Goat Creek and Piper Creek Watershed Analysis

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INTRODUCTION

1 INTRODUCTION

In May of 1996, Plum Creek Timber Company, L.P. initiated a Level 2 Watershed Analysis in the Goat Creek and Piper Creek basins, both of which are tributaries to the Swan River in northwestern Montana. 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 Goat and Piper 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. 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.

The document contains six general 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; and 6) management prescriptions developed by Plum Creek Timber Company to address each causal mechanism report for Plum Creek lands. Various maps and forms are contained in the narrative descriptions for each module.

SECTION 2

OVERVIEW

2 OVERVIEW

The following section provides an overview of the physical attributes and past land management activities within the Goat and Piper 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

Goat Creek and Piper Creek are tributaries to the Swan River in northwestern Montana. The Goat Creek watershed is 24,442 acres (38.2 mi^2) and drains west from the Swan Mountain Range. It is located 40 miles southeast of Kalispell, Montana and includes portions of Townships 23 North, Ranges 16 and 17 West, Principle Meridian (Figure 2-1a). The Piper Creek watershed is 7,910 acres (12.4 mi^2) and drains east from the Mission Mountain Range. It is located 44 miles south-southeast of Kalispell, Montana and includes portions of Townships 21 and 22 North, Ranges 17 and 18 West, Principle Meridian (Figure 2-1b).

Approximately 64.8% of the combined Goat/Piper watersheds are administered by the United States Forest Service (USFS) Flathead National Forest, 22.1% by Plum Creek Timber Company, 12.8% by the State of Montana, and 0.3% by small private landowners (See Figures 2-1a and 2-1b).

The predominant land use in the Goat and Piper Creek watersheds is forestry. In addition, both basins are used extensively for recreation (eg. hiking, hunting, fishing, firewood cutting). The upper portion of the Piper Creek watershed is in the Mission Mountain Wilderness. Several small private residences are located in the lower Piper Creek watershed and a Montana Department of Corrections boot camp is located near the mouth of Goat Creek.

2.2 TOPOGRAPHY, GEOLOGY, AND SOILS

The Swan River flows through a north-trending valley between the Mission Range on the west and the Swan Range on the east. The Piper Creek drainage begins in the Mission Range, while Goat and Squeezer Creeks originate from the Swan Range. The area is underlain by sedimentary rocks of the Spokane, Helena and Empire Formations assigned to the Belt Supergroup. They are mostly fine-grained beds of limestone, dolomite, siltite, quartzite and argillite from the pre-Cambrian or Proterozoic Era (i.e., greater than 570 million years ago) (Mudge et al. 1982).

The Swan Valley was created by an initial upward thrust of the entire block of sedimentary rocks in the area and then subsequent formation of a normal fault (Swan Fault) along the east side of the valley (Mudge et al. 1982). The upwardly thrust area east of the fault became the Swan Range, while the dip-slope portion west of the fault became the Mission Range. This faulting history has led to generally steeper and more rugged mountains in the Swan Range.

The Swan Valley and its tributary valleys were further sculpted by the numerous advancing and retreating glaciers of the Quaternary Era (the last two million years). Initially, a lobe of the Cordilleran ice sheet pushed south from British Columbia through the Swan Valley during the Bull Lake ice age approximately 100,000 years ago (Alt and Hyndman 1986). During the subsequent Pinedale ice age approximately 15,000 years ago, a Swan Valley glacier likely arose out of the Swan and Mission Ranges and flowed north to the south-flowing Cordilleran ice sheet near the present town of Bigfork (Johns 1970; Witkind 1978). Numerous alpine glaciers also expanded and retreated during these various ice ages sculpting the tributary valleys. Nearly 50 percent of the Swan River basin is mantled by glacial deposits (Whitehorse Associates 1996). Tributary valley glacial deposits composed of rock fragments in a silty clay matrix are typically less than 100 meters thick, but deposits of primarily sand and gravel in the Swan Valley can exceed 300 meters thickness (Mudge et al. 1982).

The physiography of the three drainages can be divided into two distinct areas: 1) a steeper alpine glacial valley in the upper half of the watersheds, and 2) moderate to low gradient hummocky topography within the continentally glaciated Swan River valley in the lower half of the watersheds. Figures 2-2a and 2-2b display topography, and Figures 2-3a and 2-3b display slope classes for the Goat Creek and Piper Creek watersheds, respectively.

The upper half of the Piper Creek drainage consists of alpine glacial valley terrain with numerous lakes or tarns at the headwaters leading to a valley more confined by steep hillsides. Upon exiting the alpine glacial valley, Piper Creek flows through 20 to 40 percent hillslopes of silty glacial till soil and eventually through terrain less than 20 percent. Elevations in the Piper Creek drainage range from 7,793 feet (2,375 m) in the west to 3,380 feet (1,030 m) at its confluence with the Swan River.

Goat Creek begins from a northwest trending glacial cirque valley and heads west through a glacial valley with hillslope gradients typically greater than 60 percent. Two larger tributaries, Bethel and Scout Creeks, enter from north-trending glacial valleys with equally steep hillslopes. Upon exiting the alpine glacial valley, Goat Creek flows through a short section of silty glacial till soil with topography of less than 20 percent and then continues through the poorly drained floodplains and low terraces of the Swan River. Elevations in Goat Creek range from 8,406 feet (2,562 m) in the southeast portion of the basin to approximately 3,240 feet (987 m) at its confluence with the Swan River.

Squeezer Creek originates from a glacial cirque off of Swan Peak and heads west through a confined glacial valley with slopes often exceeding 80 percent gradient. The topography in the lower half of the Squeezer Creek drainage is nearly identical to Goat Creek. Elevations in Squeezer Creek range from 9,289 feet (2,381 m) at Swan Peak in the east to approximately 3,280 feet (1,000 m) at its confluence with Goat Creek. Figure 2-4 displays the geology of the watersheds while Figure 2-5 provides the base map used for this analysis.

2.3 CLIMATE

Local climate within the Goat and Piper watersheds generally consists of warm, dry summers and cold, snowy winters. Average climate data from the Kalispell weather station, approximately 43 miles northwest of the analysis area, are shown below.

Month	High (°F)	Low (°F)	Rain (in.)	Snow (in.)
January	30	16	1.38	18
February	37	21	0.98	10
March	45	25	0.79	6
April	55	32	1.02	3
May	66	39	1.77	1
June	73	46	2.01	0
July	82	50	1.02	0
August	81	48	1.65	0
September	70	41	1.10	0
October	55	34	1.06	2
November	39	25	1.18	8
December	34	19	1.42	17

2.4 STREAMS, SUB-WATERSHEDS, AND FISH SPECIES

The Goat Creek watershed analysis area has one major sub-basin: Squeezer Creek. Squeezer Creek drains a 9703 acre area entirely on the southern half of the Goat Creek watershed. A number of smaller tributaries to Upper Goat Creek exist, such as Scout Creek and Bethel Creek, but because of the small area drained no sub-basins were delineated. Similarly, because of Piper Creek's relatively small size (7910 acres), no sub-basins were identified there either.

Fish are present throughout the Goat, Squeezer, and Piper Creek drainages, with the exception of Upper Squeezer Creek. Between stream mile 4.8 and 5.03 on Squeezer Creek a sequence of waterfalls and cascades precludes upstream movement of fish. Above this barrier, no fish have been found, either by snorkeling or electrofishing (Leathe et al., 1985; Watson, 1996).

Fish found in the analysis areas include two char species: eastern brook trout (*Salvelinus fontinalis*) and bull trout (*Salvelinus confluentus*); two trout species: westslope cutthroat trout (*Oncorhynchus clarki lewisi*) and rainbow trout (*Oncorhynchus mykiss*); one whitefish species: mountain whitefish (*Prosopium williamsoni*); and sculpin (*Cottus spp.)*. Eastern brook trout and rainbow trout are not native to the area and were planted in the Swan River basin beginning in the 1920's and 1930's, respectively.

Bull trout, brook trout, rainbow trout, and mountain whitefish are generally found in the lower reaches of Goat, Squeezer, and Piper Creeks. Westslope cutthroat trout are found throughout all the watersheds, but are most abundant in the mid to upper reaches of Goat and Piper Creeks. Many of the lakes in the upper Piper Creek watershed have been stocked with cutthroat trout. Records by Montana Department of Fish, Wildlife, and Parks do not indicate whether the fish stocked in Piper Lakes were westslope cutthroat or Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) (Rumsey, 1996).

Goat, Squeezer, and Piper Creeks provide a rich diversity of trout habitat. With regard to bull trout, Goat and Squeezer Creeks are some of the most important bull trout spawning and rearing streams in the Pacific Northwest. Over the last tens years, an average of 126 bull trout redds have been inventoried in the Goat and Squeezer Creeks (Montana Department of Fish, Wildlife, and Parks, 1996).

2.5 VEGETATION

The most common tree species in the watersheds are Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), Engelmann spruce (*Picea engelmanni*), subalpine fir (*Abies lasiocarpa*), western red cedar (*Thuja plicata*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and grand fir (*Abies grandis*). Riparian areas also contain black cottonwood (*Populus trichocarpa*), thinleaf alder (*Alnus tenuifolia*) and quaking aspen (*Populus tremuloides*).

In the understory, lower elevation vegetation includes twinflower (*Linnaea borealis L.*), blue huckleberry (*Vaccinium globulare Rydb.*), shiney-leaf spiraea (*Spiraea betulifolia*), mountain arnica (*Arnica sp.*) and one-flowered wintergreen (*Moneses uniflora*) are common. At higher elevation, common understory vegetation includes Snowberry (*Symphoricarpos albus*), shiney-leaf spiraea, twinflower, and pinegrass (*Calamagrostis rubescens*).

2.6 HISTORY OF LAND USE AND DISTURBANCE

In the Goat Creek watershed, road construction and timber harvesting began in the 1950's at the lower elevations. In the early 1960's, a logging road was constructed to access upper Goat Creek, Bethel Creek, and Scout Creek and timber harvesting began in this area.

The Piper Creek watershed was originally accessed in the early 1970's, and timber harvesting has occurred off and on since the mid-1970's. Residential home/cabin construction on the private properties in lower Piper has been most significant since 1980.

The primary naturally occurring disturbances in the watersheds are fire and flooding. Figure 2-6 displays the known fire history of the area. It is likely that much of the watersheds have been significantly disturbed by fire in the recent centuries. Since the 1930's, fires have been actively suppressed and flooding has been the primary disturbance since.

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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 course 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 and quantity 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 the Goat and Piper Creek watersheds. 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 Piper Creek, Goat Creek and Squeezer 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.

Numerous avalanche chutes, rockfalls and one large deep-seated landslide occurred naturally. Five mass wasting sites were linked to forest management activities. Six landslides were found to be associated with forest management and occurred because of steep cutslopes or concentration of runoff from roads or skid trails onto steep slopes.

The small number of landslides inventoried within the three drainages made it difficult to evaluate the potential for future mass wasting, particularly in landforms with little or no forest management activity. Most forest management activity to date has occurred on slopes less than 60% gradient, yet the remainder of the watershed area was considerably steeper. To better evaluate the gradients at which slope stability diminished, a number of road cutslopes were examined. In all three watersheds, cutslope angles of approximately 90% and greater had signs of sliding, slumping or raveling. Given the similar geology within the three watersheds a conservative gradient of 80% was chosen as potentially slide-prone areas. In areas with groundwater seepage or near streams, gradients of 60% and greater appeared to be prone to slumping or sliding. While these general numbers alone may be crude indicators of slope stability, the combination of slope gradient, slope form and water availability, which can easily be evaluated in the field, should provide relatively good predictions of slope stability at a given site.

Ten landform units were identified to categorize the sensitivity of the landscape to mass wasting, with two high hazard units and four moderate hazard units. The units with a high hazard for sediment delivery included: 1) oversteepened toe slopes, and 2) inner gorges within glaciated lands.

Despite the glaciated landscape and steep slopes, the Piper, Goat and Squeezer Creek watersheds have relatively few landslides that deliver sediment directly to streams. Forest management to date has avoided steep slopes and has not appreciably increased the amount of mass wasting. Most landslides associated with forest management occurred from steep cutslopes or concentrating drainage onto steep slopes. Much of the area without current forest management, however, is steep and has potentially unstable slopes. Despite the small amount of mass wasting within the basin, hazardous slopes could be identified with a high degree of confidence. Any future forest management in these areas will require caution. The landform units generally characterize the potential for mass wasting, but field verification is essential in many areas to identify landslide hazard.

3.2 SURFACE EROSION

Surface erosion from hillslopes and roads was examined in the Goat and Piper 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 six recently harvested areas within each watershed. At all sites, the harvest areas adjacent to streams were investigated for signs of hillslope erosion and sediment delivery. Of the six units, four were tractor logged and three were cable logged with partial suspension. 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. This is attributed to: 1) the large amount of slash retained on the forest floor (particularly in Piper Creek); 2) selection of appropriate harvest systems; 3) operating during appropriate times of the year; 4) good erosion control on skid trails; and 5) retention of a riparian buffer (filtration) strips along streams. In the sales evaluated, appropriate application of Best Management Practices and streamside management zones appeared to effectively preclude both the development of hillslope erosion sources and the potential for 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. Currently, a total of 87.3 miles of road exist in the combined Goat/Squeezer Creek watershed, and 22.3 miles exist in the Piper Creek watershed. In the Goat Creek watershed, 18 sediment delivery locations were identified along this road network. Of the 18, only one of these was in the Squeezer Creek basin. Roads in the Goat Creek basin (upstream of Squeezer Creek) are estimated to deliver 38.6 tons of sediment per year. Roads in the Squeezer basin are estimated to contribute less than 1 ton per year. For the entire Goat Creek watershed, estimated sediment production from roads is 39.3 tons per year, of which 72% comes from the road tread and 28% from the cutslopes and fillslopes. In the Piper Creek watershed, 11 sediment delivery locations were identified. These 11 locations are estimated to contribute 25.5 tons per year to the stream network tributary to Piper Creek. In both the Goat and Piper Creek watersheds, the majority of sediment comes from a minority of stream crossings. These are areas where several hundreds of feet of road tread and ditch drain directly to stream crossings. For example, in the Goat Creek watershed the worst five crossings contribute 70% of the total sediment delivered by roads in the basin.

Road erosion in the Goat Creek watershed (above Squeezer Creek) is estimated at 11% above background. Erosion rates in the Squeezer basin are estimated to be 0.2% above background, and erosion rates in the Piper Creek watershed are estimated to be 24% above background. As a result, road erosion was rated as a low hazard in all three drainages evaluated.

3.3 HYDROLOGY

A hydrologic assessment methodology was conducted to assess the hydrologic impacts of timber harvesting in the Goat and Squeezer Creeks and Piper Creek watersheds. The assessment follows the standard methodology presented in the state of Washington watershed analysis manual. Peak flows in northwest Montana may be associated with rain-on-snow (ROS) events which occur in the fall, mid-winter, or during the ablation period. Spring peak flows related to snowmelt under clear sky (CS) conditions are also common hydrologic peak events.

Observed streamflow data for Goat Creek and Piper Creek is minimal and lacking entirely for Squeezer Creek. A 20 year (WY 1972 through WY 1992) continuous record is available for the Swan River near Condon. Annual flows are likely to have occurred in the Goat Creek and Squeezer Creek basins at approximately the same time as the annual Swan River peaks recorded near Condon. For each year of the period of record the annual peakflow occurs in the spring during the peak snowmelt. The Swan River near Condon record indicates smaller peak flows do occur in the fall when relatively warm storms cause ROS peak flows. This suggests that annual peak flows in the Swan Valley tributaries may be associated with either ROS events or the annual spring runoff peak.

Based on canopy coverage, the existing vegetation condition was mapped according to a nine-division classification scheme. It is evident that almost all of the forest harvesting to date has taken place in the lower reaches of the basin, below 5,700 feet (1,750m). This elevational distribution of management is significant with respect to temperature distribution within the basins, especially during the period of spring snowmelt peaks.

ROS peak flow analyses were performed to calculate the Water Available for Runoff (WAR) for the 2, 5, 10, 25, 50, and 100-year storm events for three canopy density scenarios: fully forested, current conditions and maximum harvest. Since harvest levels are not foreseen to reach the maximum scenario, the maximum harvest scenario provided a conservative estimate of the greatest potential for hydrologic change. For the Goat Creek and Squeezer Creek basin, the maximum calculated peak flow increases are 6.5% for the current condition and 12.3% for the maximum harvest scenario. For the Piper Creek basin, the maximum calculated peak flow increases are 5.3% for the current condition and 13.3% for the maximum harvest scenario.

Spring snowmelt peak flows (CS peak flows) are an important hydrologic event in the Swan Valley tributaries. However, the standard hydrology assessment methodology does not address peak flows under CS conditions. This analysis extended the standard procedures to provide a reasonable estimate of the effects of forest management activities on CS peak flows.

For ROS peak flows, calculated peak flow changes for the current scenario are less than 10% for the basins. Peak flows augmented by increased snowmelt during rainfall does not appear to be a significant factor in the Goat Creek and Squeezer Creek or Piper Creek watersheds. For spring snowmelt conditions, the snowmelt estimates indicate that the spring peak discharge is not impacted by snowmelt in the areas of forest management based on the simulated distribution of snowmelt calculated for a hypothetical clear-sky spring day. The calculations demonstrate that the are relatively insensitive to ROS peak flows, and that the watersheds are also relatively insensitive to changes in the spring snowmelt regime for the current vegetation conditions. On this basis, a hazard rating of low was assigned for both watersheds.

Of these possible sources of error, the distribution of the spring snowpack is arguably the most significant. A simple, inexpensive monitoring program can address some of this uncertainty. An adequate monitoring program would consist of snowpack observations over the spring snowmelt period (March-June) for approximately five years. This monitoring, coupled with a continuous streamflow gage installed on one of the Swan Valley tributaries would provide a much needed record the hydrology of smaller sub-basins in the Swan Valley. At the conclusion of the monitoring program the snowpack data should be evaluated. If the lower portions of the basins can be shown to be a significant source of spring-time (clear sky) snowmelt, further analysis should be considered. A distributed vegetation-soil-hydrology model could be used to evaluate the hydrologic impacts of existing and potential forest harvest scenarios.

3.4 RIPARIAN FUNCTION

An assessment of riparian condition and function was conducted in the Goat, Squeezer and Piper Creeks 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 1994 color aerial photography (1:12,000 scale) provided by PCTC and USFS 1992 color aerial photography (1:20,000 scale) for the upper basins. Field inspections and data analysis were used to verify calls on a sub-sample of the riparian areas. Data for the assessment came from Plum Creek Timber Co. (PCTC) fisheries research crews and other data supplied by PCTC. Additional data was collected by module analysts. Approximately 50% of the stream segments were evaluated in the field.

Most segments within the watersheds met or exceeded the criteria of the assessment methodology used in the Washington Forest Practices Board Manual (WFPB, 1995). The riparian area network, as a whole, adequately provides LWD and shade to stream channels. Only two stream segments were found to be below the required criteria of the manual. These segments had been harvested before implementation of the 1991 Montana Stream-Side Management Zone law (SMZ). Both segments were below shade requirements, and may eventually become deficient in LWD. Stream temperature monitoring indicated that maximum water temperatures remained below 16 degrees C even in the shade deficient areas. Groundwater upwelling likely ameliorates the lack of shade.

The Montana SMZ law was also assessed to determine the post-harvest potential to provide LWD and shade to stream segments in the near-term. The requirements of the Montana SMZ law were determined to be effective in providing LWD and shade to moderately confined and confined channels, but the potential for deficiencies exist in stream segments exhibiting unconfined channels. This can occur were the channel migration zones (CMZ) are wider than the SMZ leave strip. In these situations the stream can potentially migrate outside of the buffer. The development of voluntary guidelines for riparian area management in stream segments exhibiting unconfined channels would be beneficial.

Since evaluation criteria were developed for forest and stream types found in Washington, the derived conclusions may be incorrect under some circumstances. In order to validate the criteria, or to develop criteria specific to this ecoregion, it is recommended that the following research and monitoring be conducted: 1) research to determine optimal LWD size and density criteria for the channel types encountered; 2) continued temperature monitoring in the analysis area; 3) data collection and analysis to develop a predictive nomograph relating stream temperature to various elevations and degrees of canopy shade; and 4) temperature monitoring of before-and-after harvest scenarios to determine actual effects.

3.5 CHANNEL CONDITION

Geologic history of the study area was found to influence the distribution of stream channel types and their potential sensitivity to forest management. Streams traversing continental glacier deposits on the floor of the Swan Valley were classified in three different Geomorphic Map Units (GMU's): 1 - Swan Floodplain, 2 - Entrenched Mainstem, and 3 - Low-gradient Pool-Riffle. Generally, these GMU's have moderate to high levels of sensitivity with respect to inputs of coarse sediment, peak flows, LWD, riparian vegetation, and channel migration processes. These GMU's were ultimately classified as the Ground Moraine GMU super-group to facilitate rapid mapping from existing classification data. Similar forest management practices are justifiable for the three GMU's in this super-group. This GMU super-group accounts for 8% of the mapped length of the channel network in the study area.

Streams that cross the interface between continental glacial deposits of the floor of the Swan Valley and the alpine glacial deposits found at the mouths of stream canyons emerging from the Swan Range and the Mission Range were classified in two GMU's. Fish habitat in GMU's 4 (Moderate Gradient Avulsing) and 5 (Braided Floodplain) is augmented owing to a favorable combination of groundwater upwelling and physical habitat characteristics controlled by LWD. These two GMU's were classified in the Mountain Front super-group, with moderate or high sensitivities to coarse and fine sediment, peak flows, LWD, riparian vegetation and channel migration processes. LWD and channel migration are particularly important to physical habitat conditions. The channels in this GMU account for 4% of the mapped channel network in the study area.

Streams flowing through the canyons carved by alpine glaciers of the Mission and Swan Ranges which were relatively steep and had stream beds typically dominated by boulders and bedrock were classified in three GMU's: 6 - Glacial Trough/Incised Mainstem, 9 - Cirque Headwaters, and 12 - Trough-wall Cascades. Except for local areas of low gradient in GMU 9, the Alpine Glacial Trough super-group has generally low sensitivity, except low to moderate sensitivity to LWD in GMU's 6 and 9. This super-group accounts for 34% of the channel network in the study area.

Ground Moraine Intermittents (GMU 7) and Scarp Slope Headwaters (GMU 8) are intermittent and/or ephemeral streams that rarely deliver surface flow to other portions of the channel network. Mapped GMU 7 channels are located in glacial deposits of the floor of the Swan Valley, and were found in many cases to lack defined channels. Those with defined channels appeared to flow only during the peak of runoff. GMU 8 channels are steep, and in some cases maintain flows during the summer. However, in most locations, they dissipate as they cross glacial deposits and merge with channels in GMU 7. The Intermittents super-group has generally low sensitivity, and accounts for 28% of mapped stream channel length.

Headwaters with Avalanche (GMU 10) and Fans (GMU 11) were found along the margins of alpine glacial canyons of the Swan Range. Most of these streams are intermittent or ephemeral and dissipate on the floors of alpine glacial troughs, but some GMU 10 streams have active or potential snow avalanche and or shallow rapid mass wasting processes capable of delivering material to GMU 6. Both GMU 10 and 11 have moderate sensitivity to coarse sediment, peak flows, LWD, catastrophic events, and riparian vegetation. In addition, GMU 11 is sensitive to channel migration processes. The Avalanche and Fan super-group account for 25% of the mapped channel network.

GMU 13, Upper Glacial Trough Alluvial, is rare (<1% of channel network), and is not included in a GMU super-group. It has characteristics of both the Mountain Front and Ground Moraine super-groups. Where it occurs, GMU 13 has unusual and favorable physical habitat.

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 1996. Module analysts conducted additional surveys 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 brook trout into Swan River tributaries began in 1926 and continued routinely through the 1950's. Rainbow trout were first introduced into the Swan River basin in 1932. As with brook trout, intensive stocking efforts were continued through the 1950's. Stocking records also indicate that Piper Lake, Scout Lake and Piper Creek have been stocked with "undesignated" cutthroat trout (westslope cutthroat and/or Yellowstone cutthroat) beginning in 1938. Surveys conducted for this analysis indicate that the lower reaches of Goat Creek and Piper Creek support all species found in the analysis area (brook trout, bull trout, cutthroat trout, rainbow trout). The middle reaches of Piper Creek and all fish-bearing reaches of Squeezer Creek support populations of brook, bull, and cutthroat trout. The upper reaches of Goat Creek support only bull trout while the upper reaches of Piper Creek support only cutthroat trout. Only one of the intermittent tributaries identified in this analysis was found to support fish. Findings of fish distribution from recent surveys were found to be analogous to surveys conducted in the early 1980's. No man-made barriers to fish movement were found in the analysis area. Hence, all upstream limits to fish distribution in the analysis area 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 unit (GMU) 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 GMU. Using module diagnostics as prescribed resulted in habitat condition calls of either fair or good for most channel segments evaluated. The quantity and quality of fish habitat, and corresponding utilization, was found to be primarily a function of channel geomorphology, as opposed to impacts from upland management activities.

Assessment of spawning distribution indicates that bull trout exhibit selection for some combination of specific habitat attributes expressed in GMUs 3 and 4. It is postulated that the combination of significant groundwater upwelling combined with the availability of spawning gravels of a sufficient size and quantity are the primary elements driving this selection.

Development of fish habitat vulnerability calls resulted from consultation with analysts responsible for the Channel Condition, Hydrologic Condition, and Riparian Function Modules. Generally, GMUs 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 gradient and wider channel migration zones.

Four areas of special interest regarding monitoring and/or research needs were identified: a population of resident bull trout may exist in the upper reaches of Goat Creek; channel segments G59 and G60 contain a stock of resident cutthroat trout which may have remained reproductively isolated from undesignated stocks of cutthroat previously planted in the Swan Valley; bull trout hybridization with resident brook trout has been confirmed in the Swan River basin and could result in significant impacts to bull trout populations; and recent ecoclassification of aquatic habitats in the Swan Valley may provide a mechanism for extrapolation of watershed analysis findings to geomorphically similar habitats outside of the analysis area.

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 to help the prescriptions team develop appropriate management responses in focused areas.

Synthesis of the of the information collected by analysts resulted in the development of 9 causal mechanism reports (CMRs) for the Goat Creek and Piper Creek analysis area. Four CMRs were developed for the existing and/or potential delivery of course and fine sediment through mass wasting processes. Three CMRs were developed for the existing and/or potential impacts resulting from harvest of riparian timber. Two CMRs were developed for the existing and/or potential delivery of fine sediment through surface erosion. These CMRs are presented in Section 5 of this report. The prescriptions team will be able to use these reports to develop management guidelines to protect vulnerable resources.

SECTION 4

RESOURCE ASSESSMENT MODULES

4A MASS WASTING MODULE

4A.1 INTRODUCTION

The purpose of this study is to evaluate landslides and other mass wasting features in three tributary watersheds of the Swan River: 1) Piper Creek, 2) Goat Creek, and 3) Squeezer Creek. The sensitivity of the watersheds to mass wasting is examined in the context of past and potential forest management activities. While the steep, mountainous terrain is often naturally prone to landslides, the removal of trees during timber harvest or road construction and the subsequent reduction in root strength can greatly 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 MATERIAL AND METHODS

Analytical methods follow guidelines from the Washington State Watershed Analysis Manual, Version 3.0 (WFPB 1995). 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. Geographic information system (GIS) computer-generated maps provided information on slope class and terrain characterization. Terrain characterization was based on landtype association and landtype classes developed by Martinson and Basko (1983) and Sirucek (unpublished) for the Flathead National Forest.

Landslides were inventoried from aerial photographs and checked with three days of field reconnaissance in August, 1996. U.S. Forest Service air photos from 1992, 1987, 1985 and 1966 were used for the upper half of the three drainages, while Plum Creek Timber Co. photos from 1994, 1984, 1970, 1963 and 1955 were used for the lower half of the drainages. The scale of the air photos varied from approximately 1:10,000 to 1:15,000. State and federal orthophoto maps were also used to better translate from the 1:15,000 scale photos to the 1:24,000 final mapping scale.

4A.3 GEOLOGIC AND PHYSIOGRAPHIC OVERVIEW

The Swan River flows through a north-trending valley between the Mission Range on the west and the Swan Range on the east. The Piper Creek drainage begins in the Mission Range, while Goat and Squeezer Creeks originate from the Swan Range. The area is underlain by sedimentary rocks of the Spokane, Helena and Empire Formations assigned to the Belt Supergroup. They are mostly fine-grained beds of limestone, dolomite, siltite, quartzite and argillite from the pre-Cambrian or Proterozoic Y Era (i.e., greater than 570 million years ago) (Mudge et al. 1982).

The Swan Valley was created by an initial upward thrust of the entire block of sedimentary rocks in the area and then subsequent formation of a normal fault (Swan Fault) along the east side of the valley (Mudge et al. 1982). The upwardly thrust area east of the fault became the Swan Range, while the dip-slope portion west of the fault became the Mission Range. This faulting history has led to generally steeper and more rugged mountains in the Swan Range.

The Swan Valley and its tributary valleys were further sculpted by the numerous advancing and retreating glaciers of the Quaternary Era (the last two million years). Initially, a lobe of the Cordilleran ice sheet pushed south from British Columbia through the Swan Valley during the Bull Lake ice age approximately 100,000 years ago (Alt and Hyndman 1986). During the subsequent Pinedale ice age approximately 15,000 years ago, a Swan Valley glacier likely arose out of the Swan and Mission Ranges and flowed north to the south-flowing Cordilleran ice sheet near the present town of Big Fork (Johns 1970; Witkind 1978). Numerous alpine glaciers also expanded and retreated during these various ice ages sculpting the tributary valleys. Nearly 50 percent of the Swan River basin is mantled by glacial deposits (Whitehorse Associates 1996). Tributary valley glacial deposits composed of rock fragments in a silty clay matrix are typically less than 100 meters thick, but deposits of primarily sand and gravel in the Swan Valley can exceed 300 meters thickness (Mudge et al. 1982).

The physiography of the three drainages can be divided into two distinct areas: 1) a steeper alpine glacial valley in the upper half of the watersheds, and 2) moderate to low gradient hummocky topography within the continentally glaciated Swan River valley in the lower half of the watersheds. The upper half of the Piper Creek drainage consists of alpine glacial valley terrain with numerous lakes or tarns at the headwaters leading to a valley more confined by steep hillsides. Upon exiting the alpine glacial valley, Piper Creek flows through 20 to 40 percent hillslopes of silty glacial till soil and eventually through terrain less than 20 percent. Elevations in the Piper Creek drainage range from 7,793 feet (2,375 m) in the west to 3,380 feet (1,030 m) at its confluence with the Swan River. Goat Creek begins from a northwest trending glacial cirque valley and heads west through a glacial valley with hillslope gradients typically greater than 60 percent. Two larger tributaries, Bethel and Scout Creeks, enter from north-trending glacial valleys with equally steep hillslopes. Upon exiting the alpine glacial valley, Goat Creek flows through a short section of silty glacial till soil with topography of less than 20 percent and then continues through the poorly drained floodplains and low terraces of the Swan River. Elevations in Goat Creek range from 8,406 feet (2,562 m) in the southeast portion of the basin to approximately 3,240 feet (987 m) at its confluence with the Swan River. Squeezer Creek originates from a glacial cirque off of Swan Peak and heads west through a confined glacial valley with slopes often exceeding 80 percent gradient. The topography in the lower half of the Squeezer Creek drainage is nearly identical to Goat Creek. Elevations in Squeezer

Creek range from 9,289 feet (2,381 m) at Swan Peak in the east to approximately 3,280 feet (1,000 m) at its confluence with Goat Creek

4A.4 LANDSLIDE INVENTORY RESULTS

Following review of the aerial photograph record and discussions with the surface erosion and stream channel analysts, very few mass wasting events were identified. The majority of the mass wasting in the three drainages was snow avalanches and rockfall in the upper portions of the watersheds. Because of the difficulty in differentiating avalanche paths and rockfall areas and the limited potential for forest management activities, individual slides of these types were not mapped or inventoried. The few remaining mass wasting sites will be discussed individually and referenced to the landform units in the proceeding section.

4A.4.1 INDIVIDUAL MASS WASTING SITES

4A.4.1.1 Goat Creek (Sec. 6, T. 23N, R. 16W) : Landform Unit 1b

A small road fill failure was noted on a larger spur road to the mainline road along Goat Creek. A locked gate prevented evaluation of the failure, but delivery of sediment to a stream seemed unlikely. Discussion with the surface erosion analyst confirmed the lack of delivery. The approximate slope gradient in the vicinity of the failure was 60%, but without further investigation the cause of the failure could not be determined.

4A.4.1.2 Goat Creek (Sec. 11, T. 23N, R. 17W) : Landform Unit 5

Smaller cutslope slumps were noted in this area with extensive groundwater seeps. The angle of repose for wetter ground was approximately 70%, but locally, lower gradient wet ground could slump. Some sediment delivery (primarily silt and smaller-sized particles) had occurred from slumping into road ditches, as well as from ditch erosion if water from the seeps was not quickly channeled across the road to the forest floor. Slash from the harvest unit was effective in minimizing sediment transport from the site.

4A.4.1.3 Squeezer Creek (Sec. 35, T. 23N, R. 17W) : Landform Unit 1b

A road leading up the face of the hillslope had numerous small cutslope slides and raveling, culminating with a larger cutslope slump and subsequent fill slope failure. The hillslope gradient was generally 60% with a planar slope form, but the cutslopes were typically greater than 90%. The site of the bigger slump had a slope gradient of approximately 60%, but had a more concave slope form and was located next to an intermittent stream draw. The slump delivered sediment to at least the next road crossing, but did not deliver sediment to fish-bearing waters since the channel disappears at the base of the hillslope and does not connect to Squeezer Creek. Much of this road system will continue to have maintenance problems as cutslopes continue to slide and ravel. Section 23 of this same township likely has similar problems as noted from aerial photographs and discussion with the channel analyst.

4A.4.1.4 Squeezer Creek (Sec. 36, T. 23N, R. 17W) : Landform Unit 1b

Based on information from the channel analyst, two linear canopy gaps were observed in 1984 aerial photography near the head of stream segment S41. One appeared somewhat younger than the other, but both presumed debris flow tracks originated at about 6,200 foot elevation in old growth timber and extended down to alluvial/debris flow fans. Much of the sediment generated presumably deposited on the fan with only small amounts of fine sediment reaching Squeezer Creek. It is hypothesized that these debris flows originated in lenses of glacial and colluvial material, probably in convergent topography above channel heads.

4A.4.1.5 Piper Creek (Sec. 19, T. 22N, 17W) : Landform Unit 6

A small slide was noted along an escarpment above Piper Creek that may have delivered a relatively small quantity of sediment to the stream. According to the channel analyst, road drainage off of compacted skid trails likely concentrated water onto the steep slope initiating the failure. The slope gradient around the failure was between 65% and 85%.

4A.4.1.6 Piper Creek (Sec. 25, T. 22N, 18W) : Landform Unit 6

A cutlsope failure triggered by either surface water concentration from skid trails above the road or interception of near-surface groundwater was noted along the road that enters the southeast quarter of the section. All of the sediment from the slump deposited on the road or a terrace above Piper Creek, without delivering to a stream.

4A.4.2 ANALYSIS OF SLOPE FAILURE ANGLES

The small number of landslides inventoried within the three drainages made it difficult to evaluate the potential for future mass wasting, particularly in landforms with little or no forest management activity. Most forest management activity to date has occurred on slopes less than 60% gradient, yet the remainder of the area requiring evaluation was considerably steeper. To better evaluate the gradients at which slope stability diminished, a number of road cutslopes were examined. In all three watersheds, cutslope angles of approximately 90% and greater had signs of sliding, slumping or raveling. Given the similar geology within the three watersheds a conservative gradient of 80% was chosen as potentially slide-prone areas. In areas with groundwater seepage or near streams, gradients of 60% and greater appeared to be prone to slumping or sliding. While these general numbers alone may be crude indicators of slope stability, the combination of slope gradient, slope form and water availability, which can easily be evaluated in the field, should provide relatively good predictions of slope stability at a given site.

4A.5 LANDFORM UNITS

The following description of ten landform units for the Piper Creek, Goat Creek and Squeezer Creek drainages was based largely on the mapping of landtype associations and landtype classes by Martinson and Basko (1983) and Sirucek (unpublished). The landform units were refined in this analysis to focus on mass wasting potential (particularly in forested areas) and provide data at a mapping scale of 1:24,000 (2 inches = 1 mile). The refinements were based on analysis of aerial photographs, topographic maps, and field surveys. Mapped hazard units (Figure 4A-1) should always be verified in the field to ensure that site conditions match the description of the landform unit. Table 4A-1 provides a summary of the landform units and their respective hazard ratings.

Table 4A-1. Summary of Mass Wasting Hazard by Landform Unit.

Uni	Landform Unit	Mass Wasting	Mass Wasting	Delivered
1a	Steep Rocklands	High	Low	Moderate
1b	Steep Alpine Lands	Moderate	Moderate	Moderate
2	Moderately Steep	Low	Low	Low
3	Deep-Seated	Moderate	Moderate	Moderate
4	Oversteepened Toe	High	High	High
5	Glacial Moraine	Moderate	Moderate	Moderate
6	Inner Gorges	High	High	High
	Gently to			
8	Alluvial Deposits	Low	Low	Low
9	Alluvial Fans	Low	Low	Low

4A.5.1 UNIT 1a STEEP ROCKLANDS

Delivered Hazard Rating: MODERATE

Steep rocklands are characterized by slopes generally greater than 80% that are prone to snow avalanches and rockfall. This unit occurs in the upper portions of all three drainages with the largest percentage area in the headwaters of Goat and Squeezer Creeks. The slopes are primarily unvegetated except by scattered low-lying herbaceous plants and shrubs. While this landform unit has the highest potential for mass wasting, the lack of forest and limited potential for sediment delivery to fish-bearing streams indicates a low to moderate sensitivity to forest management practices. Any road construction within this landform unit, however, would be highly susceptible to damage from mass wasting processes and depending on construction techniques could increase slope instability.

