelihood of local and eventual regional extinctions, but they also severely reduce their productivity and life history diversity, thereby impairing their ability to sustain angler harvest. Minimal conditions for persistence of populations within some semblance of their existing range will not necessarily suffice to maintain or restore harvestable populations. In general, the large, migratory individuals that are probably most important for maintaining connectivity among metapopulations and reproductive potential within populations are also those most highly valued by the majority of anglers and by people who value the species for nonconsumptive purposes. Therefore, maintenance of habitat conditions that encourage movement and migration of large bull trout is critical to meet both biological and cultural goals.

Cumulative Effects In Lakes

Oligotrophic lakes, such as those that support native bull trout, are highly vulnerable to the cumulative effects of land-use activities (Reavie et al. 1995) because they act as sinks for nutrients, sediments, and toxic runoff from surrounding landscapes. Human disturbances of watersheds and lake shores that tend to accelerate cumulative sedimentation (Davis 1975; Spencer 1991) and eutrophication (Reavie et al. 1995) of oligotrophic lakes may further favor introduced fishes at the expense of bull trout and other native species. For example, lake trout have declined in lakes within their native range in association with sedimentation of spawning shoals, eutrophication, and accumulation of toxic chemicals in food webs (Ryder et al. 1981).

Lake morphometry and catchment characteristics can influence the vulnerability of lakes to environmentally induced habitat changes. For example, lakes with large drainage catchments in British Columbia were most severely affected by anthropogenic eutrophication (Reavie et al. 1995). Swan Lake in Montana may be vulnerable to landscape disturbances that increase nutrient, carbon, or sediment loading to the lake because of its relatively large catchment area and shallow depth (Butler et al. 1995).

The magnitude and potential effects of limnological changes on adfluvial bull trout, however serious by implication, have gone virtually unstudied. Excepting Flathead and Swan lakes, we lack even rudimentary limnological assessments of many lakes in Montana inhabited by bull trout. Accordingly, we cannot accurately assess the magnitude of this potential problem. Many catchments have undergone more extensive land use alterations than that of Swan Lake, and limnological conditions of lakes therein may have changed significantly. No resources have been made available to continue research to better define the mechanisms driving oxygen deficits in Swan Lake or to determine how limnological changes in this and other lakes may affect bull trout survival, growth, and population dynamics.

Fragmentation, isolation, and widespread degradation of bull trout habitats render populations more vulnerable to virtually all other environmental stressors. The lower elevation rivers and lakes that historically constituted the most important habitats for maturing fluvial and adfluvial bull trout have been especially degraded by human activities. The maintenance of habitat conditions that encourage movement and migration of large bull trout is critical to both biological and cultural goals.

Uncertainty And Landscape Effects

To the best of our knowledge, no studies exist that document in detail the causal linkages between land management activities and the biological responses of a specific bull trout population. The inherent complexity and interdependence of causal mechanisms, variation among streams and watersheds (climatic, geomorphic, and biotic), and vagaries of management history among watersheds combine to preclude the possibility of a simple, mechanistic accounting for cause and effect between land use activities and status of bull trout across their range. On the other hand, several comparative watershed or landscape studies have demonstrated some predictability or pattern in the status of bull trout populations relative to gross indices of land management history. The studies we review here suggest that the response of any stream is contingent to some degree on local conditions. The response of any single population to a particular habitat alteration, therefore, cannot be predicted with certainty. However, some relatively consistent patterns of response in habitat factors known to be important to bull trout, and in bull trout populations exist. This is likely not just an artifact of insufficient research, but may reflect general patterns in the mechanics of biophysical processes in watershed ecosystems. For example, fish assemblages and habitat conditions in a study conducted in Michigan did not clearly or predictably reflect local riparian conditions or site specific land use histories, but strong negative relationships existed between landscape management at the whole watershed scale (forest alteration or loss) and the status of fish species in streams draining the watersheds (Roth et al. 1996).

As discussed in a previous section of this report, land management activities can directly impact bull trout habitats. Direct cause and effect relationships between land management activities and decreased bull trout populations have been poorly documented. Despite our inability to fully understand and predict cause and effect in these complex ecosystems, the studies cited below (and others) provide strong evidence that such cause and effect relationships do exist. If no adverse relationships existed between land management and status of bull trout, the species would not be threatened with extinction, or its recovery would already be well underway.

