Thompson River Basin Watershed Analyses:

Beatrice Creek
Boiling Springs Creek
Murr Creek

May 22, 1998

Prepared By:

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>>In Preparation by Plum Creek's Flathead Unit foresters. Will be distributed for insertion in the document at a later date.

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SECTION 1

INTRODUCTION

1 INTRODUCTION

In May of 1997, Plum Creek Timber Company, L.P. initiated a Level 2 Watershed Analysis in three tributaries to the Thompson River in western Montana: Beatrice Creek, Boiling Springs Creek, and Murr Creek. Watershed analysis is a process to address the cumulative effects of forest practices on two areas of public resources: fish habitat and water quality. The major land managing agencies in the basin were notified of the commencement of the analysis. These landowners included the Flathead National Forest, the Montana Department of Natural Resources and Conservation - Trust Land Management Division, and the Montana Department of Fish, Wildlife, and Parks.

A resource assessment team was assembled to identify hillslope areas sensitive to land management practices that could impact public resources. After sensitive areas were identified by the resource assessment team, local land managers are charged with developing methods (prescriptions) for operating in the watershed to reduce or eliminate problems in sensitive areas. In the coming months, Plum Creek land managers will be developing prescriptions to address issues on Plum Creek lands in the Beatrice, Boiling Springs, and Murr Creek watersheds. The Forest Service and State of Montana are highly encouraged to develop prescriptions for lands they manage.

The scientists conducting the resource assessment used the methods outlined in Version 3.0 of the *Standard Methodology for Conducting Watershed Analysis* (Washington Forest Practices Board, 1995). Under a Level 2 analysis, the standard methodology is followed, but more time and experienced scientists are used to conduct the analysis. In addition, deviation from the standard methodology is allowed with proper justification and documentation. Some deviation from the standard methodology was necessary to accommodate site-specific conditions in this area and to incorporate the latest scientific information.

The purpose of this report is to present the results of the resource assessment team along with all pertinent documentation and justification for delineation of sensitive areas. Hillslope hazards are addressed by the mass wasting, surface erosion, hydrologic condition, and riparian condition modules. The physical processes and potential triggering mechanisms for each hillslope hazard are described in the module reports. The vulnerability of resources are addressed by the fish habitat and channel condition modules. Because no publicly-owned works exist in any of the three watersheds (e.g. county bridges, power lines, public water supplies, etc), vulnerabilities for these features were not assessed. Both the potential and existing resource conditions are described in the module reports, as well as discussions of relevant physical processes that affect the condition of the resource.

To synthesize the results of the resource assessment, a causal mechanism report is produced for each hillslope hazard that has impacted or has the potential to adversely affect public resources. The causal mechanism report contains a description of the hillslope hazard and how land use activities trigger

or route key input variables such as coarse sediment, fine sediment, wood, water, and heat energy to public resources of concern. Local land managers then develop management options to address the issues and processes identified in each causal mechanism report.

This document contains seven sections: 1) this introduction to the watershed analysis; 2) an overview section that provides background information for the watershed analysis areas; 3) an executive summary that describes the results of the watershed analysis; 4) a detailed narrative description for each resource assessment module; 5) causal mechanism reports for all sensitive areas within the watershed. Various maps and forms are contained in the narrative descriptions for each module, as well as in associated appendices; 6) management prescriptions developed by Plum Creek Timber to address each causal mechanism report for Plum Creek lands in each watershed (in prep); and 7) an analysis of watershed similarity for watersheds in the Thompson River Basin.

SECTION 2

OVERVIEW

2 OVERVIEW

The following section provides an overview of the physical attributes and past land management activities within the Beatrice, Boiling Springs, and Murr Creek watersheds. Many of the topics in this section are addressed in more detail within the module reports in Section 4.

2.1 LOCATION, OWNERSHIP, AND LAND USE

Beatrice, Boiling Springs, and Murr Creeks are tributaries to the Thompson River in northwestern Montana. The Beatrice Creek watershed is 6,566 acres (10.3 mi.^{2}) and drains to Fishtrap Creek and the Thompson River in the southwest corner of the Thompson River Basin. It is located 15 miles northeast of Thompson Falls, Montana and includes portions of Townships 23 and 24 North, Ranges 27 and 28 West, Principle Meridian (Figure 2-1a, note: this and other figures are located at the end of the section). The Boiling Springs Creek watershed is 5,487 acres (8.6 mi.^{2}) and drains to Lower Thompson Lake in the northwest corner of the Thompson River Basin. It is located 42 miles west-southwest of Kalispell, Montana and is contained within Township 26 North, Range 27 West, Principle Meridian (Figure 2-1b). The Murr Creek watershed is 19,905 acres (31.1 mi.^{2}) and drains to the Thompson River in the northeast corner of the Thompson River Basin. It is located 36 miles southwest of Kalispell, Montana and includes portions of Townships 25 and 26 North, Ranges 25 and 26 West, Principle Meridian (Figure 2-1c). A map of the entire Thompson River Basin, with watershed analysis areas delineated is shown in Figure 2-1d.

Plum Creek owns 52.4% of the analysis watersheds. The Forest Service manages 43.8% of the analysis area, concentrated in the Murr and Beatrice Creek watersheds. The State of Montana manages 1188 acres (3.7%) of the analysis areas, distributed between the Boiling Springs and Murr Creek watersheds. Small private lands comprise only 30 acres of the total analysis area, wholly within the Murr Creek watershed (See Table 2-1).

Table 2-1. Ownership in the three watershed analysis areas and the entire Thompson River Basin.

	Plum Creek		Small Pvt		Forest Service		State		Totals	
	ac.	%	ac.	%	ac.	%	ac.	%	ac.	%
Beatrice	2507	38			4059	62			6566	100
Boiling Springs	4645	85					842	15	5487	100
Murr	9590	48	30	<1	9939	50	346	2	19905	100
Totals	16742	52.4	30	0.1	13998	43.8	1188	3.7	31958	100

The predominant land use in the analysis watersheds is forestry. A secondary use is cattle grazing of the transitional range. Grazing has been more prevalent in the Boiling Springs watershed than Murr or Beatrice. In addition, all three watersheds are used by the public for recreation, primarily hunting and firewood cutting. One small private residence is located near the mouth of Murr Creek.

2.2 TOPOGRAPHY, GEOLOGY, AND SOILS

Bedrock underlying the Thompson Basin and the analysis watersheds is predominantly composed of Precambrian hard metasedimentary rock, principally the Burke, Revett, and Wallace formations. The basin is also underlain by minor amounts (3%) of Cambrian limestone, dolomite, and shale, located in the Fishtrap Creek drainage (Harrison et al., 1986; Harrison et al., 1992). The Precambrian metasedimentary rocks were created between 1.5 billion and 800 million years ago when thousands of feet of sands, silts, and clays were deposited at the bottom of a shallow ocean (or lake) and subsequently metamorphosed by intense heat and pressure. The mountains seen today in the Thompson basin were formed 70-90 million years ago, when the North American continent collided with the floor of the Pacific Ocean. This collision resulted in thrust faults in the belt formations, whereby huge slabs of rock over-rode others, creating a series of long ridges and valleys that trend north to south between parallel valleys (Alt and Hyndman, 1986).

In the last 150,000 years, two periods of glaciation have affected about 50% of the Thompson River Basin. The Bull Lake ice age reached its maximum southern extent about 100,000 years ago, and the Pinedale ice age reached its maximum about 15,000 years ago (Jensen and Dean, 1997). Continental glaciers advancing south out of Canada covered the northern portion of the Thompson, extending southward to the vicinity of the Little Thompson River. Glacial till remaining after the glaciers melted has been dissected by numerous streams in the basin. In addition to continental glaciation, localized "alpine glaciers" affected numerous watersheds within the Thompson, primarily tributaries draining high-elevation lands in the southwest corner of the basin.

Another important influence on the landforms of the Thompson also occurred during the Pinedale ice age, when another glacier dammed the Clark Fork River near Lake Pend Oreille to create Glacial Lake Missoula. This lake filled upstream ice-free valleys to a maximum elevation of 4,200 feet. Glacial Lake Missoula sediment deposits are most visible in lower Fishtrap Creek and in the Little Thompson River watershed. These lake deposits have also been subsequently dissected by numerous streams in the basin.

Topography of the Beatrice Creek watershed is shown in Figure 2-2a. Elevations range from 7200 feet at the summit of Marmot Peak to 3340 feet at Beatrice Creek's confluence with Fishtrap Creek. Aspects are predominantly northerly, and slopes are steeper in Beatrice Creek than the other two analysis watersheds, averaging 35% (Figure 2-3a). Beatrice Creek watershed topography has been primarily derived by fluvial (non-glacial) processes, but about 25% of the area has been affected by

alpine glaciation. Bedrock geology underlying the Beatrice Creek watershed is primarily belt metasedimentary, of the Mount Shields and Shepard formations. Beatrice also contains some Cambrian limestone, dolomite, and shale at lower elevations (Figure 2-4a).

Boiling Springs Creek watershed topography is shown in Figure 2-2b. Elevations range from 5830 feet at the highest point to 3331 where Boiling Springs Creek flows in to Lower Thompson Lake. Slopes are relatively gentle (Figure 2-3b) averaging 25%. This is probably the result of the intense continental glacial imprint on this watershed. Much of the underlying bedrock is overlain by glacial till, but where bedrock is identifiable it is dominated by the Shepard Formation.

Topography of the Murr Creek watershed is shown in Figure 2-2c. Elevations range from 6763 feet at the summit of Murr Peak to 3300 feet at Murr Creek's confluence with the Thompson River. Slopes are relatively gentle, averaging about 25% (Figure 2-3c). Though Murr Creek has relatively gentle topography, the lower Murr Creek canyon (entirely on FS land) contains very steep slopes. The Murr Creek watershed has been largely shaped by fluvial (non-glacial) processes. Only the very lower portion of the watershed was covered by the continental ice sheet.

Soils within the analysis watersheds vary depending on the glacial history. The Murr and Beatrice Creek watershed soils are relatively coarse, having been derived in-situ from residual bedrock. The Boiling Springs watershed soils have a finer texture as a result of glacial deposition.

2.3 CLIMATE

Local climate within the analysis watersheds generally consists of warm, dry summers and cool, snowy winters. Average climate data from the Thompson Falls weather station, at the southern end of the analysis area, are shown in Table 2.2.

Mean annual precipitation for the analysis watersheds are estimated as follows: Boiling Springs: 27 inches; Beatrice Creek: 33 inches; and Murr Creek: 30 inches.

2.4 STREAMS, SUB-WATERSHEDS, AND FISH SPECIES

The headwaters of Beatrice Creek include some of the wettest areas in the Thompson River watershed, with annual precipitation up to 50 inches (Jensen and Dean, 1997). This is reflected by the relatively high drainage density of Beatrice Creek, which is about 2.6 mi/mi^2 compared to 2.1 mi/mi^2 for the Thompson River watershed (Jensen and Dean, 1997) and 1.7 mi/mi^2 for the watershed analysis basins (Table 4E-2). The headwaters of Beatrice Creek contain alpine glacial cirques where

Table 2-2. Climatic information for Thompson Falls, Montana.

Month	High (°F)	Low (°F)	Rain (in.)	Snow (in.)
January	34	20	2.7	14
February	42	24	2.1	6
March	51	28	1.9	4
April	62	33	1.7	0
May	71	40	2.1	0
June	78	46	2.1	0
July	87	49	1	0
August	86	49	1.3	0
September	76	42	1.3	0
October	61	34	1.8	0
November	43	28	2.7	4
December	35	23	2.8	15
Totals			23.5	43

snow accumulated to form glacial ice. The glacier in Beatrice Creek scoured rock from the cirque and deposited the debris in moraines extending downstream about half the length of the watershed. The moraines form an aquifer that is drained by perennial streams throughout the year. This source of cold water is a critical habitat factor for bull trout (*Salvelinus confluentus*).

The drainage density for Boiling Springs Creek is comparable to the basin-wide average, 1.9 mi/mi^2 and 2.1 mi/mi^2, respectively. Perennial channel density is about 0.6 mi/mi^2, somewhat lower than the Thompson River watershed average of 0.7 mi/mi^2. Streams draining headwater areas are unconfined intermittents. Many of these intermittent streams are not connected by surface flow with the perennial channel network. These channels lose flow to flat-lying glacial deposits in the generally broad valleys. The broad valley bottoms in the lower two-thirds of the watershed contain ponds, small lakes, open forest stands, meadows and wetlands.

The Murr Creek watershed analysis area has two major sub-basins: North Fork Murr Creek (10,790 acres) and South Fork Murr Creek (7,584 acres). The drainage density for Murr Creek is substantially lower than the basin-wide average, 1.4 mi/mi^2 and 2.1 mi/mi^2, respectively. Perennial channel density is about 0.6 mi/mi^2, somewhat lower than that for the Thompson River watershed average of 0.7 mi/mi^2 (Jensen and Dean, 1997). The low drainage density is attributable to intermittent channel density of about half that for the Thompson River watershed as a whole. The low drainage density in Murr Creek may represent data limitations regarding the location and length of intermittent channels, or it may reflect a significant hydrogeologic characteristic of the watershed.

Fish are present throughout all three analysis watersheds. Surveys conducted for this analysis indicate that the lower reaches of Murr Creek downstream of a barrier cascades in Section 9 support all

species found in the analysis area (brook trout, bull trout, cutthroat trout, rainbow trout). Both juvenile and adult rainbow, cutthroat, and brook trout were found in lower Murr Creek but only one adult bull trout was detected, indicating that this is not natal habitat for bull trout. Upstream of the Section 9 fish-passage barrier cascades in Murr Creek, only brook trout have been detected by population surveys. No fish have been detected by surveys upstream of the Section 11 barrier falls in the south fork of Murr Creek. This distribution pattern suggests that the reaches of Murr Creek upstream of Section 9 were never accessible to native salmonids and that these areas were successfully exploited by brook trout after they were stocked somewhere upstream of the barrier cascades.

The lower and mid-reaches of Boiling Springs Creek support brook and rainbow trout. The upper main-stem reaches of Boiling Springs support primarily brook trout. Cutthroat trout were found only in the uppermost reaches of Boiling Springs Creek. Brook trout were also found in beaver ponds in the lower reaches of the intermittent southern tributary to Boiling Springs Creek.

Beatrice Creek supports only native stocks of fish. Bull trout and cutthroat trout are found throughout the main-stem of Beatrice Creek from the mouth upstream to the fork. Upstream of the fork, bull trout are found in the lower half of the northern fork while cutthroat trout are found throughout. Only cutthroat trout were detected in the southern fork upstream to the barrier cascades in Section 11. Upstream of the barrier cascades, no fish were found by snorkel surveys.

2.5 VEGETATION

The most common tree species in the watersheds are Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), Engelmann spruce (*Picea engelmanni*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and grand fir (*Abies grandis*). Riparian areas also contain thinleaf alder (*Alnus tenuifolia*).

In the understory, common low-elevation shrubs (Plum Creek Timber Company, 1997) include shiny-leaf spiraea (*Spiraea betulifolia*), western serviceberry (*Amelanchier alnifolia*), and kinnikinnick (*Arctostaphylos uva-ursi*). Low elevation forbes include strawberry (*Fragarin virginiana*), heartleaf arnica (*Arnica cordifolia*), everlasting pussy-toes (*Antennaria racemosa*).

At higher elevations, common understory shrubs include Shiny-leaf spiraea and myrtle boxwood (*Pachistima myrsinites*). Higher elevation forbes include heartleaf arnica, beargrass (*Xerophyllum tenax*), and fireweed (*Epilobium angustofolium*).

Pinegrass (*Calamogrostis rubescens*) is the dominant grass in all watersheds, with some occurrence of Idaho fescue (*Festuca idahoensis*), blue bunch, wheatgrass (*Agropyron spicatum*), and elk sedge

(*Carex geyeri*).

2.6 HISTORY OF LAND USE AND DISTURBANCE

In the early 1950's, lower elevations of the Boiling Springs watershed began to be developed with roads and timber harvests. Harvests intensified in the 1960's and 1970's and were primarily clearcuts, with tractor logging being the harvest method. Timber harvest and road construction has been less intense in Boiling Springs in the 1980's and 1990's, and been primarily accomplished with selective harvesting.

The Beatrice Creek watershed was first developed in the late 1950's and early 1960's when the main road was constructed adjacent to the main channel. Harvesting began in earnest in the 1960's and 1970's. Minimal harvesting has occurred in the watershed since the mid-1980's. Early harvests were accomplished with tractors (often with excavated skid trails) and jammers (cable machines which required road spacing less than 500 feet). These harvest methods resulted in very severe soil disturbance and displacement.

Murr Creek was relatively undeveloped until the late 1970's, when the watershed was developed to salvage stagnant lodgepole pine stands that were infested with bark beetles. Because of the predominance of lodgepole forests, clearcuts have been the preferred silivcultural tool. Much of the North Fork Murr Creek watershed was clearcut in the early 1980's. Because of the gentle slopes, harvesting was accomplished by dispersed skidding with tractors.

Site preparation in all three watersheds through the 1980's involved broadcast burning to reduce slash levels and promote regeneration. In the 1990's broadcast burning has been almost eliminated, with land managers favoring tree-length harvesting. The result of this is that slash is concentrated (and burned) only at landings. In some cases, tractors return some logging slash to the logging area to reduce erosion on skid trails.

Grazing has been another historical disturbance which, to varying degrees, has impacted the analysis watersheds. Boiling Springs has had the longest history of grazing owing to the gentle slopes and early development of forage (as a result of 1950's-1970's harvests). Murr Creek has not been significantly grazed because forage was only recently made available in the 1980's when harvests first occurred. By that time, land managers were not trying to expand grazing programs. Beatrice Creek has had very minimal grazing due to the steep topography.

Fire was undoubtedly a major historical disturbance in the analysis watersheds. Retrospective analyses of forest stand structure in the lower Clark Fork basin has found that as much as 1/3 of the landscape was in a stand-initiation structural stage because of wildfire. Though detailed historic fire

records are not available for the analysis watersheds, pure stands of lodgepole pine in the Murr Creek watershed is evidence of wildlfires early this century.

2.7 RATIONALE FOR WATERSHED SELECTION

Because the bedrock geology in the Thompson River Basin is essentially the same, analysis watersheds were selected to encompass a cross section of glacial influences found in the basin. Murr Creek was selected because landforms were derived predominantly from fluvial processes. Boiling Springs was selected as representative of continental-glacial influenced lands. Beatrice Creek was selected because of the alpine-glacial influences. A detailed analysis (Ryel and Jensen, 1997) of watershed similarity in the Thompson River Basin is contained in Section 8.

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SECTION 3

EXECUTIVE SUMMARY

3 EXECUTIVE SUMMARY

Stream channels are shaped by a number of important variables that interact to create characteristics unique to each stream. Some variables such as the gradient, valley confinement and drainage area of a stream are relatively unchanged by human activities. Other variables, however, such as the amount of coarse and fine sediment, the amount of large wood in the stream channel, and the volume and timing of flood events can be influenced by management activities. These variables influence the channel morphology and dictate the quality of habitat available for fish. Studying the channel morphology can thus provide a surrogate assessment of the health of the stream system for fisheries. Watershed analysis identifies the physical processes important to the morphology of stream channels and how management may influence them. This section provides summaries of the findings of each of the analytical modules conducted in three watersheds within the Thompson River Basin: Beatrice Creek watershed, Boiling Springs Creek watershed, and Murr Creek watershed. The information provided can be used by resource managers to develop prescriptions to minimize or prevent problems in sensitive areas.

3.1 MASS WASTING

Landslides and other mass wasting features were examined in the Beatrice, Boiling Springs, and Murr Creek watersheds. Aerial photographs, field reconnaissance, and topographic, geologic, and landform maps were used to assess the historic and current distribution of mass wasting in the context of forest management.

Mass wasting in the three study watersheds is extremely rare, and is clearly not a dominant erosional process in these areas. In the 50 square mile analysis area, only five modern-era mass wasting sites were identified. Where forest management-related mass wasting was observed, causal mechanisms were as follows: 1) Over-steep road cutslopes where groundwater seeps were present (2 instances); 2) Fills constructed on steep slopes where road drainage was not properly managed (1 instance); and 3) Fills that were not properly constructed, coupled with groundwater seepage (1 instance). More importantly, of these four management-related landslides, no discernable sediment was routed to streams.

In localized areas elsewhere in the Thompson river drainage, mass wasting is a more dominant erosional process. These include areas in lower Fishtrap Creek and the Middle Thompson, where large streams (fourth order and larger) have dissected glacial depositional landforms. Along lower Fishtrap Creek, natural stream undercutting of an adjacent glacial terrace slope resulted in delivery of approximately 93,000 cubic yards of sediment to the creek. In another location on lower Fishtrap Creek, an old road appeared to contribute to a 4,400 cubic yard failure which delivered to the stream. Road construction on these landforms appears to be of particular concern.

The relatively benign slope gradients in the analysis watersheds (and elsewhere in the Thompson) have created a situation where standard Best Management Practices have been very effective at keeping forest management-induced mass wasting to a minimal level. Moderate-hazard landforms where extra caution is necessary, and for which Causal Mechanism Reports were written, include some slopes within Steep Fluvial Landforms, Steep Alpine Glacial Landforms, and Inner Gorge Landforms (where groundwater seepage is absent). Where groundwater seepage is present on slopes greater than 70% in Inner Gorge Landforms, a high hazard exists. As is always the case, however, on-the-ground verification on a project-by-project basis is absolutely necessary to verify information in this analysis, determine deliverability, and make appropriate management decisions.

3.2 SURFACE EROSION

Surface erosion from hillslopes and roads were examined in the Beatrice Creek, Boiling Springs Creek, and Murr Creek watersheds. The hillslope erosion assessment evaluates the occurrence of, or potential for, surface erosion from hillslopes. This includes sheet, rill, and gully erosion. This type of erosion is typically associated with exposure of bare mineral soil to raindrop splash and overland flow. The road erosion assessment evaluates the amount of sediment that can be expected from roads in the watershed. The amount of sediment delivered to streams is a function of the erosivity of the soils, road surfacing, amount and type of traffic, road drainage, and proximity to streams.

The potential for forest management to create hillslope erosion was evaluated on ten recently harvested areas distributed among the three watersheds. At all sites, the harvest areas adjacent to streams were investigated for signs of hillslope erosion and sediment delivery. Of the ten units, two were tractor logged, three were cable logged with partial suspension, and five sites had a combination of cable and tractor logging. Local areas of soil disturbance were observed on hillslopes, typically as a result of ground-based equipment operation, or by logs being skidded (by cable or tractor). Though localized soil disturbance was observed, no sediment was observed to have routed to a stream channel. Results from the field observations indicate that the application of BMP's and adherence to the SMZ law has been highly effective at minimizing hillslope erosion and preventing sediment delivery to streams.

The road erosion assessment evaluated all existing roads within the watersheds to determine the relative amounts of road-derived sediment delivered to stream channels, as opposed to background sediment delivery derived from naturally occurring erosion processes. At present, the Beatrice, Boiling Springs, and Murr Creek watersheds have a total of 53.0, 49.4, and 114.7 miles of road respectively.

In the Beatrice Creek watershed, 36 road locations were found to contribute sediment to streams. This includes 16 segments along the main road up the valley bottom. These locations were estimated to contribute 59.5 tons per year. In the Boiling Springs Creek watershed, 23 road locations were

identified as delivering sediment to streams for a total of 26.5 tons per year. In the Murr Creek watershed, 38 locations were found to contribute 26.5 tons per year.

Relative to estimated background erosion, roads in both Beatrice and Boiling Springs Creek watersheds are estimated to contribute in excess of 50% of the background erosion rate. Road erosion in Murr Creek was found to contribute less than 50% of background.

The majority of sediment volume delivered in each watershed is derived from a small number of discrete locations. In Beatrice Creek, 54% of total road sediment delivery was from the 16 road segments along the main road. In Boiling Springs, the top nine contributing locations deliver 76% of the total sediment volume from roads. This inventory will provide local managers with key information for reducing sediment delivery from roads.

3.3 HYDROLOGY

The Distributed Hydrology-Soil-Vegetation Model (DHSVM) was used to assess the effects of timber harvesting on the three analysis watersheds. DHSVM is a physically-based distributed watershed model developed at the University of Washington and the Pacific Northwest Laboratory (Richland, WA) that simulates water pathways (precipitation, interception, evapotranspiration, subsurface flow, and surface flow) for each model cell. Input data requirements include spatial data which characterizes the land surface of the modeled basin, meteorological forcings (precipitation, air temperature, wind speed, relative humidity, and radiation information), and observed streamflow and/or snow water equivalent (SWE) measurements for calibration. The spatial data requirements include digital elevation data provided by a digital elevation model (DEM), a map of the existing vegetation, and the soil distribution and characteristics. The standard modelling methodology was not used in this analysis because it assumes that winter rain-on-snow runoff events are the predominant runoff-generating mechanism. This is not the case for the Thompson River Basin and most of Western Montana, where peak flows are typically generated during spring snowmelt or rain during spring snowmelt.

Hydrologic effects related to vegetation changes were evaluated by simulating daily streamflow for the current and historical vegetation conditions for each watershed. The vegetation current condition was compiled from existing PCTC stand inventory database and US Forest Service (USFS) regional landcover and canopy density mapping. The historical vegetation scenario was modeled after Forest Service studies which estimate the relative proportions forest structure types prior to fire-suppression management policies. Considering the role of natural disturbances (forest fires) on the forest vegetation produces a historical vegetation scenario which is typically less mature relative to the current vegetation scenario. Daily stream flow was also modeled for a maximum harvest scenario for Murr Creek, Beatrice Creek, and Boiling Springs.

Simulated floods in Beatrice Creek and Murr Creek in the current condition have decreased relative to the simulated historical condition in both the Recurrence Interval and Peaks-Over Threshold (POT) analyses. In the recurrence interval analysis, similated changes in the 2-year event are -7.7%, 0.75%, and -6.3% for Beatrice, Boiling Springs and Murr Creeks respectively. Simulated changes using a POT analysis found than mean peak flows were -8.1%, 1.8%, and -5.1% for Beatrice, Boiling Springs, and Murr Creek's respectively. The model results suggests that peak flow increases of about 25-50% would be expected to be associated with the maximum harvest scenario.

The modeling results presented in this analysis suggest that relative to the historical forest condition and the effects of natural forest fires, there have not been large changes in the peak flow regimes under the current forest conditions for Beatrice Creek, Boiling Springs Creek, or Murr Creek. The channels module analysis reports a low sensitivity to peak flow changes for most of the reaches in the watersheds. Considering the modeling results and the channel analysts assessment, the hydrologic hazard rating, as describe in the Washington watershed analysis hydrology module procedures, is *LOW* for all three watersheds under the current vegetation conditions. The hydrologic modeling indicates that the hydrology hazard should be re-evaluated if proposed forest management plans would produce a vegetation scenario approaching the maximum harvest condition.

There are many sources of error which reduce confidence in the estimated peak flow changes related to forest management. The errors stem from input meteorological data, spatial data, calibration, computational error, and analysis technique. Peak flow changes related to forest management in forested watershed is a complex process and previous studies have shown that there is large variability in the response of forested basins depending on physiography, antecedent conditions, storm characteristics, and the nature and timing of hillslope disturbances. While DHSVM is described as a "physically-based" model, calibration is still required and the extent to which calibration parameters are time dependent is not known. The effects of roads, which may alter storm hydrographs in forested basins, are not considered in this analysis and the extent to which this omission introduces error is also not known. The modeled flow changes do account for climate variation as recorded at climate observation stations, and consider the spatial variability of changes in the forest vegetation and soil properties.

The effect of watershed scale may introduce error in the analysis. The watershed model was calibrated for the entire Thompson River Basin, which averages key hydraulic parameters, such as the saturated lateral hydraulic conductivity, on the spatial scale of the entire basin. DHSVM calculates streamflow at any point on the channel network within the basin, allowing assessment of peak flow changes at the sub-basin scale. However, reducing the model scale to assess peak flow changes in sub-watersheds may introduce error in the simulated streamflow analyses.

3.4 RIPARIAN FUNCTION

An assessment of riparian condition and function was conducted in the Beatrice, Boiling Springs, and Murr Creek watersheds. The assessment evaluated the condition of riparian areas relative to their ability to supply large woody debris (LWD) to stream channels and to provide shade to maintain desirable stream temperatures. The riparian areas' LWD recruitment potential and current shade levels were characterized remotely using 1993, 1994, 1995 and 1997 Plum Creek Timber Company (PCTC) color aerial photography (1:12,000 scale). Field inspections and data analysis were used to verify calls on a sub-sample of the riparian areas. Data for the assessment came from PCTC fisheries research crews, and thermograph data collected during the summers of 1995 and 1997. Additional data were collected by module analysts. Approximately 50% of stream segments were evaluated in the field.

More than 79% of riparian areas in the three study watersheds were found to currently have a moderate-to-high potential for recruiting LWD to streams. The riparian areas that were deficient in LWD recruitment potential were generally found in the upper reaches of the channel network. These are areas with naturally low densities and smaller trees due to environmental factors (i.e., talus soils, steep head wall systems, canyons, and short growing seasons). Some of the low recruitment areas in both Boiling Springs Creek and Murr Creek were attributed to timber harvesting.

In-channel LWD within much of the Boiling Springs channel network is considered to be below target due to historic (pre SMZ Law) timber harvest or areas that are naturally deficient in medium to large trees in the riparian area. In-channel LWD levels in Beatrice Creek and Murr Creek are generally on-target.

Canopy cover of the stream channel network is generally sufficient to keep stream temperature below 15°C. Five stream segments were identified as potentially having insufficient canopy cover. Two of these segments were attributed to historically-low conditions, and three were attributed to timber harvest prior to the SMZ law. Stream temperature data found streams to be generally cool, but thermographs were not located near areas identified as having harvest-effects. Additional data will be collected in 1998 to fill this data gap.

Since 1991, Montana forest practices rules have required 50-100 foot Streamside Management Zones, with retention of at least 50% of the trees. Based on photo and field observations, riparian stands which have had timber harvesting subsequent to adoption of this law have maintained the recruitment potential of the pre-harvest stand and canopy cover conditions that were close to pre-harvest. As such, it is believed that riparian stands that have been harvested since the adoption of these rules are providing adequate protection to stream, particularly on confined stream channels. Where unconfined stream channels exist, standard SMZ rules may be insufficient to protect where

the stream may be in the future.

3.5 CHANNEL CONDITION

Classification of stream channels in three sub-watersheds within the Thompson River watershed was conducted. Channel classification according to sensitivity to forest management activities was guided by Washington Watershed Analysis methodology. Channel classification was based on prior ecological classification of the area, geomorphically-based channel classification, and field observations of stream channel and landscape conditions.

Stream channel gradient (slope) is a major predictor of channel morphology and, consequently, habitat potential and channel sensitivity to changes in watershed processes potentially caused by management activities. In the three watershed analyzed, Geomorphic Channel Units (GCU's) 1 through 5 (summarized in Table 4E-1) have low stream gradients (< 4% on average), while GCU's 6 through 12 have high stream gradients (> 4% on average). Actual and potential fish habitat is significantly greater in the low gradient group compared to the high gradient group. The former group comprises about 14% of all channels, while the latter accounts for the remaining 86%.

The sensitivity to change of each GCU with respect to watershed and riparian inputs of coarse sediment, fine sediment, peak flows, large woody debris (LWD), catastrophic geologic events (landslides), and the influence of riparian vegetation and channel migration zones on channel processes is assessed. Sensitivities are summarized in Table 4E-4. In general, lower-gradient GCU's tend to be more sensitive to watershed disturbance, with some important exceptions.

The existence of channel migration zones (areas adjacent to stream channels, typically within the floodplain, where a stream has the potential to shift its locations) was evaluated in each GCU. This evaluation was intended to alert forest managers to the presence of channel and valley bottom conditions where Montana Streamside Management Zone regulations may not be adequate to maintain stream channel processes thought to be critical to formation of high quality fish habitat. GCU #4 found in Beatrice Creek, the "Conifer Floodplain CMZ", was particularly susceptible to channel migration. LWD recruited from riparian forest stands is an integral component of this channel type.

Geologic history of the study area was found to influence the distribution of stream channel types and their potential sensitivity to forest management. Glaciers overran much of the Thompson River watershed about 15,000 years ago. The dominant glacial effect was caused by continental ice flowing south from Canada, filling the mainstem valley and terminating near the southern end of the watershed. Deposits of gravel and sand-rich glacial sediment form most flat-lying valley

bottoms; stream channels have cut through these deposits in some areas (e.g. GCU #6).

A major glacial lake is thought to have stood at an elevation of about 4200 ft. In some areas, there are fine sediment deposits rich in clay and silt that were deposited in glacial lakes (e.g. GCU #3 in Boiling Springs Creek). There are some areas of deposition in upper valley bottoms apparently related to this ancient lake level (e.g. GCU #10 in Beatrice Creek).

There were also smaller, alpine glaciers that formed along mountain crests in the southern half of the watershed, typified by Beatrice Creek. These glaciers probably intersected the glacial lake; these glaciers did not apparently extend to mouth of their valleys. Streams downstream from these alpine glacial deposits may have unusual habitat potential resulting from groundwater outflow to streams.

Many mountain slopes at intermediate elevation in the watershed are underlain by bedrock on which shallow residual soils have formed and glacial deposits are generally absent. These tend to lie above areas dominated by continental glacial deposits and below areas dominated by alpine glacial processes.

3.6 FISH HABITAT

The objectives of the fish habitat module are to document existing and historic fish distribution, assess current habitat conditions, identify important habitat areas, and identify impacts to fish habitat from land management activities. The majority of the data used for this analysis was collected by Plum Creek Timber Company fisheries research personnel in 1994 and 1997. Module analysts collected additional survey data as necessary.

Trout and char species that occur in the analysis area are brook trout, bull trout, cutthroat trout and rainbow trout. Rainbow trout and brook trout are non-native species. Stocking of non-native salmonids by state personnel began in the analysis area as early as the 1930's. Stocking records of federal agencies were not assessed for this analysis, but it is likely that the Bureau of Fisheries (now the US Fish and Wildlife Service) stocked brook trout in the northern end of the Thompson River basin in the 1930's or 1940's. This assumption is based upon the fact that brook trout are prevalent in Murr and Boiling Springs creeks and state records do not document the stocking of brook trout in Murr Creek by MDFWP. Since the Bureau of Fisheries commonly stocked brook trout throughout western Montana in the 1920's through 1940's, the stocks in Boiling Springs and Murr creeks were probably established through federal efforts. State records indicate that Lower Thompson Lake was stocked annually with "undesignated" cutthroat trout (westslope cutthroat and/or Yellowstone cutthroat) from the early 1930's through 1946. Since Boiling Springs Creek is tributary to Lower Thompson Lake, some of these fish likely migrated into Boiling Springs. Undesignated cutthroat were stocked directly into Boiling Springs Creek in 1969 and into the

lower reaches of Murr Creek in 1942. Rainbow trout were first stocked in Lower Thompson Lake in 1946 and brook trout were first stocked in the lake in 1949. Currently, Lower Thompson Lake is stocked annually with rainbow trout. State records do not indicate any stocking of non-native salmonids in Beatrice Creek.

Surveys conducted for this analysis indicate that the lower reaches of Murr Creek downstream of the barrier cascades in Section 9 support all species found in the analysis area (brook trout, bull trout, cutthroat trout, rainbow trout). Both juvenile and adult rainbow, cutthroat, and brook trout were found in lower Murr Creek but only one adult bull trout was detected, indicating that this is not natal habitat for bull trout. Upstream of the Section 9 barrier in Murr Creek, only brook trout have been detected by population surveys. No fish have been detected by surveys upstream of a barrier falls in Section 11 in the south fork of Murr Creek. This distribution pattern suggests that the reaches of Murr Creek upstream of a fish-passage barrier cascades in Section 9 were never accessible to native salmonids and that these areas were successfully exploited by brook trout after they were stocked somewhere upstream of the barrier cascades. The lower and mid-reaches of Boiling Springs Creek were found to support brook and rainbow trout. The upper mainstem reaches of Boiling Springs support primarily brook trout. Cutthroat trout were found only in the uppermost reaches of Boiling Springs Creek. Beatrice Creek supports only native stocks of fish. Bull trout and cutthroat trout are found throughout the mainstem of Beatrice Creek from the mouth upstream to the fork in Section 2. Upstream of the fork, bull trout are found in the lower half of the northern fork while cutthroat trout are found throughout. Only cutthroat trout were detected in the southern fork upstream to the barrier cascades in Section 11. Upstream of the barrier cascades, no fish were found by snorkel surveys. No man-made barriers to fish movement were found in the analysis area. Hence, all upstream limits to fish distribution in the analysis areas are the result of natural barriers.

Once channel segments were delineated, habitat conditions were assessed by compiling and analyzing all available data. Data were stratified by channel segment and geomorphic channel unit (GCU) and condensed to generate metrics for assessment. Habitat metrics and field evaluations were then used to generate habitat resource condition calls (good, fair, poor) for life phases (spawning, winter/summer rearing, winter rearing) by channel segment and GCU. Channel segments in GCUs 4 and 1 (Conifer Floodplain CMZ and Alluvial Fans, respectively) were consistently found to support the best habitats for native salmonids, both in terms of habitat quality and exhibited utilization. Channel segments in GCU's 8, 9, and 10 (Perennial Headwaters, Canyons & Cascades, and Headwaters with Avalanche, respectively) were also found to support habitats important to native stocks. Introduced species were found to use habitat in the above GCUs, but surveys indicate that GCUs 2 and 5 (Forest/Meadow Complex and Confined Mainstem, respectively) contained the most important habitats for exotics. This may be an anomaly related to historic stocking locations and the distribution of the GCUs in the Thompson River basin, or GCUs 2 and 5 may contain habitat features conducive to displacement of native

stocks by exotic species.

Development of fish habitat vulnerability calls resulted from consultation with analysts responsible for the Channel Condition, Hydrologic Condition, and Riparian Function Modules. Generally, GCUs found to contain fish habitats most vulnerable to potential changes in physical input processes (especially large woody debris and sediment) were those exhibiting relatively low gradients and wider channel migration zones.

3.7 SYNTHESIS

Once the analysts had worked through their modules, the information was brought together with the data from other modules to develop a more comprehensive picture of the watersheds. The information was used to link resource effects to existing or potential hazards and to consider the existing or potential cumulative effects of forest practices. The cause and effect linkages are summarized in the causal mechanism reports to help the prescriptions team develop appropriate management responses in focused areas.

Synthesis of the information collected by analysts resulted in the development of nine causal mechanism reports (CMRs) for the analysis areas. Three CMRs were developed for potential delivery of course and fine sediment through mass wasting processes. One CMR was written for existing delivery of fine sediment through surface erosion from old roads in the Beatrice and Boiling Springs Creek watersheds.

Five causal mechanism reports were written to address riparian issues. Three related to LWD recruitment for the following conditions: 1) LWD deficient riparian areas adjacent to streams that are identified as being moderately-vulnerable to LWD recruitment; 2) LWD deficient riparian areas adjacent to streams that are identified as being highly-vulnerable to LWD recruitment; and 3) Riparian areas adjacent to streams with a moderate-to-high potential for channel migration. Another CMR was written to address canopy cover conditions in the five stream reaches identified as having deficient canopy cover. The last CMR was written to address grazing impacts on small private land in lower Murr Creek.

SECTION 4

RESOURCE ASSESSMENT MODULES

4A MASS WASTING MODULE

4A.1 INTRODUCTION

The purpose of Mass Wasting Module is to evaluate landslides and other mass wasting features in three tributary watersheds of the Thompson River: 1) Boiling Springs Creek, 2) Murr Creek, and 3) Beatrice Creek. The sensitivity of the watersheds to mass wasting is examined in the context of past and potential forest management activities. While steep, mountainous terrain is often naturally-prone to sliding, the removal of trees through timber harvest or road construction and the subsequent reduction in rooting strength can increase the potential for slope movement. Additionally, artificial increases in slope gradient from road cut slopes and fill slopes or the concentration of road drainage to specific areas can increase the likelihood of landslides. Based on the combination of landslide occurrence, landscape disturbance history, and topographic, geologic and soil mapping, areas susceptible to mass wasting can be identified. Sensitive areas are evaluated by both the potential for mass wasting and the potential for delivering sediment to sensitive stream reaches.

4A.2 MATERIALS AND METHODS

Analytical methods follow guidelines from the Washington State Watershed Analysis Manual, Version 3.0 (Washington Forest Practices Board, 1995). In that methodology, nine critical questions to be answered in the mass wasting module are as follows:

- *What are the potential sediment sources in the basin?*
- *Is there evidence of, or potential for, mass wasting in the watershed?*
- *What mass wasting processes are active?*
- *How are mass wasting features distributed throughout the landscape?*
- *What physical characteristics are associated with these features?*
- *Do landslides deliver sediment to stream channels or other waters?*
- *Do forest management activities create or contribute to instability?*
- *What areas of the landscape are susceptible to slope instability?*
- *What is the relative contribution of sediment from mass wasting compared with other sediment sources?*

Landslides and the sensitivity of the watersheds to mass wasting were evaluated using a combination of available mapping, aerial photographs and field reconnaissance. United States Geological Survey 1:24,000 (2 inches = 1 mile) scale topographic maps served as a base map. Plum Creek Timber Company 1:12,000 scale aerial photographs was used to identify and map landslides. These photographs were flown in 1997, 1995, 1994, 1993, and 1955. Geographic information system (GIS)

computer-generated maps provided information on slope-class and terrain characterization. Terrain characterization was based on Subsection and Landtype Association mapping (Jensen and Dean, 1997), from landtype mapping on the Lolo National Forest (Sasich and Lamotte-Hagen, 1989) and Kootenai National Forest (Kuennen and Nielsen-Gerhardt, 1995), and from soil surveys by the USDA Natural Resource Conservation Service (1997).

Landslides were inventoried from inspection of aerial photographs and through discussions with foresters and other analysts. This preliminary mapping was checked during four days of field reconnaissance in September and October, 1997.

4A.3 GEOLOGIC AND PHYSIOGRAPHIC OVERVIEW

The Thompson River Basin drains a land area of 410,095 acres (641 square miles). Elevations range from 2457 feet at Thompson River's confluence with the Clark Fork River (near Thompson Falls, Montana) to 7464 feet at the summit of Baldy Mountain, in the southeast corner of the Basin. Mean annual precipitation for the basin is 30.4 inches and ranges from approximately 20 at lower elevations to as much as 60 inches at the highest elevations (USDA Soil Conservation Service, 1994).

Bedrock underlying the Thompson Basin is predominantly composed of Precambrian hard metasedimentary rock, principally the Burke, Revett, and Wallace formations. The basin is also underlain by minor amounts (3%) of Cambrian limestone, dolomite, and shale, located in the Fishtrap Creek drainage (Harrison et al., 1986; Harrison et al., 1992). The Precambrian metasedimentary rocks were created between 1.5 billion and 800 million years ago when thousands of feet of sands, silts, and clays were deposited at the bottom of a shallow ocean (or lake) and subsequently metamorphosed by intense heat and pressure. The mountains we see today in the Thompson basin were formed 70-90 million years ago, when the North American continent collided with the floor of the Pacific Ocean. This collision resulted in thrust faults in the belt formations, whereby huge slabs of rock over-rode others, creating a series of long ridges and valleys that trend north to south between parallel valleys (Alt and Hyndman, 1986).

In the last 150,000 years, two periods of glaciation have affected about 50% of the Thompson River Basin. The Bull Lake ice age reached its maximum southern extent about 100,000 years ago, and the Pinedale ice age reached its maximum about 15,000 years ago (Jensen and Dean, 1997). Continental glaciers advancing south out of Canada covered the northern portion of the Thompson, extending southward to the vicinity of the Little Thompson River. Glacial till remaining after the glaciers melted has been dissected by numerous streams in the basin. In addition to continental glaciation, localized alpine glaciers affected numerous watersheds within the Thompson, primarily tributaries draining high elevation lands in the southwest corner of the basin.

Another important influence on the landforms of the Thompson also occurred during the Pinedale ice age, when another glacier dammed the Clark Fork River near Lake Pend Oreille to create Glacial Lake Missoula. This lake filled upstream ice-free valleys to a maximum elevation of 4,200 feet. Glacial Lake Missoula sediment deposits are most visible in lower Fishtrap Creek and in the Little Thompson River watershed. These lake deposits have also been subsequently dissected by numerous streams in the basin.

Because the bedrock geology in the Thompson River Basin is essentially the same, analysis watersheds were selected to encompass a cross section of glacial influences found in the valley. Murr Creek was selected because the underlying bedrock has been almost entirely shaped by fluvial (non-glacial) processes. Only 3.2% of the Murr Creek watershed is within glacial landforms (Jensen and Dean, 1997). Boiling Springs Creek is located in the northeast portion of the Basin and is unique in that it has been almost entirely continentally- glaciated (97%). Beatrice Creek is located in the southwest corner of the basin. Similar to Murr, it has been principally shaped by fluvial processes (74%), but 26% of the watershed has been affected by alpine glaciation (Jensen and Dean, 1997). For a detailed discuss of watershed characteristics, see the analysis in Section 7.

Slope distributions for the three analysis watersheds are shown in Figures 1a-1c. These slope distributions were obtained by 1:24,000 Digital Elevation Model (DEM) data. Sidle et al. (1985) suggested that 25° (47%) is a conservative lower limit for the potential initiation of shallow rapid landslides. Assuming this, we expect that the potential for shallow-rapid landsliding in the study watersheds to be limited to a very small percentage of the landscape. In the Murr and Boiling Springs watersheds , ~95% of the watershed area has slope gradients less than 25°. Beatrice Creek has the relatively higher potential based on the DEM data with almost 20% of its land area steeper than 25°.

4A.4 LANDSLIDE INVENTORY RESULTS

Following extensive review of the aerial photograph record, and from discussions with other analysts and foresters familiar with the study watersheds, <u>five</u> mass wasting sites were identified in the three study watersheds. Each slide is individually discussed in section 4A.4.1. Because of the relatively small number of landslides identified in the study watersheds, the inventory was expanded to include four other landslides <u>known</u> to occur elsewhere in the Thompson River Basin. This expanded inventory was done to gain a better understanding of mass wasting processes that are active throughout the entire Thompson River Basin, and to better associate mass wasting occurrences with particular landforms and land management situations. The expanded inventory of landslides are discussed in section 4A.4.2. Landform units shown are further discussed in section 4A.5.

4A.4.1 MASS WASTING SITES IN BEATRICE, MURR, AND BOILING SPRINGS

4A.4.1.1 Beatrice Creek (NE1/4, NE1/4, S1, T23N, R28W)

Road cutslope slump: *120' wide by 30' high by 2' deep*
Estimated volume: *270 cubic yards*
Slope gradient: *~90% (cutslope)*
Landform Unit: *2 (Steep fluvial lands)*

Description: The slide occurred in the last 10 years. The vast majority of this material deposited on the road prism. Material that did extend below the road deposited within 150 feet downslope and did not deliver to any stream. This failure appeared to result from an over-steepened cutslope that became saturated.

4A.4.1.2 Beatrice Creek (NE1/4, NW1/4, S1, T23N, R28W)

Road fill slump: *50' wide by 20' high by 2' deep*
Estimated volume: *75 cubic yards*
Slope gradient: *70-75% (fillslope)*
Landform Unit: *2 (Steep fluvial lands)*

Description: This slide occurred in the last 2 years, most likely associated with the extreme runoff events in the winter of 1996 or spring of 1997. The evacuated material moved 50 feet downslope and deposited in an unchannelized draw. Because the material is more than 1000 feet upslope of the nearest stream, it is presumed to have little or no potential impact to downstream aquatic resources or water quality.

The causal mechanism for the failure appeared two-fold. First, the fill appeared to be partly supported by old stumps that eventually rotted. Second, at the location of this failure, the road crossed a band of fissile shale (Harrison et al., 1986). This shale appeared to be relatively impermeable to water, and in the location of this failure, seeps were very prevalent. This is believed to be the primary cause of the failure.

4A.4.1.3 Beatrice Creek (NW1/4, NW1/4, S6, T23N, R27W)

Streambank slump: *35' wide by 20' high by 3' deep*
Estimated volume: *80 cubic yards*
Slope gradient: *~80% (ground slope)*
Landform Unit: *2 (Steep fluvial lands). Note: though this location is mapped as landform unit 2, the failure occurred in a very localized alluvial or glacial outwash*

deposit immediately adjacent to the stream.

Description: The slump delivered directly to Beatrice Creek. The causal mechanism appeared to be a result of natural stream migration that undercut a pocket of glacial outwash or alluvium.

4A.4.1.4 Boiling Springs (NW1/4, NW1/4, S28, T26N, R27W)

Road cutslope slump: 150' wide by 9' high by 3' deep
Estimated volume: 150 cubic yards
Slope gradient: ~80% (cutslope)
Landform Unit: 3 (Gently to moderately sloping glaciated lands)

Description: Virtually all of the material in this failure deposited in the ditch and on the road bed. None of the slide appeared to deliver to Boiling Springs Creek, located 100 feet below the road. The failure appeared to have occurred in the last 3 years and resulted from an overly-steep cutslope and numerous seeps at the toe of the cutslope (both in the vicinity of the slide and further up the ditchline).

4A.4.1.5 Boiling Springs (NW1/4, NE1/4, S14, T26N, R27W): Landform Unit 5

Road fill failure: 3' wide by 9' long by 3' deep
Estimated volume: 3 cubic yards
Slope gradient: 85% (ground slope)
Landform Unit: 5 (Steep terrace slope)

Description: This shallow-rapid fill failure is located 0.35 miles up the Boiling Springs road. The evacuated material traveled 50 feet downslope where the majority of the volume deposited behind a downed log. It appears that little or none of the material routed the remaining 100 feet downslope to Boiling Springs Creek. The exact causal mechanism for the failure was difficult to ascertain. A likely explanation is that road runoff was concentrated at this location; however, no defined drainage feature (eg. Ditch relief culvert, drive dip, etc.) was present.

4A.4.1.6 Ancient post-glacial landslides

Features that could be ancient landslides are located throughout the Boiling Springs watershed and along lower Murr Creek. These features could simply be related to the inherently hummocky glacial depositional topography, but could also be landslides that occurred as the landscape was stabilizing in the years following glacial retreat. A number of these features were investigated and none showed

any sign of recent movement, even though most had had some level of timber harvest and road construction over the last 40 years. Because of the difficulty in delineation, and apparently stable nature even where extensive forest management has occurred, no special delineation or treatment of these features was deemed necessary.

4A.4.1.7 Cliffs, rockslides, talus slopes

These features are distributed throughout the analysis area, but are concentrated in the cirque basin in the headwaters of Beatrice Creek, and in the canyon reaches of lower Murr Creek. These features are not specifically delineated in the landslide inventory, but are discused where they are prevalent in the landform unit discussion.

4A.4.2 MASS WASTING SITES ELSEWHERE IN THOMPSON RIVER BASIN

4A.4.2.1 Big Rock Creek (NE1/4, NE1/4, S1, T24N, R27W)

Streambank slump: 45' wide by 40' high by 3' deep
Estimated volume: *200 cubic yards*
Slope gradient: *90-95% (ground slope)*
Landform Unit: *5 (Steep terrace slope)*

Description: The failure resulted from stream erosion of the toe of a steep glacial terrace slope. All of the eroded material was delivered to Big Rock Creek.

4A.4.2.2 Fishtrap Creek (SW1/4, SW1/4, S22, T23N, R27W)

Glacial Terrace slump: 250' wide by 250' long by 40' deep
Estimated volume: *93,000 cubic yards*
Slope gradient: *75-85% (ground slope of terrace)*
Landform Unit: *5 (Steep terrace slope)*

Description: This failure appeared to result from natural stream erosion of the toe of a glacio-lacustrine terrace slope.

4A.4.2.3 Fishtrap Creek (SE1/4, SE1/4, S28, T23N, R27)

Road cutslope slump: 120' wide by 200' long by 5' deep
Estimated volume: *4,400 cubic yards*
Slope gradient: *95% (ground slope)*
Landform Unit: *5 (Steep terrace slope)*

Description: In contrast to the other slide on Fishtrap discussed previously, this slide appears to have been caused by an old road traversing the lower portion of the terrace slope. This road may have oversteepened the slope triggering the slide.

4A.4.2.4 Middle Thompson (S1/2, SW1/4, S13, T24N, R27W)

Road cutslope slump: 45' wide by 30' long by 1.5' deep
Estimated volume: *75 cubic yards*
Slope gradient: *70% (cutslope)*
Landform Unit: *5 (Steep terrace slope)*

Description: This failure occurred during spring snowmelt in 1997 and resulted from a series of springs coming out of a road cutslope, presumably supersaturating the slope and leading to the failure. The failure almost entirely deposited on the road tread. However, a minimal amount of the material may have been incorporated in the debris flow discussed in the next section.

4A.4.2.5 Middle Thompson (S1/2, SW1/4, S13, T24N, R27W)

Fill failure, debris flow: 5' wide by 75' long by 5' deep
Estimated volume: *~70 cubic yards*
Slope gradient: *55% (ground slope)*
Landform Unit: *5 (Steep terrace slope)*

Description: The spring that led to the cutslope failure discussed in 4A.4.2.4 diverted down the road tread and over the fillslope approximately 50 feet away from the cutslope failure. This water then super-saturated the road fillslope, leading to a debris flow which moved 300-400 feet down the hillside, depositing just upslope of the Thompson River. Upon examination, it appeared that very little of the estimated 70 cubic yard debris flow actually entered the river.

4A.5 LANDFORM UNITS

Six map units were developed to group lands that are similar with respect to their landform and mass wasting potential (Table 4A-1). Each landform unit was then evaluated with regard to the potential for mass wasting events to deliver (route) sediment to streams. This delivery potential was based on the landslide inventory and other observations by the mass wasting analyst. These two potential ratings were then combined to form an overall "Delivered Hazard Rating" for each landform unit (WFPB, 1995). Landform units and their attributes are summarized in Table 4A-1 and are mapped for the study watersheds in Figures 2a-2c. A discussion of each landform unit follows Table 4A-1.

Table 4A-1. Summary of mass wasting and delivery potential

Landform Unit	Landform	Mass Wasting Potential	Delivery Potential	Delivered Hazard Rating
1	Gently to Moderately-Sloping Fluvial Lands	Low	Low	Low
2	Steep Fluvial Lands	Moderate	Moderate	Moderate
3	Gently to Moderately-Sloping Glaciated Lands	Low	Low	Low
4	Steep Alpine Glacial Lands	Moderate	Moderate	Moderate
5	Inner Gorges in Glacial Depositional Landforms	Moderate to High	High	Moderate to High*
6	Alluvial Deposits	Low	Low	Low

* A MODERATE delivered hazard is assigned where there is no evidence of subsurface seepage as evidenced by vegetation type or wet soils. A HIGH delivered hazard is assigned where evidence of subsurface seepage of water or presence of hydrophilic vegetation exists. Because of the site-specificity of this call, on-the-ground inspection will be required to determine the appropriate hazard.

4A.5.1 UNIT 1 GENTLY TO MODERATELY-SLOPING FLUVIAL LANDS

Delivered Hazard Rating: LOW

This landform unit includes gently and moderately-sloping fluvial lands, and comprises 68.3% of the study area (almost entirely within the Murr Creek and Beatrice Creek watersheds). Slopes in this landform unit are typically less than 60%, and average 20-30%. Jensen and Dean (1997) identified

two Landtype Associations that compose this landform unit: Mountain Ridge, and Mountain Slope. No landslides were mapped in this entire 21,849 acre landform unit, despite extensive forest management activities. As such, the landform unit was deemed inherently stable and assigned a LOW hazard rating.

4A.5.2 UNIT 2 STEEP FLUVIAL LANDS

Delivered Hazard Rating: MODERATE

This landform unit consists of steep fluvially-derived mountain slopes (typically 50%-100%), often with perennial streams at the base of the unit. Because of the shallow soils and frequent presence of talus and rock outcrops, vegetation is often sparse in this unit. Jensen and Dean (1997) described this unit as a Breakland Landtype Association.

This landform occurs in lower Murr Creek and lower Beatrice Creek, and encompasses 4,357 acres (13.6%) of the analysis area. A total of three mass wasting sites were identified in this landform unit, all within Beatrice Creek. This, in combination with the localized rock outcroppings and talus slopes, leads to a moderate mass wasting potential for this unit on slopes greater than 70%. With regard to delivery potential, sediment was routed to streams in one of the three landslides. Because of the proximity of this map unit to larger streams, a moderate delivery potential was assigned. Combining these two potentials leads to an overall delivered hazard rating of MODERATE.

4A.5.3 UNIT 3 GENTLY TO MODERATELY-SLOPING GLACIATED LANDS

Delivered Hazard Rating: LOW

This landform unit consists of gently to moderately-sloping glacially-scoured mountain slopes and ridges, and glacial depositional areas. Jensen and Dean (1997) identified four Landtype Associations that compose this landform: 1) Moraine, 2) Glacial Ridge and Slope, 3) Glacial Trough, and 4) High Terrace. Where portions of these landforms have been dissected by streams to form steep inner-gorges, they are considered as Landform Unit 5. Together, Landform Unit 3 comprises 23.3% of the analysis area (7,446 acres). Only one mass wasting site was mapped in this landform unit (road cutslope failure in Boiling Springs, see 4A.4.1.4). Given the gentle slope gradients and infrequency of landslides, the landform is considered stable, and a delivered hazard rating of LOW is assigned.

4A.5.4 UNIT 4 STEEP ALPINE-GLACIAL LANDS

Delivered Hazard Rating: MODERATE

This landform unit consists of steep alpine glaciated lands. The landform unit occupies concave

erosional slopes at the headwaters of alpine-glaciated watersheds. Jensen and Dean (1997) identified two Landtype Associations that were grouped to create this lanform unit: 1) Cirque and Rocky Ridge, and 2) Glacial Basin. This landform unit only occurs in the Beatrice Creek watershed. Slope instability in this map unit was limited to cirque headwalls and rockslides in the headwaters of Beatrice. Though no management-related landslides were identified, given the locally-steep slopes and glacial influence, a moderate mass wasting potential is considered to exist on steeper slopes within the map unit (>70%). Given the proximity of this map unit to streams, a moderate delivery potential exists and overall, a MODERATE delivered hazard rating is assigned.

4A.5.5 UNIT 5 INNER GORGES IN GLACIAL DEPOSITIONAL LANDFORMS

Delivered Hazard Rating: MODERATE to HIGH (Dependent on signs of subsurface water)

This landform unit delineates areas where streams have incised in to glacial deposits. The effect of this is that sideslopes (inner gorges) adjacent to these streams can become overly-steep and subject to landsliding. In some portion of this map unit, streams appear to have reached a relatively stable position as evidence by development of a floodplain. Mass wasting in these areas appears to be often triggered by stream channel migration which undercuts adjacent glacial terraces. This was observed in the large landslide along Fishtrap Creek (and numerous other locations in Fishtrap Creek) and the landslide in Big Rock Creek. In other areas, streams appear to still be slowly downcutting in to the glacial material. This tends to exist in lower order streams that dissect the glacial landforms.

The mass wasting potential in this landform unit tends to be highly variable depending on the presence of water at slope gradient. Where springs exist, or road drainage is concentrated on slopes greater than 70%, a high mass wasting potential exists. This was found in lower Boiling Springs (4A.4.1.5.), and in the failure along the Thompson River (4A.4.2.5.). In areas where springs are not present, but slopes are greater than 70%, the mass wasting potential is considered to be moderate. The only forest management activity that appears to be of concern in this map unit is road construction. No evidence was found which indicated timber harvesting or ground-based equipment operation in this map unit contributes to slope instability.

With regard to delivery potential, due to the proximity of this landform to streams it is considered high. In combining mass wasting potential with delivery potential two separate delivered hazard ratings are assigned. These are: 1) MODERATE delivered hazard where there is no evidence of subsurface seepage as evidenced by vegetation type or wet soils, and 2) HIGH delivered hazard where evidence of subsurface seepage of water or presence of hydrophilic vegetation exists. Because of the site-specificity of this call, on-the-ground inspection will be required to determine the appropriate hazard.

4A.5.6 UNIT 6 ALLUVIAL DEPOSITS

Delivered Hazard Rating: LOW

This landform includes gently-sloped floodplains and low terraces bordering streams found in all three study watersheds. Mass wasting in this unit is limited to localized streambank erosion. The mass wasting potential, and delivered hazard in this landform unit is considered LOW.