4A.5.2 UNIT 1b STEEP ALPINE LANDS

Delivered Hazard Rating: MODERATE

Steep alpine lands are also found in all three drainages, but the frequency of mass wasting (primarily snow avalanches and rockfall) is much lower. Most of this landform was mapped in the Goat and Squeezer drainages with only a small area within the Piper Creek drainage. The slopes are generally between 40% to 80% with localized areas greater than 80%. Most of this landform is forested. While forest management practices would have little effect on mass wasting in much of this landform because of the moderate slope gradients, localized areas have a very high potential for increased slope instability following road construction and/or timber harvest. These localized areas include: 1) all slopes greater than 80%, particularly with convergent slope forms; 2) slopes greater than 60% with evidence of seeps or near-surface groundwater flow; 3) current avalanche paths; and 4) other areas with recent evidence of slope movement.

Based on observations following wildfire and timber harvest in Montana and the Washington Cascades, it should be noted that clearcut forest harvest along the ridges of steep slopes in this landform could cause an increase in snow avalanching. Some of the avalanche chutes in Squeezer Creek (e.g., the NE ¼ of Section 36, Township 23N, Range 17W) may have even been created by debris flows immediately following wildfire (D. Sirucek pers. comm.). Partial cutting may provide sufficient snow-anchoring support to prevent the initiation of snow avalanches. These ridges were not identified separately because of the difficulty in predicting exact locations and the lack of evidence to indicate that the likely small increase in snow avalanches would be detrimental to aquatic resources.

4A.5.3 UNIT 2 MODERATELY STEEP ROCKLAND

Delivered Hazard Rating: LOW

Moderately steep rocklands were identified only in the upper portion of the Piper Creek drainage. The landform unit is characterized by bedrock outcroppings on slopes ranging between 20% to 60% and is sparsely forested. There is very little likelihood that forest management activities would occur in this landform unit because of the lack of forest cover. Any road construction through this unit would likely be full-benched through bedrock. A thin soil mantle in places may be susceptible to failure, but with limited opportunity for delivery and damage to aquatic resources.

4A.5.4 UNIT 3 DEEP-SEATED LANDSLIDE

Delivered Hazard Rating: MODERATE

Two large deep-seated landslides were identified in the Piper Creek and Squeezer Creek drainages, respectively. The Piper Creek slide was mapped by Martinson and Basko (1983) and Sirucek (unpublished), but this analysis expanded and refined the exact area. The Squeezer Creek landslide was not previously mapped. While the slides are likely hundreds, if not thousands of years old, perhaps related to glacial undercutting of the slope, field investigation was not conducted to verify their age or current activity. The bulk of the Piper Creek slide off of steep (>80%) slopes deposited in the valley floor and likely dammed the stream for an undetermined period of time. The creek was pushed against the northern valley wall and may still be cutting through the landslide deposit. The gradient of Piper Creek is lower at the site of the slide deposit and for some distance upstream forming two small lakes or ponds. The lower stream gradient is due to the blockage of the valley by the slide deposit which causes sediment to collect upstream, aggrading the streambed over time. The Squeezer Creek slide is smaller than the Piper Creek slide, but may have had a similar effect on the creek. The oversteepened toe slope landform just upstream of the slide may be related to the effects of the large landslide. The sudden gradient increase in Squeezer Creek just below the slide (known as a knickpoint) is further evidence for the effects of this large landslide.

Forest management activities could impact the slope stability of the area in two ways. First, timber harvest in the upper half of the area delineated (the initiation site) could cause small shallow rapid landslides due to the steep slopes. A moderate hazard was applied, however, because the potential for delivery into fish-bearing streams is low. Second, road construction within the valley floor has the potential to destabilize the toe of the deep-seated slide. While a road cut could reactivate the bulk of the slide by affecting the surface and subsurface hydrology of the landslide, it is more likely to cause small slumps and shallow landslides. Again, a low likelihood exists for management-related delivery of appreciable amounts of sediment to streams.

4A.5.5 UNIT 4 OVERSTEEPENED TOE SLOPE

Delivered Hazard Rating: HIGH

This landform unit occurs only in the Squeezer Creek drainage in the middle portion of the upper half of the watershed. The slope is located on the south side of Squeezer Creek and is characterized by gradients greater than 80%. The formation of these particularly steep slopes is beyond on the scope of this analysis, but may be related to glacial erosion prior to the Holocene and/or the deep-seated landslide adjacent to this landform unit. Three particularly noticeable alluvial fans encroach upon the lower portion of this unit and attest to the up-slope mass wasting potential of Unit 1b in this locale. While no evidence of active mass wasting was noticeable from aerial photographs, the steep gradients and high erosion potential make forest management activities in this area particularly hazardous. The proximity of this landform to Squeezer Creek makes delivery of sediment from mass wasting likely.

4A.5.6 UNIT 5 GLACIAL MORAINE DEPOSIT WITH SEEP POTENTIAL

Delivered Hazard Rating: MODERATE

This landform unit was delineated to identify areas where road construction in particular could intercept shallow groundwater flow. The unit was delineated based on glacial deposits that were gently sloping (and were assumed have either shallow deposits on bedrock or a till layer that retards infiltration) and had substantial drainage areas with relatively low surface water drainage density feeding into them. The confidence level in their delineation is low because of the lack of field data on groundwater flow patterns. Larger groves of western red cedar (*Thuja plicata*) may be an indicator of near-surface groundwater flow and could be used in the field to identify areas with the potential for groundwater flow interception. This landform was mapped in only the Goat Creek and Piper Creek drainages.

Forest management activities in this landform, particularly road construction, can increase slope instability by oversteepening slopes, changing drainage patterns, and increasing the flow of water. The primary danger associated with this landform is cutslope failures that block relief culverts and lead to gully erosion or failure of the road prism. Re-routing water by collecting sub-surface drainage into one outlet or the combination of loss of root strength and increased flow of water by clearcutting larger tracts of forest (and thus reducing evapotranspiration) could increase slope instability if done on steeper (>60%) slopes. Slope failures, likely in the form of small slumps, may be relatively small in size, but usually have the potential to deliver to fish-bearing streams. A moderate hazard was assigned because of the uncertainty in delineating problem areas and the relatively small volumes of sediment potentially delivered to streams. This hazard unit may also occur in areas mapped as Unit 7.

4A.5.7 UNIT 6 INNER GORGES WITHIN GLACIATED LANDS

Delivered Hazard Rating: HIGH

This landform unit typically occurs within 100 feet of the stream channel of all three drainages as they flow through glaciated terrain. Most of the stream network has incised into the glacial material and locally steep hillslopes have formed adjacent to the stream channel. Sensitive areas within this landform unit include: 1) slopes greater than 80%, particularly with convergent slope forms; 2) slopes greater than 60% with evidence of seeps or near-surface groundwater flow; and 3) other areas with recent evidence of slope movement. The resolution of topographic maps and aerial photographs were insufficient to refine the mapping of this unit beyond a corridor approximately 100 feet from the stream, so field verification is essential to confirm the actual landform classification. The mapped areas that do not meet the criteria are typically part of Landform Unit #7. While the slumps and slides in this landform unit are typically small, a high hazard was assigned because of the high potential for direct delivery of sediment to fish-bearing waters

Forest management activities which can increase the risk of landsliding include both timber harvest and road construction. Timber harvest can reduce root reinforcement of the hillslope or via skid trail concentrate water flow to sensitive slopes. Road construction can also reduce rooting strength, but typically increases landslide potential by increasing slope gradient (i.e., cut and fill slopes) and/or increasing the flow of water to sensitive slopes from ditches and relief culverts.

4A.5.8 UNIT 7 GENTLY TO MODERATERATELY SLOPING GLACIATED LANDS

Delivered Hazard Rating: LOW

This landform comprises the largest area in all three stream drainages. Slope gradients are typically less than 20%, but can reach 40% or higher in areas, particularly along streams. This landform occurs in the glaciated alpine valleys of the upper watersheds as well as in the broader Swan river valley that was subjected to continental glaciation. Little opportunity for mass wasting exists in this landform because of the relatively gentle slopes and deep alluvial or glacial soils with high infiltration rates. Few slope stability problems have been observed in this landform, despite the fact that most areas have been subjected to forest management activities for many years, except in areas of steep slopes adjacent to stream channels. These areas should be mapped as Unit 6.

4A.5.9 UNIT 8 ALLUVIAL DEPOSITS

Delivered Hazard Rating: LOW

This landform corresponds closely to the landtype association mapped by Martinson and Basko (1983) and Sirucek (unpublished) with only slight modifications to refine the mapping at this scale. This landform is associated primarily with alluvial material from the Swan River, but also includes alluvial material in the lower reaches of both Goat and Squeezer Creeks. The slope gradient in this landform is typically less than 20%. Other than minor bank erosion associated with natural stream processes, no mass wasting processes were identified in this landform. Forest management activities are unlikely to cause mass wasting problems, although the loss of root strength from harvesting trees along the streambank can accelerate erosion particularly in unconfined areas with stream meandering. Current forest practices appear to leave most trees along the streambank and the hazard was considered low. This unit may include hazard areas that should be mapped as Unit 6.

4A.5.10 UNIT 9 ALLUVIAL FANS

Delivered Hazard Rating: LOW

This landform unit was mapped only on three small tributaries to Squeezer Creek just below Landform Unit 4 (Oversteepened Toe Slope). While most tributary streams draining these mountain slopes have small alluvial fans, these two particular fans were noteworthy for their relatively large size. The fans are easily detected from aerial photographs. The slope of the fans is generally less than 40%. The high infiltration rate of the alluvial material along with the relatively gentle slopes suggest a low mass wasting hazard. Forest management activities should not increase slope stability, although road construction activities just below Landform Unit 4 should be careful not to undercut a potentially unstable slope.

4A.6 CONCLUSIONS

Despite the glaciated landscape and steep slopes, the Piper, Goat and Squeezer Creek watersheds have relatively few landslides that deliver sediment directly to streams. Forest management to date has avoided steep slopes and has not appreciably increased the amount of mass wasting. Much of the area without current forest management, however, is steep and has potentially unstable slopes. Any future forest management in these areas will require caution. Most landslides associated with forest management occurred from steep cutslopes or concentrating drainage onto steep slopes. Despite the small amount of mass wasting within the basin, hazardous slopes could be identified with a high degree of confidence. The landform units generally characterize the potential for mass wasting, but field verification is essential in many areas to identify landslide hazard. Aerial photographs, maps and limited field reconnaissance did not provide adequate resolution to specifically identify all hazardous slope areas.

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4B SURFACE EROSION MODULE

4B.1 INTRODUCTION

This surface erosion analysis for the Goat and Piper Creek watersheds was conducted using procedures outlined in Standard Methodology for Conducting Watershed Analysis, Version 3.0 (Washington Forest Practices Board (WFPB), 1995). The surface erosion analysis includes an assessment of ***hillslope erosion*** and an assessment of ***roads erosion***.

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. Forest management activities have the potential to create hillslope erosion if the protective duff layer is removed and bare mineral soil is exposed during harvesting, and skidding operations.

Specific critical questions that are addressed in the hillslope erosion assessment are as follows:

* What is the hillslope erosion potential?
* Are contributing activities present?
* Is sediment delivered to streams?
* What areas are sensitive to forest practices?

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. Specific critical questions that are answered in the roads erosion assessment are as follows:

* What are the roads' erosion potential?
* Are contributing activities present?
* Is sediment delivered to streams?
* What roads are sensitive to forest practices?
* What is the potential effect of sediment on public resources?
* What is the baseline sediment level?

* What are the amounts and types of sediment contributions from forest practices?

4B.2 GEOLOGIC HISTORY AND PHYSIOGRAPHY

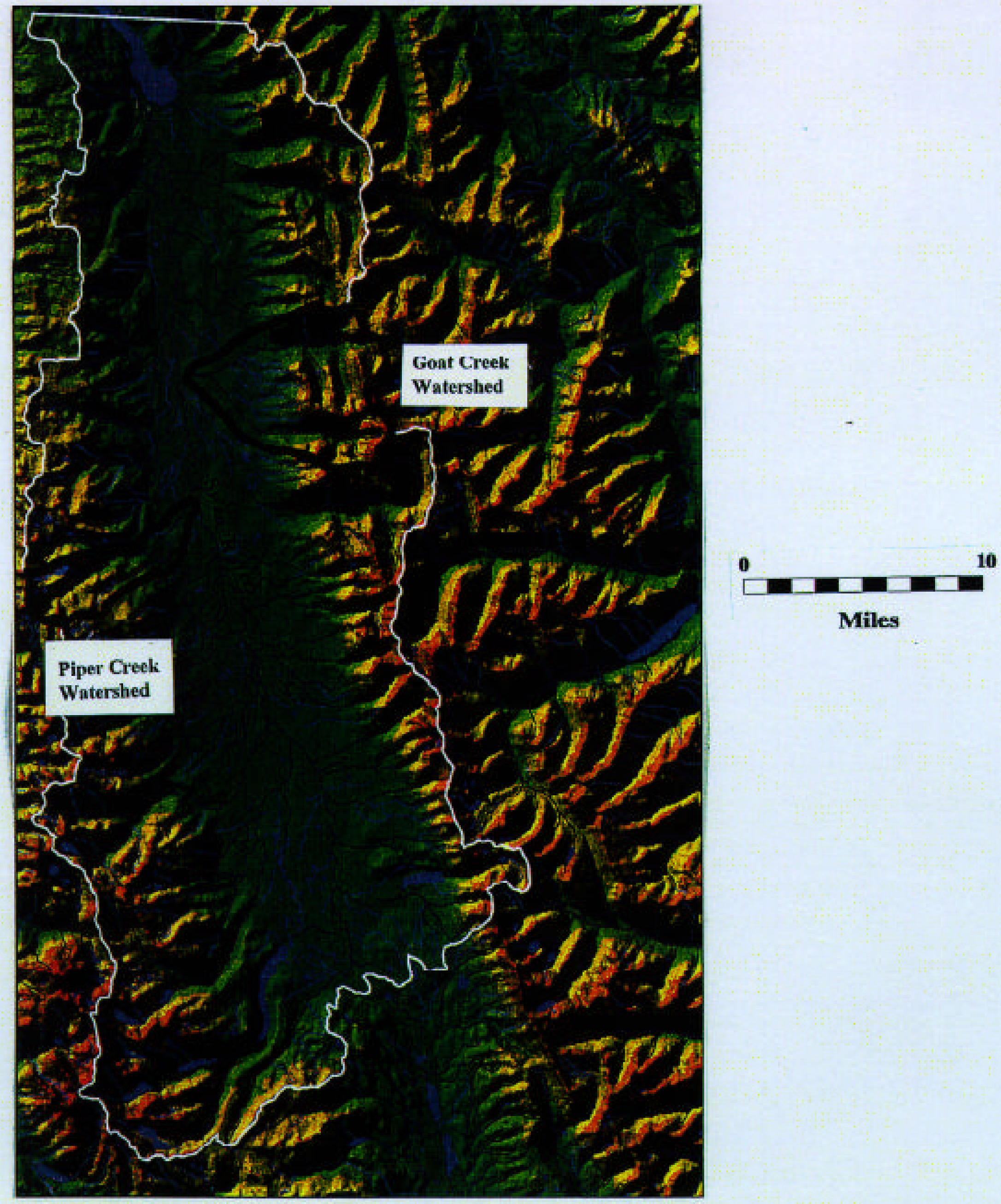
As taken from Jensen and Dean (1996):

> "The Swan Valley lies between the Mission Range on the west and the Swan Range on the east. Both ranges are Precambrian sedimentary formations. The Swan Valley was created in response to block faulting, with the upthrust fault scarp along the east side of the valley (Swan Range) and the dip slope on the west side of the valley (Mission Range). Glacial processes are evident in the topography of the Swan River basin. A lobe of the Cordilleran ice sheet pushed south through the Swan River valley during the Bull Lake ice age (Alt and Hyndman, 1986). During the subsequent Pinedale glaciation it is believed that a Swan Valley glacier arose in the Swan and Mission Mountains and flowed north to meet the south flowing Cordilleran ice sheet near Big Fork (Johns, 1970; Witkind, 1978). Evidence of glaciation include U-shaped canyons carved to the base of the mountains and an undulating valley floor with a myriad of small lakes and bogs. Nearly 50 percent of the Swan River basin is mantled by secondary glacial deposits."

The Goat Creek watershed is 24,442 acres and drains the scarp slope on the east side of the Swan Valley (See Figure 4B-1). Squeezer Creek is the largest tributary to Goat Creek and drains a 9703 acre area. As described by Jensen and Dean (1996), all of our analyses are underlain by a single geologic district: Precambrian Sedimentary (hard metamorphic rock). Both upper Goat and Squeezer Creeks were influenced by alpine glaciers that formed on the flanks of Swan Peak (9286 feet elevation). Mid-way down the watershed, these alpine glaciers coalesced with the continental glacier that filled the valley floor. At present, the lower (west) half of the watershed is overlain with gently sloping ground morrain that was left by the continental glacier. The middle reaches of each stream flows through a glacial train left by the alpine glaciers. The upper parts of each watershed drain the cirque basins below Swan Peak.

The Piper Creek watershed drains 7910 acres on the west side of the valley (drains the dip slope, see Figure 4B-1). The headwaters of Piper Creek were also influenced by alpine glaciation. As with Goat and Squeezer Creeks, the lower elevation portion of the basin was overlain by glacial till left by the Swan Valley lobe of the Cordellarian Ice Sheet.

Figure 4B-1. Topography of Swan River Basin and Location of Goat and Piper Creek Watersheds.



4B.3 HILLSLOPE EROSION ASSESSMENT

4B.3.1 SOIL ERODIBILITY

The inherent surface erosion potentials of soils in the analysis areas were assigned by Basko (1996) for each mapped landtype on the Flathead National Forest (Martinson and Basko, 1983; Sirucek, unpublished). Basko (1996) assigned an erosion hazard for each landtype based on the soil texture and the potential for sediment delivery to streams. This sediment "delivery efficiency" was determined based on slope steepness and stream drainage density. The inherent surface erosion potential for the Goat and Piper Creek watersheds are shown in Figures 4B-2a and 4B-2b.

In the Goat Creek watershed, 28% of the area is mantled by soils that are characterized by Basko as having a low surface erosion potential. These areas are typically located in the lower part of the watershed on the ground morrain and in the upper parts of the watershed that are primarily rock outcroppings. 16% of the Goat Creek watershed was assigned a moderate hazard rating, and 56% were assigned as having a high erosion potential. The areas mapped as high, are typically the steep slopes on the glacial trough walls where the stream density is relatively high.

In the Piper Creek watershed, 46% was rated as a low hazard, 42% was moderate, and 12% was characterized as "high." The moderate and high hazard areas loosely parallel Piper and Moore Creeks.

4B.3.2 HILLSLOPE EROSION AND DELIVERY

The potential for forest management to create hillslope erosion was evaluated on recently harvested areas within each watershed. Figures 4B-2a and 4B-2b show the areas that have had timber harvest activity in the Goat and Piper Creek watersheds since 1990. Of these, six sale units were visited by the author, either as part of this assessment, or during BMP audits in past years. In all sites, the harvest area adjacent to streams were investigated for signs of hillslope erosion and sediment delivery.

Of the six units, four were tractor logged and three were cable logged with partial suspension. Local areas of soil disturbance were observed on hillslopes, typically as a result of ground-based equipment operation, or by logs being skid (by cable or tractor). Though localized soil disturbance was observed, no sediment was observed to have routed to a stream channel. This is attributed to: 1) The large amount of slash retained on the forest floor (particularly in Piper Creek); 2) Selection of appropriate harvest systems; 3) Operating during appropriate times of the year; 4) Good erosion control on skid trails; and 5) Retention of a riparian buffer (filtration) strips along streams. These buffer strips averaged 75 feet in width.

The two instances where hillslope erosion was observed was on sale 2 and sale 4. On Sale 2 (Squeezer Creek), the observed erosion was on a skid trail above the road. This trail had minor

Table 4B-1. Hillslope Erosion Field Information

Site	Legal Descrip.	Sub-Basin	Soil Erosion Potential (1)	Silvi-cultural Method	Harvest Method	Ero-sion? (2)	Delivery ? (3)
1	Sec. 11 T23N R17W	Goat	Moderate/ High	Overstory Removal	Cable	No	No
2	Sec. 35 T23N R17W	Squeezer	Moderate	Overstory Removal	Cable/ Tractor	Yes	No
3	Sec. 27 T23N R17W	Squeezer	Moderate	Overstory Removal	Tractor	No	No
4	Sec. 19 T22N R17W	Piper	Low	New Forestry	Tractor	Yes	No
5	N1/2 Sec. 25 T22N R18W	Piper	Moderate/ High	New Forestry	Tractor	No	No
6	S1/2 Sec. 25 T22N R18W	Piper	High/ Moderate	New Forestry	Cable/ Tractor	No	No

(1) Based on Basko (1996)
(2) Determined by visual inspection by author
(3) Determined by visual inspection by author

gullying as a result of the steep slope and lack of appropriate drainage. The amount of erosion was estimated at less than 1 yd. This material deposited on and below the road in a slash filter windrow. None of this material appeared to route through the 100 foot buffer to Squeezer Creek. On Sale 4 (Piper Creek), gullying was observed on a skid trail on the terrace above Piper Creek. The gradient of this trail was less than 3% and water-bars were not installed. However, even with this small gradient, water was observed to have created some erosion in the trail. Some of the eroded material routed down an excavated side-hill skid trail (causing a small fill failure on the trail) and on to the Piper Creek floodplain. It appeared that this sediment deposited approximately 25 feet from the active Piper Creek channel.

4B.3.3 HILLSLOPE EROSION CONCLUSIONS

Though localized ground disturbance was observed in all units, hillslope erosion (gullying) was only observed in two of the six timber sales evaluated. In both these instances, the eroded volume was small and was not observed to deliver to any streams. In these two instances, the inherent erosion hazard was rated as "low" in the Piper sale area and "moderate" in the Squeezer sale area. The predominant triggering mechanism appeared not to be a result of the inherent erosion hazard, but rather, a failure to adequately install water-bars on skid trails. In areas where BMPs were fully implemented, no hillslope erosion was observed, even in areas characterized has having a "high" inherent erosion hazard. In the sales evaluated, appropriate application of BMP's and streamside management zones appeared to effectively preclude development of hillslope erosion sources.

The overriding factor in influencing hillslope erosion and sediment delivery in this analysis was related to application of BMPs rather than the inherent erosion hazard. Where BMPs and SMZs were appropriately applied, hillslope erosion was not observed. ***As such, developing a final map of surface erosion "hazard areas" does not appear productive for this analysis so no Surface Erosion Map Units are delineated.***

4B.4 ROADS EROSION ASSESSMENT

4B.4.1 SEDIMENT DELIVERY MODELING

Erosion from roads was evaluated using the standard methodology as outlined in WFPB (1995). The only modification to the standard procedure was to assume no sediment delivery from roads during the period of the year where they are snow covered. This was assumed to be four months of the year.

Currently, a total of 87.3 miles of road exist in the combined Goat/Squeezer Creek watershed, and 22.3 miles exist in the Piper Creek watershed. Based on maps and aerial photographs, locations where roads were proximate to streams (within 200 feet) were identified. Then, each of these sites was visited to quantify sediment delivery. This was done by determining the acreage of road treads, cutslopes, and fillslopes that could route sediment to streams at each location. In addition, observations were made of the road tread surfacing (eg. graveling), road traffic use (eg. light, moderate, heavy), and cutslope and fillslope vegetation. Based on these observations and measurements, erosion rates (tons/year) at each location were determined. For more detailed explanation of the road erosion modelling methodology, the reader is encouraged to consult WFPB (1995).

With regard to routing, if sediment from a road did not route to a perennial, fish-bearing stream, it was not included in the sediment budget. This occurred in several locales in the analysis area, particularly on the face between Goat and Squeezer Creeks. Though roads in this area deliver sediment to a number of intermittent streams on the hillside, these streams typically completely disappear (go sub-surface) in to the ground morrain when they hit the valley floor. In all cases where these sediment delivery sources were not included in the sediment budget, the stream was verified to completely disappear and not route to any fish-bearing water.

In the Goat Creek watershed, 18 sediment delivery locations were identified (See Figure 4B-4a). Of the 18, only one of these was in the Squeezer Creek basin. Roads in the Goat Creek basin (Upstream of Squeezer Creek) are estimated to deliver 38.6 tons of sediment per year. Roads in the Squeezer basin are estimated to contribute less than 1 ton per year. For the entire Goat Creek watershed, estimated sediment production from roads is 39.3 tons per year, of which 72% comes from the road tread and 28% from the cutslopes and fillslopes. Sediment delivery amounts for each location are displayed in Table 4B-2.

In the Piper Creek watershed, 11 sediment delivery locations were identified and are shown in Figure 4B-4b. These 11 locations are estimated to contribute 25.5 tons per year to the stream network tributary to Piper Creek. 83% of this is modelled to come from the road tread, while 18% is from the cutslopes and fillslopes. Sediment delivery amounts for each location in Piper Creek are summarized in Table 4B-3.

In both the Goat and Piper Creek watersheds, the majority of sediment comes from a minority of stream crossings. These are areas where several hundreds of feet of road tread and ditch drain directly to stream crossings. For example, in the Goat Creek watershed the worst five crossings contribute 70% of the total sediment delivered in the basin. A ranking of sediment sources based on the amount of delivery is include in Table A-1 in Appendix A.

Another situation that was observed in both watersheds is that in some areas roads may intercept a significant amount of shallow groundwater. Though this situation did not contribute to sediment delivery from roads, it has the potential to. The areas where this situation seemed to be most prevalent is where the ground morrain intersects with the residual hillslope. One example location is south of Goat Creek in Section 11 (T23N R17W). It also appears that the occurrence of grand fir

Table 4B-2. Road Sediment Data Calculations for the Goat Creek Watershed.

Goat Creek (Above Squeezer Creek) Road Sediment Calculations

<------ ------- ------- ROAD TREAD DELIVERY ------- ------- ------>

Stream Crossing	Contrib. Road (ft)	Tread Width (ft)	Acres Tread	Base Ero. Rate (t/ac/yr)	Gravel Factor	Traffic Factor	Snow Factor	% Delivery	Tread Erosion (tons/yr)
G1	550	15	0.19	30	0.5	2	0.67	1	3.79
G2	320	12	0.09	30	1	1	0.67	1	1.76
G3	450	12	0.12	30	1	0.02	0.67	1	0.05
G4	75	12	0.02	30	1	1	0.67	1	0.41
G5	75	12	0.02	30	1	1	0.67	1	0.41
G6	50	15	0.02	30	1	1	0.67	1	0.34
G7	50	15	0.02	30	1	1	0.67	1	0.34
G8	190	6	0.03	30	0.5	2	0.67	1	0.52
G9	0	0	0	10	0	0	0.67	1	0
G10	210	14	0.07	10	1	1	0.67	1	0.45
G11	1850	14	0.59	10	1	1	0.67	1	3.97
G12	300	14	0.1	30	1	1	0.67	1	1.93
G13	450	14	0.14	30	1	1	0.67	1	2.89
G14	200	12	0.06	30	1	1	0.67	1	1.1
G15	0	0	0	30	0	0	0.67	1	0
G16	600	15	0.21	30	1	1	0.67	1	4.13
G17	800	15	0.28	30	1	1	0.67	1	5.51
Watershed Totals:									**27.63**

<------ ------- ------- CUT/FILLSLOPE DELIVERY ------- ------>

Stream Crossing	Contrib. Cut/Fill (ft)	Cut/Fill Width (ft)	Acres Cutslope	Base Ero. Rate (t/ac/yr)	Veg. Factor	Snow Factor	% Delivery	Cut/Fill Erosion (tons/yr)	Total Erosion (tons/yr)	Road Closure Status
G1	550	16	0.2	30	0.18	0.67	1	0.73	4.52	Open
G2	320	6	0.04	60	0.37	0.67	1	0.65	2.42	Gated
G3	450	3	0.03	30	0.18	0.67	1	0.11	0.16	Gated
G4	75	6	0.01	30	0.53	0.67	1	0.11	0.52	Gated
G5	75	7	0.01	30	0.37	0.67	1	0.09	0.5	Gated
G6	50	8	0.01	30	0.37	0.67	1	0.07	0.41	Gated
G7	50	8	0.01	30	0.53	0.67	1	0.1	0.44	Gated
G8	100	15	0.03	30	0.45	0.67	1	0.31	0.83	Open
G9	550	10	0.13	10	0.18	0.67	1	0.15	0.15	Open
G10	210	10	0.05	10	0.77	0.67	1	0.25	0.7	Open
G11	1850	8	0.34	10	0.18	0.67	1	0.41	4.37	Gated
G12	300	14	0.1	30	0.77	0.67	1	1.49	3.41	Gated
G13	450	8	0.08	30	0.18	0.67	1	0.3	3.19	Gated
G14	200	8	0.04	30	0.37	0.67	1	0.27	1.37	Gated
G15	200	12	0.06	30	0.77	0.67	1	0.85	0.85	Gated
G16	600	15	0.21	30	0.53	0.67	1	2.19	6.33	Gated
G17	800	15	0.28	30	0.53	0.67	1	2.92	8.43	Gated
Watershed Totals:								**10.99**	**38.62**	

Squeezer Creek Road Sediment Calculations

<------ ------- ------- ROAD TREAD DELIVERY ------- ------- ------>

Stream Crossing	Contrib. Road (ft)	Tread Width (ft)	Acres Tread	Base Ero. Rate (t/ac/yr)	Gravel Factor	Traffic Factor	Snow Factor	% Delivery	Tread Erosion (tons/yr)
S1	50	14	0.02	30	1	2	0.67	1	0.64
Watershed Totals:									**0.64**

<------ ------- ------- CUT/FILLSLOPE DELIVERY ------- ------>

Stream Crossing	Contrib. Cut/Fill (ft)	Cut/Fill Width (ft)	Acres Cutslope	Base Ero. Rate (t/ac/yr)	Veg. Factor	Snow Factor	% Delivery	Cut/Fill Erosion (tons/yr)	Total Erosion (tons/yr)	Road Closure Status
S1	0	0	0	30	0	0.67	1	0	0.64	Open
Watershed Totals:								**0**	**0.64**	

Entire Goat Creek Basin (Upper Goat+Squeezer)

	Tread Erosion (tons/yr)	Cut/Fill Erosion (tons/yr)	Total Erosion (tons/yr)
Watershed Totals:	**28.27**	**10.99**	**39.26**

Table 4B-3. Road Sediment Data Calculations for the Piper Creek Watershed

Piper Creek Road Sediment Calculations

	ROAD TREAD DELIVERY									CUT/FILLSLOPE DELIVERY									
Stream Crossing	Contrib. Road (ft)	Tread Width (ft)	Acres Tread	Base Ero. Rate (t/ac/yr)	Gravel Factor	Traffic Factor	Snow Factor	% Delivery	Tread Erosion (tons/yr)	Contrib. Cut/Fill (ft)	Cut/Fill Width (ft)	Acres Cutslope	Base Ero. Rate (t/ac/yr)	Veg. Factor	Snow Factor	% Delivery	Cut/Fill Erosion (tons/yr)	Total Erosion (tons/yr)	Road Closure Status
P1	200	20	0.09	30	0.5	2	0.67	1	1.84	0	0	0	30	0	0.67	1	0	1.84	Open
P2	350	12	0.1	30	1	1	0.67	0.1	0.19	200	16	0.07	30	1	0.67	0.1	0.15	0.34	Gated
P3	950	20	0.44	30	0.5	2	0.67	1	8.73	950	15	0.33	30	0.18	0.67	1	1.18	9.91	*Open*
P4	50	12	0.01	30	1	1	0.67	1	0.28	50	5	0.01	30	0.53	0.67	1	0.06	0.34	Gated
P5	110	12	0.03	30	1	1	0.67	1	0.61	110	8	0.02	30	0.85	0.67	1	0.34	0.95	Gated
P6	200	21	0.1	30	0.5	2	0.67	1	1.93	150	11	0.04	30	0.85	0.67	1	0.64	2.57	Gated
P7	150	14	0.05	30	1	1	0.67	1	0.96	150	8	0.03	30	0.18	0.67	1	0.1	1.06	Gated
P8	200	15	0.07	30	1	1	0.67	1	1.38	200	10	0.05	30	0.37	0.67	1	0.34	1.72	Gated
P9	400	16	0.15	30	1	1	0.67	1	2.94	200	12	0.06	30	1	0.67	1	1.1	4.04	Gated
P10	300	16	0.11	30	1	1	0.67	1	2.2	300	8	0.06	30	0.37	0.67	1	0.41	2.61	Gated
P11	200	16	0.07	30	0.5	1	0.67	0.1	0.07	100	10	0.02	30	0.18	0.67	0.1	0.01	0.08	Open
Watershed Totals:									**21.13**								**4.33**	**25.46**	

and cedar habitat types may also be a good predictor of the potential for shallow subsurface water.

4B.4.2 NATURAL BACKGROUND EROSION

To place the modelled sediment delivery from roads in to perspective, we must compare it to the long-term, or background, erosion rate in the watershed. These background rates of erosion were estimated for each basin in two ways. First, the standard methodology (WFPB, 1995) was used to estimate annual rates of erosion based on a soil creep model. This analysis is presented in section 4B.4.2.1. Second, suspended sediment data were collected by the Flathead National Forest (USDA Forest Service, 1992) at a station on Goat Creek between 1987 and 1992. Those data are presented in section 4B.4.2.2.

4B.4.2.1 Natural Background Erosion as Determined by Soil Creep Modeling

Using the soil creep equation outlined in WFPB (1995), background rates of erosion were calculated based on the following equation.

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

Where:	2*L(m) =	Twice the length of streams in the basin (two sides per stream) in meters
	D(m) =	Soil Depth in meters
	C(m) =	Creep rate in meters per year

Based on soils data in Martinson and Basko (1983), an average soil depth (D) of 0.9 meter was assigned for each watershed. Based on slope gradients in the watershed, a soil creep rate (C) of 0.002 m/yr was assigned for Goat and Squeezer Creeks. Because average slopes were less than 30% in Piper Creek drainage, a soil creep rate of only 0.001 m/yr was assigned. Stream lengths (L) were 56,070 meters for Goat Creek, 46,300 meters for Squeezer Creek, and 34,070 meters for Piper Creek. Based on these parameters, annual eroded volumes from each watershed are shown in the following table.

Table 4B-4. Annual Background Erosion Volume by Watershed (based on soil creep)

Watershed	Erosion Volume			
	m^3/yr	$m^3/mi^2/yr$	tons/yr	$tons/mi^2/yr$
Goat	201.9	8.8	357.3	15.6
Squeezer	166.7	11.0	294.8	19.4
Piper	61.3	5.0	108.4	8.7

4B.4.2.2 Natural Background Erosion as Determined by Sediment Yield Data

The Flathead National Forest (USDA Forest Service, 1996) collected suspended sediment data at the bridge crossing over Goat Creek in SW 1/4 of Section 10 (T23N, R17W) between 1987 and 1993. The USFS also collected data on other streams tributary to the Swan River between 1987 and 1995. The annual suspended sediment loads for Goat, Lion, and Elk Creek area presented in Table 4B-5.

Table 4B-5. Suspended Sediment Yield ($tons/mi^2/yr$) for Goat, Lion , and Elk Creeks

	1987	1988	1989	1990	1991	1992	1993	1994	1995	Avg.
Goat	2.26	1.98	8.61	8.00	12.40	1.73	8.70	--	--	6.24
Upr. Lion	2.85	12.26	6.09	8.20	14.40	3.21	7.10	7.60	11.00	8.08
Elk	7.66	6.89	21.75	15.40	35.40	9.54	21.50	19.10	17.90	17.24

In comparing the suspended sediment data in Table 4B-5 with the estimates based on soil creep in Table 4B-4, we see that the estimates based on soil creep are typically about 2-3 times higher. This is to be expected since the sediment yield data collected by the USFS only includes the suspended (or fine) fraction. From soils data in Martinson and Basko (1983), we find that the soils in the Goat and Piper Creek watersheds are typically composed of 30-50% coarse fragments which would not be part of the suspended load in the stream. As such, the soil creep equation estimates are considered reasonable estimates of the background erosion rates in the basins.

4B.4.3 Erosion and Sediment Delivery Results and Conclusions

Now that estimates of background erosion rates have been made, we can put estimates of road-erosion in to perspective. By using soil creep predictions as background, road erosion in the Goat Creek watershed (above Squeezer Creek) is esimated to contribute an additional 11% above background. Erosion rates in the Squeezer basin are estimated to be only 0.2% above background, and erosion rates in the Piper Creek watershed are estimated to be 24% above background.

WFPB (1995) assumes that if erosion rates are less than 50% above background that the stream can route the incremental amount of sediment and that a low hazard exists. At present, all three basins evaluated meet this criterion and are rated as having a low hazard.