In the Swan River drainage, the density of bull trout redds in nine major spawning tributaries was inversely correlated to road density in the tributary drainage (Baxter et al., in press). Redd density in the years 1982, 1991 and 1995 appeared to be most strongly related to road densities in the mid-1970s, suggesting a lag time of a decade or more between road construction and the full manifestation of its effects on bull trout spawning populations. Possible explanations for the lag include lower erosion control standards used in earlier road construction practices, less significant effects on bull trout from recent disturbances, or some recovery from historical degradation. Little evidence was found to suggest that phsyiographic variation accounted for the observed variation in bull trout redd densities among the same nine tributaries in an examination of a large suite of map derived geomorphic variables (Baxter et al., in press).

Watershed condition in the Bitterroot National Forest, Montana, is categorized as healthy, sensitive, or high risk (Decker et al. 1993). Bull trout populations with significant numbers of individuals (10 or more fish longer than 5 inches/1000 feet) have been found only in healthy and sensitive drainages. Naturally reproducing brook trout populations with significant numbers of individuals have been found in all three drainages categories. Furthermore, only 20% of high risk drainages have been found to support bull trout, whereas 85% of them contain brook trout. Brook trout may be more competitive in drainages that have been affected by development.

An analysis of fish populations and aquatic habitats was conducted within the Columbia River Basin east of the Cascade crest as part of the Upper Columbia River Basin Ecosystem Management Project (Lee et al. 1997). Each of two analyses conducted support the general conclusion that increasing road density is correlated with declining aquatic habitat conditions and aquatic integrity. The results clearly showed that increasing road densities are associated with declines in four non-anadramous salmonid species, including bull trout. Bull trout are less likely to use moderate to highly roaded areas for spawning and rearing, and if found in these areas, are less likely to be at strong population levels.

The Eastside Forest Scientific Study Panel compiled and mapped information on the known distributions of inland native trout species of eastern Washington as part of a regional ecological assessment. The panel produced an unpublished map and overlay depicting the distribution of bull trout in relation to late successional and old growth forests in eastern Washington (Henjum et al. 1994). Visual examination (not quantified) suggests that the mapped spawning areas of bull trout are strongly associated with patches of late successional forest or watersheds where concentrations of late successional forest are greatest. Similarly, Aquatic Diversity Areas known to be disproportionately important for remaining populations of bull trout and other native fishes in eastern Oregon are strongly associated with wilderness areas and large tracts of roadless lands (Henjum et al. 1994).

Geomorphic patterns may also influence bull trout distribution and spawning density. In four Swan River tributaries recently studied, bull trout redd density and distribution was highly correlated with groundwater inflows (Baxter et al., in press). The density of bull trout spawning sites was significantly related to geomorphic units defined as riparian landtypes in the Swan River drainage (G.Watson and B. Sugden, Plum Creek Timber Company, unpublished analysis). Approximately 80% of bull trout redds occurred in only 3 of more than 20 riparian land types available to bull trout in the nine major spawning tributaries. As in other areas (Rieman and McIntyre 1995), bull trout distribution in tributaries of the Swan River was also associated with large patch sizes (G. Watson, Plum Creek Timber Company, personal communication). Bull trout occur primarily in the larger tributary watersheds (>2000 ha.). This relationship is consistent with the finding that a positive relationship exists between bull trout distribution in the Swan River tributaries and late summer stream discharge (Leathe and Enk 1985).

A hierarchical approach relating physical process at various landscape scales was used to describe the relationships among distribution and abundance of bull trout and physical and biotic factors at the site, stream, and basin scales of analysis (Watson and Hillman 1997). The analysis showed that a greater consistency of significant independent variables, and predictive capability, was exhibited at coarser (e.g., influence of valley bottom type on distribution) than at finer scales of resolution (e.g., density relationships at the basin level of analysis). The authors postulated that selection of resources by bull trout occurs in a hierarchical fashion from the geographic range, to home ranges within a geographic range (e.g., stream reaches with more and deeper pools), to selection of specific items within the habitat (e.g., undercut banks).