4A.6 CONCLUSIONS

Mass wasting in the three study watersheds is extremely rare, and is clearly not a dominant erosional process in these areas. In the 50 square mile analysis area, only five modern-era mass wasting sites were identified. Where forest management-related mass wasting was observed, causal mechanisms were as follows: 1) Over-steep road cutslopes where groundwater seeps were present (2 instances); 2) Fills constructed on steep slopes where road drainage was not properly managed (1 instance); and 3) Fills that were not properly constructed, coupled with groundwater seepage (1 instance). More importantly, of these four management-related landslides, no discernable sediment was routed to streams.

In localized areas elsewhere in the Thompson river drainage, mass wasting is a more dominant erosional process. These include areas in lower Fishtrap Creek and the Middle Thompson, where large streams (fourth order and larger) have dissected glacial depositional landforms. Along lower Fishtrap Creek, natural stream undercutting of an adjacent glacial terrace slope resulted in delivery of approximately 93,000 cubic yards of sediment to the creek. In another location on lower Fishtrap Creek, an old road appeared to contribute to a 4,400 cubic yard failure which delivered to the stream. Road construction on these landforms appears to be of particular concern.

The relatively benign slope gradients in the analysis watersheds (and elsewhere in the Thompson) have created a situation where standard Best Management Practices (Appendix 4A-2) have been very effective at keeping forest management-induced mass wasting to a minimal level. Moderate-hazard landforms where extra caution is necessary include: Steep Fluvial Landforms (Unit 2), Steep Alpine Glacial Landforms (Unit 4), and Inner Gorge Landforms (Unit 5) where groundwater seepage is not present. Where groundwater seepage is present in Landform Unit 5, a high delivered hazard exists. As is always the case, however, on-the-ground verification on a project-by-project basis is absolutely necessary to verify information in this analysis and make appropriate management decisions.

4A.7 CONFIDENCE

Recent aerial photography was available for the entire analysis area, and most of the watersheds were extensively developed, which made for easy on-the-ground observation of the landscape. All

suspected mass wasting from the air photo analysis were field-checked. Any landslides that may have been missed are likely very small. As such, confidence in the mass wasting inventory is high.

With regard to landform unit delineation, it is believed that mapping by Jensen and Dean (1997) provided a good platform. Landform Unit 5 (Inner Gorges in Glacial Depositional Landforms), polygons were hand-drawn with aid of topographic maps, aerial photography, and on-the-ground observation. Overall confidence in landform unit delineation is considered moderate. Project-level verification will be necessary to confirm landform unit interpretations.

In addition to this specific watershed analysis project, I have worked on various projects throughout the Thompson River Basin over the last six years. As such, confidence with regard to conclusions reached, including the significance of mass wasting as an erosional process, and management-related concerns, is high.

4A.8 LITERATURE CITED

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Figure 4A-1a Slope Distribution for the Beatrice Creek Watershed

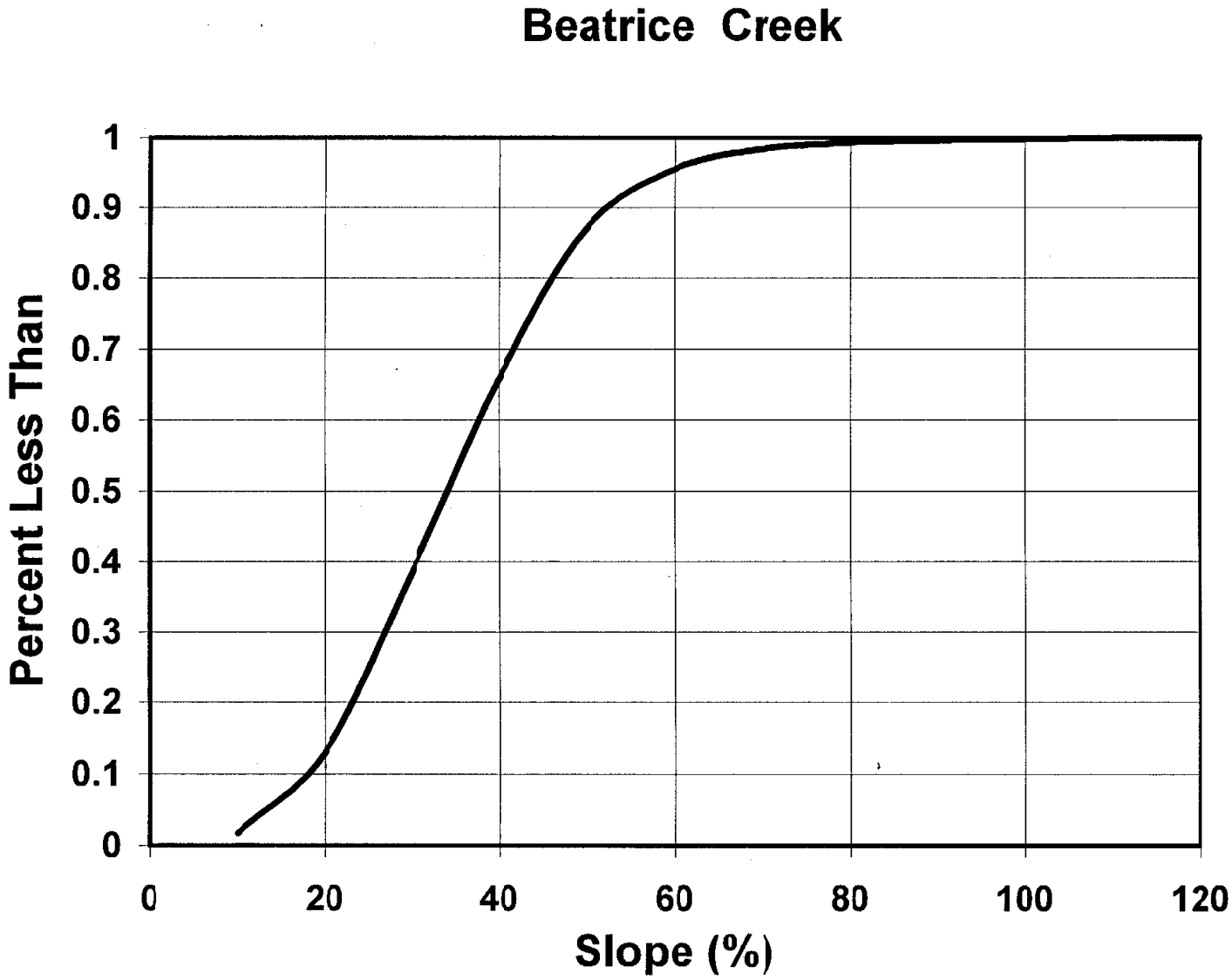


Figure 4A-1b Slope Distirbution for the Boiling Springs Creek Watershed

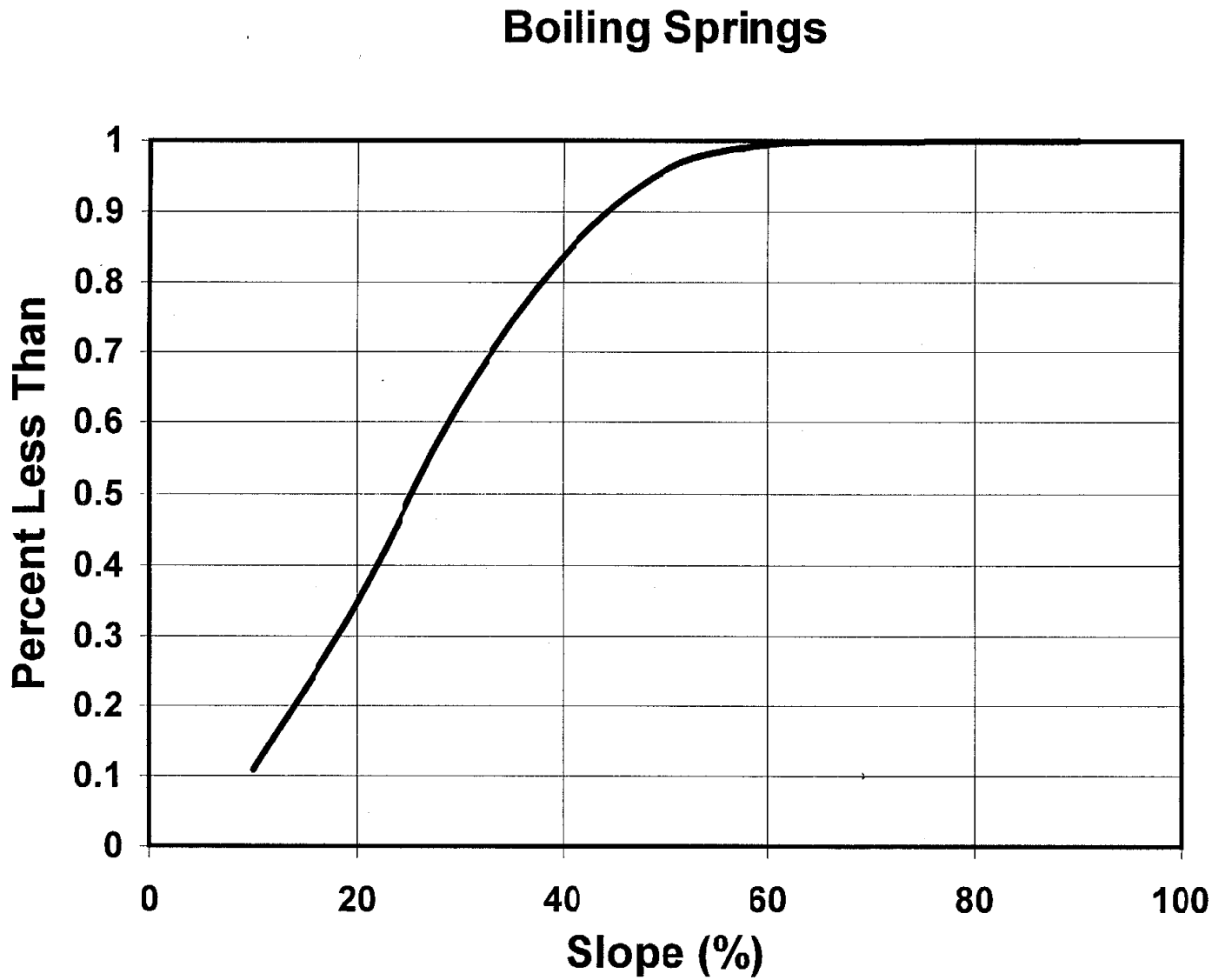
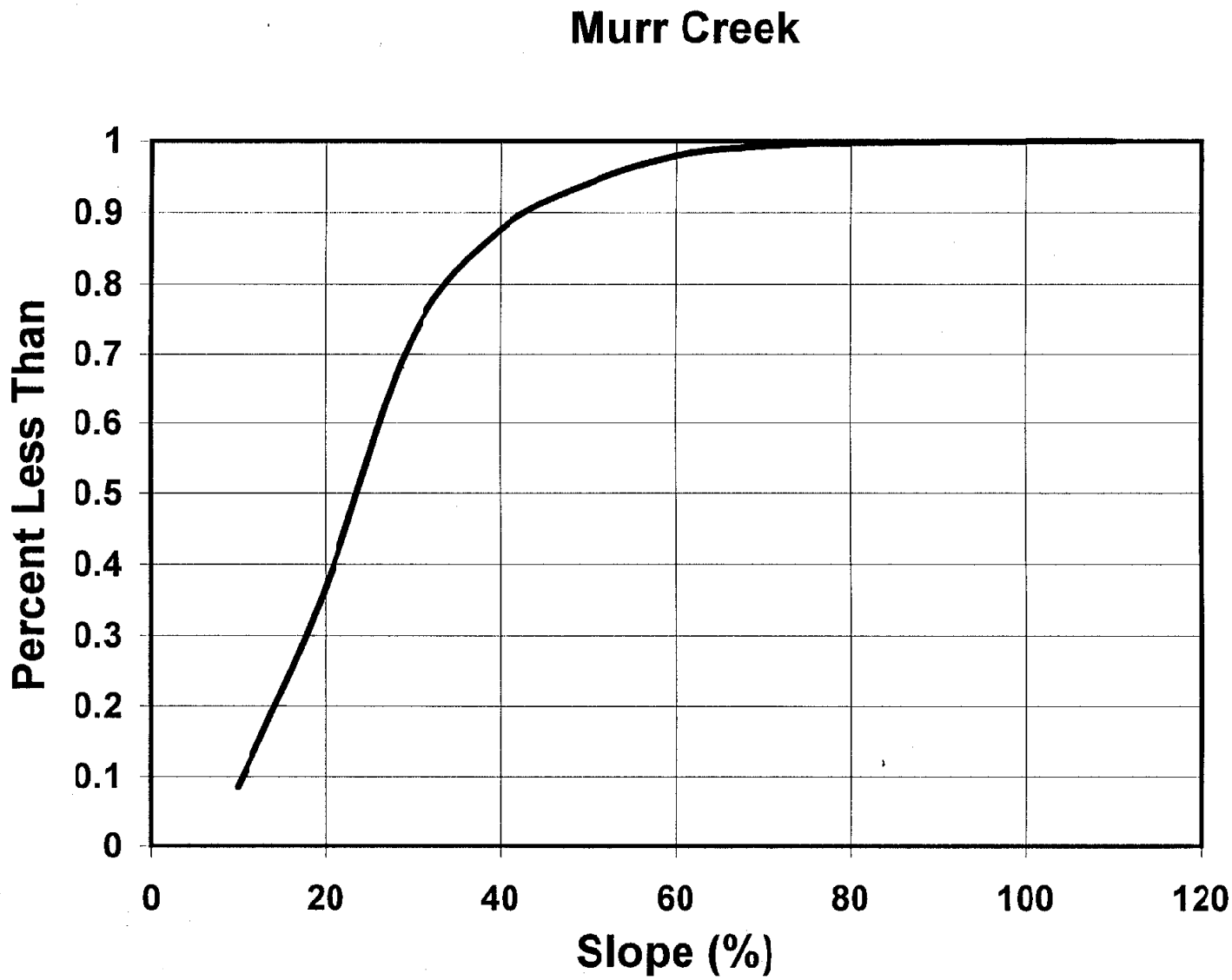
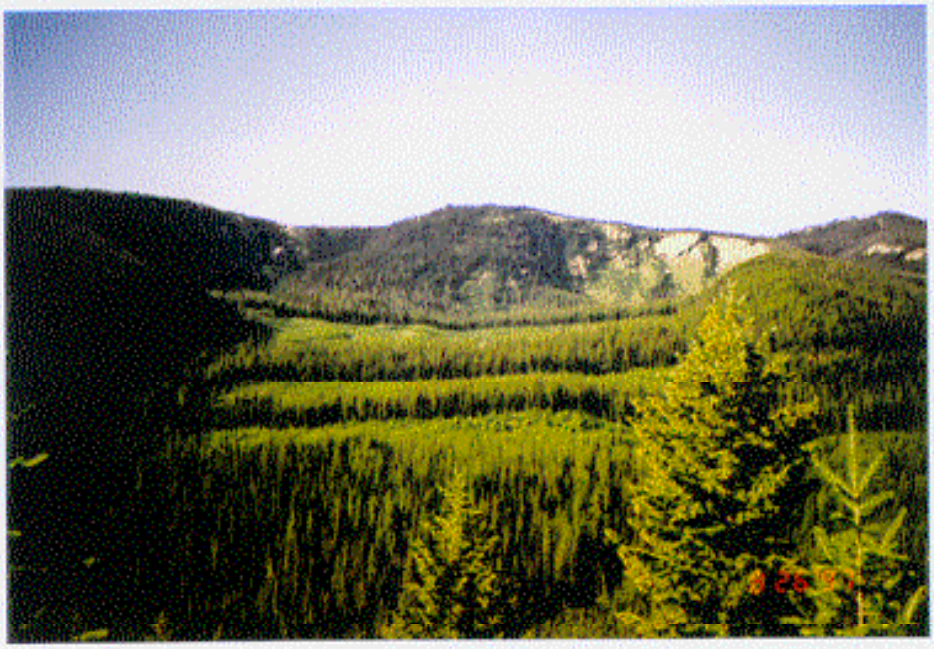


Figure 4A-1c Slope Distribution for the Murr Creek Watershed



Appendix 4A-1: Photographs of Landslides

Boiling Springs Road Cutslope Failure (NW1/4, NW1/4, S28, T26N, R27W)



Cliffs Located in a Cirque Basin in the Headwaters of Beatrice Creek

Large Glacial Terrace Erosion in Lower Fishtrap Creek (SW1/4, SW1/4, S22, T23N, R27W)

Glacial Terrace Erosion in Lower Fishtrap Creek Associated with an Old Road (SE1/4, SE1/4, S28, T23N, R27)

Road Cutslope Failure in Middle Thompson (S1/2, SW1/4, S13, T24N, R27W)

Beatrice Creek (NW1/4, NW1/4, S6, T23N, R27W)

Appendix 4A-2: Montana Best Management Practices for Forestry

A number of Montana's Best Management Practices for Forestry (December, 1997) are targeted at maintaining slope stability. Some of these are listed below. Not listed are BMP's related to road drainage control, which can also help maintain slope stability. Also not listed are administrative rules developed under the Streamside Management Zone Law.

Road Planning and Location:

- Review available information and consult with professionals as necessary to help identify erodible soils and unstable areas, and to locate appropriate road surface materials. (BMP I.A.2.)

- Locate roads on stable geology, including well-drained soils and rock formations that tend to dip into the slope. Avoid slumps and slide-prone areas characterized by steep slopes, highly weathered bedrock, clay beds, concave slopes, hummocky topography, and rock layers that dip parallel to the slope. Avoid wet areas, including moisture-laden or unstable toe slopes, swamps, wet meadows, and natural drainage channels. (BMP I.A.4.)

Road Design:

- Design roads to balance cuts and fills or use full bench construction (no fill slope) where stable fill construction is not possible. (BMP I.B.3.)

Road Construction:

- Keep slope stabilization, erosion and sediment control work current with road construction..... (BMP I.D.1.)

- Stabilize erodible, exposed soils by seeding, compacting, riprapping, benching, mulching, or other suitable means. (BMP (I.D.2)

- Minimize earth-moving activities when soils appear excessively wet. Do not disturb roadside vegetation more than necessary to maintain slope stability and to serve traffic needs. (BMP I.D.4.)

- Construct cut and fill slopes at stable angles to prevent sloughing and other subsequent erosion. (BMP I.D.5.)

- Avoid incorporating potentially unstable woody debris in the fill portion of the road prism. Where possible, leave existing rooted trees or shrubs at the toe of the fill slope to stabilize the fill. (BMP I.D.6.)

Road Maintenance:

- Avoid cutting the toe of cut slopes when grading roads or pulling ditches. (BMP I.E.3.)

- Haul all excess material removed by maintenance operations to safe disposal sites and stabilized these sites to prevent erosion. Avoid side-casting material into streams or

locations where erosion will carry materials into a stream. (BMP I.E.5.)

Timber Harvesting:

- Locate skid trails to avoid concentrating runoff and provide breaks in grade. Locate skid trails and landings away from natural drainage systems and divert runoff to stable areas. Limit the grade of constructed skid trails on geologically unstable, saturated, highly erosive, or easily compacted soils to a maximum of 30%. Use mitigating measures, such as water bars and grass seeding, to reduce erosion on skid trails. (BMP II.A.5.)

4B SURFACE EROSION

4B.1 INTRODUCTION

This analysis of surface erosion within the Thompson River Watershed was conducted according to a methodology based upon the Watershed Analysis Manual (Washington Forest Practices Board 1995). Minor modifications were made to the WFPB method to better suit the conditions in western Montana. These changes are described in the road erosion methods section below.

This module includes an analysis of two categories of erosion: hillslope erosion and erosion from roads. Hillslope erosion includes any displacement of soil (sheet, gully, or rill erosion), not associated with roads, which occurs on hillslopes. This type of erosion has been shown to be correlated with exposure of bare soil (WFPB 1995). Activities, such as forest management activities, which remove vegetation and duff, have the potential to increase hillslope erosion.

The road erosion portion of the analysis is intended to provide an accounting of sediment delivery from roads.

The objective of this surface erosion assessment is to ascertain where and how much sediment is being delivered to streams and what is the cause of that situation. The information collected over three sub-basins will be used to describe sensitive areas and causal mechanisms for sediment delivery to streams.

4B.2 GEOLOGIC HISTORY AND HYDROPHYSIOGRAPHY

Most of the Thompson River Basin, including the three sub-basins included in this analysis, is dominated by the parent materials of the feature known as the over-thrust belt. The rocks in this feature are stratified layers of Precambrian mudstone, limestone, and sandstone known as belt rocks.

The Beatrice Creek drainage and the Murr Creek drainage are predominantly underlain by belt rock. This rock tends to have low to moderate erodibility. The formations within the Beatrice drainage include the Libby, McNamara, Striped Peak, Mount Shields, Shepard formations (belt rocks), as well as areas of shale and Bonner quartzite. The rocks in the Murr Creek drainage are predominantly of the Spokane, Revett, and Burke formations (all belt rocks) with some areas of glacial deposits (Whitehorse Associates 1997).

The soils in the Boiling Springs Creek drainage are dominated by deposits of more erodible glacial material. These soils were deposited over the belt rocks as the glaciers of the most recent ice ages receded. The two most recent glacial periods which influenced this region were the Bull Run (70,000

to 130,000 years ago) and the Pinedale (10,000 to 15,000 years ago).

Drainage densities (as determined off of USGS 7.5 minute quads) in the three sub-basins included in this analysis are as follows: Beatrice, 2.27 mi/mi^2; Boiling Springs, 1.78 mi/mi^2; and Murr, 1.41 mi/mi^2.

4B.3 HILLSLOPE EROSION

4B.3.1 METHODS

Areas of recent (within the past 5 years) harvest activities were evaluated for erosion. Vegetative regrowth will mitigate erosion which has occurred on harvest units dating back earlier than 5 years from the present (WFPB 1995). A map derived from the PCTC GIS was used to locate all harvest management activities occurring in the three sub-basins within the past 5 years. Of those locations a subset was chosen based on erosion potential, proximity to streams, and accessibility.

The erosion potential maps were derived using the management considerations in the Forest Service Land System Inventories (Kuennen and Gerhardt 1984, and Sasich and Lamotte-Hagen 1988).

At each chosen harvest unit an evaluation of surface erosion was made. Where gully, rill, or surface erosion was observed, it was noted. The extent of delivery to streams was also investigated and reported.

4B.3.2 RESULTS

The recent harvest activities to be visited were chosen with an emphasis on accessible units, proximate to streams, and in a representative sample of erosion potential areas. However, as can be seen by comparing the erosion potential maps (Figures 4B-1a through 4B-1c) and the recent harvest maps (Figures 4B-2a through 4B-2c), there are few harvest units in high erosion potential areas (one in Murr, one in Boiling Springs, and zero in Beatrice), so those sites will appear to be under represented in the analysis.

The chosen sites which were evaluated as a part of this assessment are labeled in Figure 4B-2a through 4B-2c). Table 4B-1 summarizes the observations made at these field sites.

The occurrence of overland flow of water and associated sheet erosion was not observed on any of the ten harvest units visited. At sites BS1 and M2 there was some recent rill and gully erosion. The erosion at BS1 moved downhill to a wide flat area approximately 200 feet wide and was effectively buffered from the stream. No delivery was detected. At site M2, some gullying was present but the erosion did not deliver to the stream. The gullying was due to a skid trail which was in a depression

in the topography. Though not a draw by definition, this swale, acted as a drainage feature when stripped of vegetation.

Results from the field observations indicated that application of BMPs and adherence to the SMZ law has been highly effective at minimizing hillslope erosion. These practices have mitigated sediment delivery to streams to the extent that it occurs in negligible and/or undetectable amounts.

Given the lack of a representative sample of high erosion potential sites, the absence of severe hillslope erosion, and the low frequency of erosion of any sort, there was no detectable pattern of erosion from harvest units in different erosion potential areas. Therefore, no further steps have been taken to delineate erosion hazard areas. No detectable amounts of sediment were delivered to any stream and therefore, no Causal Mechanism Reports were generated to address hillslope erosion hazards.

Table 4B-1. Summary of observations at recent harvest units.

Site Number	Legal Descrip.	Sub-Basin	Soil Erosion Potential	Silvicult Prescrip	Harvest Method	Erosion ?	Delivery ?
BS1	Sec29, T26N, R27W	Boiling Springs	Moderate	Selective	Cable/ Tractor	Yes	No
BS2	Sec 29, T26N, R27W	Boiling Springs	Moderate	Selective	Cable/ Tractor	No	No
BS3	Sec 14, T26N, R27W	Boiling Springs	Moderate/ High	Precom. Thin	Cable	No	No
M1	Sec 27, T26N, R26W	Murr	Moderate	Shelter-wood	Tractor	No	No
M2	Sec 27, T26N, R26W	Murr	Moderate	Seed Tree	Cable/ Tractor	Yes	No
M3	Sec 26, T26N, R26W	Murr	Moderate/ High	Shelter-wood	Tractor	No	No
B1	Sec 3, T23N, R28W	Beatrice	Moderate	Seed Tree	Cable	No	No
B2	Sec 1, T23N, R28W	Beatrice	Low	Overstory Removal	Cable/ Tractor	No	No
B3	Sec 6, T23N, R27W	Beatrice	Low	Overstory Removal	Cable/ Tractor	No	No
B4	Sec 31, T24N, R27W	Beatrice	Low	Overstory Removal	Cable	No	No

4B.4 ROADS EROSION

4B.4.1 METHODS

The assessment of erosion and fine sediment delivery from roads is essentially an accounting procedure which involves actual field observations of erosion and delivery of sediment to streams. Streams are defined as "any drainage depression containing a defined bed and banks extending continuously below the drainage site...flow regime can be ephemeral, intermittent, or perennial." (WFPB 1995). Therefore, erosion which was delivered to a drainage feature which was known to be discontinuous below (i.e. the flow goes subsurface and does not deliver to fish-bearing waters) was not counted in the sediment budget presented below.

Using the PCTC GIS, all road segments which could potentially contribute sediment to streams were identified. Using the guidance of the WFPB manual these included all stream crossings and those road segments which parallel streams within a distance of 200 feet (referred to in this report as proximate road segments).

The contributing area associated with stream crossings was considered to be all areas of road tread, cut slope, and fill slope, which had from which water could flow to the stream. In other words, if the road tread and cut slope were relieved by a drain dip 100 feet from the culvert, then only that 100 feet between the dip and the culvert was considered in the sediment budget. Conditions were observed below that last drainage feature to verify non-delivery. If delivery was observed, it was accounted for in the budget.

Data was collected using a standard field form (Appendix A). In addition, field notes were taken when a more detailed description of the site was required. Data were collected on the area of road tread, fill slope, and cut slope which was actively eroding. Factors for gravel surfacing and traffic were applied as described in WFPB Manual (1995).

The cover factor (a modification of the WFPB method) is a mitigating multiplier which is based on the percent of the ground which is covered with non-soil material (i.e. rock, native gravel, wood, vegetation, duff, etc.). The snow factor (another modification of WFPB method) was applied as the percentage of erosion which was mitigated by the fact that the road was covered in snow. The premise is that when a road is covered with snow, there is less traffic-induced erosion.

In general, higher elevation roads were given a snow factor of 0.67 (that is, snow covers the road tread for one-third of the year) and lower elevation roads were given a factor of 0.75 (snow covers the road tread for one-quarter of the year). Aspect and micro-topography were also considered when applying this factor. Northern aspects and colder micro-topography (steep draws, etc) were given the higher mitigative factor (0.67). These factors were simply multipliers which reduced the total

amount of sediment being delivered from that location.

A base (natural) erosion rate of 10 tons/ac/year was applied for Murr and Beatrice Creeks. This rate was determined from the WFPB Manual (1995) for metamorphic rocks as the parent material. For Boiling Springs the erosion rate was assumed to be somewhat higher given the greater glacial influence in this basin. Therefore, a moderate rate of 20 tons/ac/year was assigned.

A large portion of the identified stream crossings and proximate road segments were evaluated. Those not visited included two crossings in the extreme headwaters of Beatrice Creek on Forest Service ground, three proximate road segments in Murr Creek, and two headwater crossings in Boiling Springs Creek.

To calculate the sediment contribution from each road location the area of erosion (length times width) was converted to acres and multiplied times the base erosion rate (tons/acre/year). Each mitigative factor (gravel, traffic, cover, snow, and percent delivery) was then applied and the total delivery for road tread, cut slope, and fill slope was then summed and reported as the location total in tons of sediment per year (Appendix B-1 through B-3, final column).

The location totals thus derived were summed for each basin to arrive at a roads contribution total.

4B.4.2 RESULTS

Road mileage and road densities are shown in Table 4B-2.

Table 4B-2. Road mileage and road densities.

Sub-Basin	Road Mileage (mi)	Road Density (mi/mi^2)
Beatrice	53.0	5.2
Boiling Springs	49.4	5.8
Murr	114.7	3.7
North Murr	8.8	3.7
South Murr	66.8	4.0
Lower Murr	39.1	3.3

Figures 4B-3a through 4B-3c show the road locations at which erosion was determined to be delivering to a stream. If the road was not delivering to a stream (as defined in the Introduction) the it was not considered in the sediment budget.

There were a total of 23 road segments in Boiling Springs which were delivering sediment to streams, in Beatrice there were 36 (this includes 16 segments along the main road up the valley bottom); and in Murr Creek there were 38 segments. . The data is provided in Appendix B-1 through B-3.

The majority of the sediment volume delivered in each of these three basins is from a small number of discreet locations. In Beatrice Creek (Appendix B-2) 54% of the total sediment volume from roads was from the 16 road segments (BRS1-BRS16) along the main road which parallels the creek. With crossing BX2 and segment BRS17 added to this, the contribution is 86% of the total sediment volume.

Similarly, in Murr Creek the top eight contributing locations contribute 46% of the total sediment volume from roads. In Boiling Springs Creek the top nine contributing locations deliver 76% of the total sediment volume from roads. See Appendix C for these locations ranked by drainage.

By far the greatest factor which influenced sediment volume was the road grade going into the crossing. With road grades that dipped very gently or not at all towards the stream, there will obviously be less sediment delivered to the stream. In this situation, even high cut slopes do not deliver large amounts of sediment.

Another road configuration which appeared to be associated with larger amounts of sediment was the intersection of roads near stream crossings. The location of BSX4 and BSX4b is one example of the large amount of bare soil associated with a road intersection contributing relatively large amounts of sediment.

Road erosion is an appreciable source of sediment which is above levels of natural background erosion. As will be discussed in more detail in the Discussion section below, there are a relatively small number of locations which are contributing the bulk of the sediment. Many of these instance can be explained by poorly installed or maintained mitigation features (i.e. drain dips, etc.) or by poor road location and design (i.e. road sloping down towards crossings, steep unstable side slopes, etc.).

4B.5 NATURAL BACKGROUND EROSION ESTIMATE

To gauge the impacts of man-caused sedimentation we must compare natural and man-caused sedimentation. The man-caused sedimentation is simply a sum of the hillslope and road erosion estimates. The estimate natural erosion rates two models were utilized, soil creep and weighted average by landtype.

4B.5.1 SOIL CREEP ESTIMATE

The soil creep equation was used as described in the WFPB manual (1995). Annual erosion rates are calculated using the following equation:

Annual Erosion Volume (m^3/yr) = (L*2) * D * C

where:

L	=	Length of stream channel in meters (this is doubled to account for both sides of stream)
D	=	Soil depth in meters
C	=	Creep rate in meters per year

Based on information provided in WFPB (1995) the creep rate was assigned as 0.001 m/yr for basins with average slope of <35% and 0.002 m/yr for basins with average slope of >35%. Stream length was determined by using the hydrography provided by PCTC GIS as modified for accuracy by direct observations. Soil depth was estimated using soils description in Kuennen and Gerhardt (1984) and Sasich and Lamotte-Hagen (1988). To convert m^3/yr to tons/yr a factor of 1.77 was used based on the example of the Swan Watershed Analysis (1996). The erosion rate thus derived is for both coarse and fine sediment. A percent fines figure was applied based on soils information in Kuennen and Gerhardt (1984) and Sasich and Lamotte-Hagen (1988).

Table 4B-3 shows the factors used in the soil creep equation for each basin. Murr Creek factors are also shown for the partial drainages South Murr, North Murr, and Lower Murr. Table 4B-4 shows the results of the soil creep calculations.

Table 4B-3. Factors used in soil creep erosion estimate.

Sub-Basin	Avg. Slope (%)	Stream Length (m)	Creep Rate (m/yr)	Soil Depth (m)
Boiling Springs	25	24522	0.001	0.635 (25")
Beatrice	35	37535	0.002	0.635
Murr	25	70731	0.001	0.635
North Murr	23	38682	0.001	0.635
South Murr	25	25420	0.001	0.635
Lower Murr	27	6629	0.001	0.635

Table 4B-4. Erosion estimates from soil creep equation.

	Total Erosion (tons/yr)	% Fines in Soil	Fine Sediment (tons/yr)	Sub-Basin Area (mi^2)	Fine Sediment ($tons/mi^2/yr$)
Boiling Springs	55	50	27.5	8.57	3.2
Beatrice	168.7	50	84.4	10.26	8.2
Murr	158.9	50	79.4	31.09	2.6
North Murr	87	50	43.5	16.86	2.6
South Murr	57.1	50	28.6	11.85	2.4
Lower Murr	14.9	50	7.4	2.38	3.1

4B.5.2 LANDTYPE ESTIMATE

The second estimate of natural erosion rates was made using Forest Service estimates of base surface erosion rates (USDA Forest Service, 1991) for each landtype (Kuennen and Gerhardt 1984, Sasich and Lamotte-Hagen 1988). A basin erosion rate was calculated as a weighted average by area of landtype. Table 4B-4 shows the erosion estimates derived from landtype erosion rates.

Table 4B-5. Erosion estimates from landtype base erosion rates (tons/yr).

	Total Erosion (tons/yr)	Sub-Basin Area (mi^2)	Fine Sediment ($tons/mi^2/yr$)
Boiling Springs	102.8	8.57	12.0
Beatrice	78.2	10.26	7.6
Murr	104.8	31.09	3.4
North Murr	52.6	16.86	3.1
South Murr	36.4	11.85	3.1
Lower Murr	15.8	2.38	6.6

4B.6 CONFIDENCE

The results of the Hillslope Erosion analysis are consistent with the results of other watershed analyses (PCTC 1996, PCTC 1996) and cumulative watershed effects analyses (DNRC 1996a, DNRC 1996b). This analysis relied on actual field observations by qualified individuals. For these two reasons confidence in the results is high.

The hillslope erosion analysis relies heavily on field observations by trained personnel. There was no extrapolation or assumptions associated with the actual measurement of contributing areas in the field. All of the measurements were made by only two hydrologists so the data is assumed to be consistent.

There is potential for error in the choice of a figure for background erosion from roads. The figures chosen (10 tons/ac/year for belt rock and 20 tons/ac/year for glacial influenced deposits), however, are well within the range of published estimates (WFPB 1995, King 1979)

There is also potential for error in the ocular estimates of delivery percentage and cover percentage. These calls, however, were made consistently over the entire drainage, and it is felt that the judgement of the observers was reliable.

Overall confidence in the accuracy of the results of the Surface Erosion analysis are high.

The confidence in the estimate of Natural Background Erosion is limited by the accuracy of the fundamental values which have gone into the models. The creep rates of 1 or 2 mm/year are figures which came directly from WFPB (1995). This reference states explicitly that "relatively little research has been conducted on rates of soil creep, especially in typical forested mountain watersheds." Therefore, the estimate of sediment, is only as reliable as the creep rate. Moderate confidence can be placed in this estimate.

Likewise, the estimate of natural background erosion using landtype erosion estimates is only as reliable as the individual estimates of landtype erosion. There was undoubtedly some extrapolation and assumption which went into the Forest Service landtype erosion estimates and therefore the confidence in their accuracy is also moderate.

4B.7 DISCUSSION

A comparison of fine sediment delivery rates is shown in Figure 4B-4. Both of the natural background estimates (soil creep and landtype) are shown relative to the estimated contribution from roads. Hillslope erosion contribution was considered to be negligible. Murr Creek data is shown for the entire drainage and for partial drainages (North, South, and Lower).

With the exception of Boiling Springs Creek, all basins show good agreement between the two background erosion estimates and therefore seem reliable. The two background estimates for Boiling Springs are substantially different. The explanation for this appears to be that 63.4% of the Boiling Springs drainage is in two landtypes (328 and 352) which have high natural erosion as estimated by the Forest Service. The soil creep estimate, however, will not respond to the geology of the drainage.

Given the creep rate figures in the WFPB manual, the only factor which will substantially alter the soil creep estimate is stream length.

Figure 4B-5 shows how the sediment delivery which is a result of roads compares to the background estimates. According to the WFPB manual, if sediment is increased by 50% 100%, the impact may be small, but chronically detectable. If the increase in total yield is more than 100% the change in annual sediment yield will likely exceed water quality standards and a hazard rating for surface erosion is Moderate or High.

As Figure 4B-5 shows, both Beatrice Creek and Boiling Springs Creek have roads which are estimated to increase the total annual sediment yield by 70% and 96% respectively using the soil creep background estimate. Using the landtype background estimate the sediment increase due to roads is 76% and 23% respectively.

There is little strong evidence to indicate that one of the background erosion estimates is more reliable than the other. The more conservative estimate (i.e. the one which is most protective of the aquatic resources) would be the one which consistently gave a lower figure. The lower the figure, the greater percentage increase any road sediment will represent.

To determine how evenly distributed the sediment input was over all contributing road segments a cumulative frequency analysis was performed. Figures 4B-6a through 4B-6c show these distributions. Both Beatrice and Boiling Springs Creeks show a skewed distribution. In Beatrice Creek 50% of the contributing road mileage (based on a total of 4.27 miles) are contributing 75% of the total amount of sediment coming from roads. In Boiling Springs Creek 50% of the contributing road mileage (based on a total of 1.22 contributing miles) is responsible for approximately 80% of the total road sediment.

Murr Creek has a distribution tending towards normality with 50% of the contributing road mileage (based on a total of 2.08 miles of contributing road) contributing about 60% of the total sediment attributable to roads.

These graphs are based only on contributing road mileage. It is important to note that a small portion of the total road mileage in each of the basins is responsible for sediment delivery. Table 4B-5 shows the percentage of total road mileage delivering sediment in each of the basin.

Table 4B-6. Percentage contributing road mileage of total road mileage.

Sub-Basin	Road Mileage (mi)	Contributing Road Mileage (mi)	Percent Contributing Roads of Total
Beatrice Creek	53.0	4.27	8.0
Boiling Springs	49.4	1.22	2.5
Murr	114.7	2.08	1.8

Figures 4B-7a through 4B-7c and Appendix C are provided to direct any sediment reduction efforts. The figures are similar to 4B-6a-c except that they show the actual number of contributing road segments rather than contributing road mileage. Figure 4B-7a shows that, for Beatrice Creek, reducing the sediment delivery to zero on 5 of the total 35 contributing road segments would reduce the sediment input due to roads by nearly 60%. Similar scenarios can be drawn for the other basins.

Appendix C shows the major contributing locations within the three sub-basins. By addressing the largest of these and continuing to stringently apply BMP's the sediment yield from roads could be brought down to a level of low concern.

Appendix D shows a ranked list of all contributing road segments by basin. The codes refer to locations on Figures 4B-3a through 4B-3c. By using these three sources of information (Appendix D, Figure 4B-7a - c, and Figures 4B-3a – c) managers should have the information needed to demonstrate numeric reductions in sediment yield for these three basins.

4B.8 LITERATURE CITED

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Figure 4B-4. Fine sediment delivery rates

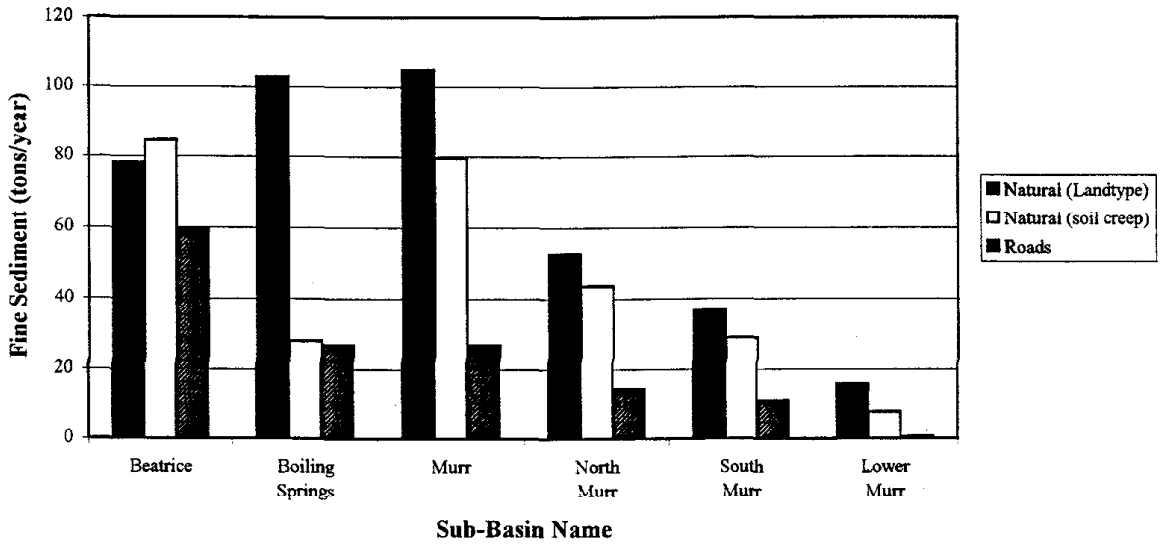


Figure 4B-5 Road sediment as a percent of natural background

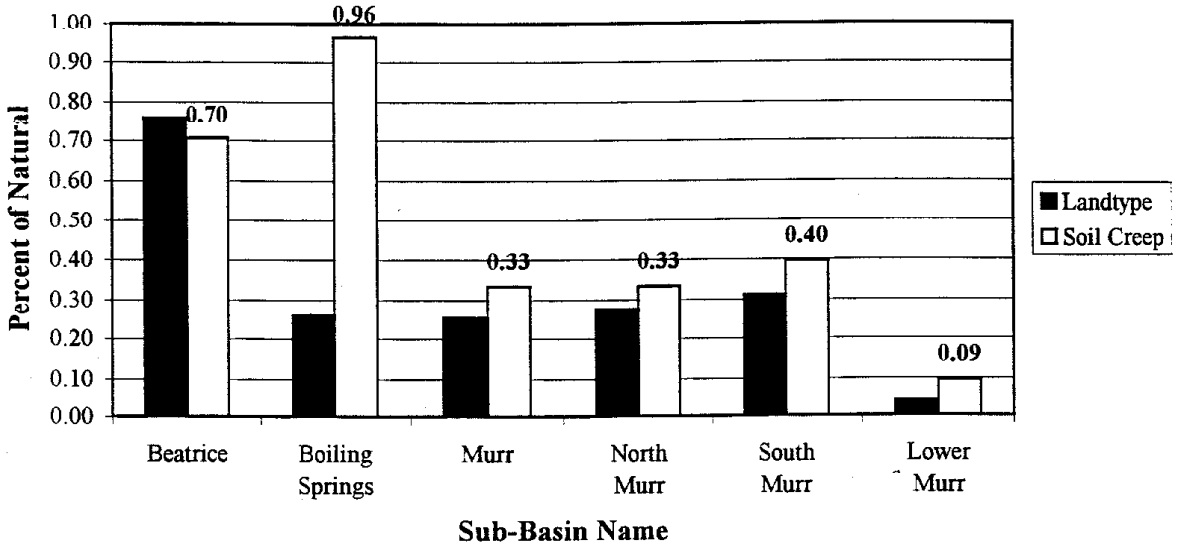


Figure 4B-6a. Beatrice Creek Cumulative Frequency Distribution *for Road Sediment*

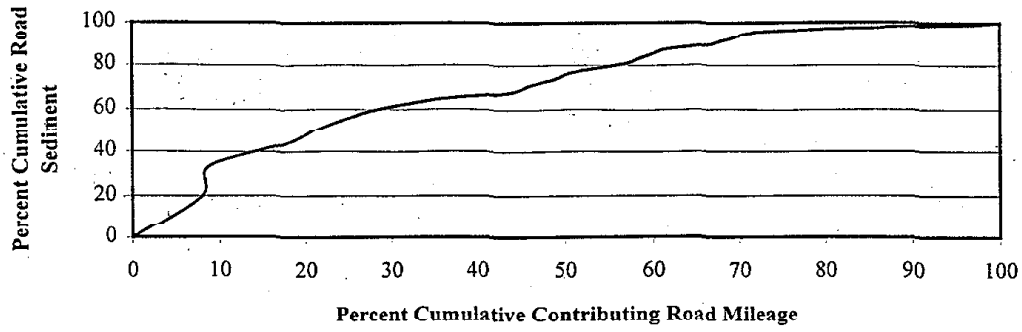


Figure 4B-6b. Boiling Springs Creek Freqency Distribution for Road Sediment

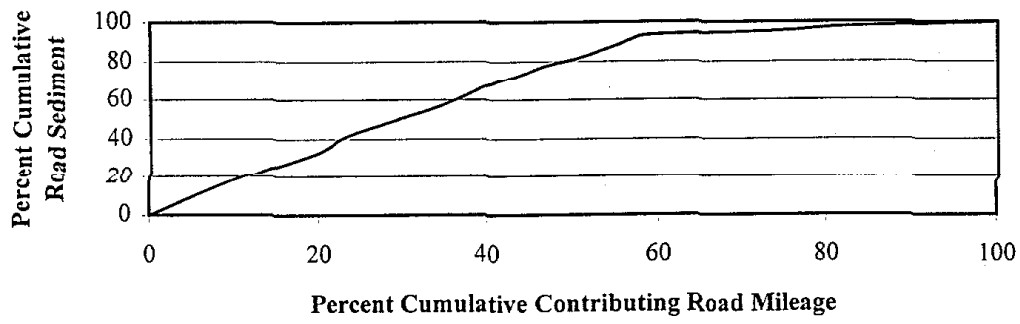


Figure 4B-6c. Murr Creek Frequency Distribution for Road Sediment

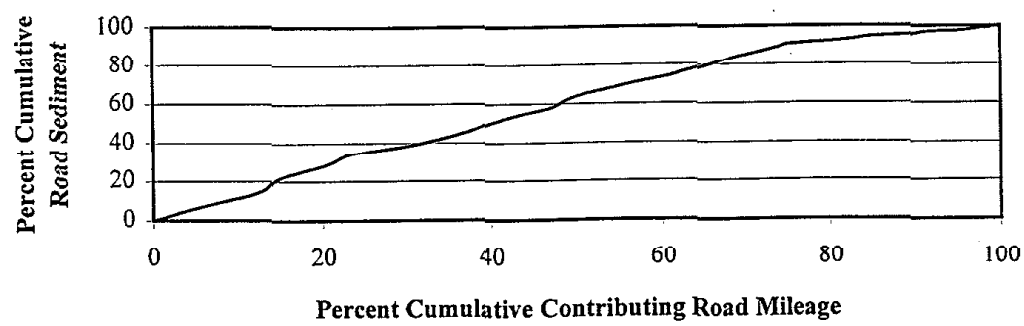


Figure 4B-7a. Beatrice Creek Percent Cumulative Sediment Per Road Segment

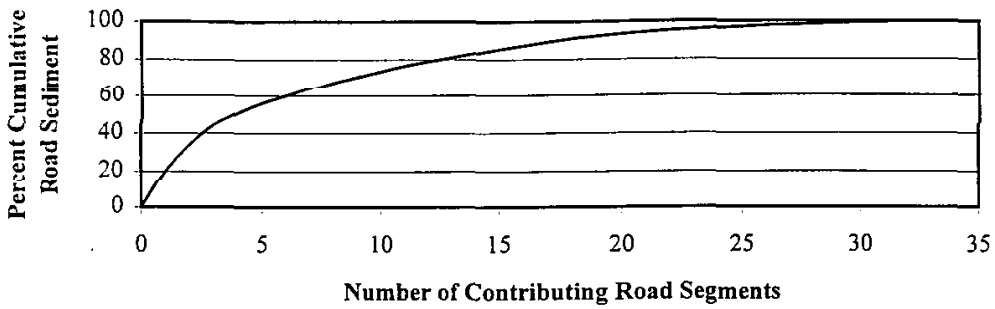


Figure 4B-7b. Boiling Springs Creek Percent Cumulative Sediment Per Road Segment

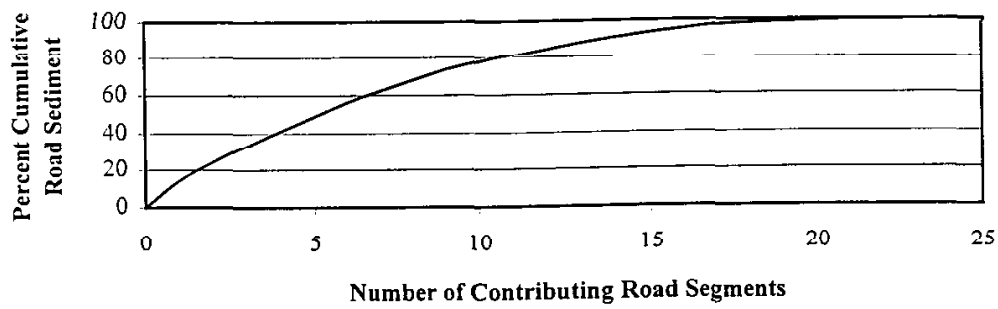
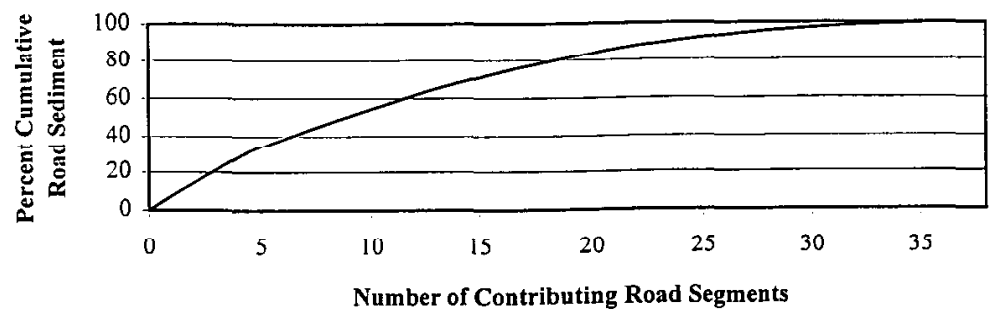


Figure 4B-7c. Murr Creek Percent Cumulative Sediment Per Road Segment



APPENDIX A

Table A-1. Sample data form.

Watershed: _____ **Page:** _____

Date: _____

Observer: _____

Location Code	ROAD TREAD INFORMATION								CUTSLOPE INFORMATION				FILLSLOPE INFORMATION				COMMENTS
	Contrib Road (ft)	Tread Width (ft)	Base Ero Rate (tons/yr)	Gravel Factor	Traffic Factor	Cover Factor	Snow Factor	% Delivery	Contrib Cutslope Length (ft)	Average Cutslope Width (ft)	Cover Factor	% Delivery	Contrib Fillslope Length (ft)	Average Fillslope Width (ft)	Cover Factor	% Delivery	

APPENDIX B

Table B-1. Road sediment data for the Beatrice Creek watershed

BEATRICE CREEK (data collected 7/8-7/10/07 CPC)																												
	<------	-------	-------	ROAD TREAD DELIVERY				------	------	------>		<------	------	------	CUTSLOPE EROSI		------>		<------	------	------	FILLSLOPE EROSION	------	------>		
Location	Contrib.	Tread	Acres	Base Erp. Rate	Gravel	Traffic	Cover	Snow	%	Treed Erosion		Contrib. Cutslope	Average Cutslope	Acres	Base Ero. Rate	Cover	%	Cutslope Erosion		Contrib. Fillslope	Average Fillslope	Acres	Base Ero. Rate	Cover	%	Fillslope Erosion		Location
Code	Road(ft)	Width (ft)	Tread	(t/ac/yr)	Factor	Factor	Factor	Factor	Delivery	(tons/yr)		Length (ft)	Width (ft)	Cutslope	(t/ac/yr)	Factor	Delivery	(tons/yr)		Length (ft)	Width (ft)	Fillslope	(t/ac/yr)	Factor	Delivery	(tons/yr)		Total (tons/yr)
BX1	60	25	0.03	10	1	2	1	0.75	1.00	0.52		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.52
BX2	1990	18	0.4	10	1	2	1	0.75	1.00	11.18		700	8	0.13	10	1.45	1.00	0.00		0	0	0.00	10	0	0.00	0.00		11.74
BX3	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX4	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX5	350	18	0.4	10	1	2	1	0.75	0.50	1.08		350	10	0.08	10	1.45	0.50	0.8		0	0	0.00	10	0	0.00	0.00		1.27
BX6	350	20	0.8	10	1	1	0	0.75	1.00	1.21		80	5	0.01	10	1.32	1.00	0.0		0	0	0.00	10	0	0.00	0.00		1.23
BX7	1720	15	0.5	10	1	0.6	0.77	0.75	0.85	1.12		0	5	0.00	10	1.77	100.00	0.0		100	1	0.02	10	0.37	0.00	0.00		1.12
BX8	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX9	200	17	0.08	10	1	0.5	0.32	0.75	0.50	0.15		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0.00	0.00		0.15
BX10	300	16	0.08	10	1	0.5	0.32	0.75	0.20	0.21		800	3	0.08	10	1.32	0.20	0.4		0	0	0.00	10	0	0.00	0.00		0.24
BX11	700	15	0.4	10	1	0.5	0.32	0.75	0.20	0.18		700	3	0.05	10	0.3	0.20	0.0		0	0	0.00	10	0	0.00	0.00		0.21
BX12	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX13	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX14	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX15	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX16	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX17	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX18	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX19	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX20	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX21	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX22	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX23	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX24	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX25	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX26	185	12	0.05	10	1	1	0.32	0.75	1.00	0.38		80	5	0.01	10	1.32	1.00	0.0		0	0	0.00	10	0	0.00	0.00		0.41
BX27	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.10	0.00		0.00
BX28	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	1.00	0.00		0.00
BX29	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.10	0.00		0.00
BX30	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX31	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	1.00	0.00		0.00
BX32	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.50	0.00		0.00
BX33	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX34	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX35	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	1.00	0.00		0.00
BX36	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX37	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0	0	0.00	10	0	0.00	0.00		0.00
BX38	700	15	0.17	10	1	1	0.53	0.75	0.15	0.08		150	20	0.07	10	1.37	0.15	0.4		0	0	0.00	10	0	0.00	0.00		0.12
BX39	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0.10	0.00		0.00
BX40	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0	0.0		0	0	0.00	10	0	0	0.00		0.00
BX41	150	15	0.09	10	1	1	0.63	0.75	0.15	0.10		150	20	0.07	10	1.53	0.15	0.5		0	0	0.00	10	0	0	0.00		0.15
BX42	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX43	75	15	0.03	10	1	1	0.63	0.75	0.25	0.05		30	5	0.00	10	1.37	0.25	0.0		20	3	0.00	10	0.18	1	0.00		0.05
BX44	100	18	0.14	10	1	1	0.45	0.75	0.15	0.05		50	3	0.00	10	1.37	0.40	0.1		0	0	0.00	10	0	0	0.00		0.05
BX45	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX46	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX47	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX48	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX49	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX50	100	15	0.1	10	1	1	0.7	0.87	1.00	0.92		100	10	0.02	10	1.63	1.00	0.4		20	5	0.00	10	0.15	0.1	0.00		1.07
BX51	150	15	0.08	10	1	1	0.63	0.87	1.00	0.58		125	10	0.03	10	1.25	1.00	0.7		20	10	0.00	10	0.77	1	0.04		0.68
BX52	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX53	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX54	100	18	0.08	10	1	1	0.63	0.75	1.00	0.02		150	8	0.03	10	1.53	0.25	0.4		50	10	0.01	10	0.2	1	0.02		0.08
BX55	0	0	0.00	10	0	0	0	0.75	0.00	0.00		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		0.00
BX56	175	15	0.06	10	1	1	0.45	0.75	0.5	0.23		180	3	0.01	10	1.45	0.4	0.2		1	2	0.00	10	1	1	0.00		0.25
Road Segments																												
BRS1	440	10	0.08	10	1	1	1	0.75	0.5	0.28		0	0	0.00	10	0	0.00	0.0		340	10	0.08	10	0.15	1	0.12		0.41
BRS2	300	20	0.7	10	1	1	1	0.75	1	2.75		0	0	0.00	10	0	0.00	0.0		860	10	0.18	10	0.15	1	0.28		3.03
BRS3	175	20	0.7	10	1	1	1	0.75	1	1.84		0	0	0.00	10	0	0.00	0.0		470	10	0.11	10	0.15	1	0.18		1.80
BRS4	125	20	0.5	10	1	1	1	0.75	1	1.12		325	8	0.06	10	1.32	0.20	0.4		320	10	0.07	10	0.15	1	0.11		1.27
BRS5	775	20	0.3	10	1	1	1	0.75	0.75	2.00		775	5	0.09	10	1.32	0.75	0.1		770	5	0.09	10	0.18	1	0.18		2.38
BRS6	1170	20	0.8	10	1	1	1	0.75	0.5	2.38		0	0	0.00	10	0	0.00	0.0		0	0	0.00	10	0	0	0.00		2.38
BRS7	2035	20	0.9	10	1	1	1	0.75	0.75	5.51		2135	8	0.39	10	0.2	0.75	0.9		2130	5	0.25	10	0.15	1	0.37		6.47
BRS8	145	20	0.4	10	1	1	1	0.75	1	2.57		745	20	0.34	10	1.32	1.00	1.8		700	10	0.16	10	0.15	1	0.24		3.80
BRS9	192	20	0.8	10	1	1	1	0.75	1	1.35		392	8	0.07	10	1.32	1.00	0.3		390	5	0.04	10	0.15	1	0.07		1.65
BRS10	175	20	0.1	10	1	1	1	0.75	0.15	0.35		200	10	0.05	10	1.32	0.15	0.2		1	0	0.00	10	0	0	0.00		0.37
BRS11	154	20	0.1	10	0	0	0	0.75	0	0.00		0	0	0.00	10	0	0.00	0.0		1	0	0.00	10	0	0	0.00		0.00
BRS12A	1385	15	0.4	10	1	1	0.28	0.75	0.1	0.38		0	0	0.00	10	0	0.00	0.0		1	0	0.00	10	0	0	0.00		0.38
BRS12B	185	15	0.4	10	1	1	0.37	0.75	1	1.77		0	0	0.00	10	0	0.00	0.0		1	0	0.00	10	0	0	0.00		1.77
BRS12C	2070	2	0.0	10	1	1	0.63	0.75	1	0.71		2070	5	0.24	10	0.63	1.00	1.0		1	0	0.00	10	0	0	0.00		2.21
BRS13	1128	15	0.5	10	1	1	0.32	0.75	0.1	0.27		1028	5	0.12	10	0.1	1.00	0.2		1021	3	0.07	10	0.1	0.2	0.01		0.40
BRS14	114	15	0.1	10	1	1	0.32	0.75	0.1	0.18		614	5	0.07	10	0.1	1.00	0.1		611	3	0.04	10	0.1	0.2	0.01		0.24
BRS15	720	15	0.5	10	1	1	0.32	0.75	0.2	0.37		720	30	0.50	10	0.63	0.30	0.4		720	5	0.08	10	0.1	0.5	0.04		1.35
BRS16	705	15	0.4	10	1	1	0.32	0.75	0.2	0.36		700	30	0.48	10	0.63	0.30	0.1		705	5	0.08	10	0.1	0.5	0.04		1.31
BRS17	300	15	0.17	10	1	1	0.63	0.75	1	0.52		290	25	0.11	10	0.77	1.00	0.9		200	150	0.69	10	1	1	8.89		8.29
Watershed Totals										43.07								7.6								9.05		59.69

APPENDIX B

Table B-2. Road sediment data for Boiling Springs Creek watershed

BOILING SPRINGS (date collected 7/8/97-7/9/97 - P.C.)																														
	<------	--------	--------	ROAD TREAD DELIVERY				--------	--------	------->		<------	--------	--------	CUTSLOPE EROS		--------	------->		<------	--------	--------	FILLSLOPE EROSIO		--------	------->		
Location Code	Contrib. Road (ft)	Tread Width (ft)	Acres Tread	Base Ero. Rate (t/ac/yr)	Gravel Factor	Traffic Factor	Cover Factor	Snow Factor	% Delivery	Tread Erosion (tons/yr)		Contrib. Cutslope Length (ft)	Average Cutslope Width (ft)	Acres Cutslope	Base Ero. Rate (t/ac/yr)	Cover Factor	% Delivery	Cutslope Erosion (tons/yr)		Contrib. Fillslope Length (ft)	Average Fillslope Width (ft)	Acres Fillslope	Base Ero. Rate (t/ac/yr)	Cover Factor	% Delivery	Fillslope Erosion (tons/yr)		Location total(tons/yr)
BSX1	200	28	013	20	0.03	2	1	0.75	1.00	0.12		0	0	0.00	20	0	0.00	0.00		40	5	0.00	20	0.35	1.00	0.03		0.15
BSX2	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX3	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX4	205	25	012	20	1	1	0.63	0.75	1.00	1.76		205	20	0.00	20	0.18	1.00	0.34		205	10	0.05	20	0.09	0.02	0.00		2.11
BSX4B	435	14	016	20	1	1	0.45	0.75	1.00	2.39		495	8	0.00	20	0.7	1.00	1.27		50	20	0.02	20	0.32	1.00	0.15		3.81
BSX5	20	12	001	20	1	0.02	0.15	0.75	1.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX6	250	17	010	20	1	1	0.53	0.75	1.00	1.46		0	0	0.00	20	0	0.00	0.00		200	2	0.01	20	0.15	0.15	0.00		1.47
BSX6B	*225*	*20*	*010*	*20*	*1*	*1*	*1*	*0.75*	*1.00*	*1.55*		*100*	*6*	*0.01*	*20*	*0.15*	*0.10*	*0.01*		*0*	*0*	*0.00*	*20*	*0*	*0.00*	*0.00*		*1.56*
BSX7	0	0	000	20	0	0	0	0.00	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX8	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX9	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX10	420	14	013	20	1	1	0.77	0.75	0.20	0.40		200	3	0.0	20	0.35	1.00	0.10		0	0	0.00	20	0	0.00	0.00		0.50
BSX11	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX12	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX13	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX14	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX15	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX16	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX17	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX18	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX19	240	12	007	20	1	1	0.15	0.75	0.15	0.15		0	0	0.00	20	0	0.00	0.00		20	2	0.00	20	0.05	1.00	0.00		0.15
BSX20	160	20	007	20	1	1	0.53	0.75	1.00	1.10		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		1.10
BSX21	0	0	000	20	0	0	0	0.75	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX22	105	20	005	20	1	1	0.63	0.75	1.00	0.72		85	10	0.0	20	0.15	0.75	0.04		0	0	0.00	20	0	0.00	0.00		0.77
BSX23	*7*	*0*	*000*	*20*	*0*	*0*	*0*	*0.75*	*0.00*	*0.00*		*0*	*0*	*0.00*	*20*	*0*	*0.00*	*0.00*		*0*	*0*	*0.00*	*20*	*0*	*0.00*	*0.00*		*0.00*
BSX24	365	15	013	20	1	1	0.45	0.67	1.00	1.78		380	8	0.0	20	0.37	1.00	0.52		0	0	0.00	20	0	0.00	0.00		2.29
BSX25	185	23	010	20	1	1	0.63	0.75	1.00	1.47		100	3	0.0	20	0.45	1.00	0.06		50	5	0.01	20	0.1	0.10	0.00		1.53
BSX26	120	15	004	20	1	1	0.85	0.67	1.00	0.55		80	5	0.0	20	0.37	0.75	0.05		10	10	0.00	20	0.77	1.00	0.04		0.64
BSX27	150	12	004	20	1	1	0	0.67	0.10	0.06		150	3	0.0	20	0.53	0.10	0.01		150	3	0.01	20	0.4	0.10	0.01		0.07
BSX28	0	0	000	20	0	0	0	0.67	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX29	150	12	004	20	1	1	0.85	0.67	1.00	0.55		30	5	0.0	20	0.53	1.00	0.04		150	5	0.02	20	0.85	1.00	0.29		0.88
BSX30	150	12	004	20	1	1	1	0.67	1.00	0.55		75	20	0.0	20	1	0.40	0.28		150	10	0.03	20	0.22	0.50	0.08		0.90
BSX31	0	0	000	20	0	0	0	0.67	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX32	400	15	014	20	1	1	0.45	0.67	1.00	1.85		125	15	0.0	20	1	1.00	0.86		0	0	0.00	20	0	0.00	0.00		2.71
BSX33	360	18	014	20	1	1	0.42	0.67	1.00	1.94		0	0	0.00	20	0	0.00	0.00		40	2	0.00	20	0.32	1.00	0.01		1.95
BSX34	0	0	000	20	0	0	0	0.67	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX35	0	0	000	20	0	0	0	0.67	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX36	0	0	000	20	0	0	0	0.67	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0	0	0.00	20	0	0.00	0.00		0.00
BSX37	240	11	005	20	1	1	0.32	0.75	1.00	0.91		100	3	0.0	20	0.45	1.00	0.06		50	5	0.01	20	0.05	0.10	0.00		0.97
Road Segments																		0.00								0.00		
BSRS1	100	18	004	20	1	1	0.37	0.75	0.1	0.06		100	3	0.0	20	0.37	0.10	0.01		100	6	0.01	20	0	0	0.00		0.07
BSRS2	370	15	013	20	1	1	0.53	0.75	0.1	0.19		370	3	0.0	20	0.35	0.10	0.00		370	3	0.03	20	0	0	0.00		0.19
BSRS3	350	15	012	20	1	1	0.53	0.75	1	1.81		350	3	0.0	20	0.53	1.00	0.26		350	3	0.02	20	0	0	0.00		2.06
BSRS4	1000	15	034	20	1	1	0.2	0.75	0.1	0.52		1000	5	0.1	20	0.35	0.10	0.01		1000	3	0.07	20	0	0.1	0.00		0.53
BSRS5	150	15	005	20	1	1	1	0.75	0.1	0.08		150	3	0.0	20	0.53	0.10	0.01		150	3	0.01	20	0.53	0.1	0.01		0.10
Watershed Totals:										21.97								1.93								0.62		26.51

Appendix B

Table B-3. Road sediment data for the Murr Creek watershed.