4B.5 CONFIDENCE IN WORK PRODUCTS

Overall, confidence in both the hillslope and roads portions of the surface erosion assessment is high. With regard to hillslope erosion processes, the author has had inventoried hundreds of timber sales in Northwest Montana. Though only six timber harvest areas were evaluated in these watersheds, many more have been observed in the Swan basin and have had similar findings. Hillslope erosion only appears to be a significant erosional process where deep soil disturbance is accompanied by a failure to implement appropriate erosion control. And even when hillslope erosion occurs, it rarely delivers to streams because of the maintenance of vegetated buffers around streams.

With regard to the road erosion portion of the analysis, the confidence is also high. The author visited all the locations in each watershed where sediment from roads has the potential to reach a stream. Though the modeled base erosion rates and mitigation coefficients are extrapolated from other regions of the country, they are reasonable estimates.

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APPENDIX A

RANKING OF ROAD SEDIMENT SOURCES

Table corrected
on 11-17-97
[illegible]
Errata.bs

Table A-1. Sediment sources ranked by their contribution

Rank	Sediment Delivery Location	Modelled Sediment Delivery (tons/year)	Management Entity(s) likely in charge of road
1	P3	9.9	USFS/PC Cost Share
2	G17	8.4	USFS
3	G16	6.3	USFS
4	G1	4.5	DNRC/PC Cost Share
5	G11	4.4	USFS/PC Cost Share
6	P9	4.0	PC
7	G12	3.4	USFS/PC Cost Share
8	**G13***	3.2	USFS/PC Cost Share
9	P10	2.6	PC
10	P6	2.6	USFS/PC Cost Share
11	G2	2.4	PC
12	P1	1.8	USFS/PC Cost Share
13	P8	1.7	PC
14	G14	1.4	USFS
15	P7	1.1	PC
16	P5	1.0	PC
17	G15	0.9	USFS
18	G8	0.8	USFS/DNRC/PC Cost Share
19	G10	0.7	USFS/PC Cost Share
20	S1	0.6	USFS/DNRC/PC Cost Share
21	G4	0.5	PC

Table A-1. Sediment sources ranked by their contribution (Continued).

Rank	Sediment Delivery Location	Modelled Sediment Delivery (tons/year)	Management Entity(s) likely in charge of road
22	G5	0.5	PC
23	G7	0.4	PC
24	G6	0.4	PC
25	P2	0.3	PC/Private
26	P4	0.3	PC
27	G3	0.2	PC
28	G9	0.2	USFS/PC Cost Share
29	P11	0.1	USFS/PC Cost Share

* **(HIGH PRIORITY): Old bridge over Scout Creek**. This old log stringer bridge (with significant fill on the top of it) has partially collapsed and should be quickly addressed before the rest of the bridge and fill goes in to the stream.

4C HYDROLOGIC CONDITION MODULE

4C.1 CURRENT WATERSHED CONDITIONS

4C.1.1 INTRODUCTION

The Goat Creek and Squeezer Creek basin is located on the east flank of the Swan Valley in northwest Montana. The headwaters of the watershed crest in the Swan Range and the basin drains west to the Swan River south of Swan Lake. The Piper Creek basin is located on the west side of the Swan Valley and drains east, joining the Swan River south of the Goat and Squeezer Creeks and Swan River confluence. The basins are entirely within Lake County and ownership is divided between the State of Montana and Plum Creek Timber Company. The Goat Creek and Squeezer Creek watershed ranges in elevation from 9,154 ft (2,790 m) at Swan Peak to 3,219 ft (981 m) at the outlet. The Piper Creek watershed ranges in elevation from 3,360 ft (1,024 m) at the outlet to 7,933 ft (2,418 m) on the western boundary.

This Hydrology Assessment Report (HAR) follows the standard methodology presented in the state of Washington watershed analysis manual (WFPB, 1995) using basin specific data where possible to model ROS peak flows. According to MacDonald and Hoffman (1995), peak flows in northwest Montana may be associated with ROS events which occur in the fall, mid-winter, or during the ablation period. The present analysis considers ROS events generically as described in the hydrologic change module (WFPB, 1995). Spring peak flows related to snowmelt under clear sky (CS) conditions are also common hydrologic peak events. The effect of timber management on CS peaks is evaluated using a method analogous the ROS method adapted for CS conditions. Hydrologic calculations and the analysis results were prepared using the Arc/Info geographic information system (GIS) software package.

4C.1.2 HYDROLOGIC ASSESSMENT UNITS

Given the lack of significant tributaries, the watersheds were not divided into sub-basins for this analysis. Therefore the basins consist of one HAU each, as shown in Table 4C-1.

Table 4C-1. Hydrologic Assessment Units and catchment areas.

HAU	Area (acres)	Area (km^2)
Goat Creek and Squeezer Creek	24,442	99.0
Piper Creek	7,907	32.0

U.S. Geological Survey (USGS) 7.5 minute (30 m resolution) digital elevation data (DEM) were acquired for Goat and Squeezer Creeks and Piper Creek for this analysis and are shown in Figures 4C-1 and 4C-2. The upper portion of the basins are characterized by recent glaciated features such as steep slopes and U-shaped valleys. The lower portion of the basins are characterized by relatively flat topography. The landtypes of the basin are well characterized in Ecological Classification of the Swan River Basin (Jensen and Dean, 1996).

The hypsometric curves calculated from the DEMs are shown in Figure 4C-3. Approximately 50% of the Goat Creek and Squeezer Creek basin is above 5,500 feet elevation. This elevation distribution is significant with respect to the temperature distribution within the basin. Because air temperature is generally inversely related to elevation in mountainous terrain (in the absence of temperature inversions), the upper basin may be significantly cooler than the lower basin.

4C.1.3 CURRENT LAND USE AND VEGETATION

The watersheds are primarily forested land managed for timber production. Only roads associated with timber harvesting are located within the watershed. The only capital improvement of the state is the State Highway 83 bridge which crosses Goat Creek near the outlet of the basin. The lower reaches of Goat, Squeezer, and Piper Creeks are active spawning reaches for Bull Trout (see fisheries module).

The primary naturally occurring disturbances in the watersheds are fire and flooding. Although an accurate fire history was not available for this analysis, it is likely that much of the watersheds have been significantly disturbed by fire in this century. After the 1900's fires have been actively suppressed and flooding has been the primary disturbance to date.

Based on canopy coverage, the existing vegetation condition was mapped according to a nine-division classification scheme: dense (D), dense natural (DN), immature management (IM), immature natural (IN), sparse managed (SM), sparse natural (SN), open managed (OM), open natural (ON), and non-forest (NF). The current forest canopy conditions, as mapped from aerial photos by Resource Mapping and Management (Bellevue, WA) and supplied by Plum Creek Timber Company are shown in Figures 4C-4 and 4C-5 and summarized in Table 4C-2.

Table 4C-2. Current vegetation classes and areas.

Goat Creek and Squeezer Creek		
Vegetation Class	**Area (acres)**	**Relative Percent (%)**
Dense	3,224.2	13.2
Dense Natural	3,262.0	13.5
Immature Managed	5,999.7	24.5
Immature Natural	3,579.3	14.6
Non-Forested	41.7	0.1
Open Managed	117.2	0.5
Open Natural	2,691.2	11.0
Sparse Managed	1,839.2	7.5
Sparse Natural	3,687.3	15.1
Total	24,441.8	100.0

Piper Creek		
Vegetation Class	**Area (acres)**	**Relative Percent (%)**
Dense	2,212.3	27.7
Dense Natural	648.9	8.2
Immature Managed	492.8	6.2
Immature Natural	534.9	6.7
Non-Forested	6.6	0.08
Open Managed	0.0	0.0
Open Natural	1,492.6	18.8
Sparse Managed	616.5	7.8
Sparse Natural	1,902.1	24.5
Total	7,906.6	100.0

In the Goat Creek and Squeezer Creek watershed, the dominant forest cover type is D and DN (combined 26.7% of the basin), and the next most prevalent cover type is IM (24.5%). In the Piper Creek watershed, the dominant forest cover type is D and DN (combined 35.9% of the basin). Comparing Figure 4C-1 with Figure 4C-3, it is evident that almost all of the forest harvesting to date has taken place in the lower reaches of the basin, below 5,700 feet (1,750m).

4C.1.4 STREAMFLOW AND CLIMATIC RECORDS

Observed streamflow data for Goat Creek and Piper Creek is minimal and lacking entirely for Squeezer Creek. A 20 year (WY 1972 through WY 1992) continuous record is available for the Swan River near Condon, a 69.1 mi^2 basin located approximately 24 miles upstream of the Swan River - Goat/Squeezer basin confluence. The US Forest Service (USFS) records instantaneous streamflow and sediment load on Goat and Piper Creeks for select days during the spring runoff season. This streamflow information was not available for this analysis, although an attempt was made to retrieve the data from the US Environment Protection Agency's STORET database. Daily observations for Goat and Piper Creeks are available for Water Year (WY) 1984 and are shown with the Swan River record in Figure 4C-6. The available streamflow record for the Swan River near Condon is shown in Figure 4C-7. The annual series for the Swan River near Condon is listed in Table 4C-3.

Table 4C-3. Annual Series for Swan River near Condon, WY 1972 through WY 1992.

Date	Discharge (cfs)	Date	Discharge (cfs)
5/20/1973	560	5/30/83	691
6/18/74	1540	6/22/84	846
6/16/75	1020	6/8/85	864
5/15/76	994	5/31/86	1090
5/3/77	616	5/1/87	665
6/9/78	821	6/8/88	591
5/27/79	960	5/11/89	942
5/26/80	1090	6/26/90	793
6/7/81	876	5/19/91	720
6/17/82	1060	5/9/92	511

Annual flows are likely to have occurred in the Goat Creek and Squeezer Creek basins at approximately the same time as the annual Swan River peaks recorded near Condon. For each year of the period of record the annual peakflow occurs in the spring during the peak snowmelt. The Swan River near Condon record indicates smaller peak flows do occur in the fall when relatively warm storms cause ROS peak flows. For the period of record of the Swan River gage, the fall ROS peaks are smaller than the annual spring peak flow.

Baseline flood frequencies and magnitudes were estimated for the Goat Creek and Squeezer Creek basin using the regional equations developed by the USGS (Omang, 1992) for northwest Montana. The estimated baseline peak flows for the 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year events are summarized in Table 4C-4. The flood magnitudes for the Swan River near Condon calculated by the Log Pearson Type III (LP3) distribution (Interagency Advisory Committee on Water Data, 1982) and using the station skew coefficient are included for reference.

Table 4C-4. Estimated Baseline Discharge (cfs)

	Recurrence Interval					
HAU	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Goat Creek and Squeezer Creek	477	612	691	789	857	925
Piper Creek	174	233	266	310	341	372
Swan Valley near Condon	836	1048	1176	1328	1434	1537

Climate data was available from the Kalispell weather station, 2,970 feet (905 m) elevation, which is approximately 43 miles (69.2 km) northwest of the Goat Creek and Squeezer Creek watershed. Snowpack information was obtained from US Natural Resources Conservation Service (NRCS) SNOTEL sites for stations near the basins. The nearest SNOTEL site is on Moss Ridge at 6,780 feet (2,067 m) elevation on the eastern border of the Swan Valley.

4C.2 PEAK FLOW ANALYSIS

Annual peak flows in the Swan Valley tributaries may be associated with ROS events or the annual spring runoff peak. Although the Swan River near Condon observed record indicates that the annual peak flow is generally associated with the spring snowmelt, the standard methodology for the hydrologic change module (WFPB, 1995) requires assessment of the hydrologic change related to forest management practices for ROS peak flows. In this analysis, ROS peak flows and spring peak flows will be discussed separately.

4C.2.1 ROS PEAK FLOW ANALYSIS

ROS peak flow analyses were performed following the method outlined in the hydrologic change module (WFPB, 1995), using basin-specific data were possible. The standard methodology calculates the Water Available for Runoff (WAR) for the 2, 5, 10, 25, 50, and 100-year storm events for three canopy density scenarios: fully forested, current conditions (Figures 4C-4 and 4C-5), and maximum harvest. To estimate the fully forested condition, managed open, immature, and sparse vegetation were assumed to be naturally dense. Areas mapped as naturally open, sparse, and immature were left as mapped. The fully forested condition is shown in Figures 4C-8 and 4C-9. To represent the maximum harvest scenario, all of the basin was assumed covered with immature managed vegetation. The maximum harvest scenario is intended to represent the hypothetical maximum harvest in the basin and as such the maximum possible management impact. Since harvest levels are not foreseen to reach the maximum scenario, the maximum harvest scenario provides a conservative estimate of the greatest potential for hydrologic change. For example, much of the upper portion of Piper Creek is classified as wilderness and will not be harvested, so that the maximum harvest scenario actually over-estimates the maximum possible hydrologic impacts. Storm parameters (precipitation, air temperature, and wind speed) are assumed to be average estimates for the conditions during the different storms.

WAR was calculated for each forest cover polygon using canopy density (F_c) values given in the hydrologic change module (WFPB, 1995). Each mapped vegetation class is associated with a fraction of forest cover (F_c) as specified in the standard methodology. To adapt this analysis for western Montana vegetation, several classifications were added at the suggestion of Resource Mapping and Management personnel (R. Marx, June, 1996). The vegetation classes and associated forest cover values are listed in Table 4C-5.

Table 4C-5. Land Use/Forest Cover and Forest Canopy Density (F_c).

Land Use/Forest Cover	$\mathbf{F_c}$
Dense	0.85
Dense Natural	0.85
Immature Managed	0.40
Immature Natural	0.40
Sparse Managed	0.20
Sparse Natural	0.20
Open Managed	0.07
Open Natural	0.07
Not Forested	0.07

The average snowmelt (SM) and WAR for each storm of a given precipitation frequency is calculated. WAR is then translated into discharge (Q cfs) by assuming that precipitation and peak flows of the same recurrence interval occur together. That is, the standard methodology assumes that the 2-year precipitation event causes the 2-year flood event, the 5-year precipitation event causes the 5-year flood event, etc.... The predicted peak flows for the three canopy scenarios are then compared.

4C.2.1.1 Storm Data

Precipitation magnitudes for 24-hour totals were estimated from the 42 year record (1947-1993, discontinuous) at Kalispell using the LP3 distribution and the station skew coefficient. For low skew coefficients, the LP3 distribution closely approximates the Gumbel distribution. Table 4C-6 lists the 24-hour precipitation magnitudes estimated from the Kalispell, MT data for the 2, 5, 10, 25, 50, and 100 year storms.

Table 4C-6. Kalispell Precipitation Magnitudes.

Return Period (yr)	**2**	**5**	**10**	**25**	**50**	**100**
24-hour Precipitation (in)	0.97	1.32	1.60	2.00	2.35	2.73

It is assumed that rainfall is uniformly distributed in the watershed, irrespective of elevation. Because precipitation generally increases with elevation, the assumption will under-estimate the rainfall at higher elevations and thus will tend to maximize the increase in WAR relative to the fully forested condition.

Air temperature (T_a) was taken as the average daily air temperature (the average of the maximum daily recorded air temperature and the minimum recorded air temperature) recorded at Kalispell for the dates corresponding to representative ROS events recorded at the Swan River near Condon (11/13/73, 1/17/74, 12/28/80, 9/23/84, and 10/17/88). The average air temperature for 5 events is 38.3 °F (3.5 °C). Air temperature was corrected for elevation using a lapse rate of 3 °F/1000 feet elevation (0.006 °C/m). The air temperature distribution is shown in Figures 4C-10 and 4C-11. Contours showing the 0 °C isotherm are included in the diagrams. Air temperature for much of the upper basin is below 0 °C and all precipitation is assumed to fall as snow.

Wind speed was estimated from the Spokane, Washington frequency curve provided in the hydrology assessment manual (WFPB, 1995). An storm wind speed of 5.5 m/s was used in this analysis. Considering this wind speed is based on observations in eastern Washington and these calculations are being performed for a basin in western Montana, the wind speed is clearly the least known parameter in the snowmelt calculations. Wind speed was modified for forest cover at each cell according to the standard manual method and the wind speed distribution is shown in Figures 4C-12 and 4C-13.

Snow Water Equivalent (SWE) was estimated using the average annual May 1 SWE at the Moss Ridge SNOTEL site. For all of the simulations, the estimated SWE exceeded the calculated snowmelt and therefore was not a limiting factor as explained in the hydrology assessment module (WFPB, 1995).

4C.2.1.2 SM Results

Snowmelt was calculated at each model cell for each of the ROS events considered in the analysis using the snowmelt model prescribed in the standard hydrology assessment (WFPB, 1995). The distribution of the calculated snowmelt for each of the storm events and the current vegetation is shown in Figures 4C-14 and 4C-15. The distribution of calculated snowmelt for each storm event for the maximum harvest scenario is shown in Figures 4C-16 and 4C-17. Calculated snowmelt is 0.0 for much of the upper basins since this area is below 0 °C (Figure 4C-10 and 4C-11). Figures 4C-14 and 4C-15 show that during an "average" ROS event, snowmelt will likely be confined to the lower basin.

4C.2.1.3 WAR Results

WAR was calculated as WAR = SM + P where P is precipitation for the three scenarios following the procedures outlined in the hydrologic change module (WFPB, 1995) for each model cell (pixel) in the basin. The completely clear-cut scenario is intended to estimate the maximum possible WAR. By the standard methodology, snowmelt and thus WAR increase with decreasing proportion of mature forest cover. Therefore, the WAR calculated for the current and maximum clear-cut conditions is larger than the WAR calculated for the fully forested scenario.

The calculated distribution of WAR for each of the storm events is shown in Figures 4C-18 and 4C-19 for the current condition and Figures 4C-20 and Figures 4C-21 for the maximum harvest scenario. As is the case for the calculated snowmelt, areas above the 0 °C contour do not contribute to WAR because precipitation is assumed to be snow and snowmelt = 0.0. The mean calculated WAR and the change in WAR for the current condition and maximum harvest scenario relative to the fully forested scenario is shown in Table 4C-7.

Table 4C-7. Mean WAR (in) and change (%) relative to the fully forested condition.

	Goat and Squeezer Creeks					
	Precipitation Events					
	2-Yr		5-Yr		10-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	0.56		0.72		0.84	
Current Condition	0.62	10.7	0.77	6.9	0.90	7.1
Maximum Harvest	0.66	17.8	0.82	13.9	0.94	11.9

	Goat and Squeezer Creeks					
	Precipitation Events					
	25-Yr		50-Yr		100-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	1.02		1.17		1.34	
Current Condition	1.07	4.9	1.22	1.7	1.40	4.5
Maximum Harvest	1.11	8.8	1.27	8.6	1.44	7.5

	Piper Creek					
	Precipitation Events					
	2-Yr		5-Yr		10-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	0.38		0.49		0.58	
Current Condition	0.44	15.8	0.51	4.1	0.60	3.5
Maximum Harvest	0.45	18.4	0.54	10.2	0.63	8.6

	Piper Creek					
	Precipitation Events					
	25-Yr		50-Yr		100-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	0.70		0.81		0.93	
Current Condition	0.72	2.9	0.83	0.67	0.95	2.2
Maximum Harvest	0.76	8.6	0.86	6.2	0.98	5.4

For events in the current condition scenario, the largest increases in WAR are associated with the 2 and 5 year storms. The relative changes decrease as the storm frequency decreases, since snowmelt is a smaller relative proportion of WAR in the precipitation larger events. For the current conditions, the maximum relative change is 15.8% for the 2-year event in Piper Creek. In the maximum harvest scenario, the relative increases in WAR are larger. For the maximum harvest scenario, the maximum relative increase in WAR is 18.4% for the 2-year in Piper Creek.

Since air temperature, wind speed, and precipitation are estimated from point measurements outside of the watershed, the model results are best considered in terms of reflecting relative changes in hydrologic response for the given vegetation scenarios. Without long-term, basin-specific hydrologic data, more accurate predictions are not possible with the standard hydrologic assessment methodology.

4C.2.1.4 ROS Peak Flows

Following the standard method to determine the sensitivity of HAUs to hydrologic change related to forest management practices, changes in WAR are translated to changes in discharge (Q) for the three scenarios. The increase in Q for the current condition relative to the fully forested scenario determines the sensitivity of the HAUs to peak flow increases related to forest management practices. Precipitation (P) versus discharge (Q) relationships, developed for the basins, are used to translate WAR to Q.

The method outlined in the manual relates like-frequency P and Q events. Figure 4C-22 is a plot of P vs. Q for the 2, 5, 10, 25, 50, and 100 year P (Table 4C-6) and Q (Table 4C-4) events for the Goat Creek and Squeezer Creek basin. Precipitation is as previously defined and is not corrected for elevation. A second-order polynomial having the form $Q = A*(P^2) + B*(P) + C$ where Q is in cfs and P is in inches was fit to the relationship $Q = f(P)$. A similar relationship was developed for Piper Creek where A = -27.305, B = 210.84, and C = -1.31. The relatively high coefficient of determination does not necessarily imply confidence in the relationship, however, since the relationship is based on the improbable assumption of a causal relationship between P and Q events of the same frequency. Discharge (Q) was calculated for each scenario and storm frequency by substituting WAR for P in the Q = f(P) relationship.

ROS peak discharge estimates for the different scenarios are shown in Table 4C-8. The maximum peak flow increases are associated with the high frequency storms (2-year recurrence interval). For the Goat Creek and Squeezer Creek basin, the maximum calculated peak flow increases are 6.5% for the current condition and 12.3% for the maximum harvest scenario. For the Piper Creek basin, the maximum calculated peak flow increases are 5.3% for the current condition and 13.3% for the maximum harvest scenario.

Table 4C-8. Estimated Q (cfs) and change (%) relative to the fully forested condition.

	Goat and Squeezer Creeks					
	Precipitation Events					
	2-Yr		5-Yr		10-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	325		389		437	
Current Condition	346	6.5	410	5.4	457	4.6
Maximum Harvest	365	12.3	428	10.0	474	8.5

	Goat and Squeezer Creeks					
	Precipitation Events					
	25-Yr		50-Yr		100-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	503		555		612	
Current Condition	522	3.8	573	3.2	628	2.6
Maximum Harvest	538	7.0	588	5.9	642	4.9

	Piper Creek					
	Precipitation Events					
	2-Yr		5-Yr		10-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	75		95		111	
Current Condition	79	5.3	99	4.2	115	3.6
Maximum Harvest	85	13.3	105	10.5	121	9.0

	Piper Creek					
	Precipitation Events					
	25-Yr		50-Yr		100-Yr	
Scenario	Mean	Change (%)	Mean	Change (%)	Mean	Change (%)
Fully Forested	133		151		171	
Current Condition	137	3.0	154	2.0	174	1.8
Maximum Harvest	142	6.8	160	6.0	179	4.7

The analysis indicates that for the current condition, the basins do not experience increases in ROS peak flows greater than 10% relative to the fully forested scenario. For the maximum harvest scenario, the relative change for the 2-year event does exceed 10%. However, this scenario is intended to demonstrate the range of peak flow changes and does not represent a likely harvest scenario. Under the WFPB manual guidelines (1995), both basins are rated as **LOW** sensitivity to ROS related peak flow changes resulting from forest management activities.

Confidence in this sensitivity rating must be considered low. While this analysis has used basin-specific data where possible, the approach is consistent with the methodology presented in the manual. Although the stream gage and climatologic data provide reasonable estimates of historical conditions, ambiguities and errors the scenarios and storm types overwhelm confidence in the data. Possible errors in the method include: relating WAR for ROS storms to a P vs. Q relationship which must inherently include ROS storms, assumed forest canopy density fractions, and assuming a linkage of similar frequency P and Q events.

4C.2.2 CS PEAK FLOW ANALYSIS

Spring snowmelt peak flows (CS peak flows) are an important hydrologic event in the Swan Valley Tributaries. However, the standard hydrology assessment methodology does not address peak flows under CS conditions. This analysis extends the standard procedures to provide a reasonable estimate of the effects of forest management activities on CS peak flows.

4C.3.2.1 CS Model

The CS modeling followed an approach which was intended to be analogous to the ROS analysis. Snowmelt at a point is calculated using relatively simple index equations (US Corps of Engineers, 1956). Input parameters are estimated from available data, and WAR is calculated for the three vegetation scenarios: fully forested, current conditions, and maximum clear-cut. Whereas spring peak flow hydrographs are typically 4-7 days in duration, the CS model presented here calculates snowmelt for a 24-hour period. Therefore, relating WAR (daily peak snowmelt) to discharge is not possible in this analysis. Previous studies of forest management effects on the timing and magnitude of spring peak flows (Cheng, 1989) suggest that peak flows occur earlier in the snowmelt season and may increase with timber management. In this analysis, the distribution of estimated snowmelt for a hypothetical clear, warm spring day is used to indicate the areas of maximum snowmelt and thus the areas most likely to be sensitive to timber harvest.

To calculate CS snowmelt, the snowmelt equations developed by the US Corps of Engineers (1956) and simplified by Dunne and Leopold (1978) were used. The equations were developed for clear-sky snowmelt conditions at latitudes of about 46 degrees.

Equations

Open Areas (<10% Tree Cover)

$$M = 0.0125Q_s(1-\alpha) + (1-0.1C)(0.104T_a-2.13) + 0.013T_a + 0.00078U(0.42T_a+1.51\ T_d) \quad (1)$$

Lightly Forested (10-60% cover)

$$M = 0.01(1-F)Q_s(1-\alpha) + 0.00078U(0.42T_a+1.51T_d) + 0.14FT_a$$

(2)

Heavily Forested (>80% cover)

$$M = 0.00078U(0.42T_a+1.51T_d) + 0.14T_a$$

(3)

M = melt cm/day
Q_s = insolation (cal/cm^2/day)
T_a = air temperature (°C)
T_d = dew point temperature(°C), assumed = T_a (rh = 100%)
U = wind speed (km/day), modified for forest cover
α = snow surface albedo (assumed 0.55)
C = cloud cover fraction, estimated from mean difference of daily T_{max} and T_{min}
F = forest canopy density (decimal fraction)

Each parameter was estimated from available data and snowmelt modeled for each forest cover condition (fully forested, current condition, and maximum harvest). For the CS analysis WAR reduces to snowmelt (SM) because P = 0.0. The areas of maximum snowmelt are compared with the current vegetation distribution to determine the hydrologic sensitivity to CS conditions.

4C.2.2.2 Parameter Estimates

The required inputs for the CS snowmelt equations described were either assumed as indicated above or estimated from available data. The average air temperature was calculated as the average of the daily mean air temperature on the date of the annual spring peak for the period of record (14.88 °C). Wind speed was assumed 1.0 m/s (86.4 km/day) to simulate warm, sunny, calm conditions. Since the calculations were intended to simulate a clear day, cloud cover was set to 0.0 (C = 0.0). Air temperature was distributed over the basin using a lapse rate of 3 °F/1000 feet (0.006 °C/m). For the purposes of the snowmelt calculations, the spring snowpack was assumed to exceed the calculated snowmelt everywhere in the basin.

Insolation (Q_s) is the dominant heat source during spring snowmelt and is assumed to be dominated by direct beam radiation under clear sky conditions. Insolation was estimated by calculating the average insolation for each pixel in the basin. Using the data tables in Fons et al (1960), direct beam insolation was calculated for north, south, east, west, northeast-southwest, and northwest-southeast aspects for the slope of each pixel. The slope and aspect of each pixel was calculated using the Arc/Info LATTICEPOLY function and each pixel is assigned a calculated insolation value based on the slope and aspect combination. Figures 4C-23 and 4C-24 show the distribution of aspect classifications for the basins. Insolation was calculated for May 5 at 46° Latitude, assuming an atmospheric transmissivity of 0.90, a solar declination (δ) of 16°, and numerically integrated from solar noon. Snowmelt was then calculated using Equations (1-3) based on the vegetation at each pixel.

4C.2.2.3 CS SM Results

The distribution of calculated snowmelt for a hypothetical spring day is shown in Figures 4C-25 and 4C-26 for the current condition and Figures 4C-27 and 4C-28 for the maximum harvest scenario. The model produces reasonable estimates of daily snowmelt for the given conditions. The simulated snowmelt shows that most of the snowmelt under reasonable, average conditions would occur at the lower elevations of the basin. This area corresponds to the warmer air temperatures, which is the dominant heat source in the spring snowmelt process. The areas of maximum calculated snowmelt are likely to be the areas most sensitive to timber harvesting, since these areas receive the greatest heat flux during the snowmelt season.

Errors resulting from the necessary approximations and inherent in the method limit the quantitative interpretation of this analysis. Only one input variable, air temperature is estimated from measurements near the basins. All others are assumed or estimated from literature. While the input variables are best, reasonable approximations, the lack of measured and/or field verified data limits the applicability of the analysis. This analysis assumes that the fully forested condition ($F_c = 0.85$) is the "natural" base-case scenario which may in fact may not be the case. Fire plays an important role in thinning the forest canopy, and the base-case may be a predominantly sparse forest canopy. If a sparse forest canopy were used instead of a dense forest canopy in the base scenario, the estimated relative changes would be significantly less. However, it should be noted that the "natural" forest canopy is also a potential error in the ROS analysis.

A major potential error is the distribution of the spring snowpack. An effort was made to obtain Advanced Very High Resolution Radar (AVHRR) scenes of the Swan Valley to map the typical spring snowpack. Unfortunately, a scene with suitable resolution was not located. Given the elevation distribution of the basin (Figure 4C-3), a significant snowpack lingers in the upper basin well into June and July (G. Watson, pers. comm., May 1996) after the lower basin is snow-free. A field visit to area during June, 1996, confirmed that during the "typical" spring runoff peak flow the lower portion of the basin is snow-free. The lower-basins, which contain most of the current timber harvest disturbance, may typically be snow free before the annual CS peak flow, and therefore would not be a contributing source area to the spring peak flow. Based on this reasoning, the watershed has a **LOW** sensitivity to hydrologic change related to forest management for CS peak flows. In the event that subsequent concerns are raised regarding the hydrologic impacts of forest management in the lower basin, a relatively inexpensive voluntary monitoring program, discussed later, may be implemented.

4C.3 EFFECTS OF PEAK FLOW CHANGES ON PUBLIC RESOURCES

Peak flow effects for ROS related peaks and CS related peaks are considered in this analysis.

For ROS peak flows, calculated peak flow changes for the current scenario are less than 10% for the basins. Peak flows augmented by increased snowmelt during rainfall does not appear to be a significant factor in the Goat Creek and Squeezer Creek or Piper Creek watersheds. For spring snowmelt conditions, the snowmelt estimates indicate that the spring peak discharge is not impacted by snowmelt in the areas of forest management based on the simulated distribution of snowmelt calculated for a hypothetical clear-sky spring day. On this basis, the hazard rating is **LOW** for the both watersheds. The **LOW** rating is based on calculations which extend the established manual method to cover CS snowmelt conditions. It is subject to the same ambiguities, errors, and assumptions that the standard method contains.

4C.4 MONITORING

Uncertainty in the hydrologic analysis does not justify prescriptive treatments, such as reducing the rate timber harvesting, based on the hydrologic sensitivity. A voluntary monitoring program, which specifically addresses the hydrologic issues, is suggested.

Uncertainty in the hydrologic analysis is associated with errors in the climatologic variables, the distribution of the spring snowpack, the snowmelt model, the distribution scheme used to spatially represent the variables, the forest canopy representation, the melt-discharge relationships, and the lack of any routing mechanism. Of these possible sources of error, the distribution of the spring snowpack is arguably the most significant. A simple, inexpensive monitoring program can address some of this uncertainty.

An adequate monitoring program would consist of snowpack observations over the spring snowmelt period (March-June) for approximately five years. The recommended program would consist of bi-monthly observations of snow stakes at observable locations in the upper and lower basin. The snow stakes should be installed on representative aspects and elevations such that they are visually accessible. Field notes should record the following: snow stake number and location, date, air temperature, snow depth, and a sketch of the snow distribution in the sub-basin on a topographic base map. The date of the final disappearance of the snowpack should also be recorded.

A continuous streamflow gage installed on one of the Swan Valley tributaries would provide a much needed record the hydrology of smaller sub-basins in the Swan Valley. As the US Forest Service currently maintains several streamflow stations for instantaneous observations, it may be possible to collaborate and upgrade an existing gage location.

At the conclusion of the monitoring program the snowpack data should be evaluated. If the lower portions of the basins can be shown to be a significant source of spring-time (clear sky) snowmelt, further analysis should be considered. A distributed vegetation-soil-hydrology model could be used to evaluate the hydrologic impacts of existing and potential forest harvest scenarios.