In the Columbia River Basin analysis discussed above (Lee et al. 1997), an analysis was conducted using classification and regression trees (CART) as the statistical model to elucidate the relationship between a set of predictor variables and a fish species presence or status. The patterns in current bull trout distributions are consistent with existing knowledge on bull trout habitat relationships. Mean annual air temperature was important in discrimination of bull trout status. Watersheds less than 5.1 °C mean annual air temperature were roughly four times more likely to have bull trout present and ten times more likely to support strong populations than warmer areas. Other variables in the model suggest bull trout are more likely to be found in areas with lower road densities; forested rather than unforested areas; mid-size streams, on steeper, wetter, higher elevation; and more erosive lands. These results are consistent with the view that bull trout associate with cold, relatively pristine environments, but do not exclude bull trout from all landscapes influenced by human disturbance.

We consider the patterns documented in the studies cited above to be highly relevant to bull trout conservation. Each example provides evidence that is circumstantial, but considered together, their implications are compelling. We suffer from a lack of scientific certainties in describing and predicting these linkages, as well as insufficient or ineffective allocation of scientific resources to the problem by agencies and industry. To ignore information that lacks absolute scientific certainty, or to pretend that we have the scientific and practical capability to micro-manage land management activities and isolate and treat all negative effects site specifically, places the resource in peril of irreversible loss (Bella and Overton 1972; Regier and Baskerville 1986; Frissell and Bayles 1996). The inability to predict the specific outcome of a particular environmental alteration dictates that extreme caution be used before any new practice is introduced. Proceeding under the assumption that present practices are sufficient is indefensible, considering that contemporary and past practices together have combined to jeopardize the status of the species. The consequences of even a small action can be irreversible for a population in decline or on the brink of extinction.

Many of the landscape level changes made within the range of bull trout in the past 150 years have been detrimental to the species. Many of these changes are irreversible and will affect bull trout survival and recovery for decades or centuries. Identifying the interactive and cumulative effects of these activities on bull trout is difficult and is not well addressed in our report. Bull trout are affected by the interactive effect of habitat change and introduction of non-native fish. Due to the bull trout's need for pristine habitats, many habitat alterations tend to favor other species of fish. Because of this, habitat protection for bull trout becomes more important. Landscape level analysis of bull trout populations provide strong evidence that a cause and effect relationship exists between bull trout populations and land management activities. The evidence is circumstantial, but compelling.

A Recommended Monitoring Based Strategy For Reducing Effects Of Land Management Activities On Bull Trout Habitat

Bull trout require cold, clean water in streams with complex habitat that remains connected to allow fish movement among stream systems. Management activities that compromise these requirements have the potential to reduce survival of bull trout at one or more life history stages. In the preceding sections of this report, we described habitats required by bull trout at all life history stages. We then described how a variety of land management practices can alter these habitats and reduce the survival of bull trout. In this section, we provide recommendations to maintain quality bull trout habitats by reducing impacts from land management activities. Our recommendations are in the form of a framework rather than a detailed strategy, and do not imply a set process, regulatory mechanisms, or authorities.

Goal Of The Monitoring Based Strategy

Our goal in this effort is to provide for streams and lakes which are cold, clean, complex and connected. The strategy relies heavily on establishing a baseline of existing conditions and monitoring to ensure those conditions are maintained or improved. To accomplish this, we propose a set of criteria based standards against which proposed activities should be evaluated. Through this process, and adaptive management feedback, we hope to gain information that will subsequently allow us to determine which activities in particular areas will or will not adversely impact bull trout habitat requirements. This information can subsequently be applied through adaptive management approaches to modify and improve land management activities to further reduce detrimental impacts to bull trout. In addition, the process will provide some impetus for improvements in areas that are currently contributing to a reduction in bull trout viability by identifying factors leading to degradation of habitat. This proposed strategy is not meant to replace existing mechanisms for protecting stream systems. Rather, it will complement existing mechanisms by increasing our understanding of the effects of land management activities on stream systems and bull trout populations.

Limitations Of Existing Strategies

Several strategies have been developed and implemented to reduce the impacts of land management activities on stream habitats. Some of these strategies were developed to reduce impacts of specific activities such as timber harvest and related practices on stream habitats (e.g.,Montana Streamside Management Act, Washington Forest Practices Act, Oregon Forest Practices Act). Other strategies were developed to address impacts from a variety of land management activities on specific groups of fishes, such as anadramous or inland salmonids (e.g.,FEMAT, PACFISH, INFISH, CRIT-FISH, Fish 2000). These strategies rely on identifying a buffer zone adjacent to stream channels and limiting specific activities within these buffer zones. Also included in some strategies are specific instream habitat thresholds. The habitat thresholds serve as trigger values which alter standards and guidelines dependent on the habitat's existing condition.