MURR CREEK (data collected 7/15 & 7/30/97 PC and also other days by BS)																														
	<------	-------	-------	ROAD TREAD DELIVERY						------>	<------	-------	-------	CUTSLOPE EROS		-------	------>	<------	-------	-------	FILLSLOPE EROSIO		-------	------>		
Location Code	Contrit. Road (f)	Tread Width (ft)	Acres Tread	Base Ero. Rate (t/ac/yr)	Gravel Factor	Traffic Factor	Cover Factor	Snow Factor	% Delivery	Tread Erosion (tons/yr)	Contrib. Cutslope Length (f	Average Cutslope Width (ft)	Acres Cutslope	Base Ero. Rate (t/ac/yr)	Cover Factor	% Delivery	Cutslope Erosion (tons/yr)	Contrib. Fillslope Length (f	Average Fillslope Width (ft)	Acres Fillslope	Base Ero. Rate (t/ac/yr)	Cover Factor	% Delivery	Fillslope Erosion (tons/yr)	Location Total (tons/yr)
MX1	25	14	001	10	0.5	1	0.63	0.75	1.00	0.02	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.02
MX2	10	15	002	10	1	1	1	0.75	0.60	0.08	150	15	0.05	10	0.77	0.10	0.04	10	2	0.00	10	0.37	1.00	0.00	0.12
MX3	310	18	014	10	1	1	0.63	0.75	0.80	0.87	250	15	0.08	10	0.7	1.00	0.60	120	10	0.03	10	0.1	1.00	0.03	1.50
MX4	210	18	010	10	1	1	0.63	0.75	0.40	0.31	150	15	0.05	10	0.77	0.75	0.30	100	5	0.01	10	0	1.00	0.00	0.61
MX5	210	15	009	10	1	1	0.1	0.75	1.00	0.65	200	10	0.05	10	0.45	1.00	0.21	200	4	0.02	10	0.18	1.00	0.03	0.89
MX6	310	15	012	10	1	1	0.15	0.75	1.00	0.90	300	8	0.05	10	0.15	1.00	0.08	100	4	0.01	10	0.15	0.10	0.00	0.99
MX7	0	15	002	10	1	1	1	0.75	0.00	0.00	40	5	0.00	10	0	100.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX8	610	15	021	10	1	1	0.1	0.75	1.00	1.55	450	10	0.10	10	0.22	1.00	0.23	150	5	0.02	10	0.15	1.00	0.03	1.80
MX9	170	15	006	10	1	1	0.6	0.75	1.00	0.44	150	15	0.05	10	0.45	1.00	0.23	250	25	0.14	10	0.2	1.00	0.29	0.96
MX10	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX11	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX12	200	15	007	10	1	1	0.45	0.75	0.50	0.26	200	3	0.01	10	0.63	0.75	0.07	0	0	0.00	10	0	0.00	0.00	0.32
MX13	150	20	007	10	1	1	0.7	0.75	0.40	0.21	100	3	0.01	10	0.63	0.40	0.02	0	0	0.00	10	0	0.00	0.00	0.22
MX14	400	18	017	10	1	1	0.2	0.75	0.10	0.12	250	5	0.03	10	0.5	0.40	0.06	0	0	0.00	10	0	0.00	0.00	0.18
MX15	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX16	10	20	002	10	1	1	0.7	0.75	0.50	0.09	0	0	0.00	10	0	0.00	0.00	30	2	0.00	10	0.18	1.00	0.00	0.09
MX17	500	15	017	10	1	1	0.15	0.75	0.25	0.32	500	3	0.03	10	0.7	0.15	0.04	100	3	0.01	10	0	0.00	0.00	0.36
MX18	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX19	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX20	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX21	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX22	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX23	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX24	360	18	014	10	0.5	1	0.85	0.67	0.50	0.24	275	6	0.04	10	0.18	1.00	0.07	50	15	0.02	10	0.15	1.00	0.03	0.34
MX25	115	18	008	10	0.5	1	0.77	0.67	0.50	0.13	125	6	0.02	10	0.18	1.00	0.03	30	15	0.01	10	0.18	1.00	0.02	0.18
MX26	120	18	005	10	0.5	1	0.77	0.67	0.50	0.08	80	6	0.02	10	0.18	1.00	0.02	0	0	0.00	10	0	0.00	0.00	0.10
MX27	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.10	0.00	0.00
MX28	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	1.00	0.00	0.00
MX29	510	15	017	10	1	1	0.18	0.75	0.20	0.26	0	0	0.00	10	0	0.00	0.00	100	2	0.00	10	0	1.00	0.00	0.26
MX30	110	15	005	10	1	1	0.22	0.75	1.00	0.39	100	10	0.02	10	0.12	0.30	0.01	100	5	0.01	10	0	0.00	0.00	0.40
MX31	410	15	014	10	1	1	0.45	0.75	0.75	0.77	0	0	0.00	10	0	0.00	0.00	100	2	0.00	10	0.05	0.10	0.00	0.78
MX32	710	20	033	10	0.5	2	0.77	0.67	0.50	1.11	300	7	0.05	10	0.12	1.00	0.06	50	8	0.01	10	0.12	1.00	0.01	1.18
MX33	340	18	015	10	1	1	0.7	0.67	1.00	1.00	500	7	0.08	10	0.12	1.00	0.10	0	0	0.00	10	0	0.00	0.00	1.09
MX34	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX35	240	15	008	20	1	1	0.3	0.75	0.50	0.62	200	10	0.05	10	0.18	1.00	0.08	50	20	0.02	10	0.1	1.00	0.02	0.73
MX36	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX37	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0.00
MX38	310	15	010	10	1	1	0.63	0.67	1.00	0.69	225	8	0.04	10	0.18	1.00	0.07	25	8	0.00	10	0.26	1.00	0.01	0.78
MX39	115	18	008	10	1	1	1	0.67	1.00	0.51	150	10	0.03	10	0.25	1.00	0.09	50	10	0.01	10	0.26	0.75	0.02	0.62
MX40	610	15	022	10	1	1	1	0.67	1.00	1.50	600	8	0.11	10	0.37	1	0.41	40	5	0.01	10	0.53	1	0.03	1.94
MX41	710	15	025	10	1	1	1	0.67	0.90	1.50	600	8	0.11	10	0.37	1.00	0.41	0	0	0.00	10	0	0	0.00	1.90
MX42	210	20	011	10	1	1	0.58	0.75	1.00	0.86	225	8	0.04	10	0.3	1.00	0.12	200	5	0.02	10	0.18	0.3	0.01	1.00
MX43	0	0	000	10	0	0	0	0.75	0.00	0.00	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0	0	0.00	0.00
MX44	240	16	009	10	1	1	0.58	0.67	1.00	0.59	200	4	0.02	10	0.22	1.00	0.04	75	6	0.01	10	0.18	1	0.02	0.65
MX50	240	20	011	10	1	2	1	0.66	1.00	1.52	675	6	0.09	10	0.37	1.00	0.34	20	6	0.00	10	0.33	1	0.01	1.87
MX51	110	18	005	10	1	1	1	0.67	1.00	0.33	50	4	0.00	10	0.22	1.00	0.01	50	5	0.01	10	0.37	1	0.02	0.36
MX98	210	15	007	10	1	1	0.77	0.75	1.00	0.52	150	5	0.02	10	0.5	1.00	0.09	100	4	0.01	10	0.37	1	0.03	0.64
MX99	15	12	002	10	1	1	0.29	0.75	0.50	0.08	0	0	0.00	10	0	0.00	0.00	30	2	0.00	10	1	0	0.00	0.08
Road Segments																	0.00							0.00	
MRS1	140	15	003	10	1	1	0.63	0.67	1	0.23	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0.15	1	0.00	0.23
MRS2	540	15	017	10	1	1	0.63	0.67	1	1.15	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0.15	1	0.00	1.15
MRS3	310	15	012	10	1	1	0.63	0.67	1	0.81	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0.15	1	0.00	0.81
MRS4	210	15	007	10	1	1	0.63	0.67	1	0.46	0	0	0.00	10	0	0.00	0.00	0	0	0.00	10	0.15	1	0.00	0.46
MRS5	410	15	014	10	1	1	0.63	0.67	1	0.92	0	0	0.00	10	0	0.00	0.00	30	10	0.01	10	0.63	1	0.04	0.97
Watershed Totals										22.08							3.81							0.66	26.54

APPENDIX C

Table C-1. Ranking of major sediment sources.

BOILING SPRINGS		BEATRICE		MURR	
Road Location Code	Sediment Delivery (tons/yr)	Road Location Code	Sediment Delivery (tons/yr)	Road Location Code	Sediment Delivery (tons/yr)
BSX4B	3.45	BX2	11.16	MX40	1.79
BSX32	2.42	BRS1-BRS16	29.45	MX41	1.77
BSX24	2.12	BRS17	6.34	MX50	1.75
BSX4	2.02			MX8	1.74
BSRS3	2			MX3	1.34
BSX33	1.95			MX32	1.15
BSX6B	1.56			MRS2	1.15
BSX25	1.51			MX33	1.06
BSX6	1.47				
Sum (% of sub-basin total)	18.5 tons/yr (69.8% of sub-basin total)		46.95 tons/yr (78.9% of sub-basin total)		11.75 tons/yr (44.3% of sub-basin total)

APPENDIX D

Table D-1. Ranking of road segments by sediment contribution.

Rank	Beatrice	Boiling Springs	Murr
1	BX2	BSX4B	MX40
2	BRS17	BSX32	MX41
3	BRS7	BSX24	MX50
4	BRS8	BSX4	MX8
5	BRS2	BSRS3	MX3
6	BRS5	BSX33	MX32
7	BRS6	BSX6B	MRS2
8	BRS12C	BSX25	MX33
9	BRS3	BSX6	MX42
10	BRS12B	BSX20	MX6
11	BRS9	BSX37	MRS5
12	BRS15	BSX30	MX9
13	BRS16	BSX29	MX5
14	BRS4	BSX22	MRS3
15	BX5	BSX26	MX38
16	BX6	BSRS4	MX31
17	BX7	BSX10	MX35
18	BX50	BSRS2	MX44
19	BX51	BSX19	MX98
20	BX54	BSX1	MX39
21	BX1	BSRS5	MX4
22	BX26	BSX27	MRS4
23	BRS1	BSRS1	MX30
24	BRS13	BSX5	MX51
25	BRS10		MX17
26	BRS12A		MX24
27	BX56		MX12
28	BX10		MX29
29	BRS14		MRS1
30	BX11		MX13
31	BX41		MX14
32	BX9		MX25
33	BX38		MX2
34	BX43		MX26
35	BX44		MX16
36			MX99
37			MX1

4C HYDROLOGY MODULE

4C.1 INTRODUCTION

This hydrologic analysis report describes the analyses used to assess the hydrologic sensitivities to the cumulative impacts of timber management the three tributaries of the Thompson River. The Distributed Hydrology-Soil-Vegetation Model (DHSVM) was implemented on the Thompson River Basin and used as a tool to assess the hydrologic response to changes in vegetation. The effect of timber harvest on peak flows was evaluated by simulating streamflow at the outlet of each of the watersheds for three vegetation scenarios and comparing simulated flood events. The model implementation and calibration on the Thompson River Basin is described in Wetherbee (1998).

The analysis essentially follows the methodology described in the hydrologic change module of the Washington Watershed Analysis procedures (WFPB, 1995). The method prescribed in the Washington process aims to address the following *critical questions*:

- What are the current watershed conditions influencing hydrologic response?
- What is the history of floods and disturbances of hydrologic significance in the watershed?
- What is the influence of land use on runoff during storm events which generate peak flows?
- What are the effects of changes in runoff on peak flows?
- What are the effects of changes in peak flows on public resources?

To address these questions, the general hydroclimatology of the area is briefly described, the basin characteristics are discussed, and DHSVM is used to evaluate changes in peak regimes related to changes in the forest canopy. The standard modelling methodology was not used because it assumes that winter rain-on-snow runoff events are the predominant runoff-generating mechanism. This is not the case for the Thompson River Basin and most of Western Montana, where peak flows are typically generated during spring snowmelt or rain during spring snowmelt (MacDonald and Hoffman, 1995)

Beatrice Creek, Murr Creek, and Boiling Springs Creek are tributaries of the Thompson River Basin in northwest Montana. The Thompson River Basin is a 410,095 acre (640 mi^2) watershed which drains the northeast portion of the Lower Clark Fork Basin, which is a tributary of the Columbia Basin (Figure C-1). The Boiling Springs Creek watershed is located in the northeast portion of the Thompson River Basin, draining northwest to the Thompson Lakes (Figure 2-1d). Murr Creek is located on the west northwest flank of the Thompson River basin, draining east-southeast to the main stem of the Thompson River (Figure 2-1d). Beatrice Creek is located in the southwest portion of the

basin. It drains to the northwest to Lower Fish Trap Creek, which joins the main stem of the Thompson River near it's outlet (Figure 2-1d).

The watersheds were not further subdivided since each watershed is itself a sub-basin of the Thompson River and DHSVM simulated streamflow at the outlet of each watershed. Table C-1 lists the basins and the corresponding areas.

The primary historical disturbances in the watersheds have been forest fires. A recent US Forest Service (USFS) report (Hessburg et al., 1998) suggests that prior to fire suppression management policy, at least 30% of the landscape in the lower Clark Fork Basin was in a stand initiation stage of forest development due to the frequent occurrence of forest fires. The primary activity in the watersheds in recent times is timber harvesting.

4C.2 STREAMFLOW AND CLIMATIC RECORDS

The Thompson River Basin is part of the Columbia River basin and ranges in elevation from 752 m (2467 ft) at the outlet to 2273 m (7451 ft) at Mt. Baldy at the southern end of basin. Streamflow is recorded by a US Geological Survey (USGS) streamflow monitoring station located on the Thompson River near the confluence with the Clark Fork River (USGS Station Number 12389500). The streamflow record is continuous from 1957 to the present.

Climatic data are available from the National Weather Service and it cooperators for Thompson Falls, Libby, and Kalispell. Figure C-2 shows the annual precipitation for Thompson Falls, Kalispell, and Libby. Mean annual precipitation at Thompson Falls is 0.59 m (23.2 in), Libby receives 0.47 m (18.5 in) annually, and the mean annual precipitation for Kalispell is 0.43 m (16.9 in).

The total annual discharge for the Thompson River is shown in Figure C-3. The annual peak flow series, derived from the daily streamflow record, is shown in Table C-2. Generally, the annual peak flow occurs during the spring, when snow ablation rates are at their peak and are often augmented by rainfall events.

The flood frequency distribution for the Thompson River Basin was calculated from the 39-year streamflow record at the USGS gage (Table C-3). The flood magnitudes were calculated according to the procedures described in Interagency Memorandum (1982) using the Log Pearson Type III distribution and the station skew coefficient. Given the 39 year gage record, the 50 and 100 year events should be considered estimates. Table C-4 lists the flood magnitudes for the tributary watersheds scaled by area.

Channel observations reported by O'Connor (person. comm., 1/26/98) suggest bankfull flows

substantially larger than those estimated by scaling the Thompson River flows. The discrepancy may be related to several factors. Beatrice Creek (6,570 acres) is about 1.5% of the total area of the TRB (410,095 acres) and scaling peak flows by area for watersheds of widely different areas introduces routing and storage errors because those factors are not scaled by area. Also, the frequency of the bankfull flow is unknown in the Thompson River watersheds, although bankfull floods are often considered to have recurrence intervals between two and five years.

4C.3 CURRENT LAND USE AND VEGETATION

All three of the watersheds are primarily forested land managed for timber production. Only roads associated with timber harvesting are located with watersheds and there are no publicly owned capital improvements within any of the watersheds. Bridges that cross the outlets of Boiling Springs Creek and Murr Creek are the property of PCTC.

Digital elevation models (DEM) for the three watersheds are shown in Figure C-4. The DEM data is described in the main body of this report and was used to simulate the streamflow at the outlet of the watersheds. Histograms of the watershed elevations are shown in Figure C-5, and the elevation cumulative frequency curves are shown in Figure C-6. Boiling Springs Creek ranges in elevation from 1023 m (3355 ft) at the outlet to 1768 m (5799 ft) at the southwest boundary. The mean elevation of Boiling Springs Creek is 1293 m (4241 ft). Murr Creek ranges in elevation from 1012 m (3319 ft) at the outlet to 2044 m (6704 ft) at the watershed divide. Relative to Boiling Springs Creek and Beatrice Creek, Murr Creek is generally higher (Figure C-6). The mean elevation of Murr Creek is 1578 m (5176 ft). Beatrice Creek ranges in elevation from 1064 m (3490 ft) at the outlet to 2167 m (7108 ft) on its southeastern boundary.

Existing vegetation conditions were compiled as describe in the main body of this report from the PCTC stand inventory database and the USFS Northern Region Landcover and Canopy Project (Redmond and Prather, 1996). Tables C-5 through C-7 list the current vegetation types and associated areas for each of the basins. In these tables the vegetation description codes consists of a two place species identification followed by a two digit size class and stocking description. Species descriptions are as follows: 90-rocky or barren; 94-grasslands; 95-brush; AF-Subalpine Fir; DF-Douglas Fir; ES-Engelmann Spruce; GF-Grand Fir; HP-White Pine; LP-Lodgepole Pine; MH-Mountain Hemlock; PP-Ponderosa Pine; WL-Western Larch. Stocking descriptions are described by PCTC.

Forest vegetation in the watersheds is dominated by Douglas- fir, lodgepole pine, and western larch. The fraction of forest canopy cover, estimated from the timber cruise stand density observations, provide an estimate of the relative hydrologic maturity of the of the forest canopy. Figure C-7 shows histograms of canopy density in the three watersheds based in the PCTC stand inventory. For

Beatrice Creek, the mean canopy density is 50%. In Boiling Springs Creek the mean canopy density is 27%, and the mean canopy density in Murr Creek is 41%. The three watersheds have similar average canopy densities, which suggests that they will have similar hydrologic sensitivities for the current stand conditions. Of the three watersheds, Boiling Springs Creek contains the largest proportion of relatively immature forest.

4C.4 PEAK FLOW ANALYSIS

Peak flow sensitivities were analyzed by using DHSVM to simulate long term streamflow records for different vegetation scenarios as describe in the main body of this report. An additional scenario was modeled for Boiling Springs Creek, Murr Creek, and Beatrice Creek: the maximum harvest condition. Stream flow at the outlet of each of the watersheds was simulated from WY 1961 through WY 1996 for the three scenarios. Flood frequencies were calculated for each of the simulated vegetation scenarios and compared as discussed in this report. Changes in simulated flood magnitudes are then used as the basis to assess the hydrologic sensitivities of the watersheds.

The historical base condition was approximated using the USFS regional historical stand description (Hessburg et al., 1998) for the Lower Clark Fork basin. Vegetation parameters for the historical USFS structural classes were assigned from the PCTC vegetation database (Plum Creek Timber Company, 1997) which was developed for 850 vegetation plots on PCTC-owned land throughout the TRB. At each vegetation plot, the PCTC database reports structure stage and key vegetation parameters such as canopy closure and tree height. Table C-8 lists the USFS structural classes and key vegetation parameters. Invariant parameters are listed in Wetherbee (1998).

To simulate the spatial distribution of the historical vegetation scenario, the relative percentages were recalculated from the cumulative percent probability density function. Each pixel in the basin was randomly assigned a real number between 0 and 1, then classified by vegetation according to the probability density function. The resulting vegetation distributions are shown in Table C-9.

This representation of the historical, unmanaged vegetation condition is an approximation since it does not consider geomorphologic factors such as the areal extent of riparian zones and fire burns. A more realistic scenario is to consider geomorphic characteristics, such as aspect and patch size, in the historical condition. However, without basis to determine these effects on the spatial distribution of the historical condition, we have used the random distribution as a first order approximation

The maximum harvest scenario is simply represented by representing all forest vegetation as the stand initiation structural class (Table C-8). This scenario is intended to provide an index of the maximum possible streamflow change in the watersheds. It is not intended to represent a likely future harvest scenario.

4C.4.1 PEAK FLOW CHANGES

Peak flow changes were calculated as describe in the main body of the report. The recurrence interval analysis emphasizes the largest simulated peaks, because only the largest annual peaks flows are included in the calculation. The peaks-over-threshold analysis (POT) provides a broader indication of the direct and magnitude of the simulated peak flow changes because it include flows that occur, on average, about 3-4 time per year.

4C.4.1.1 Recurrence Interval Analysis

Tables C-10 and C-11 show the results of the recurrence interval analysis, where discharge (cms) is listed for the historical (Base), current (Cur), and maximum harvest (Max) vegetation scenarios, and the change (ΔQ) is expressed as a percentage of the historical flow.

Simulated floods in Beatrice Creek and Murr Creek in the current condition have decreased relative to the simulated historical condition. Simulated peak flows in Boiling Springs Creek show a small increase. Peak flow changes for the maximum scenario relative to the base case condition are larger than peak flow changes reported for paired watershed studies with smaller proportions of immature forest canopy (Cheng, 1989). The model results suggests that peak flow increases of about 35-50% would be expected to be associated with the maximum harvest scenario.

4C.4.1.2 Peaks-Over-Threshold (POT) Analysis

The POT series for each basin - vegetation scenario combination was generated from the simulated daily streamflow series using the thresholds shown in Table C-12. The change relative to the historical base case is calculated for each recurrence interval and for each watershed for the current condition and the maximum harvest scenario.

To estimate the change in the POT series for the current vegetation relative to the historical scenario, the mean peak flow from the POT series was calculated for each scenario. The mean floods for the two scenarios were then compared and the change relative to the historical scenario was calculated. Tables C-13 and C-14 lists mean peak flows (Q in cms), the number of peak events (n) , the standard deviation (stan. dev.), and the percent change (ΔQ in percent) calculated from the POT series.

Generally, simulated flood magnitudes in the current condition have decreased relative to the simulated historical condition. Simulated peak flow changes for the maximum harvest scenario relative to the historical scenario increased by 25% to 50%.

4C. 5 DISCUSSION

The peak flow changes shown in Tables C-10, C-11, C-13, and C-14 reflect the modeled characteristics of the overstory canopy in the historical and current vegetation scenarios. In the modeled historical condition, the relative percentage of immature forest is larger than in the current condition, as discussed in Wetherbee (1998). Considering forest fires in the historical base case scenario reduces the simulated peak flow changes because much of the modeled historical watershed is in a stand initiation of stage of forest development.

There are many sources of error which reduce confidence in the estimated peak flow changes related to forest management. The errors stem from input meteorological data, spatial data, calibration, computational error, and analysis technique. Peak flow changes related to forest management in forested watershed is a complex process and previous studies have shown that there is large variability in the response of forested basins depending on physiography, antecedent conditions, storm characteristics, and the nature and timing of hillslope disturbances. While DHSVM is described as a "physically-based" model, calibration is still required and the extent to which calibration parameters are time dependent is not known. The effects of roads, which may alter storm hydrographs in forested basins, are not considered in this analysis and the extent to which this omission introduces error is also not known. The modeled flow changes do account for climate variation as recorded at climate observation stations, and consider the spatial variability of changes in the forest vegetation and soil properties.

The effect of watershed scale may introduce error in the analysis. The watershed model was calibrated for the entire Thompson River Basin, which averages key hydraulic parameters, such as the saturated lateral hydraulic conductivity, on the spatial scale of the entire basin. DHSVM calculates streamflow at any point on the channel network within the basin, allowing assessment of peak flow changes at the sub-basin scale. However, reducing the model scale to assess peak flow changes in sub-watersheds may introduce error in the simulated streamflow analyses.

4C.6 EFFECTS OF PEAK FLOW CHANGES ON PUBLIC RESOURCES

The modeling results presented in this analysis suggest that relative to the historical forest condition and the effects of natural forest fires, there have not been large changes in the peak flow regimes under the current forest conditions for Beatrice Creek, Boiling Springs Creek, or Murr Creek. The channels module analysis reports a low sensitivity to peak flow changes for most of the reaches in the watersheds. Considering the modeling results and the channel analysts assessment, the hydrologic hazard rating, as describe in the Washington watershed analysis hydrology module procedures (Washington State Forest Practice Board, 1995), is **LOW** for all three watersheds under the current vegetation conditions. The hydrologic modeling indicates that the hydrology hazard should be re-evaluated if proposed forest management plans would produce a vegetation scenario approaching the

maximum harvest condition.

4C.7 MONITORING

Additional hydroclimatological data would increase our understanding of the dominant hydrologic processes in the Thompson River Basin, improve the watershed model performance, and increase confidence in the model results. Since DHSVM considers the spatial effects of timber management, it offers the potential for use in watershed design to minimize streamflow, and thus sediment transport, effects. A voluntary monitoring program would assist future hydrologic analyses in the Thompson River Basin.

Precipitation patterns within the basin vary considerably and precipitation gages in the mid- and northern portions of the Thompson River catchment would improve the resolution of the rainfall patterns. Stream gage data from a Thompson River watershed, such as Murr Creek, would aid the development of relationships between the long term record on the Thompson River at Thompson Falls and streamflow in the watersheds.

4C.8 REFERENCES

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TABLES

Table C-1. Hydrologic Assessment units and catchment areas.

Watershed	Area (acres)	Area (km^2)
Boiling Springs Creek	5,490	22.0
Murr Creek	19,918	79.7
Beatrice Creek	6,570	26.3

Table C-2: Annual peak discharge, Thompson River, Montana (1956-1994).

Date	Q (cfs)	Q (cms)	Date	Q (cfs)	Q (cms)	Date	Q (cfs)	Q (cms)
5/21/56	4900	138.7	5/27/70	2670	75.6	5/31/84	1200	34.0
5/21/57	2930	82.9	5/13/71	3870	109.5	5/4/85	1540	43.6
5/12/58	1970	55.8	6/1/72	4250	120.3	5/29/86	1690	47.8
6/6/59	2930	82.9	5/19/73	1010	28.6	5/1/87	1840	52.1
5/13/60	2600	73.6	1/16/74	3680	104.1	4/18/88	982	27.8
5/27/61	3520	99.6	6/3/75	2420	68.5	5/8/89	2030	57.5
5/26/62	1730	49.0	5/11/76	3380	95.7	4/22/90	1550	43.9
5/25/63	1390	39.3	12/3/77	525	14.9	5/19/91	3000	84.9
6/9/64	5360	151.7	3/31/78	1750	49.5	5/8/92	816	23.1
4/22/65	2880	81.5	5/25/79	2250	63.7	5/15/93	1550	43.9
5/7/66	2090	59.1	6/14/80	2200	62.3	4/25/94	970	27.5
5/23/67	3980	112.6	5/23/81	1820	51.5	12/1/95	2100	59.4
5/23/68	1240	35.1	5/27/82	2560	72.4	2/9/96	4140	117.2
4/25/69	2830	80.1	5/27/83	1820	51.5			

Table C-3: Estimated flood magnitudes at Thompson River, Montana, for selected flood frequencies.

	Recurrence Interval					
Discharge	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
cfs	2213	3295	3965	4750	5292	5798
cms	62.6	93.3	112.2	134.4	149.8	164.1

Table C-4: Estimated flood magnitudes for Boiling Springs Creek, Murr Creek, and Beatrice Creek in cms.

	Recurrence Interval					
Discharge	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Boiling Springs Creek	0.8	1.2	1.5	1.7	1.9	2.1
Murr Creek	3.1	4.6	5.5	6.6	7.3	8.0
Beatrice Creek	1.0	1.5	1.8	2.2	2.4	2.6

Table C-5: Beatrice Creek vegetation types, fractional canopy coverage, and area.

Table C-5.			
Description	**Fraction Canopy Cover**	**Area (acre)**	**Relative Percent**
9000	0.03	89.0	1.4
9400	0.03	38.9	0.6
9500	0.03	177.9	2.7
AF13	0.13	27.8	0.4
AF21	0.32	77.8	1.2
AF32	0.70	489.3	7.6
DF00	0.10	33.4	0.5
DF11	0.06	77.8	1.2
DF13	0.18	16.7	0.3
DF21	0.15	361.4	5.6
DF22	0.22	150.1	2.3
DF23	0.48	144.6	2.2
DF31	0.19	361.4	5.6
DF32	0.32	100.1	1.5
DF33	0.53	38.9	0.6
DF41	0.36	16.7	0.3
DF51	0.39	5.6	0.1
DF52	0.39	2057.1	31.8
ES13	0.23	11.1	0.2
ES52	0.93	61.2	0.9
GF23	0.59	55.6	0.9
HP13	0.19	16.7	0.3
HP32	0.99	50.0	0.8
LP13	0.10	55.6	0.9
LP21	0.15	5.6	0.1
LP23	0.66	166.8	2.6

Table C-5.			
Description	**Fraction Canopy Cover**	**Area (acre)**	**Relative Percent**
LP32	0.60	177.9	2.7
LP42	0.51	656.0	10.1
MH13	0.24	5.6	0.1
MH21	0.32	66.7	1.0
MH32	0.71	16.7	0.3
MH33	0.79	33.4	0.5
PP00	0.07	16.7	0.3
PP12	0.14	44.5	0.7
PP31	0.21	5.6	0.1
PP51	0.38	61.2	0.9
WL00	0.08	11.1	0.2
WL12	0.16	27.8	0.4
WL22	0.24	11.1	0.2
WL23	0.32	111.2	1.7
WL31	0.22	16.7	0.3
WL32	0.45	111.2	1.7
WL51	0.56	411.4	6.4
	Totals	**6471.5**	**100.0**

Table C-6: Boiling Springs Creek vegetation types, fractional canopy coverage, and area.

Table C 6.			
Description	**Fraction Canopy Cover**	**Area (acre)**	**Relative Percent**
8000	0.027	61.2	1.0
9400	0.03	38.9	0.6
9600	0.03	89.0	1.4
9700	0	16.7	0.3
AF13	0.13	5.6	0.1
DF00	0.1	94.5	1.5
DF13	0.18	400.3	6.5
DF21	0.15	422.5	6.9
DF22	0.22	166.8	2.7
DF31	0.19	1206.4	19.6
DF32	0.32	105.6	1.7
DF33	0.53	77.8	1.3
DF41	0.36	139.0	2.3
DF42	0.48	200.1	3.2
DF43	0.63	16.7	0.3
DF52	0.39	628.2	10.2
ES41	0.39	44.5	0.7
ES42	0.63	16.7	0.3

Table C-6.			
Description	**Fraction Canopy Cover**	**Area (acre)**	**Relative Percent**
GF00	0.05	33.4	0.5
GF13	0.08	44.5	0.7
GF21	0.16	22.2	0.4
GF31	0.19	27.8	0.5
LP13	0.1	272.4	4.4
LP21	0.15	77.8	1.3
LP22	0.36	44.5	0.7
LP23	0.66	5.6	0.1
LP31	0.32	22.2	0.4
LP32	0.6	50.0	0.8
LP33	0.7	16.7	0.3
LP42	0.51	77.8	1.3
PP13	0.21	133.4	2.2
PP31	0.21	255.7	4.1
PP41	0.32	22.2	0.4
PP51	0.38	227.9	3.7
WL00	0.08	311.3	5.0
WL13	0.2	305.8	5.0
WL21	0.15	5.6	0.1
WL22	0.24	61.2	1.0
WL31	0.22	83.4	1.4
WL33	0.54	61.2	1.0
WL41	0.47	122.3	2.0
WL42	0.52	55.6	0.9
WL51	0.56	94.5	1.5
	Totals	**6165.7**	**100.0**

Table C-7. Murr Creek vegetation types, fractional canopy coverage, and area.

Table C-7.			
Description	**Fraction Canopy Cover**	**Area (acre)**	**Relative Percent**
8000	0.03	144.6	0.7
8100	0.04	5.6	0.0
9000	0.03	984.1	4.8
9400	0.03	55.6	0.3
9500	0.03	594.9	2.9
AF11	0.13	22.2	0.1
AF13	0.13	94.5	0.5
AF23	0.77	22.2	0.1
AF31	0.48	111.2	0.5
AF32	0.70	422.5	2.1
AF33	0.75	50.0	0.2

Table C-7.			
Description	Fraction Canopy Cover	Area (acre)	Relative Percent
AF41	0.58	16.7	0.1
DF00	0.10	189.0	0.9
DF13	0.18	33.4	0.2
DF21	0.15	467.0	2.3
DF22	0.22	22.2	0.1
DF31	0.19	361.4	1.8
DF32	0.32	22.2	0.1
DF33	0.53	55.6	0.3
DF41	0.36	77.8	0.4
DF52	0.39	2,779.8	13.6
ES33	0.61	5.6	0.0
ES41	0.39	27.8	0.1
ES42	0.63	38.9	0.2
GF13	0.08	27.8	0.1
GF21	0.16	50.0	0.2
GF32	0.45	16.7	0.1
GF41	0.36	33.4	0.2
LP11	0.04	11.1	0.1
LP12	0.02	750.6	3.7
LP13	0.10	1,523.4	7.5
LP21	0.15	72.3	0.4
LP22	0.36	372.5	1.8
LP23	0.66	1,401.0	6.9
LP31	0.32	161.2	0.8
LP32	0.60	439.2	2.1
LP33	0.70	300.2	1.5
LP42	0.51	5,187.2	25.4
WL00	0.08	1,173.1	5.7
WL12	0.16	50.0	0.2
WL13	0.20	850.6	4.2
WL23	0.32	55.6	0.3
WL31	0.22	105.6	0.5
WL32	0.45	278.0	1.4
WL33	0.54	44.5	0.2
WL41	0.47	250.2	1.2
WL42	0.52	11.1	0.1
WL51	0.56	661.6	3.2
	Totals	**20,431.8**	**100.0**

Table C-8: USFS historical vegetation classification and assigned vegetation classes from the PCTC database.

USFS Structural Class	USFS Relative Proportion of Basin	Canopy Density (%)	Overstory Height (m)	Overstory Leaf Area Index
Stand initiation	32.7	14	11.3	0.5
Stem exclusion, open canopy	15.7	49	16.6	1.0
Stem exclusion, closed canopy	10.3	77	16.3	1.5
Understory re-initiation	16.4	37	15.7	2.25
Young multi-story	14.3	45	15.1	2.25
Old multi-story	0.2	64	19.5	3.0
Old single-story	2.2	64	19.5	3.0
Open (rock, shrub, barren)	8.0	14	11.3	0.5

Table C-9: Historical vegetation distribution.

Watershed	Structural Class								
	Stand Initiation (%)	Stem Exclusion, Open Canopy (%)	Stem Exclusion, Closed Canopy (%)	Understory Re-initiation (%)	Young Multi-story (%)	Old Multi-story (%)	Old Single-story (%)	Open (%)	Total (%)
Beatrice Creek	29.4	16.5	11.6	15.2	15.1	0.3	2.5	9.4	100.0
Boiling Springs Creek	29.9	14.3	8.7	13.5	12.4	12.4	2.3	6.5	100.0
Murr Creek	32.7	15.6	10.5	16.3	13.9	0.1	2.2	8.6	100.0

Table C-10: Simulated peak flows and differences for the current vegetation and the historical base scenario.

	Recurrence Interval														
	2-yr			5-yr			10-yr			25-yr			50-yr		
Watershed	Base	Cur	ΔQ	Base	Cur	ΔQ	Base	Cur	ΔQ	Base	Cur	ΔQ	Base	Cur	ΔQ
Beatrice Creek	1.04	0.96	-7.7	1.51	1.43	-5.3	1.82	1.77	-2.7	2.22	2.21	-0.5	2.52	2.55	-1.2
Boiling Springs Creek	0.55	0.57	0.75	0.75	0.78	4.0	0.88	0.93	5.7	1.04	1.12	7.7	1.16	1.25	7.8
Murr Creek	2.37	2.22	-6.3	3.32	3.12	-6.0	4.01	3.73	-7.0	4.94	4.54	-8.1	5.68	5.16	-9.2

Table C-11: Simulated peak flows and differences for the maximum harvest vegetation and the historical base scenario.

	Recurrence Interval														
	2-yr			5-yr			10-yr			25-yr			50-yr		
Watershed	Base	Max	ΔQ	Base	Max	ΔQ	Base	Max	ΔQ	Base	Max	ΔQ	Base	Max	ΔQ
Beatrice Creek	1.04	1.48	42.3	1.51	2.12	40.4	1.82	2.58	41.8	2.22	3.15	41.9	2.52	3.59	42.5
Boiling Springs Creek	0.55	0.83	50.9	0.75	1.17	56.0	0.88	1.40	59.1	1.04	1.71	64.4	1.16	1.94	67.2
Murr Creek	2.37	3.57	50.9	3.32	4.84	45.8	4.01	5.69	41.9	4.94	6.78	37.2	5.68	7.61	34.0

Table C-12: Thresholds used to generate the POT for the TRB watersheds.

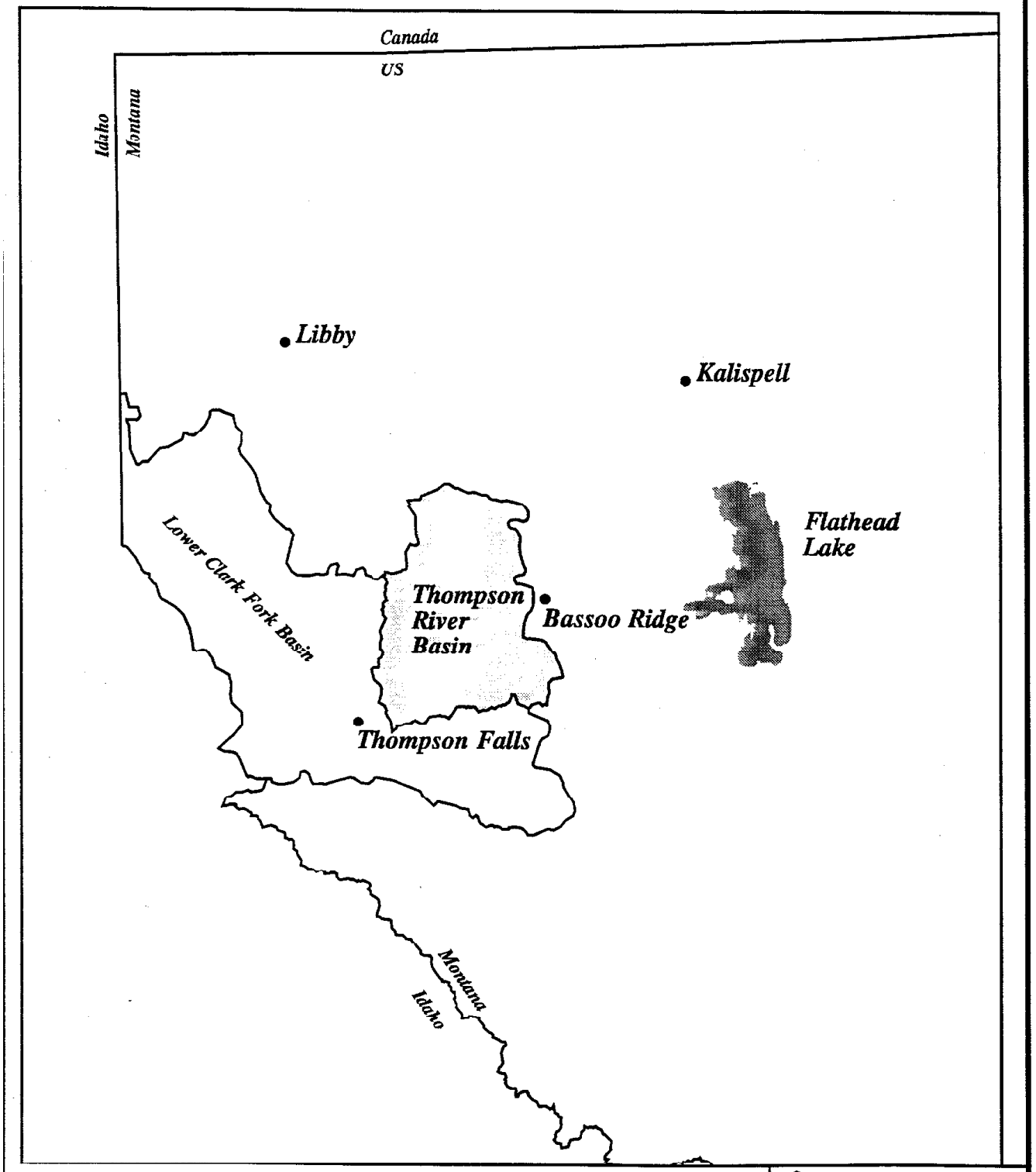
Watershed	**Historical Vegetation Threshold (cms)**	**Current Vegetation Threshold (cms)**	**Maximum Harvest Vegetation Threshold (cms)**
Beatrice Creek	0.65	0.60	0.80
Boiling Springs Creek	0.40	0.40	0.60
Murr Creek	1.60	1.50	2.20

Table C-13: Mean peak flows calculated from the POT series and simulated change for the current condition relative to the modeled historical scenario.

	Historical Vegetation Scenario			Current Vegetation Scenario			Change in mean peak flow (%)
Watershed	Q (cms)	n	stan. dev.	Q (cms)	n	stan. dev.	ΔQ
Beatrice Creek	0.99	121	0.35	0.91	124	0.34	-8.08
Boiling Springs Creek	0.56	116	0.15	0.57	126	0.17	1.79
Murr Creek	2.37	123	0.79	2.25	122	0.81	-5.06

Table C-14: Mean peak flows calculated from the POT series and simulated change for the maximum harvest condition relative to the modeled historical scenario.

	Historical Vegetation Scenario			Maximum Harvest Vegetation Scenario			Change in mean peak flow (%)
Watershed	Q (cms)	n	stan. dev.	Q (cms)	n	stan. dev.	ΔQ
Beatrice Creek	0.99	121	0.35	1.24	125	0.51	25.25
Boiling Springs Creek	0.56	116	0.15	0.84	118	0.25	50.00
Muir Creek	2.37	123	0.79	3.20	139	0.98	35.02



Scale 1:1230324

0km 10km 20km 30km 40km

0mi 10mi 20mi

N W E S

Data Source: MT GLIS Library

Thompson River Basin

Thompson River Hydrologic Analysis

Figure C-1. Thompson River location map.

File: e:/thomp_gis/pltloc01.aml

Date: 3/12/98 By: CSM

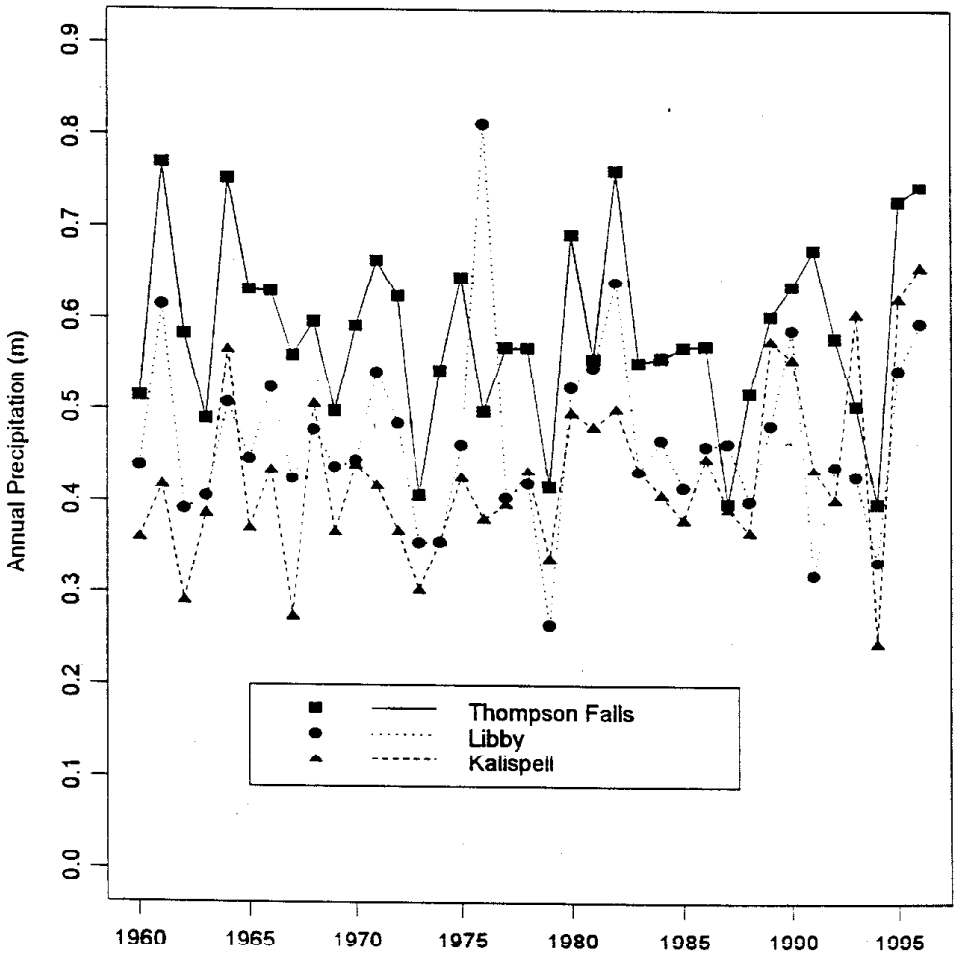


Figure C-2. Annual precipitation at Thompson Falls, Libby, and Kalispell.

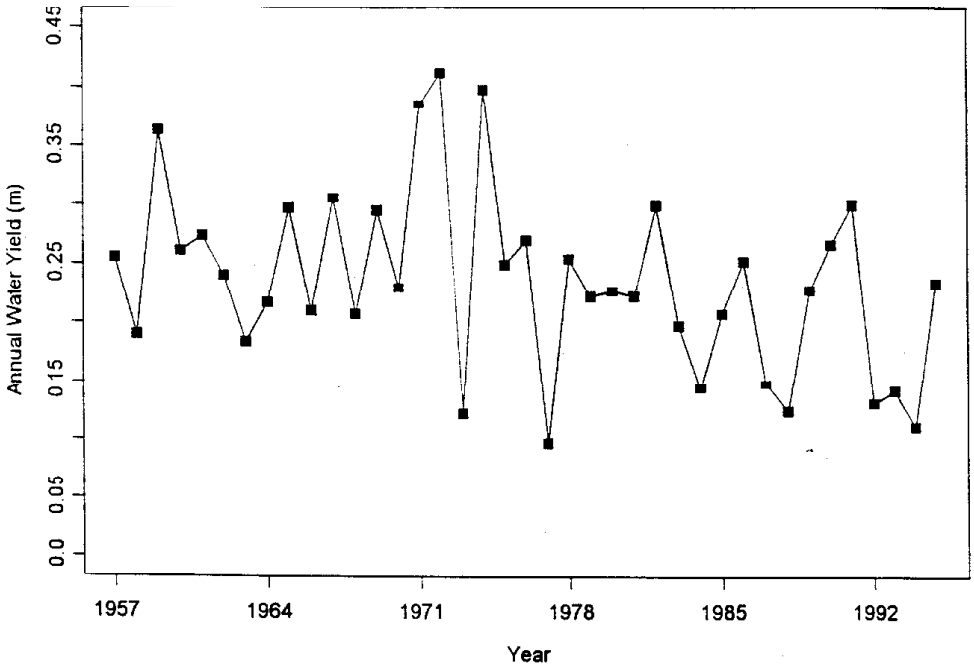
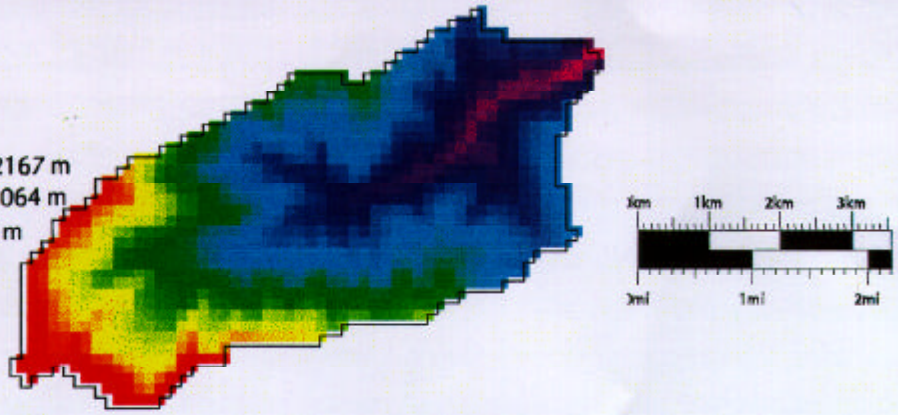


Figure C-3. Annual water yield, Thompson River at Thompson Falls, MT.

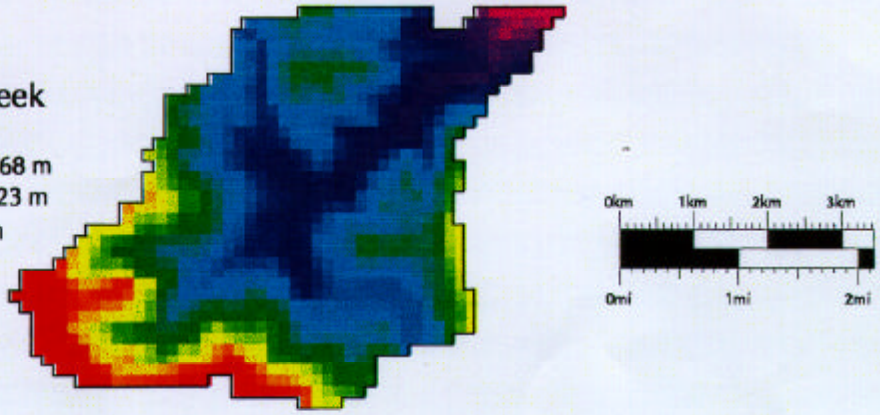
Beatrice Creek

Area: 26.19 sq.km.
Maximum Elevation: 2167 m
Minimum Elevation: 1064 m
Mean Elevation: 1516 m



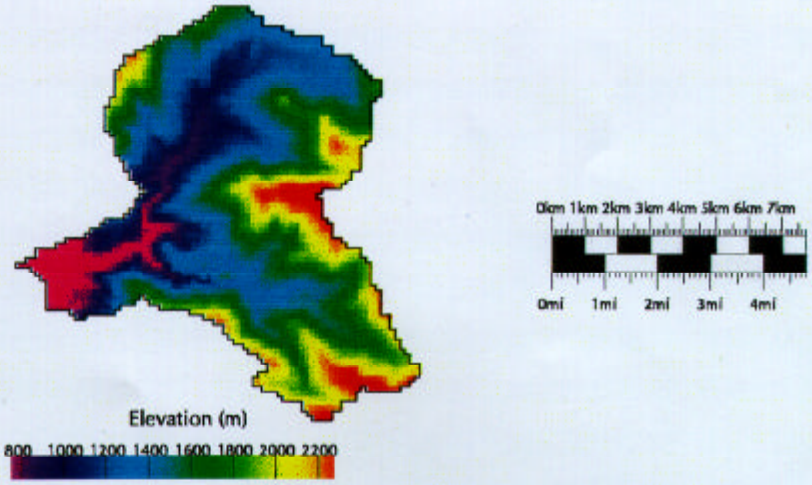
Boiling Springs Creek

Area: 24.95 sq.km.
Maximum Elevation: 1768 m
Minimum Elevation: 1023 m
Mean Elevation: 1293 m



Murr Creek

Area: 82.69 sq.km.
Maximum Elevation: 2044 m
Minimum Elevation: 1012 m
Mean Elevation: 1578 m



Data Source:
USGS 3-arc second digital elevation model

Thompson River Hydrologic Analysis

Figure C-4. Thompson River Subbasins DEMs.

File: e:/thomp_gis/pltdemsub01.aml

Date: 3/24/98 By: CSM

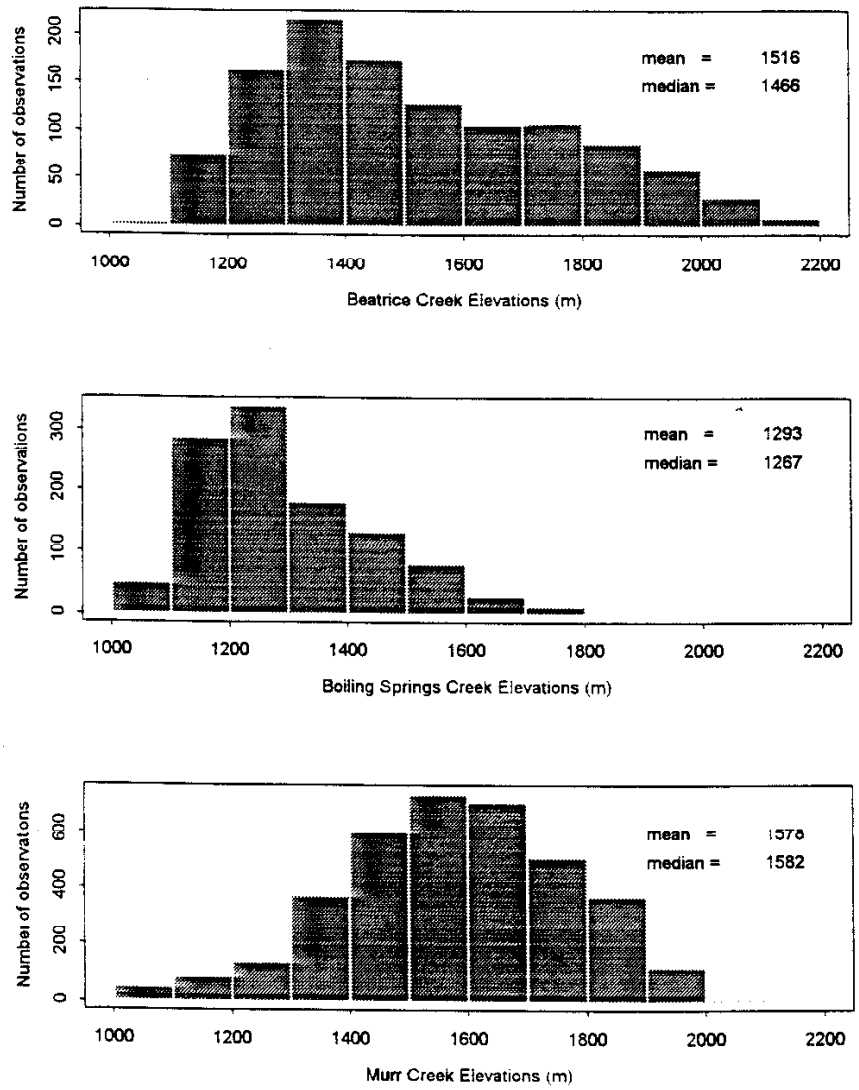


Figure C-5. Elevation histograms for Beatrice Creek, Boiling Springs Creek, and Murr Creek.