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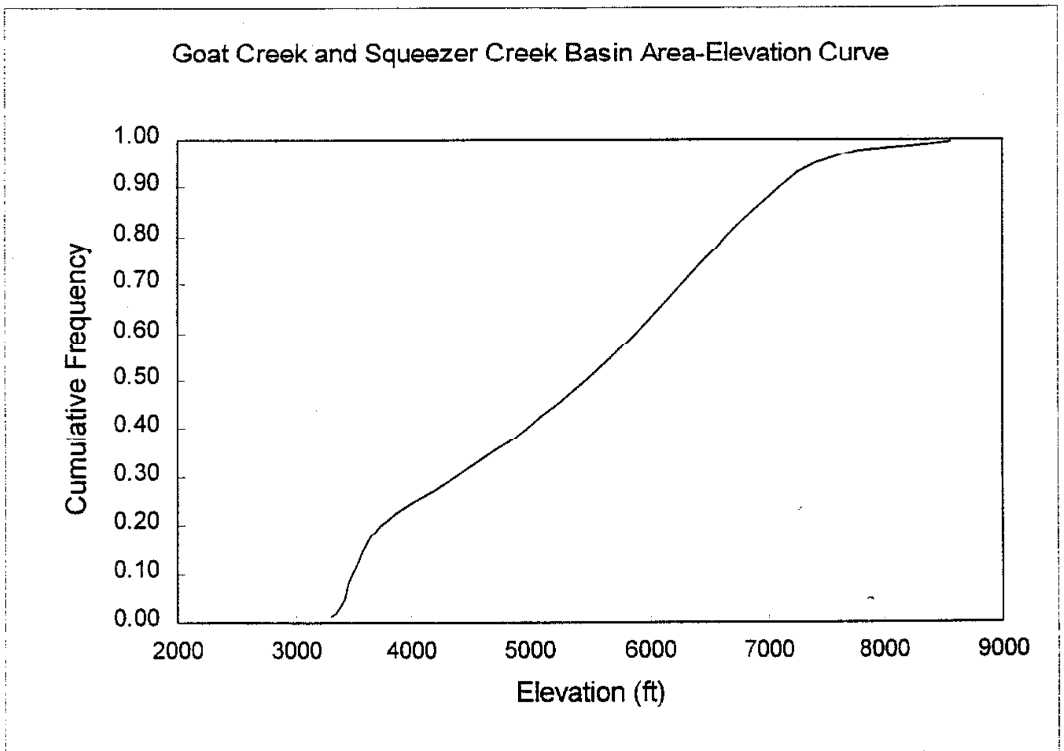
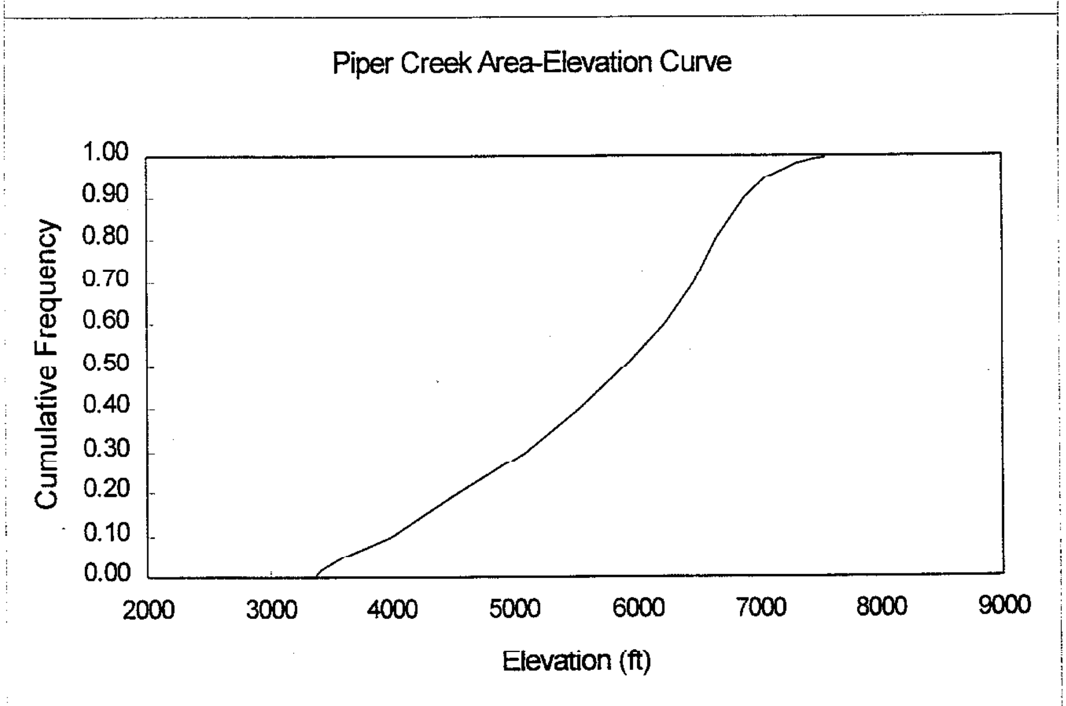
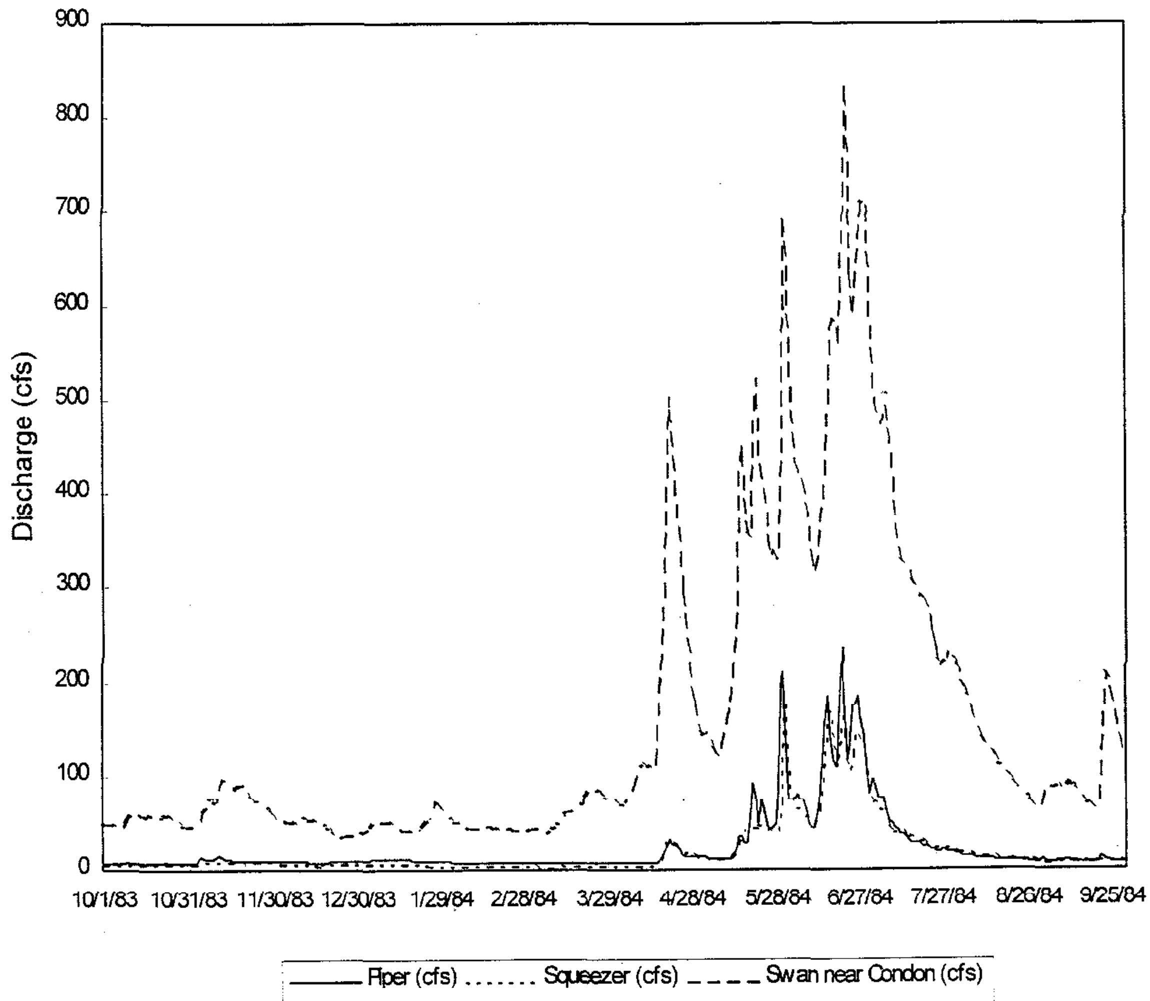
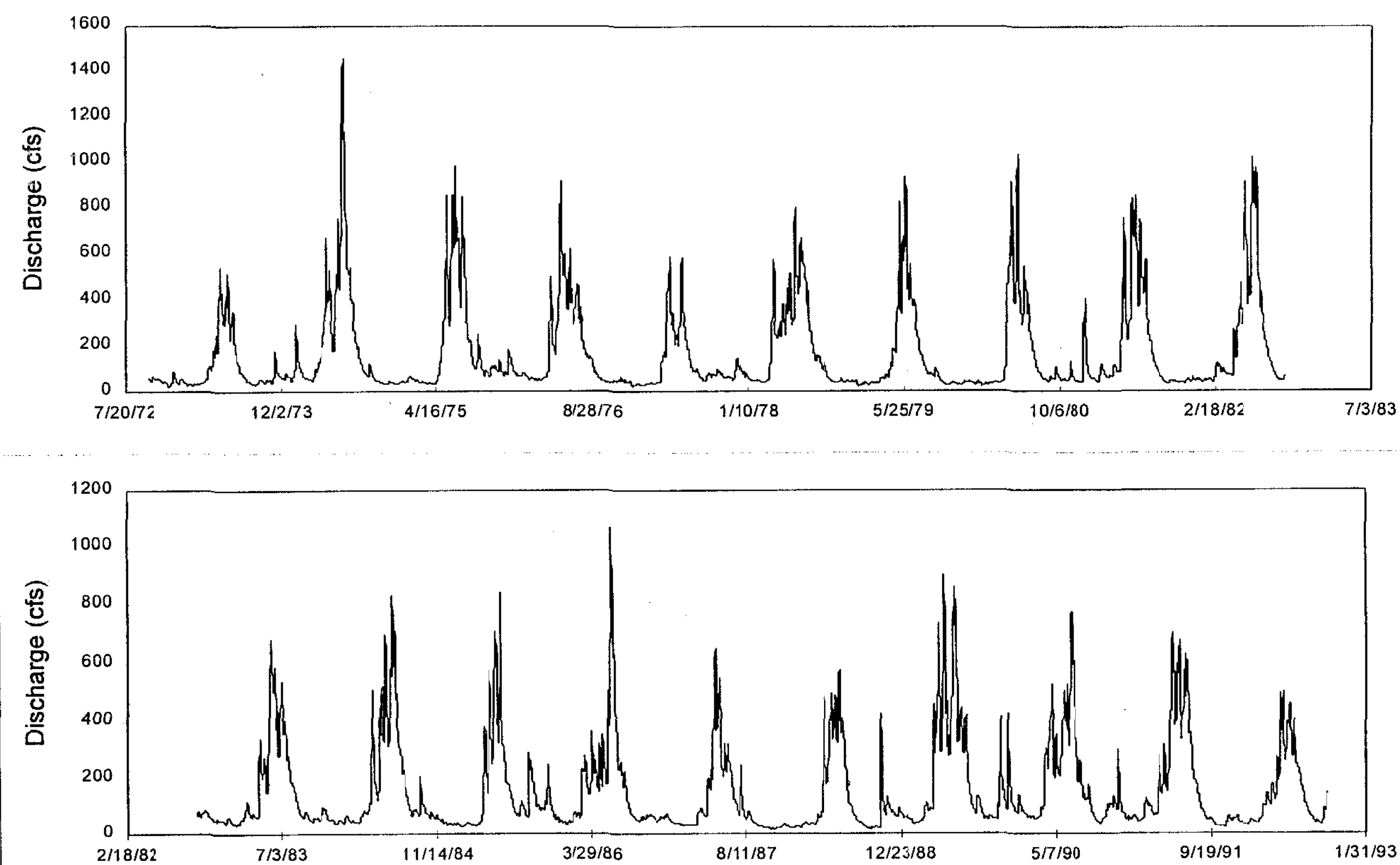




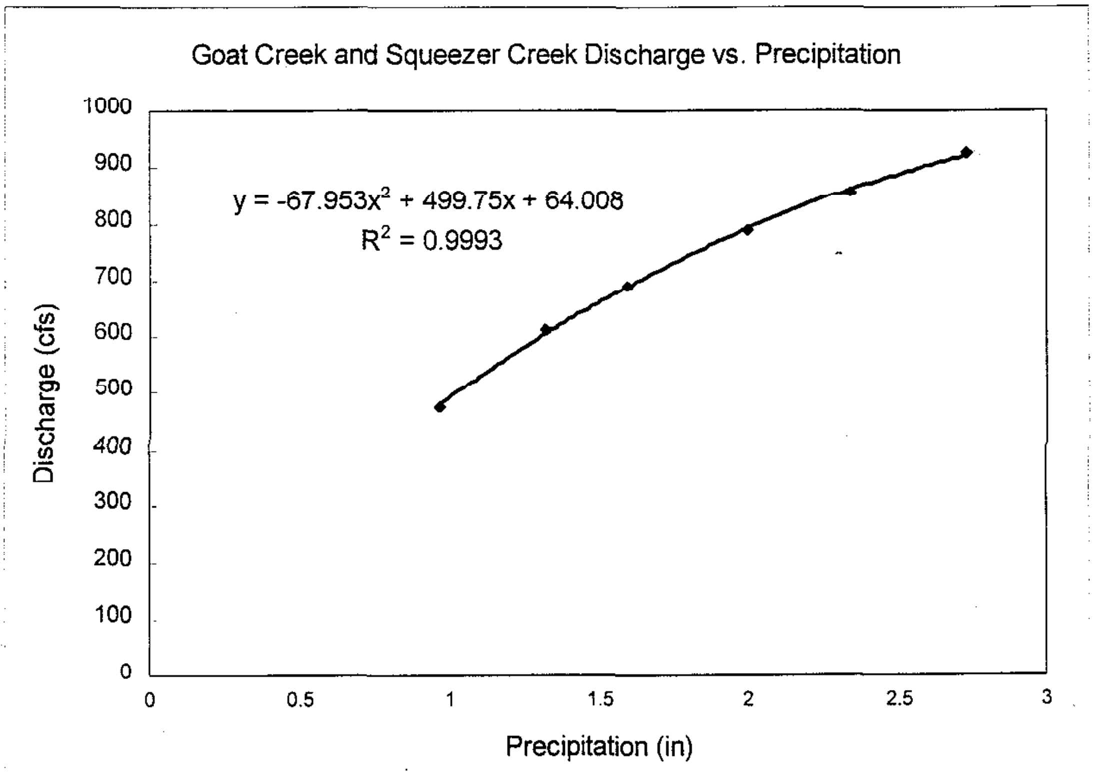
ARCTIC GEOSCIENCE, INC.	Figure 4C-3. Area- elevation curves for Goat and Squeezer Creeks (top) and Piper Creek (bottom).	By: PKW	Date: 11/13/96	Project No: 96-0183
		Checked: BDB	Date: 11/13/96	File Path: sun c:\swan\f4c-3
	PLUM CREEK TIMBER COMPANY	Scale: N/A	Figure 4C-3	



ARCTIC GEOSCIENCE, INC.	Figure 4C-6. Average daily streamflow (cfs), WY 1984, for Goat Creek, Piper Creek, and the Swan River near Condon, MT.	By: PKW	Date: 11/23/96	Project No: 96-0183
		Checked: BDB	Date: 11/23/96	File Path: medved\c:\swan\f4c-6.ppt
	PLUM CREEK TIMBER COMPANY	Scale: N/A	Figure 4C-6	



ARCTIC GEOSCIENCE, INC.	Figure 4C-7. Observed average daily streamflow (cfs), WY 1973 through WY 1992, for the Swan River near Condon, MT.	By: PKW	Date: 11/13/96	Project No: 96-0183
		Checked: BDB	Date: 11/13/96	File Path: medved\c:\swan\f4c-7.ppt
	PLUM CREEK TIMBER COMPANY	Scale: N/A	Figure 4C-7	



ARCTIC GEOSCIENCE, INC.	Figure 4C-22. Precipitation (in) - Discharge (cfs) relationship for Goat and Squeezer Creeks.	By: PKW	Date: 11/23/96	Project No: 96-0183
		Checked: BDB	Date: 11/23/96	File Path: medved\c:\swan\f4c-22.ppt
	PLUM CREEK TIMBER COMPANY	Scale: N/A	Figure 4C-22	

4D RIPARIAN FUNCTION MODULE

4D.1 INTRODUCTION

An assessment of riparian condition and function was conducted in Goat, Squeezer and Piper creeks of the Swan Valley between May and October 1996.

The two primary questions that this analysis will address 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?

The assessment of large woody debris (LWD) recruitment and riparian shade follows the *Standard Methodology for Conducting Watershed Analysis*, Washington State Forest Practices Board 1995 (the manual). Data for the assessment came from Plum Creek Timber Co. (PCTC) fisheries research crews and data supplied by PCTC. Additional data was collected by module analysts.

4D.1.1 SOURCES OF INFORMATION

The riparian condition calls relative to LWD recruitment were characterized remotely using color aerial photography. The primary photography used for the analysis were 1994 PCTC Color photos (1:12,000 scale) for the lower portions of the WAUs and 1992 USFS color aerial photography (1:20,000 scale) for the upper portions of the watersheds. 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, channel migration zones (CMZ), and in-stream LWD.

Surveys were conducted in selected areas to quantify riparian condition calls. Listed areas that were surveyed can be found in Table 4D-1. Data that was collected in the survey include CMZ delineation, riparian tree species, size, density, and LWD accumulation. Data collection efforts were supplemented by fisheries habitat research that was being conducted in conjunction with the W.A. by PCTC.

PCTC fisheries research crews collected additional data in selected areas within the WAU. Data collected by the crew included in-stream LWD, CMZ, current and potential riparian tree cover, and canopy density measurements that were used in this analysis.

Information collected by the channel analyst was use to determine channel sensitivity to LWD inputs and as another source of field data on in-stream wood and functions.

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 was analyzed and interpreted with respect to the critical question of 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?

The standard assessment described in the manual was used for this assessment.

To determine whether a riparian area is functioning 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). 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).

Data from current riparian stands on tree size, stocking, canopy density, CMZ and LWD levels were recorded to determine whether stands were functioning. Based on these features of functional riparian areas some assumptions were used in the analysis of the riparian areas. The site-potential tree height for the Swan Valley based on personal observations is 110 ft., effective tree height would be 93.5 ft., and shading to the stream would be provided from trees from zero out to 77 ft from the bank. These distances fit in with the 23 m (75 ft.) strip that was analyzed in riparian area.

Aerial photography was used to characterize the forest composition of 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 this figure may more appropriately represent three-quarters to 100% of the "site potential tree height". All streams within the watershed analysis that met criteria of the manual were classified for hazard calls. The riparian areas that were not classified were greater than 20% channel slope and areas where intermittent waters do not reach a main stream network. Photo pairs were examined and riparian stands were delineated on 1:24,000 GIS base maps provided by PCTC. Riparian segments were broken out into riparian condition codes. These codes delineated riparian strips by the combination of dominant vegetation, tree size, and stocking density. For example, a riparian area with a call of conifer-mature-dense (CMD) was dominated by conifers with trees of medium DBH and dense stocking, Table 4D-2 has a further breakdown of these calls.

4D.2.2 RESULTS

4D.2.2.1 Riparian Forest Condition

Most of the riparian areas within the Piper Creek drainage have been unmanaged in order to provide cover for Elk Migration Corridors (Pat Caffery, PCTC Forester, pers. comm.). This along with Montana SMZ law that was adopted in 1991 has helped to provide good riparian stands.

Riparian condition calls were used to classify the LWD recruitment potential of the riparian area. 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-3.

More than 92% of riparian areas have good stand conditions and 70% had high recruitment potential as defined in Table 4D-4. Recruitment potential is based on the riparian condition calls from aerial photos and field inspections. The 30% of stands that did not have a high recruitment potentials were generally found on the upstream reaches of the stream network. These are areas with naturally low densities and small size trees due to environmental factors (i.e., talus soils, steep head wall systems, and short growing season). A break down of recruitment potential calls by segment can be found in Table 4D-5.

Only three segments on the mainstem creeks (S2, P4.2, P7) showed reduced riparian recruitment potential due to harvest within riparian area. All of these sites were harvested before the implementation of the Montana SMZ law. Most low and moderate recruitment calls were due to naturally occurring conditions on the land as evidenced by historic aerial photography (pre-management conditions).

Table 4D-6 lists average channel width, average dbh, and average LWD functional diameter.

4D.2.2.2 In-Channel LWD

In-channel LWD with the watershed analysis area is generally high in comparison to most watersheds that the evaluation tool was developed in Table E-1 of the Channel Conditon Module lists LWD levels. In-Channel LWD was considered on target in the analysis area. Most segments had a high number functional pieces of wood per channel width. Segments with the largest accumulation were in GMU's 2, 4, and 5. These GMU's are also areas with high potential of channel migration (Channel Condition Module).

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 stands due to the fact that little management that had occurred within the watersheds previous to this time. The current riparian conditions within the watershed are similar to what was present in 1955. Most harvest before the 1955 photos occurred in the lower portions of the watershed generally near main roads into area along lower Goat, Piper Creeks and the benches above Squeezer Meadows.

Extensive field review of many of the mature stands and SMZs within the analysis area suggest that, early harvest seemed to be dominated by single tree selection and removal. This low impact harvest method has left many riparian stands intact and has provided the system with healthy riparian stands. Later harvests after 1955 photos were fairly intensive tractor logging operations through the area removing half of the volume. These harvests mainly occurred away from the riparian areas.

4D.2.2.4 Characteristics of Riparian Trees

Riparian trees in the WAU are predominantly conifers with an under-story of deciduous shrubs and trees. Most riparian areas are dominated by conifer-medium-dense stands in the lower elevation reaches with conifer-medium-sparse in the upper headwaters of the analyses area. Segment S2 in the Squeezer Meadows area is currently and was historically dominated by a mixture of conifer and deciduous trees.

4D.2.2.5 LWD in Intermittent Channels

Large woody debris was not sampled in intermittent channels within the system. Most of the intermittent streams in the Piper, Goat and Squeezer system were dry and all exhibited flows going sub-surface before reaching Piper, Goat and Squeezer Creek.

4D.2.2.6 Hazard Calls

Under the standard methodology in the manual, LWD hazard calls are based on a matrix Table 4D-6 which considers channel sensitivity to LWD from the channel analyst (Table-E6 from Channel Condition Module), LWD recruitment potential, Table 4D-3, and current condition of the in-stream LWD. The in-stream LWD is a on or off call based on the number of functional pieces per-channel width. A close inspection of this matrix shows that channel sensitivity largely determines the hazard ratings.

Channel sensitivity ratings were determined collectively by the analysis team during synthesis. Resulting hazard calls were mapped on Figure 4D-1 and reported in Table 4D-5. High LWD hazard ratings generally coincided with gravel or cobble dominated sections that were very responsive to LWD inputs.

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?

In addition to using the guidelines from the manual, stream temperature data are presented and also analyzed

The guidelines used to determine shade impact in this analysis follow the manual. Since the streams in Montana are not rated in the same manner as Washington, the more stringent temperature classification of AA (max temp.= 16° C) was used for the analysis. Most segments within the analysis met or exceeded the requirements for shade within elevation zones. The use of aerial photo interpretation to estimate canopy closure was supplemented with field measurements to estimate canopy closure with canopy densitometer measurements (Table 4D-8). Stream temperature was monitored in 1995 and 1996 in selected areas of the WAU (Table 4D-9).

Surveys were conducted in selected areas to quantify riparian shading. Listed areas that were surveyed can be found in Table 4D-1. 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 W.A. by PCTC.

4D.3.2 RESULTS

Canopy closure in all measured sections met or exceed the Washington model in all but 2 channel segments based on aerial photo analysis. Only segments S2 and P7 do not meet shade requirements of the Washington process. The Segment number, target shade, estimated canopy closure, and actual shade is listed in Table 4D-8.

The Class AA standards for shade and temperature were applied to all perennial waters below 4500 ft. Montana does not have a temperature requirement for streams in the SMZ laws, but does have an indirect shade requirement in the retention of 50% of the trees. This requirement to meet temperature requirements is similar those adopted in the Oregon Forest Practices Act, 1994. Approximately 30 percent of these segments were surveyed for canopy closure using a densitometer. Most segments within the WAU complied with the canopy closure requirements of the manual.

4D.3.2.1 High Shade Impact Channel Segment S2

Section S2 shows signs from the earlier photos that it did not exhibit much for shade cover historically. S2 is probably low naturally but timber harvest has also decreased overall shading of the area. The natural low shading was due to beaver dams and a high make up of deciduous trees within the Squeezer Meadows area. The lower Squeezer Creek thermistor was located above the old road crossing at the downstream end of the diminished canopy area. In two years of monitoring temperature, this area did not exceed the AA class ratings.

4D.3.2.2 High Shade Impact Channel Segment P7

Segment P7's openness is due to harvest in the 1980's though the lower half of P7. A clearcut harvest occurred along one side of the creek with a new channel forming in the cut. There is some potential for LWD recruitment in area, but long-term LWD recruitment and shade is diminished. The P7 segment is below the middle thermistor site and temperatures in this zone were well below the standards. Temperature of the stream at this point did not exceed the AA classification.

4D.3.2.3 High Shade Impact Channel Segment P4.2

Channel segment P4.2 was a unique area in that looking at from aerial photos seemed to meet the criteria of the manual for contain enough canopy closure. P4.2 runs though an area of private cabins. During field surveys of this section there was found many open areas due to clearing for cabin/summer home building on the banks of Piper Creek though the area. The canopy loss in this area is generally along one side of the creek, with canopy removal generally amounting to 100 to 150 ft strips with return to trees. Canopy closure through this area will probably not get better over time due to the cabins along this reach of the creek. Due to the size of the channel in this area, approximately 15 ft, brush probably accounts for most of the shading in this unconfined segment. The lowest thermistor on Piper Creek is below the last cabin along the creek and should be equilibrated by this point. This thermistor remained below 14° C in 1995 and 1996 and the effects of the shade predictive model is not overly evident.

4D.3.2.2 Interpretation of Stream Temperature

Water temperature was measured using Onset Optic StowAway Temperature loggers. These thermistors were set to record temperature every 30 minutes. Ten sites were sampled in the WAU area with Table 4D-9. All temperature probes were put out during high water run off, this causes a problem with Bethel Creek site. It was not in the water when it was retrieved in the fall, and on closer examination of graph it had probably dewatered around 8/4/96. The highest maximum temperature observed was 14.54 degrees in Segment S2 of Squeezer Creek. No Sites within the W.A. exceeded the AA standards in the two years of long term monitoring that occurred.

4D.4 RIPARIAN FUNCTION BY GMU

4D.4.1 GMU 1: SWAN FLOODPLAIN

This GMU is characterized by Riparian Condition Calls of CMD/CLD along its banks with moderate hazard calls due to large CMZ's and sensitivity to LWD inputs within these units. LWD recruitment is from bank erosion and blowdown. LWD functions mostly in jams or large single pieces to provide the habitat. The required canopy closures based on the temperature model from the manual in these areas need to be 50 - 60% or greater to provide adequate shading.

4D.4.2 GMU 2: ENTRENCHED MAINSTEM

This GMU is characterized by Riparian Condition Calls of CMD along its banks with moderate hazard calls due to high sensitivity to LWD inputs. LWD recruitment is from bank erosion and blowdown. LWD is the dominant pool formation feature in this unit. LWD functions mostly in jams and large single pieces to provide the habitat. Required canopy closure in the GMU ranges from 40-50% or greater to provide adequate shading. Ground water upwelling may play a significant role in maintaining stream temperature.

4D.4.3 GMU 3: LOW GRADIENT POOL RIFFLE

This GMU is characterized by mixed conifer/deciduous vegetation with CMD as the dominant call. These areas are associated with the Squeezer Meadows area with its historic signs of beaver activity and large deciduous composition. LWD inputs are from bank erosion, blowdown and movement into area during high flows. LWD functions in jams and singularly and the channel is highly sensitive to its inputs. Required canopy closure in this GMU range from 40-50%. Standard practices may not supply the need long-term LWD due to the potential for channel migration. Ground water upwelling may play a significant role in maintaining stream temperature.

4D.4.4 GMU 4: MODERATE GRADIENT AVULSING

This GMU is characterized by conifer vegetation with CMD/CLD as the dominant call. LWD inputs are from bank erosion and blow down. LWD functions singularly or in jams providing the major source of roughness to the stream. This GMU is sensitive to LWD inputs and LWD is functional about 70% of the time. The riparian hazard call is moderate. Required canopy closure in this GMU range from 30-50%. Standard practices may not supply the need long-term LWD due to the potential for channel migration. Ground water up welling may play a significant role in controlling temperature.

4D.4.5 GMU 5: BRAIDED FLOODPLAIN

This GMU is unique to Piper Creek and is characterized by conifer vegetation (cedar dominant) with CMD/CLD as the dominant call. LWD inputs are from bank erosion, windfall and channel migration. This GMU is highly sensitive to LWD inputs and is the primary pool forming feature in this GMU. Standard practices may not supply the need long-term LWD due to the potential for channel migration. Required canopy closure is from 20-30% in this GMU. Ground water up welling may play a significant role in controlling temperature.

4D.4.6 GMU 6: GLACIAL TROUGH/INCISED MAINSTEM

This GMU is characterized by conifer vegetation with CMD/CLD as the dominant call. LWD inputs are limited due to the structure of the stream which is deeply incised, boulder controlled system. LWD functions secondarily within the system by setting up step pools. These stream sections are low to moderate sensitivity to LWD inputs and have a moderate LWD hazard call. Required canopy closure in this section is 0 to 30 %.

4D.4.7 GMU 7: GROUND MORAINE INTERMITTENT

This GMU was not sampled in the field due to going sub-surface before reaching the main channel. Vegetation within this GMU is mixed with both deciduous and coniferous calls, sizes and density. This is due to management within these segments. LWD functions secondarily within these units due to limited flows. Channel sensitivity to LWD inputs is low and the hazard rating is also low. Required canopy within these units varies from 0 to 40% depending on its location.

4D.4.8 GMU 8: SCARP-SLOPE HEADWATERS

This GMU comprises a large portion of the intermittent channel network in the Goat/Squeezer watersheds. Dominant vegetation call is CSS/CMS/MSS. LWD functions locally to store sediment, and LWD inputs are from bank erosion and limited mass wasting. The channel sensitivity to LWD inputs is moderate and LWD hazard call is low. Required canopy closure is 0% for this GMU due to the elevation based on the model, but standard practices apply. Due to the size of the channel (<3 ft.) most canopy shading is provided by deciduous shrubs.

4D.4.9 GMU 9: CIRQUE HEADWATERS

GMU 9 comprises a large portion of the watershed. Dominant vegetation call is CMS/CMD. LWD functions locally to produce pool habitats, but is controlled by bolder/bedrock stream structure. LWD inputs are from bank erosion and limited mass wasting. The channel sensitivity to LWD inputs is moderate and LWD hazard call is low. Required canopy closure is-0% for this GMU due to the elevation based on the model, but standard practices apply.

4D.4.10 GMU 10: HEADWATERS WITH AVALANCHE

Vegetation in this GMU is predominantly conifer, CMD close to the main Goat and Squeezer channel and often CMS in the upper elevations. LWD functions as sediment traps. LWD enters the GMU primarily from avalanches and bank erosion. Channel sensitivity to LWD is moderate and hazard rating is moderate. Required canopy closure is 0% for this GMU due to the elevation based on the model, but standard practices apply.

4D.4.11 GMU 11: FANS

Vegetation in this GMU is characterized by CMD. LWD functions to trap sediment and slow movement of sediments through the area. Channel sensitivity to LWD is moderate and LWD hazard call is moderate. Standard practices apply for providing stream shade.

4D.4.12 GMU 12: TROUGHWALL CASCADES

Vegetation in this GMU is dominated by CMD/CMS calls. LWD does not function significantly in this GMU due to the channel roughness and steepness with little moveable sediment to store. The LWD sensitivity of the stream is low and the LWD hazard rating is low. Required canopy closure is 0% for this GMU due to the elevation based on the model, but standard practices apply.

4D.4.13 GMU 13: GLACIAL TROUGH ALLUVIAL

Vegetation in this GMU is CMD/CLD. LWD functions in jams to form pools and as sediment traps. LWD sensitivity is moderate and the hazard rating is moderate. The required canopy closure in this GMU is 0-10%, but standard practices apply.

4D.5 CONFIDENCE

Confidence in mainstem LWD and riparian stand conditions is high. Many sites within the W.A. were sampled or walked through to determine their condition. Confidence in tributary/intermittent streams is moderate due to the fewer field inspections that were conducted in these areas.

Confidence in the shade component is high. The canopy densitometer measurements agreed with the aerial photo interpretation of shade along the creek. More than 34% of the segments had field measurements conducted within them. The temperature monitoring within the watershed helped to determine temperature ranges within the Swan Valley. Water temperature measurements helped to determine that temperature requirements are currently being met by riparian areas.

4D.6 DISCUSSION

Since 1991 Montana forest practices rules have required 50 - 100 ft SMZ with retention of 50% of the trees. Harvested riparian stands after the adoption of these laws retained the recruitment potential of the unmanaged stand. Riparian stands that have been harvested are providing adequate protection to stream (Table 4D-9). The only classes where discrepancies were noted between photo classification and field surveys were 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 they will most likely meet the needs of healthy riparian area particularly in moderately confined to confined channel types based on the CMZ, (McGreer, 1994). Examples of these types can be seen in GMU's 6, 9, 11, and 13. The Montana SMZ law does not account well in moderately confined to unconfined channels. These are areas with wider CMZs that standard buffer stips may leave the stream unprotected due to channel migration. GMU's 4 and 5 are examples of these areas where LWD is important and potential for the stream to move is high. Buffer strips within these GMU's need to take the CMZ into account when they are designed.

4D.6.1 LWD RECRUITMENT PROCESSES

The LWD debris recruitment processes in the analysis area are dominated by bank erosion, blowdown, and channel migration. 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 relatively high when compared to Module Diagnostics. The main reasons for high LWD level are probable: low decomposition rates and most runoff events do not move material out of the system. Areas with high LWD are associated with GMU's 2, 4, and 5 these GMU's have also the highest incidences of channel migration.

4D.6.2 CHANNEL MIGRATION ZONE

Channel migration zones in the WAU's are created by the power and the confinement of the stream. In a review of the historic aerial photos there is little evidence of channel movement due to the high canopy closure. 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. Appendix E, The Stream Channel Assessment contains a more detailed breakdown of CMZ and should be looked at for further explanation of the process.

4D.6.3 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 creek. 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. In Table 4D-6 is a breakdown of average DBH and average LWD functional size by segment surveyed. The average DBH of the stands compared favorably with average functional diameter of LWD.

4D.6.4 INTERPRETATIONS OF TEMPERATURE

Continuous monitoring within the W.A. area by PCTC personal has not shown any significant temperature increases. This may be due to the ground water up welling that is common in the Swan Valley. The data from these monitoring sites seem to be representative of each other over the two years that monitoring has occurred. Data from the canopy closure data shows that most segments are in compliance with Washington Standards. These requirements seem to work within the Swan, but further research needs to be conducted on temperature and canopy closure to determine the validity of its use in inter-mountain forests. Ground water up-welling produces a confounding effect within this system. Because of the lack of canopy closure at the lower Squeezer creek site it would be expected to exhibit a much higher water temperature than the rest of the sites. Compared to Lower Goat Creek Site, there is not much difference in temperature. This maybe due to groundwater up-welling, and these zones may have more of an effect on controlling stream temperature than canopy closure in this area.

4D.7 AREAS OF SPECIAL CONCERN AND CMRS

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 WAU in good shape. GMU's 2, 4, and 5 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.

Causal Mechanism Reports were written for Segments P7 (GMU 5) and S2 (GMU 3), and GMU's GMU 1 though 11, and 13, and channel segement 59 and 60 (Section 5, Casual Mechanism Reports)..

4D.8 MONITORING

More research needs to be conducted into adequacy of Montana SMZ Laws to determine if they are adequate and development of additional guidelines if needed. Research and management recommendations include:

1. The development of voluntary guidelines in GMU 3, 4, 5 to address timber management within the CMZs so as to provide for long-term LWD recruitment,
2. Research into LWD debris optimal numbers to develop a better predictive model of for the Rockies,
3. Continuation of temperature monitoring in the WAU,
4. The Development of Montana canopy closure/stream temperature nomogragh,
5. Temperature sampling in shade impacted zones to determine actual effects.

Monitoring recommendations for this area includes looking at long-term temperature monitoring at the established temperature sites in the Swan Watershed Analysis area to track the long term stream temperature. Additional monitoring should include the placement of thermistors within the high shade impact areas to determine how much heating is occurring in these zones.

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APPENDIX A

RIPARIAN FUNCTION MODULE TABLES

Table 4D-1. Riparian Function Sample Locations.

Segment #	GMU	Riparian Strip Validation[1]	In-Stream LWD[2]	CMZ[3]	Canopy Closure[4]	Temperature[5]
Piper Creek						
P4.2	2	N	N	N	Y	Y
P4.3	4	N	Y	Y	Y	N
P5.1	4	N	Y	Y	Y	N
P7	5	Y	Y	Y	Y	Y
P11	6	Y	Y	Y	Y	N
P12	6	Y	Y	Y	Y	N
P13	7	Y	Y	Y	Y	N
P15.2	6	Y	Y	Y	Y	N
P16	6	Y	Y	Y	Y	Y
P28	9	Y	Y	Y	Y	N
Goat Creek						
G1	1	Y	N	N	N	N
G3	2	Y	Y	Y	Y	Y
G4	2	Y	Y	Y	Y	Y
G6	4	N	Y	Y	Y	N
G7	4	N	Y	Y	Y	Y
G8	6	Y	Y	Y	Y	N
G9	6	N	Y	Y	Y	N
G11	13	Y	Y	Y	Y	Y
G20	6	Y	Y	Y	Y	Y
G23	9	Y	Y	Y	Y	N
G36	6	Y	Y	Y	Y	Y
G37	12	Y	Y	Y	Y	N

Segment #	GMU	Riparian Strip Validation[1]	In-Stream LWD[2]	CMZ[3]	Canopy Closure[4]	Temperature[5]
G40	9	Y	Y	Y	Y	N
Squeezer Creek						
S1.2	2	N	Y	Y	Y	N
S2	3	Y	Y	Y	Y	Y
S6	4	N	Y	Y	Y	Y
S8	6	N	Y	Y	Y	N
S11	6	Y	Y	Y	Y	N
S20	9	Y	Y	Y	Y	N

[1] Point-Quarter sampling density estimates, and disturbance calls
[2] Functional and Non-Functional LWD size an location recorded
[3] Average CMZ size recorded
[4] In-stream Canopy closure recorded using spherical densitometers
[5] Long-term temperature monitoring occurred using thermistors

Table 4D-2. 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.

Table 4D-3. Recruitment Potential Ratings.

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

Table 4D-4. Riparian Recruitment Potential, within the Analysis Area.