Previous strategies have been based on set numbers, both for streamside buffer widths and habitat threshold values. Although some strategies incorporate flexibility in modifying the specific numbers, procedures for modifications are often ambiguous. Most of the discussion of the merits of these strategies has focused on the numeric standards, while the goals of providing quality fish habitat are often overlooked. Many of the existing strategies have been subject to the following criticisms:

> Streamside Buffers : Development of streamside buffers has been based on several factors, including maintenance of large woody debris, stream shading, sediment filtering, and bank protection. Proposed buffers are based on published literature, which has primarily focused on timber harvest and related activities. These cited studies have been conducted on a variety of landscapes in varying geomorphologic and climatic settings. Depending on the setting and objectives of these studies, buffer widths from 50 feet to the watershed boundary have been justified. It is therefore difficult, if not impossible, to identify buffer widths that are universally appropriate. Many of the strategies that use streamside buffers assume that limiting management activities within these buffers will eliminate adverse impacts on instream fish habitat. Streamside buffers are often applied as the default, with little understanding of a stream's existing condition or potential to meet habitat objectives.
>
> Habitat threshold values: Threshold values for habitat components are based on descriptors of "good" fish habitat. These values serve as default values for all streams covered by a specific strategy. Although most strategies that incorporate habitat thresholds allow for site specific modification, default values are applied most often. Streams flow through a wide range of geologic conditions and landforms, which influence stream and habitat characteristics. Some of the habitat threshold values used may not be within the natural potential of some streams, while other streams may have much higher natural potential than a given threshold value.
>
> Applying the concept of habitat threshold values assumes that some level of impact to fish habitat is acceptable and will not reduce survival. This concept also assumes that our knowledge of fish habitat requirements is at a level that we can determine these values. When habitat threshold values are applied, management activities tend to push habitat components towards these values by limiting impacts when the threshold is exceeded and allowing impacts when existing conditions are below the threshold. Although this concept may be applicable for managing strong populations of fish, it is not adequate for managing depressed fish populations. Fish populations become depressed because survival has been reduced from some previous level. In most instances, survival has been reduced at more than one life stage. Any further reduction in survival resulting from impacted habitat is likely to further reduce population levels.
>
> Monitoring: Although some level of monitoring is included in most existing strategies, monitoring often focuses on implementation and compliance (Are the buffers the standard width? Did activities occur within the buffers?) instead of effectiveness. Many of the existing strategies operate under the assumption that the strategy will be effective if implemented. Monitoring of implementation and compliance gives little or no consideration to the

effectiveness of the strategy in maintaining or improving fish habitats. Determining the effectiveness of any strategy is critical for determining whether or not the goals are being met.

Proposed Strategy

A critical aspect of this process is that of monitoring current and future conditions that are important for bull trout. It is the opinion of the MBTSG that for most areas, current water quality and fish habitat monitoring efforts on both private and public land in Montana are insufficient to draw conclusions about either current habitat condition or trend. This strategy relies on monitoring to establish both current condition and potential and/or measured impact of proposed and ongoing activities. By suggesting the specific indices to be measured or observed, we expect standardization of data collection. This should help to ensure that the data that are collected will maintain their value and applicability over time. Knowledge gained through reporting and review of monitoring results will be incorporated through an adaptive management process to increase our knowledge base on effects of various activities. If monitoring demonstrates that a specific activity is not having a measurable, detrimental impact on bull trout habitat, this activity may occur in the future in areas with similar conditions without further monitoring. Activities demonstrated to have detrimental impacts will need to be eliminated or altered. As this knowledge base increases, we will learn which activities will not need continued monitoring and which activities need to be altered.

This strategy includes 3 major parts (Tables 3 and 4):

1) Monitoring - The strategy encourages and relies on monitoring of habitat components. Recommended monitoring includes both establishing baseline conditions and effectiveness monitoring. Monitoring indices are suggested for each of the habitat components.

2) Criteria based standards - Narrative criteria are provided for each of the major habitat components that we have identified as being important to bull trout. These criteria have been set at a level which, if met, should provide quality habitat conditions and minimize impacts of land management to bull trout habitats.