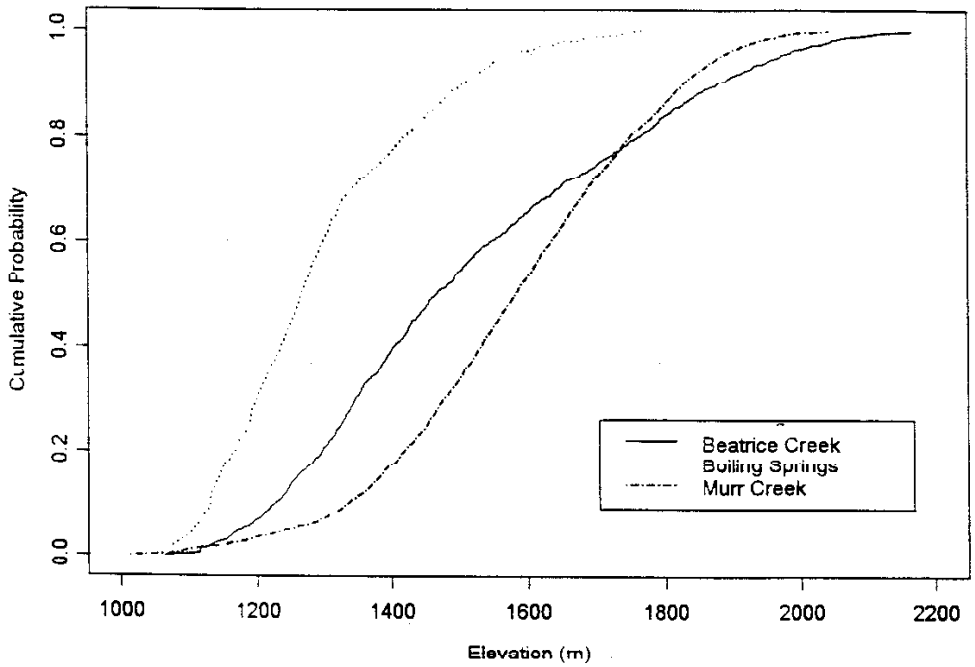


Figure C-6. Elevation cumulative frequency curves for Beatrice Creek, Boiling Springs Creek, and Murr Creek

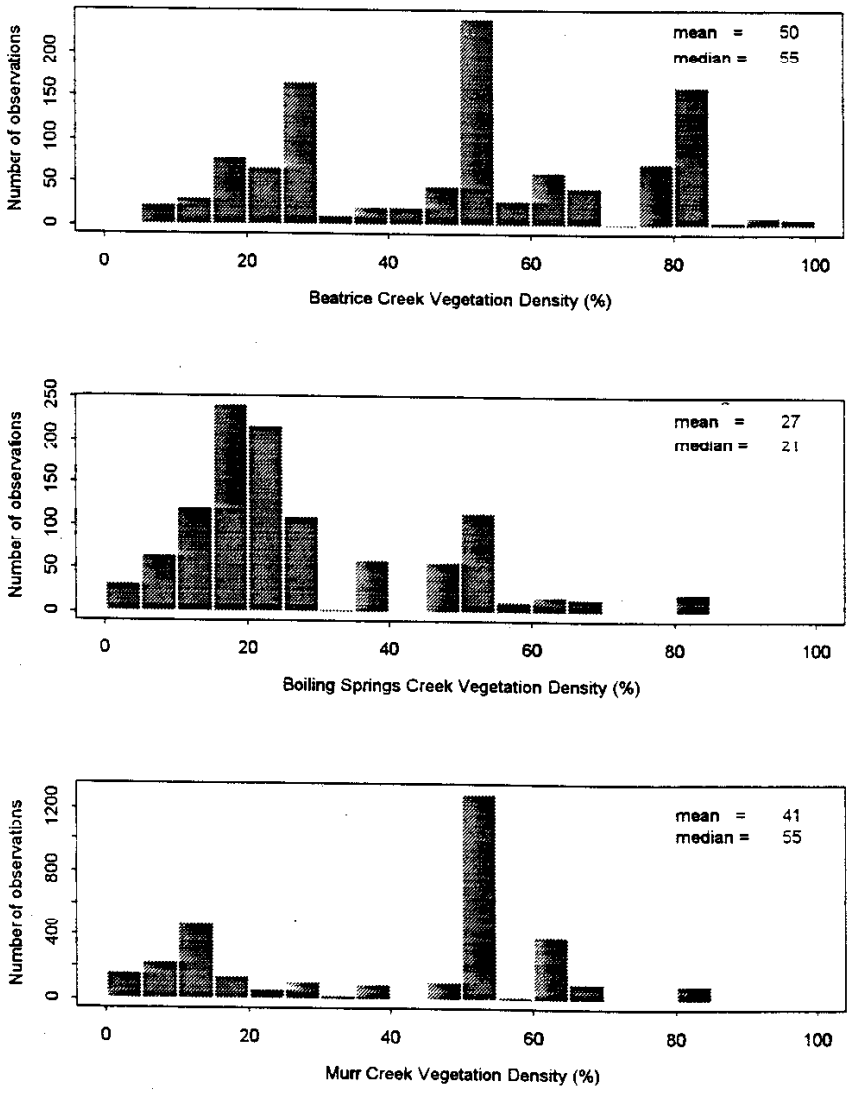


Figure C-7. Canopy density histograms for Beatrice Creek, Boiling Springs Creek, and Murr Creek.

4D RIPARIAN FUNCTION MODULE

4D.1 INTRODUCTION

An assessment of riparian condition and function was conducted in Boiling Springs, Murr and Beatrice creeks of the Thompson River Valley between May and October 1997.

The two primary questions addressed in this analysis are:

1. What is the condition of the riparian zone relative to its ability to supply large woody debris to the stream in the near-term?

2. What is the current degree of canopy closure provided by riparian vegetation relative to what is needed to maintain desirable stream temperatures?

This assessment of large woody debris (LWD) recruitment and riparian shade follows the *Standard Methodology for Conducting Watershed Analysis*, Washington State Forest Practices Board, (WFPB,1995). Modifications of the standard procedure were made as necessary to address the unique environment of the northern Rocky Mountains. Specific deviations to the standard methodology, and the justifications, are described in the text.

This report has four main sections. The first section deals with the first primary question on LWD recruitment and current/historical condition of the riparian area. The next section addresses the second primary question about canopy closure and stream temperature. The third section deals with extrapolating riparian condition to Geomorphic Channel Units (GCU) that are described in Section 4E. These GCU's are used to expand this information to the entire Thompson Valley as a whole. The remaining sections of this module report includes: Areas of Special Concern; Casual Mechanism Reports; and Monitoring in the watersheds.

4D.1.1 SOURCES OF INFORMATION

Riparian zone condition relative to LWD recruitment and canopy cover were characterized using color aerial photography. The primary photography used for the analysis were 1993, 1994, 1995 and 1997 PCTC color photos (1:12,000 scale).

Field inspections were used to verify calls on a sub-sample of the riparian area. Data collected from the field inspections was used to correct riparian calls, recruitment potential, define channel migration zones (CMZ), and in-stream LWD.

Field surveys of riparian conditions verified and supplemented photo-interpretations. Data collected in the field surveys include CMZ boundaries (width); riparian tree species, sizes, densities; LWD accumulation; and canopy cover. Data collection efforts were supplemented by fisheries habitat research that was being conducted in conjunction with the watershed analysis by PCTC during the summer of 1997. In addition, stream temperature data supplemented the shade analysis. Field information collected by the channel analyst was used to determine channel sensitivity to LWD inputs.

4D.2 LWD RECRUITMENT SECTION

4D.2.1 INTRODUCTION/METHODOLOGY

In this section, data from aerial photos, field inspections of riparian stands, and in-stream LWD were analyzed and interpreted with respect to the critical question for this section:

> *What is the condition of the riparian zone relative to its ability to supply large woody debris to the stream in the near-term?*

To determine whether riparian areas are functioning properly and providing adequate protection to the stream, it is necessary to look at what functions are being provided and how far from the stream this is occurring. Functional riparian stands provide shading, LWD, nutrient flux, litter inputs, bank stability, and sediment trapping and filtration (McGreer 1996). The removal of riparian vegetation potentially reduces stream habitat complexity by decreasing the amount of LWD available for recruitment into the stream. LWD helps form pools, regulate sediments, and create complex fish habitats (Bisson et al. 1987; Bilby and Ward 1989). Reductions in LWD can diminish channel stability. Input of LWD 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 LWD recruitment to the stream channel. The probability of a tree falling into a stream in order to provide LWD is a function of the trees 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 LWD and that 80% of LWD originates within 0.62 tree heights of the stream channel (McDade et al 1990, Van Sickel and Gregory 1990). The size and density of LWD needed to remain in place and function properly varies according to stream size and morphology. Generally, as stream size increases, the size of LWD available from adjacent stands must increase proportionately (Bilby 1985).

Aerial photography was used to characterize the forest composition of the riparian area out to 23 m (75 ft) on both sides of the stream. This distance in Washington represents half of the "site potential tree height." In Montana, where trees are typically smaller than Eastern Washington, this figure may more appropriately represent three-quarters to 100% of the "site potential tree height".

Photo pairs were examined and riparian stands were delineated on 1:24,000 GIS base maps provided by PCTC. Riparian segments along all streams in the study watersheds were broken into riparian condition codes. These codes delineated riparian strips using 3 differentia: Dominant vegetation; Tree size; and Stocking density. For example, a riparian area identified as "conifer-mature-dense (CMD)" is dominated by conifers with trees of medium DBH and dense stocking, Table 4D-1 has a further breakdown of these calls.

Table 4D-1. Riparian condition codes.

Dominant Vegetation Type		Average Tree Size (D.B.H.)[1]		Stand Density Class[2]	
>70% Conifer	C	<12	Small (S)	>1/2 Ground Exposed	Sparse (S)
>70% Hardwood	H	>12 and <20	Medium (M)	<1/2 Ground Exposed	Dense (D)
All Other Cases	M	>20	Large (L)		

[1] DBH size in inches.
[2] Stand density using Eastern Washington stocking.

Riparian condition assessments were made for both sides of each channel segment in the study watersheds. These channel segments were adapted from the "Ecological Classification Thompson River Basin Montana" (1997). A map of these channel segments can be found in Figures 4D-1a through 4D-1c (located at the end of this section).

Riparian condition calls were used to classify the LWD recruitment potential for the riparian area on both sides of the stream. The recruitment potential rating describes the likelihood that the riparian zone will provide functional LWD in the near-term. A riparian area with a call of "CMD" has a high potential of providing adequate LWD to the stream in the near-term. A further breakdown of calls can be seen in Table 4D-2. These photo-interpreted calls were verified during field surveys.

Table 4D-2. Recruitment potential ratings.

Recruitment Potential Rating	Riparian Condition Codes
Low	HSS, HSD, MSS, MSD, CSS, CSD, HMS, HLS
Moderate	HMD, MMS, CMS, CLS, HLD, MLS
High	CMD, MMD, MLD, CLD

Based on the module diagnostics (WFPB,1995) 2 pieces of LWD per channel width is considered to be adequate for Western Washington where this module was developed. After applying this standard

to surveyed areas with minimal disturbance, in Montana however, it seemed to be eliminating areas that were functioning correctly. In a recently completed study on LWD in eight minimally-disturbed western Montana streams, Hayes (1996) concluded: "It is obvious that streams in Montana are different enough that west-coast data does not transfer well to this area." Based on the Hayes study, and analyst discussion during the Synthesis process, it was decided that a target (minimum functioning) condition 1 piece of LWD per channel width is more appropriate. This is consistent with modifications that have been made in other watershed analyses conducted in Eastern Washington in similar habitat types (O'Connor, personal communications). Channel segments that had more than 1 piece of LWD per channel width were considered to be "on target" for having an adequate supply of wood.

Under the standard methodology in the manual, LWD hazard calls are based on a matrix shown in Table 4D-3. This table considers channel sensitivity to LWD (as determined by the channel analyst), LWD recruitment potential, Table 4D-2, and the current condition of the in-stream LWD. A close inspection of this matrix shows that channel sensitivity and LWD numbers largely determine the hazard ratings.

Table 4D-3. LWD recruitment hazard call matrix (LWD recruitment potential x channel sensitivity).

LWD ON TARGET		CHANNEL SENSITIVITY		
LWD OFF TARGET		LOW	MOD	HIGH
LWD RECRUIT-MENT POTENTIAL	LOW	LOW	MOD	HIGH
		LOW	HIGH	HIGH
	MOD	LOW	MOD	MOD
		LOW	HIGH	HIGH
	HIGH	LOW	MOD	MOD
		LOW	HIGH	HIGH

4D.2.2 RESULTS

4D.2.2.1 *Riparian Forest Condition*

More than 79% of riparian areas in the three study watersheds were found to have good stand conditions (defined as having a moderate-to-high recruitment potential), and 66% of riparian areas

had a high recruitment potential (as defined in Table 4D-2). The 34% of stands that did not have a high recruitment potentials were generally found in the upper reaches of the channel network. These are areas with naturally low densities and smaller trees due to environmental factors (i.e., talus soils, steep head wall systems, canyons, and short growing seasons). Some of the low recruitment areas in both Boiling Springs Creek and Murr Creek were attributed to timber harvesting. A break-down of recruitment potential calls by segment can be found in Table 4D-4.

4D.2.2.2 *In-Channel LWD*

In-channel LWD ratings are also summarized in Table 4D-4. In-channel LWD within much of the Boiling Springs channel network is considered to be "off" due to timber harvest or areas that are naturally deficient in medium to large trees in the riparian area. In-channel LWD levels in Beatrice Creek and Murr Creek are generally "on" with only a few segments being below target. These segments are in naturally low-recruitment areas based on historic aerial photos. Most segments with the largest accumulations of LWD were found in Geomorphic Channel Units (GCU) 2, 4, and 5. These GCU's are also areas with higher potential of channel migration. GCU's are stream segments with similar functions. For a more detailed description of GCU's see Section 4E.

Table 4D-4. Riparian Condition Code, Recruitment Potential, and Hazard Calls by GMU and Segment in the Watershed Analysis Area.

Watershed	Segment	GMU	Segment Length (m	Riparian Condition Code L	Riparian Condition Code R	Recruitment Potential Rating L	Recruitment Potential Rating R	Channel Sensitivity	In-Channel LWD Rating	LWD Recruitment Hazard L	LWD Recruitment Hazard R	Impacts*
Boiling Springs	250	1	221	CMD	CMD	H	H	M	OFF	H	H	N
	333	1	942	CSS/CMD	CSS/CMD	L/H	L/H	M	OFF	H	H	N,H
	209	2	1002	CMD	CMD	H	H	M	OFF	H	H	N
	291	2	422	CMS/CMD	CMD	M/H	H	M	OFF	H	H	N,H
	315	2	938	CMS/CMD	DSS/CMD	L/H	L/H	M	ON	M	M	N
	328	3	1077	MSD	MSD	L/H	L/H	M	ON	M	M	N
	257	6	462	CMD	CMD	H	H	L/M	OFF	H	H	H
	335	8	143	CMD	CMD	H	H	M	OFF	H	H	H
	337	8	10	CMD	CMD	H	H	M	OFF	H	H	H
	348	8	1039	MSD/CMD	MSD/CMD	L/H	L/H	M	OFF	H	H	H
	350	8	109	CMD	CMD	H	H	M	OFF	H	H	H
	353	8	351	CSS/CMD	CSS/CMD	L/H	L/H	M	OFF	H	H	H
	355	8	355	CSS/CMD	CSS/CMD	L/H	L/H	M	OFF	H	H	H
	258	12	1609	CMS	CMS	M/H	M/H	M	ON	M	M	H
Murr	472	1	156	CMD	CMD	L	L	M	OFF	H	H	N,G
	344	2	1147	MSS	MSS	L	L	M	ON	M	M	H
	362	2	894	MSS	MSS	L	L	M	ON	M	M	H
	370	2	291	CMD	CMD	H	H	M	ON	M	M	H
	382	2	1158	CMS	CMD	M	H	M	ON	M	M	N
	384	2	137	CMD	CMD	H	H	M	ON	M	M	H
	387	2	146	CMD	CMD	H	H	M	ON	M	M	H
	410	2	1028	CMS	CMD	M	H	M	ON	M	M	N
	478	4	1581	CMD	CMD	H	H	H	ON	M	M	N
	513	4	861	CMD	CMD	H	H	H	ON	M	M	N
	458	5	661	CMD	CMD	H	H	H	ON?	M	M	N
	475	5	1703	CMD	CMD	H	H	H	ON	M	M	N
	361	8	361	CMS	CMD	M	H	L	OFF	H	H	H
	367	8	1464	CMS	CMD	M	H	L	OFF	H	H	N,H
	379	8	552	CMD	CMD	H	H	L	OFF	L	L	N
	389	8	2296	CMD	CMD	H	H	L	OFF	L	L	N
	505	8	1842	CMD	CMD	H	H	M	ON	M	M	N
	515	8	334	CMD	CMD	H	H	L	OFF	L	L	N
	524	8	595	CMD	CMD	M	H	L	OFF	L	L	H
	574	8	4024	CSD	CSD	L	L	L	OFF	L	L	H
	627	8	3504	CMD	CMD	H	H	L	ON	L	L	H
	632	8	83	CMD	CMD	H	H	L	OFF	L	L	H
	446	9	1363	CMD	CMS	M	M	L	OFF	L	L	N
	480	9	288	CMD	CMD	H	H	L	ON	L	L	N
	481	9	345	CMD	CMD	H	H	L	ON	L	L	N
	495	9	1643	CMD	CMD	H	H	L	ON	L	L	N
	497	9	290	CMS	CMS	M	M	L	ON	L	L	N
	501	9	613	CMD	CMD	H	H	L	ON	L	L	N
	508	9	793	CMS	CMS	M	M	L	ON	L	L	N
Beatrice	1660	4	605	MMD	CMD	H	H	H	ON?	M	M	H,R
	1680	4	305	MMD	CMD	H	H	H	ON?	M	M	H,R
	1706	4	305	CMD	CMD	H	H	H	ON	M	M	H,R
	1709	4	28	CMD	CMD	H	H	H	ON	M	M	H,R
	1759	4	725	CMD	CMD	H	H	H	ON	M	M	N
	1770	4	171	CMD	CMD	H	H	H	ON	M	M	N
	1772	4	77	CMD	CMD	H	H	H	ON	M	M	N
	1791	4	721	CMD	CMD	H	H	H	ON	M	M	N
	1641	5	1352	MSD	CMD	L	H	H	ON	H	M	H,R
	1797	6	124	CMD	CMD	H	H	M	ON	M	M	H,R
	1800	6	353	CMD	CMD	H	H	M	ON	M	M	H
	1815	6	225	CMD	CMD	H	H	M	ON	M	M	H
	1820	6	508	CMD	CMD	H	H	M	ON	M	M	H
	1821	6	8	CMD	CMD	H	H	M	ON	M	M	H,R
	1849	6	926	CMD	CMD	H	H	M	ON	M	M	N
	1856	7	275	CMD	CMD	H	H	M	ON	M	M	N
	1883	7	2220	CMD	CMD	H	H	M	OFF	H	H	N,H
	1896	7	231	CMD	CMD	H	H	M	OFF	H	H	H
	1912	7	1086	CMD	CMD	H	H	M	ON	M	M	N,R
	1608	9	49	CMD	CMD	H	H	L	OFF	L	L	N
	1754	10	495	CMD/MMD	CMD/MSD	H/M	H/M	H	OFF	M/H	M/H	N,H
	1777	10	398	MMD	MMD	H	H	H	ON	M	M	H
	1788	10	321	CMS	CMS	M	M	H	ON	M/H	M/H	N,H

* H1 = Harvest before MT SMZ Law, H2 = Harvest after MT SMZ Law, N = Natural (same as 1955 photo's), R = Road Building

4D.2.2.3 *Historical Riparian Forest Stand Conditions*

For this part of the analysis aerial photography from 1955 was used to determine base-line conditions for the watershed. These photos were beneficial in determining historic condition of the stands due to the fact that little management had occurred within the watersheds previous to 1955. In general timber stands within the watersheds were dominated with lodgepole pine stands in the upland areas and areas of ponderosa pine, Douglas-fir and western larch. The photo's showed a patchwork mosaic of stand-replacing fires with remnant larch or fir in the overstory. The upper Murr Creek drainage is dominated by dense lodgepole pine stands with a small average diameter.

Riparian areas within the basin are similar to uplands but were dominated by Englemann spruce and Douglas-fir. Others species present include sub-alpine fir, lodgepole pine, western larch, ponderosa pine, and mountain hemlock, with a strong deciduous community present along the banks dominated by thin leaf alder.

In 1955 Beatrice and Murr Creek had not been entered to harvest. Boiling Springs had limited harvests in the lower sections near the chain lakes and Part of Sections 16 and 17 ,T26N, R27W.

Extensive field review of many of the mature stands and riparian areas within the watersheds suggest that early harvest seemed to be dominated by tractor skidding. Harvests after 1955 were accomplished with intensive tractor logging operations which removed half of the volume. These harvests mainly occurred away from the riparian areas.

4D.2.2.4 *Characteristics of Riparian Trees*

Riparian areas within Boiling Springs and Beatrice Creek are dominated by a strong deciduous cover along the bank with conifers set back over the top of deciduous trees. These deciduous trees average 3 to 4 inches in diameter. Murr Creek is dominated by conifer species near the banks. Tree species in the riparian areas are dominated by Douglas-fir, Engleman spruce, sub-alpine fir, western larch, alder and cottonwood. Riparian areas were generally stable with limited loss of trees due to natural processes of bank erosion or blowdown.

4D.2.2.5 *LWD in Intermittent Channels*

Large woody debris was not sampled in intermittent channels within the analysis watersheds. Most intermittent streams had minimal flow during the summer months. Only one stream mapped as intermittent was determined to be perennial through field surveys. It is located in Section 8, T26N, R27W of the Boiling Springs watershed and is associated with a small lake.

4D.2.2.6 *Hazard Calls*

LWD hazard calls for each channel segment are shown in Table 4D-4. Table 4D-5 summarizes the percentage of each watershed and GCU that had LWD hazard ratings of High, Medium, or Low. Overall most segments have a Medium LWD Hazard (79.6 %) with Low LWD Hazards (11.9 %) and High LWD Hazard (8.5 %) occurring in the remaining segments. The reason for the majority of the channel segments within the watersheds received a Medium LWD hazard rating is due to fact that only GCU 9 had a Low LWD Sensitivity Rating with rest of the GCU's having a Moderate or High sensitivity to LWD input.

Channel sensitivity ratings were determined collectively by the analysis team during synthesis. Resulting hazard calls for each segment are reported in Table 4D-3. Channel segments are depicted in Figure 4D-1a through 4D-1c (located at the end of this module report). High LWD hazard ratings generally coincided with gravel or cobble dominated sections that were very responsive to LWD inputs. This map was then adjusted to lower intermittent stream channels from moderate to low in areas where they joined perennial channels that had a Low LWD Hazard call. Intermittents that went sub-surface before connecting with perennial channels were also down graded to Low LWD hazard calls. Areas of Naturally Low LWD Recruitment were also mapped in all three watersheds. These areas were part of lake/meadow complexes in Boiling Springs, Glacial Talus Cirque basins in Beatrice, and Bedrock controlled canyons in Murr. All locations were observed to be the same in the 1955 aerial photos and appear to be naturally occurring areas.

Table 4D-5. Summary of riparian hazard calls for each watershed and geomorphic channel unit.

Location	Riparian Hazard Calls By Percentage of Stream Network		
	High	Medium	Low
Murr Creek	3	74	23
Beatrice Creek	9	91	1
Boiling Springs Creek	26	74	0
GCU 1	100	0	0
GCU 2	29	71	0
GCU 3	0	100	0
GCU 4	0	100	0
GCU 5	36	63	0
GCU 6	11	89	0
GCU 7	64	36	0
GCU 8	25	0	75
GCU 9	0	0	100
GCU 10	34	66	0
GCU 11	0	100	0
GCU 12	0	100	0

4D.2.3 CONFIDENCE

Confidence in mainstem LWD and riparian stand conditions is high. Many sites within the watershed analyses areas were sampled or walked through to verify photo-interpreted conditions. Confidence in tributary/intermittent streams is moderate due to the fewer field inspections that were conducted in these areas.

4D.2.4 DISCUSSION

Since 1991, Montana forest practices rules have required 50-100 foot Streamside Management Zones, with retention of at least 50% of the trees. Based on photo and field observations, riparian stands which have had timber harvesting subsequent to adoption of this law have maintained the recruitment potential of the pre-harvest stand. As such, it is believed that riparian stands that have been harvested since the adoption of these rules are providing adequate protection to stream. Some riparian harvests, especially in Murr Creek and Boiling Springs Creek, prior to passage of the law did not provide adequate protection. The only discrepancies that were noted between photo classification and field surveys were in conifer stands with trees in the medium and large size categories. This does not create a problem with the hazard ratings because they both have the same potential for providing LWD.

In a review of scientific literature to look at the effectiveness of Montana's SMZ law has shown that it will most likely meet the needs of healthy riparian area particularly in moderately confined to confined channel types (McGreer, 1994). Examples of these types can be seen in GCU's 6, 7, 8, 9, 10, and 11. The Montana SMZ law does not account well in moderately confined to unconfined channels. These are areas with channel migration zones that exceed standard buffer strips, which may leave the stream unprotected in the event the channel moves. GCU's 1, 2, 3 ,4, 5 and 12 are examples of these areas where LWD is important and potential for channel migration is high. Buffer strips within these GCU's need to take the CMZ into account when they are designed.

4D.2.4.1 *LWD Recruitment Processes*

The LWD debris recruitment processes in the analysis area are dominated by bank erosion, blowdown, and channel migration. In rare instances, small amounts of wood enter the system by landslides, avalanches and other mass wasting process. Even with this limited source of wood entering the system, the LWD levels within the channel segments are adequate. The main reasons for LWD levels being adequate are the presumably low decomposition rates of in-stream wood and the less active hydrologic system that does not routinely export wood out of the watershed. Areas with high LWD are associated with GCU's 2, and 4 these GCU's have also the highest incidences of channel migration.

4D.2.4.2 *Channel Migration Zones*

Channel migration zones in the watersheds are created by the power and the confinement of the stream. In a review of historic aerial photos there is little evidence of channel movement due to the high canopy closure and relatively small streams. The only areas that showed channel migration were in GCU 1 (Fans). This does not mean that channels are static and that potential movement will not occur. In areas with a wider CMZ, LWD plays a dominant role in the make up of the stream. LWD

acts as a filter, and helps to dissipate energy from the stream, but it also plays a significant role in causing stream channel migration and overflow channels. If properly implemented, the Montana SMZ law should provide for adequate future LWD in confined channel types. The law does not account for potential movement of the stream within the CMZ. Future harvests should consider the CMZ boundary when designing the SMZ to make sure and provide adequate long-term LWD for the stream. The analyst expected to see more sign of channel movement in Boiling Springs than was seen in the aerial photo's. During field surveys in Boiling Springs, the analyst noticed that the stream seemed to be under-fit to the basin (i.e. the stream was small relative to the watershed size). This muted hydrologic system may explain the lack of observable channel movement.

4D.2.4.3 *Characteristics of Riparian Stands*

The current riparian stands have the ability to supply needed LWD to the streams in the near term as well as into the future. Stand health and large scale disturbance (i.e., fire, blowdown) could increase immediate LWD and cause a long-term decline. Most riparian stands are dominated by mature trees with regeneration in areas with enough solar radiation reaching the ground.

The riparian stands along the mainstem riparian areas have the correct make-up of trees to supply needed wood to the channel. An assumption made by the analyst is that if the riparian stand average D.B.H. is bigger or equal to the average functional diameter of LWD in the stream than these stands have the potential to provide LWD of the right size for the stream. Based on field examinations of channel segments, the riparian areas seem to be able to provide sufficient numbers and sizes of large woody debris.

4D.3 SHADE HAZARD SECTION

4D.3.1 INTRODUCTION/METHODOLOGY

The objective in this part of the assessment is to answer the critical question:

> *What is the current degree of canopy closure provided by riparian vegetation relative to what is needed to maintain desirable stream temperatures?*

Maximum stream temperature occurs during the summer and is controlled by midday air temperature and exposure to solar radiation. Shading to the streams in Montana is provided by 0.5 and 0.7 of the site-potential tree height (McGreer, 1996). Given average riparian tree heights, shade can typically be provided up to 50-70 feet away from streams.

The guidelines used to determine shade impact in this analysis follow the procedures outlined in the

manual, except that an improved model (nomograph) developed from stream temperature data in Idaho and Montana is used to determine the minimum canopy requirements to achieve a maximum weekly temperature of 15° C (Plum Creek Timber Company, 1998). The preliminary regression used in the nomograph is as follows:

$$\text{Temperature } (^{\circ}C) = 27.43 - 0.00185(\text{Elevation}) - 0.10917(\text{Canopy}) \qquad (r^2 = 0.62)$$

The temperature model is still under development. A manuscript will be prepared with the final analysis in early 1998. Table 4D-6 shows the required canopy closure necessary to maintain maximum weekly stream temperatures at 15° C for different elevation bands along the channel network.

Aerial photo interpretation was used to estimate canopy closure along the channel network. These photo-interpretations were supplemented with field measurements which measured canopy closure with a concave spherical canopy densitometer.

Surveys were conducted in selected areas to quantify riparian shading. Data that was collected in the survey included, canopy closure and in-stream temperature. Data collection efforts were supplemented by fisheries habitat research that was being conducted in conjunction with the Watershed analyses by PCTC. Water temperature was measured using Onset Optic StowAway Temperature loggers. These thermistors were set to record the average temperature every 30 minutes. All thermographs were deployed by mid-July, after high water runoff.

Table 4D-6 Minimum canopy closure necessary to keep maximum weekly stream temperatures below 15°C at various elevations.

Elevation	Minimum shade required to maintain weekly max temperatures below 15°C
>6141	<10
5551-6141	10
4960-5551	20
4370-4960	30
3780-4370	40
3190-3780	50
2600-3190	60
2010-2600	70
1420-2010	80
<1420	90

4D.3.2 RESULTS

Figures 4D-2a through 4D-2c (located at the end of the module report) show the estimated canopy closure over the entire stream network along with actual densitometer reading where they were taken. Stream temperatures were monitored in 1997 in selected areas of the Watersheds (Table 4D-7 and Figures 4D-2a through 4D-2c.

Canopy closure in all measured sections met or exceed the Eastern Washington requirements in all but 2 channel segments based on aerial photo analysis. Only segments 472 in Murr and 315 in Boiling Springs Creek do not meet shade requirements of the Washington process. Both of these segments were also areas that were historically low in canopy closure from the 1955 photos.

Other Segments within Boiling Springs an Murr Creek did not meet the more stringent requirement of Plum Creek's model for the northern Rockies. These variances amounted to 11.9% of the perennial channels. The channel segment number, target shade, estimated canopy closure, actual shade and comparison of Plum Creek's model with the Washington model is shown in Table 4D-7. The shaded area in Table 4D-7 highlights the areas where the model requires more shade than the estimate.

Field verification of canopy cover estimates were made on approximately 50 percent of the perennial segments. In most cases, field measurements of canopy compared well with photo-interpreted estimates.

4D.3.2.1 *High Shade Impact Channel Segment 315 and 472*

Segment 315 located in Boiling Springs and Segment 472 in Murr are areas of naturally low shade based on the historic aerial photos. These areas do not seem to have changed significantly from 1955. The Murr Creek site is part of large alluvial fan where the stream frequently migrates, which results in brush being the dominant vegetation. The Boiling Springs sites are part of natural meadow complex that were also open in the 1995 photos. No Causal Mechanism Reports (CMR's) were written for these segments since they were part of naturally occurring low shade areas.

Table 4D-7. Comparison of Estimated , Actual Canopy Closure, and Required Canopy Closure by Washington andPreliminary PCTC models for the Watersheds by GMU and Segment.

Drainage	Segment	GMU	Segment Length (m	Estimate Canopy	Actual Canopy	Washington DEQ Standard 16°C	PCTC Nomograph All Data Average DI	Notes
Boiling Springs	250	1	221	70-90	83.6	50	50	
	333	1	942	70-90	66.9	40	40	
	289	2	1882	70-90	79.9	40	50	
	291	2	422	70-90		40	50	
	315	2	938	0-20	22.8	40	50	Historically Low
	328	3	1077	70-90		40	40	
	257	6	462	70-90	82.5	50	50	
	335	8	143	70-90		40	40	
	337	8	10	70-90		30	40	
	348	8	1039	70-90	90.1	20-30	40	
	350	8	109	>90		10	30	
	353	8	351	20-40		0-10	30	
	355	8	355	90		0-10	30	
	258	12	1609	70-90	8	30-50	40-50	
Murr	472	1	156	0-20		50	50	Historically Low
	344	2	1147	20-40	23.8	0-10	30	Harvest
	362	2	894	40-70	13.3	0-10	30	Harvest
	370	2	291	20-40		0-10	30	
	382	2	1158	20-40	28.86	0-10	30	
	384	2	137	20-40		0-10	40	
	387	2	146	20-40		0-10	40	
	410	2	1028	20-40	15.6	0-10	30	
	478	4	1581	40-70	40.7	50	50	Harvest
	513	4	861	70-90	70.3	0-10	30	
	458	5	661	40-70		30	40	
	475	5	1703	70-90	67.1	30-40	40	
	361	8	361	20-40		0-10	30	
	367	8	1464	40-70	69.5	0-10	30	
	379	8	552	70-90		0-10	30	
	389	8	2296	70-90	83.7	0-10	10-30	
	505	8	1842	70-90	85.3	0-10	20-30	
	515	8	334	40-70		0-10	20-30	
	524	8	595	40-70		0-10	20-30	
	574	8	4024	40-70		0-10	10-30	
	627	8	3504	40-70	52.1	0-10	10-30	
	632	8	83	40-70		0-10	10	
	446	9	1363	40-70	64.6	0-10	20-30	
	480	9	288	70-90	53.1	40	50	
	481	9	345	70-90		40	50	
	495	9	1643	40-70	49.9	10-20	40	
	497	9	290	40-70		10	30	
	501	9	613	40-70		0-10	30	
	508	9	793	40-70		0-10	30	
Beatrice	1660	4	605	70-90		40	50	
	1680	4	305	70-90		40	50	
	1700	4	305	70-90	74.9	40	50	
	1709	4	28	70-90		40	50	
	1759	4	725	70-90	69.3	40	50	
	1770	4	171	70-90		40	50	
	1772	4	77	70-90		40	40	
	1701	4	721	70-90	61.1	30	40	
	1641	5	1352	70-90	68.5/82.8*	50	50	
	1797	6	124	70-90		30	40	
	1800	6	353	70-90	73.1	30	40	
	1815	6	225	90		30	40	
	1820	6	508	70-90	72.2	20	40	
	1821	6	8	70-90		10	40	
	1849	6	926	70-90	76.7	10	30	
	1856	7	275	70-90		0-10	20-30	
	1883	7	2220	70-90	63.3	0-10	30	
	1896	7	231	70-90		0-10	10	
	1912	7	1086	70-90	49.3	0-10	20	
	1608	9	49	70-90		50	50	
	1754	10	495	70-90	79.9	40	40	
	1777	10	398	70-90		20	40	
	1788	10	321	70-90	89.2	20	40	

Shaded area shows where estimated or actual canopy closure is less than required by the models

Table 4D-8. Temperature Data from fixed recording sites in Boiling Springs, Murr and Beatrice Creeks in Thompson Valley 1997.

Temperature Location	Temperature (C)			Average Max Temperature (C)			Estimated Temperature PCTC Nonograph Average DI*	Elevation	Canopy Closure			
	Average	Min	Max	3 day	7 day	14 day			Actual Canopy Closure	Estimate	WA Required Canopy	PCTC Nonograph Average DI at 15°C*
Lower Boiling Springs	10.2	3.3	15.3	15.1	14.8	14.4	12.2	3360	82.8	(70-90)	50	56.9
Upper Boiling Springs	11.5	3.0	19.9	19.2	18.9	18.4	18.1	3720	22.8	(0-20)	40	50.8
Murr	9.7	3.5	14.5	14.2	14.0	13.5	15.4	3450	51.8	(70-90)**	50	55.4
Lower Beatrice	7.7	5.0	10.8	10.3	10.0	9.7	12.0	3430	83.6	(70-90)	50	55.7
Upper Beatrice	7.4	4.9	9.3	9.1	8.9	8.6	12.1	3990	73.1	(70-90)	30	46.2

* Preliminary Temperature Nomograph Development in Rockys by PCTC

** Based on Riparian Module definitions, but Analyst estimated at 60 % cover for area

4D.3.2.2 *High Shade Impact Channel Segments 344, 362, and 478*

Channel Segments 344, 362, and 478 are located in Murr Creek and were identified as having insufficient canopy cover. These segments are associated with harvested areas and naturally low areas of the Canyon area of Murr Creek. These segments did not meet the canopy closure requirements of PCTC temperature nomograph. However, measured water temperature s recorded within the fish bearing zone of Murr Creek did not exceed 15 ^{0} C.

4D.3.2.3 *Interpretation of Stream Temperature*

Five sites were sampled in the watershed analysis areas (Figures 4D-2a through 4D-2c). Summary data from these five sites is provided in Table 4D-8. The highest maximum temperature observed was 19.9°C at the upper Boiling Springs Creek site. The Murr and Beatrice Creek sites were below 15°C with two Boiling Springs Creek site exceeding 15°C. Due to heavy snow packs and late run off this year it was expected that stream temperatures would be below average. For the summer of 1997, the Plum Creek nomograph over-estimated actual temperature observed in Murr and Beatrice (as expected given the cool summer and high flows), but underestimated temperatures in Boiling Springs Creek. Other process seem to be occurring in Boiling Springs other than canopy and elevation in controlling temperature.

4D.3.3 CONFIDENCE

Confidence in the shade component is high. The canopy densitometer measurements agreed with the aerial photo interpretation of shade along surveyed stream reaches. More than 50% of the perirenal segments had field measurements conducted within them. Temperature monitoring within the watershed helped to determine temperature ranges within the Thompson Valley. Water temperature measurements helped to determine that temperature requirements are currently being maintained within desirable levels.

4D.3.4 INTERPRETATIONS OF TEMPERATURE

Monitoring within the watershed analyses area has not shown any significant temperature increases. This may be due to groundwater up-welling in Murr and Beatrice Creek. The data from these monitoring sites seem to be representative of other sites within Thompson Valley that have been monitored in the past.

4D.4 RIPARIAN FUNCTION BY GCU

Summarizing riparian zone function by GCU was developed as a way to expand and interpret areas

outside of the individual watersheds analyzed, to the watersheds within the Thompson River Basin. GCU's were developed by the channel analyst to group similar functioning channel segments within the basins.

4D.4.1 GCU 1: FANS

This a minor GCU within the watersheds. The GCU is characterized by Riparian Condition Calls of MSS, CSS, and CMD with High hazard calls due to LWD being off targets and its High sensitivity to LWD inputs. LWD functions mostly as single pieces and providing bank protection. Where LWD is present in large enough numbers it will function in pool formation. Required canopy in this area is 50-60% depending on elevation. The stream is prone drastic movements within its CMZ.

4D.4.2 GCU 2: FOREST / MEADOW COMPLEX

This GCU is characterized by Riparian Condition Calls of MSS, MSD, CSS, DSS and CMD with Moderate to High hazard calls due to moderate sensitivity to LWD inputs. LWD functions mostly as single pieces and in jams to provide habitat. Required canopy in this area is 30-60% depending on elevation.

4D.4.3 GCU 3: MEADOW POND COMPLEX

This GCU is characterized by Riparian Condition Calls of MSD with Moderate hazard calls because of moderate sensitivity to LWD inputs. Riparian zones are sensitive to the removal of trees due to the limited number of conifers present. Current riparian cover is import for providing bank stability and protection. Grasses, shrubs and deciduous trees are the dominant providers of bank stability and protection in this GCU. LWD functions mostly as single pieces and in jams to provide habitat, with beaver activity providing many of the pools (current/historic). Required canopy in this area is 50-60% depending on elevation.

4D.4.4 GCU 4: CONIFER FLOODPLAIN CMZ

This GCU is characterized by Riparian Condition calls of MMD and CMD with high recruitment potential with moderate hazard calls because of High sensitivity to LWD inputs. The channel is very prone to movement. LWD functions in jams and individual pieces creating pools, side channels and providing bank protection. Required canopy in this area is 50-60% depending on elevation.

4D.4.5 GCU 5: CONFINED MAINSTEM

This GCU is characterized by Riparian Condition Calls of MSD and CMD with moderate hazard

calls because of the moderate sensitivity to LWD. LWD functions in jams and single pieces to form pools or provide protection. Channel movement is found only in isolated areas in the GCU. Required canopy in this area is 50-60% depending on elevation.

4D.4.6 GCU 6: INCISED GLACIAL TILL

This GCU is characterized by Riparian Condition Calls of CMD with moderate hazard calls because of the High sensitivity to LWD. LWD functions in jams and single pieces to form pools or provide protection where large enough concentrations occur. Riparian trees function in bank stability and shade requirements. Required canopy in this area is 30-60% depending on elevation.

4D.4.7 GCU 7: ALPINE GLACIAL HEADWATER

This GCU is characterized by Riparian Condition Calls of CMD with moderate to high hazard calls because of the Moderate sensitivity to LWD and LWD being off target in some segments. LWD functions in jams and single pieces to form pools, or bank protection. Riparian trees function in bank stability and shade requirements. Required canopy in this area is 10-40% depending on elevation.

4D.4.8 GCU 8: PERENNIAL HEADWATER

This GCU is characterized by Riparian Condition Calls of CSS, CMS, MSD, and CMD with Low to High hazard calls because of the Low to Moderate sensitivity to LWD, and LWD being off target in some segments. Low Calls occurred in non-fish bearing waters. LWD functions in jams and single pieces secondarily too bed form to form pools. Riparian trees function in bank stability and shade requirements. Required canopy in this area is 10-40% depending on elevation.

4D.4.9 GCU 9: CANYONS AND CASCADES

This GCU is characterized by Riparian Condition Calls of CMS, and CMD with Low hazard calls because of the Low sensitivity to LWD. LWD functions in jams and single pieces secondarily too bed form to form pools. Riparian trees function in bank stability and shade requirements. Required canopy in this area is 10-40% depending on elevation.

4D.4.10 GCU 10: HEADWATERS

This GCU is characterized by Riparian Condition Calls of MSD, CMS and CMD with Medium to High hazard calls because of the High sensitivity to LWD. LWD functions in jams and single pieces and is the primary cause of pool formation. Riparian trees function in bank stability and shade requirements. Required canopy in this area is 40-50% depending on elevation.

4D.4.11 GCU 11: CONFINED INTERMITTENTS

This GCU is characterized by a variety of Riparian Condition Calls with Low to Medium hazard calls because of the Moderate sensitivity to LWD. LWD functions in jams and single pieces and is important in sediment trapping. Riparian trees function in bank stability and shade requirements. Required canopy in this area is 10-60% depending on elevation. Standard Forest Practices apply within these areas.

4D.4.12 GCU 12: UNCONFINED INTERMITTENTS

This GCU is characterized by a variety of Riparian Condition Calls with Low to Medium hazard calls because of the Moderate sensitivity to LWD. LWD functions in jams and single pieces and is important in sediment trapping. Riparian trees function in bank stability and shade requirements. Required canopy in this area is 10-60% depending on elevation. Standard Forest Practices apply within these areas.

4D.5 AREAS OF SPECIAL CONCERN

Standard practices will most likely be adequate within most of this watershed analysis area. The majority of riparian areas are relatively intact and functioning leaving Watersheds in a adequate condition. GCU's 2, and 4 are important for spawning bull trout, are highly sensitive to LWD inputs and have higher potential of channel movement. Harvest within these zones will probably require wider buffer strips that take into account the potential CMZ and the need for greater shade.

4D.6 MONITORING

Monitoring recommendations for the Thompson River.

1. LWD research to develop a better understanding of sizes and numbers of pieces in function riparian areas to better use the WFPB standards in Montana/Rocky Mountains.

2. Due to the higher than expected water temperatures in Boiling Springs Creek, it is felt that a small study should be undertaken to determine the full extent of the temperature plume. This could be accomplished by putting in a array of temperature probes to quantify temperatures along the length of Boiling Springs Creek.

3. Temperature should also be looked at in the upper Murr drainage in areas where harvest has significantly lowered canopy closure to determine if adverse temperatures exist.

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4E CHANNEL MODULE

4E.1 INTRODUCTION

This analysis of stream channel processes and conditions in the Thompson River watershed of northwestern Montana was conducted to identify stream reaches that are vulnerable to disturbance by forest management practices. The intent is to conserve aquatic habitat by mitigating or avoiding habitat degradation that could potentially result from natural resources management.

This analysis was guided by Version 3.0 of the Standard Methodology for Conducting Watershed Analysis (Washington Forest Practices Board, 1995). These techniques have been applied to three sub-watersheds in the Thompson River drainage (408,000 ac). The sub-watersheds were selected to represent the range of physical watershed attributes. Murr Creek covers about 19,900 ac in the northeast portion of the Thompson River, Boiling Springs Creek drains about 5,500 ac in the northwest, and Beatrice Creek covers about 6,400 ac and is located in the west central portion of the Thompson River watershed.

Ecological classification of the Thompson River was completed by Whitehorse Associates (1997). The classification provided data from resource maps and remote sensing sources pertaining to riparian vegetation, bedrock geology, glacial history, and valley bottom characteristics. Interpretation of these data provided initial hypotheses regarding channel characteristics and a means of selecting field survey locations.

In addition to the objectives of channel assessment for a standard watershed analysis described below, this assessment is intended to develop the data and interpretations necessary to extrapolate channel classification and channel vulnerability assessments to the Thompson River watershed as a whole. The ability to extrapolate channel classification based on intensive field observations (i.e. watershed analysis), and to evaluate the accuracy of extrapolations is critical to the economical design and implementation of aquatic conservation strategies. It is intended that the ecological classification (Whitehorse Associates, 1997) and the intensive field-based channel classification developed in this Level 2 watershed analysis serve as the basis for extrapolating channel classification and vulnerability assessments.

4E.1.1 WATERSHED ANALYSIS CRITICAL QUESTIONS

This analysis of stream channels is supplemented by the other modules of the methodology. The analysis of stream channels is closely associated with and supports the analysis of fish habitat. The assessment of stream channel conditions is intended to address the following questions posed in the Standard Methodology, Stream Channel Assessment (Washington Forest Practices Board, 1995):

-What is the spatial distribution of channel response types?

-Is there evidence of channel change from historic conditions?

-What do existing channel conditions indicate about past and present active geomorphic processes?

-What are the likely responses of channel reaches to potential changes in input factors?

-What are the dominant channel- and habitat-forming processes in different parts of the channel network?

The Standard Methodology provides protocols and forms that may be used to develop the data necessary to answer these questions. Those forms and techniques necessary to address the questions listed above were used; in many cases alternative forms or techniques were used. This approach did not reduce the level of confidence in the assessment necessary to guide the development of forest land use practices appropriate in this WAU.

The essential product of the stream channel assessment is a set of "geomorphic channel units-GCU's" (also referred to as "geomorphic map units-GMU's"). The GCU's are groups of stream segments with similar geomorphic characteristics and similar potential response to watershed inputs of sediment, large woody debris and water.

4E.1.2 HABITAT GUILD CLASSIFICATION

Channels in the Thompson River watershed were classified by the watershed assessment team on the basis of the ecological classification of the Thompson River watershed. These stream classes are referred to as guilds. A secondary goal of this assessment is to relate GCU's determined using the watershed analysis methodology to guilds in a manner that allows for extrapolating to streams that are not in the watershed analysis sub-basins.

The primary objective of field work for this project was to conduct watershed analysis according to the Washington methodology for Level 2 watershed analysis. Consequently, field surveys were guided more by the needs of the watershed analysis process than by the secondary priority of testing the accuracy of the guilds. Data analysis and channel classification is concerned primarily with the watershed analysis process as it applies to the three sub-basins.

Following the watershed analysis section of this report, an analysis of the relationship between habitat guilds and GCU's is presented.

4E.1.3 EVALUATION OF CHANNEL MIGRATION ZONES

Previous work on channel migration zones (CMZ's) and their influence on aquatic habitat (Swan Valley Watershed Analysis, 1996) suggested that these areas are likely to have relatively high aquatic habitat value. A provisional CMZ classification system was developed to assist in the recognition and management of these channel reaches (O'Connor, unpublished manuscript, see Appendix E-2). Field data, observations, and interpretation of CMZ's for each GCU in the Thompson will be analyzed in terms of the CMZ classification system as a test of its validity.

4E.2 OVERVIEW OF WATERSHED GEOMORPHOLOGY

In this section, major geomorphic influences and landscape characteristics are described for each of the three watersheds analyzed. In addition, the geomorphic channel units (GCU's) found in each watershed are identified with reference to major landforms. Selected characteristics of the GCU's are shown in Table 4E-1.

4E.2.1 BEATRICE CREEK

The headwaters of Beatrice Creek include some of the wettest areas in the Thompson River watershed, with annual precipitation up to 50 inches (Whitehorse Associates, 1997. This is reflected by the relatively high drainage density of Beatrice Creek, which is about 2.6 mi/mi^2 compared to 2.1 mi/mi^2 for the Thompson River watershed (Whitehorse Associates, 1997) and 1.7 mi/mi^2 for the watershed analysis basins (Table 4E-2).

The headwaters of Beatrice Creek contain alpine glacial cirques where snow accumulated to form glacial ice. The glacier in Beatrice Creek scoured rock from the cirque and deposited the debris in moraines extending downstream about half the length of the watershed. The moraines form an aquifer that is drained by perennial streams (GCU 6- Incised Glacial Till and GCU 7-Alpine Glacial Headwater; see Figure 4E-1a) throughout the year. This source of cold water is a critical habitat factor for bull trout (*Salvelinus confluentus*).

Based on field evidence of moraine deposits, the glacier probably did not extend far beyond the confluence with a perennial tributary on the north bank about halfway down the watershed. This location also roughly coincides with the 4,200 ft elevation contour that marks the height of glacial Lake Missoula. The glacier may have at times blocked the mouth of the north bank tributary, causing deposits to accumulate in that valley. Alternatively, or in combination with glacier blockage, the deposits may have been caused by the shoreline of Lake Missoula. These circumstances are responsible for an unusual perennial channel type, GCU 10-Headwater in Valley Fill.

The remainder of Beatrice Creek downstream of the confluence with the perennial north bank stream

is likely fluvio-glacial outwash that has been reworked by the stream over the past 10,000 plus years. This reach provides significant bull trout habitat, and is primarily GCU 4-Conifer Floodplain CMZ, with GCU 5-Confined Mainstem in the lower mile. Tributaries in the lower half of the basin are confined intermittent streams (GCU 11) which drain relatively long, moderately steep, forested mountain hillslopes mantled with residual soils formed in Belt series bedrock.

At its confluence with Fishtrap Creek, Beatrice Creek drops over a short valley side wall (GCU 9) that was probably created by glacial or fluvio-glacial erosion of the Fish Trap Creek valley.

4E.2.2 BOILING SPRINGS CREEK

This watershed receives between 25 and 30 inches of precipitation annually (Whitehorse Associates, 1997), which is typical for most of the Thompson River watershed. The drainage density for Boiling Springs Creek is comparable to the basin-wide average, 1.9 mi/mi^2 and 2.1 mi/mi^2, respectively. Perennial channel density is about 0.6 mi/mi^2, somewhat lower than that for the Thompson River watershed average of 0.7 mi/mi^2.

The headwaters of Boiling Springs Creek were overridden by continental glacial ice (Whitehorese Associates, 1997), however, deposits were relatively shallow. On many slopes, soils appear to be a mixture of residual soils and glacial soils. Streams draining headwater areas are unconfined intermittents (GCU 12; see Figure 4E-1b). Many of these intermittent streams are not connected by surface flow with the perennial channel network. These channels lose flow to flat-lying glacial deposits in the generally broad valleys. A single reach of GCU 8-Perennial Headwater delivers surface flow to the valley bottom. At the gradual transition from mountain slope to valley bottom, the stream diminishes in slope and becomes GCU 1-Alluvial Fan.

The broad valley bottoms in the lower two-thirds of the watershed contain ponds, small lakes, open forest stands, meadows and wetlands. GCU 2-Forest/Meadow Complex, occupies gently-sloping portions of the valley where stream channels meander through alternating bands of meadow and forest vegetation. These valleys are filled with glacial and fluvio-glacial sediment, including significant fine-grained lacustrine deposits that seal the bottoms of lakes and ponds. The flattest, wettest of these areas are traversed by channels in GCU 3-Meadow/Pond Complex.

At the mouth of Boiling Springs Creek, the channel is GCU 6-Incised Glacial Till, where the stream, probably augmented by glacial meltwater, cut through glacial till deposits to reach the base level of Thompson Lake. At the bottom of this short canyon, an alluvial fan was built. Although active alluvial fan processes were probably associated primarily with the period immediately following the retreat of glacial ice, this lowest reach of Boiling Springs Creek is classified as GCU 1 (Alluvial Fan).

Table 4E-1. Selected Geomorphic Charnel Unit (GCU) characteristics for Thompson River Watershed Analysis sub-basins.

GCU	# of Field Sites (& Fish Sites)	Morphology (Montgomery & Buffington, 1997)	Slope (%)	Bankful Width (m/ft)	Bankfull Depth (m/ft)	Entrenchment Ratio (Rosgen, 1994)	Width / Depth Ratio	Avg. Adjacent Hillslope (%)	LWD Load	Stream Power Index (Slope* BD*100)	d50 (mm/in)
1- Alluvial Fans	2	Forced pool riffle, step pool & plane bed	3.8	2.6 (8.5)	0.4 (1.3)	2.7	6.8	28	Low-Moderate	1.4	61 (2.4)
2-Forest / Meadow Complex	6	Forced pool riffle & plane bed	2.3	4.5 (15)	0.5 (1.6)	4.5	11	29	Low meadows, Mod-High forest	1.1	45 (1.8)
3-Meadow / Pond Complex	1	Pool-riffle	0.7	3.7 (12)	0.4 (1.3)	6.5	8.7	0	Low except beaver	0.3	24 (0.9)
4-Conifer Floodplain CMZ	6	Forced pool riffle & plane bed	2.7	8.1 (27)	0.6 (2.0)	3.2	14	67	Mod.- High	1.4	80 (3.1)
5-Confined Mainstem	3	Plane bed & forced pool riffle	2.8	8.0 (26)	0.6 (2.0)	1.9	15	71	Low-Moderate	1.5	82 (3.2)
6-Incised Glacial Till	4	Step pool	8.4	3.5 (11)	0.5 (1.6)	2.3	7.7	47	Moderate	3.7	85 (3.3)
7-Alpine Glacial Headwater	1	Cascade & step pool	19	3.3 (11)	0.3 (1.0)	1.6	10	93	Moderate	6.2	83 (3.2)
8-Perennial Headwater	5	Step pool & cascade or forced pool riffle	7.9	3.1 (10)	0.3 (1.0)	3.4	8.6	30	Mod. -High	2.5	84 (3.3)
9-Canyons & Cascades	1	Cascade & step pool	10	8.5 (28)	0.6 (2.0)	1.4	14	100	Low-Mod.	6.0	250 (10)
10-Headwater in Valley Fill	4	Step pool	8.1	2.6 (8.5)	0.3 (1.0)	2.1	9.4	43	Mod.-High	2.2	49 (1.9)
11-Confined Intermittent	4	Step pool & cascade	22	1.1 (3.6)	0.2 (0.7)	2.7	4.5	55	Moderate	4.8	64 (2.5)
12-Unconfined Intermittent	5	Step pool & cascade	9.5	1.7 (5.6)	0.3 (1.0)	23	7.6	8	Moderate	2.1	50 (1.9)

Table 4E-2. Drainage density data for the study area. Data for the Thompson River watershed is from Whitehorse Associates (1997). Areas for watershed analysis basins was determined from topographic maps generated from digital elevation data by Plum Creek Timber Company. Channel length data were also provided by Plum Creek.

Watershed	Area (mi2)	Length of perennial Streams (mi)	Length of intermittent streams (mi)	Drainage Density (mi/mi^2)	Perennial Stream Drainage Density (mi/mi^2)
Beatrice	10.00	7.15	18.84	2.60	0.72
Boiling Springs	8.60	5.11	10.80	1.85	0.59
Murr	31.90	21.23	24.82	1.44	0.67
Total	50.50	33.50	54.50	1.74	0.66
Thompson River Basin	636.00	417.00	909.00	2.10	0.70

4E.2.3 MURR CREEK

This watershed receives between 25 and 35 inches of precipitation annually (Whitehorse Associates, 1997), which is slightly wetter than average for the Thompson River watershed. The drainage density for Murr Creek is substantially lower than the basin-wide average, 1.4 mi/mi^2 and 2.1 mi/mi^2, respectively. Perennial channel density is about 0.6 mi/mi^2, somewhat lower than that for the Thompson River watershed average of 0.7 mi/mi^2 (Whitehorse Associates, 1997). The low drainage density is attributable to intermittent channel density of about half that for the Thompson River watershed as a whole. The low drainage density in Murr Creek may represent data limitations regarding the location and length of intermittent channels, or it may reflect a significant hydrogeologic characteristic of the watershed.

Murr Creek differs from Beatrice and Boiling Springs Creeks in that it has few if any glacial deposits above the lower mile of the watershed. Hillslopes are mantled with shallow residual soils. Glacial till or moraines were not observed in the Murr Creek watershed above the lower mile as the stream drops into the Thompson River valley. Glacial ice may well have spilled over the ridge to the north and occupied the headwaters of the North Fork Murr Creek and produced glacial runoff, as suggested by Whitehorse Associates (1997), but no significant glacial or fluvio-glacial deposits were observed.

Both Confined and Unconfined Intermittents (GCU's 11 and 12; see Figure 4E-1c), drain the hillslopes in the upper valleys. Perennial Headwaters (GCU 8) drain some of the same valleys, and have well-developed valley bottoms despite their relatively steep slope. The mainstem of North Fork Murr Creek lies in a relatively broad valley, and flows through a system of meadows and riparian forest stands (GCU 2) until it drops abruptly into the canyon of the North Fork (GCU 9). This drop off lies near the 4200 ft contour, suggesting the possibility that the apparently fluvial deposits in the valley bottom meadows of the North Fork may be related to the fluctuating level of Lake Missoula that created a base level high in the watershed.

The unnamed south fork of Murr Creek also flows through a spectacular 2 mile long canyon (GCU 9). At the head of this canyon, far removed from known fish populations, lies a reach of relatively low-gradient mainstem channel with a well-developed floodplain (GCU 4). A long, relatively low-gradient, but confined reach of mainstem Murr Creek (GCU 5) and a shorter canyon reach form the transition from the headwaters and canyons to the Thompson River valley. Another set of transitions occur at the level of the valley as the confinement of Murr Creek relaxes. The final canyon reach (GCU 9) abruptly gives way to a moderately sloping confined reach (GCU 5), which becomes a reach characterized by channel migration processes (GCU 4) where the valley of Murr Creek widens and significant deposits of coarse sediment are found. This reach becomes the alluvial fan of Murr Creek (GCU 1) where the channel crosses the valley floor terrace of the Thompson River.

4E.3 CURRENT CHANNEL CONDITIONS-GCU DESCRIPTIONS

4E.3.1 METHODS

Stream channel surveys were conducted specifically for this module at 42 sites in the WAU. The locations of sample sites are displayed in Figure 4E-1a, b and c (located at the end of the module report) for the Beatrice, Boiling Springs, and Murr Creek watersheds, respectively. These data were supplemented by survey data collected at another 30 sites by the fish habitat and riparian function assessment team. Their field data included basic channel geometry and morphology data which could be used to extrapolate GCU classifications to segments not visited or surveyed by the stream channel assessment team.

Selection criteria for field survey sites included accessibility, and the need to see a representative sample of channel types and conditions. Larger perennial channels were given preference because of higher fish use, and because many smaller channels are intermittent or ephemeral.

Field surveys were conducted using a form based on the recommendations of the Standard Method, modified for convenience without losing detail required to answer critical questions of the assessment. The data in Table 4E-3 were collected according to the descriptions and criteria set forth in the survey protocol in the Appendix. The protocol provides information necessary to understand some

of the coded data and measurement techniques.

The "diagnosis" of channel conditions and the basis for GCU's classification are the data in Table 4E-3, riparian and fish habitat data, watershed geomorphic conditions as reflected in topography and historic aerial photographs, and prior classification work (Whitehorse Associates, 1997). The rationale and justification for delineation of GCU's are provided in narrative form in the GCU descriptions in the following section.