Stream	Low Recruitment Potential		Moderate Recruitment Potential		High Recruitment Potential	
	Number of Channel Segments	Percent of Total Segments	Number of Channel Segments	Percent of Total Segments	Number of Channel Segments	Percent of Total Segments
Piper	2	6	12	33	22	61
Goat	5	10	7	14	39	76
Squeezer	2	8	4	16	19	76
TOTAL	9	8	25	22	80	70

Table 4D-5 Riparian Condition by segment Piper Creek watershed

Segment	Riparian Condition Codes[1]	LWD Recruit Potential[2]	LWD Channel Rating[3]	LWD Channel Sensitivity[4]	Hazard Rating[5]
P1	CMS	MOD	ON	MOD	MOD
P2	CMD	HIGH	ON	MOD	MOD
P3	CMD	HIGH	ON	MOD	MOD
P4.1	CMD	HIGH	ON	HIGH	MOD
P4.2	CMD	HIGH	ON	HIGH	MOD
P4.3	CMD	HIGH	ON	HIGH	MOD
P5.1	CMD	HIGH	ON	HIGH	MOD
P5.2	CMD/CLD	LOW/MOD	ON	MOD	MOD
P6	CMD	MOD	ON	MOD	MOD
P7A	MSS/CSS	MOD	ON	HIGH	HIGH
P7B	CMD/CLD	HIGH	ON	HIGH	MOD
P8	CMD	HIGH	ON	MOD	MOD
P9	CMD	HIGH	ON	MOD	MOD
P10	CMD	HIGH	ON	MOD	MOD
P11	CMD/CLD	HIGH	ON	MOD	MOD
P12	CMD/CLD	HIGH	ON	MOD	MOD
P13	CMD	HIGH	ON	MOD	MOD
P14	CMD	HIGH	ON	MOD	MOD
P15.1	CMD	HIGH	ON	HIGH	MOD
P15.2	CMD	HIGH	ON	LOW	LOW
P15.3	CMD	HIGH	ON	HIGH	MOD

Segment	Riparian Condition Codes[1]	LWD Recruit Potential[2]	LWD Channel Rating[3]	LWD Channel Sensitivity[4]	Hazard Rating[5]
P15.4	CMD	HIGH	ON	LOW	LOW
P16	CMD	HIGH	ON	LOW	LOW
P17	CMD	HIGH	ON	LOW	LOW
P18	CMD	HIGH	ON	LOW	LOW
P19	CMS	HIGH	ON	LOW	LOW
P20	CMS	MOD	ON	LOW	LOW
P21	CMS	MOD	ON	LOW	LOW
P22	CMS	MOD	ON	LOW	LOW
P23	CMS	MOD	ON	LOW	LOW
P24	CMD	HIGH	ON	LOW	LOW
P25	CMS	MOD	ON	LOW	LOW
P26	CMS	MOD	ON	LOW	LOW
P27	CMS	LOW	ON	LOW	LOW
P28	CMS	MOD	ON	LOW	LOW
P29-40	CMS	MOD	ON	LOW	LOW

[1] Riparian condition codes based on Table 4D-2
[2] Riparian Recruitment Potential based on Table 4D-4
[3] LWD level Based on Table E1 from Stream Channel Assessment Module
[4] Channel Sensitivity Rating from Table E1
[5] Based on matrix in Table 4D-7

Table 4D-5. Riparian Condition by segment Goat Creek watershed

Segment	Riparian Condition Codes[1]	LWD Recruit Potential[2]	LWD Channel Rating[3]	LWD Channel Sensitivity[4]	Hazard Rating[5]
G1	CMD/CLD	HIGH	ON	MOD	MOD
G2	CMD/CLD	HIGH	ON	HIGH	MOD
G3	CMD	HIGH	ON	HIGH	MOD
G4	CMD	HIGH	ON	HIGH	MOD
G5	CMD	HIGH	ON	HIGH	MOD
G6	CMD	HIGH	ON	HIGH	MOD
G7	CMD	HIGH	ON	HIGH	MOD
G8	CMD	HIGH	ON	MOD	MOD
G9	CMD/CLD	HIGH	ON	MOD	MOD
G10	CMD	HIGH	ON	MOD	MOD
G11	CMD	HIGH	ON	HIGH	MOD
G12	CMD	HIGH	ON	HIGH	MOD
G13	CMD	HIGH	ON	LOW	MOD
G14	CMD	HIGH	ON	MOD	MOD
G15	CMD	HIGH	ON	MOD	MOD
G16	CMD	HIGH	ON	MOD	MOD
G17	CMD	HIGH	ON	MOD	MOD
G18	CMD	HIGH	ON	LOW	MOD
G19	CMD	HIGH	ON	MOD	MOD
G20	CMD	HIGH	ON	MOD	MOD
G21	CMD	HIGH	ON	MOD	MOD

Segment	Riparian Condition Codes[1]	LWD Recruit Potential[2]	LWD Channel Rating[3]	LWD Channel Sensitivity[4]	Hazard Rating[5]
G22	CMD	HIGH	ON	MOD	MOD
G23	CMD	HIGH	ON	MOD	MOD
G24-25	CMD	HIGH	ON	MOD	MOD
G26	CMD	HIGH	ON	MOD	MOD
G27-35	CMD	HIGH	ON	MOD	MOD
G36	CMD	HIGH	ON	LOW	MOD
G37	CMD	HIGH	ON	MOD	MOD
G38	>20%	HIGH	ON	MOD	MOD
G39	CMD	HIGH	ON	MOD	MOD
G40	CMD	HIGH	ON	MOD	MOD
G41-42	CMS	MOD	ON	MOD	MOD
G43	CMS	LOW	ON	MOD	MOD
G44	CMS	MOD	ON	MOD	MOD
G45	CMS	MOD	ON	MOD	MOD
G46-49	CMS	MOD	ON	MOD	MOD
G50	CMD	HIGH	ON	MOD	MOD
G52-54[A]					
G55	CMD	HIGH	ON	MOD	MOD
G56	CMD	HIGH	ON	MOD	MOD
G57	CMD/DSS	HIGH/LOW	ON	MOD	MOD
G58	CMS	MOD	ON	MOD	MOD
G59	CMD/CSS	HIGH/LOW	ON	MOD	MOD

Segment	Riparian Condition Codes[1]	LWD Recruit Potential[2]	LWD Channel Rating[3]	LWD Channel Sensitivity[4]	Hazard Rating[5]
G60	CSS/CMS	LOW/MOD	ON	MOD	MOD
G61	CMS	MOD	ON	MOD	MOD
G62	CMS	MOD	ON	MOD	MOD
G63	CMD	HIGH	ON	MOD	MOD
G64-68	CMS	MOD	ON	MOD	MOD
G69	CMS	MOD	ON	MOD	MOD
G70	CMS	MOD	ON	MOD	MOD
G71	CMS	MOD	ON	MOD	MOD
G72	CMD	HIGH	ON	MOD	MOD
G73	CMD	HIGH	ON	MOD	MOD
G74	CMD/CSS	HIGH/LOW	ON	MOD	MOD

[1] Riparian condition codes based on Table 4D-2
[2] Riparian Recruitment Potential based on Table 4D-4
[3] LWD level Based on Table E1 from Stream Channel Assessment Module
[4] Channel Sensitivity Rating from Table E1
[5] Based on matrix in Table 4D-7
[A] G52-54 not classified due going sub-surface and not part of stream network

Table 4D-5. Riparian Condition by segment, Squeezer Creek watershed.

Segment	Riparian Condition Codes[1]	LWD Recruit Potential[2]	LWD Channel Rating[3]	LWD Channel Sensitivity[4]	Hazard Rating[5]
S1.1	CMD	HIGH	ON	HIGH	MOD
S1.2	CMD/CMS	MOD	ON	HIGH	MOD
S2A	MSS	MOD	ON	HIGH	HIGH
S2B	CMS	HIGH	ON	HIGH	MOD
S3	CMD	HIGH	ON	HIGH	MOD
S4	CMD	HIGH	ON	HIGH	MOD
S5	CMD/CLD	HIGH	ON	HIGH	MOD
S6	CMD/CLD	HIGH	ON	HIGH	MOD
S7	CMD/CLD	HIGH	ON	MOD	MOD
S8	CMD/CLD	HIGH	ON	MOD	MOD
S9	CMD	HIGH	ON	MOD	MOD
S10	CMD	HIGH	ON	MOD	MOD
S11	CMD	HIGH	ON	MOD	MOD
S12	CMD	HIGH	ON	MOD	MOD
S13-20	CMD	HIGH	ON	MOD	MOD
S21-23	MMS/CMS	MOD	ON	MOD	MOD
S24-25	CMD/CMS	HIGH	ON	MOD	MOD
S26	CMD	HIGH	ON	MOD	MOD
S27	CMS/CSS	LOW/MOD	ON	MOD	MOD
S28	CSS	LOW	ON	MOD	MOD

Segment	Riparian Condition Codes[1]	LWD Recruit Potential[2]	LWD Channel Rating[3]	LWD Channel Sensitivity[4]	Hazard Rating[5]
S29	CMD	HIGH	ON	MOD	MOD
S30	CLMD/CSS	HIGH/LOW	ON	MOD	MOD
S31-33	CMD	HIGH	ON	MOD	MOD
S34	CMD	HIGH	ON	MOD	MOD
S35	CMS	MOD	MOD	MOD	MOD
S36	CMD	HIGH	ON	MOD	MOD
S37-56	CMD	HIGH	ON	MOD	MOD

[1] Riparian condition codes based on Table 4D-2
[2] Riparian Recruitment Potential based on Table 4D-4
[3] LWD level Based on Table E1 from Stream Channel Assessment Module
[4] Channel Sensitivity Rating from Table E1
[5] Based on matrix in Table 4D-7

Table 4D-6 LWD Recruitment Hazard Call Matrix (LWD Recruitment Potential x Channel Sensitivity).

LWD ON TARGET / LWD OFF TARGET	LOW	MOD	HIGH
LOW	LOW	MOD	HIGH
	LOW	HIGH	HIGH
MOD	LOW	MOD	MOD
	LOW	HIGH	HIGH
HIGH	LOW	MOD	MOD
	LOW	HIGH	HIGH

Table 4D-7. Canopy Closure in the Swan W.A

Stream	Segment Number	Canopy Closure Required	Canopy Closure Estimated	Canopy Closure Actual
Piper	1	60	40-70	-
	2	60	40-70	-
	3	60	40-70	-
	4.1	60	40-70	-
	4.2	50	40-70	64.2
	4.3	50	40-70	78.9
	5.1	50	40-70	78.4
	5.2	40	70-90	-
	7	30	70-90	88.1
	8	30	70-90	-
	9	20	70-90	-
	10	20	70-90	-
	11	30	70-90	88.8
	12	20	70-90	90.7
	13	20	70-90	89.7
	15.1	20	40-70	-
	15.2	10	40-70	75.8
	15.3	10	40-70	-
	15.4	10	40-70	-
Goat	1	60	70-90	-
	2	60	70-90	-
	3	50	40-70	54.2
	4	50	40-70	-
	5	50	70-90	-
	6	40	70-90	-
	7	40	70-90	89.6
	8	40	40-70	-
	9	30-20	40-70	-
	10	20	40-70	-
	11	30	40-70	54.3
	12	10	40-70	-
	20	10	40-70	-
	36	10	40-70	-
Squeezer	1	60	40-70	-
	1.2	60	40-70	62.5
	2	50	40-70	43.1
	3	50	40-70	-
	4	40	70-90	-
	5	40	70-90	-
	6	40	70-90	90.8
	7	30-20	40-70	-
	8	20-10	40-70	-
	36	30-10	70-90	-

Table 4D-8. Swan Watershed Analysis temperature data, 1995 and 1996.

Stream	Channel Segment #	Legal	1995 Max Temp.	1995 3-cay Max	1995 7-day Max	1996 Max Temp.	1996 3-day Max	1996 7-day Max
Bethel Creek	G20	NE1/4 S7, R16W, T23N	n/a	n/a	n/a	12.14*	11.88*	11.2*
Upper Goat Bridge	G36	NE1/4 S7, R16W, T23N	n/a	n/a	n/a	9.63	9.42	9.32
Goat Spawning	G7	E1/2 S10, R17W, T23N	9.8	9.64	9.29	9.8	9.64	9.53
Lower Goat Bridge	G4	NW1/4 S16, R17W, T23N	12.08	11.93	11.33	11.46	11.36	11.06
Lower Goat	G3	SW1/4 S17, R17W, T23N	13.75	13.55	12.89	12.67	12.57	12.29
Upper Squeezer	S6	SE1/4 S27, R17W, T23N	9.39	9.29	9.06	9.24	9.19	9.06
Lower Squeezer	S2	NW1/4 S21, R17W, T23N	13.14	12.99	12.14	14.54	14.28	13.52
Upper Piper	P16	NW1/4 S26, R17W, T22N	n/a	n/a	n/a	11.78	11.57	11.03
Middle Piper	P11	NE1/4 S25, R17W, T22N	11.85	11.8	11.47	12.01	11.85	11.57
Lower Piper	P4.2	NE1/4 S18, R17W, T22N	13.63	13.84	12.88	13.33	13.28	12.88

* = Temperature probe was not in water at time of removal, temperature maximums are based on examination of the temperature graph. and it was deterimed that it probably became exposed to air temperatures around 8/3/96. The Upper Goat Bridge thermistor maxed on 7/31/96 and the max temperature for Bethel was on 8/1/96.

Table 4D-9 Average channel migration zone and riparian wood distribution.

Segment	GMU	Logging in Riparian Area	Avg. CMZ Width per Side	Avg. CMZ		Average Riparian Trees				Canopy Closure %	Avg. Func. Diameter LWD
						> 8 in		< 8 in			
				Left	Right	DBH	Height	DBH	Height		
Squeezer											
S2	3	Y	79	83	75	13.5	57	3.3	23	43.1	6.7
S7	6	Y	56	43	69	16.9	58	4.2	26	90.8	12.3
S11	6	N	61	15	108	15.2	57	4.1	27	74.0	6.2
S20	9	N	1	0	2	13.3	63	4.2	27	93.4	4.6
Goat											
G3	2	Y	57	34	80	15.9	64	4.4	29	54.2	13.0
G11	13	Y	68	23	114	14.9	61	3.2	23	54.3	14.7
G20	6	N	16	15	18	13.4	52	2.6	15	82.7	15.3
G23	9	N	21	19	23	15.2	57	4.5	27	60.3	12.2
G23	9	N	1	1	2	14.7	50	4.0	24	57.8	10.0
G36	6	N	9	3	15	12.9	61	4.0	25	73.7	12.9
G37	12	N	9	5	4	12.7	48	3.6	22	52.2	15.1
G40	9	N	19	23	15	12.8	47	3.2	18	50.1	10.4
Piper											
P4.2	2	Y	26	1	51	16.2	68	3.7	24	64.2	18.1
P7	5	Y	112	160	65	17.8	70	4.3	25	88.1	13.1
P13	7	Y	6	12	1	12.4	62	4.5	31	89.7	4.3
P16	6	N	44	23	65	13.8	61	4.8	27	79.9	8.6

4E CHANNEL CONDITION MODULE

4E.1 INTRODUCTION

This analysis of the Goat, Squeezer and Piper Creek watersheds in the Swan River valley of northwest Montana was conducted using guidelines of a Washington regulatory program known as Watershed Analysis. This process has no statutory standing in Montana, and the results of the analysis are intended to serve as voluntary guidelines or recommendations for best management practices.

4E.1.1 WATERSHED ANALYSIS CRITICAL QUESTIONS

This analysis of stream channels was conducted under guidelines for Version 3.0 of the Standard Methodology for Conducting Watershed Analysis, established under the authority of the Washington Forest Practices Board. The analysis 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.

4E.1.2 ISSUES OF SPECIAL CONCERN

This analysis also addresses concerns regarding stream channel sedimentation raised by Weaver and Fraley (1991), and considers the adequacy of regulations under the Montana Streamside Management Zone Law in locations where stream channel location shifts significantly over time. The process of groundwater upwelling is thought to have a significant effect on bull trout habitat in the study area. The general conceptual character of groundwater upwelling is considered.

4E.1.3 COMPARISON OF EXISTING CLASSIFICATION TO GMU'S DEVELOPED FOR THIS PROJECT

In addition, this analysis compares different approaches to channel classification for management purposes. This analysis designates stream channel response segments on the basis of conditions specific to the Goat, Squeezer and Piper Creek watersheds. These designations are compared to various levels of classification developed for the Swan River ecosystem based on combinations of field surveys and remote sensing (e.g.Whitehorse Associates, 1996; USDA Forest Service, 1995), and to the "stream guilds" proposed by Plum Creek Timber.

4E.2 OVERVIEW OF BASIN GEOMORPHOLOGY

In this section, the fundamental geologic structure and glacial history of the study area is described. Sources for these descriptions include Whitehorse Associates (1996) and interpretation of field observations in the summer of 1996. The underlying geologic structure largely determines the character of stream channels. The geomorphic map units (GMU's) described in a later portion of this report are reference to relate them to large-scale landforms. Major characteristics of the GMU's are summarized in Table 4E-1. Channel segments and field survey sites visited specifically for this assessment are shown on Map 4E-1. The resulting GMU classifications are shown in Map 4E-2.

4E.2.1 SWAN VALLEY GROUND MORAINE

The axis of the Swan Valley is oriented north-south and the Swan River flows northward. The valley is bounded on the east by the mountains of the Swan Range and on the west by the Mission Range. The floor of the Swan Valley is mantled with thick glacial deposits of the continental ice sheet which moved south from present-day Canada twice during the past 100,000 years. These deposits, referred to generally as "Ground Moraine" (Whitehorse Associates, 1996) have been reworked by stream channels over the past 10,000 to 15,000 years following the retreat of the most recent glacial advance. This portion of the Swan Valley is also called the Continental Glacial Valley geologic subsection (Whitehorse Associates, 1996).

Table 4E-1. GMU Characteristics, Goat-Squeezer-Piper Watersheds, Swan Valley, Montana

GMU	Morphology	Flow	Slope (%)	Confine-ment	Bankful Width (ft)	Bankfull Depth (ft)	Lowest Terrace Height (ft)	Average Adjacent Hillslope (%)	LWD Load	Channel Migration Zone	Stream Power Index (Depth x Slope metric)
1--Swan Floodplain	Pool-riffle	Per.	1.5	Unconfined	36	1.5	2.8	0	Moderate	Modest	0.7
2--Entrenched Mainstem	Forced pool-riffle & Plane bed	Per.	1.9	Moderate	25	1.8	2.8	19	High	Modest	1.0
3--Low-gradient Pool-riffle	Pool-riffle	Per.	0.9	Unconfined	28	1.5	2.3	0	Low	Significant	0.4
4--Moderate-gradient Avulsing	Forced pool-riffle & Step-pool	Per.	3.6	Moderate	24	1.6	2.5	43	High	Significant	1.8
5--Braided Floodplain	Braided & FPR & SP	Per.	2.2	Moderate/ Unconfined	25	1.3	2.0	18	High	Significant	1.0
6--Glacial Trough/ Incised Mainstem	Step-pool	Per.	7.9	Confined	20	1.6	2.0	58	Mod. Low	None	3.7
7--Ground Moraine Intermittents	Colluvial	I/E & Per.	--	--	--	--	--	--	--	--	Low
8--Scarp-slope Headwaters	Step-pool & Cascade	Per. & I/E	--	--	--	--	--	--	--	--	Substantial, but no delivery
9--Cirque Headwaters	Cascade & Step pool,	Per.	4-20	Confined	9	1.6	--	--	Mod. Low	Minimal	Mod. High & delivering
10--Headwaters w/Avalanche	Cascade	I/E	>>20	Confined	--	--	--	--	Unknown-Mod. Low?	Minimal	High & delivering
11--Fans	Variable	I/E & Per.	2-8	Variable	--	--	--	--	Mod. Low?	Modest	Variable
12--Trough-wall Cascades	Cascade	I/E & Per.	8-20+	Confined	--	--	--	--	Mod. Low?	None	High & delivering
13--Upper Glacial Trough Alluvial	Forced pool-riffle & Plane bed	Per. & I/E	2.5	Moderate	24	1.8	2.5	45	Mod. Low	Modest	1.4

Stream channels are generally incised at two different scales. Large scale incision that probably occurred as the landscape adjusted to the retreat of glacial ice and when stream power was likely much greater owing to glacial meltwater. This larger-scale channel incision has left modern stream valleys 10's of feet lower than surrounding glacial deposits. More recent incision of incised valley bottoms has occurred, leaving channels bounded by alluvial terraces about 3 to 5 feet high that are rarely flooded in most areas.

Mass wasting in this portion of the landscape is restricted to occasional small-scale shallow rapid landslides on steep slopes adjacent to incised valley bottoms. Slope failures are more likely where the stream channel erodes the base of these slopes. This process does not deliver significant quantities of sediment to stream channels. A greater quantity of sediment is produced from persistent bank erosion of alluvial terraces, augmented by larger-scale erosion of terraces when debris jams form and force the channel to cut a new path. This process is referred to as channel migration. GMU's 1, 2, 3, 4 and 5 generally fit this pattern.

In GMU's 4 and 5, channel migration processes are significantly more intense. These GMU's are located at the boundary where alpine glacial deposits and alluvial fan deposits meet the continental glacial deposits of the Swan Valley. The geomorphic history of this area was dynamic; sediment eroded from alpine glacial valleys would deposit as the channel slope moderated and as it became unconfined by valley walls. This region would have many characteristics of alluvial fans, with braided, shifting channels responding to sediment deposition. As sediment supply declined, channels incised the alluvial materials and became more stable. The concentration of boulders and cobbles was high, limiting the depth of incision, and forcing channels to adjust laterally and frequently overtop their banks.

The location of these channels near the mouths of mountain canyons increases the potential for delivery of coarse sediment from upstream and maintains a high water table from groundwater upwelling. The high water table makes the riparian stands vulnerable to windthrow. Large woody debris recruited to the channel creates sediment storage in the channel, and forces additional lateral adjustment (channel migration), which in turn recruits additional LWD and removes sediment from storage in alluvial terraces. The high concentration of LWD in GMU's 4 and 5 promotes gravel storage in reaches that might otherwise be powerful enough to strip gravel from the bed, leaving a cobble-boulder substrate.

The upper surfaces of the ground moraine deposits in the Swan Valley are laced with mapped channels that are frequently unchanneled swales. These glacial deposits are porous in many areas, and water infiltrates to the water table, inhibiting formation of channels. In some areas, depressions are found and small ponds or wetlands may form. Well-defined intermittent channels are uncommon, and perennial channels in this region are rare. These channels are represented by GMU 7.

Escarpments of the Swan Range are the scarp slope of thrust faults. These escarpments are drained by small steep streams rising on strong, dense Precambrian sedimentary rocks and are mapped as GMU 8. Many of these streams are perennial and are mapped as tributaries to channels of GMU 7. Consequently, in many cases the waters that rise on these slopes ultimately deposit their sediment load on the footslopes joining the escarpment to the Swan Valley ground moraines, and the water infiltrates to the water table. In some cases, there are continuous defined channels linking GMU 8 to GMU 7, and GMU 7 segments may sometimes link to other perennial segments. In general, however, GMU 8 comprises an isolated channel network. GMU 8 was unique to the scarp slopes on the Swan Range escarpment in this analysis, however, a similar channel type may occur on the dip slope of the Mission Range in other areas of the Swan Valley.

4E.2.2 GLACIAL TROUGHS AND ALPINE BASINS

The headwaters of Goat and Squeezer Creeks lie in the Swan Range; the headwaters of Piper Creek lie in the Mission Range. Snow accumulation zones for these glaciers have been described and mapped by Whitehorse Associates (1996) as "Glacial Basins" and "Rockland". Alpine glaciers formed in both ranges and scoured canyons in an east-west orientation. These alpine glaciers reached the Swan Valley and may have merged with continental ice (Whitehorse Associates, 1996). The resulting valley landforms have been called "Glacial Troughs" (Whitehorse Associates, 1996), and the valley floors have been mapped as "Ground Moraine".

The alpine glacial (ground moraine) deposits have been incised by the mainstems of all three streams, a process that undoubtedly transported significant quantities of sediment to the Swan Valley. These streams are mapped in GMU 6, which gradually gives way to GMU's 4 and 5. Given than GMU 6 is incised in glacial deposits, it is possible that streamside landslides could occur, particularly where the channel intersects the toe of slopes. However, no significant landslides of this type were observed in the field, although one was mapped in Piper Creek (Whitehorse Associates, 1996). It should be assumed that GMU 6 is capable of producing significant sediment locally along its banks.

Tributaries to GMU 6 include perennial and intermittent streams draining glacial cirque basins (GMU 9), perennial and intermittent streams that tumble across the steep walls of the glacial troughs from hanging valleys as cascades and falls (GMU 12), and intermittent streams that drain snow avalanche chutes (GMU 10). A small group of channel segments were mapped as fans (GMU 11) which formed on the gentler slopes of the glacial trough floors at the mouths of some tributaries. There may be a larger number of fans than mapped because not all alluvial fans have topographic or morphologic expression that can be detected on maps or aerial photos. This is particularly true in Squeezer Creek, owing to the proximity of avalanche chutes to the valley floor, which has dense forest cover.

GMU 10, headwaters with avalanche, is the channel unit most likely to generate significant quantities of sediment from hillslope mass wasting. The dominant, most persistent process is snow avalanche, which has some capacity to scour stream channels and uproot trees. In some areas, however, these steep channels cross glacial deposits that have remained on trough walls, and there is evidence of shallow rapid landsliding and debris flow initiation from virgin forest sites.

GMU 13 is a unique channel unit formed in Goat Creek below the confluence with Bethel Creek. It has characteristics very similar to GMU 2, but is located in the upper portion of an alpine glacial trough where two major cirque basins intersect. This area appears to be a distinct moraine or outwash deposit that has created valley floor slopes that are much gentler than in channels above or below the deposit. This channel type may occur rarely in the upper reaches of other alpine glacial valleys tributary to the Swan Valley.

4E.3 HISTORIC CHANNEL CONDITIONS

Aerial photography for the Goat, Squeezer, and Piper watersheds was reviewed using a 3x mirror stereoscope to identify channel reaches with evidence of historic change in pattern or process. Photography was available for most areas in private or State of Montana ownership for the years 1955, 1963, 1970, 1984, and 1994. More limited coverage was available for primarily Forest Service lands in the upper watersheds, primarily from 1968 and 1994.

In general, there was virtually no significant change detected in channel position or process over the period of record, which begins at a time when there had been very little forest management activity. This rather surprising result is attributed in part to the limits of scale in aerial photography. This was especially true in these watersheds since riparian forest canopy has remained dense along most streams, limiting the proportion of channel that was visible. In addition, mainstem channels are rarely more than about 25 ft (8 m) wide, which is equivalent to 0.04 in (1 mm) on 1:12,000 scale photography. Finally, the geomorphology of these basins is largely unaffected by significant mass wasting processes, and the hydrologic regime is dominated by spring snowmelt floods which have a more restricted range of peak flows than in rain or rain-on-snow dominated watersheds. Consequently, the scale of channel change is modest, and frequently occurs in areas adjacent to stream channels that are concealed by forest canopy.

From the inspection of the aerial photography of the study area, it was concluded that riparian forest stands have not been heavily harvested in most areas, and that riparian forest stand conditions were good with respect to stream shading function and recruitment of LWD. The latter was demonstrated by the relatively high LWD counts for most surveyed reaches (see Riparian Function assessment). Riparian stands adjacent to a few stream segments have been subject to significant harvest that at least temporarily affected riparian forest function. These are the upper portion of G3, G4 and lower G5, and S2.

It should be noted that there appeared to be systematic increases in channel width and gravel bar frequency in 1994 color photography. This seemed curious because there was no obvious near channel disturbance or mass wasting that delivered significant quantities of sediment thought to be necessary to induce such a channel response. Closer inspection of the photography revealed a likely explanation. The 1994 photography was taken during flights on June 20 when the sun's position created virtually no shadow in stream corridors. All other photography was taken in late summer or early fall, and had significant shading of stream corridors. The hypothesis of channel widening was rejected and attributed to this significant difference in photography which allowed for a much better view of stream channel conditions in 1994 relative to earlier sets of photography.

4E.4 ISSUES OF SPECIAL CONCERN

4E.4.1 CHANNEL SEDIMENTATION

4E.4.1.1 Concerns Raised by Weaver and Fraley (1991)

Research regarding the potential effects of streambed sedimentation on bull trout spawning habitat in the Flathead River Basin was conducted as a portion of a larger multi-factor study regarding effects of management on aquatic resources. Weaver and Fraley (1991) found that emergence of bull trout and westslope cutthroat fry from redds declined as the proportion of sediment < 6.35 mm diameter in spawning gravels increased.

The following discussion examines the portion of Weaver and Fraley's study that deals with bull trout, but it is relevant to the case of westslope cutthroat. They present tabular data summarizing the particle size distribution of actual spawning sites. They next describe experimental mixtures of spawning gravel, and state that the experimental mixtures were designed to be as similar as possible to natural spawning gravels. These two sets of data were not presented in a fashion that allowed direct comparison.

Experimental results were analyzed using linear regression techniques. The number of fry emerging were plotted as a function of the percentage of sediment < 6.35 mm. A statistically significant inverse relationship was found between emergence and percentage of sediment < 6.35 mm. Their experimental result indicates that survival to emergence can be significantly affected by concentration of fine sediment in spawning gravels. The missing context from this result is a discussion of how closely the experimental sediment mixtures resemble the size distributions of natural spawning gravel, as noted above.

Figure 4E-1 shows the size distribution of Weaver and Fraley's experimental mixtures along with subsurface size distributions from Goat Creek (derived from point counts of gravel bars with the surface armor removed). Although these field data are few, they suggest that typical stream gravels have a median grain size closest to that in the experimental mixtures with 30 to 50% of sediment < 6.35 mm. Data from streambed core sampling collected at 29 streams in the Flathead basin (Weaver and Fraley 1991, p. 30) provide additional perspective on typical concentrations of sediment < 6.35 mm (Table 4E-2). These data demonstrate that the range of observed sediment < 6.35 mm is centered between 30% and 40%, with four-fifths of the observations falling between 25% and 40%.

Table 4E-2. Selected statistics regarding sampling distribution for sediment < 6.35 mm diameter, after Weaver and Fraley (1991).

Mean	36.4 %
Std. Dev.	6.1%
Std. Error	1.1%
Maximum	50.3%
Minimum	24.8%
10th Percentile	25%
90th Percentile	40%

Returning to the question of the effect of sediment < 6.35 mm on emergence of fry from redds, it is evident that spawning gravels did not contain less than about 25% sediment finer than 6.35 mm and it only rarely contained more than 40% sediment < 6.35 mm. This suggests that spawning habitat in Flathead basin tributary streams naturally have significant quantities of fine sediment in the range of concentrations that were shown to be associated with decreased emergence success. This indicates that a significant range of emergence success can be expected, independent of management activities and their effects on streambed sediment.

Weaver and Fraley cite monitoring data from West Jim Creek and Lion Creek that suggested that logging causes erosion that can significantly increase the percentage of sediment < 6.35 mm. In the first year following harvest, the mean for sediment < 6.35 mm increased to about 50% from about 41%. An upstream control site was unchanged over the same period. While demonstrating the potential for short-term habitat degradation attributable to logging, this monitoring experiment did not identify sediment sources, the route sediment traveled from disturbed ground surfaces, nor the size distribution of sediment delivered from disturbed areas.

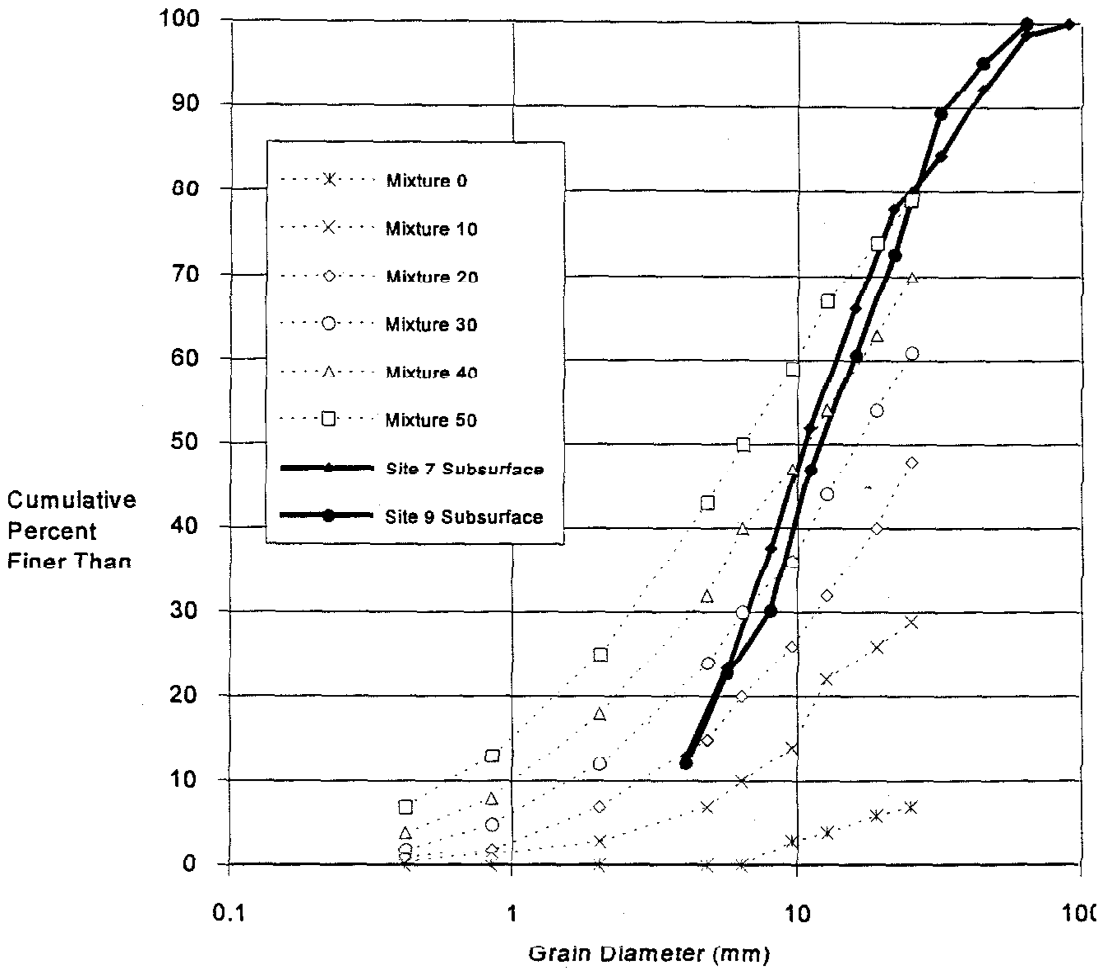

Figure 4E-1. Comparison of grain size distribution of experimental sediment mixtures used by Weaver and Fraley (1991) to subsurface grain size distribution measured at two sites in Goat Creek. Data for "Mixture 0" through "Mixture 50" are those presented by Weaver and Fraley. Data for sites 7 & 9 were collected in the field in August 1996, using a subsurface pebble count technique that has previously been found to produce distributions in reasonable agreement with distributions generated from bulk sampling techniques. The comparison suggests that typical streambed gravel mixtures are comparable to experimental mixtures that have moderate to high amounts of sediment < 6.35 mm.

Both the quantity and size of sediment delivered from management sources needs to be considered in evaluating effects on sediment size distribution on stream beds. Detailed investigation of the harvested area would have been useful in that specific activities or sites are likely to account for management related erosion. In addition, identification of sediment source areas and delivery mechanisms would help determine the sediment grain sizes that reach streams. Road-related disturbance of ground surfaces are often the most significant potential sediment source areas.

Chronic erosion from road surfaces are likely to deliver sediment sizes smaller < 2 mm (Reid and Dunne, 1984). Sediment sizes < 0.5 to 1 mm diameter are typically transported in suspension in gravel bed streams. Consequently, a large proportion of sediment most likely to be delivered from road and other surface erosion will tend to be flushed through the channel network relatively quickly. Sediment sizes between about 2 mm and 6 mm are likely to be transported as bedload, and to be stored in stream channels in significant quantities and requiring longer periods of time to be routed through the channel network (see following section for further discussion).

The quantity of sediment in the fraction between 2 mm and 6.35 mm diameter is likely to be the result of long-term watershed erosion and sedimentation processes that control the production and transport of bedload. This fraction of material represents 0, 7, 13, 18, 22 and 25% of the material in the 0, 10, 20, 30, 40 and 50% mixtures used in Weaver and Fraley's experiments. If it could be demonstrated that this fraction is not very sensitive to forest management, then the suggested potential effects of forest management on spawning habitat would probably be significantly reduced. On the other hand, sediment in this size range delivered to streams would probably be routed downstream slowly, and thus have a relatively persistent effect.

Weaver and Fraley's work suggests that sediment < 6.35 mm would degrade the quality of spawning habitat, and argue that land management (forestry) can be shown to increase streambed sedimentation. While the fundamental substance of their assertion is not disputed, the actual and potential effects of forest management activities on streambed sediment is complex, and requires a more detailed accounting of sediment sources, delivery rates, and transport rates in streams. Important and potentially significant factors not considered by Weaver and Fraley is the size of sediment likely to be delivered from management-related sources, which is probably substantially finer than 6.35 mm. Focusing on specific sediment sources and delivery paths to streams has the potential to allow land managers to improve management practices and reduce the delivery of fine sediment to streams.

4E.4.1.2 Bedload Sediment Storage and Residence Time

In the preceding section, it was suggested that sediment in the 2 to 6 mm size range is likely to be transported as bedload sediment in streams used for spawning by cutthroat and bull trout. In this section, the quantity of sediment and the transport rate of sediment are estimated to provide perspective on the spatial and temporal scales of bedload transport in the study area using lower Goat Creek as a representative case study. This section will show that bedload sediment resides in stream reaches for periods on the orders of centuries and are transported downstream at rates on the order of 10's to 100's of ft per year, implying that changes in streambed conditions related to bedload are, to large extent, controlled by watershed processes occurring over periods of centuries.

4E.4.1.2.1 Definitions and Assumptions

Bedload sediment is transported in contact with streambeds, either rolling or bouncing along the bed, with lengthy periods in storage on the bed or in gravel bars. Bedload sediment ranges in size from 1 to 2 mm up to the largest particles transported, typically cobbles. It has been theorized and demonstrated that bedload of different sizes are entrained and transported at much the same rate, despite differences in size (Parker and Klingeman, 1982, Wilcock 1992, Hassan et al., 1992). This phenomena is sometimes referred to as "equal mobility". If some simplifying assumptions are made regarding the relationship between grain size and transport rate, the total amount of sediment in storage can be compared with estimated or measured transport rates to yield estimates of the residence time and average velocity of bedload in a given stream reach.

Residence time for bedload is an estimate of the average length of time required for an individual particle of gravel to be transported through a specified stream reach. The residence time can be calculated by dividing volume or mass of bedload sediment stored in the reach of interest by the average bedload transport rate for the reach of interest (Dietrich et al. 1982), yielding residence time. The average transport rate for individual clasts of gravel can be computed by dividing the length of the stream reach of interest by the residence time.

For the purposes of this analysis, it is assumed that sediment coarser than about 2 mm is transported as bedload, and that all bedload, regardless of size, is transported at one average rate proportional to unit stream power. This assumption has been shown to be reasonable by tracer studies of bedload transport over a range of stream sizes (Hassan et al. 1992, O'Connor 1994).

Sediment storage in streams channels was measured in several surveyed reaches. This was done by measuring the dimensions of gravel bars and channel bed deposits. Portions of the bed with particularly coarse material were assumed to be essentially immobile; for mainstem reaches of Goat, Squeezer and Piper Creek that were surveyed, sediment clasts coarser than about 128 mm were considered immobile (Whiting and Bradley, 1993). For areas with relatively fine sediment that was obviously transportable, the potential scour depth was estimated. The measured sediment volumes were converted to an average depth of mobile sediment for different surveyed reaches, which can then be used to estimate total storage as a function of channel width and reach length. The nature of these data require that they produce only an estimated minimum quantity of sediment in storage. The estimate is reliable within an order of magnitude, and the possible range of valid estimates is represented by a low and a high estimate for reaches of interest.

In addition, the sediment "reservoir" for which residence time was calculated was defined as the sediment stored in active channel deposits. It was assumed that there is no significant exchange of sediment with terraces. In fact, there is evidence of some significant exchanges of sediment between terraces and active channels in areas where there is a channel migration zone. If these additional volumes of sediment were incorporated with the active channel reservoir, computed residence times would increase significantly. Hence the residence time estimates given below are inherently conservative and probably underestimate true residence times.