3) Caution Zones - These are areas, identified for each of the habitat components, within which land management activities have the greatest potential to adversely affect bull trout habitat. Land management activities are not categorically prohibited or restricted within these caution zones by this strategy. However, because activities that occur within the caution zone inherently pose some risk, they should not occur unless monitoring occurs or sufficient information is available to reliably demonstrate that the activity will not adversely affect the habitat components. Caution zones are identified for each habitat component within both core areas and nodal habitats.

Monitoring

We recognize that aquatic systems are dynamic and variable by nature. This variability must be considered when designing a monitoring program. Variability can be addressed through a well designed monitoring program, using control sites, sites above and below affected areas, or comparing paired watersheds. It is important to understand that we are not recommending a site potential based strategy, where habitat potential is used as the baseline from which to evaluate effects. Rather, this strategy is based on using the current condition as a point of reference or baseline. This does not infer that this baseline should act as a threshold. It serves more as the baseline from which to measure effects of management activities. A premise of the strategy is that we want to reduce or eliminate management induced detrimental changes in bull trout habitat, regardless of current condition.

One intended outcome of this strategy is to provide incentive for cooperative monitoring programs. Monitoring programs should be established for all restoration/conservation areas. Cooperative monitoring programs provide the ability to share costs of monitoring, reduce redundancy, focus monitoring programs to meet local needs, and synthesize population and habitat data. Having a cooperative monitoring program in place provides a base program to which new activities can be referred. It also provides an opportunity for small landowners and others with limited funds to participate. Combining habitat and population monitoring is important in evaluating overall success of the strategy.

A strength of this recommended strategy is its flexibility. The strategy does not focus on limiting specific activities; instead, it focuses responsibility on the land managers to ensure that their activities will maintain or enhance (i.e., not diminish) bull trout habitat. Land managers must ensure this by monitoring suggested components and adjusting land management activities based on monitoring results. If land management activities are proposed within bull trout core areas or nodal habitats, they must be designed to not adversely impact habitat components. The land manager must monitor to determine whether their initial assumption was correct, i.e., that the activity did meet the criteria. If monitoring results suggest that their activities did not meet the criteria, then the land manager would adjust future activities to ensure that they do meet the criteria.

The type of monitoring for any given activity will depend on the magnitude and nature of risk posed to bull trout habitat. Certain activities will be identified (through a screening process) as needing to go through the habitat monitoring process. At a minimum, all projects or activities that require a new decision or a new or continuing permitting action by any federal, state, or local authority and meet any of the following should be screened:

1) Any ground or vegetation disturbing activity, and any activity that alters the structure or flow of water in a stream channel, wetland, or floodplain;

2) Any activity resulting in or pertaining to the discharge or release of pollutants or hazardous substances into the ground or water;

3) Any activity that could result in or pertains to alteration, appropriation, or allocation of the quantity or quality of surface and subsurface waters.

Monitoring for some components may produce quantitative and rigorous data, and for others it may lead to a more qualitative description of current conditions and proposed improvements. By design, this process has been left open to some interpretation. For example, habitat indices other than those listed in Tables 3 and 4 might be identified as more appropriate in specific circumstances. This provides the opportunity for creative approaches. There should, however, be standardization and oversight of the sufficiency and scientific validity of the monitoring efforts within a basin.

This strategy requires a set process to screen proposed activities for monitoring needs and to provide recommendations and review for monitoring programs. We foresee an implementation of the strategy following a model similar to that presented in Figure 2. A screening committee would review proposed projects for monitoring requirements and provide recommendations to revise and improve monitoring plans. To incorporate local knowledge and required expertise, screening committees should be formed for each of the three major bull trout areas (Kootenai, Flathead above Kerr Dam, and the Clark Fork). Screening committees should include a core group representing the scientific disciplines of fisheries, hydrology, soils, and vegetation ecology disciplines. Other expertise could be used as needed. An oversight committee would be required to recommend monitoring methodologies, design monitoring programs, review monitoring reports, and maintain consistency. This type of process would incorporate adaptive management so that we can learn and improve our monitoring efforts.