Channel sensitivity to watershed inputs (coarse sediment, fine sediment, peak flows, LWD and catastrophic mass wasting events as per the Washington methodology), and channel sensitivity to supplementary riparian characteristics included in this watershed analysis (riparian vegetation and channel migration zones), is summarized in Table 4E-4.

4E.3.2 GEOMORPHIC CHANNEL UNITS (GCU'S)

The 12 GCU's defined for the Murr, Boiling Springs and Beatrice Creek watersheds are described in the following section. A description of the defining characteristics of each GCU is accompanied by summary observations and interpretations of channel conditions and processes. Conditions and processes are described for three elements and scales of channel morphology: the sediment grains comprising the stream bed, morphological features at the reach scale, and floodplain/hillslope interactions at the reach scale. The GCU description concludes with a table summarizing the sensitivity of each GCU to watershed inputs of coarse sediment, fine sediment, peak flows, and large woody debris (LWD), and the significance of catastrophic watershed events, riparian vegetation, and channel migration to channel condition. A brief statement regarding the level of confidence associated with the delineation and assessment of sensitivities for each GCU is also presented. Figures 4E-1a, b & c display the locations of GCU's in the channel network and the sites surveyed by the channel assessment team. Table 4E-5 summarizes the length of channels in the various GCU's for the three analysis areas combined.

Stream gradient (slope) is a major predictor of channel morphology and, consequently, habitat potential and channel sensitivity to changes in watershed processes potentially caused by management activities (e.g. Montgomery and Buffington, 1997). In the three watershed analyzed, GCU's 1 through 5 (refer to Table 4E-1) have low stream gradients (< 4% on average), while GCU's 6 through 12 have high stream gradients (> 4% on average). Actual and potential fish habitat is significantly greater in the low-gradient group compared to the high-gradient group. The former group comprises about 14% of all channels, while the latter accounts for the remaining 86%. In the GCU descriptions below, some characteristics of streams are described in relation to the range of conditions observed in the "lower-gradient GCU's" or the "higher-gradient GCU's". These groupings will be useful when considering how Level 2 watershed analysis channel classification can be integrated with guilds developed through primarily remote sensing techniques.

Table 4E-3. Summary inventory data for stream channel assessment. Refer to Appendix for explanation of abbreviations and techniques.

Site	Seg. ID	VBT	CO	Guild	Sq mi	Sq km	SLS Slope	Field Slop	SPI	Unit SPI	Hillslope L	Hillslope	VW	FPW	BW	Ent Ratio	BD	W/D Ratio	T1	T2	T3	Roughnes	Floodplain	Bank Eros	SSMW	Disturbanc	Riparian L	Riparian R	Bedrock/P	LWD	Bars	D50visual	D50(mm)	D84(mm)	Rough Ht	Fine Sed	Morpholog	Length (m)
GMU 1																																						
B33	333	1410		1 1(G)	2.94	6.70	0.4	3.5	2.8	1.2	33	0		7.7	2.1	3.7	0.35	6.0	0.36	1.2		B/F,V	Dsd	SS	N	L	DSS/D	DSS/D	M-ex.zien	SFR	CF	17	53		15	MP	FPR/SP/P	80
B39	350	1410		1 1(G)	9.41	22.37	3.7	4	4.8	1.6	65			9.2	3	1.7	0.4	7.5	0.4	0.8	1.5	B/V,W	Cd	SS	N	L	CMD	CMD	N	SFA	FP	34	59		20	MP/B	SP/PB	80
Mean					6.1	14.6	4.6	3.8	3.7	1.4	49	0		8.5	2.6	2.7	0.4	6.8	0.4	1.0	1.5											26	61		17			
GMU 2																																						
M4	410	1130		2 1(G)	16.65	30.68	0.7	3.6	8.5	1.4	45	45	90	30	6.8	5.2	0.58	10.1	0.8			F/B,W	Cs	CS	N	Prior beav	meadow	meadow	N	S/CM/FA/	CF/P	19	47	178		SP	FPR/PB	128
M5	344	1130		1 1(G)	6.06	14.36	1.6	3.6	5.1	1.5	23	40		19	3.2	5.7	0.66	4.9	0.9			B/V,W	Cs	SS	N	L	MSS	MSS	M/patty br	C/V,FR	FP	20	36	130		SP/H	FPR/PB	128
M8	370	1130		2 E	13.38	31.82	2	2.8	8.4	1.4	48	40	60	17	6.1	2.8	0.48	12.7	0.5	1		B/V,W	Cs	SS	N	N	CMD	CM/SD	M	AFA	FPR	15	59	250		SP	FPR/PB	150
B56	315	1410		1 1(G)	6.59	15.67	1.1	1.6	1.5	0.6	19	0		19	3.4	5.1	0.3	11.4	0.4	3.7		B/C/F/V,	Cds	SS	N	L	CS/MS	CS/MS	M-ex.ziey	SFR	FP	10	30	225	3	MAP/B	PR/PB	160
B58	291	1320		1 N	7.12	16.93	2.9	3	5.1	1.1	65	40	25	11	4.9	2.3	0.38	19.9	0.5	3.8		B/F,B/V,W	Cds	SS	N	N	CMD	CMD	N	CFA	CF	14	59		14	MP/B	FPR	150
B57	299	1320		1 N	8.08	19.19	2	1.2	1.7	0.4	3	0		25.9	2.9	9.2	0.28	19.1	2.48	3.8		F/B/V,W	Cds	SS	N	L	CMS	MSS	N	S/CFA	CF	18	31			MP/B	PR/FPR	100
Mean					9.8	22.8	1.7	2.3	5.8	1.1	31	28	57.7	19.8	4.5	4.5	0.3	13.3	0.8	3.8												16	45	196	11			
St.Dev.					4.3	10.3	0.8	0.7	3.0	0.6	26	21	33.6	6.5	1.3	1.8	0.1	3.1	3.2	3.1												3	10	53	4			
GMU 3																																						
B3c	328	1410		1 1(G)	4.38	10.37	1	0.7	1.8	0.3	3	0		24	3.7	6.5	0.43	8.7	0.45	3.8	1.5	B/V	Cds	CS	N	N	meadow	meadow	M-ex.zley	SM/FA	FP	18	31	335		MAP/B	FR/PB	100
GMU 4																																						
M9	478	1420		2 T	34.29	81.45	3.7	1.2	7.8	0.6	83	80		55	10	5.5	0.66	15.6	2.85	1.5		W/P	Cds	CS/M	S/CM	N	CS/MS/D	MS/D	C/banked	C/A/V/DA	AF/M	61	64			SP/B	SP/FPR/P	220
M15	515	1220		2 J	8.30	19.75	3.3	4	7.5	1.6	55	55		14	4.8	3.1	0.4	11.4	3.6	0.95		B/C,W/V	Csd	SS	N	N	CMD	CS/MD	C/patty bed	CFA	FICF	17	83	140	15	SP/B	FPR/PB	50+
M17	478	1420		2 T	34.66	82.41	3.7	2	23.1	1.4	100	66	58	62	17	3.8	0.7	23.8	3.8			F/V	Cds	C/AS	N	N	DSD/CMD	DSD/CMD	N	SFA	AM	28	54		12	SP/B	FPR/PB	50+
B7	1779	1120		2 G	7.47	17.76	7.3	3.5	11.1	1.6	36	70	35	15	6.5	5.4	5.6	13.7	0.55	1.1		C,B/V,W	Cs/D	SS	N	Rd	CMD	CMD	N	CFA	C/A/F/A	14	82		18	SAM/B	FPR/PB	133
B10	1706	1120		2 1(G)	9.78	23.20	0.6	2.5	8.5	1.5		46		21	6.5	3.3	2.6	13.6	1			W/P,V	Cds	CS	N	L,Rd	CMS	CMD	N	C/A/V/DA	AF/M	17	80		14	AP/B	FPR	100
B11	1660	1220		2 J	10.37	24.66	3.5	3	7.4	1.6		69		16	4.7	3.5	0.55	9.8	0.45	0.65		C/F/V/P	Cd	SS	N	N	CMD	CMD	N	SFA	CF/A	18	30		13	MP/B	FPR/PB	100
Mean					17.5	41.5	3.3	3.7	15.8	1.4	68	67	52	28.8	8.1	3.2	6.6	13.8	8.7	1.1												28	58		15			
St.Dev.					13.2	31.4	2.9	1.0	6.1	0.3	28	15	25	18.8	4.6	0.4	0.1	5.3	0.2	0.2												18	14		2			
GMU 5																																						
M10	478	1420		2 T	54.34	81.40	3.7	2.7	15.4	1.9	80	69		12	8.2	1.4	0.7	11.8	0.60			C,W,F	Cd	CS/M	N	N	CMD	CMS/D	C/banked	A/C/FA	FP	19	84	297	15	SP/B	PS/FPR	260
M16	476	1220		2 J	33.09	78.67	2.4	3.8	12.5	1.6	80	35		18	6.8	2.3	0.66	15.6	0.5	0.96		B,F	Cd	SM	N	N	CS/MD	CS/MD	M	DM/A	FI	27	91		19	SP	PB/SP	125
B12	1641	1220		2 J	10.86	25.70	2.8	3	10.1	1.1	75			16	4	2.1	0.38	24.0	0.45			C/F/W/V	Cds	CS	N	Rd	DSD	CMD	N	CFA	AM/F	21	73		13	MP/B	FPR/PB	90
Mean					28.1	62.0	3.0	2.8	12.7	1.6	77	52		15.3	6.0	1.9	0.6	15.4	0.5	1.0												22	82		15			
St.Dev.					13.2	31.3	0.7	0.2	2.6	0.4	8	37		3.8	1.1	0.6	0.2	7.5	0.3													4	9		3			
GMU 6																																						
B8	1816	1120		2 1(G)	4.34	10.55	5.1	5.7	17.3	4.9	38	39		8.8	3.8	1.8	0.55	7.2	0.8			B/F,W,V	C	SS	N	L	CMS	CMD	M	CFA	CF	39	95		36	SP	SP/C	100
B6	1800	1120		2 1(G)	1.95	4.63	10.8	12	11.9	4.5	25	25		5.4	2.5	2.2	0.38	6.5	0.8			B/B/F,W	D	C/AS	N	L	CMS	CMD	N	CFA	CF	17	86			MP	SP/C	80
B9	1848	1120		2 1(G?)	3.50	8.31	9.2	6.5	12.8	2.9	35	45		15	4.5	3.3	0.46	10.0	0.7	1.4	5	B,F/W	Cs	S/CS	N	N	CMS	CMD	N	C/A/FA	CF	21	85		19	SP	SP/FPR/P	90
B20	357	1320		1 N	9.27	22.05	7.5	6.8	8.7	3.0	75	100	14	6.7	3.2	1.8	0.46	7.1	0.53	1.8		B,B/V	Dd	SS	SL	L	DSD	DSD	N	SFA	FPR	20	74		31	SP	SP/C	110
Mean					4.8	11.3	8.0	8.4	12.7	3.7	43	51	14.0	9.2	3.5	2.3	0.5	7.7	0.7	1.6	5.0											24	85		29			
St.Dev.					2.2	7.5	1.4	2.8	3.3	0.9	22	33		4.8	0.9	0.7	0.1	1.6	0.1	0.3												8	9		8			
GMU 7																																						
B2	1665	1110		1 A	0.78	1.95	14.5	15	23.8	6.2	58	88	8.2	5.4	3.3	1.6	0.55	10.0	0.8			B/F,W	D	SS	N	NL	CMS/D	CMS/D	M	CFA	CF	30	83		17	SP	C/SP	100
GMU 8																																						
M1	574	1210		1 H	2.88	6.80	4.5	5.0	8.8	2.4	33	50		13	3.7	3.5	0.48	7.7	0.66			W/V/Bk	Cs	SS	N	L	CSS	CSD	N	C/A/FA	FF	16	36	190		SP/H	SP/FPR,P	110
M7	351	1130		1 1(G)	3.78	9.00	4.9	5	11.8	3.0	15	10		15	0.8	2.9	0.4	14.9	0.40	0.8		V/B/W/C	Cs	SS	N	L	CMS/D	MSS	C/patty bed	CFA	FF		110	100		SP/H	SP/FPR	100
M13	389	1210		1 H	1.39	3.31	12.9	13	7.2	3.1	68	69	22	6.7	2.3	2.9	0.26	9.2	0.3	0.8		B/C,W,V	Ds	CS	N	L	CSD	CSS	C	C/A/FA	FF	18	158		22	N	C/SP	75
M14	505	1220		1 I	1.60	3.80	5.4	9	7.4	2.8	23	30	15	13	2.8	4.7	0.35	7.3	0.3			B/C,V/W	Cs	CS	N	N	CMD	CMD	C/patty bed	CFA	FF	22	91		16	SP	C/SP	106
BX2	348	1320		1 1(B)	1.28	3.01	9.7	12	7.4	3.2	45	45	18	5.5	2.4	2.3	0.28	8.8	0.58	1.1	1.8	B,F	Cds	SS	N	L	CMS/D	CMS	N	S/CFA	FF	17	81		16	SP	C/SP	80
BQ1	353	1310		1 1(L)	0.50	1.19	10.7	8	1.8	2.0	15	15		3.3	3.8	3.5	0.22	4.3	0.33	3.53	1.8	B/C,V,W	Cs	SS	N	L	MSS	MSD	N	SFR	FF	17	49			SP	SP	120
Mean					1.9	4.5	8.0	8.6	7.4	2.8	33	34	18.7	9.2	3.8	3.2	0.3	8.8	0.5	0.8	1.8											18	84	158	18			
St.Dev.					1.2	2.8	3.6	3.2	3.2	0.5	17	19	3.1	4.7	1.7	0.8	0.1	3.3	0.1	0.2												2	46	11	4			
GMU 9																																						
M12	481	1420		2 1(T)	33.45	79.64	9.0	10	51.8	6.0	150	100		15	8.5	1.4	0.8	14.3				B/Bk	N	SS	SL	N	CSS	CSS	A	C/A/AA	FP	38	303		40	H	C/SP	125
GMU 10																																						
B3	1764	1210		1 H	0.84	2.00	10.6	8	4.7	2.1	73	20	34	6.3	2.2	2.8	0.27	8.3	3.55	0.8		Bk/W/C,W	Cs	SS	N	L	MSD	MSD	N	CFR	C/AF	12	45			M/SP/B	SP/PB/FP	80
B4	1777	1210		1 H	1.09	2.66	5.6	8.6	4.7	1.6	73	20		4.5	2.5	1.6	0.26	11.6	0.4			C/V/W	Cs	SS	N	L	MSS	MSS	N	CFR/A	CF	19	53			MP/B	SP/FPR/P	60
B8	1708	1210		2 1(G)	1.78	4.18	7.8	9.3	5.3	1.5	40	35	13	4.8	2.8	1.7	0.3	9.1	0.8	1.5		W/Bk,C/F	D	C/AS	N	L	MS/MD	CSD	N	C/A/FDR	CF	23	51		13	SAM/B	SP/FPR/P	82
Mean					1.2	3.0	8.7	8.6	4.9	1.6	69	25	23.4	5.2	2.5	2.0	0.3	9.7	0.8	1.2												18	49		13			
St.Dev.					0.5	1.1	4.0	0.6	3.4	0.3	17	8	15.0	1.0	0.4	0.7	0.0	1.7	0.2	0.6												8	6					
GMU 11																																						
M3	INT			INT	0.64	1.63		15	5.8	4.6	15	46		5.3	1.3	4.0	0.30	4.3	0.4	0.65		C/Bk,V/W	Cs	SS	N	L	CMD	CMD	C/patty bed	CFA	FP	13	77	268		SP	SP/C	100
M11	INT			INT	0.67	1.38		21	7.8	5.3	75	80		3.1	1.6	1.4	0.25	6.0	0.4			B/W,F	Cd	CS	N	L	CSS	CSS	N	CFA	CF	8	48	133		AB	SP/C	58
B13	INT			INT	0.48	1.14		20	5.5	5.0					1.1		0.25	4.4												CFA		14	68				C/SP	
Mean					0.6	1.3		18.7	6.4	4.9	42.5	67.5		3.7	1.3	2.7	0.3	4.9	0.4	0.7												12	64	193				
St.Dev.					0.09	0.2		3.3	1.3	0.4	35.8	31.8		2.2	0.2	1.9	0.0	0.8	0.0													3	16	92				
GMU 12																																						
M2	INT			INT	0.81	2.18		3.5	2.7	1.8	15	15		66	1.4	47.1	0.36	6.0	0.8	0.8		V/B/W	Cs	SS	N	N	CS/MD	CS/MD	N	AD/FA	FP	23	23	190		SP/H	SP/FPR	60
M6	INT			INT	1.40	3.34		5	3.8	2.0	13	10		7.8	1.5	5.2	3.4	3.8	0.5			V/Bk,W	Cs	SS	N	L	HSD/CSS	HSD/CSS	N	SFR	FP	15	47	115		SP	PB/SP	32
B1	INT			INT	0.20	0.48		15	3.8	3.0	3	0		20	1.2	16.7	3.2	9.0	0.3			V/W/C	Csd	SS	N	L	CSS/D	CSS/D	N	CF/DR	CF	10	87			SP	C/SP	30
B14	INT			INT	0.34	0.66		7	4.9	1.4					3.5		3.2	17.9												CFA		20					C/SP	
BX10	INT			INT	0.07	0.16		30	2.3	4.6					0.8		0.15	3.5												CP		17	56				COL	
BX11	INT			INT	0.13	0.30		15	2.3	2.2					1		0.15	8.7												SM		19	57				COL	
Mean					0.5	1.2		12.6	3.1	2.5	8	8		31.3	1.6	23.0	1.2	6.8	0.5	0.8												17	54	153				
St.Dev.					0.5	1.3		9.6	1.0	1.1	8	0		30.7	1.0	21.7	3.1	5.4	0.2													5	17	53				

Table 4E-4. Physical sensitivity of GCU's to watershed inputs and other riparian factors in Thompson River watershed analysis sub-basins. Initial physical sensitivity ratings are modified as warranted when ecological criteria supersede physical criteria or when a borderline physical sensitivity is present.(e.g. low-moderate); these are indicated by bold italics.

GCU	Coarse Sediment	Fine Sediment	Peak Flows	LWD	Catastrophic Events	Riparian Vegetation	Channel Migration Zones
1- Alluvial Fans	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Low-Moderate *Moderate*
2-Forest / Meadow Complex	Moderate	Low-Moderate *Moderate*	Moderate	Moderate-High *Moderate*	Moderate	High	Moderate
3-Meadow / Pond Complex	Low	Moderate	Low	Low-Moderate *Moderate*	Low	High	Low-Moderate *Low*
4-Conifer Floodplain CMZ	Moderate *High*	Low-Moderate *Moderate*	Moderate	High	Moderate	High	High
5-Confined Mainstem	Low	Low	Low	Moderate	Low	Moderate	Low-Moderate *Moderate*
6-Incised Glacial Till	Low	Low	Low	Low-Moderate *Moderate*	Low-Moderate *Low*	Low-Moderate *Moderate*	Low-Moderate *Moderate*
7-Alpine Glacial Headwater	Low	Low	Low-Moderate *Low*	Moderate	Low-Moderate *Low*	Low-Moderate *Moderate*	Low

Table 4E-4. (Continued)

8-Perennial Headwater	Low	Low	Low-Moderate *Low*	Moderate	Low	Low-Moderate *Moderate*	Moderate
9-Canyons & Cascades	Low	Low	Low	Low	Low	Low	Low
10-Headwater in Valley Fill	Moderate	Low-Moderate *Moderate*	Low-Moderate *Moderate*	Moderate-High *High*	Low	Moderate	Moderate
11-Confined Intermittent	Moderate	Low	Low-Moderate *Low*	Moderate	Low	Moderate	Low
12-Unconfined Intermittent	Low	Low	Low	Low-Moderate *Moderate*	Low	Moderate	Low

Table 4E-5. Summary of channel length for each GCU in the watershed analysis sub-basins of the Thompson River. The percentage of total channel length ("All Channels") is given along with the percentage of perennial channels. Channels mapped as intermittent account for over 60 percent of stream length.

Geomorphic Channel Unit	Channel Length (mi)	Channel Length (km)	% of All Channels	% of Perennial Channels
1	0.7	1.1	0.8	2.1
2	5.2	8.4	5.9	15.6
3	0.8	1.3	0.9	2.4
4	2.9	4.7	3.3	8.7
5	2.6	4.2	3.0	7.8
6	1.6	2.6	1.8	4.8
7	2.4	3.9	2.7	7.2
8	13.1	21.1	14.9	39.2
9	3.3	5.3	3.8	9.9
10	0.8	1.3	0.9	2.4
11	24.9	40.1	28.3	
12	29.6	47.6	33.7	
Total	87.9	141.4	100	100

4E.3.2.1 *GCU 1: Alluvial Fans*

This GCU is comprised of three stream segments located at the mouths of Murr Creek and Boiling Springs Creek, and above a meadow in upper Boiling Springs Creek. It contains 0.8% of channel length in the study area, and 2.1% of perennial channel length. Segments in this GCU lie at the junction of streams with lakes, meadows and valley bottom where channel gradient declines. Channels are incised in alluvium that has been deposited in the fan. The heads of fan segments are typically entrenched because of changes in climate and watershed hydrology associated with the retreat of glaciers about 15,000 years ago. Portions of this GCU are active depositional areas, typically on the lowest portions of the fan where channel entrenchment and local slope declines near the present elevational base level of the modern stream.

Geomorphics Characteristics and Conditions

Observed channel morphology in GCU 1 includes pool-riffle, forced pool-riffle and plane bed reaches. Observed slopes are less than 4%. Channels are typically entrenched in the upper portions of the fan, where long term reduction in sediment supply to channels has allowed the stream to incise the fan. Channel gradient declines sufficiently somewhere in the GCU segment to create hydraulic conditions where sediment may be deposited, and fan building may be occurring (e.g. the mouth of Murr Creek). Channels flow on alluvial sediment carried from upstream, and recruited locally by bank erosion. Channels are unconfined by valley walls, but are in many places confined by terraces where the channel is relatively entrenched. Erosion and sedimentation processes are relatively inactive in

entrenched reaches, and moderately active in deposition zones. During peak flow events the streambed can be mobilized, potentially causing bank erosion and channel migration, particularly in depositional portions of fan GCU's.

Sediment Size and Stream Power

The overall median grain size on the bed is coarse gravel (about 60 mm or 2.4 in), about the middle of the range for lower-gradient GCU's. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars in entrenched reaches has $d_{50} \approx 20$ mm (0.8 in). Fresh gravel deposits near the mouth of Murr Cr. have $d_{50} \approx 50$ mm (2.0 in). Average unit stream power (1.4) is relatively low, and typical for lower-gradient reaches.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is variable with position in the fan GCU. The highest observed entrenchment ratio was 3.7; the lowest was 1.7. In most locations, the bankfull flow is contained within a terrace. Channel bottoms are alluvium or lacustrine clay. Elements of flow resistance (channel roughness) are variable, including banks armored by cobbles and roots, boulders projecting from the bed, stems of riparian vegetation, gravel bars, and LWD. Observed LWD abundance is relatively low, but LWD is a potentially significant component of channel morphology that could form more numerous and deeper pools. Gravel bars are relatively uncommon except in depositional reaches. Bar types are forced and point bars in entrenched reaches, with some multiple/medial bars in deposition zones. Fine sediment is moderately abundant and is deposited both in patches and in small bars.

Reach-Scale Floodplain and Hillslope Interactions

Where the channel is entrenched and confined by terraces, the width of the floodplain is small and deposition is limited to the inset floodplain area. Where entrenchment is slight, floodplain surfaces may remain confined by terraces, but the floodplain is large enough for side channels to form. In deposition zones, the peak flows generally overtop the bank and the floodplain width is much larger than the bankfull width. Riparian vegetation is highly variable and ranges from meadow and deciduous trees and shrubs in slightly entrenched areas and deposition zones to mixed conifer adjacent to more entrenched reaches. Bank erosion is typically small in entrenched reaches, but may be much greater in deposition zones and/or where channel migration is likely.

Channel Migration Zones

This GCU may potentially contain CMZ types 1, 2 and 3. In entrenched reaches, CMZ type 3 occurs, and active channel migration is expected to be associated only with LWD jams, but was not observed in the field. In moderately entrenched reaches, CMZ type 2 occurs, and side channels were observed in the field indicating some active CMZ's. In slightly entrenched reaches (corresponding to deposition zones), CMZ type 1 occurs, and significant shifts in channel position are possible (e.g. Murr Creek). The degree of active channel migration is probably related to LWD abundance in CMZ types 2 and 3.

Table 4E-6. Summary of channel sensitivity ratings and criteria, GCU 1, Alluvial Fans.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Physical Criteria for Channel Sensitivity Rating
Coarse Sediment	Moderate / Moderate	Relatively-high geomorphic potential for deposition, but generally low delivery of coarse sediment from hillslopes.
Fine Sediment	Low / Low	Despite deposition potential, stream power is sufficient to transport most fines through these channels.
Peak Flows	Moderate / Moderate	Depositional reaches are susceptible to bed scour and channel migration.
LWD	Moderate / Moderate	Deeper pools and side channels can be formed because gravel substrate is mobile and entrenchment is low enough to permit channel migration.
Landslides or Floods	Moderate / Moderate	Natural deposition zone for rare watershed events that produce and transport large volumes of sediment.
Riparian Vegetation	Moderate / Moderate	Depositonal character enhanced by vegetation, particularly in less entrenched reaches. Potentially bank erosion limited by roots.
Channel Migration Zone	Low-Moderate / Moderate	Low channel migration in entrenched reaches (CMZ type 3). Moderate channel migration in moderately and slightly entrenched reaches (CMZ types 1 and 2); higher potential with increased LWD load or coarse sediment supply.
Confidence	High	All fan reaches classified in this GCU were observed in the field.

4E.3.2.2 *GCU 2: Forest/meadow Complex*

This GCU is comprised of long, contiguous stream segments located in the middle reaches of Murr Creek and Boiling Springs Creek. This GCU contains 5.9% of channel length in the study area, and a whopping 15.6% of perennial channels. Segments in this GCU have low to moderate gradients and lie within areas of glacial sediment deposits (Boiling Springs Cr.), or near the temporary base level (≈ 4200 ft) created by Lake Missoula (i.e. Murr Creek). Valley bottoms are wide. Riparian vegetation alternates between meadow and forest types, and historic beaver activity probably had a significant effect. Channels are incised in alluvium and/or fluvio-glacial sediment. Some reaches mapped as GCU 2 may have characteristics similar to GCU 3 (Meadow-Pond Complex).

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 2 is predominantly forced pool-riffle and plane bed, with pool-riffle morphology in lower gradient reaches. Observed slopes ranged from about 1 to 3 %, with the average 2.3%. Floodplains are typically confined by ancient terraces, but modern channels are slightly entrenched relative to the modern floodplain. Long term reduction in sediment supply and/or climate change has induced channels to incise the valley floors. Channel gradient varies, creating reaches of

relatively high deposition potential where gradient declines. Overall gradient is sufficient to route most channel-stored sediment out of the GCU. Channels flow on alluvial and fluvio-glacial sediment carried from upstream, and recruited locally by bank erosion. Channels are rarely confined by valley walls, and are generally confined by terraces where the channel is relatively entrenched. Erosion and sedimentation processes are moderately active in the lower-gradient reaches. During peak flow events the streambed can be mobilized in most locations, potentially causing bank erosion and channel migration in lower-gradient reaches.

Sediment Size and Stream Power

The overall median grain size on the bed is coarse gravel (about 45 mm or 1.8 in). This is in the low portion of the range for lower-gradient GCU's. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 16$ mm (0.6 in). Average unit stream power index (1.1) is relatively low, and is typical for lower-gradient reaches. Values ranged from 0.4 (very low for the study area) to 1.6.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is variable, but is relatively low. Average entrenchment ratio is 4.5, ranging from 2.3 to 6.3 (defined as slightly entrenched by Rosgen). In most locations, the bankfull flow may spread onto a relatively wide floodplain surface inset in the valley floor. Channel bottoms are generally alluvium and fluvio-glacial deposit, but may possibly include lacustrine clay. Dominant elements of flow resistance (channel roughness) are banks armored by cobbles and roots, stems of riparian vegetation, and LWD. In some reaches, boulders protruding from the bed and gravel bars offer significant flow resistance. Observed LWD abundance is relatively low, particularly in meadows, but LWD is abundant locally and is a significant component of channel morphology that could form more numerous and deeper pools. Gravel bars are relatively uncommon except in local depositional reaches. Bar types are predominantly forced, with some point bars in deposition zones. Fine sediment is moderately abundant and is deposited both in patches and in small bars in Boiling Springs Creek, but is sparse in Murr Creek.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are continuous and generally large enough for side channels to form. Overbank flow is not uncommon. Riparian vegetation is highly variable and ranges from meadow and deciduous trees and shrubs in meadow areas to mixed conifer in forested reaches. Bank erosion is typically small, but can be much greater where larger point bars form. Common side channel are evidence of widespread channel migration on the floodplain.

Channel Migration Zones

This GCU contains CMZ type 2. Side channels were common within the floodplain, and were observed to be associated with LWD in many cases. Average floodplain and CMZ width was about 20 m (66 ft). Many reaches appeared to have relatively small volumes of coarse sediment stored in

bars, suggesting that LWD may be the primary cause of channel avulsions (formation of side channels). Where gravel bars were relatively large, channel migration was more active.

Table 4E-7. Summary of channel sensitivity ratings and criteria, GCU 2, Forest/Meadow Complex.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Moderate / Moderate	Generally low level of deposition observed, but potential for channel migration associated with significant deposition is high. Hillslope inputs of coarse sediment are very low.
Fine Sediment	Low-Moderate / Moderate	Levels of fine sediment deposition are relatively high for the study area, but are not typically sufficient to significantly affect channel morphology. Levels of fine sediment are high enough to affect quality of fish habitat.
Peak Flows	Moderate / Moderate	Reaches with abundant gravel bars are susceptible to scour; channel migration processes could be accelerated by increased peak flows, particularly if LWD is present.
LWD	Moderate-High / Moderate	LWD appears to be instrumental to channel migration processes and has the potential to form pools. LWD load is variable, and is less significant in meadow reaches.
Landslides or Floods	Moderate / Moderate	Potential response to rare floods is significant; no evidence of significant landslide effects.
Riparian Vegetation	High / High	Relatively wide floodplain and channel migration potential increases potential influence of riparian vegetation.
Channel Migration Zone	Moderate / Moderate	Wide floodplains and common side channels indicate significant CMZ, but variable LWD load and low coarse sediment moderate the intensity of channel migration. Use by native fish not presently significant.
Confidence	High	A high proportion of segments in this GCU were surveyed.

4E.3.2.3 *GCU 3: Meadow/pond Complex*

This GCU is comprised of long, contiguous stream segments located in the middle and upper reaches of Boiling Springs Creek. This GCU contains 0.9% of channel length in the study area, and 2.4% of perennial channel length. Segments in this GCU have very low gradients and lie within areas of glacial-lacustrine sediment deposits. Small lakes, ponds and wet meadows occupy wide valley bottoms. Riparian vegetation is primarily meadow with some trees (mostly hardwoods). Current and historic beaver activity has had a significant effect on this channel type. Channels are incised in fluvio-glacial and laocustrine sediment. Some reaches mapped as GCU 3 may have characteristics similar to GCU 2 (Forest/Meadow Complex).

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 3 is predominantly pool-riffle and plane bed. Observed slopes were <1%. Floodplains are typically confined by ancient terraces, but modern channels are slightly entrenched relative to the modern floodplain, which is very wide relative to channel width. Channels are relatively narrow and deep with densely-vegetated banks. Long term reduction in sediment supply and/or climate change has induced channels to incise the valley floors. Although channel gradient is sufficient to transport gravel, the ponds and lakes capture most sediment that reaches this GCU. Sediment in transport in channels is recruited locally by bank erosion. Erosion and sedimentation processes are moderately active in stream reaches. During peak flow events the streambed can be mobilized in most locations, potentially causing bank erosion.

Sediment Size and Stream Power

The overall median grain size on the bed is gravel (about 24 mm or 1.0 in). This is the finest median grain size observed in the study area. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 18$ mm (0.7 in). The unit stream power index (0.3) is the lowest observed in the study area.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is very low. Entrenchment ratio is 6.5 (defined as slightly entrenched by Rosgen). In most locations, the bankfull flow spreads onto a wide floodplain surface inset in the valley floor. Channel bottoms are generally alluvium and fluvio-glacial deposit, but may possibly include lacustrine clay. Dominant elements of flow resistance (channel roughness) are banks strengthened by grasses. Observed LWD abundance is relatively low, but LWD is present locally and is a significant component of channel morphology that could form more numerous and deeper pools. LWD appears to be recruited from coniferous forest stands that occupy well-drained terraces in close proximity to the channel. Gravel bars are relatively uncommon and are predominantly forced. The channel is typically too narrow for point bars to form. Fine sediment is abundant and is deposited both in patches and in small bars. Fine sediment is expected to be a significant component of the bed material given the gradient of the GCU.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are continuous and large enough for side channels to form. Overbank flow is not uncommon. Riparian vegetation is predominantly meadow grasses, with locally dense deciduous trees and shrubs. Bank erosion is typically small, with the major nodes of erosion occurring where side channels form or rejoin the main channel. Side channel are indicative of channel migration on the floodplain.

Channel Migration Zones

This GCU contains CMZ type 1, which is predicted to have a high propensity to channel migration. Actual channel migration as observed in the field is relatively infrequent, but when it occurs it has

morphological significance. Side channels were present in the floodplain, and were observed to be associated with beaver dams in some cases. Floodplain and CMZ width was about 24 m (78 ft). There were small volumes of coarse sediment stored in bars, suggesting that LWD may be the primary factor in formation of side channels. Given the low abundance of and recruitment potential for LWD, beaver activity is implicated as the main cause of channel migration. Gradual bank erosion at stream bends also occurs, but the densely-vegetated bank are relatively resistant to erosion. Stream power is low, so channel migration by gradual bank erosion is probably of secondary importance.

Table 4E-8. Summary of channel sensitivity ratings and criteria, GCU 3, Meadow/Pond Complex.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Low / Low	Coarse sediment is not delivered in quantities that could induce channel response.
Fine Sediment	Moderate / Moderate	Fine sediment is a significant component of bed material owing to low stream power and glacial deposits. Low stream power prevents fine sediment from being rapidly routed downstream. Where delivered from upland sources, accelerated deposition could occur.
Peak Flows	Low / Low	Low gradient, wide floodplain, and lakes and ponds would buffer these streams from peak flow effects.
LWD	Low-Moderate / Moderate	Despite low natural abundance and recruitment, LWD is present and is locally significant in formation of pools and side channels.
Landslides or Floods	Low / Low	Low gradient and broad valleys, floodplains and lakes create common flooding and prevent delivery of landslide material.
Riparian Vegetation	High / High	Channel banks are maintained by dense grasses. Deciduous shrubs and trees add root strength and food sources for beaver.
Channel Migration Zone	Low-Moderate / Low	Wide floodplains and common side channels indicate significant CMZ, but low LWD load and low coarse sediment minimize channel migration. Beaver dams may be primary cause of channel migration. Use by native fish not presently significant.
Confidence	Moderate	Few sample sites, but predictable morphology. Some GCU 2 and GCU 12 segments may fit GCU 3.

4E.3.2.4 *GCU 4: Conifer Floodplain CMZ*

This GCU is comprised of a long, contiguous set of stream segments in lower Beatrice Creek and two isolated reaches in Murr Creek. This GCU contains 3.3% of channel length in the study area, and 8.7% of perennial stream length. Segments in this GCU have low to moderate gradients on mainstem streams draining areas of about 7 mi^2 or more. Streams lie in steep-sided valleys with moderately-wide valley bottoms. Channels are incised in relatively shallow alluvium and/or fluvio-glacial sediment. The groundwater table is high. Riparian vegetation is dominated by conifers. Relatively high stream power, in combination with conifers prone to windthrow and relatively high volume of bed load sediment, induce high channel migration potential. Portions of segments mapped as GCU 5 may have characteristics of GCU 4.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 4 is forced pool-riffle and plane bed. Observed slopes ranged from about 1 to 4 %, with the average 2.7%. Floodplains are typically confined by terraces, but channels infrequently intersect valley walls. Modern channels are slightly entrenched relative to the modern floodplain. Long term reduction in sediment supply and/or climate change has induced channels to incise the valley floors. Channel gradient varies within the range noted above, creating reaches of relatively high deposition potential where gradient declines. Overall stream power is sufficient to transport most channel-stored sediment. However, because sediment storage in active bars, side channels and terraces is significant, bedload is routed through this GCU relatively slowly. The majority of active bedload sediment is recruited from long-term storage in terraces by bank erosion and channel avulsion. Erosion and sedimentation processes are active, particularly in the lower-gradient reaches and where channel migration and channel avulsions occur. During peak flow events the streambed can be mobilized in most locations, potentially causing bank erosion and channel migration. Windthrow of riparian conifers is also most likely during periods of peak flow, when the water table in the riparian zone is highest.

Sediment Size and Stream Power

The overall median grain size on the bed is small cobble (about 80 mm or 3.1 in). This is in the high portion of the range for lower-gradient GCU's, and reflects relatively high stream power. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 26$ mm (1.0 in). Average unit stream power index (1.4) is typical for lower-gradient reaches. Values ranged from 0.8 to 1.8. Total stream power (11.0) is relatively high because of high channel width.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is relatively low. Average entrenchment ratio is 3.2, ranging from 2.4 to 3.8 (defined as slightly entrenched by Rosgen). In many locations, the bankfull flow may spread onto a relatively wide floodplain surface inset in the valley floor. The width of floodplain varies locally, but increases with decreasing slope. The floodplain contains islands isolated by channel avulsion. In some short reaches, the channel may be tightly confined by terraces, but these reaches are in the

minority. Channel bottoms are generally alluvium and fluvio-glacial deposits, lateral boundaries may occasionally include bedrock exposed in the valley wall. Dominant elements of flow resistance (channel roughness) vary from reach to reach, and most commonly include LWD, form roughness created by gravel bars, stems of riparian vegetation, and cobbles protruding from the bed. Observed LWD abundance is relatively high, and abundant locally, frequently forming jams. LWD is a significant component of channel morphology that forms more numerous and deeper pools and contributes to channel migration. Gravel bars are relatively common, except in lower gradient reaches where they may be abundant. Bar types include forced, alternate and multiple, the latter being more typical in lower gradient reaches. Fine sediment is moderately abundant and is deposited both in patches and in small bars in Beatrice Creek, but is sparse in Murr Creek.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are generally continuous, with occasional reaches of channel confined within terraces. Floodplains are, nevertheless, typically significant with frequent side channels and high flow channels. Overbank flow is not uncommon. Riparian vegetation is relatively consistent with a shrub understory and mature conifer overstory. Bank erosion is typically small, but increases with decreasing slope and corresponding deposition of larger gravel bars. Common side channels, islands and LWD are evidence of widespread channel migration on the floodplain.

Channel Migration Zones

This GCU contains CMZ type 2, which is predicted to have a high potential for channel migration. Actual migration is frequent and significant. Side channels were common within the floodplain, and were observed to be associated with LWD in many cases. Average floodplain and CMZ width was about 27 m (89 ft), but varied widely (14-62 m). Many reaches appeared to have relatively large volumes of coarse sediment stored in bars, often associated with LWD and channel avulsions (formation of side channels). Where gravel bars were relatively large, and/or LWD more abundant, channel migration is likely to be more active.

Table 4E-9. Summary of channel sensitivity ratings and criteria, GCU 4, Conifer Floodplain CMZ.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Moderate / High	Channels have significant volume of bedload sediment in storage in active channel bars, which contribute to initiation of channel migration and bank erosion. Delivery of coarse sediment from hillslope sources is rare, however, significant inputs would induce channel response. Potential local aggradation could cause channel flow to dissipate as subsurface flow.
Fine Sediment	Low-Moderate / Moderate	Fine sediment accumulates in small patches and bars in association with channel roughness elements. Abundance is sparse in Murr Cr., and moderate in Beatrice Cr. Habitat vulnerability is moderate owing to the potential negative effects of fine sediment on spawning habitat.
Peak Flows	Moderate / Moderate	Presence of mobile bedload and potential bank erosion and channel migration indicate potential channel response to increased peak flows, including potential scour or burial of redds.
LWD	High / High	LWD is effective in forming pool habitat, and contributes significantly to channel migration processes and formation of side channels. LWD creates channel roughness that induces deposition and sorting of gravel. Long-term reduction of LWD inputs would potentially simplify channel morphology. GCU is currently utilized by native and exotic salmonids.
Landslides or Floods	Moderate / Moderate	Streamside landslides have been observed, although they are rare and not apparently related to management. Steep slopes adjacent valley bottom create potential for mass wasting. Flood response would likely include accelerated channel migration.
Riparian Vegetation	High / High	Riparian conifers are integral component of channel morphology.
Channel Migration Zone	High / High	Channel migration processes are active, and maintenance of side channels and floodplain are required to preserve spawning gravel deposition and rearing habitat. If streamflow were concentrated in single thread channel, gravels would be rapidly flushed downstream, and more vulnerable to scour.
Confidence	High	High proportion of segments observed or sampled; reach in Beatrice Creek may contain significant length of GCU 5.

4E.3.2.5 *GCU 5: Confined Mainstem*

This GCU is comprised of a few stream segments located at the mouth of Beatrice Creek and in Murr Creek below the confluence of North Fork Murr Creek. This GCU contains 3.0% of channel length in the study area, and 7.8% of perennial stream length. Segments in this GCU have low to moderate gradients on mainstem streams draining areas of about 10 mi^2 or more. Streams lie in steep-sided valleys with moderately-narrow valley bottoms. Channels are incised in bedrock mantled with

shallow alluvial and/or fluvio-glacial deposits. Riparian vegetation is dominated by conifers. Relatively high stream power and relatively high degree of channel confinement promote rapid transport of sediment downstream. Portions of segments mapped as GCU 5 may have characteristics of GCU 4.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 5 is plane bed and forced pool-riffle. Observed slopes ranged from about 2 to 4 %, with the average about 3%. Floodplains are typically confined by narrow terraces and/or valley walls. Portions of valley walls are oversteepened by stream incision. Modern channels are moderately entrenched relative to the modern floodplain. Long term reduction in sediment supply and/or climate change has induced channels to incise the valley floors. Channel gradient varies somewhat within the range noted above, creating reaches where there is some deposition potential for coarse sediment. Stream power is sufficient to transport most channel-stored sediment. There are relatively few significant gravel bars and infrequent side channels. Hence, bedload is routed through this GCU relatively quickly. The majority of active bedload sediment is delivered from channels upstream, with some recruitment from long-term storage in terraces by bank erosion and channel avulsion. Erosion and sedimentation processes are moderately active in some areas, but plane bed reaches are armored with boulders and cobbles. During peak flow events the streambed can be mobilized in many areas, but degree of armoring limits channel scour. LWD contributes to channel morphology, but is only moderately effective at creating scour pools owing to armoring and high stream power that sweeps most LWD to channel margins.

Sediment Size and Stream Power

The overall median grain size on the bed is small cobble (about 82 mm or 3.2 in). This is in the high portion of the range for lower-gradient GCU's, and reflects relatively high stream power. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 22$ mm (0.9 in). Average unit stream power index (1.6) is the highest found for lower-gradient reaches. Values ranged from 1.1 to 1.9. Total stream power (12.7) is relatively high because of high channel width.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is relatively high. Average entrenchment ratio is 1.9, ranging from 1.4 to 2.3 (defined as moderately entrenched by Rosgen). In many locations, the bankfull flow may spread onto a relatively narrow floodplain. In many reaches, the channel may be tightly confined by terraces and valley walls. Channel bottoms are generally coarse alluvium and/or fluvio-glacial deposits, with bedrock exposed occasionally in the channel bottom or margin. Dominant elements of flow resistance (channel roughness) are cobbles and boulders protruding from the bed, form roughness created by boulder steps. LWD contributes to flow resistance in some reaches. Typical LWD abundance is relatively high, but variable from reach to reach. LWD has the greatest influence in debris jams; single stems are frequently swept to the channel margin by powerful peak flows. LWD is a significant

component of channel morphology locally, but the degree of armoring on the bed limits formation of scour pools. Most pools are associated with large boulder, channel bends and bedrock outcrops. LWD jams create potential for channel avulsion. Individual stable LWD pieces may induce deposition of gravel in patches near channel margins. Gravel bars are relatively uncommon, particularly in Murr Creek. Bar type is predominantly forced. Fine sediment is relatively sparse and is deposited both in patches and in small bars. Fine sediment is more abundant in Beatrice Creek.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are discontinuous, separated by reaches of channel confined within terraces and valley walls. Floodplains are significant, but relatively narrow with infrequent side channels and high flow channels. Overbank flow is not common. Riparian vegetation is relatively consistent with a shrub understory and mature conifer overstory. Bank erosion is relatively common, perhaps because channel adjustment to peak flow occurs more readily in a lateral direction than vertical owing to limited bed scour. Infrequent overflow channels are evidence of limited channel migration on the floodplain.

Channel Migration Zones

This GCU contains CMZ type 3, which is predicted to have a moderate potential for channel migration. Evidence of channel migration suggests it occurs infrequently. Side channels were uncommon, and were observed to be associated with LWD and relatively large gravel bars. Average floodplain and CMZ width was about 15 m (50 ft), with relatively little variation owing to the degree of channel entrenchment. Although uncommon, side channels formed by avulsion reduce stream power locally and induce gravel deposition. Gravel patches potentially suitable for spawning are relatively limited in this GCU.

Table 4E-10. Summary of channel sensitivity ratings and criteria, GCU 5, Confined Mainstem.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Low / Low	High stream power and low sediment supply from hillslopes makes channel response from inputs unlikely.
Fine Sediment	Low / Low	High stream power prevents significant accumulation of fine sediment.
Peak Flows	Low / Low	Coarse bed sediment makes increased scour unlikely; channel morphology is typically resistant to change due to increased peak flow.
LWD	Moderate / Moderate	Effect of LWD on channel morphology is significant, but not dominant. Much LWD in this type of channel has little effect on channel morphology.
Landslides or Floods	Low / Low	High stream power and channel entrenchment create efficient routing of sediment and water. Landslide inputs were not observed in the study area, but if present, could have significant effects on channel morphology (probably positive effects on fish habitat).
Riparian Vegetation	Moderate / Moderate	Riparian vegetation helps maintain streambanks and provides for LWD recruitment.
Channel Migration Zone	Low-Moderate / Moderate	Channel avulsions & side channels are uncommon, but are likely to create favorable habitat conditions by locally reducing stream power and inducing gravel deposition.
Confidence	Moderate	Substantial segment length in Murr Cr. not observed, and could contain reaches of GCU 4 or GCU 9.

4E.3.2.6 *GCU 6: Incised Glacial till*

This GCU is comprised of a few stream segments located in the middle reaches of Beatrice Creek and at the mouth of Boiling Springs Creek. This GCU contains 1.8% of channel length in the study area, and 4.8% of perennial stream length. Segments in this GCU have moderately steep gradients. Streams lie in moderate to steep-sided valleys with narrow valley bottoms. Channels are incised in glacial till; further erosion of the channel bottom is limited by the high concentration of boulders and large cobbles. High stream power and high degree of channel confinement promote rapid transport of sediment downstream. Portions of segments mapped as GCU 6 may have characteristics of GCU 4 and GCU 5.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 6 is primarily step-pool, with elements of cascade and forced

pool-riffle in steeper and gentler reaches, respectively. Observed slopes ranged from about 6 to 12%, with the average about 8%. Floodplains are typically confined by narrow terraces and/or valley walls. Portions of valley walls are oversteepened by stream incision. Modern channels are moderately entrenched relative to the modern floodplain. The retreat of glacial ice allowed streams to erode through glacial till deposits in these reaches. Channel gradient and confinement varies somewhat within the range noted above, creating reaches where there is significant deposition of coarse sediment and some channel avulsion. Stream power is sufficient to transport most channel-stored sediment. There are relatively few significant gravel bars and side channels. Hence, bedload is routed through this GCU relatively quickly. The majority of active bedload sediment is delivered from channels upstream, with some recruitment from long-term storage in terraces by bank erosion and by shallow mass wasting on steep slopes adjacent to channels. Erosion and sedimentation processes are moderately active in a few areas, but step-pool and cascade reaches are armored with boulders and cobbles. During peak flow events the streambed can be mobilized in a few areas, but the degree of armoring limits channel scour. LWD contributes to channel morphology by forming steps and debris jams, but is only moderately effective at creating scour pools owing to armoring and bed morphology and narrow channel width that reduces potential for LWD to become incorporated in the channel.

Sediment Size and Stream Power

The overall median grain size on the bed is small cobble (about 85 mm or 3.3 in). This is in the high portion of the range for lower-gradient GCU's, and reflects high stream power. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 24$ mm (1.0 in). Average unit stream power index (3.7) is in the middle of the range for higher-gradient reaches. Values ranged from 2.9 to 4.6. Total stream power (12.7) is relatively high because of moderately-high channel width and slope.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is relatively high. Average entrenchment ratio is 2.3, ranging from 1.8 to 3.3. However, the value 3.3 is atypical for this channel type. Neglecting that outlier, average entrenchment ratio is 1.9, defined as moderately entrenched by Rosgen (1994). In some locations, the bankfull flow may spread onto a relatively narrow floodplain. In many reaches, the channel may be tightly confined by terraces and valley walls. Channel bottoms are generally coarse alluvium and/or fluvio-glacial deposits, with large boulders frequently exposed in the channel bottom and margin. Dominant elements of flow resistance (channel roughness) are boulders protruding from the bed, form roughness created by boulder steps. Secondary roughness elements are LWD, streambanks and stems of riparian vegetation. Typical LWD abundance is moderate. LWD has the greatest influence in debris jams and large logs that form steps in the channel. LWD is a significant component of channel morphology locally, but the degree of armoring on the bed limits formation of scour pools, and the narrow channel width and high concentration of boulders in the bed inhibit integration of LWD into the channel bed. Most pools are associated with boulder steps. LWD jams create limited potential

for channel avulsion on narrow floodplains. Gravel bars are relatively common. Bar type is predominantly forced. Fine sediment is relatively sparse and is deposited in patches.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are discontinuous, separated by reaches of channel confined within terraces and valley walls. Floodplains are locally significant, but narrow with rare side channels and high flow channels. Overbank flow is not common. Riparian vegetation is relatively consistent with a shrub understory and mature conifer overstory. Bank erosion is not uncommon, perhaps because channel adjustment to peak flow occurs more readily in a lateral direction than vertical owing to limited bed scour. Rare side channels and overflow channels are evidence of channel avulsion and limited channel migration on the floodplain.

Channel Migration Zones

This GCU contains CMZ type 5, which is predicted to have a low to moderate potential for channel migration. Evidence of channel migration suggests it occurs infrequently. Side channels were uncommon, and were observed to be associated with LWD and lower-gradient, less confined (entrenched) reaches. Typical floodplain and CMZ width was about 6 m (20 ft), with relatively little variation except in uncommonly wide, moderate-gradient reaches (e.g. site B9). Although uncommon, side channels formed by avulsion reduce stream power locally and induce gravel deposition.

Table 4E-11. Summary of channel sensitivity ratings and criteria, GCU 6, Incised Glacial Till.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Low / Low	High stream power and low sediment supply from hillslopes makes channel response from inputs unlikely.
Fine Sediment	Low / Low	High stream power prevents significant accumulation of fine sediment.
Peak Flows	Low / Low	Coarse bed sediment makes increased scour unlikely; channel morphology is typically resistant to change due to increased peak flow.
LWD	Low-Moderate / Moderate	Effect of LWD on channel morphology is locally significant, but limited. Much LWD in this type of channel has little effect on channel morphology.
Landslides or Floods	Low-Moderate / Low	High stream power and channel entrenchment create efficient routing of sediment and water. Landslide inputs were observed in the study area, and would likely have significant transient effects on channel morphology that would probably have largely positive effects on fish habitat by introducing gravel, LWD, and channel complexity.
Riparian Vegetation	Low-Moderate / Moderate	Riparian vegetation helps maintain streambanks and provides for LWD recruitment.
Channel Migration Zone	Low-Moderate / Moderate	Channel avulsions & side channels are rare, but are likely to create favorable habitat conditions by locally reducing stream power and inducing gravel deposition.
Confidence	High	High number of survey sites for a relatively uncommon channel type.

4E.3.2.7 *GCU 7: Alpine Glacial Headwater*

This GCU is limited to two stream segments located in the upper reaches of Beatrice Creek. This GCU contains 2.7% of channel length in the study area, and 7.2% of perennial stream length. Segments in this GCU have steep gradients. Streams lie in shallow, steep-sided valleys with narrow valley bottoms. Channels are incised in glacial till; further erosion of the channel bottom is limited by the high concentration of boulders and large cobbles. High stream power and high degree of channel confinement promote rapid transport of sediment downstream.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 7 is cascade and step-pool. Observed slopes ranged from about 12-25%, with the average about 19%. Floodplains are discontinuous, and occur where valley walls are less confining. Portions of valley walls may be oversteepened by stream incision. Valley

wall slope lengths are about 30 m (100 ft) or less. Channels are moderately entrenched relative to the modern floodplain. The retreat of glacial ice allowed streams to erode through glacial till deposits in these reaches. Channel gradient and confinement varies somewhat within the range noted above, creating reaches where there is significant deposition of coarse sediment. Stream power is sufficient to transport most channel-stored sediment. LWD jams create most of the sediment storage in these channels, consequently, the routing of bedload sediment through this GCU depends on the rate of recruitment of LWD that forms debris jams. The majority of active bedload sediment is supplied by hillslope creep processes, including bank erosion, and by shallow mass wasting on steep slopes adjacent to channels. Erosion and sedimentation processes are moderately active in a few areas, primarily where there are LWD jams, but step-pool and cascade reaches that dominate the channel are armored with boulders and cobbles. During peak flow events the streambed can be mobilized in a few areas, but the degree of armoring limits channel scour. LWD contributes to channel morphology by forming steps and debris jams, but is only moderately effective at creating scour pools owing to armoring and bed morphology and narrow channel width that reduces potential for LWD to become incorporated in the channel.

Sediment Size and Stream Power

The overall median grain size on the bed is small cobble (about 83 mm or 3.2 in). This is in the high portion of the range for higher-gradient GCU's, and reflects high stream power. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 20$ mm (0.9 in). Typical unit stream power index (6) is in the upper range for higher-gradient GCU's. Total stream power is typically about 20, which is also in the upper end of the range because of high slope.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is relatively high. Typical entrenchment ratio is 1.6, defined as moderately entrenched by Rosgen (1994). In some locations, the bankfull flow may spread onto a relatively narrow floodplain. In most reaches, the channel is confined by terraces and valley walls. Channel bottoms are generally coarse alluvium and/or fluvio-glacial deposits, with large boulders frequently exposed in the channel bottom and margin. Bedrock is occasionally exposed in the channel bottom. Dominant elements of flow resistance (channel roughness) are boulders protruding from the bed and form roughness created by boulder steps, with LWD important locally. Typical LWD abundance is in the moderate range. LWD has the greatest influence in debris jams and large logs that form steps in the channel. LWD is a significant component of channel morphology locally, but the degree of armoring on the bed limits formation of scour pools, and the narrow channel width and high concentration of boulders in the bed inhibit integration of LWD into the channel bed. Most pools are associated with boulder steps. LWD jams create narrow floodplains in some reaches. Gravel bars are relatively common. Bar type is predominantly forced. Fine sediment is sparse and is deposited in patches.

Reach-Scale Floodplain and Hillslope Interactions

Stream reaches with floodplains are short and discontinuous, separated by reaches of channel confined within terraces and valley walls. Floodplains are locally significant, but are very narrow. Overbank flow is not common. Bank erosion of valley walls formed in glacial debris is the primary sediment production process. Bank erosion could cause small streamside landslides.

Channel Migration Zones

This GCU is expected to be too steep to permit channel migration. Evidence of unambiguous channel migration was not found in the field. A narrow floodplain is established where LWD jams form and capture sediment, but these areas are neither wide enough nor frequent enough to make significant channel migration possible.

Table 4E-12. Summary of channel sensitivity ratings and criteria, GCU 7, Alpine Glacial Headwater.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Low / Low	High stream power and low magnitude of sediment supply from hillslopes makes channel response from inputs unlikely.
Fine Sediment	Low / Low	High stream power prevents significant accumulation of fine sediment.
Peak Flows	Low-Moderate / Low	Coarse bed sediment makes increased scour unlikely; channel morphology is typically resistant to change due to increased peak flow, except for the limited extent of LWD-stored sediment.
LWD	Low-Moderate / Moderate	Effect of LWD on channel morphology is locally significant with respect to sediment storage, but is limited. Much LWD in this type of channel has little effect on channel morphology.
Landslides or Floods	Low-Moderate / Low	High stream power and channel entrenchment create efficient routing of sediment and water. Landslide inputs were not observed in the study area, and would likely have significant transient effects on channel morphology that would probably have largely positive effects on downstream fish habitat by introducing gravel to the channel network.
Riparian Vegetation	Low-Moderate / Moderate	Riparian vegetation helps maintain streambanks and provides for LWD recruitment.
Channel Migration Zone	Low / Low	Channel migration processes are not significant.
Confidence	Moderate	Observations of one survey site cannot account for potential variability, but channels of this type are relatively consistent. In addition, there is no known fish use.

4E.3.2.8 *GCU 8: Perennial Headwaters*

This GCU is comprised of several stream segments located in the headwaters of Murr Creek and Boiling Springs Creek. These segments are the upper reaches of the perennial channel network in these areas. This GCU contains 14.9% of channel length in the study area, and 39.2% of perennial stream length. Segments in this GCU have moderately steep gradients. Streams lie in moderately-sloping valleys with moderately-wide valley bottoms. Channels are incised in valley bottoms, but hillslope lengths are typically less than 50 ft (15 m). These channels are primarily in terrain mantled with residual soils (i.e. Murr Creek), and to a lesser extent in shallow glacial till (i.e. Boiling Springs Cr.). Erosion of the channel bottom is limited by the high concentration of boulders and large cobbles. Moderately-high stream power promotes transport of sediment downstream. Portions of segments mapped as GCU 8 may have characteristics of GCU 6 and GCU 10.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 8 is primarily step-pool, with elements of cascade and forced pool-riffle in steeper and gentler reaches, respectively. Observed slopes ranged from about 5 to 13%, with the average about 8%. Floodplains are typically confined by terraces and/or valley walls. Valley side slopes average 30%. Channels are slightly entrenched relative to the modern floodplain. Side channels are common. Stream power is sufficient to transport most channel-stored sediment, but power is relatively low for higher gradient GCU's in the study area. There are relatively few significant gravel bars. Hence, the modest quantity of bedload observed in the GCU is routed downstream relatively quickly. The majority of active bedload sediment is delivered by bank erosion of terraces. Erosion and sedimentation processes are minimally active. Step-pool and cascade reaches are armored with boulders and cobbles. During peak flow events the streambed can be mobilized in a few areas, but the degree of armoring limits channel scour. LWD contributes to channel morphology by forming steps and debris jams, but is only moderately effective at creating scour pools owing to armoring and bed morphology and narrow channel width that reduces potential for LWD to become incorporated in the channel.

Sediment Size and Stream Power

The overall median grain size on the bed is small cobble (about 84 mm or 3.3 in). The median grain size at individual sites varies widely however, ranging from 36 to 158 mm. This relatively wide range of grain size reflects moderate stream power for a higher-gradient GCU as well as variation in sediment supply. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx$ 18 mm (0.7 in). Average unit stream power index (2.6) is in the lower-middle of the range for higher-gradient reaches. Values ranged from 2.0 to 3.2. Total stream power (7.4) is moderate for the higher-gradient GCU's because of declining channel width and depth that occurs in the headwaters of channel networks.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is relatively low. Average entrenchment ratio is 3.2, ranging from 2.3 to 4.7. This is defined as slightly entrenched by Rosgen (1994). In most reaches, the bankfull flow spreads onto a relatively wide floodplain. In most reaches the floodplain is continuous, but is occasionally tightly confined by terraces and valley walls. Channel bottoms are variable, ranging from coarse alluvium to large, flat, angular cobbles and boulders that appear to be belt bedrock that has weathered in situ (typical for Murr Creek). Elements of flow resistance (channel roughness) are numerous; a dominant roughness element cannot be identified. Boulders and cobbles protruding from the bed, LWD, streambanks and stems of riparian vegetation are typical components of flow resistance. Typical LWD abundance is moderate. LWD has the greatest influence in debris jams and large logs that form steps in the channel. LWD is a significant component of channel morphology locally, but the degree of armoring on the bed and relatively shallow bankfull depth limits formation of scour pools, and the narrow channel width and high concentration of boulders in the bed inhibit integration of LWD into the channel bed. LWD jams create limited potential for channel avulsion. Gravel bars are relatively uncommon and of small size. Bar type is predominantly forced. Fine sediment is sparse or absent, and is deposited in small patches when present.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are mostly continuous, but reaches of channel confined within terraces and valley walls were observed, and tend to be steeper. Floodplains are significant, and typically have side channels and high flow channels. Overbank flow is not uncommon. Riparian vegetation is relatively consistent with a shrub understory and mature conifer overstory. Bank erosion is not uncommon, perhaps because channel adjustment to peak flow occurs more readily in a lateral direction than vertical owing to limited bed scour. Side channels and overflow channels are evidence of channel avulsion and limited channel migration on the floodplain.