4E.4.1.2.2 Sediment Storage and Bedload Transport Estimates

The estimated average depth of mobile sediment (typically < 128 mm) for various surveyed reaches are summarized in Table 4E-3. These data serve as the basis for the high and low range estimates of the quantity of sediment in storage used to estimate residence times and average transport rates.

Table 4E-3. Summary of data used to estimate in-channel sediment storage for residence time computations. Mean depth for GMU 2 & 4 sites combined is given, plus or minus the 95% confidence interval for the mean. Survey sites can be located on Map 4E-1.

Survey Site	GMU	Mean Depth of Mobile Sediment (m)	Mean Bankfull Width (m)	Mobile Sediment Volume per Unit Channel Length (m^3/m)
5	2	0.12	7.7	0.9
9	2	0.13	7.3	0.9
18	2	0.16	7.6	1.2
11	4	0.11	8.6	0.9
19	4	0.07	6.9	0.5
16	4	0.20	8.2	1.6
Mean	**2 & 4**	**0.13 ± .04**	7.7	**0.7 (Low)--1.3 (High)**
12	3	0.34	9.8	3.3
20	5	0.26	7.9	2.1

Sediment transport data were available from a monitoring site on Goat Creek about 1 mile upstream of the confluence with Squeezer Creek. Consequently, the lower mainstem of Goat Creek (segments G3-G7) was chosen to estimate representative residence time for mainstem reaches used by bull trout for spawning. The length of this reach is about 3.3 miles (5300 m), and the mean bankfull width is about 7.7 m. The low range sediment storage estimate is therefore (5300 m) x (7.7 m) x (0.13-0.04 m), or about 3700 m^3. The high range estimate utilizes the upper bound of the 95% confidence interval for depth (0.13 m + 0.04 m), and yields about 6900 m^3.

Bedload transport rates were based on monitoring data for Goat Creek collected by the Flathead National Forest. The low range estimate for bedload was derived from mean annual suspended load for 1987-1991 (USDA Forest Service, 1992), which was reported as 6.7 t/mi^2/yr. Bedload can be estimated as equivalent to 4% of suspended load (Nelson, 1982). For Goat Creek, the mean annual bedload (low range) is about 6 t/yr. For typical bulk density of streambed sediment, this is equivalent to about 12 m^3/yr.

The high range estimate for bedload was based in part on unpublished monitoring data provided by the Flathead National Forest. These data consist of 3 years of intermittent bedload transport sampling, coupled with measurements of stream discharge, which allowed development of a predictive equation for bedload transport as a function of discharge. The original data give bedload transport rates in t/day. The equation,

$$\log(\text{bedload rate}) = 1.41 (\log(\text{discharge}))-2.83,$$

had $p < 0.0007$ and r^2 of 0.41, and predicts bedload transport in units of t/day as a function of mean daily discharge in units of cfs. Based on observed discharge at the sampling station in Goat Creek, and local and regional gaging data (see Hydrology module), the annual spring floods were characterized as having an average discharge of 150 cfs and a duration of 21 days. Using 150 cfs in the equation and computing bedload transport for 21 days of flow yields the high range bedload estimate of about 38 t/yr, or roughly 76 m^3/yr. Although this is a crude estimate, it provides a second, independent basis for estimating residence times; the accuracy required is roughly order-of-magnitude.

Another means of checking on the accuracy of bedload transport estimates is to estimate sediment input rates. A reasonable order-of-magnitude estimate for sediment transport rate is the sediment input rate, which can be computed based on assumed creep rates, stream length and bank height (refer to the Surface Erosion assessment for further discussion). For Goat Creek, the estimated sediment input rate was about 360 t/yr. Assuming that 50% of this material was > 2 mm diameter, and assuming a bedload density of 2 t/m^3, estimated bedload input is about 90 m^3/yr. This is in reasonably good agreement with the high range estimate presented above.

4E.4.1.2.3 Residence Time and Transport Distances

Given the high range and low range estimates for both sediment storage and bedload transport rates above, a range of residence times can be computed. These are summarized in Table 4E-4.

Table 4E-4. Summary of residence time estimates and related quantities for Goat Creek, segments G3-G7. The low range estimate for residence time is the low range estimate for bedload storage divided by the high range estimate for bedload transport rate. The low range estimate for bedload velocity is the reach length (5300 m) divided by the high range estimate for residence time. The "most likely" estimate is based on the high range of bedload storage and the high range for bedload transport.

	Bedload Storage (m^3)	Bedload Transport Rate (m^3/yr)	Residence Time (yr)	Mean Bedload Velocity (m/yr)
Low Range	3700	12	49	9
High Range	6900	76	580	110
Most Likely	6900	76	91	58

Given the likelihood that there is substantial exchange of sediment between the active channel and alluvial terraces because of channel migration, it is likely that the high range estimate for storage is most accurate (but likely underestimated). Given the estimated sediment input rate for the watershed, the high range estimate for bedload transport is probably more reliable. Consequently, a set of "most likely" values for residence time and bedload velocity were also computed.

The significance of these residence times with respect to potential effects of forest management is that any hypothesized inputs of sediment from management sources will be superimposed on a channel system in which bedload supply has evolved over periods of at least several decades. Although short-term changes induced by management may occur, natural fluctuations in long-term watershed processes may mask short-term effects. Moreover, the bedload material in storage on the bed was in all likelihood eroded from the watershed many decades or centuries earlier. Thus, the fundamental character of the bedload stored in the channel (and therefore the quality of spawning habitat) is determined by long-term watershed erosion and sedimentation processes.

The foregoing discussion is not intended to dismiss the hypothesis that land management activities may affect erosion and sedimentation processes, and therefore the quality of spawning gravel. Rather, the intent is to frame the hypothesis in the context of "natural" watershed geomorphology so that the risks to habitat posed by forest management may be appropriately evaluated.

4E.4.2 CHANNEL MIGRATION ZONES

The review of historic aerial photography revealed no significant changes in stream channel width or position. Field observations of channel conditions revealed that there are areas of episodic channel shifts (avulsions) of varying degrees of frequency and intensity in some GMU's. These channel changes are indicated by fresh gravel deposits atop alluvial terraces, braided channels, and overflow channels that are inundated only during peak flow periods or during rare flood events.

In a watershed that is relatively stable geomorphically, the importance of these alluvial channel processes are magnified, particularly with respect to recruitment of LWD to stream channels. LWD in GMU's 4 and 5 is an integral component of stream channels that creates step-pool and forced pool riffle, forms debris jams that accumulate gravel and sometimes force the channel to shift, creating side channels and overflow channels. LWD is important in maintaining spawning habitat by creating a wide range of flow velocities and depths, and by sorting gravel.

LWD also dissipates the stream energy available to transport bedload by creating side channels, contributing to flow resistance, and reducing local channel slope. This is particularly important in GMU 4, where channel gradient is relatively steep and spawning gravels would tend to be transported to lower gradient reaches downstream. These reaches are thought to critical for bull trout spawning because of upwelling groundwater that keeps winter temperatures relatively warm and summer temperatures relatively cool. Loss of adequate spawning gravels from these reaches would likely be detrimental to bull trout populations.

Channel migration and bank erosion appear to be significant processes recruiting LWD to stream channels, particularly those in GMU's 2, 3, 4, 5 and 13. Counts of LWD pieces (>10 cm diameter and > 2 m long) at numerous sites revealed that those GMU's with the highest incidence of channel migration, GMU's 2, 4 and 5, have the highest LWD counts (Figure 4E-2). GMU's 4 and 5, where channel migration is thought to be most frequent, higher proportions of LWD pieces are buried in either the channel bed or the alluvial terrace (Figure 4E-3). This suggests that the channel bed has a greater likelihood of shifting its position, thereby creating greater incidence of buried LWD.

Channel shifts also increase the potential for riparian trees to be recruited to stream channels by bank erosion, form debris jams, and induce further channel shifting. The morphology of this system appears to be governed by positive feedback that creates conditions that tend to reinforce the interactions between LWD, riparian stands, and stream channels. Upwelling groundwater may also play a role in creating soil and microclimatic conditions favorable to red cedar (Dean Siurcek, pers. comm.), a species that is extremely persistent in stream channels because it resists decay.

The Montana Streamside Management Zone Law provides for significant future LWD recruitment to stream channels by retaining at least half of the stems in riparian forest stands. The rules for

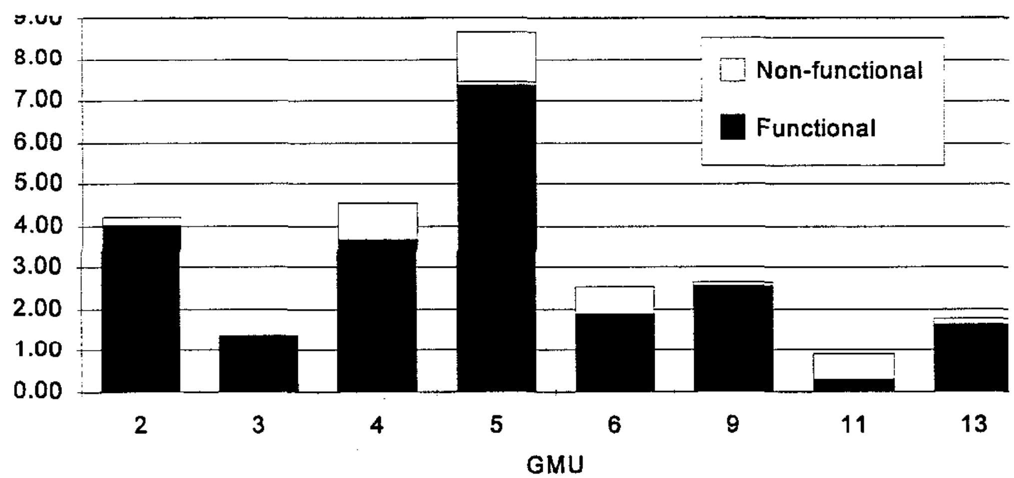

Figure 4E-2. Large woody debris abundance and function in the Goat/Squeezer and Piper Creek watersheds, Swan Valley, Montana. Units are LWD pieces per unit channel length, where length is scaled in terms of bankfull widths. Functional LWD was considered to be LWD that was substantially in contact with the stream at a stage approximately that of the mean annual flood. Scaled in this way, functional LWD counts >2 indicate good habitat conditions for salmonids under State of Washington guidelines.

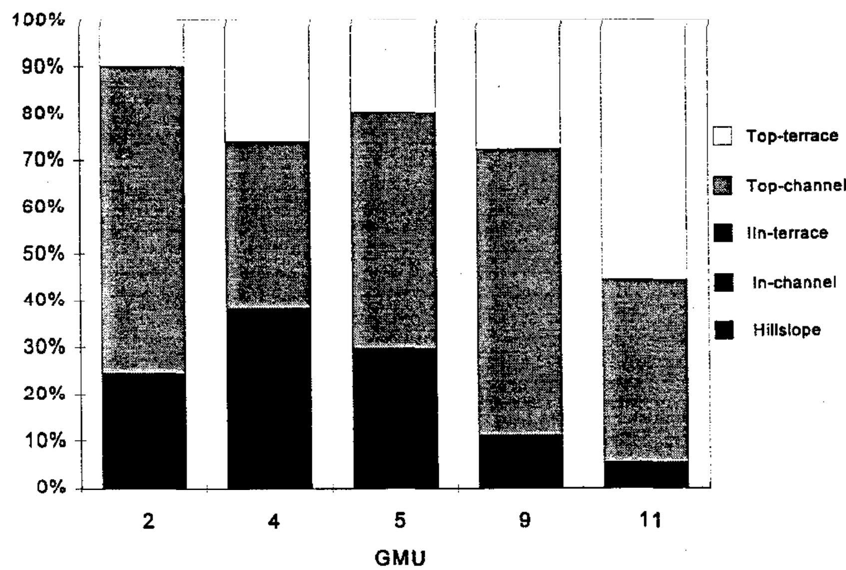

Figure 4E-3. Burial class distribution for large woody debris for selected GMU's inGoat/Squeezer and Piper Creek watersheds, Swan Valley, Montana. In-channel and in-terrace classes are partially-buried in alluvial deposits. Relatively high percentages of buried LWD in GMU's 2, 4 and 5 are interpreted to indicate that channel migration is a significant process, whereas in GMU's 9 and 11, low burial percentages suggest that channel migration is much less significant.

implementation of this law do not recognize channel migration as a process that can significantly change channel position. This creates the potential for harvest in areas that may be a future location of stream channels, and could result in a significant long-term decline in LWD recruitment.

In the Goat, Squeezer and Piper Creek watersheds, the width of active channel migration zones are typically no more that 1 to 2 bankfull channel widths. However, based on field survey data of floodplain widths and heights, potential channel migation zones are wider, typically about 2.5 bankfull channel widths for GMU 2, about 5 bankfull widths for GMU 3 and 4, and about 10 or more bankfull widths for GMU 5. Determination of CMZ width for management purposes should be performed in the field.

Typical configurations of the channel migration zone in GMU 4 is shown in Figure 4E-4. To increase the likelihood that long term LWD recruitment is maintained at levels near pre-management rates under provisions of the Montana Streamside Management Law, it is recommended that channel migration zones are identified in the field and treated like the ordinary high water mark for purposes of implementation. This is similar to the provisions in the law for riparian wetlands, however, areas in the channel migration zone probably will not always meet wetland criteria.

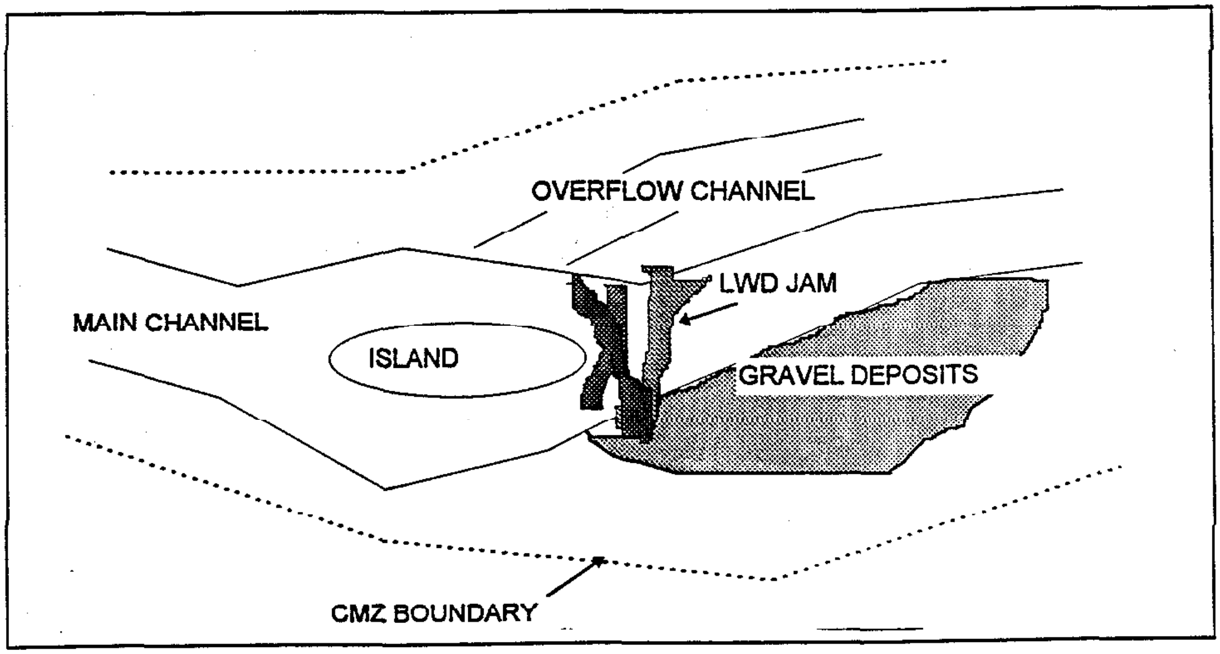

Figure 4E-4. Typical features of channel migration zones as observed in the field (no scale). The dashed line represents a CMZ boundary that might be treated as the equivalent of ordinary high water marks for purposes of implementation of existing Streamside Management Zone rules.

4E.4.3 GROUNDWATER UPWELLING

The proximity of primary bull trout habitat to upwelling groundwater has been hypothesized and demonstrated formally and informally (see Fish Habitat Assessment). In the Swan Valley, areas of over-winter rearing have been identified by surveys of stream channels in winter that locate portions of the stream channels that are not iced over or affected by anchor ice. These areas generally correspond to areas where bull trout prefer to spawn. These conditions are thought to be the direct result of groundwater upwelling that maintain appropriately cool water temperatures in summer and relatively warm temperatures in winter.

In the Goat/Squeezer and Piper watersheds, bull trout spawning is most concentrated in GMU's 4 and 5 (see Fish Habitat module), just downstream of the contact between the Swan Valley ground moraine deposits and the mountain escarpments of the Swan Range and the Mission Range. Relatively intense groundwater upwelling can be expected in these areas for several reasons, including topographic gradients, the character of alpine glacial troughs, and likely subsurface hydraulic gradients on or near floor of the Swan Valley. Figure 4E-5 is a conceptual cartoon of the groundwater system that is likely to exist near the mouth of alpine glacial canyons in the Swan Valley.

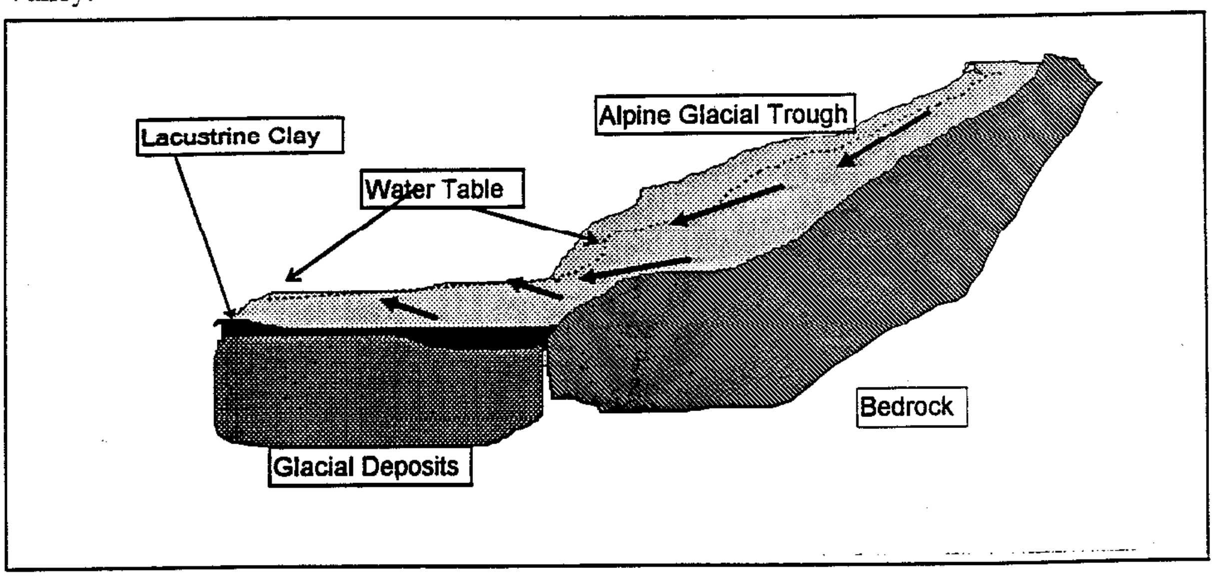

Figure 4E-5. Hypothetical conceptualization of groundwater conditions at the interface between alpine glacial canyons and glacial deposits of the Swan Valley. Dark arrows indicate hypothesized groundwater gradients. Relatively impermeable bedrock of the Swan and Mission Ranges creates a significant aquifer in alpine valleys filled with glacial deposits. Groundwater gradients would be expected to be roughly parallel to the valley floor. Where this groundwater plume intersects with the Swan Valley, it may encounter the Swan Valley water table, or perched water tables created by lenses of glacial lacustrine clay. The alpine groundwater cannot infiltrate already-saturated glacial sediments, and is instead forced to the surface via the streambed gravels.

Layers of lacustrine clay (deposited in glacial lakes), were exposed in the channel bed of Squeezer Creek (segments S2 & S3, survey sites 12 & 14, see Map 4E-1). Taken together with the topography and vegetation of the "Squeezer Meadows" area (T23N R17W Sec. 21), these channel bottom exposures of lacustrine clay suggest a more or less continuous layer of clay that would create a perched water table, forcing alpine groundwater to upwell and to sustain a shallow surface aquifer, rather than infiltrate to a deeper aquifer. This hypothesized shallow groundwater system may help explain the high density of bull trout spawning in this portion of Squeezer Creek (see Fish Habitat assessment for further discussion). In the absence of perched water tables, the upwelling of alpine groundwater would likely be confined to an area near the canyon mouth, where a topographic mound of groundwater supplied by alpine sources can intersect stream beds.

Land management can affect the behavior of aquifers. However, given the likely depth of shallow aquifers in the alpine canyons (probably several meters), the strong seasonal nature of groundwater recharge, and the dispersion of forest management activities in time and space, it is unlikely that current practices would have a significant effect on groundwater conditions in these aquifers. The hypothesized groundwater system described above is quite general, and at present is supported by general principles of geohydrology and reasoning based on observed conditions.

4E. 5 CURRENT CHANNEL CONDITIONS-GMU DESCRIPTIONS

4E.5.1 METHODS

Stream channel surveys were conducted specifically for this module at 38 sites in the WAU. The location of sample sites is displayed on Map E-1. These data were supplemented by survey data collected by the Riparian Function assessment team. Their field data included basic channel geometry and morphology data which could be used to extrapolate GMU 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. Few sites were located in alpine and subalpine headwater areas because of access limitations and because the potential for adverse management is low, in part because of wilderness designation.

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-5 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 GMU's classification are the data in Table 4E-5, riparian and fish habitat data, watershed geomorphic conditions as reflected in topography and historic aerial photographs, and prior classification work (USDA Forest Service, 1995; Whitehorse Associates 1996). The rationale and justification for delineation of GMU's are provided in narrative form in the GMU 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-6.

4E.5.2 GEOMORPHIC MAP UNITS (GMU'S)

The 13 GMU's defined for the Goat, Squeezer and Piper Creek watersheds are described in the following section. A general description of each GMU is accompanied by brief statements identifying the most important factors that determined the sensitivity of each GMU to the following inputs: coarse sediment, fine sediment, peak flows, large woody debris (LWD), catastrophic events, riparian vegetation, and channel migration. A brief statement of regarding the level of confidence associated with the assessment of sensitivities for each GMU. Map 4E-2 displays the location of GMU's in the channel network; specific survey sites in GMU's can be cross-referenced using Map 4E-1 (location) and Table 4E-5 (survey data).

4E.5.2.1 GMU 1: Swan Floodplain

This minor GMU is comprised of short reaches of Goat and Piper Creeks near their confluence with the Swan River. This GMU contains < 1% of channel length in both the Goat/Squeezer and Piper Creek WAU's. Segments in this GMU lie in the Swan River floodplain. Channels are incised in alluvium that has been transported by the Swan River. This GMU is similar to GMU 3, but is more entrenched as has fewer gravel bars. It is distinguished by its position on the Swan floodplain and channel migration zone.

4E.5.2.1.1 Channel Characteristics and Conditions

Channels in GMU are moderately entrenched, with sinuous low gradient channels flowing on alluvial gravel deposited from upstream and recruited locally by bank erosion. Channels are unconfined by valley walls. Erosion and sedimentation processes are moderatly active; at peak flow events the streambed can be mobilized causing bank erosion and resulting in channel migration. Channel morphology is pool-riffle with a few plane bed reaches. Observed slopes in this GMU average 1.5%.

Table 4E-5. Survey data summary for stream channel assessment, Swan Valley, Montana. For description of data and coding refer to the Appendix.

Site	GMU	Channel Type	Channel Slope (%)	SPI BW*BD*S	UNIT SPI BD*Slope	Maximum Slope(	Average Slope(	Channel Confine.	VWBW	BWBD	Valley Width (m)	Bankfull Width (m)	Bankfull Depth (m)	Terrace 1 Ht. (m)	Terrace 2 Ht. (m)	Channel Roughness	Floodplain	Bank Erosion	Streamside Mass Wast	Disturb.	Riparian Stand	Bedrock/ Parent Mat	LWD	LWD per unit length (BW's)	Bars	Mobile Sed Depth (m)	Mobile d50	Roughness Height (cm)	Fine Sed	Length Observed	Observers	Date
35	1	PR	1.5%	7	0.7	0	0	U	00	24.4		11.0	0.45	0.85	1.5	F,W,BK	C	CS	N	R	CMS	M	CMA		FP/F		22		C/A,B/P	300	GS	27-Aug
14	2	FPR	1.3%	7	0.8	65	65	MC	60	14.9	53.6	9.0	0.60	1	1.1	W/F	D	SS	N	L	CM/LD	M	CFA		CF		27	F	MP/B	300	MC&GS	21-Aug
5	2	FPR	1.5%	6	0.6			MC/C	00	14.8		7.7	0.53	1.25	1.95	I/W,C,BK	D	SS	N	L	CMD	N	CFA	1.8	CF/A	0.12	32	13	SP/B	200	MC&GS	19-Aug
[illegible]	2	PB/FF	1.5%	7	0.9	95	45	MC	32	13.2	17.2	7.9	0.60	0.9	1.3	W,F,V	C	SS	SM	L	CMD	N	CFA		CFM		22	5	I/A,P/B	150	MC&GS	19-Aug
16	2	FPR/PI	1.6%	6	1.1	0	0	MC/C	24	7.9	13.2	5.5	0.70	0.8	1.4	WBK,F	D	CS	N	L	CMD	N	CF		CFA		38.5	12	SP	150	MC&GS	21-Aug
[illegible]	2	PB	2.0%	10	1.2	0	0	MC	00	13.3		8.0	0.40			B	D/I	SS	N	N	CMD	A	SM		?				MP/B		MO	29-May
12	2	PB/FPI	2.3%	8	1.0	0	0	U	00	19.7		8.9	0.45	0.65	1.4	F,W	C	CS	N	N	CMD	A	CFA		C/AA		32		CP/B	250	GS	27-Aug
31	2	FPR	2%	7	0.9	0	0					7.8	0.38	0.66		W/F	C	SS	N	L	CMD	A	CFA		CM/A		22		CB/P	250	GS	28-Aug
1	2	FPR/P3	2.5%	10	1.4	90	45	MC	00	13.2		7.3	0.56	0.766667	1.2	WBK,V/F	D	CS	N	L	CMS	A	CFA		CFA	0.13	22	15	MP/B		MC&GS	20-Aug
19	2	FPR	2.2%	9	1.2	0	0	MC	27	13.8	20.9	7.4	0.55	0.9	1.55	W,F/C	C/D	CS	N	N	MMD	A	CFA	3.7	CF		32		S/MP	200	MC&GS	22-Aug
			1.8%	7.0	1.0	31	19		17	13.8	28.3	7.7	0.64	0.90	1.4									2.7		0.13	28	11.3				
																								(3.0 +/- 1.3)								
11	3	PR	0.8%	3	0.4	0	0	U	84	20.7	83.9	9.6	0.47	0.7	1.1	WF,BK/V	C	SS	N	L	MS/MD	M	CFA/R		AF/PM	0.34	19	F	AP/B	500	MC&GS	21-Aug
26	3	PR/B	1.0%	3	0.4	0	0	U	00	18.8		7.1	0.43	0.7	1.1	WF,BK	C	CS	N	N	MSD	M	B/CFA		C/A,M/T/A		22		C/A,P/B	280	GS	27-Aug
			0.9%	3	0.4	0	0		37	19	83	8.4	0.48	0.7	1.1									(2.9 +/- 1.1)		0.34	19					
4	4	FPR	3.0%	7	0.9	0	0	MC/U	00	25.0		7.5	0.3			BK/T,W	D/I	SS	N	N	CMD	A	CF		C/A,F/P				SP/B		MO	29-May
31	4	PB/SP	3.0%	10	1.3	80	54	MC	24	18.1	18.7	7.8	0.43	0.8	1	C,B/W,F	I	CS	N	R	CMD	A	CFA		FF		32	30	SP	300	GS	27-Aug
11	4	FPR/SP	3.3%	17	2.0	85	43	MC	28	14.3	22.1	8.8	0.80	0.95	1.3	W,F - B,W	C	SS	N	L	CMD	A	CFA	6.2	CFA-FF	0.11	22	25	SP	350	MC&GS	20-Aug
13	4	PB/SP	3.3%	12	2.0	90	35	C/MC	20	9.6	11.8	5.9	0.80	0.8	1.8	B,W	D	SS	N	L	MS/MO	A	SF		FF		32	31	MP/B	100	MC&GS	21-Aug
10	4	SP/FPR	3.4%	14	1.7	45	46	MC	00	18.3		8.2	0.50	0.75	1	W,F,C	D	CS	N	L	CMD	A	CF	4.2	CF	0.23	27	18	SP	250	MC&GS	21-Aug
4	4	FPR/SP	4.3%	17	2.4	56	52	MC	38	13.1	27.5	7.2	0.55	0.7	1.2	B/W	D	SS	N	L	CMD	M	AF/DA		CF		22	17	MP/B	250	MC&GS	19-Aug
19	4	SP	4.5%	18	2.3	80	70	MC	11.9	13.8	110.1	6.8	0.50	0.43	1.1	W,F/C	C/D	CS	N	L	CMD	A	CFA	3.5	CF	0.07	38.5	18	MP/B	200	MC&GS	22-Aug
			3.6%	13.2	1.8	66	43		18	16.0	38.0	7.4	0.60	0.76	1.2									4.6		0.14	28	32				
																								(0.9 +/- 0.1)								
27	5	B/FPR/PR	0.8%	3	0.3	40	40	U				9.4	0.37	0.8		I/W,B/BK	C	AS	N	L	CMS	A	CFA		CF		19		C/A,P/B	200	GS	28-Aug
21D	5	FPR/BR	1.4%	4	0.6			MC	10	23.7		8.3	0.35	0.4	0.95	F,W	C	CS	N	L	MD	A	CFA		AM		32		SP/B	80	MC&GS	23-Aug
20	5	SP	2.2%	11	1.4	45	0	MC	11.1	12.5	80.0	7.8	0.63	0.8	0.82	W	C	AS	N	R	CMD	A	ADA	7.3	C/AF	0.16	32	N/A	AP/B	300	MC&GS	22-Aug
22	5	BR/SP	2.6%	8	1.1	20	15	U	1.0	16.0		7.2	0.40	0.6	1	F/BK,W,V	C	CS	N	R	CMD	M	CFA		AM		22		AP/B	100	MC&GS	23-Aug
21U	5	PB/C	3.7%	9	1.5			MC	1.0	14.6		5.9	0.40	0.9		B	D	SS	N	R	CS	A	SFA		FF		32	26	SP	75	MC&GS	23-Aug
			2.2%	6.9	1.0	36	18		16	17.2	80.0	7.7	0.4	0.6	0.9									7.3		0.16	27	29				
																								(8.4)								
7	6	SP	6%	23	3.9	130	65	C	19	8.1	17.6	5.90	0.65	0.85	1.8	B,W	D	SS	N	R	CMD	A	CF		FF		32	34	SP	150	MC&GS	22-Aug
11	6	SP/B	7.0%	32	4.2	90	80	C	17	12.7	20.1	7.6	0.60	0.7	1.3	B,W,F	D	SS		R	CSMD	N	CF,MA		CF		38.5	22	SP/B	300	MC&GS	23-Aug
5	6	SP	8.2%	28	3.3	75	80	C	11	13.7	18.6	8.8	0.63	0.7		B,W	D/I	SS	N	L	CMD	A	CFA		FF	0.02	32	34	SP	200	MC&GS	20-Aug
13	6	SP	8.2%	24	3.1			C	10	15.3		7.8	0.50	0.66	1.6	B/BR	D	N	N	R	CSD	D	SFA		FF		45	38	SP/B	450	MC&GS	23-Aug
18	6	SP	7.3%	14	2.6	100	74	MC	13	15.4	12.1	5.4	0.35	0.55	0.9	C/W,B	C/D	SS	N	R	CMD	A	CFA		C/FF		22	20	SP	300	GS	26-Aug
30	6	SP/R	10.2%	25	4.1	110	90	C	8	15.1	9.8	6.1	0.40	0.8		B,B2,W,R	D	CS	N	L	CMD	M	CFA		FF		22	28	SP/B	200	GS	26-Aug
3	6	C/SF	12.0%	38	8.0	0	0	C/MC	10	12.0		6.0	0.50			B,BK	D/I	SS	N	L	C,SM,D	A	SM		FFS						MO	29-May
29	6	SP/R	12.1%	24	4.9	65	39	MC	6	12.2	7.6	4.9	0.40	0.45	1	B,W	D	SS	N	R	CSD	A	CFA		FF/M		27	35	SP/B	200	GS	26-Aug
			8.2%	26.4	4.0	81	68		18	13.2	14.2	6.8	0.5	0.6	1.3									(2.1 +/-1.1)		0.02	31	30				
13	7	B/FPR	2.3%	1	0.7	0	0	U	1.0	6.6		2.0	0.30			BK,V	C	CS	N	L	MSS	A	SFR	(1.6)	CM				A	50	GS	27-Aug
17	9	SP	5.0%	6	1.5			C	8	13.7	7.2	4.1	0.30	0.4	2.1	B,C	D	CS	N	R	CSS	A	CF,MA		FF	0.18	22	18	SP	50	MC&GS	24-Aug
16	9	SP/I	4.5%	6	1.4			MC	11	11.8	7.8	3.6	0.30	0.35	0.66	F,C,W	C	CS	N	R	CM/SS	M	CFA	1.2	CF/A	0.12	18	9	SP/B	50	MC&GS	24-Aug
			4.8%	6.0	1.4				1.8	12.8	7.4	3.8	0.3	0.4	1.3									(2.2 +/- 0.7)		0.14	20.5	13.6				
15	10	SP/C	18.0%	3	3.8			C	1.8	5.5	2.7	1.1	0.20			B/F,W	D/I	SS	N	R	CMS	A	CFA		CF/I		18	8	SP	75	MC&GS	24-Aug
10	11	SP/PS	9.3%	12	4.2	0	0	C	10	8.7		3.0	0.45	0.7	1.7	W,B,F	D/I	AS	N	D/A	CMD	M	CFA	0.8	FA	0.08	22	11	MP		MC&GS	20-Aug
2	11	C	23.0%	4	5.3	0	0	C/MC	10	3.0		0.7	0.23			B,W,V	I	CS	N	R	CMD	A	CM		FF		16		MP		MO	29-May
			16.1%	8.1	4.7	0.0	0.0		10	4.8		1.9	0.3	0.7	1.7											0.08	19					

Table 4E-6. Goat/Squeezer and Piper Creeks physical channel sensitivity. These sensitivity ratings are modified as warranted by the Fish Habitat assessment when physical criteria are superceded by biological criteria.

GMU	COARSE SEDIMENT	FINE SEDIMENT	PEAK FLOWS	LWD	CATASTRO-PHIC EVENTS	RIPARIAN VEGETATION	CMZ
1--Swan Floodplain	Moderate	Low	Low/Mod.	Moderate	Low	Low/Mod.	Moderate
2--Entrenched Mainstem	Mod./High	Low	Moderate	High	Low	Moderate	Moderate
3--Low-gradient Pool-riffle	High	Moderate	Moderate	High	Low	Mod./High	Moderate
4--Moderate-gradient Avulsion	Mod./High	Low/Mod.	Moderate	High	Low/Mod.	Mod./High	High
5--Braided Floodplain	High	Moderate	Moderate	High	Low	Mod./High	High
6--Glacial Trough/Incised Mainstem	Low/Mod.	Low	Low	Low/Mod.	Low/Mod.	Low	Low
7--Ground Moraine Intermittents	Low/High*	Low/High*	Moderate	Moderate	Low	Mod./High	Low
8--Scarp-slope Headwaters	Moderate	Low	Low/Mod.	Moderate	Low/Mod.	Low/Mod.	Low
9--Cirque Headwaters	Low/Mod	Low/Mod.	Low/Mod.	Low	Low/Mod.	Low	Low/Mod.
10--Headwaters with Avalanche	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Low
11--Fans	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Mod./High
12--Trough-wall Cascades	Low	Low	Low	Low	Low	Low	Low
13--Upper Glacial Trough Alluvial	Mod./High	Low./Mod.	Moderate	High	Low/Mod.	Moderate	Moderate

* Denotes unusual channel conditions where perennial and/or long-duration intermittent flow occurs--salmonids have been observed infrequently in this GMU; most channels in this GMU ephemeral or non-channeled swales where there is insignificant flow and no downstream routing.

Highly-mobile channel substrate is gravel ($d_{50} \approx 22$ mm). Form roughness (gravel bars) and LWD provide the primary form of flow resistance. Banks and vegetation are secondary roughness factors. Bars are relatively uncommon, but are either forced or point bars where present. Fine sediment is abundant and is deposited both in pools and in bars.

This GMU is sensitive to LWD and sediment. LWD is recruited locally and is immobile during all but high peak flows and plays a large role in diverting flows, creating scour pools, and is associated with channel migration.

4E.5.2.1.2 Coarse Sediment

Moderate sensitivity. The relatively low frequency of bars in this GMU suggests that coarse sediment has not tended to accumulate in recent times. Deposition of gravel bars would tend to encourage bank erosion, leading to further bar growth.