Criteria Based Standards

Our proposed strategy is not based upon setting specific numeric targets or thresholds. Instead, narrative criteria are used to describe an objective for several of the most important physical components required by bull trout (Table 3 and 4). In place of strict numeric thresholds or restrictions on specific activities, this approach attempts to foster an environment of responsibility. The criteria based standards are based on habitat components known to be important to bull trout. These components, and their descriptors, were identified in the first section of this document. Meeting the criteria should minimize adverse impacts to bull trout habitats and provide quality habitat conditions for bull trout.

Caution Zones

These are areas, identified for each of the habitat components, within which land management activities have the greatest potential to adversely affect bull trout habitat. Caution zones are identified for each habitat component within both core and nodal habitats. We have identified two caution zones: (1) 100 year floodplain[1] (FEMAT 1993) plus 150 feet on either side, and (2) the hydrologic boundary of the watershed. The 100 year floodplain was chosen based on the need to fully incorporate the channel migration zone 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) it provides sufficient width to filter most sediment from non-channeled surface runoff from most slope classes; (3) it provides some microclimate and shallow groundwater thermal buffering to protect aquatic habitats inside the channel and channel migration zone; and (4) it provides an appropriate margin error for unanticipated channel movement, hillslope, and soil stability, blowdown, wildfire, operator error, tree disease, and certain other events that may be difficult or impossible to foresee on a site-specific basis.

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[1] To determine the extent of the 100 year floodplain, include those areas that meet any of the following conditions:

a) the area physically vulnerable to channel migration, channel occupation or reoccupation, or channel abandonment during a 100-year recurrence interval flood or during 100 years of channel development, including the area affected by historical and foreseeable backwater and diversion effects of ice flows and ice jams in winter;

b) the likely extent of overland flow that occurs at least once in 100 years (accounting for both mainstem and proximal tributary sources of ground and surface water, approximately equal to the 100-year peak of the variable source area for stormflow);

c) the area where the 100-year maximum water table stage in an alluvial aquifer or zone of hyporheic flow exchange lies at or within 50 cm of the soil surface;

d) the topographic area of the valley floor and immediately adjacent benches encompassing patches of hydrophilic vegetation or hydric soils.

Because management activities that occur within a caution zone inherently pose some risk, activities occurring within the caution zones should be designed to not adversely impact the habitat components. Monitoring would be required to demonstrate the project was properly designed, unless sufficient information is already available to reliably determine that no adverse impacts will occur.

Shortcomings Of Proposed Strategy

We recognize that this type of approach has several shortcomings:

<u>The strategy deals primarily with new activities.</u> It does not directly address past activities that have adversely impacted bull trout habitats. It also may not directly address some ongoing activities. In keeping with the goal of providing quality bull trout habitats, restoration of impacted habitats will be needed and ongoing activities may need to be altered to reduce or eliminate cumulative impacts. Collection of reliable baseline information through monitoring programs should help to identify existing degraded habitats. Effective and well directed restoration requires this level of baseline data. Currently there is little incentive for collection of this information. As the base of information develops, it should become clear which past and ongoing activities are contributing to net habitat degradation and need to be addressed.

<u>The strategy does not address problems occurring in habitat outside of core and nodal areas, nor does it directly address other native aquatic species.</u> Bull trout appear to have the narrowest habitat requirements of the native fishes with which they coexist. Providing high quality bull trout habitats within core areas should benefit other native fishes within these areas. Further analysis will be needed to address the sufficiency of this approach for the conservation of these other fish species. Likewise, additional analysis will be needed to assess the effectiveness of this strategy in maintaining bull trout viability across western Montana. In such an analysis, the interactions of factors other than habitat (e.g., introduced fishes, fisheries management, illegal harvest) will need to be addressed.

<u>Limitations of monitoring.</u> Because this strategy relies on monitoring to demonstrate that activities do not adversely impact bull trout habitats, it is important to recognize that some negative impacts will occur. Monitoring does not prevent adverse impacts from occurring; it only documents whether or not they have occurred. In addition, some impacts may not be measurable as a result of technical or design limitations. It is the intent of this strategy that the knowledge gained from monitoring will be applied to accurately assess existing conditions and encourage practices that will minimize future adverse impacts. Core and nodal areas with large amounts of land in small private ownership add a layer of complexity to monitoring that needs to be further examined.