Channel Migration Zones

This GCU contains CMZ type 4, which is predicted to have a moderate potential for channel migration. Observations of side channels indicate that channel migration occurs primarily by channel avulsion, and that it is spatially common on floodplains in this GCU. Side channels were associated with LWD and lower-gradient, less confined (entrenched) reaches. Typical floodplain and CMZ width was about 9 m (30 ft), and ranged from 3 to 15 m. Relatively wide floodplains and high frequency of side channels in this headwater GCU may have hydrologic significance with respect to routing of peak flows.

Table 4E-13. Summary of channel sensitivity ratings and criteria, GCU 8, Perennial Headwaters.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Low / Low	Moderately-high stream power and low sediment supply from hillslopes makes channel response from inputs unlikely.
Fine Sediment	Low / Low	High stream power (and often low sediment supply) prevents significant accumulation of fine sediment.
Peak Flows	Low-Moderate / Low	Coarse bed sediment makes increased scour unlikely; channel morphology allows flood energy to dissipate in side channels and on the floodplain.
LWD	Moderate / Moderate	Effect of LWD on channel morphology is significant, but limited. LWD has greatest effect by creating steps and inducing channel avulsion.
Landslides or Floods	Low / Low	There was no evidence of delivery of sediment to this GCU by landslides; flood flows spread on a relatively wide floodplain.
Riparian Vegetation	Low-Moderate / Moderate	Riparian vegetation helps maintain streambanks and provides for LWD recruitment.
Channel Migration Zone	Moderate / Moderate	Channel avulsions & side channels are common, and the floodplain is surprisingly well-developed for a headwater channel. Significance may be in slowing the delivery of peak flows downstream.
Confidence	High	Sufficient survey sites for a steep channel type; some intermittents (GCU 11) may be perennial.

4E.3.2.9 *GCU 9: Canyons & Cascades*

This GCU is comprised of stream segments located primarily in the canyon of Murr Creek near the confluence of the South Fork, and a short segment at the mouth of Beatrice Creek. This GCU contains 3.8% of channel length in the study area, and 9.9% of perennial stream length. Segments in this GCU have moderately steep gradients. Stream segments in Murr Creek lie in bedrock canyons; at the mouth of Beatrice Creek, the channel drops over a valley wall, cutting a shallow canyon above its confluence with Fish Trap Creek. High stream power and high degree of channel confinement promote rapid transport of sediment downstream. Portions of segments mapped as GCU 9 may have characteristics of GCU 5.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 9 is cascade and step-pool. Observed slopes ranged from about 5 to 10%, with the average about 8%. Segment slopes from digital elevation data range from 5 to 19%, with the average about 10%. Floodplains are typically confined by valley walls and

boulders. Valley walls typically have slopes > 100%. The canyon of Murr Creek was inundated by Lake Missoula, but the origin of the canyon probably precedes the most recent glaciation. Glacial ice and or meltwater eroded the valley of Fish Trap Creek and left the mouth of Beatrice Creek hanging about 50-100 ft above the post-glacial grade of Fish Trap Creek. Channel gradient and confinement varies, creating reaches where there is some deposition of coarse sediment, but little or no channel avulsion. Stream power is sufficient to transport most channel-stored sediment. There are relatively few significant gravel bars associated with tail outs of large pools formed in bedrock and boulder steps. Bedload is routed through this GCU relatively quickly. The majority of active bedload sediment is delivered from channels upstream, with some recruitment from long-term storage in terraces by bank erosion and by shallow mass wasting (primarily rock fall) on steep slopes adjacent to channels. Erosion and sedimentation processes are active in only a few areas. Most of the channel bed is armored with boulders and bedrock. LWD contributes little to channel morphology as the steepness of the channel and the prevalence of boulders and bedrock outcrops tend to suspend LWD that reaches the channel above the bed. Large debris jams probably form and increase sediment storage potential of the channel. LWD is not effective at creating scour pools.

Sediment Size and Stream Power

The overall median grain size on the bed is in the size class of boulders (roughly > 250 mm or 10 in), by far the greatest for any GCU. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 38$ mm (1.5 in). Average unit stream power index (4.8) is near the top of the range for higher-gradient reaches. Values ranged from 2.9 to 4.6. Total stream power index of about 30 is at the upper end of the range for the project area because of moderately-high channel width and high channel slope.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is relatively high. Typical entrenchment ratio is about 1.6, which at the low end of the range for the study area. This is defined as moderately entrenched by Rosgen (1994). The bankfull flow has limited opportunity to onto a narrow floodplain. Channel bottoms are generally boulders and cobbles, with some bedrock exposures. Dominant elements of flow resistance (channel roughness) are boulders protruding from the bed, form roughness created by boulder steps, and bedrock. In some areas, LWD provides some roughness. Average LWD abundance is moderate, but varies widely. LWD recruitment rates are high because of the delivery of fallen trees from steep valley walls. LWD has the greatest influence in debris jams, and may be a significant component of channel morphology locally, but the degree of armoring on the bed limits formation of scour pools, and the narrow channel width and high concentration of boulders in the bed inhibit integration of LWD into the channel bed. Most pools are associated with bedrock and boulder steps. Gravel bars are uncommon. Bar type is predominantly forced, located at the tails of deep pools. Fine sediment is sparse to not present on the bed.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are absent or discontinuous. Overbank flow is not common. Riparian vegetation is limited by the bedrock and coarse substrate on valley bottom. Typical vegetation are a sparse shrub understory and sparse mature conifer overstory. Bank erosion is uncommon because of the prevalance of boulders and bedrock on the channel bed and banks.

Channel Migration Zones

This GCU is expected to be too steep to permit channel migration. Evidence of unambiguous channel migration was not found in the field. A narrow floodplain is established where canyon walls open and local valley slope moderates.

Table 4E-14. Summary of channel sensitivity ratings and criteria, GCU 9, Canyons & Cascades.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Low / Low	High stream power and low sediment supply from hillslopes makes channel response from inputs unlikely.
Fine Sediment	Low / Low	High stream power prevents significant accumulation of fine sediment.
Peak Flows	Low / Low	Coarse bed sediment makes increased scour unlikely; channel morphology is typically resistant to change due to increased peak flow.
LWD	Low / Low	Effect of LWD on channel morphology is locally significant, but extremely limited. Most LWD in this type of channel has little effect on channel morphology.
Landslides or Floods	Low / Low	High stream power and channel entrenchment induce efficient routing of sediment and water. Landslide inputs were not observed in the study area, but could have significant transient effects on channel morphology that would probably have largely positive effects on fish habitat by introducing gravel for routing to habitat areas downstream.
Riparian Vegetation	Low / Low	Riparian vegetation provides for LWD recruitment.
Channel Migration Zone	Low / Low	Channel migration processes are not active.
Confidence	Moderate	One survey site supplemented by four fish habitat survey sites; possible that reaches of GCU 5 may be mapped in GCU 9 in Murr Creek.

4E.3.2.10 *GCU 10: Headwater in Valley Fill*

This GCU consists of a few contiguous stream segments on a headwater tributary of Beatrice Creek. This GCU contains 0.9% of channel length in the study area, and 2.4% of perennial stream length. Segments in this GCU have moderately steep gradients and lie in moderate to steep-sided valleys with wide valley bottoms. Channels are slightly incised in valley fill that was probably deposited near the shoreline of ancient Lake Missoula. Erosion of the channel bottom is limited by relatively low stream power and LWD. Transport of sediment downstream is relatively slow.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 6 is primarily step-pool, with elements of plane be and forced pool-riffle. Observed slopes ranged from about 6 to 8%, with the average about 7%. Floodplains are typically confined by terraces, and by valley walls in a few areas. Channels are moderately entrenched relative to the floodplain. The retreat of glacial ice and recession of Lake Missoula allowed streams to erode through sediment deposited in shoreline deltas. Channel confinement varies somewhat, creating reaches where there is more frequent channel avulsion. Stream power is sufficient to mobilize most channel-stored sediment, but gravel bars and side channels are relatively common. Consequently, bedload is routed through this GCU relatively slowly. The majority of active bedload sediment is produced by channel incision (bed erosion) and bank erosion. Erosion and sedimentation processes are active in most areas. During peak flow events the streambed can be generally mobilized. Channel scour and incision are limited by modest stream power and LWD that creates step-pool morphology. LWD contributes to channel morphology by forming steps and debris jams, and is moderately effective at creating scour pools. Narrow channel width reduces potential for LWD to become incorporated in the channel.

Sediment Size and Stream Power

The overall median grain size on the bed is gravel (about 49 mm or 1.9 in). This is in the low portion of the range for higher-gradient GCU's, and reflects modest stream power and high channel roughness. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 18$ mm (0.7 in). Average unit stream power index (1.9) is at the low end of the range for higher-gradient reaches. Total stream power (4.9) is also near the low end of the range for higher-gradient reaches because of modest slope and relatively small channel width and depth.

Reach-Scale Characteristics of Channel Morphology

Observed entrenchment is relatively high. Average entrenchment ratio is 2.0, ranging from 1.6 to 2.8. This is defined as moderately entrenched by Rosgen (1994). In many locations, the bankfull flow spreads onto a relatively narrow floodplain. In some reaches the channel may be tightly confined by terraces and valley walls. Channel bottoms are generally coarse alluvium and/or fluvio-glacial deposits, with boulders exposed in the channel bottom in some areas. Elements of flow resistance (channel roughness) are varied, including LWD, banks, vegetation, boulders and cobbles protruding

from the bed, form roughness created by LWD steps. Typical LWD abundance is moderate, but in some areas, LWD load has been reduced by historic timber harvest. LWD has the greatest influence in debris jams and logs that form steps in the channel. LWD is a significant component of channel morphology. It limits channel erosion, and contributes to formation of scour pools. The narrow channel width inhibits integration of LWD into the channel bed. LWD jams create potential for channel avulsion on narrow floodplains. Gravel bars are relatively common. Bar type is predominantly forced. Fine sediment is relatively common and is deposited in patches and bars.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are largely continuous, but sometimes separated by reaches of channel confined within terraces and valley walls. Floodplains are significant, containing side channels and high flow channels. Overbank flow is not common. Riparian vegetation (a shrub understory and mixed hardwood and conifer overstory) limits bank erosion and creates significant channel roughness. Bank erosion is not uncommon, in part because of the fine-grained material in the banks and the presence of LWD that directs stream energy against banks in some locations.

Channel Migration Zones

This GCU contains CMZ type 5, which is predicted to have a low to moderate potential for channel migration. Evidence of channel migration suggests it occurs with significant frequency. Side channels were common, and were observed to be associated with LWD and lower-gradient, less confined (entrenched) reaches. Typical floodplain and CMZ width was about 5 m (16 ft), with relatively little variation. Side channels formed by avulsion reduce stream power, which is already relatively low, accentuating the tendency for sediment deposition.

Table 4E-15. Summary of channel sensitivity ratings and criteria, GCU 10, Headwater in Valley Fill.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Moderate / Moderate	Modest stream power and high sediment supply from terraces and channel bed (incision) makes channel response from inputs likely; hillslope inputs appear to be small.
Fine Sediment	Low-Moderate / Moderate	Modest stream power and moderately-high supply from bank erosion allow for modest accumulation of fine sediment, additional fine sediment inputs could reduce quality of habitat for native fish.
Peak Flows	Low-Moderate / Moderate	Relatively fine-grained sediment in bed and banks creates potential for increased bed and bank erosion. Riparian vegetation and moderately abundant LWD limit potential erosion.
LWD	Moderate-High / High	Effect of LWD on channel morphology is significant. Where steps or jams form, bed erosion (incision) is limited upstream, and pools are scoured downstream. LWD is also the main agent of channel avulsion. Much LWD in this type of channel (i.e. in Beatrice Creek), is a relict of a previously harvest stand.
Landslides or Floods	Low / Low	There was no evidence of mass wasting that delivered sediment to these channels, which are typically separated from hillslopes by a wide terrace. Flood flows spread on to a narrow, but largely continuous floodplain.
Riparian Vegetation	Moderate / Moderate	Riparian vegetation helps maintain streambanks and provides for LWD recruitment.
Channel Migration Zone	Moderate / Moderate	Channel avulsions & side channels are common, and are likely to maintain favorable habitat conditions by reducing stream power and inducing gravel deposition and discouraging channel incision.
Confidence	High	High number of survey sites for an unusual GCU.

4E.3.2.11 *GCU 11: Confined Intermittent*

This GCU consists of intermittently-flowing (seasonal) headwater stream segments in Murr Creek and Beatrice Creek. This GCU contains 28.3% of channel length in the study area. Segments in this GCU have steep gradients and lie in moderate to steep-sided valleys with narrow valley bottoms. Erosion of the channel bottom is limited by relatively high channel roughness. Transport of sediment downstream is relatively rapid.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 11 is primarily step-pool and cascade, with some colluvial channel characteristics. Observed slopes ranged from about 15 to 21%, with the average about 19%. Floodplains are typically discontinuous and confined by terraces and valley walls. Channels are moderately entrenched relative to the floodplain. Channel confinement relaxes particularly in reaches near confluences with perennial channels downstream, creating reaches where there is more frequent channel avulsion. Stream power is sufficient to mobilize much channel-stored sediment, but large cobbles and boulders are essentially immobile. Gravel bars and side channels are relatively uncommon. Consequently, bedload is routed through this GCU relatively quickly. The majority of active bedload sediment is produced by bank erosion and hillslope creep processes. Erosion and sedimentation processes are not active in most portions of the channel bed, except where LWD jams create pockets of stored sediment or where gradient and/or confinement decrease. During peak flow events, portions of the streambed not armored by boulders and cobbles can be mobilized. Channel scour and incision are limited by coarse substrate and high flow resistance. LWD contributes to channel morphology by forming steps and debris jams which cause sediment deposition and some channel avulsion. Narrow channel width reduces potential for LWD to become incorporated in the channel.

Sediment Size and Stream Power

The overall median grain size on the bed is on the boundary between gravel and cobble size classes (about 64 mm or 2.5 in). This is in the middle portion of the range for higher-gradient GCU's, and reflects moderately-high stream power that is attenuated by high channel roughness. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 12$ mm (0.5 in). Average unit stream power index (4.9) is in the middle of the range for higher-gradient reaches. Total stream power (6.4) is also near the middle of the range for higher-gradient reaches because of modest slope and relatively small channel width and depth.

Reach-Scale Characteristics of Channel Morphology

Average entrenchment ratio for two sites is 2.7, ranging from 1.4 to 4.0. These intermittent channels lie at the bottom of small, v-shaped headwater valleys, and although they cannot migrate significantly, there are areas where a surprisingly wide floodplain has developed. Channel bottoms are generally coarse alluvium and/or fluvio-glacial deposits, with boulders and cobbles exposed in the channel bottom in most areas. Elements of flow resistance (channel roughness) are varied, including LWD, banks, vegetation, boulders and cobbles protruding from the bed, form roughness created by boulder steps. Typical LWD abundance is moderate. LWD has the greatest influence in debris jams and logs that form steps in the channel. LWD is a significant component of channel morphology that creates sediment storage sites, contributes to formation of scour pools, and creates potential channel avulsion. The narrow channel width inhibits integration of LWD into the channel bed. Gravel bars are small where present. Bar type is forced. Fine sediment was observed to be abundant in some sites and sparse in others, apparently depending on recent local disturbance and flood history.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are discontinuous, with observed widths ranging from about 2 to 5 m (6 to 16 ft). Overbank flow is not common. Riparian vegetation (a shrub understory and mixed hardwood and conifer overstory) limits bank erosion and creates significant channel roughness. Bank erosion is not uncommon, in part because of the fine-grained material in the banks and the presence of LWD that directs stream energy against banks in some locations.

Channel Migration Zones

This GCU is expected to be too steep to permit channel migration. Evidence of some channel avulsion was, however, found in the field. A narrow floodplain is established where valley walls open and local valley slope moderates. Side channels formed by avulsion reduce sediment transport capacity and promote deposition. Intermittent streams comprise the majority of the channel network in the study area, and play a potentially significant role in routing of sediment, particularly fines, from watershed slopes to perennial streams utilized by fish. Fine sediment storage is increased by channel avulsions, LWD and floodplain area.

Table 4E-16. Summary of channel sensitivity ratings and criteria, GCU 11, Confined Intermittent.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Moderate / Moderate	Modest stream power and small channel create potential bank erosion if significant inputs of coarse sediment occur. Hillslope inputs appear to be small, primarily from creep processes.
Fine Sediment	Low / Low	Modest stream power and high channel roughness allow for modest accumulation of fine sediment. Significance relates primarily to routing of fine sediment to downstream habitats.
Peak Flows	Low-Moderate / Low	Potential erosion of banks, including hillslopes, could result from peak flow increases. Riparian vegetation and moderately abundant LWD limit potential erosion. Effects on fish habitat would be indirect, no fish use.
LWD	Moderate / Moderate	Effect of LWD on channel morphology is significant. Where steps or jams form, sediment deposition occurs upstream, and pools are scoured downstream. LWD is also the main agent of channel avulsion, and contributes to high channel roughness.
Landslides or Floods	Low / Low	There was no evidence of mass wasting that delivered sediment to these channels. Flood flows would have limited effects owing to position in watershed.
Riparian Vegetation	Moderate / Moderate	Riparian vegetation helps maintain streambanks and provides for LWD recruitment.
Channel Migration Zone	Low / Low	Channel avulsions & floodplain are uncommon, but likely significant with respect to fine sediment routing. CMZ width is small and localized. Management considerations: minimize disturbance by equipment, provide for modest LWD recruitment and maintenance of riparian vegetation.
Confidence	Moderate	Small sample of widely distributed GCU.

4E.3.2.12 *GCU 12: Unconfined Intermittent*

This GCU consists of intermittently-flowing (seasonal) headwater stream segments in Murr Creek, Beatrice Creek, and Boiling Springs Creek. This GCU contains 33.7% of channel length in the study area. Segments in this GCU have moderate to steep gradients and lie in valleys with wide bottoms and gently-sloping hillslopes. In many areas, the channel lies in wetland settings. Erosion of the channel bottom is limited by low stream power and relatively high channel roughness. Transport of sediment downstream is relatively slow.

Geomorphic Characteristics and Conditions

Observed channel morphology in GCU 12 is variable, and includes step-pool with elements of plane

bed and forced pool-riffle, step-pool and cascade, and colluvial channels. Observed slopes ranged from about 5 to 30%, with the average about 13%. Floodplains are typically continuous. Channels are slightly entrenched relative to the floodplain. Multiple channels are common, but contemporary channel avulsion may not be the process responsible for their formation. Peak stream power is sufficient to mobilize much channel-stored sediment, but small cobbles are essentially immobile. Annual flow duration capable of sediment transport is quite limited. Gravel bars are relatively uncommon. Channel roughness is high and side channels not uncommon, consequently, bedload is routed through this GCU relatively slowly. The majority of active bedload sediment is produced by bank erosion. Erosion and sedimentation processes are not active in most portions of the channel bed, except where LWD jams, other roughness elements, and side channels create pockets of stored sediment. During peak flow events, portions of the streambed not armored by cobbles can be mobilized. Channel scour and bank erosion are limited by coarse substrate and high flow resistance. LWD contributes to channel morphology by forming steps and debris jams which cause sediment deposition and some channel avulsion. Narrow channel width reduces potential for LWD to become incorporated in the channel.

Sediment Size and Stream Power

The overall median grain size on the bed is gravel (about 50 mm or 2.0 in). This is in the low portion of the range for higher-gradient GCU's, and reflects moderately-low stream power that is attenuated by high channel roughness. The highly-mobile component of the channel substrate that is sorted on the surface of gravel bars has $d_{50} \approx 17$ mm (0.7 in). Average unit stream power index (2.5) is near the bottom of the range for higher-gradient reaches. Total stream power (3.1) is also near the bottom of the range for higher-gradient reaches because of modest slope and relatively small channel width and depth.

Reach-Scale Characteristics of Channel Morphology

Average entrenchment ratio for three sites is > 10. These intermittent channels lie at the bottom of small, u-shaped headwater valleys, and although they cannot migrate significantly, a wide floodplain has developed. Channel bottoms are generally coarse alluvium and/or fluvio-glacial deposits, with cobbles and boulders exposed in the channel bottom in most areas. Elements of flow resistance (channel roughness) are primarily vegetation, banks and LWD. Typical LWD abundance is moderate, but it varies from sparse to abundant. LWD is a major element of channel roughness, but also forms steps in the channel. LWD is a significant component of channel morphology that creates sediment storage sites, contributes to formation of scour pools, and creates potential for channel avulsion. The narrow channel width inhibits integration of LWD into the channel bed. Gravel bars are small where present. Bar type is forced. Fine sediment was observed to be sparse, despite low stream power, suggesting that valley form limits delivery of fine sediment from hillslopes.

Reach-Scale Floodplain and Hillslope Interactions

Floodplains are continuous, with observed widths ranging from about 8 to > 60 m (27 to > 195 ft).

Overbank flow is common. Riparian vegetation (a shrub understory and mixed hardwood and conifer overstory) limits bank erosion and creates significant channel roughness. Bank erosion is not uncommon, in part because of the fine-grained material in the banks and the presence of LWD that directs stream energy against banks in some locations.

Channel Migration Zones

This GCU include channels expected to be too steep to permit channel migration and channels in CMZ type 4, where channel migration potential is expected to be moderate. Evidence of some side channels was found in the field over a wide range of slopes. The wide valley bottoms in this GCU tend to have a shallow water table and some wetland characteristics. Multiple channels may proliferate because of frequent seasonal saturation and relatively high slopes that induce channel formation. Side channels may not in general be formed by avulsion, but the presence of LWD may promote avulsion during unusually high runoff. The wetland character of these areas reduce sediment delivery to channels and promote deposition. Intermittent streams comprise the majority of the channel network in the study area, and play a potentially significant role in routing of sediment, particularly fines, from watershed slopes to perennial streams utilized by fish. Fine sediment storage is increased by channel avulsions, LWD and floodplain area.

Table 4E-17. Summary of channel sensitivity ratings and criteria, GCU 12, Unconfined Intermittent.

Watershed Input or Influence	Physical Channel Sensitivity / Habitat Vulnerability	Primary Criteria for Sensitivity Rating
Coarse Sediment	Low / Low	Wide valley bottoms prevent delivery of significant coarse sediment to channels.
Fine Sediment	Low / Low	Modest stream power and high channel roughness promote accumulation of fine sediment. Valley form limits fine sediment delivery. Significance relates primarily to routing of fine sediment to downstream habitats.
Peak Flows	Low / Low	Potential erosion of banks could result from peak flow increases, but wide floodplain reduces stream energy. Riparian vegetation and moderately abundant LWD limit potential erosion. Effects on fish habitat would be indirect; no fish use in intermittents.
LWD	Low - Moderate / Moderate	Effect of LWD on channel morphology is significant. Where steps form, sediment deposition may occur, and pools may be scoured downstream. LWD is a potential agent of channel avulsion, and contributes to high channel roughness.
Landslides or Floods	Low / Low	There was no evidence of mass wasting that delivered sediment to these channels. Flood flows would have limited effects owing to position in watershed headwaters and wide floodplain.
Riparian Vegetation	Moderate / Moderate	Riparian vegetation helps maintain streambanks and provides for LWD recruitment.
Channel Migration Zone	Low / Low	Channel avulsions are uncommon, but broad floodplain and wetland-like conditions is significant with respect to low fine sediment production and routing. Management considerations: minimize disturbance by equipment, provide for modest LWD recruitment and maintenance of riparian vegetation.
Confidence	Moderate	Low sample size for widely distributed GCU.

4E.4 PREDICTION OF CHANNEL SENSITIVITY AND HABITAT VULNERABILITY-RELATIONSHIPS BETWEEN GCU'S AND GUILDS

Stream channels were classified on a preliminary basis by Plum Creek Timber Co. using data from the ecological classification (Whitehorse Associates, 1997). The initial classification used two parameters: valley bottom type and combined stream order. The valley bottom types are listed in Table 4E-18. Combined stream order groups streams according to the Strahler stream order, where streams of first and second order are classified as combined order one, streams of third and fourth order are classified as combined order two, and fifth and sixth order streams are classifed as combined order three. Combining these two criteria, and eliminating groups that represent less than one percent

of stream length in the Thompson River watershed, resulted in 21 "stream guilds".

The distribution of channel slope in each of the initial guilds were evaluated as a preliminary assessment of the degree of accuracy they might provide in predicting channel morphology and, therefore, general habitat characteristics. Channel slope is widely regarded as a key variable in predicting channel characteristics and morphology (e.g. Montgomery and Buffington, 1997, Rosgen, 1994). Widely used channel classification systems group channels according to slope, among other variables (Table 4E-19).

The range of slopes within the spread of one standard deviation on either side of the mean value is a measure of the expected accuracy of the channel morphology prediction that might be made on the basis of guilds (Table 4E-20). As can be seen in Table 4E-19, there is relatively high variability in channel morphology for channel slopes less than three percent, with less morphologic variability for channels steeper than three percent. Potential channel response to changes in watershed inputs of water, sediment and LWD increase with decreasing channel slope. Cascade channels (> 6.5 percent slope) are relatively insensitive to changes, channel types with slopes < 3 percent are sensitive to change, with the step-pool channel type predicted to have intermediate sensitivity (Montgomery and Buffington, 1997).

The slope range for guilds (Table 4E-20) provides an initial assessment of their predictive value with respect to channel morphology. Based on the spread of channel slope defined by the mean segment slope plus or minus one standard deviate for each guild, it is likely that channels classified in guilds A, B, F, H, and O are each dominated by a relatively uniform morphologic type, with corresponding sensitivity. These guilds represent about 25 percent of the channel segments in the Thompson River. The remaining guilds, however, have sufficient slope variation to be weak predictors of channel morphology.

Table 4E-18. Valley bottom types as defined by Whitehorse Associates, 1997. Refer to the ecological classification report, pages 3-129 through 3-131 for valley bottom type classification criteria and descriptions.

Valley-Bottom Type	VBT Identification Number	Average Stream Grade (%)
Alpine Glacial Basin	1110	18
Alpine Glacial Train	1120	8
Glacial Outwash	1130	5
Cascade	1205	31
Fluvial Basin	1210	19
Fluvial V-Erosional Canyon	1220	9
Fluvial V-Depositional Canyon	1230	3
Continental Cascade	1305	23
Continental Fluvial Basin	1310	13
Continental V-Erosional Canyon	1320	6
Continental V-Depositional Canyon	1330	3
Glacio-Lacustrine Basin, Unconfined	1410	2.1
Glacio-Lacustrine Basin, Confined	1420	4.1
Glacio-Lacustrine Canyon	1430	1.3

Table 4E-19. Channel morphology classes and typical slope ranges for classification (after Washington Forest Practices Board, 1995, and Montgomery and Buffington, 1997).

Channel Morphology	Corresponding Watershed Analysis Channel Slope Classes	Typical Observed Slope Range (%)
Pool-riffle	0-1	< 1.5
Forced pool-riffle	1-2, 2-4	< 2.5
Plane bed	1-2, 2-4	1.5 - 3.0
Step-pool	2-4, 4-8	3 - 6.5
Cascade	4-8, 8-20	> 6.5

Table 4E-20. Stream guilds based on valley bottom type and combined stream order. Guilds denoted by (*) have a range of slopes (the mean +/- one standard deviation) that suggest the guild class will have reasonably good predictive value with respect to stream morphology. Other guilds have wide variation in slope in the range of 0 to 6.5 percent, with attendant variation in channel morphology (see Table 4E-19).

VBT	Stream Order	n	Guild	% of Stream Segments	GIS/ DEM Chanl. Slope Stats (%)				
					Mean	StDev	Median	Max	Min
1110	1&2	71	A*	7.8%	16.9	11.6	13.6	65.4	0.4
1120	1&2	14	B*	1.5%	10.5	5.1	10.5	20.9	4.0
1120	3&4	38	C	4.2%	5.5	3.9	4.1	15.2	0.6
1130	1&2	40	D	4.4%	4.1	4.3	3.1	25.7	0.0
1130	3&4	75	E	8.2%	3.1	2.6	2.3	14.0	0.0
1205	1&2	30	F*	3.3%	28.7	14.1	25.3	67.2	8.0
1210	3	15	G	1.6%	11.1	7.3	8.1	26.1	2.6
110	1&2	86	H*	9.5%	13.2	7.3	13.0	39.3	0.3
1220	1&2	82	I	9.0%	9.6	6.0	8.6	35.1	0.8
1220	3&4	144	J	15.8%	6.1	4.4	4.8	22.9	0.4
1230	3&4	51	K	5.6%	3.8	4.2	2.4	24.3	0.0
1310	1&2	15	L	1.6%	6.1	3.1	6.3	10.7	0.2
1320	3	16	M	1.8%	4.4	3.0	3.6	11.8	0.2
1320	1&2	27	N	3.0%	7.1	5.3	5.5	21.5	2.0
1330	5	11	O*	1.2%	1.2	0.8	1.0	3.1	0.1
1330	3&4	21	P	2.3%	3.1	3.6	1.7	15.2	0.1
1410	1&2	25	Q	2.7%	4.3	5.7	1.7	19.8	0.4
1410	3&4	19	R	2.1%	2.0	2.9	0.7	10.3	0.1
1420	1&2	44	S	4.8%	4.0	2.4	3.6	10.1	0.0
1420	3&4	64	T	7.0%	3.4	2.5	3.5	10.8	0.1
1430	5	22	U	2.4%	2.6	4.0	1.7	19.9	0.4

The likely inaccuracy of the guilds in predicting channel morphology as indexed by channel slope was anticipated prior to field surveys. Fish habitat surveys conducted in the three watershed analysis sub-basins as well as in the other stream segments in the Thompson River watershed included channel slope classes as an additional criterion. These habitat surveys include enough morphological data to allow assessment regarding proposed channel classification that synthesizes the results of ecological classification (guilds) with watershed analysis channel types (geomorphic channel units-GCU's).

Field data on channel slope suggest that a significant proportion of the variation of channel slope within guilds (Table 4E-20) may be attributable to limited accuracy of digital elevation data used to generate slope of stream channel segments. Mean channel slope for each GCU calculated from field measurements correlates closely with mean channel slope for each GCU calculated from slope data for stream segments generated from digital elevation data (Table 4E-21). Stream segments were defined by confluences with other channels, consequently, some of the segments were quite short.

Digital elevation data points do not always coincide with stream channel locations, and the computer generally selects the nearest point to calculate slope. Over longer segments, these elevation approximations are not significant, but over short segments, they may lead to significant over- and under-estimates of channel slope. This characteristic of digital elevation data suggests that the foregoing identification of guilds that are likely to accurately predict channel morpology is relatively robust..

Table 4E-21. Comparison of mean channel slope calculated for perennial stream GCU's from field observations and from digital elevation data. Field observations include data from fish habitat surveys.

GCU	Mean Channel Slope from Digital Elevation Data (%)	Mean Channel Slope from Field Observations (%)
1	3.6	3.2
2	2.4	2.0
3	1.0	0.7
4	3.4	3.3
5	3.0	3.1
6	8.9	9.3
7	18.5	19
8	9.4	7.6
9	10.8	7.5
10	6.7	6.6

If channel slope calculations from digital elevation data can be adjusted to compensate for short channel segments, or if the average for each guild can be assumed to be representative and that potential significant errors are few, then correlations between the guilds (Table 4E-19) and GCU's (e.g., Table 4E-22) may be relatively simple. For instance, if GCU's are divided into two major groups, the lower- and higher-gradient GCU's, and channel segments are represented by guilds, a few correlations appear. Lower-gradient GCU's are associated almost exclusively with commonly occurring guilds E and Q. Guild R is also associated with lower-gradient GCU's, but is uncommon. Guilds C, J and N are significant, commonly occurring constituents of both lower- and higher-gradient GCU's. Guilds D and T occur infrequently, but appear in both higher- and lower-gradient GCU's. Guilds A, H and I occur commonly and are associated almost uniquely with higher-gradient GCU's. Guilds G, K, and L occur infrequently, and are associated with higher-gradient GCU's.

Table 4E-22. Channel segment data for stream guilds sorted by GCU. Correlations and patterns relating GCU's to guilds can serve as a guide to extrapolating watershed analysis results to channel segments throughout the Thompson River watershed.

WATERSHED	REACH	GCU	LENGTH (meters)	VBT CODE	STREAM ORDER	GRADE (%)	VBT	COR	GUILD
Boiling Springs	250	1	221	1410	2	3.7	1410	1	[Q]*(2-4)
Boiling Springs	333	1	942	1410	2	5.4	1410	1	[Q]*(4-8)
Murr	472	1	156	1410	4	1.7	1410	2	[R]*(1-2)
Boiling Springs	289	2	1882	1320	2	2.0	1320	1	N(2-4)
Boiling Springs	291	2	422	1320	2	2.9	1320	1	N(2-4)
Boiling Springs	315	2	938	1410	2	1.1	1410	1	[Q](*1-2)
Murr	344	2	1147	1130	2	1.6	1130	1	[D]*1-2)
Murr	384	2	137	1130	3	0.0	1130	2	[E]*(0-1)
Murr	410	2	1028	1130	3	0.7	1130	2	[E]*(0-1)
Murr	382	2	1158	1130	3	1.6	1130	2	E(1-2)
Murr	370	2	291	1130	3	2.0	1130	2	E(2-4)
Murr	362	2	894	1130	3	3.9	1130	2	E(2-4)
Murr	387	2	146	1130	3	8.2	1130	2	[E]*(8-20)
Boiling Springs	328	3	1077	1410	2	1.0	1410	1	[Q](*1-2)
Murr	513	4	861	1220	3	2.2	1220	2	J(2-4)
Murr	478	4	1581	1420	4	3.7	1420	2	T(2-4)
Beatrice	1706	4	305	1120	4	0.6	1120	2	[C]*(0-1)
Beatrice	1772	4	77	1120	4	0.7	1120	2	[C]*(0-1)
Beatrice	1709	4	28	1120	4	3.4	1120	2	C(2-4)
Beatrice	1791	4	721	1120	4	4.3	1120	2	C(4-8)
Beatrice	1759	4	725	1120	4	5.2	1120	2	C(4-8)
Beatrice	1770	4	171	1120	4	7.3	1120	2	C(4-8)
Beatrice	1660	4	605	1220	4	2.5	1220	2	J(2-4)
Beatrice	1660	4	305	1220	4	3.0	1220	2	J(2-4)
Murr	475	5	1703	1220	4	2.4	1220	2	J(2-4)
Murr	458	5	661	1220	3	3.7	1220	2	J(2-4)
Beatrice	1641	5	1352	1220	4	2.9	1220	2	J(2-4)
Boiling Springs	257	6	462	1320	2	7.5	1320	1	N(4-8)
Beatrice	1821	6	8	1110	3	2.8	1110	2	*(2-4)
Beatrice	1849	6	926	1110	3	9.2	1110	2	*(8-20)
Beatrice	1815	6	225	1120	3	8.1	1120	2	[C]*(8-20)
Beatrice	1797	6	124	1120	4	10.4	1120	2	[C]*(8-20)
Beatrice	1800	6	353	1120	3	10.8	1120	2	[C]*(8-20)
Beatrice	1820	6	508	1120	3	13.2	1120	2	[C]*(8-20)
Beatrice	1883	7	2220	1110	2	14.5	1110	1	A(8-20)
Beatrice	1912	7	1086	1110	2	18.5	1110	1	A(8-20)
Beatrice	1896	7	231	1110	2	19.8	1110	1	A(8-20)
Beatrice	1856	7	275	1110	3	21.3	1110	2	*(>20)

Table 4E-22 (continued)

WATERSHED	REACH	GCU	LENGTH (meters)	VBT CODE	STREAM ORDER	GRADE (%)	VBT	COR	GUILD
Boiling Springs	353	8	351	1310	2	10.7	1310	1	[L]*(8-20)
Boiling Springs	335	8	143	1320	2	5.7	1320	1	N(4-8)
Boiling Springs	348	8	1039	1320	2	9.7	1320	1	[N]*(8-20)
Boiling Springs	350	8	109	1320	2	17.4	1320	1	[N]*(8-20)
Boiling Springs	355	8	355	1320	2	18.9	1320	1	[N]*(8-20)
Boiling Springs	337	8	10	1320	2	21.5	1320	1	[N]*(>20)
Murr	361	8	361	1130	2	4.6	1130	1	[D]*(4-8)
Murr	574	8	4024	1210	1	4.5	1210	1	H(4-8)
Murr	367	8	1464	1210	2	6.0	1210	1	H(4-8)
Murr	632	8	83	1210	2	7.9	1210	1	H(4-8)
Murr	379	8	552	1210	2	9.5	1210	1	H(8-20)
Murr	389	8	2296	1210	1	12.9	1210	1	H(8-20)
Murr	515	8	334	1220	2	2.7	1220	1	[I]*(2-4)
Murr	505	8	1842	1220	2	5.4	1220	1	I(4-8)
Murr	627	8	3504	1220	2	5.6	1220	1	I(4-8)
Murr	524	8	595	1220	1	6.8	1220	1	I(4-8)
Murr	480	9	288	1220	4	4.6	1220	2	J(4-8)
Murr	446	9	1363	1220	3	6.4	1220	2	J(4-8)
Murr	508	9	793	1220	3	9.8	1220	2	J(8-20)
Murr	495	9	1643	1220	3	12.9	1220	2	J(8-20)
Murr	501	9	613	1220	3	15.1	1220	2	J(8-20)
Murr	497	9	290	1220	3	18.8	1220	2	J(8-20)
Murr	481	9	345	1420	4	8.2	1420	2	[T]*(4-8)
Beatrice	1608	9	49	1230	4	10.4	1230	2	[K]*(8-20)
Beatrice	1777	10	398	1210	2	6.8	1210	1	H(4-8)
Beatrice	1754	10	495	1210	2	10.6	1210	1	H(8-20)
Beatrice	1788	10	321	1210	3	2.6	1210	2	[G]*(2-4)
Boiling Springs	258	12	1609	1320	1	7.8	1320	1	N(4-8)

4E.5 REFERENCES

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APPENDIX E-1

Stream Channel Survey Protocol & Glossary

Segment: [L#] Letter-number pair identifies hydrologic sub-basin and response segment identification number e.g. T1 = Tacoma Creek sub-basin, segment #1, or other identifier.

Channel Type [LL/LL] Letters indicate the dominant and sub-dominant channel reach types as defined by Montgomery and Buffington (TFW-SII10-93-002). Two types are often necessary to characterize the morphology of a given location.

C = cascade **SP** = step-pool **PB** = plane bed **F/PR** = (forced) pool-riffle
R = regime **B** = braided **BR** = bedrock

Observed Slope: [%] Number is the average of field observations of channel slope in percent; the individual observations are recorded in the spreadsheet cell, which is a formula that calculates the average.

SPI: [#.#] The steam power index is the product of bankfull depth (m), bankfull width (m) and mean channel slope (%), and is a quantitative index of total stream power.

Unit SPI: [#.#] The steam power index is the product of bankfull depth (mand mean channel slope (%), and is a quantitative index of the average total shear stress for a given site.

Max[imum] & Avg. Hillslope Angle: [%] Number is the maximum and/or average observed hillslope angle measured in the field with a clinometer. In most cases, the angle of both hillslopes is recorded in a valley cross-section sketch in field notes.

Channel Confinement: [L/L] First letter(s) in the sequence indicates the confinement class derived from topographic maps; second letter(s) are the field-based classification of channel confinement.

C = Confined: channel is prevented from changing its location by valley or terrace walls that are resistant to erosion; expected ratio of valley width to bankfull channel width is < 2.

MC = Moderately Confined: channel is able to erode its banks and move laterally in many locations, but stream banks that effectively resist erosion also constrain channel substantially; the expected ratio of valley width to bankfull channel width

is hypothetically between 2 and 4.

U = Unconfined: channel is able to move laterally in virtually all locations; ratio of valley width to bankfull channel width is expected to be > 4.

VW/BW Ratio: [#] Number is the ratio formed by dividing the valley width (VW) by the bankfull channel width (BW).

Valley Width: [#] Number is the measured width (m) of the valley floor, with valley floor edge defined by the break in slope where the hillslope intersects the channel, terrace, or floodplain. The valley width may not always coincide with the width of the floodplain.

Bankfull Channel Width: [#] Number is the measured width (m) of the bankfull channel, defined by high water marks indicated by strand lines or sediment deposits, and vegetation.

Bankfull Channel Depth: [#] Number is the measured average depth (m) of flow at bankfull stage (i.e, the mean annual flood, R.I. ≈ 1.5 yr.) Not normally equal to the top of the bank, which is typically the elevation of the low terrace.

Channel Roughness: [LLLLL] Letters represent the channel elements that provide resistance to flow at bankfull stage in descending order of importance; the dominant element is listed first. If elements are equally influential, they are separated by a "/".

B = Boulders **C** = Cobbles**V** = Live woody vegetation
R = Bedrock **F**=Bedforms (large gravel bars)**W** = Large woody debris
Bk= Banks & Roots

Floodplain: [Ls] Letter represents the observed distribution of the floodplain that is regularly occupied during periods of peak flows under the modern hyrologic regime (as opposed to, for example, the hydrologic regime associated with the most recent glacial advance). Evidence indicating floodplain extent includes side channels, strand lines, sediment deposits, and vegetation; when significant evidence of overbank flow is observed, the lowercase "s" is included. The longitudinal continuity and presence or absence of an active floodplain are assessed. In channels steeper than about 4 percent slope the "floodplain" may consist of poorly-sorted coarse sediment and debris laying in bars adjacent to the channel deposited during episodes of peak flow.

C = Continuous or nearly-continuous floodplain
D =Discontinuous but significant floodplain
I =Inactive floodplain (i.e. terrace with no evidence of historic flow).

N =No floodplain (i.e. a severely confined channel).
s =significant evidence of overbank flow; e.g. side channels, deposits,strand lines

Entrenchment: [#] Average measured height of terrace surfaces above average elevation of channel bottom. Includes an observation for the active (lowest) terrace, often coincident with the floodplain, and an observation for the inactive (higher) terrace, if present. A zero indicates that the given terrace was absent. The relative positions of terraces are represented in a cross-section sketch of the valley bottom in field notes.

Disturbance: [LLLL] Letters represent the observed disturbances that may have affected the condition of the channel or the riparian zone. *These are given in no particular order* and are intended merely to note historic disturbances that could be influential.

L = Logging **D** = Debris flow/torrent**IG** = Inner gorge mass wasting
F = Flood (severe) **R** = Rip-rap channel banks**N** = None
S – Streamside landslides**Rd** – Road**A** – Avalanche

Riparian: [LLL#] Letters represent riparian condition codes used in version 3 of the riparian module. The first letter indicates the type of forest stand, the second indicates its average size class, and the third indicates the degree of canopy closure. The number following the letters, if present, is the estimated age (yr) of the dominant of riparian trees.

First Letter: **C** = Conifer **D** = Deciduous **M** = Mixed
Second Letter: **Small** = DBH < 30 cm **Medium** = 30 cm < DBH < 50 cm **Large** = DBH > 50 cm
Third Letter: **Sparse** – More than 1/3 of ground is exposed (western Washington)
Dense = Less than 1/3 of ground is exposed (western Washington)

Bedrock/Parent Material: [L...] Letter (and additional characters) represents the presence, absence and extent of bedrock exposed in the channel bed and channel margins observed in the field. If other types of parent material, e.g. indurated glacial till, lacustrine clay, saprolite, etc. this is noted; the key observation is exposure of non-alluvial material.
N = None observed **M** = Present but minimal**C** = Common**D** = Dominant

Bank Erosion: [LL] Letter represents the relative abundance (longitudinal distribution) and size (vertical height relative to avg. bank height (bh)).
Abundance: **Sparse** **Common** **Abundant** **None**
Size: **Small** (ht. = bh) **Medium** (ht.> bh, up to 5(bh)) **Large** (ht.≥ 5(bh))

Streamside Mass

Wasting: [LL] Same criteria as bank erosion. It should be acknowledged that the distinction between bank erosion and streamside mass wasting can be difficult to determine. However, streamside mass wasting is usually associated with a landform (e.g. inner gorge) or material type (e.g. lacustrine clay), and appears to be caused by at least one mechanism other than bank erosion. This observation can be important to assessment of sediment supply to channels. These features are of a scale that rarely can be seen in aerial photography, and are unlikely to be recognized in other assessment modules.

LWD: [LLjL] Letters describe the relative abundance and effectiveness of LWD in the bankfull channel. The first letter refers to abundance. The second letter refers to the degree of function of LWD that is present; the subscript 'j' refers to LWD that is functional primarily in LWD jams rather than as isolated pieces. The third character indicates whether there is evidence of recent or active recruitment of LWD to the channel.

Abundance: **Sparse** **Common** **Abundant**

Function: **Minimal** = LWD present in the channel has insignicant effect on local channel processes. **Functional** = LWD present in the often has significant effect on local channel processes. **Dominant** = LWD exerts an overwhelming influence on channel function and morphology.

Recruitment: **Active** = Fresh wood in or above the channel, or other evidence of ongoing recruitment **Relict** = LWD is present, but is old/decayed and adjacent forest stands are logged or young seral stage **None** = No evidence of LWD recruitment

Bars: [LLLL] Letters represent the relative abundance and type of bars (accumulations of mobile sediment) in and adjacent to the channel. The first letter in the sequence indicates the abundance; subsequent letters indicate the type of bar. If different types of bars are present in substantial numbers, then sub-dominant bar types are indicated with subsequent letters in descending order of relative abundance. A "/" separating letters indicates that the bars are of equivalent abundance; similarly, if two different bar types are present and they have different levels of abundance, then a letter code for abundance appears associated with each bar type.

Abundance: **Few** = present, but comprise an insignificant portion of the surface area within the bankfull channel. **Common** = bars frequently occur and occupy a significant portion of the surface area within the bankfull channel. **Abundant** = bars are nearly continuous and occupy the majority of the surface area within the bankfull channel.

Bar Types: **Forced** = bars formed upstream and downstream of channel obstruction such as boulder or LWD steps. **Point** = point bars formed in alluvial settings opposite pools at outsides of meander bends; reserved for low gradient riffle-pool morphology where helical flow at meander bends is present. **Medial** or **Multiple** = bars forming in center of channel or in a braided channel or in a complex pattern such as might be found at a LWD jam. **Isolated** = bars are isolated to patches with low relief on the bed formed in the lee of small channel

obstructions that do not span the channel such as boulders; typically used in plane-bed morphology.
Alternate = Lateral linear bars on channel margins, typically on alternate sides of channel, often with relatively low relief

Surface d50: (##) The mesh diameter in mm of the sieve that would catch a sediment grain representative of the median grain size found on the surface of bars composed of mobile sediment. This grain diameter is intended to represent the maximum average diameter of bedload being routed through the channel during typical peak flows (e.g. the average annual flood). Coarse grains such as boulders are explicitly excluded because they are effectively immobile with respect to sediment routing.

Roughness Height: (##) The height above the bed of sediment grains at approximately the 84th percentile of a surface pebble count. This is ***not*** the diameter of the grain--it is the height of the particle protruding in the flow. This typically is represented by the c-axis diameter (shortest axis) of the 84th percentile grain.

Fine Sediment: [LL] Letters represent the relative abundance and type of accumulations of sand (diameter less than 1 mm) in the bankfull channel. The first letter indicates abundance; the second letter indicates the type of accumulation.

Abundance: Sparse = Relatively infrequent accumulations. **M** = Intermediate frequency of accumulations. Abundant = Relatively frequent accumulations.
Type of Accumulation: **P** = Isolated pockets, patches and deposits in pool bottoms.
Bars = Fine sediment accumulated in bar forms with substantial relief above the channel bed, including deposition that fills a substantial portion of pool volume.

APPENDIX E-2

Geomorphology of Channel Migration Zones and Implications for Riparian Forest Management

DRAFT MANUSCRIPT

GEOMORPHOLOGY OF CHANNEL MIGRATION ZONES AND IMPLICATIONS FOR RIPARIAN FOREST MANAGEMENT

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Introduction

The concept of channel migration zones (CMZ's) is a consequence of the fact that stream channels are dynamic features of the landscape that change position on valley floors under some circumstances. CMZ's may be defined as terraces and/or floodplain areas adjacent to stream channels that have a high likelihood of being occupied by the stream channel at some time in the forseeable future. The Washington Forest Practices Board (1995) defined the channel migration zone as "...the area that streams have recently occupied (in the last few years or less often decades), and would reasonably be expected to occupy again in the near future." Lateral shifts of stream channels may occur suddenly as the result of flood flows and/or reduced channel capacity caused by sedimentation or debris jams, or gradually as a stream erodes the outside edge of meander bends.

Identification of CMZ's and adoption of specialized management practices in these areas will reduce potential long-term adverse effects of riparian forestry on aquatic ecosystems. Existing regulations relating to forestry activities in riparian zones typically establish limits on harvest activities near stream channels based on the location of ordinary high water (OHW). These regulations are generally intended to provide for shading of the stream surface and recruitment of large woody debris (LWD) to stream channels. CMZ's require specialized management because existing regulations may fail, in some areas, to provide the desired levels of shade or LWD recruitment following episodes of channel migration.

Channel Migration Processes

Lateral shifts in stream channels occur both suddenly and gradually. When a stream channel avulses, that is, when streamflow spills out of the banks of an existing channels, a new channel may be eroded in a short period of time. Channel avulsion typically occurs when the existing channel is incapable of carrying all of the water and sediment supplied to it.

During periods of high stream flow or floods, avulsions may occur at locations where channel morphology forces flow velocity to decrease and flow depth to increase. This often occurs at sharp bends in the channel. If the flow depth exceeds the height of the bank on the outside of the bend, water may spill over the bank. This water may then spread over a floodplain surface or, if the valley has a relatively steep slope and topographic features that concentrate the overbank flow, it may erode a new channel.

Channel avulsions are also caused by deposition of sediment and/or LWD that reduce channel capacity and increase flow depth. Formation of large gravel bars or debris jams may also re-direct high velocity streamflow toward banks. When such flows encounter erodible banks

and/or relatively low-lying terrace surfaces, a new channel may form. In some cases, the new channel will accomodate all of the streamflow and the former channel may be abandoned. In other cases, the new channel may carry excess flows only and the existing channel maintains its character. In still other cases, both new and existing channels may carry water under base flow conditions.

Gradual changes in channel position also occur, most often in low-gradient channels (approximately < 1% slope), as the outer bank of a meander bend is eroded during periods of routine (e.g. annual) peak flow. Bank materials for these low-gradient channels tend to be fine-grained, and are therefore susceptible to erosion. Avulsions may also occur in these types of streams, however, terrace surfaces adjoining such low-gradient streams tend to be nearly level and overbank flow is more likely to spread on a floodplain where there is insufficient slope to erode a new channel.

Gradual channel migration as conceived here occurs during most years at annual rates that are a fraction of the bankfull channel width. In contrast, channel migration by avulsion is conceived to occur sporadically and result in lateral shifts in channel position ranging in size from the bankfull channel width to the valley width. With respect to the former process, the rate of channel migration may be slow enough to allow harvest and regeneration of forest stands in riparian areas subject to channel migration. In the case of the latter process, channel migration is sudden and can occur anywhere within the CMZ. Consequently, if maintenance of aquatic ecosystem structure associated with channels in CMZ's is a priority, riparian forest conditions must be maintained in a state that would allow new channels to recruit significant quantities of LWD.

Occurrence of CMZ's as a Function of Channel Type

In order for channel migration to occur, the valley width must be sufficiently large to accomodate lateral shifts in position. Channels that are confined by valley walls are not prone to channel migration. The definition of a confined channel in common usage relates the bankfull channel width to the valley width. Rosgen (1994) defined the "flood prone width" as the width of a surface perpendicular to the trend of the valley or channel defined at an elevation twice that of the bankfull depth (corresponding to a flow with recurrence interval of about 1.5 to 2 years). The flood prone width corresponds to elevations of relatively frequent floods (< 50 yr recurrence interval). The ratio of flood prone width to bankfull width is the entrenchment ratio.

Entrenched channels have an entrenchment ratio (ER) ≤ 1.4, moderately entrenched channels have $1.4 < ER \leq 2.2$, and slightly entrenched channels have $ER > 2.2$ (Rosgen, 1994). Interpreted for purposes of predicting potential channel migration, slightly entrenched channels (Rosgen Types E, C, D and DA) have the greatest potential for channel migration, while moderately entrenched channels (Rosgen Type B) have modest potential. Entrenched channels (Rosgen Types A, F and G) have little or no potential for channel migration.

Using Rosgen's system of channel classification, channels prone to channel migration might

include Types E, C, D and DA, which are defined to have slopes < 2% (Rosgen 1994). Type B channels with some channel migration potential range in slope from 2% to 4%. Hence, channels with slope > 4% could be excluded on the basis of interpretation of Rosgen's classification system.

An alternative to Rosgen is the channel classification system defined for watershed analsyis by the State of Washington (Washington Forest Practices Board, 1995). In this system, confined channels are defined to be those in which the ratio of valley floor or floodplain width to channel width is < 2. Channels with moderate confinement have ratios between 2 and 4, and unconfined channels have values ratios > 4. The means to define the valley width in this system are not precisely defined, leading to a somewhat ambiguous classification. However, using this system, channels with valley width to channel width ratios > 2 could be expected to have potential for channel migration.

The Washington method classifies stream channels according to slope classes that roughly correpsond to channel morphologic types defined by Montgomery and Buffington (1993). These slope classes are < 1%, 1-2%, 2-4%, 4-8%, 8-20% and > 20%. Field observations by the author suggest that channel migration occurs in valleys as steep as the 8-20% slope class, typically in reaches where channel slope declines relative to areas upstream. However, as slope increases, valley confinement and channel entrenchment generally increase and thereby limit the horizontal range of migration. In other words, valley width is rarely >2 bankfull width in channels with slopes > 8%. Field observations by the author suggest that significant channel migration occurs infrequently where channel slope > 5%. On the basis of field experience and the Washington classification system, CMZ's would be limited to channels with slopes < 8% with moderately confined or unconfined boundaries.

For the purposes of investigating hypotheses proposed regarding CMZ processes, it is suggested that the entrenchment ratio definition of Rosgen (1994) be used in conjunction with channel morphologic slope classes of Montgomery and Buffington (1993). Rosgen's entrenchment ratio is well-defined, and is a sensitive indicator of potential lateral flow dispersion that is required for channel migration. Montgomery and Buffington's channel classification system provides more complete description of channels steeper than 4%, and more explicitly integrates watershed process with channel classification. These slope classes are modified for classification of CMZ's. The slope classes of interest are < 1%, 1-4%, and 4-8%; they are used in the preliminary CMZ classification system (Table 2). Channels steeper than 8% are assumed to be sufficiently entrenched that the channel position cannot shift.

Influence of Disturbance Regimes on Channel Migration Processes

As noted earlier, channel migration by avulsion, and to some extent gradual migration by bank erosion, occur in response to deposition of coarse sediment or LWD in stream channels that locally reduce channel conveyance, forcing streamflow out of the existing channel. Channel migration in a particular stream reach subject to significant inputs of sediment or LWD will tend to occur if the channel is relatively unconfined (i.e. the ER is relatively large). Thus, in watersheds with higher rates of coarse sediment input, a higher incidence of channel migration

might be expected in stream reaches with high ER's (Table 1). Reaches with high rates of LWD recruitment and/or LWD deposition and high ER's would also be expected to have higher incidence of channel migration. Channels with a large ER in watersheds with relatively low input rates for coarse sediment or LWD would be expected to have a significantly lower incidence of channel migration. Finally, channels with small ER's and low rates of LWD recruitment and low supply of coarse sediment would be expected to have no significant channel migration.

The geomorphic development of stream reaches with significant channel migration zones probably occurs over relatively short periods of geologic time (thousands of years). Channel migration processes require a relatively wide valley bottom with an elevation near that of the channel bed (i.e. a high ER). These conditions typically occur when the supply of coarse sediment is in balance with or greater than the stream's transport capacity for coarse sediment. When sediment supply exceeds transport capacity, stream channels aggrade (bed elevation increases), and tend to migrate laterally across the valley floor, depositing sediment on the floodplain. If sediment supply is interrupted, or transport capacity (streamflow) increases, stream channels begin to incise the valley deposits and become entrenched, and former floodplains may become terraces that are infrequently flooded or entirely isolated from the stream. Channel migration diminishes or ceases.

Table 1. Hypothesized likelihood of significant channel migration as a funciton of channel entrenchment (confinement) and supply of sediment and/or LWD.

Entrenchment Ratio	Low Sediment/LWD Supply	High Sediment/LWD Supply
ER > 2.2 (unconfined)	Moderate	High
1.4 < ER ≤ 2.2 (intermediate confinement)	Low-Moderate	Moderate-High
ER ≤ 1.4 (confined)	Low	Low

In the case of sediment supply ≥ transport capacity, positive feedback tends to maintain conditions favorable to channel migration. Assuming a high ER, it is likely that a high water table will exist at least seasonally in the floodplain. The high water table increases the likelihood of significant blowdown of trees. Recruitment of entire trees by this mechanism increases the potential for debris jam formation that induces channel avulsion. Channel avulsion also recruits LWD. High LWD concentration in stream channels increases channel roughness and decreases sediment transport capacity. Under these circumstances, it is possible that LWD recruitment to the channel may to some extent compensate for reductions in sediment supply and maintain conditions favorable to channel migration.

Historic changes in sediment supply and regional hydrology in many areas of the northwestern United States are related to the retreat of glaciers in the past 10,000 to 100,000 years. In most

areas, stream channels have incised valley floor deposits and created one or more sets of terraces that are no longer subject to innudation. Thus, regional conditions suggest that incidence of channel migration should be diminishing. Areas where high LWD recruitment occurs may therefore be locations where channel migration processes are maintained, despite regional geologic trends that reduce potential for channel migration.

If this hypothesis is correct, decreases in long-term LWD recruitment to certain stream channels could induce essentially irreversible changes in channel morphology. Decreases in LWD recruitment could occur as the result of stand-replacing fires, logging, or other disturbance to riparian forest stands. In terms of gross channel morphology (and fish habitat), existing forced pool-riffle channels in reaches with active channel migration would be gradually transformed to entrenched plane-bed reaches. Changes in significant fish habitat variables likely would include increased particle size of stream bed sediment, reduced frequency and size of gravel bars, a decrease in the frequency and depth of pools, and decreased variation in stream velocity and depth.

Large scale production of coarse sediment by mass wasting, in some cases due to management, has been observed to induce channel aggradation and channel migration (O'Connor and Cundy 1993, O'Connor 1997). This occurs in geologic settings where channels are prone to migration processes, and have been subject to previous cycles of aggradation and degradation. In some areas where recent channel aggradation and migration has been observed, riparian forest stands in the channel migration zone had been converted to younger serai stands by prior timber harvest (O'Connor and Cundy 1993, O'Connor 1997). It is hypothesized that channel and aquatic habitat conditions in these areas would be significantly different had larger trees been present to be recruited when the stream channel began to aggrade. Large diameter, lengthy pieces of LWD with attached rootwads have the highest likelihood of remaining stable in a channel, and can establish stable nodes in the channel. Such "anchors" can promote the development of persistent pools, islands, and side channels that might otherwise be eroded or filled by coarse sediment in a stream reach where an episode of sediment-induced channel migration is occurring.

Identification and Mapping of CMZ's

An hypothetical classification of channel migration potential by channel slope and entrenchment/confinement is presented in Table 2. This preliminary classification is based on prior observations of stream channels in the Pacific Northwest and professional judgement. It is intended as an initial hypothesis to be tested and revised through field observations. Figures 1 though 5 provide summary information and a sketch of representative channel conditons for the five cases in which significant channel migration is hypothesized in Table 2. Summary characteristics of the 5 proposed CMZ types are presented in Table 3 for ease of comparison.