4E.5.2.1.3 Fine Sediment

Low sensitivity. Relatively high concentrations of fine sediment in this GMU reflect low gradients and watershed position. In addition, bank material composed of Swan River alluvium is rich in fine sediment. Relatively high fine sediment is expected on the bed in the GMU, and the degree of entrenchment suggests that fine sediment will be flushed out sufficiently during periods of high flow to prevent accumulations that could significantly affect channel form or process.

4E.5.2.1.4 Peak Flows

Low to moderate sensitivity. The relatively fine channel substrate is scourable during peak flows, and channel entrenchment assures concentration of increased flows in the channel, rather than spreading onto a floodplain surface. Downstream grade control is the Swan River, so potential entrenchment due to sustained flow increases is limited.

4E.5.2.1.5 Large Woody Debris

Moderate sensitivity. LWD can form scour pools and induce sediment deposition, and contributes to flow resistance. Few field observations were made in this GMU, but on the basis of channel gradient and sediment characteristics, it is likely that LWD will have significant morphologic effects on the stream channel. Confidence in this sensitivity call is moderate; the greatest uncertainty is the extent to which LWD accumulates in this GMU.

4E.5.2.1.6 Catastrophic Events

Low sensitivity. Mass wasting cannot directly affect this alluvial, valley bottom GMU.

4E.5.2.1.7 Influence of Riparian Vegetation

Low sensitivity. Channels are typically entrenched in gravel-rich alluvium, and the influence of vegetation is on these materials has been observed to be minimal in the Swan Valley according to Dean Sirucek (pers. comm. 1996).

4E.5.2.1.8 Channel Migration Zone

Moderate sensitivity. The relatively strong degree of entrenchment of this GMU suggests that channel migration is not frequent. However, bank materials are erodible, and major changes in channel position could be caused by shifting of the Swan River.

4E.5.2.1.9 Confidence

Moderate confidence. Only one location was visited in the field. Observations of these reaches in aerial photographs suggests that this GMU is relatively consistent in character. Channels with this gradient and substrate typically have relatively predictable characteristics.

4E.5.2.2 GMU 2: Entrenched Mainstem

This GMU encompasses segments in the lower mainstem channels of Piper, Goat, and Squeezer Creeks. These segments lie in relatively-broad alluvial valleys and are moderately entrenched in the valley floor. This GMU contains 5-7 % of the length of the channel network in the Goat-Squeezer and Piper Cr. WAU's.

4E.5.2.2.1 Channel Characteristics and Conditions

Channel segments in this GMU are somewhat incised in old alluvial terraces. In-channel sediment is transported from upstream sources and recruited locally by bank erosion.. The substrate is generally mobile during annual peak flows. This GMU is moderately confined by terraces and, occasionally, valley walls.

Channel morphology is primarily plane bed with some areas of forced pool riffle. LWD in the channel promotes the formation of bars and scour pools and is an important factor determining local morphology. Where LWD is common, forced-pool-riffle morphology is generally dominant. Lack of LWD in the channel however, tends to be associated with plane bed morphology. Channel slope based on field observations averages 1.9%, and ranges from 1.3% to 2.5%.

The more-mobile fraction of the channel substrate is gravel ($d_{50} \approx$ 28mm); the median grain size on the bed is 64-90 mm (coarse gravel and small cobble). Flow resistance is provided by LWD, bed forms (gravel bars), and stream banks. LWD is common in the channel, forming jams, promoting scour, and causing deposition of sediment. Bank erosion is relatively common throughout this GMU. Terraces in this GMU are composed of alluvium and are therefore susceptible to erosion especially where wood is abundant. Bar forms are also common, and are generally forced, alternate, or medial. Fine sediment is commonly found in patches, bars, and pool bottoms.

This GMU is sensitive to wood and sediment. Stream power is low for this GMU. Sediment is transported through this system relatively slowly. LWD in the channel is relatively stable, causing local accumulation of sediment. These accumulations of sediment cause local channel migration and bank erosion.

Occasional side channels are present, indicating some historical channel migration or avulsion. Data on LWD position in the channel indicate relatively high proportions of buried LWD, also suggesting significant historical channel migration. The moderate degree of channel entrenchment, however, suggests that the potential for active channel migration is localized.

4E.5.2.2.2 Coarse Sediment

Moderate to high sensitivity. Increased delivery of coarse sediment to response segments in this GMU are likely to result in temporary deposition of the sediment in bars in the bankfull channel. Increases in the number and size of bars can be expected to result in bank erosion which adds coarse sediment to the channel (a positive feedback cycle). However, the low stream power and moderate entrenchment of this GMU do not allow for large scale channel shifting, mitigating the sensitivity to some degree.

4E.5.2.2.3 Fine Sediment

Low to moderate sensitivity. Fine sediment tends to be temporarily deposited in LWD-related bars and pools as it move downstream. Increased delivery of fine sediment would likely result in increased deposition in pools and bars. However, these increases are unlikely to result in significant changes in channel morphology or processes.

4E.5.2.2.4 Peak Flows

Moderate sensitivity. Observations of the channel bed and channel morphology indicate that sediment composing the stream bed is likely mobilized during peak flows associated with peak snow melt. Analysis of channel hydraulics and sediment transport suggests that although the bed is commonly mobilized, the channel surface tends to be armored by larger, less mobile particles ($q_* \approx 0.13$; Dietrich et al., 1989). Consequently, despite the fact that entrenchment would allow increased flow to be transformed into deeper flow (as opposed to flow spreading on a wide floodplain), and despite the fact that the channel bed is generally mobile, the sensitivity to peak flows is moderated by the degree of armoring of the bed.

4E.5.2.2.5 Large Woody Debris

High sensitivity. The presence or absence of LWD can have a profound influence on reach morphology. Most of these reaches have a plane bed morphology; when LWD is present, these same reaches are likely to develop forced pool-riffle morphology. LWD significantly increases opportunities for pool formation and sediment storage, as well as active floodplain features. Increased LWD would also tend to induce higher rates of bank erosion locally because some LWD will divert flows against streambanks. In general, LWD introduces a certain degree of instability in channel beds, particularly as it is recruited to a channel and is moved to a stable location.

4E.5.2.2.6 Catastrophic Events

Low sensitivity. The mass wasting potential in this GMU is very small as channels rarely impinge on valley walls that could generate small landslides. Streamside mass wasting is of insufficient frequency and size to significantly alter channel morphology.

4E.5.2.2.7 Influence of Riparian Vegetation

Moderate sensitivity. The capacity of channels in this GMU to erode their banks are somewhat inhibited by riparian vegetation, including both shrubs and trees. Vegetation adds root strength, helps armor banks, and help in the establishment of stable side channels and islands.

4E.5.2.2.8 Channel Migration Zone

Moderate sensitivity. Although channels are generally entrenched, there are a significant number of side channels and short braided reaches throughout the GMU, indicating modest channel migration potential.

4E.5.2.2.9 Confidence

High confidence. A high proportion of number of segments and length of GMU were observed. Substantial additional observations were made from roads and historic aerial photographs. Channel form and processes are somewhat variable, and field observations were likely to have encompassed the full range of channel conditions.

4E.5.2.3 GMU 3: Low Gradient Pool Riffle

This GMU is composed of low gradient reaches flowing through unconfined alluvial valleys found in the lower reaches of Squeezer Creek. This GMU has low streampower, is less entrenched, and has more sediment storage in bars and on the channel bed than most other GMU's. The stream network in this GMU comprises about 2% of the stream channel network in the Goat-Squeezer watershed; it does not occur in the Piper Creek watersheds.

4E.5.2.4.1 Channel Characteristics and Conditions

Channel segments in this GMU flow on alluvium transported from upstream sources and recruited locally by channel migration and bank erosion. The active floodplain is continuous and channels are generally unconfined by valley walls or terraces. Erosion and sedimentation processes are highly active. During peak flow events the streambed is mobilized and bank erosion and/or channel migration may occur. Braided channels occur locally; these side channels are generally stabilized by riparian vegetation, including shrubs. Although evidence of recent side-channel formation was not observed, the presence of floodplain sloughs and braided channel reaches indicates that channel migration is an active process.

Channel morphology is pool-riffle with a few plane bed and braided reaches. Alluvial pool riffle morphology is most common in reaches where channel gradient is <1%; observed slopes in this GMU average 0.9%.

Mobile channel substrate is composed of gravels ($d_{50} \approx 19$ mm), finer than elsewhere in the watershed. Median grain size of the entire channel bed was essentially identical to the highly-mobile fraction of channel substrate. Form roughness (gravel bars) was the primary source of flow resistance. LWD, banks, and vegetation are secondary roughness elements, but can be dominant locally. Bars are common channel features; multiple/medial and point bars are the most common type of bar found in this GMU. Fine sediment is very abundant and is deposited in pools, bars and in patches on the channel bed.

GMU 3 can be characterized as a response unit with respect to sediment and wood. This GMU has low stream power and sediment is routed relatively slowly. LWD is recruited locally from riparian forest stands. Recruitment processes include windthrow and bank erosion, and the recruitment zone expands in areas where channel migration occurs. LWD is immobile except during high peak flows, and plays a role in creating scour pools, diverting flows, and is associated with the formation of side channels.

4E.5.2.3.2 Coarse Sediment

High sensitivity. Increased delivery of coarse sediment to response segments in this GMU is likely to result in temporary deposition in bars due to the low stream power of the channel. Increases in the size and number of bars tends to cause channel shifting and bank erosion which in turn causes increased sediment inputs. Consequently, significant increases in coarse sediment load could have significant impacts on channel condition. Given the quantity of sediment stored in bars, the increase in delivery of coarse sediment would need to be concentrated in time and space to affect channel processes.

4E.5.2.3.3 Fine Sediment

Moderate sensitivity. Sediment in the sand size classes are well represented in the bed and bars of this segment. Low stream power per unit width of channel indicated that fine sediment will tend to be deposited to a greater extent than in other GMU's. Sand sized particles comprise a relatively large percentage of the bed material, and significant increases in supply of fine sediment could increase the volume of gravel bars.

4E.5.2.3.4 Peak Flows

Moderate sensitivity. Although these channels store sediment that is easily mobilized during periods of peak flow, peaks flows tend to spread onto a locally-variable floodplain, thereby limiting the potential extent of streambed scour.

4E.5.2.3.4 Large Woody Debris

High sensitivity. Channel beds and banks are composed primarily of mobile sediment that is easily eroded by scour around LWD. The low stream power and unit stream power suggest that any LWD would tend to remain in channels and function to create scour pools and side channels.

4E.5.2.3.5 Catastrophic Events

Low sensitivity. The potential for catastrophic mass wasting in this GMU is very low; there are no adjacent hillslopes with any potential for mass wasting.

4E.5.2.3.6 Influence of Riparian Vegetation

Moderate to high sensitivity. The capacity of channels in this GMU to erode their banks is inhibited by riparian vegetation, including both shrubs and trees. Vegetation adds root strength to bars and islands, as well as providing roughness to slow water and prevent scour.

4E.5.2.3.7 Channel Migration Zone

Moderate sensitivity. There is evidence of secondary side channels within floodplain areas of this GMU, however, those that were observed were not recently formed. Beaver activity appears to contribute to formation of side channels.

4E.5.2.3.8 Confidence

High confidence. Relative to other GMU's a relatively high proportion of number of segments and length of GMU were observed. Substantial additional observations were made from historic aerial photographs. Channel form and processes are relatively consistent in this GMU; field observations were likely to have encompassed the range of channel conditions.

4E.5.2.4 GMU 4: Moderate Gradient Avulsing

Channels in this GMU lie near the geologic contact between mountains of the east and west margins of the Swan Valley and the glacial deposits mantling the Swan Valley. This part of the landscape has probably been more dynamic over time because streams emerging from confined alpine glacial valleys had an opportunity to spread on the gently sloping valley floor. In addition, these streams cut through glacial deposits in the alpine valleys, and at one time carried a high sediment load. In these areas, groundwater draining from the alpine glacial valleys tends to upwell from the channel bed in this GMU. This has a moderating influence in summer and winter, keeping stream temperatures warmer in winter and cooler in summer. This may also contribute to microclimatic and soil conditions that favor cedar. This GMU comprises 2-3% of the channel network in the Goat/Squeezer WAU and 4% in the Piper Creek WAU.

4E.5.2.4.1 Channel Characteristics and Conditions

Channels segments in this GMU are moderately confined by valley walls or terraces, and generally flow on alluvium delivered from upstream sources and recruited locally by bank erosion. Overflow channels on the floodplain are common, and sediment and water are frequently routed into them. Erosion and sedimentation processes are active in these segments, and bank erosion induced by overflow channels and channel migration is significant. Channels in GMU 4 are relatively dynamic, with a relatively wide channel migration zone.

Channel morphology is primarily forced-pool-riffle and step pool with a few short reaches of plane bed. Morphology is largely dependent on the abundance of LWD in the channel. Lack of LWD in these channels tends to promote plane bed features. Where LWD is common, individual pieces promote forced-pool-riffle morphology. When LWD accumulates in jams, step pool morphology develops. Jams are instrumental in creation of side channels and overflow channels. Channel slopes based on field observations ranged from 3 to 4.5%, and averaged 3.6%.

Median grains sizes on the streambed range from (64 to 128 mm) coarse gravel to cobbles. The highly-mobile fraction of the channel bed is gravel ($d_{50} \approx 30$ mm), which accumulates in bars associated with roughness elements. LWD, boulders, and bed forms (gravel bars) provide most of the channel roughness and forced bars are common. Fine sediment however, is relatively sparse in channels indicating that it is generally routed downstream rather than deposited in the channel.

This GMU is sensitive to LWD and sediment. LWD is generally bigger than the carrying capacity of channels in this GMU and therefore either remains in place or is transported a short distance downstream where it may become part of a jam. In either case, LWD provides roughness that helps capture coarse sediment and promotes the formation of steps and pools. Total sediment storage in the active channel is greater than most other GMU's within the WAU.

4E.5.2.4.2 Coarse Sediment

Moderate to high sensitivity. Coarse sediment storage in this GMU is already relatively high. Delivery of additional coarse sediment has the potential to increase bank erosion and induce channel shifting, which would further increase sediment delivery to the reach, creating a positive feedback cycle.

4E.5.2.4.3 Fine Sediment

Low to moderate sensitivity. Fine sediment is generally routed through this GMU and is only infrequently deposited in bars. However, given the degree of roughness in the channel and the ability of the channel to spill out into it's floodplain, significant increases in fine sediment delivery could result in substantial deposition, particularly in overflow and side channels.

4E.5.2.4.4 Peak Flows

Moderate sensitivity. Significant increases in peak flows could rearrange LWD, cause the formation of additional side channels, increase bank erosion, and scour the channel bed. However, the high frequency of overflow channels would reduce the concentration of increased flows.

4E.5.2.4.5 Large Woody Debris

High sensitivity. LWD is a critical component in influencing channel morphology. LWD provides roughness for the formation of steps and pools and creates a capture mechanism for the deposition of coarse sediment. LWD jams are instrumental in creation of overflow and side channels.

4E.5.2.4.6 Catastrophic Events

Low to moderate sensitivity. There is very little potential for mass wasting to deliver coarse sediment to the channel in this GMU. Channels are generally not confined by valley walls and hillslopes average only 45%. However, this GMU is located near the mouths of mountain canyons where it is possible that extraordinary hydrologic events could induce delivery of large volumes of coarse sediment related to mass wasting on alpine canyon walls, or large scale bank erosion.

4E.5.2.4.7 Influence of Riparian Vegetation

Moderate to high sensitivity. Riparian vegetation, primarily trees, can be important in creating and maintaining floodplain features such as side channels and helping anchor LWD structures that extend into the floodplain. In addition, riparian vegetation is important in for recruitment of LWD to channels.

4E.5.2.4.8 Channel Migration Zone

High sensitivity. This GMU has the most active channel migration zone in the WAU, except perhaps for GMU 5. Channel migration is thought to be a major mechanism for recruitment of LWD to the channels, which in turn reinforces the tendency for channel migration or the formation of overflow channels. The loss of this source of LWD has the potential to significantly alter this GMU in the long term. Anticipated channel changes include reduction of the quantity of spawning gravels and pools and a shift in channel morphology to plane bed.

4E.5.2.4.9 Confidence

High confidence. Relative to other GMU's a very high proportion of number of segments and length of GMU were observed. Channel form and processes are moderately variable and field observations were likely to have encompassed the full range of channel conditions.

4E.5.2.5 GMU 5: Braided Floodplain

This GMU is found in Piper Creek above and below the confluence with Moore Creek. These segments lie in low gradient deposition zones in mainstem valleys that flow through accumulated alluvial gravel. GMU 5 is similar to GMU 4 but has a lower gradient and a higher frequency of channel braiding. This GMU is bounded at both downstream and upstream ends by segments of GMU 6. The proximity of this GMU to the former interface between alpine glacial ice and continental glacial ice indicates that complex fluvio-glacial flow patterns were partly responsible for the characteristics of this GMU (and GMU 4). GMU 5 comprises 8% of the channel network length in the Piper Creek WAU and is not found in the Goat-Squeezer WAU.

4E.5.2.5.1 Channel Characteristics and Conditions

Channel segments in this GMU flow through alluvium and glacial deposits, including lacustrine sediment. Deposition at slope transitions from steeper upstream reaches induces fan-like processes and braided channels. Channel substrate is easily scoured and consists primarily of fine gravel. Although typically unconfined, channels are locally constrained on one bank by valley walls.

Channel morphology is complex, including reaches of braided, plane bed, forced-pool-riffle, and step pool. LWD in the channel promotes the formation of bars and scour pools and is generally the dominant factor in morphology. Where LWD is common, forced-pool-riffle and step pool morphology is common. Lack of LWD in the channel, however, will tend to result in plane bed morphology. Braiding is common throughout due to fan-like aggradation and interactions between abundant LWD and peak flow. Channel slope based on field observations averages 2.2%, but is often < 1%.

The substrate is relatively fine where LWD is abundant, but is typically gravel. Relatively mobile patches of gravel had $d_{50} \approx$ 27mm. LWD and bed forms (gravel bars) provide most of the roughness in the channel. LWD is common in the channel and is significant in forming jams, promoting scour, and deposition of sediment. Bank erosion is relatively common throughout the GMU, and is commonly found in areas with braided channels. Bar forms are also very common, and where found are generally forced, alternate, or medial. Fine sediment is abundant and is commonly found in patches, bars, and pool bottoms.

This GMU is regarded as response unit in regard to wood and sediment. Both the stream power index and the unit stream power index are low for this GMU. Sediment is slowly transported through this system due to the low streampower compounded by braided channels and high roughness from LWD. LWD is generally stable, and contributes to formation of braided channels and channel migration.

4E.5.2.5.2 Coarse Sediment

High sensitivity. Increased delivery of coarse sediment to channels in this GMU could result in deposition of the sediment in bars in the bankfull channel that could increase channel migration and bank erosion.

4E.5.2.5.3 Fine Sediment

Moderate sensitivity. Fine sediment is deposited in bars, bed and pools within this GMU and is a substantial portion of the channel bed. Significant increases in fine sediment delivery are likely to result in additional deposition, which could result in somewhat increased bank erosion and channel shifting.

4E.5.2.5.4 Peak Flows

Moderate sensitivity. This GMU is sensitive to the balance between sediment transport and supply. Given the abundance of fines in the channel and bars, increases in peak flows could affect channel condition, causing increased scour and, over time, leading to downcutting in the channel. During peak flows, channels in this GMU are scoured and fine sediment is routed downstream. These sensitivities to peak flows are moderated by the abundance of braided channels and local overbank flow, which would tend to spread peak flows rather than concentrate them.

4E.5.2.5.5 Large Woody Debris

High sensitivity. The presence or absence of LWD can have a profound influence on reach morphology. Some of these reaches have a LWD-controlled step pool morphology; when LWD is absent these same reaches are likely to develop plane bed morphology. LWD significantly increases opportunities for pool formation and sediment storage, as well as active floodplain features. Increased LWD would also tend to induce a higher rate of bank erosion.

4E.5.2.5.6 Catastrophic Events

Low sensitivity. Mass wasting has relatively little potential to deliver sediment to this GMU because the valley bottoms are wide and the channel rarely impinges on valley walls.

4E.5.2.5.7 Influence of Riparian Vegetation

Moderate to high sensitivity. Trees, roots, and shrubs are significant components of banks and can contribute in reducing bank erosion. Trees and brush may also be influential in establishing and maintaining floodplain features such as side channels.

4E.5.2.5.8 Channel Migration Zone

High sensitivity. The frequent presence of braided channels and high flow and overbank channels, and observed active formation of side channels indicate a highly-active channel migration zone. The interaction between LWD, coarse sediment, and peak flow drive the processes responsible for channel migration.

4E.5.2.5.9 Confidence

High confidence. A high proportion of number of segments and length of GMU were observed. Substantial additional observations were made from historic aerial photographs. Channel form and processes are fairly consistent in this GMU and field observations were likely to have encompassed the full range of channel conditions.

4E.5.2.6 GMU 6: Glacial Trough/ Incised Mainstem

Channels in this GMU comprise a significant proportion of Piper (15%) and Goat/Squeezer (10%) WAU channel networks. These channels flow though bedrock-walled troughs formed by alpine glaciers. The valley bottoms have variable glacial deposits, and channels are incised. In some areas the channel floor is bedrock. Channel slope is moderate to steep.

4E.5.2.6.1 Channel Characteristics and Conditions

Channels in this GMU are confined in moderately steep glacial valleys. Large boulders and bedrock are common channel features. Channel morphology is step pool with significant reaches of steeper cascade morphology. Steps are commonly composed of boulders, and occasionally LWD, but bedrock steps also occur. Channels in this GMU are steep with slopes that average 7.9% and range from 6 to 12%.

Roughness (resistance to flow) is primarily provided by boulders and bedrock. Bedrock is a common component of the channel bottom and in places can dominate channel processes. LWD is secondary in providing roughness to the channels. Where LWD is present, it can have a significant influence by creating steps and inducing deposition of mobile sediment. The relatively narrow, incised channels do not recruit LWD efficiently, and the high proportion of boulder and bedrock on channel beds significantly reduce the potential for LWD to form scour pools.

High stream power and confinement in this GMU causes the balance between sediment transport and sediment supply to favor transport. Moreover, there was little apparent sediment supply from bank erosion; banks are typically armored by boulders. There are few bars in this GMU and where they are found they are usually forced by wood and rock. Mobile bar deposits have an average sediment size (d_{50}) of 30 mm and fine sediment is sparse and is usually found either in pools or in the few forced bars.

4E.5.2.6.2 Coarse Sediment

Low to moderate sensitivity. Coarse sediment delivered to this GMU has only a moderate ability to affect the channel condition. Slugs of coarse sediment could accumulate in bars as it is routed downstream. The channel banks in this GMU are generally armored, so significant bank erosion in response to an increase in coarse sediment is not expected.

4E.5.2.6.3 Fine Sediment

Low sensitivity. Fine sediment is quickly routed through this GMU and has very little ability to affect channel processes or condition.

4E.5.2.6.4 Peak Flows

Low sensitivity. Peak flows are confined within an incised channel, and increased flow would tend to increase stream power, rather than spread onto a floodplain. However, the substrate in this GMU is generally protected by surface armor that is scarcely mobile. Peak flows have the ability to rearrange LWD and some sediment, but not to effect major channel change.

4E.5.2.6.5 Large Woody Debris

Low to moderate sensitivity. The ability of LWD to influence channel processes is hampered by the inability of LWD to get into the channel. Where LWD is incorporated in the channel it is generally functional in trapping sediment and setting up steps, but it does not significantly affect physical channel function or condition.

4E.5.2.6.6 Catastrophic Events

Low to moderate sensitivity. Mass wasting is not a common feature in this GMU, but adjacent steep hillslopes mantled with glacial deposits in some locations creates the potential for large pulses of coarse sediment to be delivered to the channel. Hillslope angles can exceed 100% and mass wasting that does occur has a high probability of delivering coarse sediment to the channel.

4E.5.2.6.7 Influence of Riparian Vegetation

Low sensitivity. Riparian vegetation is relatively insignificant in influencing channel process and function.

4E.5.2.6.8 Channel Migration Zone

Low sensitivity. The incised channel condition and armored banks make the channel location on the valley bottom extremely stable, barring unprecedented catastrophic mass wasting.

4E.5.2.6.9 Confidence

Moderate to high confidence. Relative to other GMU's a modest proportion of length of this GMU was observed. Channel form and processes appear to be consistent, but it is possible that field observations were insufficient to have captured uncommon channel conditions. Of interest were areas in upper Squeezer Creek and upper Piper Creek observed on aerial photographs and landscape maps that appeared to have potential or existing delivery of sediment by avalanche runouts and/or streamside landslides in glacial sediments.

4E.5.2.7 GMU 7: Ground Moraine Intermittents

This GMU is composed primarily of non-channeled swales and ephemeral channels mapped as tributaries to Goat, Squeezer, and Piper Creeks. In most cases, these mapped watercourses are not capable of transporting sediment and do not have defined channels. In rare cases, they may have perennial flow. These tributaries generally flow in an east-west direction and typically lose water by infiltration to the water table in glacial deposits at the foot of escarpments of the Mission Range and the Swan Range. These mapped watercoures are, for the most part, relict channels from periods of wetter climate and/or high rates of melt of glacial ice. Segments in this GMU comprise approximately 17% of mapped channel length in the Goat/Squeezer watershed and 22% of mapped channel length in Piper Creek, including a significant intermittent tributary (Moore Creek).

4E.5.2.7.1 Channel Characteristics and Conditions

Channels in this GMU are typically unconfined or undefined. In many cases, they may meet established criteria for defining wetlands. During summer months, most defined channels are dry. During wet months, some watercourses in this GMU may sustain sufficient flow to transport sediment; these are segments G59-G61, G63, and P13-14 (Moore Creek). Channel morphology for those segments with defined channels range from poorly-developed braided channel (site 33, segment G60) to cascade (Moore Creek, segment P13). Channel roughness, where applicable, is primarily in the form of banks, vegetation, and boulders and cobbles.

The only reach of GMU 7 known to have perennial flow and to support resident salmonids is G59 and G60. This apparently-unique reach is significantly different from other segments in GMU 7, but still logically fits the overall criteria for the GMU. Consequently, channel sensitivities for this reach of perennial stream (segments G59 & G60) are treated as a special case of GMU 7. Future management of forest stands near GMU 7 is of concern for fish habitat only in these atypical circumstances.

4E.5.2.7.2 Coarse Sediment

Low sensitivity for poorly-defined channels and swales; high for perennial stream segments. In the case of high sensitivity reaches, delivery of coarse sediment to this GMU will result in deposition In most cases, channels in this GMU do not have excess stream power enough to move or sort coarse sediment.

4E.5.2.7.3 Fine Sediment

Low sensitivity for poorly-defined channels and swales; high for perennial stream segments. In the case of high sensitivity reaches, delivery of fine sediment to this GMU will result in deposition, possibly substantial. Channels in this GMU have limited stream flow and transport capacity, and may not be capable of rapidly flushing fine sediment, which could then accumulate in the channel bed, burying gravel or filling pools.

4E.5.2.7.4 Peak Flows

Moderate sensitivity. Given the abundance of fine sediment in channels and apparent lack of transport capacity, increased peak flows should significantly affect channels in this GMU. Significantly increased flows might be sufficient to erode channels in broad swales. The lack of confinement and ability of flows to spread mitigates the sensitivity to a large extent, and vegetation will resist channel incision.

4E.5.2.7.5 Large Woody Debris

Low sensitivity for unchannel swales; moderate for stream segments with defined channels. LWD that enters channels in this GMU is likely to remain in place. Given the generally limited streamflow in these channels, LWD will generally have a secondary effect on channel conditions.

4E.5.2.7.6 Catastrophic Events

Low sensitivity. Mass wasting potential in this GMU is very low. What potential exists for mass wasting comes primarily through delivery of sediment from upstream sources where there is little evidence of significant mass wasting.

4E.5.2.7.7 Influence of Riparian Vegetation

Moderate sensitivity for unchannel swales; high sensitivity for stream segments with defined channels. Vegetation including grasses and shrubs may prevent some areas of these mapped watercourses from becoming defined channels that transport sediment. In these areas, disturbance of vegetation should be avoided. In defined channels, vegetation including deciduous tress may play an important role in limiting channel incision.

4E.5.2.7.8 Channel Migration Zone

Low sensitivity. These channels and swales have insufficient streamflow to cause channel migration or, in most cases, channel formation.

4E.5.2.7.9 Confidence

Moderate confidence. Channels in this GMU are non-existent or poorly-developed. Only a small number of channels were observed. However, observations of channel conditions over the GMU are only slightly variable and observations likely covered the range of conditions.

4E.5.2.8 GMU 8: Scarp-Slope Headwaters

This GMU is composed of small channels with slopes > 20% draining steep structural breaklands found in the scarp slope geologic district (Whitehorse Associates, 1996). This GMU was not found in the Piper Creek watershed, but was about 13% of the channel network in the Goat/Squeezer watershed. These channels are perennial in many cases, but typically dissipate on the mountain footslopes and give way to the unchanneled swales of GMU 7.

4E.5.2.8.1 Channel Characteristics and Conditions

These small channels are typically < 3 ft (1 m) wide and are confined by valley side walls. Channel morphology is cascade. Although capable of transporting sand and gravel, sediment input was limited. Bedrock is sometimes exposed in the channel bed.

4E.5.2.8.2 Coarse Sediment

Moderate sensitivity. Inputs of coarse sediment would be temporarily deposited in channels, forcing some lateral bank erosion. Gravel size material would likely be routed downstream over moderately-long periods.

4E.5.2.8.3 Fine Sediment

Low sensitivity. Inputs of fine sediment would tend to be routed downstream, however, temporary deposition would be unlikely to significantly affect channel form or process.

4E.5.2.8.4 Peak Flows

Low sensitivity. Seasonal peak runoff is of sufficient magnitude to transport available sediment. Increased peak flow is unlikely to scour channels that have limited sediment supply and bedrock exposures.

4E.5.2.8.5 Large Woody Debris

Moderate sensitivity. LWD is capable of storing sediment in step structures and is likely to reside in place for long periods once recruited to stream channels.

4E.5.2.8.6 Catastrophic Events

Low to moderate sensitivity. Mass wasting events were not observed to affect these channels, either in the field or as seen in aerial photographs. Given the steep adjacent hillslopes and confined channels, however, there is at least some potential for significant effects of mass wasting.

4E.5.2.8.7 Influence of Riparian Vegetation

Low to moderate sensitivity. In some areas, riparian vegetation may strengthen streambanks composed of finer-textured soils, and reduce potential bank erosion.

4E.5.2.8.8 Channel Migration Zone

Low sensitivity. Tight confinement and bedrock prevent channel migration.

4E.5.2.8.9 Confidence

Low to moderate. Few reaches of this GMU were observed in the field, however, topographic maps and aerial photography suggest that there is little significant variation.

4E.5.2.9 GMU 9: Cirque Headwaters

Channels in this GMU comprise a significant proportion (40%) of Piper Creek in the Mission Mountain Wilderness, and are the dominant channel type in the headwaters of Piper Creek. They represent a substantial portion of Goat/Squeezer Creek (14%) channels, and are also located in basin headwaters. They have been classified as cirque-related streams because they drain areas mapped as "alpine glaciated basin" landtypes by Whitehorse Associates (1996) and because they have a large-scale stair-step profile where moderately steep reaches are punctuated by short steep reaches or lakes in the cirque basins.

4E.5.2.9.1 Channel Characteristics and Conditions

These channel segments have slopes that range from 8% to >20%. In the field, slopes of relatively flat reaches were about 5%. Steeper reaches are confined by bedrock valley walls and banks with cobbles and boulders. These reaches have cascade morphology. Lower-gradient reaches, typically 5-8% slope are moderately confined and have step pool morphology where steps are formed by boulders and LWD. Primary roughness elements are boulders and bedrock. These lower gradient reaches have modest stream power, and some coarse sediment accumulates. Median diameter of mobile bedload was about 20 mm. The source of mobile coarse sediment is bank erosion in reaches with finer-textured terrace soils, and snow avalanche and other alpine processes in *GMU 10*.

4E.5.2.9.2 Coarse Sediment

Low to moderate sensitivity. In bedrock and boulder dominated cascade reaches, coarse sediment will not affect channels. In lower gradient reaches, increased delivery of coarse sediment would cause local deposition in bars and limited bank erosion/channel migration in moderately confined areas with finer-textured terrace soils.

4E.5.2.9.3 Fine Sediment

Low to moderate sensitivity. In steep cascade reaches, fine sediment will not accumulate. In lower gradient reaches, increased delivery of fine sediment could result in local deposition in pools. Given relatively low stream power, pool infilling might be somewhat persistent in areas with unusually low gradient or high channel roughness. Bank erosion and/or channel migration in moderately confined reaches with finer-textured terrace soils can deliver fine sediment to this GMU.

4E.5.2.9.4 Peak Flows

Low to moderate sensitivity. Most reaches are dominated by boulders and bedrock, but some lower gradient reaches have more depositional conditions and finer channel substrate that could be vulnerable to increased scour and transport if peak flows increased significantly.

4E.5.2.9.5 Large Woody Debris

Low to moderate sensitivity. Although LWD can be significant locally, the overall character of this GMU is controlled by boulders and bedrock that create cascade and step-pool structures.

4E.5.2.9.6 Catastrophic Events

Low to moderate sensitivity. Although snow avalanches affect tributary streams, most avalanches runout and deposit within the lower reaches of GMU 10, substantially moderating potential disturbance.

4E.5.2.9.7 Influence of Riparian Vegetation

Low to high sensitivity. In steeper reaches dominated by bedrock and boulders, riparian vegetation has little effect on channel structure. In some low gradient areas with lower gradient and finer textured soils, riparian vegetation can be very important to the integrity and stability of banks.

4E.5.2.9.8 Channel Migration Zone

Low to moderate sensitivity. In areas with low channel gradient and finer-textured streambanks, there is limited potential for channel migration, particularly if LWD is abundant.

4E.5.2.9.9 Confidence

Moderate. Although relatively few sites were visited, the position of this GMU in the upper reaches of the watersheds in subalpine settings reduces the likelihood of logging and road building. These upper watershed positions are dominated by resistant beds and coarse material, and the assessment of this GMU addresses the portions of these channels that are sensitive to watershed inputs. Limited field surveys were supplemented by assessments of Forest Service researchers familiar with this channel type (Dean Siurcek, Flathead N.F.).

4E.5.2.10 GMU 10: Headwaters with Avalanche

This GMU comprises 30% of the channel network in the Goat/Squeezer Creek watershed, and are also located in basin headwaters. Channels in this GMU were not found in Piper Creek. These channels have snow accumulation zones along ridge tops near the channel heads, usually in landtypes described as "rockland on oversteepened cirque headwall and alpine ridge" or "extremely steep structural breaklands" (Whitehorse Associates, 1996). As channels descend steep valley walls mapped as the latter landtype above or as "glacial troughwalls", snow avalanche chutes are common, with avalanche runout zones occurring near the valley floor where slope declines over alpine glacial debris. Where deeper soils occur along these channels, typically in lenses of glacial sediments plastered on valley walls in the glacial troughwall landtype, there is potential for shallow rapid mass wasting, including debris flow (e.g. segment S41).

4E.5.2.10.1 Channel Characteristics and Conditions

These channel segments have slopes that range from 8% to >20%; typical slopes calculated from topographic maps are 50% to 70%. Flow is ephemeral, and channel formation on upper slopes is likely related to avalanche. Slopes decline near valley floors, where avalanches typically come to rest. The steep upper reaches are confined by bedrock valley walls, with bedrock and cobbles and boulders forming channel substrate in the avalanche chutes. These reaches have cascade morphology. Lower-gradient reaches usually confined and have step pool and cascade morphology where steps are formed by boulders and LWD. Primary roughness elements are boulders and bedrock. These lower gradient reaches, typically < 8% slope, have modest stream power, and some coarse sediment accumulates. Median diameter of mobile bedload was about 16 mm. The source of mobile coarse sediment is bank erosion in reaches with deeper soils, snow avalanche, gullies near channel heads, and shallow rapid mass wasting. These processes in this GMU are thought to be one of the major sources of sediment delivered from hillslopes under existing watershed conditions.

4E.5.2.10.2 Coarse Sediment

Moderate sensitivity. Reaches in this GMU on mountain footslopes may have enough sediment deposition and substantial areas of banks with erodible materials to anticipate changes in channel conditions if the supply of coarse sediment were to increase significantly. These channels are expected to have episodic delivery of coarse sediment under "natural" conditions.

4E.5.2.10.3 Fine Sediment

Low sensitivity. Channel morphology and hydrology make substantial deposition of fine sediment unlikely, except in association with mass wasting events that will also deposit significant coarse sediment. Fine sediment alone will not significantly affect channel form or processes.

4E.5.2.10.4 Peak Flows

Moderate sensitivity. Sufficient erodible material is present in the channel and in banks in reaches crossing mountain footslopes to anticipate significant potential increases in bank erosion and channel scour if peak flow increases were persistent.

4E.5.2.10.5 Large Woody Debris

Moderate sensitivity. The reaches of this GMU crossing mountain footslopes have significant accumulations of LWD, both from avalanche processes and other causes of tree mortality. LWD functions as sediment storage traps that slow the rate of transport of sediment from source areas to downstream channels, primarily GMU 9 and 6.

4E.5.2.10.6 Catastrophic Events

Moderate sensitivity. Snow avalanches are widespread, but there is little evidence regarding their frequency. Most avalanches deposit on the upper half of the mountain slopes, upstream from the more sensitive reaches on footslopes. Mass wasting potential, including debris flow, also exists in areas with deeper glacial soils on steep slopes.