Table 3. Criteria applicable in **Core Areas**

Component	Caution Zone	Criteria	Suggested Indices
Temperature	100 year floodplain + 150 ft	- No measurable detrimental[1] change in water temperature	- Seven day moving average of maximum water temperature.
Clean Substrate	Watershed	- No measurable detrimental change in sediment delivery to stream channels in sensitive reaches[2] (spawning and rearing habitats) - No measurable detrimental change in percent intergravel fine sediment in spawning areas - Where management induced sediment delivery is occurring, a net decrease in sediment delivery.	- Intergravel material less the 6.35 mm - Substrate score - Cumulative size distribution of surface material - Sediment budget models
Habitat complexity	100 year floodplain +150 ft.	- Maintain sufficient habitat complexity to provide for needs of all stages of multiple life histories. This includes: - No measurable detrimental change in sinuosity or channel length - No measurable detrimental change in instream LWD - Maintain or enhance natural processes and rates of LWD recruitment. - Maintain groundwater/stream channel/floodplain interactions. - No measurable detrimental change in pool frequency or pool depth - No measurable detrimental change in area of beaver ponds or floodplain wetlands - No measurable detrimental change in area of floodplain forest and shrubland vegetative communities. - Maintain or increase representation of late seral vegetative communities.	- Channel geometry, length, sinuosity - Frequency of LWD - Frequency of pools - Pool residual depth - Valley bottom cover types - Groundwater indices (water temperature and/or ocular assessment of winter ice cover).
Adequate streamflow	100 year floodplain. +150 ft	- No measurable detrimental change in instream flows - Maintain or promote natural hydrograph pattern	- Stream discharge - Hydrograph
Channel stability	Watershed	- No measurable detrimental change in channel stability - Maintain stream channel dynamic equilibrium [3]	- Cumulative width/depth ratio - Channel cross sections.
Connectivity	100 year floodplain + 150 ft	- No loss of biological connectivity between or within core and nodal habitats	- Fish passage - Loss of fish in withdrawals
Stable vegetated banks	100 year floodplain + 150 ft	- No measurable detrimental change in bank stability - No measurable detrimental change in undercut banks - No measurable detrimental change in stabilizing vegetation	- % streambank actively eroding. - % streambank structurally altered.
Chemical water quality	Watershed	- No measurable detrimental change in surface and intergravel water quality	- Water quality measurement standard methods

[1] A change in a component in a direction that is adverse to growth or survival of bull trout