In low-gradient channels (approximately < 1% slope), where channel migration is both gradual and sudden, stream channels are relatively sinuous, stream bends may have a short radius of curvature, and the pattern of channel migration can often be mapped from aerial photographs. Channels of this type are usually wide enough to be visible despite riparian canopy. In many

cases, former channel positions may be determined on the basis of topography and/or vegetation, including oxbow lakes. The CMZ in this setting may often be defined in plan form as the area within the meander belt formed by the bends of the river or by the limits of the floodplain. In addition, field identification may benefit from relatively well-defined terraces that correspond to abandoned, inactive terraces within which a lower set of active terraces can be identified that correspond with the CMZ. It may be possible in some cases to quantify channel migration rates from aerial photo records for this channel type. If rates can be calculated, potential management responses can be made more objectively.

In steeper channels (approximately > 1% slope), channel migration is more likely to occur because of sudden channel avulsion. When the channel is wide enough to be visible despite the riparian canopy, it is often possible to observe the position of historic channels. In addition, vegetation types may aid in the identification of channel migration patterns. Mapping of historic channel shifts (where visible in photographs), may serve as the basis for CMZ delineation, however, field surveys may better define the specific circumstances under which channel avulsions occur and thereby narrow the spatial extent of the CMZ.

Stream channels narrower than about 30 to 40 feet typically can be difficult to observe in aerial photographs, depending on riparian forest conditions and the quality and scale of photography. In such areas, evidence of channel migration is difficult to obtain from aerial photographs. Field surveys would generally be required to locate riparian areas where channel migration processes are active. Characterization and mapping of areas of active channel migration is recommended in order to distinguish among areas of frequent and infrequent migration, which would likely have significant management implications.

Mapping the spatial and temporal frequency of channel avulsions could provide an objective basis for delineation of CMZ's and development of management practices to maintain long-term riparian function. Frequency or rate of channel migration can possibly be accomplished through a combination of aerial photo mapping and field dendrochronology. Quantification of rates or frequency is desireable to provide more objective data for consideration of management responses.

Table 2. Classification of channel migration processes by stream channel slope and confinement classes and hypotheses regarding frequency and process.

Confinement or Entrenchment	< 1 % Channel Slope	1 - 4 % Channel Slope	4 - 8 % Channel Slope
Confined/ Entrenched (ER ≤ 1.4)	*Uncommon channel type;* no hypotheses regarding channel migration processes	*Channel migration unlikely*	*Channel migration* unlikely
Moderately *Confined/* Moderately Entrenched (1.4 < ER ≤ 2.2)	Uncommon channel type; *no hypotheses regarding* channel migration processes	**CMZ 3** *Channel migration by* avulsion is not uncommon, but is likely to be spatially-discontinuous, depending on local variation in valley slope and width and disturbance regime	**CMZ 5** *Channel migration by* avulsion is uncommon, and is likely related to debris flows and torrents; may be locally significant depending on local variation in valley slope and width and disturbance regime
Unconfined or Slightly Entrenched (ER > 2.2)	**CMZ 1** Channel migration by *gradual erosion of* meander bends is common, avulsions may also occur. Areas of potential migration are spatially continuous and include much or all of the floodplain.	**CMZ 2** Channel migration by *avulsion may be common*. Areas of potential migration are spatially discontinuous and include much or all of the floodplain.	**CMZ 4** Channel migration by *avulsion may be* common, and is likely to be related to alluvial fan and debris flow fan processes. Process may be spatially discontinuous continuous, or *localized*, depending on fan-building processes.

Table 3. Summary characteristics of hypothesized channel migration zone (CMZ) types.

CMZ CHARACTERISTIC	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5
Channel Migration Potential (1)	High	High	Moderate	Moderate	Low-Moderate
Channel Migration Processes	Bank erosion and Avulsion	Avulsion	Avulsion	Avulsion (alluvial & debris flow fans)	Avulsion (debris flow & debris torrent)
Entrenchment Ratio	ER > 2.2	ER > 2.2	1.4 < ER ≤ 2.2	ER > 2.2	1.4 < ER ≤ 2.2
Slope	< 1 %	1-4 %	1-4 %	4-8 %	4-8 %
Channel Morphology	Pool-riffle, Braided	Forced pool-riffle, plane bed, step pool	Forced pool-riffle, plane bed, step pool	Step-pool, cascade, plane bed	Step-pool, cascade, plane bed
Distribution of CMZ	Continous	Discont-inuous	Discont-inuous	Variable	Localized
Sinuosity	High	Moderate	Moderate	Low	Low
Bed/Bank Material	Silt, Sand & Gravel	Gravel & Cobble	Gravel & Cobble	Cobble & Boulder	Cobble & Boulder
CMZ Sensitivity to LWD (2)	Moderate	High	High	Moderate	High
CMZ Sensitivity to Coarse Sediment	High	High	High	High	Moderate

Notes

1. Channel migration potential is evaluated relative to other CMZ types. The actual occurrence of channel migration is thought to be a function of both local and upstream disturbance (e.g. Table 1), and variation in local channel slope and confinement within a reach of the given type.

2. The influence of LWD on channel migration processes is affected by channel width. As bankfull channel width increases, a smaller proportion of LWD is likely to have an effect on channel morphology because LWD pieces that are shorter than the bankfull width will tend to be transported downstream. In Washington and Oregon, LWD abundance in stream channels with bankfull widths between 30 and 50 feet decreases significantly compared to narrower channels (e.g. Bilby and Ward, 1991).

Management Implications

The preceding sections described CMZ processes and identification. This section discusses potential response to CMZ delineation in the context of riparian forest management. Riparian forests generally have significant existing regulatory protection (e.g. Montana Streamside Management Zone Law). The central objective of the following discussion is to consider whether existing riparian regulations are sufficient for CMZ's, and if not, what actions should be considered to enhance the protection of aquatic ecosystem function in CMZ's. In general, when existing riparian management zones have a width on each stream bank less than the bankfull channel width, it is much more likely that existing leave tree requirements will be inadequate. If the width of the existing riparian management zone on each bank is a multiple (e.g. 3 or 4) of the bankfull channel width, it is much more likely that existing leave tree requirements will be adequate.

Case 1: CMZ Width ≤ Riparian/Streamside Management Zone.

An identified CMZ may fall entirely within the limits of existing regulatory streamside or riparian management zones. In these cases, the primary concern is whether existing regulatory requirements for leave trees are sufficent to maintain aquatic ecosystem function in the CMZ. The number, size and location of leave trees should be considered in relation to the number and size of LWD pieces functioning in the CMZ. The managment goal should be to ensure that if a channel shift occurs, the number, size and species of LWD pieces recruited to the new channel is comprable to that in existing channels in adequately-functioning comprable channels in comprable CMZ's. Potential differences in the importance of LWD in different types of CMZ's (see Table 3), might also serve as a criteria. In addition, estimates of frequency and spatial distribution of channel migration events (avulsions) or rate of bank erosion (gradual migration) could be relevant factors in determining appropriate criteria for leave trees.

Case 2: CMZ Width > Riparian/Streamside Management Zone

An identified CMZ may extend beyond the limits of existing regulatory streamside or riparian management zones. In these cases, the main concerns are the risk of channel migration beyond the existing leave tree zone and the adequacy of existing leave tree requirements for maintenance of aquatic ecosystem function in the CMZ. At a minimum, extending the regulatory requirements for leave trees in the riparian management zone to include the CMZ should be considered. Estimates of the frequency and spatial distribution of channel migration events (avulsions) or rate of bank erosion (gradual migration) that could lead to channel migration beyond the boundary of the existing riparian managment zone could be relevant in determining appropriate criteria for leave trees in the CMZ outside the riparian management zone. The number, size and location of leave trees should be considered in relation to the number and size of LWD pieces functioning in the CMZ. The managment goal should be to ensure that if a channel shift occurs, the number, size and species of LWD pieces recruited to the new channel is comprable to that in existing channels in adequately-functioning comprable channels in comprable CMZ's. Potential differences in the importance of LWD in different

types of CMZ's (see Table 3), might also serve as a criteria.

Further Research

Further research is needed to test the applicability of the proposed CMZ classification system. This should include a literature review, but emphasis should be on field identification and mapping. An investigation of the relationship between LWD abundance, function and size in relation to stream size and CMZ type would help provide criteria for leave trees. Data on the frequency of channel abvulsion and channel migration and bank erosion rates would also provide relevant perspective on the design of managment strategies for maintaining aquatic ecosystem function in CMZ's.

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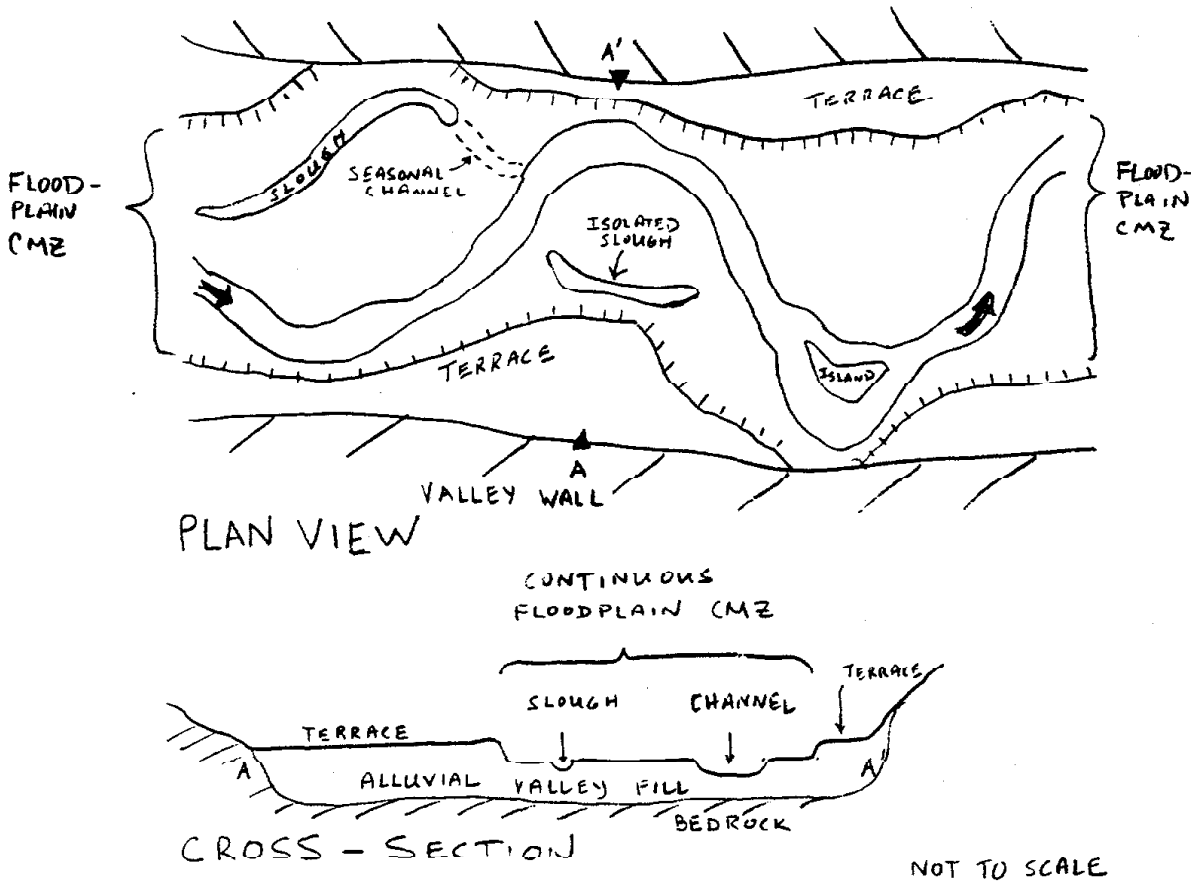
Acknowledgements

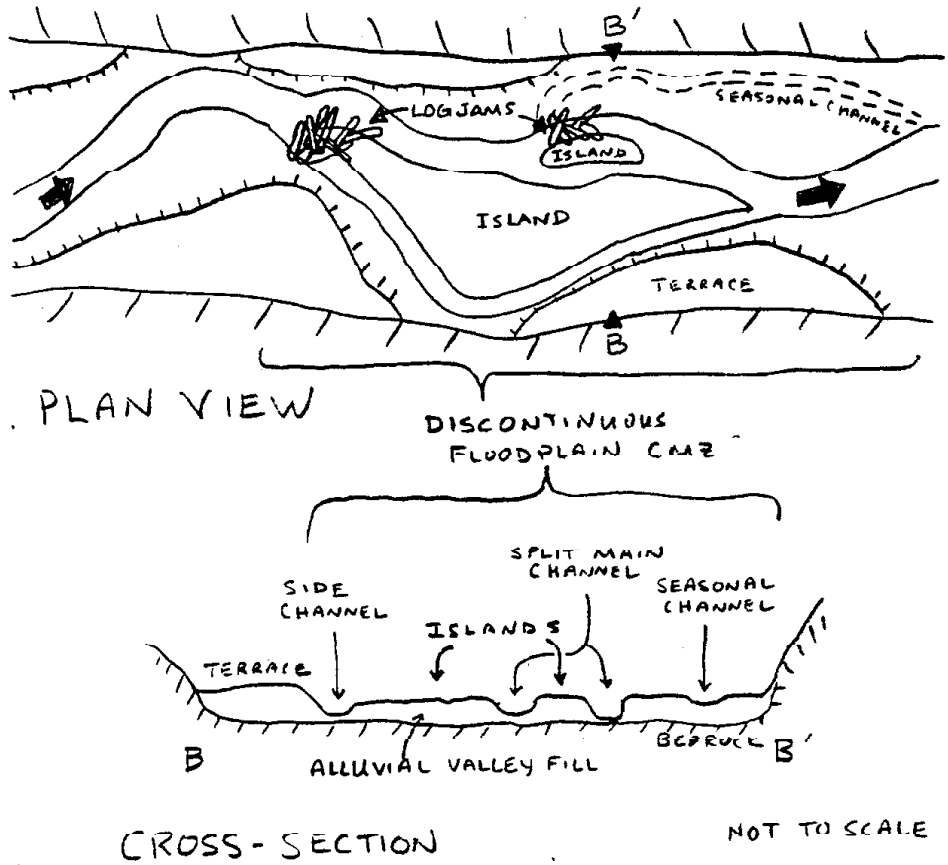
Greg Watson, Plum Creek Timber Co. conceived the project and participated in early development of CMZ classification schemes. Greg Watson and Brian Sugden, Plum Creek Timber Co., reviewed a preliminary draft of this report and provided several suggestions for improvements. The author takes responsibility for any errors.

CMZ TYPE 1: SLIGHTLY ENTRENCHED, CHANNEL SLOPE < 1%



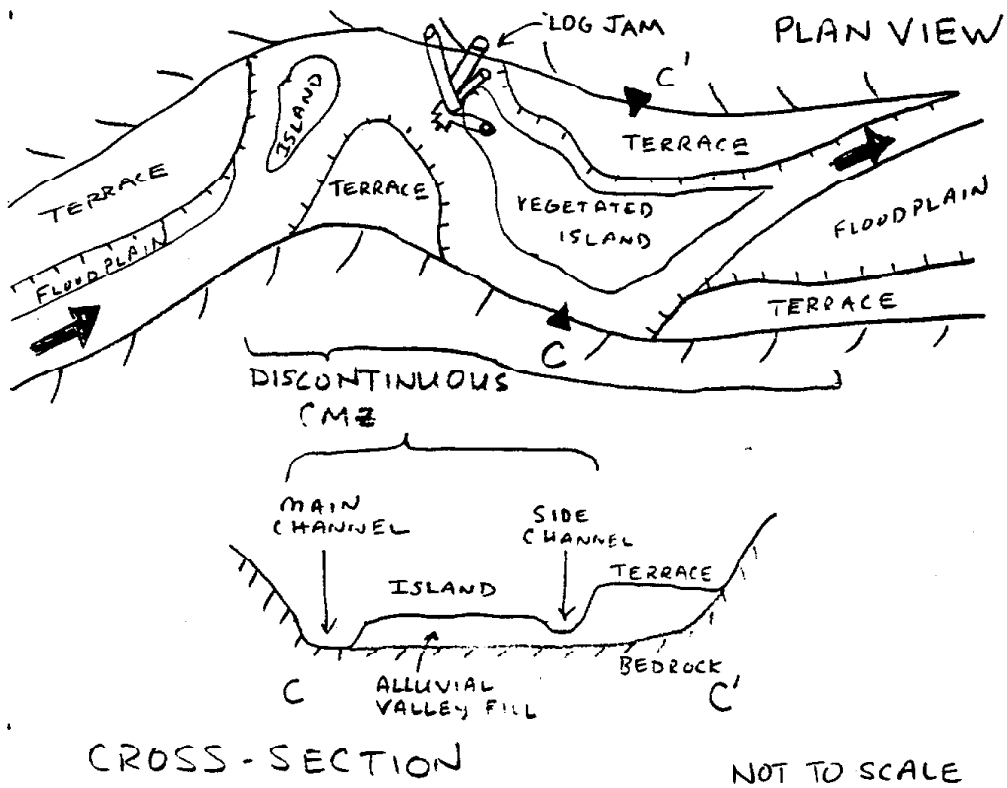
Entrenchment Ratio	> 2.2	Channel Migration Potential	High
Slope	< 1%	Channel Migration Processes	Gradual erosion and avulsion
Sinuosity	High	Distribution of CMZ	Continous across floodplain
Bed/Bank Materials	Silt, Sand & Gravel	Sensitivity to LWD	Moderate
Channel Morphology	Pool-riffle, Braided	Sensitivity to Coarse Sediment	High

CMZ TYPE 2: SLIGHTLY ENTRENCHED, CHANNEL SLOPE 1 - 4%



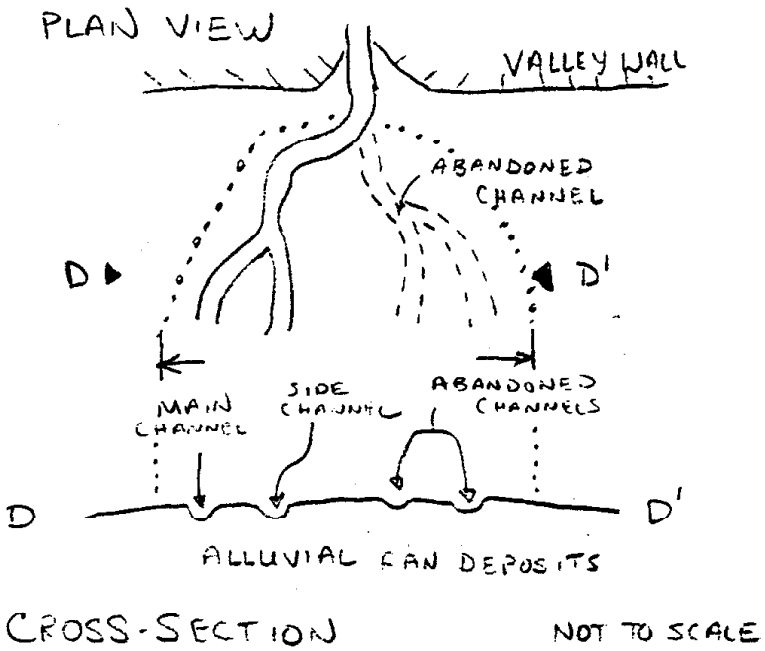
Entrenchment Ratio	> 2.2	Channel Migration Potential	High
Slope	1-4 %	Channel Migration Processes	Avulsion
Sinuosity	Moderate	Distribution of CMZ	Discontinuous along valley length
Bed/Bank Materials	Gravel & Cobble	Sensitivity to LWD	High
Channel Morphology	Forced pool-riffle, plane bed, step pool	Sensitivity to Coarse Sediment	High

CMZ TYPE 3: MODERATELY ENTRENCHED, CHANNEL SLOPE 1 - 4%



Entrenchment Ratio	1.4 < ER ≤ 2.2	**Channel Migration Potential**	Moderate
Slope	1-4 %	**Channel Migration Processes**	Avulsion
Sinuosity	Moderate	**Distribution of CMZ**	Discontinuous
Bed/Bank Materials	Gravel & Cobble	**Sensitivity to LWD**	High
Channel Morphology	Forced pool-riffle, plane bed, step pool	**Sensitivity to Coarse Sediment**	High

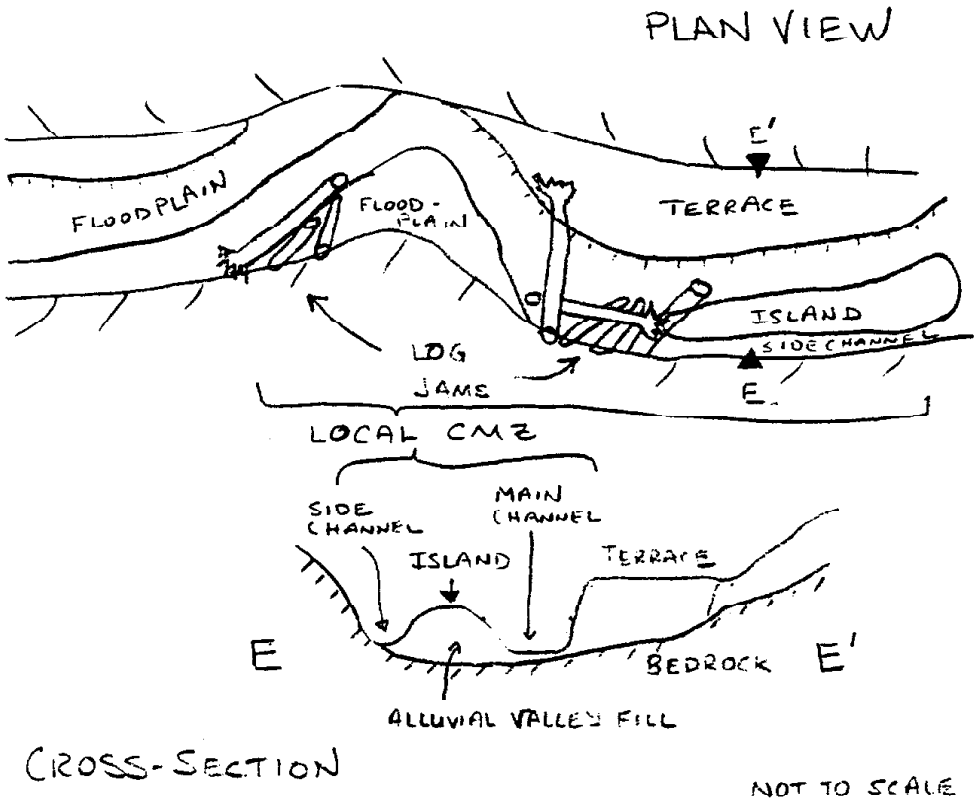
CMZ TYPE 4: SLIGHTLY ENTRENCHED, CHANNEL SLOPE 4 - 8%



4

Entrenchment Ratio	> 2.2	Channel Migration Potential	Moderate
Slope	4-8 %	Channel Migration Processes	Avulsion (alluvial or debris flow fan)
Sinuosity	Low	Distribution of CMZ	Variable
Bed/Bank Materials	Cobble & Boulder	Sensitivity to LWD	Moderate
Channel Morphology	Step-pool, cascade, plane bed	Sensitivity to Coarse Sediment	High

CMZ TYPE 5: MODERATELY ENTRENCHED, CHANNEL SLOPE 4 - 8%



Entrenchment Ratio	1.4 < ER ≤ 2.2	Channel Migration Potential	Low-Moderate
Slope	4-8 %	Channel Migration Processes	Avulsion
Sinuosity	Low	Distribution of CMZ	Localized
Bed/Bank Materials	Cobble & Boulder	Sensitivity to LWD	High
Channel Morphology	Step-pool, cascade, plane bed	Sensitivity to Coarse Sediment	Moderate

4F FISH HABITAT MODULE

The objectives of the fish habitat module are four-fold: 1) document existing and historic distribution of salmonid fishes in the analysis area; 2) acquire information regarding current fish habitat conditions; 3) delineate local areas of habitat important for the maintenance of self-sustaining fish populations; and 4) identify, through coordination with other modules, past and potential future impacts to fish habitat from land management activities. An essential premise to this module is that fish populations within the analysis area are locally adapted to the historic, pre-management, range of habitat conditions and that any significant, anthropogenically-derived deviation in habitat conditions will result in negative impacts to fish populations. Fish habitat is evaluated by comparing current in-stream conditions to target conditions derived from data collected from streams draining unmanaged watersheds (Peterson et al 1992).

4F.1 COORDINATION WITH OTHER MODULES

Since fish habitat assemblages are largely a function of channel geomorphology (Benda et al 1992), a logical approach to defining the effects of upland management activities upon fish habitat involves segregating habitat features among various stream reaches that may respond differently to modified input processes. This approach also provides a common baseline for synthesis of information provided by other modules. Therefore, fish distribution and habitat information was stratified by channel segments and geomorphic channel units (GCU) as delineated in the Channel Condition Module (Section 4E). Once data was obtained, sorted, and assessed within most of the fish-bearing channel segments, analysts from the Fish Habitat, Channel Condition, and Riparian Function Modules coordinated information to develop a matrix that defines vulnerability ratings for fish habitat within channel segments.

4F.2 SOURCES OF INFORMATION

Information for this module was obtained from several sources. Preliminary stratification of stream channel segments was provided by Whitehorse Associates (1997). The Montana Department of Fish, Wildlife and Parks (MDFWP) provided information regarding fish stocking history and fishing regulations (Rumsey 1997). The majority of the data used for this analysis was collected by Plum Creek Timber Company fisheries research personnel in 1994 and 1997. All available information was evaluated and data gaps were identified. Module analysts conducted additional surveys during the summer and fall of 1997 to collect information necessary to complete the module (habitat data and fish distribution). Data was also provided by the Channel Condition and Riparian Function Modules during synthesis.

4F.3 FISH MANAGEMENT

Recreational sport fishing is currently permitted throughout the Thompson River basin, including the streams in this analysis area. All rivers and streams are open for fishing from the third Saturday in May until November 30. The daily limit is 20 brook trout and 5 of any combination of rainbow trout and cutthroat trout, only one exceeding 14 inches. The Thompson River and its tributaries are closed to the taking of, and/or intentional fishing for, bull trout.

MDFWP records indicate that stocking of non-native salmonids by state personnel began in the analysis area as early as the 1930's. Stocking records of federal agencies were not accessed for this analysis, but it is likely that the Bureau of Fisheries (now the US Fish and Wildlife Service) stocked brook trout in the northern end of the Thompson River basin in the 1930's or 1940's. This assumption is based upon the fact that brook trout are prevalent in Murr and Boiling Springs creeks and state records do not document the stocking of brook trout in Murr Creek by MDFWP. Since the Bureau of Fisheries commonly stocked brook trout throughout western Montana in the 1920's through 1940's, the stocks in Boiling Springs and Murr creeks were probably established through federal efforts. State records indicate that Lower Thompson Lake was stocked annually with "undesignated" cutthroat trout from the early 1930's through 1946. Undesignated as defined by MDFWP indicates that the stock origin was not recorded. Hence, the introduced trout could have been either westslope cutthroat and/or Yellowstone cutthroat. Since Boiling Springs Creek is tributary to Lower Thompson Lake, some of these fish likely migrated into Boiling Springs. Undesignated cutthroat were stocked directly into Boiling Springs Creek in 1969 and into the lower reaches of Murr Creek (Sec. 8, T25N, R26W) in 1942. Rainbow trout were first stocked in Lower Thompson Lake in 1946 and brook trout were first stocked in the lake in 1949. Currently, Lower Thompson Lake is stocked annually with rainbow trout. State records do not indicate any stocking of non-native salmonids in Beatrice Creek.

4F.4 FISH DISTRIBUTION

Figures 4F-1a, 4F-1b, and 4F-1c (note: all figures and tables are located at the end of this module report) display current known distribution of trout and char in the Beatrice Creek, Boiling Springs Creek, and Murr Creek watersheds, respectively (note: these figures, and all tables are located at the end of this module report). Surveys conducted for this analysis indicate that the lower reaches of Murr Creek downstream of the barrier cascades in Section 9 support all species found in the analysis area (brook trout, bull trout, cutthroat trout, rainbow trout). Both juvenile and adult rainbow, cutthroat, and brook trout were found in lower Murr Creek but only one adult bull trout was detected, indicating that this is not natal habitat for bull trout. Upstream of the Section 9 barrier in Murr Creek, only brook trout have been detected by population surveys. No fish have been detected by surveys upstream of the Section 11 barrier falls in the south fork of Murr Creek. This distribution pattern suggests that the reaches of Murr Creek upstream of Section 9 were never accessible to native

salmonids and that these areas were successfully exploited by brook trout after they were stocked somewhere upstream of the barrier cascades. The upper reaches of the north fork of Murr Creek were found to have perennial flow and likely support brook trout also. However, fish surveys have not been conducted in these reaches and fish presence needs to be documented.

The lower and mid-reaches of Boiling Springs Creek were found to support brook and rainbow trout. The upper mainstem reaches of Boiling Springs support primarily brook trout. Cutthroat trout were found only in the uppermost reaches of Boiling Springs Creek, specifically in channel segment 348. Brook trout were also found in beaver ponds in the lower reaches of the intermittent southern tributary to Boiling Springs Creek, in Sections 21 and 28.

Beatrice Creek supports only native stocks of fish. Bull trout and cutthroat trout are found throughout the mainstem of Beatrice Creek from the mouth upstream to the fork in Section 2. Upstream of the fork, bull trout are found in the lower half of the northern fork while cutthroat trout are found throughout. Only cutthroat trout were detected in the southern fork upstream to the barrier cascades in Section 11. Upstream of the barrier cascades, no fish were found by snorkel surveys. However, a module analyst reported during synthesis that fish was observed in channel segment 1849. Hence, the upstream extent of fish distribution should be validated in the southern fork through more extensive surveys.

No man-made barriers to fish movement were found in the analysis area. A triple culvert near the mouth of Boiling Springs Creek likely hinders upstream movement of smaller fish (< 6 inches) during base flow periods since the outlets of the CMPs are perched approximately 9 inches above the water surface elevation at low flow. Periodic manipulation and diversion of the lower reaches of Murr Creek by private entities likely causes stranding of fish due to dewatering.

4F.5 FISH HABITAT ATTRIBUTES OF GEOMORPHIC UNITS

Once channel segments were delineated by Channel Condition Module analysts, habitat conditions were assessed by compiling and analyzing all available data. Data were stratified by channel segment and geomorphic unit (GCU) and condensed to generate metrics for assessment as defined by Forms F-2 and F-3 of the fish habitat module methodology (Washington Forest Practices Board 1995). These metrics are summarized in Table 4F-1. Habitat metrics and field evaluations were then assessed by using Table F-2 of the methodology to generate habitat resource condition calls for life phases by channel segment and GCU. Table 4F-2 summarizes habitat condition calls for channel segments and GCUs. Data collection and assessments were focused on channel segments in the watersheds that comprise the majority of available fish habitat in the analysis area. This section summaries the general attributes of fish habitat and species use in the respective GCUs. GCU definitions are found in the Channel Condition Module.

4F.5.1 ALLUVIAL FANS (GCU 1)

Fish-Bearing Channel Segments: Murr - 472, 478; Boiling Springs - 333, 250

This minor GCU comprises short segments of Murr and Boiling Springs creeks at their mouths as well as a small segment in upper Boiling Springs. All species found in the analysis area are expected to use habitat in this GCU , at some time of the year. Brook trout and rainbow trout are more likely to use this GCU for spawning and rearing due to their documented association with low gradient reaches. Cutthroat trout and bull trout primarily use this GCU as a migration corridor to access areas more conducive to their habitat preferences. These channel segments likely are important in providing winter rearing habitat (in the form of deep pools and side channels) for all salmonids and spawning habitat for rainbow trout. Rearing habitat is of low quality due to the low pool frequency and lack of adequate cover. Habitat features in these channel segments are predominantly wide, moderately deep riffles interspersed with few primary pools. Spawning gravel is available in pool tail-outs, on bars and behind obstructions. Spawning gravel quality is questionable, however, due to accumulations if fine sediment in the gravels and a high likelihood of redd scour. Hence, incubation success is expected to be poor. Rearing habitat is provided by pocket pools formed behind larger substrate particles, wood cover, and primary pools. Pools tend to be formed mostly by bed scour with wood acting as the secondary pool forming mechanism. When wood is available in sufficient sizes and quantities to remain stable, pools tend to be deeper and more abundant. The availability of rearing habitat is likely limited by the availability of wood to form pools and cover, and by fine sediments filling interstitial spaces between large substrate particles. No barriers to migration exist in this GCU.

4F.5.2 FOREST/MEADOW COMPLEX (GCU 2)

Fish-Bearing Channel Segments: Murr - 410, 387, 384, 382, 370, 362, 344;
Boiling Springs - 289, 291, 315, 333

Channel segments in this GCU occur in the mid- to upper reaches of North Fork Murr Creek and the mid-reaches of Boiling Springs Creek. A variety of size classes of brook trout and rainbow trout occur in these channel segments, suggesting that all life requisites are supported, at moderate to high densities. Spawning gravel is available, found on bars, behind obstructions, and in pool tailouts. Spawning gravel quality is poor because of high accumulations of fine sediment. Incubation success is expected to be poor for both fall and spring spawning species. Rearing habitat is provided by low-energy glides and primary pools. Most pools are formed by scour associated with woody debris and secondarily by bedform. Primary pool frequency is generally poor but cover provided by woody debris is fair. Large substrate particles (> 12 in.) are generally infrequent and cobble and gravel are the dominant substrates. Winter rearing habitat is provided through pool depth, debris complexes, and side channels. Woody debris tends to function both in jams and as individual pieces to form

habitat features. Moderate to large pieces of woody debris tend to function individually. No migration barriers are evident in this GCU.

4F.5.3 MEADOW/POND COMPLEX (GCU 3)

Fish-Bearing Channel Segments: Boiling Springs - 328, Undesignated

Channel segments in this minor GCU are unique to the mid-reaches of Boiling Springs Creek. This GCU is comprised of a series of low gradient flowing segments interspersed with beaver ponds and are populated exclusively with brook trout. Spawning gravels are available, but quality is questionable due to high concentrations of fine sediment. Both summer and winter rearing habitat quality is moderate to high, primarily provided by numerous beaver ponds. Pool formation is primarily a function of beaver activity, but woody debris and bed scour are important in flowing segments. LWD of various sizes functions individually and in jams to provide habitat features. Riparian vegetation, in the form of shrubs and trees, is important for channel stability and for the formation of undercut banks. No migration barriers occur in this GCU.

4F.5.4 CONIFER FLOODPLAIN CMZ (GCU 4)

Fish-Bearing Channel Segments: Murr - 478; Beatrice - 1641, 1660, 1680, 1706, 1709, 1759, 1770, 1772, 1791

Channel segments in this GCU occur mostly in the lower and middle reaches of Beatrice Creek and in one reach of lower Murr Creek. In Beatrice Creek, all size classes of cutthroat and bull trout are supported in this GCU. In Murr Creek, most size classes of brook, cutthroat, and rainbow trout are supported. Therefore, this GCU likely supports all life requisites for these three species. Accumulations of spawning gravels are generally frequent, most commonly associated with LWD obstructions and in pool tailouts. Concentrations of fine sediment are mostly low, and substrate stability appears to be fair. Smaller size classes of gravel are likely unstable. Incubation success is expected to be good for fall spawners, especially bull trout (due to their propensity to deposit eggs in the larger gravel classes), and moderate to poor for spring spawners due to the potential for redd scour. Rearing habitat is provided by primary pools, side channels, and low-energy pockets associated with woody debris. Pool frequency is poor to fair and pools are of sufficient residual depth for winter rearing. Pool formation is almost exclusively associated with flow obstructions created by woody debris. LWD of moderate to large sizes functions in jams and individually. Riparian vegetation, both shrubs and trees, is important for channel stability, maintaining the integrity of undercut banks, and for anchoring instream LWD. Winter rearing habitat is provided through large substrate particles, side channels, and deep primary pools. No likely migration barriers were observed in this GCU.

4F.5.5 CONFINED MAINSTEM (GCU 5)

Fish-Bearing Channel Segments: Murr - 478, 475, 458; Beatrice - 1641

Channel segments in this GCU occur in the mid- and lower reaches of Murr Creek and the lower reaches of Beatrice Creek. In Beatrice Creek, this GCU supports bull and cutthroat trout while in Murr Creek, brook and cutthroat trout. Spawning gravels are available but not abundant in this GCU and are found in bars, pool tailouts, and associated with woody debris. Concentrations of fine sediment are low and spawning gravel stability was rated as fair. Incubation success is expected to be fair for both fall and spring spawners. Rearing habitat is provided by primary pools and wood cover. Pool frequency is fair and most pools are of sufficient residual depth for winter rearing. Pool formation is primarily associated with woody debris but pools also are created from bed scour when LWD is not present. LWD is common and functions individually and in jams, in moderate to large sizes, to provide habitat features. Numerous large substrate particles and deep pools provide winter rearing habitat. No migration barriers were found in this GCU.

4F.5.6 INCISED GLACIAL TILL (GCU 6)

Fish-Bearing Channel Segments: Beatrice - 1797, 1800, 1815, 1820; Boiling Springs - 257

Channel segments in this GCU occur in the mid-reaches of Beatrice Creek and the lower portion of Boiling Springs. Cutthroat and bull trout are supported in Beatrice and this GCU supports relatively high densities of juvenile rainbow trout in Boiling Springs. Spawning habitat is limited in this GCU due to sparse gravel availability. When spawning gravels were encountered, accumulations were found in the few low energy areas available, generally bars associated with LWD and boulder accumulations. Gravels were relatively free of fine sediments but stability was judged to be poor. Redd scour is expected to impact embryo survival, especially for spring spawners. Rearing habitat is provided by scour and dam pools formed primarily by bedrock outcrops and boulders but also by woody debris. Where stable LWD is present, pools generally tend to be more abundant. LWD functions in jams and as individual pieces when large enough to be stable. Apart from LWD recruitment and shade, riparian vegetation does not play a significant role in the maintenance or creation of available fish habitat (i.e. channel stability, undercut banks). Winter rearing habitat in expected to be fair because of the availability of deep pools and large substrate particles with interstitial spaces free of fine sediment. Side channel habitats are rare. One channel segment in this GCU, 1820 (Beatrice Creek) exhibited a series of cascades that pose as a barriers to upstream fish migration.

4F.5.7 ALPINE GLACIAL HEADWATER (GCU 7)

Fish-Bearing Channel Segments: None Identified

Channel segments within this GCU were not evaluated since no fish-bearing segments exist in the analysis area.

4F.5.8 PERENNIAL HEADWATERS (GCU 8)

Fish-Bearing Channel Segments: Boiling Springs - 335, 337, 348, 350, 355

Fish-bearing channel segments in this GCU occur exclusively in the upper reaches of Boiling Springs Creek and support brook trout at moderate to low densities and cutthroat trout at very low densities. Spawning gravels are uncommon and fine sediment concentrations are low. Incubation success is expected to fair, but redd stability is questionable. Rearing habitat is provided by primary pools and infrequent side channels. Pools are formed primarily by bed scour associated with boulder/cobble accumulations, and secondarily by LWD. Woody debris functions in jams and as individual pieces of small to moderate sizes. Pool frequency is generally poor and pools tend to be too shallow for winter rearing. Because of steeper gradient sections interspersed throughout these channel segments, upstream passage in this GCU can be difficult for smaller resident trout.

4F.5.9 CANYONS & CASCADES (GCU 9)

Fish-Bearing Channel Segments: Murr - 481, 480, 446, 495, 497, 501; Beatrice - 1608

The moderate to high gradient reaches of this GCU occur in the mid-reaches of Murr Creek and at the mouth of Beatrice Creek. Dominant substrates are bedrock, boulder, and large cobble. Numerous step pools comprise the available rearing habitat and are predominantly formed by boulder accumulations and bedrock outcrops. LWD rarely forms pools and only in jams of moderate to large pieces. Spawning gravels are rare due to high stream power. Winter rearing habitat is provided by deep pools and interstitial spaces between substrate particles. Barriers and impediments to upstream migration (cascades and falls) occur throughout this GCU.

4F.5.10 HEADWATERS WITH AVALANCHE (GCU 10)

Fish-Bearing Channel Segments: Beatrice - 1788, 1777, 1754

Fish-bearing channel segments in this GCU occur exclusively in the upper reaches of the northern fork of Beatrice Creek and primarily support cutthroat trout at moderate to low densities. Spawning gravels are relatively common, fine sediment concentrations are low, and gravel stability is fair.

Incubation success is expected to fair. Winter rearing habitat is provided by primary pools and large substrate particles. Woody debris is of primary importance in providing habitat features, especially pools, resulting in fair rearing habitat. Woody debris functions in jams and as individual pieces of small to moderate sizes. No upstream passage barriers were identified in this GCU.

4F.5.11 CONFINED INTERMITTENT (GCU 11)

Fish-Bearing Channel Segments: None Identified

Channel segments within this GCU were not evaluated since no fish-bearing segments were found. Field observations indicate that channels are generally too steep and too small to support fish.

4F.5.12 UNCONFINED INTERMITTENT (GCU 12)

Fish-Bearing Channel Segments: None Identified

Channel segments within this GCU were not evaluated since no fish-bearing segments were found.

4F.6 RELATIVE STATUS OF CHANNEL SEGMENTS

The habitat condition calls, field evaluation, and knowledge of species distribution were used to designate the channel segments' relative importance for life phases of salmonid species found in the analysis area. Important channel segments were rated as primary or secondary habitat for life phases for both native species (cutthroat trout, bull trout) and introduced species (brook trout, rainbow trout). A rating of primary for any channel segments indicates that this segment is considered critical in providing the specific habitat element(s) necessary for the success of the given species type and life phase (native or introduced). A rating of secondary indicates that the channel segments are, or will likely be, utilized by the given species type for the specific life phase to a moderate extent and that these segments, while still important to the respective populations, are not believed to be of the relative habitat value of "primary" segments. In the event of conflicting information regarding habitat use, designation of important channel segments was biased to favor native species over introduced species.

4F.6.1 SPAWNING AND INCUBATION HABITAT

Spawning habitat is evaluated by assessment of the quantity, quality, and likely stability of the gravels during the season that embryos are expected to be in the redd environment. Generally, spring spawning species (rainbow trout, cutthroat trout) are most vulnerable to redd scour during high

spring freshets and fall spawning species (bull trout, brook trout) are most vulnerable to the accumulation of fine sediments in the redd environment and scour events during fall and winter. Data regarding specific utilization of segments was also used to assign the relative importance of channel segments as spawning habitat.

Through use of available data and field reconnaissance, spawning habitats were rated based on perceived importance to salmonid species. Fish distribution, spawning habitat availability, and spawning habitat quality were evaluated to designate channel segments as primary, or secondary spawning habitat. For native trout, the following channel segments were deemed important: Primary Spawning - Segments 478 (Murr), 348 (Boiling Springs), 1706, 1772, 1759 (Beatrice); Secondary Spawning - Segments 472 (Murr), 333 (Boiling Springs), 1788, 1680 (Beatrice). For introduced trout: Primary Spawning - Segments 478, 475, 458, 410 (Murr), 289, 250 (Boiling Springs); Secondary Spawning - Segments 472, 495, 382 (Murr), 315, 333, 328 (Boiling Springs).

4F.6.2 SUMMER/WINTER REARING HABITAT

Diagnostic analysis for summer/winter rearing habitat is primarily based on two factors, pool frequency and the amount of in-channel large woody debris (see Table 4F-2). Population survey data collected for this analysis, displayed in Table 4F-3, was also used to assess the relative importance of channel segments for rearing habitat.

Limited temperature monitoring has been conducted in the WAU and is presented in the Riparian Function Module. Water temperatures in excess of optimal ranges can diminish reproduction and survival rates of salmonids. Results indicate that, throughout the analysis area, water temperatures are conducive to salmonid rearing except for the possible exception of the mid-reaches of Boiling Springs Creek where temperatures approach the thermal tolerances of native species (see Riparian Function Module).

Available data and field reconnaissance were used to rate rearing habitats based on perceived importance to salmonid species. Fish distribution, rearing habitat availability, and rearing habitat quality were evaluated to designate channel segments as primary, or secondary rearing habitat. For native trout, the following channel segments were deemed important: Primary Rearing - Segments 478 (Murr), 348 (Boiling Springs), 1759, 1788, 1680 (Beatrice); Secondary Rearing - Segments 472, 480 (Murr), 333 (Boiling Springs), 1706, 1641, 1791 (Beatrice). For introduced trout: Primary Rearing - Segments 478, 495, 475, 410 (Murr), 257, 315, 333 (Boiling Springs); Secondary Rearing - Segments 472, 458, 382 (Murr), 289, 328 (Boiling Springs).

4F.6.3 WINTER REARING HABITAT

Winter rearing habitat is evaluated for channel segments by assessing the quality and availability of two major components utilized by salmonid species during low flow, cold water periods. Several studies have noted winter concentrations of juvenile salmonids in side channel habitats and in stream reaches with significant amounts of large substrate. Various channel segments in the analysis area are also influenced by groundwater inflow that allows them to remain ice-free. Large substrate provides interstitial spaces that allow fish to avoid anchor ice and to minimize energy expenditures. Even though not required by watershed analysis diagnostics, the availability of large, deep pools and the degree of substrate embeddedness were also considered. As with other habitat elements, winter rearing habitats are categorized by channel segment within the general context of geomorphic features exhibited in the analysis area.

Available data and field reconnaissance were used to rate winter rearing habitats based on perceived importance to salmonid species. Fish distribution, habitat availability, habitat quality, and the likelihood of groundwater influence were evaluated to designate channel segments as primary, or secondary winter rearing habitat. For native trout, the following channel segments were deemed important: Primary Winter Rearing - Segments 478 (Murr), 348 (Boiling Springs), 1641, 1706, 1772, 1788 (Beatrice); Secondary Winter Rearing - Segments 472, 481 (Murr), 333 (Boiling Springs), 1777, 1680, 1759 (Beatrice). For introduced species: Primary Winter Rearing - Segments 478, 410, 382 (Murr), 257, 328 (Boiling Springs); Secondary Winter Rearing - Segments 480, 495 (Murr), 333, 250, 289 (Boiling Springs).

4F.7 VULNERABILITIES

Development of fish habitat vulnerability calls resulted from consultation with analysts responsible for the Channel Condition, Hydrologic Condition, and Riparian Function Modules. Table 4F-4 displays relative fish habitat vulnerabilities to modification of important input processes necessary for the creation and maintenance of habitat features within the analysis area. For fish-bearing channel segments within each geomorphic unit, analysts considered habitat concerns for each life phase to ascertain the degree that fish habitat features are potentially vulnerable to changes in input processes that would significantly deviate from historic, "natural" variation. Degrees of vulnerability are rated as low, moderate, or high. That is, a vulnerability rating of high suggests that significant variations of the given input processes have a high probability of degrading fish habitat features critical to fish reproduction and survival. Conversely, a low vulnerability rating suggests that either significant shifts in habitat quality are not likely to occur, or if they do occur, fish populations are not likely to be impacted.

In most cases, habitat vulnerabilities are analogous to channel sensitivity ratings (see Channel

Condition Module). Exceptions to this trend were identified. Analysts determined that, in these instances, important habitat features were more sensitive to modifications of the given input factor than suggested by channel sensitivity ratings.

The vulnerability of fish habitat to coarse sediment inputs for channel segments in GCU 4 was upgraded from moderate to high. Accelerated inputs of coarse sediment to these channel segments would likely impact fish habitat by reducing pool depth, increasing rates of channel avulsion, and potentially causing fish passage impediments through streambed aggradation and subsequent channel dewatering.

The vulnerability of fish habitat to fine sediment inputs for channel segments in GCUs 2, 4, and 10 was upgraded to moderate. Increased fine sediment delivery to these habitats would likely cause diminished embryo survival in redds, and increase substrate embeddedness, impacting winter rearing habitat.

The vulnerability of fish habitat to LWD inputs for channel segments in GCUs 2, 3, 6, and 10 was upgraded either to moderate or high. Since LWD is a very important component for the creation and maintenance of high quality fish habitat in these GCUs, a reduction of LWD recruitment would result in significant losses of habitat complexity and quality.

4F.8 CONFIDENCE

Confidence is high for fish distribution throughout stream segments in the analysis area. Comprehensive snorkel surveys were conducted in channel segments throughout the analysis area in 1994 and 1997 to document fish distribution. Population surveys were conducted above and below suspected passage barriers to empirically document their effectiveness as obstacles to upstream fish migration.

Except as noted below, confidence is high for habitat condition calls and habitat vulnerability ratings for all GCUs. Extensive field review and data collection was conducted by analysts for the Riparian Condition, Channel Condition, and Fish Habitat Modules. Adequate samples were collected from representative segments of GCUs. Data were share by analysts and consensus was reached on hazard, sensitivity, and vulnerability calls during synthesis. Confidence is low for GCU 3 since only cursory field evaluation was conducted for the fish-bearing channel segments. Confidence is moderate for habitat condition and vulnerability ratings for GCU 8 since rigorous data collection was conducted in only one fish-bearing segment of this GCU (348). However, field reconnaissance of other channel segments in GCU 8 indicates that the analyzed segment is likely representative of fish habitat and subsequent vulnerabilities found in this GCU.

Confidence is high for channel segment importance ratings (i.e. Primary or Secondary) for summer rearing habitat for salmonids. Extensive habitat analyses and population surveys were conducted in the analysis area in the summers of 1994 and 1997 and were used to assess both habitat quality and the relative distribution and abundance of fish species. Confidence is moderate for segment importance ratings for winter rearing habitat and for spawning habitat. Winter surveys have not been conducted in the analyses area to determine fish distribution and habitat use patterns, and spawning surveys have not been conducted for cutthroat, rainbow, brook, or bull trout. Therefore, only habitat analyses and diagnostics were used to determine the relative importance of channel segments.

4F.10 LITERATURE CITED

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Table 4F-1. Habitat metrics by channel segment.

	Segment Number				
	472	315	333	344	410
Geomorphic Unit	1	2	2	2	2
Distance Surveyed (m)	200	100	100	100	146
Channel Gradient (%)	1	2	2	2	1
% Canopy Shade	12.7	58.3	88.9	23.8	15.6
% Pool Area	30.9	0	28.1	0	63.8
# of Pools	4	0	5	0	2
Channel Widths/Pool	16.5	N/A	10	N/A	14.6
LWD/Channel Width	0.75	2.7	0.56	1.7	10.6
% of Pools w/Wood Cover	75	N/A	80	N/A	100
Mean % Wood Cover in Pools	4.3	N/A	4.4	N/A	21.5
% Boulder Cover	14.7	8.5	0.3	67.5	34.8
Dominant Substrate	Cobble	Gravel	Gravel	Boulder	Silt/Clay
Sub-Dominant Substrate	Gravel	Cobble	Cobble	Cobble	Boulder
Mean Wetted Width (m)	3.2	2.8	1.3	2.6	3.5
Mean Channel Width (m)	4.9	4	2	3.4	5
Mean Wet Width Pools (m)	3.9	N/A	1.4	N/A	5
Mean Residual Depth Pools (m)	0.55	N/A	0.27	N/A	1.19
Mean Residual Depth Pools with Wood (m)	0.55	N/A	0.3	N/A	1.19
Mean Residual Depth Pools w/o Wood (m)	0.56	N/A	0.18	N/A	N/A
Mean % Surface Fines	19.1	3.4	1.6	42.5	71
Mean Volume of LWD (cubic m)	N/A	0.3	0.67	0.29	0.14

	Segment Number				
	382	362	289	478	1706
Geomorphic Unit	2	2	2	4	4
Distance Surveyed (m)	122	100	134	358	146
Channel Gradient (%)	1	2	2	2	4
% Canopy Shade	28.9	13.3	79.9	24.3	74.9
% Pool Area	17.8	15.4	9.5	14.5	21.6
# of Pools	3	2	3	7	5
Channel Widths/Pool	8.1	20	10.1	5	4.6
LWD/Channel Width	2.1	1.7	0.9	1	3.7
% of Pools w/Wood Cover	100	100	100	57	100
Mean % Wood Cover in Pools	8.3	8	3.33	4.9	9.2
% Boulder Cover	1.1	29	1.75	20.2	6.6
Dominant Substrate	Cobble	Cobble	Gravel	Cobble	Cobble
Sub-Dominant Substrate	Gravel	Boulder	Cobble	Boulder	Gravel
Mean Wetted Width (m)	3.6	1.8	3.1	4.2	4.43
Mean Channel Width (m)	5	2.5	4.4	9.6	6.3
Mean Wet Width Pools (m)	4.1	2	3.3	3.9	5.4
Mean Residual Depth Pools (m)	0.63	0.49	0.21	0.56	0.79
Mean Residual Depth Pools with Wood (m)	0.63	0.49	0.21	0.56	0.79
Mean Residual Depth Pools w/o Wood (m)	N/A	N/A	N/A	0.49	N/A
Mean % Surface Fines	21.6	61	3.7	5.8	6.4
Mean Volume of LWD (cubic m)	0.31	0.23	0.39	0.89	0.58

	Segment Number				
	1759	1791	475	478	1641
Geomorphic Unit	4	4	5	5	5
Distance Surveyed (m)	183	146	483	100	183
Channel Gradient (%)	6	5	3	3	4
% Canopy Shade	69.3	61.1	54.2	42.8	68.5
% Pool Area	28.9	21.1	21	44.8	24.6
# of Pools	7	5	10	4	4
Channel Widths/Pool	3.1	5.12	5.2	2.2	4.4
LWD/Channel Width	4	1.5	2.5	5.4	4
% of Pools w/Wood Cover	100	100	31.3	75	100
Mean % Wood Cover in Pools	19.9	5.8	3.4	3.5	6.3
% Boulder Cover	1	19.6	51.8	76.4	6.8
Dominant Substrate	Cobble	Cobble	Boulder	Boulder	Cobble
Sub-Dominant Substrate	Gravel	Gravel	Cobble	Cobble	Gravel
Mean Wetted Width (m)	5.7	3.8	5.6	5	7.1
Mean Channel Width (m)	8.3	5.7	9.4	11.2	10.4
Mean Wet Width Pools (m)	6.5	4.4	6.8	5.8	7.2
Mean Residual Depth Pools (m)	0.78	0.66	0.72	0.89	0.7
Mean Residual Depth Pools with Wood (m)	0.78	0.66	0.63	0.9	0.7
Mean Residual Depth Pools w/o Wood (m)	N/A	N/A	0.7	0.86	N/A
Mean % Surface Fines	6	1.5	5.7	11.3	2.4
Mean Volume of LWD (cubic m)	0.78	0.49	0.77	N/A	0.49

Table 4F-1. Habitat metrics by channel segment (continued).

	Segment Number				
	1820	257	1849	348	480
Geomorphic Unit	6	6	6	8	9
Distance Surveyed (m)	146	146	122	100	183
Channel Gradient (%)	15	8	8	10	6
% Canopy Shade	72.2	82.5	76.7	90.1	53.1
% Pool Area	7.9	21.9	17.4	18.2	53
# of Pools	2	10	4	5	5
Channel Widths/Pool	18.2	4.2	8.2	10.5	5.4
LWD/Channel Width	9.5	0.8	1.9	0.5	3.5
% of Pools w/Wood Cover	100	70	100	100	80
Mean % Wood Cover in Pools	22.5	1.1	6.3	6.4	1.6
% Boulder Cover	45.2	44.6	32.4	10.5	42.8
Dominant Substrate	Boulder	Boulder	Cobble	Gravel	Boulder
Sub-Dominant Substrate	Cobble	Cobble	Boulder	Cobble	Cobble
Mean Wetted Width (m)	3.5	2.4	3	1.2	6
Mean Channel Width (m)	4	3.5	3.7	1.9	6.8
Mean Wet Width Pools (m)	4	2.5	3.2	1.5	5.3
Mean Residual Depth Pools (m)	0.85	0.29	0.59	0.21	1.36
Mean Residual Depth Pools with Wood (m)	0.85	0.32	0.59	0.21	0.67
Mean Residual Depth Pools w/o Wood (m)	N/A	0.21	N/A	N/A	4.1
Mean % Surface Fines	1.4	1.3	1.7	1.4	2.3
Mean Volume of LWD (cubic m)	0.38	0.45	0.21	0.63	0.57

	Segment Number				
	495	501	446	1754	1788
Geomorphic Unit	9	9	9	10	10
Distance Surveyed (m)	234	100	146	100	100
Channel Gradient (%)	7	8	5	7	5
% Canopy Shade	27.4	0	64.6	79.9	69.2
% Pool Area	16.3	0	10	2.5	19.1
# of Pools	5	0	2	2	6
Channel Widths/Pool	9	N/A	13.2	27.7	5.75
LWD/Channel Width	1.1	4.6	0.4	0.9	1.6
% of Pools w/Wood Cover	80	N/A	100	100	100
Mean % Wood Cover in Pools	1.6	N/A	1.5	11	11.2
% Boulder Cover	64.4	60	40.2	1.7	19.9
Dominant Substrate	Boulder	Boulder	Cobble	Gravel	Cobble
Sub-Dominant Substrate	Cobble	Bedrock	Boulder	Cobble	Boulder
Mean Wetted Width (m)	3.6	5.2	3.7	1.2	2.2
Mean Channel Width (m)	5.2	6.4	5.5	1.8	2.9
Mean Wet Width Pools (m)	3.7	N/A	3.5	1.2	2.6
Mean Residual Depth Pools (m)	0.98	N/A	0.8	0.37	0.31
Mean Residual Depth Pools with Wood (m)	0.98	N/A	0.8	0.37	0.31
Mean Residual Depth Pools w/o Wood (m)	0.99	N/A	N/A	N/A	N/A
Mean % Surface Fines	0	0	4.1	2.4	5.1
Mean Volume of LWD (cubic m)	1.8	N/A	0.26	0.08	0.41

Table 4F-2. Habitat condition calls by channel segment.

	Segment Number									
	472	**GMU 1**	315	333	344	410	382	362	289	**GMU 2**
Summer/Winter Rearing										
Percent Pool	Poor	**Poor**	Poor	Fair	Poor	Good	Poor	Poor	Poor	**Poor**
Pool Frequency	Poor	**Poor**	Poor	Poor	Poor	Poor	Poor	Poor	Poor	**Poor**
Debris Pieces/Channel Width	Poor	**Poor**	Good	Poor	Fair	Good	Good	Fair	Fair	**Fair**
% Wood Cover in Pools	Poor	**Poor**	N/A	Fair	N/A	Good	Fair	Fair	Poor	**Fair**
Habitat Condition Call	*Poor*	***Poor***	*Fair*	*Fair*	*Fair*	*Good*	*Fair*	*Fair*	*Fair*	***Fair***
Winter Rearing										
Substrate	Fair	**Fair**	Poor	Fair	Fair	Fair	Poor	Fair	Poor	**Fair**
Off - Channel	Fair	**Fair**	Poor	Poor	Poor	Good	Fair	Poor	Poor	**Poor**
Habitat Condition Call	*Fair*	***Fair***	*Poor*	*Poor/Fair*	*Poor*	*Fair/Good*	*Fair*	*Poor/Fair*	*Poor*	***Poor/Fair***
Upstream Adult Migration										
Holding Pools	Fair	**Fair**	Poor	Fair	Poor	Good	Fair	Fair	Fair	**Fair**
Access to Spawning	Fair	**Fair**	Good	Good	Fair	Good	Good	Good	Good	**Good**
Habitat Condition Call	*Fair*	***Fair***	*Fair*	*Fair/Good*	*Fair*	*Good*	*Fair*	*Good*	*Fair/Good*	***Fair/Good***
Spawning and Incubation										
Gravel Quality	Good	**Good**	Poor	Good	Poor	Poor	Poor	Poor	Poor	**Poor**
Fines in Gravel	Poor	**Poor**	Poor	Fair	Poor	Poor	Poor	Poor	Fair	**Poor**
Redd Scour	Fair	**Fair**	Fair	Fair	Fair	Fair	Fair	Fair	Fair	**Fair**
Gravel Quantity	Fair	**Fair**	Good	Fair	Poor	Poor/Fair	Poor/Fair	Poor	Poor	**Poor**
Habitat Condition Call	*Fair*	***Fair***	*Poor/Fair*	*Fair*	*Poor*	*Poor*	*Poor*	*Poor*	*Poor/Fair*	***Poor***

	Segment Number									
	478(4)	1706	1759	1791	**GMU 4**	475	478(5)	1641	**GMU 5**	1820
Summer/Winter Rearing										
Percent Pool	Poor	Poor	Fair	Poor	**Poor**	Poor	Good	Poor	**Fair**	Poor
Pool Frequency	Poor	Fair	Poor	Fair	**Poor/Fair**	Poor	Fair	Fair	**Fair**	Poor
Debris Pieces/Channel Width	Fair	Good	Good	Fair	**Good**	Good	Good	Good	**Good**	Fair
% Wood Cover in Pools	Fair	Fair	Good	Fair	**Fair**	Poor	Poor	Fair	**Poor**	Poor
Habitat Condition Call	*Fair*	*Fair*	*Fair/Good*	*Fair*	***Fair***	*Poor/Fair*	*Fair*	*Fair*	***Fair***	*Poor*
Winter Rearing										
Substrate	Good	Good	Fair	Fair	**Good**	Good	Good	Fair	**Good**	Fair
Off - Channel	Fair	Poor	Poor/Fair	Poor/Fair	**Fair**	Poor	Poor	Fair	**Poor**	Poor
Habitat Condition Call	*Fair/Good*	*Fair*	*Fair*	*Fair*	***Fair***	*Fair*	*Fair*	*Fair*	***Fair***	*Poor/Fair*
Upstream Adult Migration										
Holding Pools	Fair	Fair	Fair	Fair	**Fair**	Fair	Good	Fair	**Fair**	Fair
Access to Spawning	Fair	Good	Good	Good	**Good**	Good	Good	Good	**Good**	Poor
Habitat Condition Call	*Fair*	*Good*	*Fair/Good*	*Fair/Good*	***Fair/Good***	*Good*	*Good*	*Good*	***Good***	*Poor*
Spawning and Incubation										
Gravel Quality	Fair/Good	Good	Good	Good	**Good**	Fair	Fair/Good	Fair	**Fair**	Poor
Fines in Gravel	Poor/Fair	Good	Good	Good	**Good**	Fair	Fair	Good	**Fair**	Good
Redd Scour	Fair	Fair	Fair	Fair	**Fair**	Fair	Fair	Fair	**Fair**	Poor
Gravel Quantity	Fair/Good	Fair	Fair	Fair	**Fair**	Poor	Fair	Good	**Fair**	Poor
Habitat Condition Call	*Fair*	*Fair/Good*	*Fair/Good*	*Fair/Good*	***Fair/Good***	*Fair*	*Fair*	*Fair/Good*	***Fair***	*Poor*

Table 4F-2. Habitat condition calls by channel segment (continued).