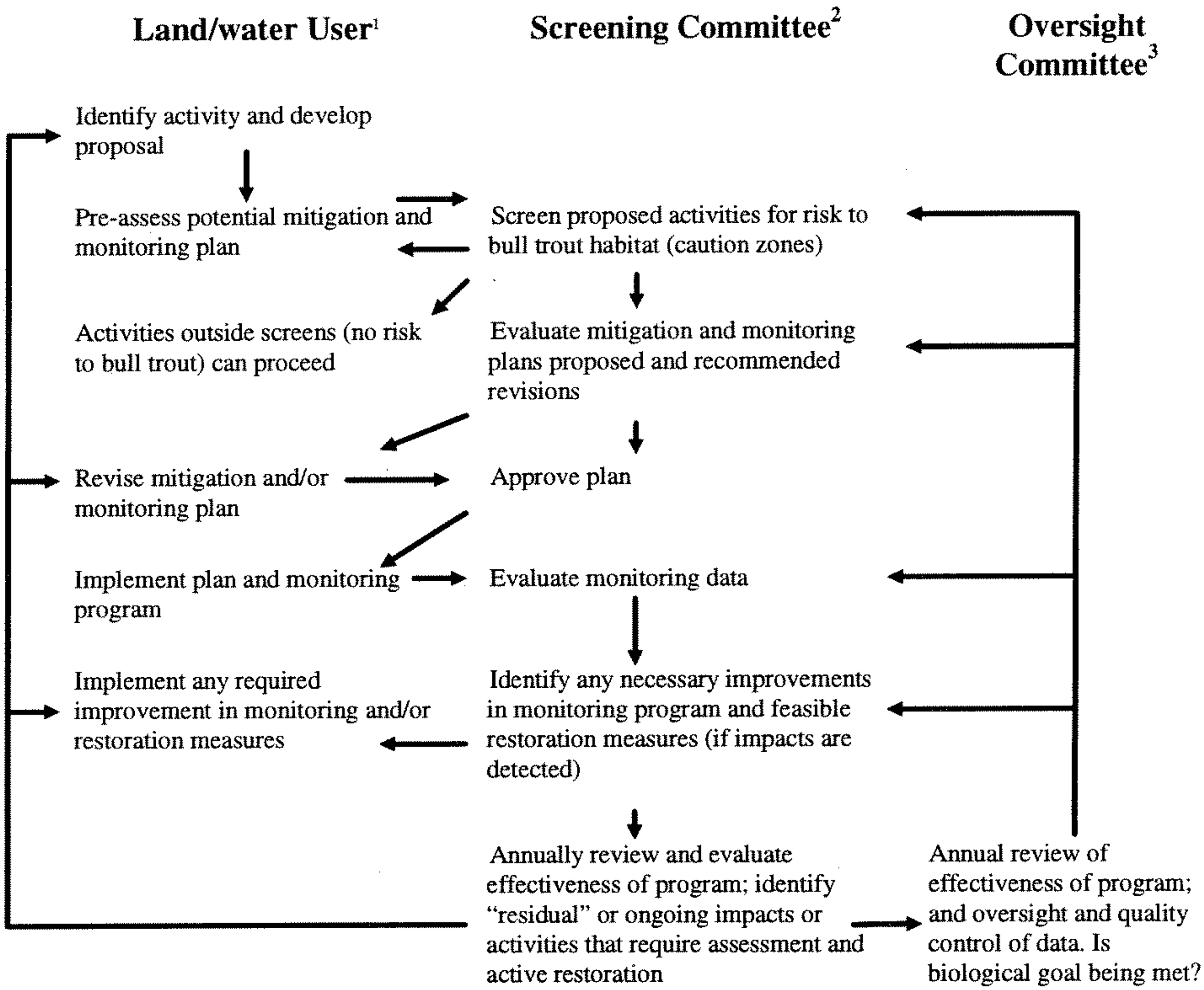
[2] Sensitive reaches are those that meet the following criteria: <3% gradient, spawning or rearing present, or as identified by fisheries biologist and/or technical screening committee

[3] Dynamic equilibrium is defined as a balance between stream energy (essentially amount of streamflow) and sediment load so that the channel form and character remain unchanged

Table 4. Criteria applicable in **Nodal Areas**

Component	Caution Zone	Criteria	Suggested Indices
Temperature	100 year floodplain + 150 feet, including tributaries that provide or have potential to provide thermal refugia.	- Maintain sufficient thermal refugia to support residence throughout summer months	- Frequency and distribution of thermal refugia
Habitat complexity	100 year floodplain + 150 feet	- No measurable detrimental change in channel geometry, channel length, or channel sinuosity. - Maintain groundwater/stream channel/floodplain interactions - No measurable detrimental change in area of beaver ponds and floodplain wetlands - Maintain or enhance natural processes and rates of LWD recruitment. - No measurable detrimental change in area of floodplain forest and shrubland vegetative communities.	- Sinuosity, channel length - Area of floodplain wetlands
Adequate streamflow	Watershed	- Maintain or promote natural hydrogaph pattern to maintain hydrologic process of bedload supply and transport.	- Stream discharge. - Hydrograph
Connectivity	100 year floodplain + 150 feet	- No loss of biological connectivity between or within core and nodal habitats	- Fish passage - Loss of fish in withdrawals
Stable vegetated banks	100 year floodplain + 150 feet	- No measurable detrimental change in bank stability - No measurable detrimental change in undercut banks - No measurable detrimental change in stabilizing vegetation	- % streambank erosion - % streambank structurally altered.
Chemical water quality	Watershed	- No measurable detrimental change in water quality	- Water quality measurement standard methods

Figure 2. Recommended implementation and review steps of the monitoring based strategy.



[1] Land/Water User - any person, organization, or agency that proposes a project or activity in a core or nodal area that requires a new decision or a new or continuing permitting action by any federal, state, or local authority.

[2] Screening Committee - Includes individuals with expertise in the disciplines of fisheries, hydrology, soils, and vegetation ecology. Other expertise will be utilized as needed. Three screening committee's are proposed - one each in the Kootenai, Flathead, and Clark Fork drainages.

[3] Oversight Committee - Should have expertise in land management, study design, application of statistics, and monitoring strategies.

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