	Segment Number									
	257	1849	GMU 6	348	GMU 8	480	495	501	446	GMU 9
Summer/Winter Rearing										
Percent Pool	Fair	Poor	**Poor**	Fair	**Fair**	Good	Poor	Poor	Poor	**Poor**
Pool Frequency	Fair	Poor	**Fair**	Poor	**Poor**	Poor	Poor	Poor	Poor	**Poor**
Debris Pieces/Channel Width	Poor	Fair	**Fair**	Poor	**Poor**	Good	Fair	Good	Poor	**Fair**
% Wood Cover in Pools	Poor	Poor	**Poor**	Fair	**Fair**	Poor	Poor	N/A	Poor	**Poor**
Habitat Condition Call	*Fair*	*Poor*	***Poor***	*Poor/Fair*	***Poor/Fair***	*Fair*	*Poor*	*Poor*	*Poor*	***Poor***
Winter Rearing										
Substrate	Good	Fair	**Fair**	Fair	**Fair**	Good	Good	Fair	Fair	**Good**
Off - Channel	Poor	Poor	**Poor**	Poor	**Poor**	Poor	Poor	Poor	Poor	**Poor**
Habitat Condition Call	*Fair*	*Poor/Fair*	***Poor/Fair***	*Poor*	***Poor***	*Fair*	*Fair*	*Poor/Fair*	*Poor/Fair*	***Fair***
Upstream Adult Migration										
Holding Pools	Fair	Poor	**Fair**	Fair	**Fair**	Good	Good	Poor	Fair	**Fair**
Access to Spawning	Fair	Poor/Fair	**Poor/Fair**	Poor/Fair	**Poor/Fair**	Poor	Poor	Poor	Fair	**Poor**
Habitat Condition Call	*Fair*	*Poor*	***Poor/Fair***	*Poor/Fair*	***Poor/Fair***	*Poor*	*Poor*	*Poor*	*Fair*	***Poor***
Spawning and Incubation										
Gravel Quality	Good	Fair	**Fair**	Fair	**Fair**	Fair	Fair	Fair	Fair	**Fair**
Fines in Gravel	Good	Good	**Good**	Good	**Good**	Good	Good	Good	Fair	**Good**
Redd Scour	Poor	Poor	**Poor**	Poor	**Poor**	Poor	Poor	Poor	Poor	**Poor**
Gravel Quantity	Poor/Fair	Poor	**Poor**	Poor	**Poor**	Poor	Poor	Poor	Poor	**Poor**
Habitat Condition Call	*Fair*	*Poor*	***Poor***	*Poor*	***Poor***	*Poor/Fair*	*Poor/Fair*	*Poor/Fair*	*Poor/Fair*	***Poor/Fair***

	Segment Number									
	1754	1788	GMU 10							
Summer/Winter Rearing										
Percent Pool	Poor	Fair	**Poor/Fair**							
Pool Frequency	Poor	Poor	**Poor**							
Debris Pieces/Channel Width	Fair	Fair	**Fair**							
% Wood Cover in Pools	Fair	Fair	**Fair**							
Habitat Condition Call	*Poor/Fair*	*Fair*	***Fair***							
Winter Rearing										
Substrate	Fair	Good	**Fair/Good**							
Off - Channel	Poor	Poor	**Poor**							
Habitat Condition Call	*Poor/Fair*	*Fair*	***Fair***							
Upstream Adult Migration										
Holding Pools	Poor	Good	**Fair**							
Access to Spawning	Fair	Fair	**Fair**							
Habitat Condition Call	*Poor/Fair*	*Fair*	***Fair***							
Spawning and Incubation										
Gravel Quality	Fair	Fair	**Fair**							
Fines in Gravel	Good	Fair	**Fair/Good**							
Redd Scour	Fair	Fair	**Fair**							
Gravel Quantity	Fair	Fair	**Fair**							
Habitat Condition Call	*Fair*	*Fair*	***Fair***							

Table 4F-3. Fish densities by channel segment
(Number of individuals/100 squaremeters)

Segment	GMU	Bull Trout 0 - 3"	Bull Trout 3 - 6"	Bull Trout 6 - 9"	Bull Trout 9 - 12"	Bull Trout > 12"	Brook Trout 0 - 3"	Brook Trout 3 - 6"	Brook Trout 6 - 9"	Brook Trout 9 - 12"	Brook Trout > 12"	Cutthroat Trout 0 - 3"	Cutthroat Trout 3 - 6"	Cutthroat Trout 6 - 9"	Cutthroat Trout 9 - 12"	Cutthroat Trout > 12"	Rainbow Trout 0 - 3"	Rainbow Trout 3 - 6"	Rainbow Trout 6 - 9"	Rainbow Trout 9 - 12"
Beatrice																				
1641	5		0.07	0.21		0.14							0.21	0.48	0.28	014				
1706	4	0.19	1.11	0.19	0.37							0.56		1.12	0.56	037				
1759	4											0.21	0.32	1.16	0.63	032				
1791	4												0.19	0.75	0.19	019				
1788	10			0.56								1.12		2.24						
1754	10											0.84	0.84	1.68	0.84					
Boiling Spings																				
257	6						0.37	0.37		0.19							13.3	9.15	2.99	0.75
289	2						0.22	4									4.89	2.89		
315	2						4.8	8.16									5.76	3.84	2.88	
333	2						28.6	17.7	10.1											
348	8						12.6	2.52	0.84				4.2							
Murr																				
472	1						3.47	2.52	0.63			2.05	0.47				0.63	0.94		
478	4						2.5	2.3	0.26	0.13		1.32	0.46				0.39	0.2		
478	5						4.4	5.2	2	2.2		1.2	0.3							
480	9					0.09	0.18	0.99	1.7	1.26	0.72									
475	5						1.14	1.56	1.79	1.53	0.13									
North Fork Murr																				
446	9								1.12	0.37										
410	2						3.18	3.92	8.78	4.3	1.87									
382	2						3.23	1.61	2.96		0.27									
362	2							3.36	12.1	2.02	0.67									
344	2						4.2	3.36	5.46	4.2	0.42									
South Fork Murr																				
495	9						2.69	1.35	2.2	0.61	0.86									
501	9						0.77	0.96												

Table 4F-4. Fish habitat vulnerability to changes in input process.

Geomorphic Unit	Coarse Sediment	Fine Sediment	Peak Flows	LWD	Catastrophic Events	Riparian Vegetation	CMZ
Alluvial Fans (GMU 1)	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Low/Moderate
Forest/Meadow Complex (GMU 2)	Moderate	Moderate*	Moderate	Moderate*	Moderate	High	Moderate
Meadow/Pond Complex (GMU 3)	Low	Moderate	Low	Moderate*	Low	High	Low/Moderate
Conifer Floodplain CMZ (GMU 4)	High*	Moderate*	Moderate	High	Moderate	High	High
Confined Mainstem (GMU 5)	Low	Low	Low	Moderate	Low	Low	Low/Moderate
Incised Glacial Till (GMU 6)	Low	Low	Low	Moderate*	Low/Moderate	Low/Moderate	Low/Moderate
Alpine Glacial Headwater (GMU 7)	Low	Low	Low/Moderate	Moderate	Low/Moderate	Low/Moderate	Low
Perennial Headwater (GMU 8)	Low	Low	Low/Moderate	Moderate	Low	Low/Moderate	Moderate
Canyons & Cascades (GMU 9)	Low	Low	Low	Low	Low	Low	Low
Headwater in Valley Fill (GMU 10)	Moderate	Moderate*	Low/Moderate	High*	Low	Moderate	Moderate
Confined Intermittent (GMU 11)	Moderate	Low	Low/Moderate	Moderate	Low	Moderate	Low
Unconfined Intermitent (GMU 12)	Low	Low	Low	Low/Moderate	Low	Moderate	Low

* - Indicates habitat vulnerability rating different than channel sensitivity rating. See text for explanation.

SECTION 5

CAUSAL MECHANISM REPORTS

5 CAUSAL MECHANISM REPORTS

Once the analysts have worked through their modules, they must bring the information together with the data from other modules to develop a more comprehensive picture of the watershed. The information is used to link resource effects to existing or potential hazards and to consider the existing or potential cumulative effects of forest practices. The cause and effect linkages are summarized in the causal mechanism reports to help the prescriptions team develop appropriate management responses in focused areas.

Typically, five input variables are addressed; coarse sediment, fine sediment, large woody debris, water, and heat energy (temperature). Changes in the amount or timing of the input variables are evaluated for their potential to affect the public resources of fish and water quality.

Areas of resource sensitivity are identified based on the likelihood of adverse change and deliverability to a vulnerable resource. The resource assessment team rates the likelihood of adverse change and the resource vulnerability as "low," "medium," or "high". A "low" rating generally means there is minimal likelihood that there will be adverse change and deliverability. A "medium" rating means there is generally a significant likelihood adverse change and deliverability. A "high" rating generally means that adverse change and deliverability is more likely than not with a reasonable degree of confidence. Please note that the terms "medium" and moderate" are used interchangeably in the report. Management rule calls are generated for the sensitive areas based on the following matrix:

Table 5-1. Management Response for Areas of Resource Sensitivity

		LIKELIHOOD OF ADVERSE CHANGE AND DELIVERABILITY		
		LOW	**MODERATE**	**HIGH**
RESOURCE VULNERABILITY	**LOW**	*Standard Rules*	*Standard Rules*	*Prevent or Avoid*
	MODERATE	*Standard Rules*	*Minimize*	*Prevent or Avoid*
	HIGH	*Standard Rules*	*Prevent or Avoid*	*Prevent or Avoid*

If standard Best Management Practices and Streamside Management Zone rules are not adequate to protect the resource in a given area, a "resource sensitive area" is delineated. Some hazard areas identified by the resource assessment team may not be considered resource sensitive areas if significant impacts cannot be delivered. The resource sensitive areas are designated relative to the hazard area, rather than to the stream segments with the affected resource.

Once the resource assessment team has delineated sensitive areas, they must identify the processes and mechanisms by which forest practices can influence these areas. This information is conveyed to the prescriptions team in the "Causal Mechanism Report Summary."

The causal mechanism report summary has a brief problem statement, identifies triggering mechanisms, describes the rule call, and provides additional comments that the prescription team may find useful for developing appropriate management practices. The problem statement, or "situation statement", is constructed to clearly define the watershed process and associated input variables, the location of the hazard area, the activity which affects the watershed process, and the resource effects. The completion of all these elements within the situation statement is necessary to establish the linkage of hazard to vulnerable resources.

The triggering mechanism describes in detail how natural or management-related activities influence the watershed process of concern. The resource assessment team must be as specific and detailed as possible so the prescriptions team can develop alternatives that address the exact problem. Additional comments can be provided to give more details on the sensitive area or to give guidance on the scientific data available for a particular watershed processes.

A causal mechanism report is completed for each resource sensitive area in the watershed. These reports provide a brief and focused summary of problem areas that can be used easily by the prescriptions team. The prescriptions team can then work closely with the resource assessment team to ensure that all prescriptions address the triggering mechanisms and protect the vulnerable resource.

5.1 CAUSAL MECHANISM REPORT SUMMARIES

A total of nine causal mechanism report summaries were written for the Thompson Watershed analysis areas. The resource sensitive areas have been delineated regardless of ownership and have both natural and management-related triggering mechanisms. The maps with the delineated resource sensitive areas are found in the module reports and are referenced in each causal mechanism report.

CAUSAL MECHANISM REPORT - A1

Sensitive Area:	Slopes in excess of 70% on Steep Fluvial Lands (Landform Unit 2) where the potential exists for eroded material to be routed to streams
Sub-Basins:	Beatrice (Figure 4A-2a) Murr (Figure 4A-2c)
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	MODERATE
Resource Vulnerability:	HIGH
Rule Call:	PREVENT or AVOID

SITUATION SENTENCE:

Input	Coarse and fine sediment
Time Frame	from past and potential future
Watershed Process	landslides on slopes exceeding 70% contained within
Unit Location	Landform Unit 2
Activity	due to balanced road construction and addition/concentration of water from road drainage
Conditions	where the potential exists to route sediment to streams
Channel Effects	leading to accumulation of coarse and fine sediment
Location	in any fish-bearing segment
Resource Effects	which can 1) reduce egg to fry survival by cementing gravels and reducing the flow of oxygen in redds, and 2) reduce winter rearing habitat by filling the interstitial spaces of gravel and cobble substate for resident trout and fluvial bull trout. Extensive deposition in channel segments of GCU 4 in Beatrice Creek may potentially impede migration during base-flow peroids.

TRIGGERING MECHANISMS:

1) Balanced road construction or reconstruction

2) Cutslopes greater than 1:1

3) Road drainage addition, concentration from culverts, waterbars, dips, etc.

ADDITIONAL COMMENTS:

Not every acre contained within Lanform Unit 2 contains the hazard conditions of sideslopes greater than 70% and delivery potential to streams. Field inspection during road construction/re-construction is necessary to properly determine whether a hazard truly exists.

CAUSAL MECHANISM REPORT - A2

Sensitive Area:	Slopes in excess of 70% on Steep Alpine-Glaciated Lands (Landform Unit 4) where the potential exists for eroded material to be routed to streams.
Sub-Basins:	Beatrice (Figure 4A-2a)
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	MODERATE
Resource Vulnerability:	MODERATE
Rule Call:	MINIMIZE

SITUATION SENTENCE:

Input	Coarse and fine sediment
Time Frame	from potential future
Watershed Process	landslides on slopes exceeding 70% contained within
Unit Location	Landform Unit 4
Activity	due to road construction and addition/concentration of water from road drainage
Conditions	where the potential exists to route sediment to streams
Channel Effects	leading to accumulation of coarse and fine sediment
Location	in any fish-bearing segment
Resource Effects	which can 1) reduce egg to fry survival by cementing gravels and reducing the flow of oxygen in redds, and 2) reduce winter rearing habitat by filling the interstitial spaces of gravel and cobble substate for resident trout and fluvial bull trout. Extensive deposition in channel segments of GCU 4 in Beatrice Creek may potentially impede migration during base-flow peroids.

TRIGGERING MECHANISMS:

1) Balanced road construction or reconstruction

2) Cutslopes greater than 1:1

3) Road drainage addition, concentration from culverts, waterbars, dips, etc.

ADDITIONAL COMMENTS:

Not every acre contained within Lanform Unit 4 contains the hazard conditions of sideslopes greater than 70% and delivery potential to streams. Field inspection during road construction/re-construction is necessary to properly determine whether a hazard exists.

CAUSAL MECHANISM REPORT - A3

Sensitive Area:	Slopes in excess of 70% on Inner Gorges in glacial depositional landforms where the potential exists to route sediment to streams.
Sub-Basins:	Beatrice (Figure 4A-2a) Murr (Figure 4A-2b) Boiling Springs (Figure 4A-2c)
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	MODERATE to HIGH (dependent on presence of groundwater seepage)
Resource Vulnerability:	MODERATE to HIGH
Rule Call:	MINIMIZE or PREVENT/AVOID

SITUATION SENTENCE:

Input	Coarse and fine sediment
Time Frame	from past and potential future
Watershed Process	landslides on slopes exceeding 70% contained within
Unit Location	Landform Unit 5
Activity	due to road construction and addition/concentration of water from road drainage
Conditions	where potential exists to route sediment to streams
Channel Effects	leading to accumulation of coarse and fine sediment
Location	in any fish-bearing segment

Resource Effects . . . . . which can 1) reduce egg to fry survival by cementing gravels and reducing the flow of oxygen in redds, and 2) reduce winter rearing habitat by filling the interstitial spaces of gravel and cobble substate for resident trout and fluvial bull trout. Extensive deposition in channel segments of GCU 4 in Beatrice Creek may potentially impede migration during base-flow peroids.

TRIGGERING MECHANISMS:

1) Balanced road construction or reconstruction

2) Cutslopes greater than 1:1

3) Road drainage addition, concentration from culverts, waterbars, dips, etc.

ADDITIONAL COMMENTS:

In this map unit, a moderate hazard exists on slopes exceeding 70% where no field inspection does not reveal the occurrance of groundwate seepage and potential exists to route sediment to streams. The rule call in this situations is MINIMIZE.

Where groundwater seepage is present on slopes exceeding 70% and the potential exists for sediment to be routed to streams a high hazard exists. The rule call in this situation is PREVENT/AVOID.

Not every acre contained within Lanform Unit 5 contains the hazard conditions of sideslopes greater than 70% and slopes, groundwater presence, and delivery potential to streams. Field inspection during road construction/re-construction is necessary to properly determine whether a hazard exists.

CAUSAL MECHANISM REPORT - B1

Sensitive Area:	Road locations that deliver sediment to streams
Sub-Basins:	Beatrice Creek (Figure 4B-3a, Table C-1 (Apdx C) Boiling Springs Creek (Figure 4B-3b, Table C-1 (Apdx C)
Input Variable:	Fine Sediment
Delivered Hazard:	HIGH
Resource Vulnerability:	MODERATE
Rule Call:	PREVENT or AVOID

SITUATION SENTENCE:

Input	Fine sediment
Time Frame	from existing
Watershed Process	road surface erosion in areas
Unit Location	mapped in Figures 4B-3a and 4B-3b and prioritized in Table C-1 (Appendix C).
Activity	due to old erosion control standards (BMP practices) which resulted in long road delivery distances
Conditions	proximate to stream channels
Channel Effects	leading to accumulation of fine sediment in
Location	moderately vulnerable channel segments
Resource Effects	which can 1) reduce egg to fry survival by cementing gravels and reducing the flow of oxygen in redds, and 2) reduce winter rearing habitat by filling the interstitial spaces of gravel and cobble substate for resident trout and fluvial bull trout.

TRIGGERING MECHANISMS:

Stream crossings and road segments (parallel to streams) that are not up to current BMP standards.

ADDITIONAL COMMENTS:

Because the transportation network in these watersheds has been largely developed, new road construction using modern standards is not expected to materially contribute to stream sedimentation, particularly if existing sources are dealt with.

Though Murr Creek was assigned a low hazard with regard to overall sediment delivery to streams, opportunities exist to reduce sediment loading. These opportunities are prioritized in Table C-1 (Appendix C), and delineated on Figure 4B-3c.

CAUSAL MECHANISM REPORT - D1

Sensitive Area:	Riparian areas and channel migration zones adjacent to GCU 4
Sub-Basins:	Beatrice (Figure 4E-1a) Murr (Figure 4E-1c)
Input Variable:	Large Woody Debris (LWD)
Delivered Hazard:	MODERATE (Segments: 478, 513, 1660, 1680, 1706, 1709, 1759, 1770, 1772, 1791; See Figure 4D-1a and Figure 4D-1c for segment locations)
Resource Vulnerability:	HIGH
Rule Call:	PREVENT OR AVOID

SITUATION SENTENCE:

Input	Lowered LWD recruitment, bank stability and channel movement within the CMZ
Time Frame	from past and potential future
Watershed Process	loss of bank stability, long-term LWD recruitment, and channel movement within
Unit Location	GCU 4
Activity	due to harvest within the riparian area, removing trees along the stream banks, disturbing potential streamside brush
Conditions	within the CMZ of streams where the channel has the potential to move outside the harvest buffer area
Channel Effects	leading to decreased LWD recruitment, lowered bank stability and potential channel movement
Location	in fish bearing areas with Moderate to High vulnerabilities

Resource Effects . . . . . which can 1) reduce channel complexity and increse potential bed scour and bank erosion, 2) reduce summer and winter rearing and spawning habitat (quality) and/or increase fine sediment in spawning gravels (quality), 3) lowering survivial by lowering carrying capacity of embryo and juvenile salmonids.

TRIGGERING MECHANISMS:

1. Future harvest within the CMZ reducing the density of larger riparian conifers below a level needed to supply suitable LWD for recruitment.

2. Disturbance of streambank tree roots and floodplain vegetation causing bank instability

3. Harvest within the CMZ leaving the stream unprotected if the stream moves outside of a regulatory buffer zone.

ADDITIONAL COMMENTS:

LWD levels are adequate and potential recruitment trees are present within these areas. Harvest within these areas should be designed to address these unique conditions and hazards.

CAUSAL MECHANISM REPORT - D2

Sensitive Area: Channel segments with a moderate vulnerability to Large Woody Debris recruitment. These include channels in the following GCU's:

GCU 1
GCU 2
GCU 3
GCU 5
GCU 6
GCU 7
GCU 8
GCU 11
GCU 12

Sub-Basins: Beatrice
Boiling Springs
Murr

Input Variable: Large Woody Debris

Delivered Hazard: MODERATE (segments 315, 328, 344, 362, 370, 382, 384, 387, 410, 458, 475, 1796, 1800, 1815, 1820, 1821, 1849, 1856, and 1912)

HIGH (segments 250, 333, 289, 291, 257, 335, 337, 348, 350, 353, 355, 472, 361, 367, 1641, 1883, and 1896)

Resource Vulnerability: MODERATE

Rule Call: MINIMIZE for MODERATE delivered hazard

PREVENT or AVOID for HIGH delivered hazard

SITUATION SENTENCE:

Input ..... Loss of long-term LWD

Time Frame ..... from past and potential future

Watershed Process	reductions of LWD recruitment
Unit Location	in riparian areas mapped as Moderate or High on Figure 4D-2
Activity	due to timber harvest prior to the SMZ law
Conditions	where reductions have already occurred
Channel Effects	leading to loss of in-channel LWD
Location	in specified segments within GCU's 1, 2, 3, 5, 6, 7, 8, 11, and 12
Resource Effects	which can 1) reduce the number of pools and channel complexity, and 2) reduce the quality/quantity of summer/winter habitat for trout

TRIGGERING MECHANISMS:

1. Additional removal of recruitable trees

ADDITIONAL COMMENTS:

Areas classified has a high hazard were harvested prior to passage of the Montana SMZ law. Future management should restrict further harvest and promote conifer regrowth growth within these areas. Current LWD is generally adequate, but long-term LWD has been reduced.

Because the Beatrice Creek road parallels channel segments 1641, 1600, and 1680, all LWD recruitment in this area must come from the south side of the stream. As such, future harvests on the south side of the stream should be designed to not reduce LWD recruitment potential.

CAUSAL MECHANISM REPORT - D3

Sensitive Area:	Stream segments 1754, 1777 and 1788 (GCU 10)
Sub-Basins:	Beatrice
Input Variable:	Large Woody Debris
Delivered Hazard:	MODERATE (segment 1788) HIGH (segments 1754, and 1777)
Resource Vulnerability:	HIGH
Rule Call:	PREVENT OR AVOID

SITUATION SENTENCE:

Input	Lowered LWD recruitment, bank stability and channel movement within the CMZ
Time Frame	from past and potential future management, leading to
Watershed Process	loss of bank stability, long-term LWD recruitment, and channel movement
Unit Location	within CMZ of the channel segments and the potential LWD recruitment area
Activity	Harvest within the riparian area, removing trees along the stream banks, disturbing brush
Conditions	within the CMZ of stream were the channel has the ability to move outside of harvest buffer area
Channel Effects	Leading to decreased LWD recruitment, lowered bank stability and potential channel movement
Location	in fish bearing areas with MODERATE to HIGH vulnerabilities

Resource Effects . . . . . which can 1) reduce channel complexity and increase potential bed scour and bank erosion, 2) reduce summer and winter rearing and spawning habitat (quantity) and/or increase fine sediment in spawning gravels (quality), 3) lowering survival by lowering carrying capacity of embryo and juvenile salmonids.

TRIGGERING MECHANISMS:

1. Future harvest within the CMZ reducing the density of larger riparian conifers below a level needed to supply suitable LWD for recruitment.

2. Disturbance of streambank tree roots and floodplain vegetation causing bank instability

3. Harvest within the CMZ leaving the stream unprotected if it moves outside of regulatory buffer zone.

ADDITIONAL COMMENTS:

LWD levels are adequate and potential recruitably trees are present within these within the Moderate areas. LWD levels in High areas ar currently adequate, but future levels may be reduced due to an inadeqate supply of potential LWD. Harvest with in these areas should be implemented to address the potential resource vulnerabilities of these areas when developing the harvest prescriptions.

CAUSAL MECHANISM REPORT - D4

Sensitive Area:	Stream segments 315, 472, 344, 362, and 478 (Table 4D-7)
Sub-Basins:	Boiling Springs Murr
Input Variable:	Solar Radiation
Delivered Hazard:	HIGH
Resource Vulnerability:	MODERATE
Rule Call:	PREVENT or AVOID

SITUATION SENTENCE:

Input	Increased short wave radiation inputs
Time Frame	from past and potential future
Watershed Process	canopy cover removal over streams
Unit Location	in channel segments 315, 472, 344, 362, and 478
Activity	due to riparian timber harvest, grazing, and natural causes
Conditions	is causing summertime stream warming
Channel Effects	
Location	in fish bearing reaches bordering the listed channel segments and for some distance downstream
Resource Effects	affecting rearing temperatures for resident fish.

TRIGGERING MECHANISMS:

1. Riparian timber harvest that reduces shade levels.

2. Streamside cattle grazing that reduces streambank cover, or contributes to channel widening.

ADDITIONAL COMMENTS:

The significance of forest management effects on stream temperature will be further studied in these reaches in 1998. Results of that additional analysis could result in modification of this CMR.

CAUSAL MECHANISM REPORT - D5

Sensitive Area:	Stream Segment 472
Sub-Basins:	Murr
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	HIGH
Resource Vulnerability:	MODERATE
Rule Call:	PREVENT or AVOID

SITUATION SENTENCE:

Input	Coarse and fine sediment
Time Frame	from past and potential future
Watershed Process	bank erosion and channel incision
Unit Location	in stream segment 472
Activity	due to livestock grazing and mechanical disturbance
Conditions	of riparian shrubs is resulting in
Channel Effects	accumulation of coarse and fine sediment, and channel widening
Location	in channel segment 472
Resource Effects	which can 1) reduce egg to fry survival by cementing gravels and reducing the flow of oxygen in redds, and 2) reduce winter rearing habitat by filling the interstitial spaces of gravel and cobble substate for resident trout and fluvial bull trout.

TRIGGERING MECHANISMS:

1. Cattle grazing along stream bank

2. Equipment operation along the stream course.

ADDITIONAL COMMENTS:

This part of Murr Creek is on small private land. Following the spring, 1997 runoff, major channel alterations on lower Murr Creek occurred affecting an irrigation diversion structure the private landowner had. To remedy the problem, the landowner used heavy equipment to reconstruct the diversion. The Flathead County Conservation District is working with the landowner to find a solution to his problem at present.

SECTION 6

PRESCRIPTIONS

Note: Prescriptions will be written in the coming months.

SECTION 7

WATERSHED SIMILARITY ANALYSIS

WATERSHED SIMILARITY ANALYSIS
THOMPSON RIVER BASIN
MONTANA

Prepared for:

PLUM CREEK TIMBER
COLUMBIA FALLS, MONTANA

Prepared by:

Ron Ryel
and
Sherman Jensen

WHITEHORSE ASSOCIATES
Logan, Utah

APRIL, 1997

7.1 INTRODUCTION

White Horse Associates (1997) performed an ecological classification for the Thompson River Basin in northwestern Montana to provide information useful in resource management. This hierarchical classification provided attributes at seven levels for 33 watersheds. Attributes used in the classification included: ecoregion, geologic district, subsection, landtype association, landtype, valley-bottom type and valley-bottom habitat. A statistically-based cluster analysis was performed using these attributes to group similar watersheds.

7.2 METHODS

Cluster analysis is designed to group objects into categories based on similarity or dissimilarity of attributes. While various methods exist, fuzzy clustering was chosen for this analysis because it does not force objects into a single group and can be effective in identifying outlying objects. The method also avoids the problem of inseparably joined objects inherent to traditional hierarchical clustering methods.

Fuzzy clustering allows objects to be classified into more than one cluster and is a generalization of partition clustering methods (e.g., k-means and medoid). In regular clustering each object can be a member of only one cluster. However, fuzzy clustering allows the value of attributes of objects to be spread over multiple clusters, reducing the negative effect of outlying objects. The number of clusters most appropriate for a set of objects was determined by three criteria statistics (average silhouette, Dunn's partition coefficient, Kaufman's partition coefficient). Objects are assigned to clusters where their membership probability is highest.

Clustering of watersheds considered the hierarchy of attributes. Since the entire Thompson River basin was classified into one ecoregion (Northern Rockies Ecoregion) and one geologic district (metasedimentary), subsection was the broadest hierarchical division which contained multiple types (*alpine glaciated lands, fluvial lands, continental glaciated erosional lands* and *continental glaciated depositional lands*). Clustering was conducted starting with subsection attributes of watersheds and also included landtype association, valley bottom type and valley bottom habitat. Landtype was not considered in the clustering. Percentages of watershed area comprised of members of these hierarchical divisions was used as attribute data for clustering. Attribute data were not transformed or standardized for analysis. Two to ten clusters were considered in each analysis.

Linear discriminant analysis was used to test the strength of the resulting clusters. A set of prediction equations based on independent variables are used to classify objects into groups in discriminant analysis. If clustering is successful, the values of the attributes used in clustering an object should predict cluster membership.

7.3 RESULTS AND DISCUSSION

Final clustering of watersheds was performed at two levels: (1) subsection; and (2) landtype association and valley bottom type. Initial clustering at the subsection level was chosen as clusters using only the subsection attributes was nearly identical to clustering using subsections in various combinations with landtype associations, valley-bottom types and valley bottom habitats (not shown). Two to five clusters had similar criteria statistics, and three clusters were chosen based upon the of grouping watersheds with similar geomorphic character. These clusters based upon subsections (expressed as a percent of the watershed) were named: (1) continental glaciated watersheds; (2) alpine glaciated watersheds; and (3) fluvial watersheds. Mean and individual watershed values for subsection attributes are listed in Table 3-1. Numeric codes are listed in APPENDIX A. Discriminant analysis using the four subsections was able to correctly predict classification for 32 of 33 watersheds (Chippy Creek was incorrectly classified as a fluvial watershed instead of alpine glaciated watershed).

The second level of clustering was nested within each of the three clusters identified in the first level of clustering. The attributes used for second level clustering were: 1) landtype association (expressed as a percent of the watershed); 2) valley-bottom type (expressed as a percent of the valley-bottom landtype in the watershed); and 3) valley-bottom landtype (expressed as a percent of the watershed), as listed in Table 3-1. Membership probabilities for watersheds in each cluster are also listed in Table 3-1 and watersheds in each cluster are ordered by this value. Nearly identical clustering was found when valley-bottom habitat was included (not shown). Similar clusters were also found when only valley-bottom types, valley-bottom habitats and area of valley-bottom landtype were considered (not shown). Mean and individual watershed values for each cluster are listed in Table 3-1. In an attempt to reduced the number of clusters, some clusters within this second level were combined based on similarity in attributes and the results of clustering with fewer clusters. Discriminant analysis based on parameters shown in Table 3-2A were able to correctly place all objects in the correct first and second level clusters. A search routine was used to find the minimum set of variables necessary to predict the correct classification of watersheds. More variables were necessary to predict the correct combined clusters (Table 3-2b).

Combined clusters are illustrated in Figure 3-1.Brief descriptions of each combined cluster follow. Dominant classes comprise more than 15 percent of at least one watershed in the cluster.

Cluster 1-1&2: The dominant subsections are *continental glaciated erosional lands* (1300), *continental glaciated depositional lands* (1400) and *fluvial lands (1200)*. The dominant landtype associations are *mountain slope* (1202), *continental glaciated ridge and slope* (1301) and *high terrace* (1401). The valley-bottom landtype comprises 9 to 21 percent of the watershed. Dominant valley-bottom types are *fluvial basin* (1210), *glacio-lacustrine basin unconfined* (1410) and *glacio-lacustrine basin confined* (1420). Upper Fishtrap watershed is somewhat anomalous in having a higher proportion of *fluvial lands* and including *alpine glaciated lands.*

Cluster 1-3: The dominant subsections are *continental glaciated erosional lands, continental glaciated depositional lands* and *fluvial lands.* The dominant landtype associations are *continental glaciated ridge and slope* (1301), *high terrace* (1401) and *mountain slope* (1201). The valley-bottom landtype comprises 14 to 32 percent of the watershed. Dominant valley-bottom types are *glacio-lacustrine basin confined* (1420), *glacio-lacustrine basin unconfined* (1410), *continental fluvial basin* (1310) and *glacial outwash* (1130). Davis Creek watershed is anomalous in having: 1) smaller valley-bottom landtype; 2) lower proportion of *fluvial lands* and higher proportion of *continental glaciated erosional lands;* and 3) lower proportion of *glacio-lacustrine basin unconfined* (1410) valley-bottom type. Davis Creek appears to fit better with cluster 1-1&2.

Cluster 1-4: The dominant subsections are *continental glaciated erosional lands, continental glaciated depositional lands* and *fluvial lands.* The dominant landtype associations are *continental glaciated ridge and slope* (1301), *high terrace* (1401) and *mountain slope* (1202). The valley-bottom landtype comprises 32 to 45 percent of the watershed. The dominant valley-bottom type is *glacio-lacustrine basin confined* (1420).

Cluster 2-1&5: The dominant subsections are *fluvial lands* (1200) and *alpine glacial lands* (1100). The dominant landtype associations are *mountain slope* (1202), *alpine glacial trough* (1103), *mountain ridge* (1201), *breakland* (1203) and *glacial moraine* (1104). The valley-bottom landtype comprises 8 to 10 percent of the watershed. The dominant valley-bottom types are *glacio-lacustrine basin confined* (1420), *glacial outwash* (1130) and *alpine glacial basin* (1110).

Cluster 2-2: The dominant subsections are *alpine glacial lands* (1100) and *fluvial lands* (1200). The dominant landtype associations are *alpine glacial trough* (1103), *cirque and rock ridge* (1102) and *alpine glacial basin* (1102). The valley-bottom landtype comprises 3 to 8 percent of the watershed. The dominant valley-bottom types are *alpine glacial basin* (1110) and *alpine glacial train* (1120).

Cluster 2-3&4: The dominant subsections are *fluvial lands* (1200) and *alpine glacial lands* (1100). The dominant landtype associations are *mountain slope* (1202), *alpine glacial trough* (1103) and *breakland* (1203). The valley-bottom landtype comprises 4 to 5 percent of the watershed. The dominant valley-bottom types are *fluvial cascade* (1205), *fluvial V-erosional canyon* (1220), *fluvial basin* (1210) and *glacial basin* (1110).

Cluster 3-1: The dominant subsections are *fluvial lands* (1200) and *continental glaciated erosional lands* (1300). The dominant landtype associations are *mountain slope* (1202), *mountain ridge* (1201), *breakland* (1203) and *continental glaciated ridge and slope* (1301). The valley-bottom landtype comprises 6 to 14 percent of the watershed. The dominant valley-bottom types are *glacio-lacustrine basin confined* (1420), *fluvial basin* (1210), *fluvial V-depositional canyon* (1230), *fluvial V-erosional canyon* (1220) and *glacial outwash* (1130).

Cluster 3-2: The dominant subsections are *fluvial lands* (1200), *continental glaciated depositional lands* (1400) and *continental glaciated erosional lands* (1300). The dominant landtype associations are *mountain slope* (1202), *high terrace* (1402) and *continental glaciated ridge and slope* (1301). The valley-bottom landtype comprises 25 to 33 percent of the watershed. The dominant valley-bottom type is *glacio-lacustrine basin confined* (1420).

Cluster 3-3: The dominant subsections are *fluvial lands* (1200) and *continental glaciated erosional lands* (1400). The dominant landtype associations are *mountain slope* (1202), *mountain ridge* (1201), *breakland* (1203) and *continental glaciated ridge and slope* (1301). The valley-bottom landtype comprises 3 to 6 percent of the watershed. The dominant valley-bottom types are *fluvial basin* (1210), *fluvial V-erosional canyon* (1220), *fluvial cascade* (1205) and *fluvial V-depositional canyon* (1230).

Table 3-1. Results of two levels of fuzzy clustering to assess watershed similarity, Thompson River basin.

Watershed	LEVEL		MEM	SUBSECTION				LANDTYPE ASSOCIATION											VBLT	VALLEY BOTTOM TYPE												
	1	2	PROB	1100 (%)	1200 (%)	1300 (%)	1400 (%)	1101 (%)	1102 (%)	1103 (%)	1104 (%)	1201 (%)	1202 (%)	1203 (%)	1301 (%)	1401 (%)	1402 (%)	1403 (%)	(%)	1110 (%)	1120 (%)	1130 (%)	1205 (%)	1210 (%)	1220 (%)	1230 (%)	1305 (%)	1310 (%)	1320 (%)	1330 (%)	1410 (%)	1420 (%)	1430 (%)
Lang Creek	1	1	091	0.0	7.5	61.6	30.9	0.0	0.0	0.0	0.0	0.0	66.8	0.7	18.5	12.6	1.4	0.0	12.7	0.0	0.0	0.0	2.4	15.5	0.0	0.0	0.0	0.0	1.3	0.0	20.0	60.8	0.0
Upper Fishtrap	1	1	035	9.9	39.6	33.6	16.9	2.7	0.9	4.9	1.5	6.8	31.1	1.6	31.8	15.3	3.2	0.2	20.6	1.8	4.4	0.0	0.5	6.4	1.5	0.0	0.1	3.5	0.7	6.3	12.7	62.[illegible]	0.0
Boiling Springs Creek	1	2	098	0.0	3.0	96.5	0.5	0.0	0.0	0.0	0.0	3.0	0.1	0.0	89.7	5.1	2.1	0.0	9.4	0.0	0.0	0.0	0.0	1.3	0.0	0.0	3.7	9.1	13.8	0.0	70.7	0.0	0.0
MEAN				**3.3**	**15.7**	**63.9**	**16.1**	**0.9**	**0.3**	**1.6**	**0.5**	**3.3**	**32.7**	**0.8**	**46.6**	**11.0**	**2.2**	**0.1**	**14.2**	**0.6**	**1.5**	**0.0**	**1.0**	**7.7**	**0.5**	**0.0**	**1.3**	**4.2**	**5.3**	**2.1**	**34.5**	**41.0**	**0.0**
Thompson Lakes	1	3	079	0.0	7.5	61.6	30.9	0.0	0.0	0.0	0.0	0.7	6.5	0.2	60.7	23.0	2.1	6.7	32.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	4.4	0.5	0.0	45.4	49.6	0.0
Davis Creek	1	3	039	0.0	0.3	84.1	15.6	0.0	0.0	0.0	0.0	0.3	0.0	0.0	84.1	15.3	0.3	0.0	14.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.2	0.0	0.0	9.6	74.2	0.0
McGregor Creek	1	3	033	0.0	31.3	50.8	15.9	0.0	0.0	0.0	14.2	1.5	28.4	2.3	39.5	3.5	3.1	7.6	29.0	0.0	0.0	39.1	0.6	2.2	0.8	3.0	0.3	3.4	0.0	0.0	40.2	10.[illegible]	0.0
MEAN				**0.0**	**11.7**	**65.5**	**20.8**	**0.0**	**0.0**	**0.0**	**4.7**	**0.8**	**11.6**	**0.8**	**61.4**	**14.0**	**1.8**	**4.8**	**25.3**	**0.0**	**0.0**	**13.0**	**0.3**	**0.7**	**0.3**	**1.0**	**0.1**	**8.0**	**0.2**	**0.0**	**31.7**	**44.4**	**0.0**
Indian Creek	1	4	073	0.0	23.8	38.0	33.2	0.0	0.0	0.0	0.0	5.2	22.8	0.8	38.4	32.4	0.3	0.1	35.7	0.0	0.0	0.0	0.0	2.7	0.7	0.0	0.0	2.1	0.0	0.0	0.0	94.4	0.0
Lower Little Thompson	1	4	070	0.0	10.7	46.6	42.7	0.0	0.0	0.0	0.0	1.6	8.9	0.1	46.4	39.3	3.6	0.0	44.8	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.0	2.6	0.5	10.9	0.0	85.5	0.0
Lazier Creek	1	4	067	0.0	0.4	55.9	34.6	0.0	0.0	0.0	0.0	1.0	8.4	0.0	55.9	34.3	0.3	0.0	32.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	4.8	0.0	0.0	0.0	94.7	0.0
Middle Thompson	1	4	062	0.0	23.6	33.1	38.3	0.0	0.0	0.0	0.0	4.1	21.6	2.6	32.9	33.9	4.8	0.0	40.0	0.0	0.0	0.0	0.3	1.9	0.1	0.2	0.1	1.8	0.0	0.0	5.9	80.9	9.1
MEAN				**0.0**	**12.4**	**43.4**	**37.2**	**0.0**	**0.0**	**0.0**	**0.0**	**3.0**	**15.4**	**0.9**	**43.4**	**35.0**	**2.3**	**0.0**	**38.2**	**0.0**	**0.0**	**0.0**	**0.1**	**1.3**	**0.2**	**0.1**	**0.1**	**2.8**	**0.1**	**2.7**	**1.5**	**88.4**	**2.3**
SUBSECTION 1 MEAN				**1.0**	**15.9**	**56.2**	**26.0**	**0.3**	**0.1**	**0.5**	**1.6**	**2.4**	**19.5**	**0.8**	**49.8**	**21.5**	**2.1**	**1.5**	**27.1**	**0.2**	**0.4**	**3.9**	**0.4**	**3.1**	**0.3**	**0.3**	**0.5**	**4.8**	**1.7**	**1.7**	**20.5**	**61.2**	**0.9**
Big Rock Creek	2	1	081	30.0	69.3	2.1	1.6	2.4	0.1	22.8	3.1	19.2	40.5	8.1	2.1	1.4	0.2	0.0	7.7	11.4	0.0	30.1	8.2	14.2	10.3	0.0	0.0	0.0	0.0	0.0	0.0	25.4	0.4
Upper Little Thompson	2	1	034	64.3	31.2	1.1	0.4	4.1	0.5	33.5	17.5	9.8	26.4	5.2	1.2	0.3	1.5	0.0	10.5	12.6	0.5	60.4	11.4	4.6	4.0	1.6	0.0	0.4	0.0	0.0	0.0	4.4	0.0
Big Hole Creek	2	5	084	47.2	52.8	0.0	0.0	9.5	3.1	24.3	10.3	12.5	33.0	0.2	0.0	6.7	0.4	0.0	8.9	17.7	0.0	0.0	7.3	10.7	2.2	0.2	0.0	0.0	0.0	0.0	0.0	61.9	0.0
Chippy Creek	2	5	036	17.7	75.7	1.4	5.2	1.7	0.1	12.9	2.2	22.3	36.9	17.2	1.4	5.1	0.1	0.0	10.4	5.6	0.0	13.6	7.0	13.1	8.2	0.0	0.0	0.0	0.0	0.0	0.0	52.3	
Bear Creek	2	5	028	27.9	69.1	0.1	2.9	3.4	0.0	21.9	2.6	15.0	37.1	17.0	0.1	2.4	0.5	0.0	7.6	13.9	8.3	0.0	13.0	9.8	14.9	0.0	0.0	0.0	0.0	0.0	0.0	36.0	4.1
MEAN				**37.4**	**59.6**	**1.0**	**2.0**	**4.2**	**0.8**	**23.1**	**7.1**	**15.8**	**34.8**	**9.5**	**1.0**	**3.2**	**0.6**	**0.0**	**9.0**	**12.2**	**1.8**	**20.8**	**9.4**	**10.5**	**7.9**	**0.4**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**36.0**	**0.9**
West Fork Fishtrap	2	2	095	69.6	28.8	1.6	0.0	17.9	0.6	31.7	7.9	8.9	17.1	3.6	1.6	0.0	0.3	0.4	8.0	33.7	55.7	0.0	4.3	5.2	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
Four Lakes Creek	2	2	025	87.0	13.0	0.0	0.0	26.0	26.5	19.3	14.8	1.7	7.1	3.3	0.0	0.0	0.9	0.5	3.3	77.1	6.9	0.0	7.6	0.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MEAN				**78.3**	**20.9**	**0.8**	**0.0**	**21.9**	**8.5**	**25.5**	**11.4**	**5.3**	**12.1**	**3.4**	**0.8**	**0.0**	**0.6**	**0.4**	**5.7**	**55.4**	**31.3**	**0.0**	**6.0**	**2.6**	**4.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.6**	**0.0**	**0.8**	**0.0**

Table 3-1. Results of two levels of fuzzy clustering to assess watershed similarity, Thompson River basin.

Watershed	LEVEL 1	LEVEL 2	MEM PROB	SUBSECTION 1100 (%)	1200 (%)	1300 (%)	1400 (%)	LANDTYPE ASSOCIATION 1101 (%)	1102 (%)	1103 (%)	1104 (%)	1201 (%)	1202 (%)	1203 (%)	1301 (%)	1401 (%)	1402 (%)	1403 (%)	VBLT (%)	VALLEY BOTTOM TYPE 1110 (%)	1120 (%)	1130 (%)	1205 (%)	1210 (%)	1220 (%)	1230 (%)	1305 (%)	1310 (%)	1320 (%)	1330 (%)	1410 (%)	1420 (%)	1430 (%)
Jungle Creek	2	3	085	24.0	75.0	0.0	0.0	2.3	0.9	20.8	0.0	10.4	61.4	4.2	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	36.1	8.0	34.9	0.0	0.0	0.0	0.0	0.0	0.0	20.1	0.4
Deerhorn Creek	2	3	037	32.5	67.4	0.0	0.1	12.5	1.5	18.6	0.0	5.7	59.4	0.0	0.0	0.1	2.4	0.0	4.2	2.2	0.0	0.0	40.1	32.6	22.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
Middle West Fork	2	4	090	30.6	69.4	0.0	0.0	14.5	6.7	6.6	2.7	3.8	29.8	32.9	0.0	0.4	2.5	0.2	4.2	15.6	5.6	0.0	28.8	20.2	29.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Beatrice Creek	2	4	024	26.2	73.8	0.0	0.0	6.8	0.0	19.4	0.0	13.6	49.6	8.8	0.0	0.0	1.8	0.0	5.1	32.8	13.4	0.0	10.1	34.5	9.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MEAN				**28.3**	**71.7**	**0.0**	**0.0**	**9.0**	**2.3**	**16.3**	**0.7**	**8.4**	**50.1**	**11.5**	**0.0**	**0.1**	**1.7**	**0.0**	**4.4**	**12.7**	**4.8**	**0.0**	**28.8**	**23.8**	**24.1**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**5.3**	**5**
SUBSECTION 2 MEAN				**41.5**	**57.0**	**0.6**	**0.9**	**9.2**	**4.5**	**21.1**	**5.6**	**11.2**	**36.2**	**9.1**	**0.6**	**1.5**	**1.0**	**0.1**	**6.7**	**20.2**	**8.2**	**9.5**	**15.8**	**13.9**	**13.1**	**0.2**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**18.3**	**0.6**
Lower Fishtrap	3	1	055	0.0	89.8	0.1	0.1	0.0	0.0	0.0	0.0	9.4	56.0	22.6	0.5	8.5	3.0	0.0	14.0	0.0	0.0	0.0	1.3	19.3	5.0	8.6	0.0	0.0	0.0	0.4	0.0	48.3	17.1
North Fork Little Thompson	3	1	055	2.1	94.5	0.0	3.4	2.1	0.0	0.0	0.0	17.1	64.5	12.5	0.4	2.5	0.9	0.0	6.8	0.0	0.0	0.0	9.7	20.1	17.8	0.0	0.0	0.0	0.0	0.0	0.0	52.4	0.0
Meadow Creek	3	1	053	0.0	72.3	20.5	7.2	0.0	0.0	0.0	0.0	6.8	62.2	2.4	20.5	6.8	1.3	0.0	12.3	0.0	0.0	0.0	0.7	23.0	6.6	27.3	0.0	7.0	1.7	0.0	0.0	33.3	0.3
Lower Thompson	3	1	046	5.4	85.4	3.2	6.0	3.4	1.2	0.8	0.0	4.1	38.7	35.8	3.8	8.6	3.6	0.0	8.5	1.7	0.0	0.0	9.6	12.0	0.0	38.9	0.0	0.0	0.0	0.0	0.0	26.9	10.9
Calico Creek	3	1	044	0.0	79.4	14.8	5.8	0.0	0.0	0.0	0.0	12.0	66.9	0.0	14.8	5.5	0.8	0.0	8.2	0.0	0.0	0.0	14.3	8.8	8.6	0.0	0.0	3.3	0.0	0.0	0.0	65.1	0.0
Mary Creek	3	1	043	0.0	96.8	1.8	1.4	0.0	0.0	0.3	2.3	30.2	57.7	5.8	1.8	1.3	0.5	0.0	6.5	0.0	0.0	42.4	2.2	19.2	12.4	0.0	0.0	0.5	0.0	0.0	0.2	22.6	0.0
MEAN				**1.3**	**46.4**	**6.7**	**5.6**	**0.9**	**0.2**	**0.2**	**0.4**	**13.3**	**57.7**	**13.2**	**7.0**	**5.5**	**1.7**	**0.0**	**9.4**	**0.3**	**0.0**	**7.1**	**6.3**	**17.1**	**8.4**	**12.5**	**0.0**	**1.9**	**0.3**	**0.1**	**0.0**	**41.5**	**4.7**
Semam Creek	3	2	0.79	0.0	51.6	30.6	17.8	0.0	0.0	0.0	0.0	13.6	35.1	2.9	30.3	17.8	0.4	0.0	24.9	0.0	0.0	0.0	5.3	0.0	0.0	0.0	1.8	1.8	2.5	0.3	0.0	88.4	0.2
Little Rock Creek	3	2	0.77	0.4	54.5	15.9	29.2	0.4	0.0	0.0	0.0	11.5	32.9	10.1	15.6	29.5	0.0	0.0	32.9	0.0	0.0	0.0	0.0	3.8	1.6	0.0	0.0	0.5	0.8	0.2	0.0	93.1	0.0
MEAN				**0.2**	**53.0**	**23.2**	**23.5**	**0.2**	**0.0**	**0.0**	**0.0**	**12.5**	**34.0**	**6.5**	**22.9**	**23.6**	**0.2**	**0.0**	**28.9**	**0.0**	**0.0**	**0.0**	**2.7**	**1.9**	**0.8**	**0.0**	**0.9**	**1.2**	**1.7**	**0.1**	**0.0**	**90.8**	**0.1**
Anne Creek	3	3	0.66	1.9	98.1	0.0	0.0	1.9	0.0	0.0	0.0	21.7	65.0	11.4	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	18.7	68.4	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bay State Creek	3	3	0.63	10.4	89.6	0.0	0.0	0.0	2.2	8.3	0.0	18.0	47.4	24.1	0.0	0.0	0.1	0.0	3.4	14.8	0.0	0.0	19.0	65.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	
Mudd Creek	3	3	0.50	0.0	70.6	28.2	1.2	0.0	0.0	0.0	0.0	14.1	56.5	0.0	27.9	0.0	1.5	0.0	6.4	0.0	0.0	0.0	2.5	45.3	4.0	26.8	0.0	6.8	13.9	0.7	0.0	0.0	0.0
Shroder Creek	3	3	0.46	0.0	85.0	14.6	0.4	0.0	0.0	0.0	0.0	27.5	44.1	13.5	14.6	0.4	0.0	0.0	5.0	0.0	0.0	0.0	3.8	32.9	48.6	0.0	2.8	4.5	0.0	0.0	0.0	4.9	2.4
MEAN				**3.1**	**85.8**	**10.7**	**0.4**	**0.5**	**0.5**	**2.1**	**0.0**	**20.3**	**53.2**	**12.2**	**10.6**	**0.1**	**0.4**	**0.0**	**4.5**	**3.7**	**0.0**	**0.0**	**11.0**	**53.1**	**16.4**	**6.8**	**0.7**	**2.9**	**3.5**	**0.2**	**0.0**	**1.2**	**0.6**
SUBSECTION 3MEAN				**1.7**	**80.6**	**10.8**	**6.9**	**0.7**	**0.3**	**0.8**	**0.2**	**15.5**	**52.3**	**11.7**	**10.9**	**6.7**	**1.0**	**0.0**	**11.0**	**1.4**	**0.0**	**3.5**	**7.3**	**26.6**	**9.8**	**8.5**	**0.4**	**2.1**	**1.6**	**0.1**	**0.0**	**36.5**	**2.6**
OVERALL MEAN				**14.8**	**53.4**	**21.2**	**10.7**	**3.4**	**1.6**	**7.5**	**2.4**	**10.1**	**37.0**	**7.6**	**19.2**	**9.5**	**1.3**	**0.5**	**14.5**	**7.3**	**2.9**	**5.6**	**8.0**	**15.2**	**8.0**	**3.3**	**0.3**	**2.2**	**1.1**	**0.6**	**6.2**	**37.8**	**1.4**

Table 3-2. Variables used in discriminate analysis to predict results of clustering.

SUBSECTION CLUSTER		
1 (4)	2 (5)	3 (3)
LTA 1202	LTA 1103	VBT area
LTA 1401	LTA 1403	VBT 1210
VBT 1320	VBT 1130	VBT 1305
	VBT 1205	VBT 1330
	VBT 1420	

A. Original Clustering.

SUBSECTION CLUSTER		
1 (3)	2 (3)	3 (3)
LTA 1201	LTA 1202	VBT area
LTA 1202	LTA 1301	VBT 1210
LTA 1401	LTA 1402	VBT 1305
LTA 1403	LTA 1403	VBT 1330
VBT area	VBT area	
VBT 1230	VBT 1220	
VBT 1310	VBT 1330	
	VBT 1420	

B. Grouped clustering.

Thompson River Basin
Watershed Similarity Analysis

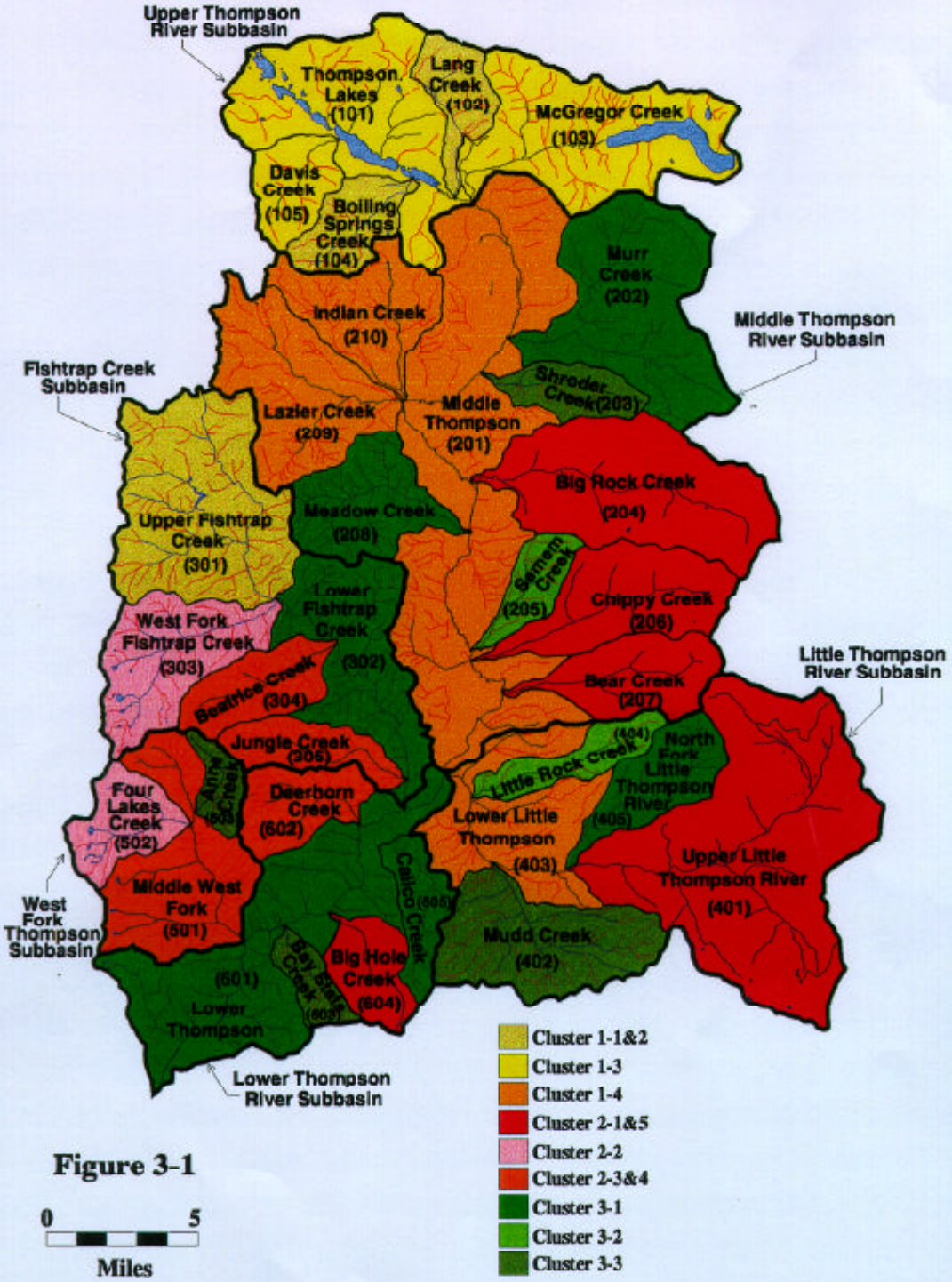

Figure 3-1

Note: Hydrology from 1:24,000 scale USFS Cartographic Feature Files. Subbasins digitized from 1:24,000 scale quads.

APPENDIX A - LEGENDS

SUBSECTION LEGEND

1100 = Alpine glaciated lands
1200 = Fluvial lands
1300 = Continental glaciated erosional lands
1400 = Continental glaciated depositional lands

LANDTYPE ASSOCIATION LEGEND

1101 = Cirque and rocky ridge
1102 = Alpine glacial basin
1103 = Alpine glacial trough
1104 = Alpine glacial moraine
1201 = Mountain ridge
1202 = Mountain slope
1203 = Breakland
1301 = Continental glaciated ridge and slope
1401 = High terrace
1402 = Floodplain and alluvium
1403 = Water

VALLEY-BOTTOM TYPE LEGEND

1110 = Alpine glacial basin
1120 = Alpine glacial train
1130 = Glacial outwash
1205 = Fluvial cascade
1210 = Fluvial basin
1220 = Fluvial V-erosional canyon
1230 = Fluvial V-depositional canyon
1305 = Continental cascade
1310 = Continental fluvial basin
1320 = Continental V-erosional canyon
1330 = Continental V-depositional canyon
1410 = Glacio-lacustrine basin (unconfined)
1420 = Glacio-lacustrine basin (confined)
1430 = Glacio-lacustrine canyon