4E.5.2.10.7 Influence of Riparian Vegetation

Moderate sensitivity. Riparian vegetation along reaches on mountain footslopes probably reduces potential bank erosion.

4E.5.2.10.8 Channel Migration Zone

Low sensitivity. Even in areas with lower channel gradient and finer-textured streambanks, there is limited potential for channel migration owing to channel confinement and slope.

4E.5.2.10.9 Confidence

Moderate. Few sites were visited in the field, but many were inspected on aerial photographs. There are probably some unmapped alluvial fans (GMU 11) at the bottom of GMU 10 segments where slope declines on glacial deposits in valley bottoms. Several were mapped where there was evidence of fan deposits or processes in aerial photographs. Field verification is recommended prior to management activities near GMU 10 segments as they intersect valley floors.

4E.5.2.11 GMU 11: Fans

Alluvial fans of GMU 11 account for 1% of channel length in the Goat/Squeezer watershed. This GMU did not occur in Piper Creek. This GMU occurs where steep headwater streams of GMU 10 encounter valley floors, but not in all cases. Fans were defined where there was some evidence of channel migration, multiple channels, or sudden delivery of avalanche or mass wasting debris. Several unmapped fans may occur at the bottom of GMU 10 segments. Zones of active alluvial fan processes are likely to be a small portion of mapped fan segments. One segment (G12) corresponds to an alluvial fan mapped by Whitehorse Associates (1996). However, channel segments G48 & G49 (GMU 10) also cross an area mapped as alluvial fan, but were not classified in GMU 11. Fans identified from aerial photographs in Squeezer Creek were not mapped by Whitehorse Associates (1996).

4E.5.2.11.1 Channel Characteristics and Conditions

These channels are expected to have a variety of slopes, ranging from <1% to 20%. Their defining characteristic is a sharp decline in slope relative to the upstream reach and sufficient delivery of sediment to develop alluvial fan processes and forms, including braided channels, channel migration and channel avulsion. In some cases, portions of the channel are incised in older fan deposits. Morphology observed in the field included step pool and cascade in incised reaches. Morphology of lower gradient, active alluvial fan reaches probably include forced pool riffle, braided and plane bed and are unconfined to moderately confined.

4E.5.2.11.2 Coarse Sediment

Moderate sensitivity. Coarse sediment delivery to active or incised fan reaches would likely result in channel shifting or bank erosion.

4E.5.2.11.3 Fine Sediment

Low sensitivity. Channel morphology and hydrology make substantial deposition of fine sediment unlikely, except in association with mass wasting events that will also deposit significant coarse sediment. Fine sediment alone will not significantly affect channel form or processes.

4E.5.2.11.4 Peak Flows

Moderate sensitivity. Active alluvial fans will have substantial quantities of erodible channel bed and bank material, however, the prevalence of braided channels reduces the potential for concentration of increased peak flows.

4E.5.2.11.5 Large Woody Debris

Moderate sensitivity. Significant accumulations of LWD, both from avalanche processes and fan processes such as channel migration, function to store sediment, slowing the rate of transport of sediment from source areas to downstream channels, primarily GMU 9 and 6.

4E.5.2.11.6 Catastrophic Events

Moderate sensitivity. Although alluvial fans are typically subject to episodic inputs of coarse material, it appears that avalanches and debris flows in this area do not often deliver material to fans. Upstream deposition of material and subsequent delivery by fluvial processes is the more likely fan-building scenario.

4E.5.2.11.7 Influence of Riparian Vegetation

Moderate sensitivity. Riparian vegetation reduces potential bank erosion.

4E.5.2.11.8 Channel Migration Zone

Moderate sensitivity. Channel migration can be expected in portions of fan segments that are subject to active alluvial fan processes.

4E.5.2.11.9 Confidence

Low to moderate. Segments mapped as GMU 11 were based on either field evidence or aerial photo evidence. There may be several more fan reaches at the bottom of segments in GMU 10 that have not been mapped. Active alluvial fan zones were not observed in the field, but were inferred to occur in areas upstream.

4E.5.2.12 GMU 12: Troughwall Cascades

This GMU comprises about 5% of channels in both Piper and Goat Creeks. It was not recognized in Squeezer Creek. These channels are steep, and include significant waterfalls or high gradient cascades. They occur in locations where alpine glaciers created "hanging valleys"; the streams emerging from these alpine cirque valleys cross very steep terrain to reach mainstem streams below. This GMU is similar to GMU 6, but is steeper and is not deeply incised in glacial deposits.

4E.5.2.12.1 Channel Characteristics and Conditions

These channel segments have slopes that range from 8% to >20%; local slopes may exceed 50%. Flow is perennial, and is fed by alpine cirque lakes. Slopes may decline near valley floors. These segments are confined by bedrock valley walls, with bedrock and cobbles and boulders forming channel substrate, and have cascade morphology. Lower-gradient reaches may have step pool morphology where steps are formed by boulders and LWD. Primary roughness elements are boulders and bedrock. Little accumulation of sediment is anticipated because lakes upstream reduce downstream sediment delivery.

4E.5.2.12.2 Coarse Sediment

Low sensitivity. Low delivery and armored channel beds and banks are unlikely to respond to coarse sediment. High stream power is likely to route material downstream.

4E.5.2.12.3 Fine Sediment

Low sensitivity. Channel morphology and hydrology make substantial deposition of fine sediment unlikely.

4E.5.2.12.4 Peak Flows

Low sensitivity. Generally armored beds and banks are not susceptible to erosion caused be peak flow increases.

4E.5.2.12.5 Large Woody Debris

Low sensitivity. These boulder and bedrock dominated channels do not respond significantly to LWD that may enter the channels. There is little potential to scour pools because the bed contains little mobile sediment, and no significant sediment storage associated with LWD.

4E.5.2.12.6 Catastrophic Events

Low sensitivity. Upstream lakes reduce potential for routing of catastrophic events, and armored beds and banks are not particularly sensitive to any delivered material.

4E.5.2.12.7 Influence of Riparian Vegetation

Low sensitivity. Streambanks are armored by boulders and bedrock.

4E.5.2.12.8 Channel Migration Zone

Low sensitivity. Banks are largely armored, and avulsion is unlikely in confined armored channels.

4E.5.2.12.9 Confidence

Low to moderate. Although these segments were not surveyed, one was observed in the field. Others were observed in aerial photographs.

4E.5.2.13 GMU 13: Upper Glacial Trough Alluvial

There is one segment in Goat Creek (G11) assigned to this GMU; it accounts for 2% of the channel length in the Goat Creek drainage. This area is at the confluence of two cirque valleys, Bethel Creek and upper Goat Creek. This unique GMU located near the head of a glacial trough landform, mapped as "moraine from limestone, 0-20% slope" by Whitehorse Associates (1996), may be an area of glacial recessional outwash. This hypothesis is based on field observations of the valley floor in this area which is hummocky, possibly reflecting erosion by braided outwash channels, as well as the uncompacted character of the material that suggests that these sediments were not overridden by glacial ice. The lower portion of this segment is marked by a sharp break in slope, suggesting the presence of a moraine that may have dammed the valley.

4E.5.2.13.1 Channel Characteristics and Conditions

This GMU is very similar to GMU 2 in most respects. The following describes characteristics and sensitivities that are distinct from GMU 2.

4E.5.2.13.2 Coarse Sediment

Moderate to high sensitivity. The proximity of this channel type to long, steep mountain slopes suggests that there is the potential for significant episodic delivery of coarse sediment produced by mass wasting events. Large pulses of coarse sediment from these potential sources are anticipated to cause local channel aggradation and channel migration or avulsion. Field observations in autumn 1996 revealed that streamflow diminishes to subsurface flow, indicating that the channel is sensitive to aggradation effects.

4E.5.2.13.3 Catastrophic Events

Low to moderate sensitivity. Although there were no observed mass wasting events affecting GMU 13, much of segment G11 is at the foot of steep (90%), long hillslopes on glacial troughwalls that have mass wasting potential.

4E.5.2.13.4 Channel Migration Zone

Moderate sensitivity. There is evidence of channel migration associated with debris jams forcing peak flows to erode new channels in terraces. The potential for mass wasting adds a second potential cause of significant channel migration.

4E.5.2.13.5 Confidence

High. This GMU is rare, and was visited in the field. Its character is very similar to that of GMU 2 as noted above. The chief distinguishing characteristics are related to valley scale geologic features.

4E. 6 COMPARISON OF AQUATIC HABITAT GUILDS TO CHANNEL GEOMORPHIC MAP UNITS

In this section, channel geomorphic map units (GMU's) are compared to aquatic habitat guilds developed by Plum Creek Timber for the Swan Valley (see Fish Habitat assessment). The guilds were developed by overlaying riparian land type classes (RLT's-USDA Forest Service 1995), stream order class, stream flow class (perennial stream were included, intermittents were excluded), and land type classes (Whitehorse Associates, 1996). The guild classification scheme was developed to serve as a tool for identifying fish habitat types for management purposes. There are about 80 guilds that have been classified for the Swan Valley by this method; only 13 GMU's were identified using the Washington methodology. Hence, it is expected that there may be several guilds associated with each GMU.

Comparing GMU classifications with guild classifications is intended to determine the extent to which guilds coincide with GMU's, and the level of confidence with which guilds can be used to predict stream sensitivity to management. Ultimately, it is hoped that the guilds can be used as a first approximation of channel sensitivity in the Swan Valley by extrapolating GMU sensitivity determinations for the Goat/Squeezer and Piper Creek watersheds to guild classes in other portions of the Swan Valley.

Table 4E-7 summarizes the results of comparing guilds with GMU's. Although individual guilds are not uniquely associated with a single GMU, it is evident that each guild is associated with a limited range of GMU's. Moreover, if the GMU's are re-classified into"super-groups" of GMU's with similar geomorphology and sensitivity to management, then it may be possible to assign less specific, but generally consistent channel sensitivity calls on the basis of guild classification. This approach could be largely automated, but would have to be confirmed and corrected as necessary by a person familiar with the criteria of and rationale for the classification scheme, as well as terrain and channels in the Swan Valley. Nevertheless, map classifications are sometimes inconsistent with field conditions. High confidence in assignment of channel sensitivity calls to guilds on the basis of GMU associations can only be attained if field reconnaissance is conducted to verify consistency of channel characteristics with GMU and guild classification.

In the paragraphs below, the relationship between each GMU and the guilds associated with it are discussed. The discussion is organized according to proposed geomorphic super-groups and the guild associations with each GMU. Particular attention is given to guilds that appear in different GMU super-groups with significantly different sensitivity to inputs, and to field and map criteria that might be used to determine the appropriate sensitivity (GMU) classifications.

Table 4E-7. Comparison of GMU classifications to guild classifications. The three components of the guild classifications are riparian land type (RLT), stream order where first and second order streams are classified as "1" and third and fourth order streams are classified as "2", and land type classes are assigned a numeric designation (see Whitehorse Associates, 1996). In the "Segments" column below, the suffix "P" (e.g. S3P) indicates that the specified guild was mapped in a portion of segment S3.

GMU	RLT	ORDER	LAND TYPE	SEGMENTS
1	FL2D	2	7	
2	NL2A	2	7	P4.1, P4.2, S3P
2	FL2C	2	3	G2,G3,G4,G5
2	FL2C	2	7	S1.2, S3P
3	FL2C	2	3	S1.1P
3	FL2C	2	7	S2P
4	NL2A	2	7	P4.3, S4P, S5
4	SL2A	2	7	P5.1, S6
4	SL2B	2	7	G6, G7P
4	SL2B	2	13	G7P
5	MS5A	2	7	P7
5	SL3B	1	7	P12, P15.2
6	MS3A	1	13	G16P
6	MS3A	1	6	G16P
6	MS3B	1	13	G15
6	MS3B	1	7	G36P
6	MS3B	2	7	S9
6	MS5A	2	7	G21
6	NL2A	1	7	P16P
6	SL2A	2	7	P5.2, G22, S7,S8, S10, S11
6	SL2A	1	7	P15.4, P16P
6	SL2B	2	7	G8, G9P, G10P, G20
6	SL2B	2	13	G9P
6	SL2B	1	7	G36P
6	SL3B	2	7	P11
6	SL3B	1	7	P12, P15.2
6	WL5A	1	7	G36P
6	WS5A	1	7	G13
7	MS3B	1	7	P13P
7	SL2A	1	7	P14
9	MS3A	1	6	G23, G27P, S14P, S15, S17P
9	MS3A	1	13	G27P
9	MS3A	1	7	S20P
9	MS3A	1	13	S20P, S13, S14P
9	MS3A	1	11	S16P, S17P
9	MS4A	1	6	G40P, S14P
9	SL2A	1	6	G18P, G27P
9	SL2A	2	7	S12P
9	SL3A	1	6	G39
9	SL5A	1	10	S19P
9	VS3A	1	13	S16P
9	VS4A	1	10	S19P
10	WS5A	1	13	G45P
10	SL5A	1	4	G45P
10	MS4A	1	13	G46P
10	MS4A	1	10	G46P
11	NL2A	2	7	G12
12	MS3B	1	7	G14P
13	NL2A	2	7	G11

There are three proposed super-groups that incorporate almost all of the stream segments to which a guild was attributed in the Goat/Squeezer and Piper Creek watersheds: Ground Moraine, Mountain Front, and Alpine Glacial Trough. These three GMU super-groups contain the vast majority of stream reaches containing potential fish habitat. They are discussed first. Next, significant anomalies in the classification system are described. Finally, two additional super-groups are proposed that do not, except in rare cases, contain potential fish habitat: Intermittent Streams and Avalanche & Fan. While these latter two super-groups do not *generally* have potential fish habitat, they may be useful for management purposes.

4E.6.1 GROUND MORAINE SUPER-GROUP

The Gound Moraine Super-group includes GMU 1, 2 and 3. Geographically, this super-group lies in the main Swan Valley, in areas removed from the zone of contact between the alpine glacial troughs and the ground moraines of the Swan Valley. The geologic materials underlying this super-group are modern alluvium of the Swan River and its tributaries, and the thick and variable moraine deposits associated primarily with continental glaciers that swept through the Swan Valley. GMU's in the Ground Moraine Super-group have similar channel sensitivity, except with respect to fine sediment where GMU 3 has moderate sensitivity.

GMU 1 is associated with the the floodplain of the Swan River, and is thought to have distinctive vegetation and sediment deposits. The only mapped guild in GMU 1 is FL2D-CO2-LTC7. This guild was not associated with any other GMU in the watershed analysis project area. However, the sample size should be regarded as too small to conclude that FL2D-CO2-LTC7 is uniquely associated with GMU 1. Fortunately, GMU 1 is readily recognizable owing to its proximity to the Swan River and the distinctive character of topography and vegetation of the Swan River floodplain, detectable in aerial photography.

GMU 2 is associated with NL2A and FL2C guilds. NL2A-CO2-LTC7 is a guild that appears in GMU's 4, 7, 11 and 13, as well as GMU 2. Except for GMU 7, this group of GMU's have generally similar channel sensitivity. Nevertheless, the high habitat values associated with GMU 4 make it necessary to more carefully evaluate the classification of segments in NL2A-CO2-LTC7. If this guild occurs near the mouth of an alpine glacial trough, it should be tentatively assigned to GMU 4, pending field reconnaissance.

GMU 3 is associated only with FL2C guilds. However, FL2C guilds are also associated with GMU 2. GMU 3 is distinctive for its low channel slope ($\leq$ 1%), extent of sediment deposition on the stream bed, fine grain sizes on the bed, and pool-riffle morphology. This GMU, owing to its low slope, is potentially a response segment more sensitive to changes in inputs to the watershed than GMU 2, and therefore may be worth distinguishing. Consequently, FL2C guilds should be assigned to GMU 3 to avoid understating potential sensitivity, pending field reconnaissance.

4E.6.2 MOUNTAIN FRONT SUPER-GROUP

The Mountain Front Super-group includes GMU's 4 and 5. This super-group is located in the vicinity of the contact between the alpine glacial troughs and the ground moraines of the Swan Valley. The geologic materials underlying this super-group are modern alluvium, and variable glacial deposits including those from both continental and alpine glaciers. GMU's in this super-group have similar channel sensitivity, and are distinguishable from the Ground Moraine Super-group sensitivities primarily by their high sensitivity to channel migration zones.

GMU 4 is associated with NL2A and SL2A & B guilds. NL2A-CO2-LTC7 is a guild that appears in GMU's 2, 7, 11 and 13, as well as GMU 4. Except for GMU 7, this group of GMU's have generally similar channel sensitivity. Nevertheless, the high habitat values associated with GMU 4 make it necessary to more carefully evaluate the classification of segments in NL2A-CO2-LTC7. If this guild occurs near the mouth of an alpine glacial trough, it should be tentatively assigned to GMU 4, pending field reconnaissance.

SL2A-CO2-LTC7, SL2B-CO2-LTC7, and SL2B-CO2-LTC13 are also associated with GMU 4. These guilds are more frequently found in GMU 6, which has much lower sensitivity in general than GMU 4. Consequently, these guilds should be more carefully evaluated and/or field checked for assignment of sensitivity. Again, if these guilds occur near the mouth of an alpine glacial trough, it should be tentatively assigned to GMU 4, pending field reconnaissance.

Some of the key distinguishing field characteristics for GMU 4 are slope of 3 to 5%, forced pool riffle and step pool morphology, a high LWD load and high degree of interaction between LWD, the channel and the channel migration zone, and high density of cedar in the riparian forest stand. In contrast, GMU 2 has little cedar in the riparian zone, the channel slope is 1 to 2.5%, LWD load is more modest, and the channel is more entrenched and interacts to a lesser degree with the floodplain (much less evidence of channel migration). In contrast to GMU 4, GMU 6 has slopes > 5%, channel morphology is dominated by boulders and step pool morphology, with insignificant channel migration.

GMU 5 occurred in the same geologic region as GMU 4, but is somewhat anomalous. GMU 5 contained two guilds: MS5A-CO2-LTC7 and SL3B-CO1-LTC7. Both of these guilds also appear in GMU 6, but in locations in the Swan Range far upstream from the contact zone between alpine and continental glaciers. GMU 5 is distinguished from GMU 4 by lower channel slopes ranging from <1% to nearly 4%, and a channel migration zone that contain more permanent side channels. Sediment deposition tends to be more intense than in GMU 4, and the degree of entrenchment less than in GMU 4. If guilds MS5A-CO2-LTC7 or SL3B-CO1-LTC7 are located in the glacial contact zone, they should be classified in this super-group, tentatively as GMU 5, pending field investigation.

4E.6.3 ALPINE GLACIAL TROUGH SUPER-GROUP

GMU's 6, 9 and 12 are the constitute this super-group. These perennial streams include the mainstem streams flowing down the valleys created by alpine glacial troughs and their tributaries emerging from alpine cirques and cascading down the walls of the troughs. Geologic materials for this group include bedrock, but boulders are often the dominant component of the channel bed, particularly in GMU 6, where the substrate consists primarily of alpine glacial deposits. These GMU's have similar sensitivities to inputs, which are typically low/moderate.

GMU 6 is associated with a relatively large number of guilds, but the most common guilds are of the MS3A & B, SL2A & B and SL3B RLT groups. Other RLT groups represented are WL5A, WS5A, MS5A and NL2A. The groups SL2A & B, SL3B, NL2A, and MS5A have been observed to overlap with GMU's 4 and 5 in the sensitive Mountain Front super-group.

GMU 9 commonly includes RLT groups MS3A and SL2A, which overlap with GMU 6. SL2A is also associated with GMU 4. GMU 9 includes guilds from RLT groups MS4A, SL3A, SL5A, VS3A and VS4A.

Only one guild was found associated with GMU 12: MS3B-CO1-LTC7. The remaining segments were intermittent streams. This small sample size does not facilitate prediction. Refer to the GMU description for GMU 12 to ascertain its salient characteristics.

Geographic location in the watershed is a strong criterion for determining the GMU group which best fits the guilds commonly associated with the Alpine Glacial Trough super-group, as well as the GMU within the super-group. For locations within about 1 mile of the mountain front (and the contact between alpine and contintental glacial deposits), a presumptive assignment should be for Mountain Front super-group until a field determination can be made. For reaches located farther upstream, the presumptive assignment should be for GMU 6 along mainstems and GMU 9 for tributaries.

Land type class "LTC7" is also strongly associated with GMU 6, whereas GMU 9 is rarely associated with LTC7. The primary field criterion distinguishing GMU 6 and GMU 9 is the boulder-dominated step pool morphology which typifies GMU 6. In contrast, GMU 9 frequently has bedrock outcrops in the channel bed, and has a stair-step profile with a signficantly-longer wavelength that creates areas of lower gradients around 5% alternating with cascade reaches with slopes of 10 to 20% or more.

4E.6.4 SIGNIFICANT ANOMALIES

This subsection discusses guilds that were occasionally found associated with GMU's that are atypical. These cases highlight the need for review and revision of GIS-generated guild and/or

GMU assignments by appropriate personnel.

GMU 13 is a low-gradient channel type located in alpine glacial valley that is rare, but potentially of high significance for fish habitat. It is classified in the guild NL2A-CO2-LTC7, which is generally found associated with GMU 2 and GMU 4, which are located in or near the floor of the Swan Valley. GMU 13 is sensitive to inputs, but is surrounded by GMU's of the Alpine Glacial Trough super-group that are not very sensitive to inputs. Where guilds with low channel slope (e.g. NL's and SL's) occur in alpine glacial troughs, an effort should be made to determine their habitat potential.

GMU 5 is unusual, but significant, with respect to fish habitat. Where it was found in Piper Creek, it was classified in guilds that are frequently associated with channels of significantly lower potential habitat value (RLT groups MS5A and SL3B). Given the evidence that the Mountain Front super-group that contains GMU's 4 and 5 is of high habitat value, field reconnaissance of channel segments in this region is warranted to ensure that guild and GMU classifications are consistent with field conditions. In the case of segment P7, the RLT classification (MS5A) appears to have been in error; in the absence of field reconnaissance, such mapping errors are inevitable in any classification system.

GMU 7 typically contains only intermittent streams with very low sensitivity to management, with few exceptions. Some of the streams mapped as intermittent may in fact be spring-fed perennial streams, with significant habitat (e.g. G59 & G60). This case is an unpredictable anomaly discovered by field reconnaissance. Moore Creek below Moore Lake in the Piper Creek watershed (segments P13 & 14) were assigned to GMU 7, but were somewhat anomolous to that GMU. This reach has significant seasonal flow, but consistently goes dry in the summer.

GMU 8 contains stream channels that are mapped as intermittent, and therefore were not associated with guilds. Field observations revealed that a substantial number of these streams were flowing in late summer, but that for the most part the flow infiltrated glacial deposits where these small streams reached the floor of the Swan Valley. There are apparently some exceptions (e.g. G64), where surface flow persists on the Swan Valley floor.

4E.6.5 AVALANCHE AND FAN SUPER-GROUP

This super-group includes GMU's 10 and 11. These GMU's were not mapped in the Piper Creek watershed, located in the dip slope geologic district. However, in other Swan Valley watersheds rising in the Mission Range, these GMU's may exist. In the watershed analysis study area, these GMU's were found only in the Goat/Squeezer drainage. The only segment thought to contain potential fish habitat is G12, which is mapped in GMU 11 (Fans) and in the guild NL2A-CO2-LTC7. This guild is associated with GMU's 2, 4, 7 and 13. Despite the low incidence of mapped fish habitat in GMU 11, fan segments may potentially contain fish habitat. This depends largely on whether fish have access to these stream reaches. Guilds mapped in GMU 10 included MS4A-CO1-LTC10 & LTC13, SL5A-CO1-LTC4, and WS5A-CO1-LTC13.

GMU 10 (steep headwater streams with avalanche and mass wasting potential), and GMU 11 (fans at the mouths of GMU 10 channels where they intersect alpine valley floors), are geomorphically linked and could be managed as a unique stream system. Snow avalanche and rare debris flow events triggered near the heads of GMU 10 channel segments produce sediment and LWD that is eventually deposited in alluvial fans formed where the steep channels intersect flat valley bottoms of the alpine glacial troughs.

Based on aerial photo interpretation and limited field observations, it appeared that only a few active alluvial fans were present, and that most GMU 10 segments did not terminate in significant alluvial fans. Forest cover on the valley floors and mountain footslopes obscured the ground surface where alluvial fans would be expected in most locations. Field reconnaissance would be necessary to determine the degree to which alluvial fan processes are active at the mouth of GMU 10 segments. This level of effort would be warranted when proposed forest management operations are being planned for areas drained by GMU 10. Evidence of active fan building would be a strong indication that mass wasting hazards exist in GMU 10, and appropriate precautions be taken.

4E.6.6 INTERMITTENTS SUPER-GROUP

This super-group contains GMU's 7 and 8. Most of these stream segments are either ephemeral or intermittent; many scarcely have identifiable channels. In most cases, segments in this super-group cannot deliver sediment to reaches with fish habitat, and their management does not affect fish habitat. There are rare cases, identified in the field, where these channels have strong seasonal or even perennial flow, and may potentially deliver sediment to downstream fish habitat. In general, however, this super-group contains channels where effects of management on potential fish habitat are minimal.

4E.6.7 EXTRAPOLATION OF GUILDS TO GMU SUPER-GROUPS

The foregoing analysis revealed that guilds are a useful tool for predicting channel sensitivities to forest management activities (as are GMU classifications). To facilitate extrapolation of guilds classifications to appropriate channel sensitivites ascribed to a GMU, specific GMU's are grouped at a more general level, combining GMU's with similar patterns of channel sensitivity and geologic characteristics into GMU super-groups. Guilds classification provides reasonably consistent predictions regarding which GMU super-group a given stream segment would best fit. These patterns of association are summarized in Table 4E-8.

Table 4E-8. Observed occurrence of habitat guilds in GMU super-groups. All possible combinations of GMU's and guilds found in the Swan Valley ecosystem are not necessarily represented in this study area. "*" indicates guilds where field verification is warranted to avoid significant mis-classification.

GMU SUPER GROUP (GMU'S)	GUILD CLASSIFICATION			ASSOCIATED GMU'S	
	Riparian Land Type Class	Stream Order Class	Land Type Class	Within Super-group	In Other Super-groups
GROUND MORAINE (1,2,3)	FL2D	2	7	1	-
	NL2A	2	7	2 *	4,7,11,13
	FL2C	2	3	2,3	-
MOUNTAIN FRONT (4,5)	FL2C	2	7	2,3	-
	NL2A	2	7	4 *	2,7,11,13
	SL2A	2	7	4 *	6,9
	SL2B	2	7	4 *	6
	SL2B	2	13	4 *	6
	MS5A	2	7	5 *	6
ALPINE GLACIAL TROUGH (6,9,12)	SL3B	1	7	5 *	6
	MS3A	1	6	6,9	-
	MS3A	1	7	6,9	-
	MS3A	1	11	9	-
	MS3A	1	13	9	-
	MS3B	1	7	6,12	7
	MS3B	1	13	6	
	MS3B	2	7	6	
	MS4A	1	6	9	10
	MS5A	2	7	6	5 *
	NL2A	1	7	6	
	SL2A	1	7	6	7
	SL2A	2	7	6,9	4 *
	SL2A	1	6	9	
	SL2B	2	7	6	4 *
	SL2B	2	13	6	4 *
	SL2B	1	7	6	
	SL3A	1	6	9	
	SL3B	2	7	6	
	SL3B	1	7	6	5 *
	SL5A	1	10	9	
	VS3A	1	13	9	
	VS4A	1	10	9	
	WL5A	1	7	6	
INTER-MITTENTS (7,8)	WS5A	1	7	6	
	MS3B	1	7	7	6,12
	SL2A	1	7	7	6
AVALANCHE AND FAN (10,11)	MS4A	1	10	10	
	MS4A	1	13	10	
	NL2A	2	7	11	2,4 *,7,13
	SL5A	1	4	10	
	WS5A	1	13	10	
(13)	NL2A	2	7	NA	2 *,4 *,7,11

It is apparent from Table 4E-8 that several guilds have been mapped in more than one GMU super-group. This indicates that extrapolation of these patterns to other watersheds in the Swan Valley should be conducted with caution and with adequate field verification, particularly where guilds have been associated with multiple GMU super-groups. In addition, all possible combinations of guilds and GMU's in the Swan Valley have not necessarily been observed in this project. Moreover, it is possible that heretorfore unrecognized GMU's may occur in portions of the Swan Valley outside of the study area of this watershed analysis project.

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APPENDIX A

STREAM CHANNEL SURVEY PROTOCOL & GLOSSARY

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-SH10-93-002). 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: **S**parse = 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: **S**parse **C**ommon **A**bundant **N**one
Size: **S**mall (ht. = bh) **M**edium (ht.> bh, up to 5(bh)) **L**arge (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.

<u>LWD</u>: [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.

<u>Abundance</u>: Sparse Common Abundant

<u>Function</u>: **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.

<u>Recruitment</u>: 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

<u>Bars</u>: [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.

<u>Abundance</u>: **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.

<u>Bar Types</u>: **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

<u>Surface d50</u>: (##) 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. **B**ars = Fine sediment accumulated in bar forms with substantial relief above the channel bed, including deposition that fills a substantial portion of pool volume.

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 units (GMU) as delineated in the Channel Condition Module. 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. Background information regarding fish habitat, fish populations, and fish distribution was obtained from Leathe and Enk (1985) and Weaver and Fraley (1991). Preliminary stratification of stream channel segments was based on the work of Sirucek and Bachurski (1995). The Montana Department of Fish, Wildlife and Parks (MDFWP) provided information regarding fish stocking history and fishing regulations (Rumsey 1997), and fish distribution and bull trout redd surveys (Weaver 1997). The majority of the data used for this analysis collected by Plum Creek Timber Company fisheries research personnel in 1994 and 1996. All available information was evaluated and data gaps were identified. Module analysts conducted additional surveys during the summer and fall of 1996 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 in the Piper Creek portion of the analysis area. The Goat Creek drainage is closed to fishing year-round. Piper Creek is open for fishing from the third Saturday in May until November 30. The daily limit for Piper Creek is 20 brook trout and 5 of any combination of rainbow trout and cutthroat trout, only one exceeding 14 inches. The Swan 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 began in the Swan River basin as early as the 1920's. Stocking of brook trout into Swan River tributaries began in 1926 and continued routinely through the 1950's. Rainbow trout were first introduced into the Swan River basin in 1932. As with brook trout, intensive stocking efforts were continued through the 1950's. Records indicate that Piper Lake was first stocked with "undesignated" cutthroat trout in 1938. 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. Stocking of Piper Creek and Piper Lake with undesignated cutthroat stocks continued through 1966. In the Goat Creek watershed, undesignated cutthroat trout were planted in Scout Lake in 1969 and westslope cutthroat trout were introduced into Squeezer Lake in 1988 and 1992. The survival of the fish planted in Scout Lake and Squeezer Lake is unknown.

4F.4 FISH DISTRIBUTION

Figure 4F-1 displays current known distribution of trout and char in the Goat Creek and Piper Creek analysis area. Surveys conducted for this analysis indicate that the lower reaches of Goat Creek and Piper Creek support all species found in the analysis area (brook trout, bull trout, cutthroat trout, rainbow trout). The middle reaches of Piper Creek and all fish-bearing reaches of Squeezer Creek support populations of brook, bull, and cutthroat trout. The upper reaches of Goat Creek support only bull trout while the upper reaches of Piper Creek support only cutthroat trout. Only one of the intermittent tributaries identified in this analysis was found to support fish. Even though not surveyed during this analysis, the lower reaches of a small tributary to Goat Creek, identified as channel segments G59 and G60, are reported to contain cutthroat trout (Hair 1996). These findings mimic those of Leathe et al (1985), who report essentially the same species distribution patterns as found in this analysis. This suggests that there has been no longitudinal variance in species distribution over the past 12 years. Such variance would not be expected, based on the conclusions of Leathe and Enk (1985), who found that fish species abundance and distribution within Swan River tributaries were strongly influenced by channel gradient.

The only high-elevation lake in the analysis area that has documented fish presence is Piper Lake, containing cutthroat trout. Time and access constraints precluded the establishment of trout presence or absence in Moore Lake and in the high-elevation lakes in the headwaters of Piper Creek and Squeezer Creek. No documentation regarding fish use of these lakes was found. As mentioned previously, Rumsey (1997) reports that cutthroat trout were stocked in Scout Lake and Squeezer Lake. Field surveys of Scout Lake provided no evidence of fish life, indicating that the population of stocked fish perished and/or emigrated downstream.

No man-made barriers to fish movement were found in the analysis area. All upstream limits to fish distribution in the analysis area are the result of natural barriers. Impassable falls and/or cascades preclude upstream movement in channel segments G14, G21, G37, G45, P31, and S8. Except for the tributaries containing channel segments G59 and P13, stream channels classed as Ground-Moraine Intermittents (GMU 7, see Channel Condition Module) tended to be intermittent and "sub-out" prior to reaching mainstem, fish-bearing channel segments, precluding access by fish. Channel segment P13 (Moore Creek) was found to deliver flow to Piper Creek in late spring, but the lower one-third of this segment was found to lack surface flow by late June. The potential for fish utilization of this channel segment cannot be rejected, but significant use is doubtful due to its ephemeral nature and poor habitat quality resulting from steep gradient. The lower half of channel segment G11 in upper Goat Creek was also found to exhibit intermittent flow by late summer, but bull trout were found upstream of this location.

Two interesting anomalies regarding fish distribution occur in the analysis area. Only bull trout were found to occur in the fish-bearing segments of Goat Creek upstream of, and including, channel segment G9. Evaluation of channel gradients and habitat attributes suggests that this area would also be expected to support cutthroat trout. However, extensive population surveys failed to detect cutthroat in this area. Leathe et al (1985) indicate that a 3 meter falls at km 8.5 (in segment G9) forms a barrier to upstream fish movement. This "barrier" was not evaluated in this analysis, but bull trout are found upstream of this location. Perhaps this falls forms a barrier to upstream migration by cutthroat trout, but not to larger, adfluvial bull trout. The second anomaly is the absence of all fish species in Squeezer Creek upstream of the barrier falls/cascades in channel segment S8. If fish were never introduced upstream of this barrier, the absence of fish in channel segment S8 through S18 would likely be explained. However, westslope cutthroat trout have been stocked in Squeezer Lakes in 1988 and 1992 (Rumsey 1997) and habitat quantity and quality is good in these downstream segments. Current theory in conservation biology suggests that native stocks would pioneer and establish healthy populations in these unexploited channel segments draining unmanaged areas (Frissel et al 1995). Intensive surveys have not detected cutthroat trout in the aforementioned channel segments. Empirical observations indicate that fish distribution and relative abundance in the analysis area is a function of channel geomorphology and accessibility, rather than the extent and degree of past land management.

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 (GMU) 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 GMU. Table 4F-2 summarizes habitat condition calls for channel segments and GMUs. Data collection and assessments were focused on channel segments in the Goat Creek and Piper Creek 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 GMUs. GMU definitions are found in the Channel Condition Module.

4F.5.1 SWAN FLOODPLAIN (GMU 1)

Fish-Bearing Channel Segments: G1, P1

This minor GMU comprises short segments of Goat and Piper Creeks near their confluence with the Swan River. All species found in the analysis area are expected to use habitat in this GMU , at some time of the year. Brook trout and rainbow trout are more likely to use this GMU for spawning and rearing due to their documented association with low gradients reaches. Cutthroat trout and bull trout primarily use this GMU as a migration corridor to access areas more conducive to their habitat preferences. These channel segments likely are most important in providing winter rearing habitat(in the form of deep pools) and refugia from high flows in the mainstem Swan River. Rainbow trout may use this GMU for spawning and incubation. Rearing habitat for cutthroat trout and bull trout is of low quality due to the lack of large substrate particles and adequate cover. Habitat features in these channel segments are predominantly wide, moderately deep glides 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 GMU.

Table 4F-1. Habitat Metrics By Channel Segment.

	Segment Number				
	G2 (GMU 2)	G3 (GMU 2)	G4 (GMU 2)	G5 (GMU 2)	P4.2 (GMU 2)
Distance Surveyed (m)	100	744	100	100	134
% Canopy Shade	31.7	44.1	44	46	65.6
% Pool Area	16.2	22.8	28.5	30.9	63.8
# of Pools	3	19	2	3	8
Channel Widths/Pool	3.3	4	4.7	2.8	2.2
LWD/Channel Width	5.4	4.9	3.3	1.8	6.5
% of Pools w/Wood Cover	100	84.2	100	66	100
Mean % Wood Cover in Pools	7.3	13.4	6	4	21.3
% Boulder Cover	2.7	2.5	0.8	0.2	19.6
Dominant Substrate	Gravel	Cobble	Gravel	Cobble	Cobble
Sub-Dominant Substrate	Cobble	Gravel	Cobble	Gravel	Boulder
Mean Wetted Width (m)	6.81	6.72	7.68	7.62	4.09
Mean Channel Width (m)	10.1	9.78	10.66	11.8	7.62
Mean Wet Width Pools (m)	7.11	6.94	7.92	7.82	3.96
Mean Residual Depth Pools (m)	0.71	0.69	0.88	0.69	0.53
Mean Residual Depth Pools with Wood (m)	0.71	0.68	0.88	0.63	0.53
Mean Residual Depth Pools w/o Wood (m)	N/A	0.74	N/A	0.81	N/A
Mean % Surface Fines	12.2	12.8	19	23	8.7
Mean Volume of LWD (cubic m)	N/A	0.47	0.3	N/A	1.45

	Segment Number				
	S1.2 (GMU 2)	S3 (GMU 2)	S1.1 (GMU 3)	S2 (GMU 3)	G7 (GMU 4)
Distance Surveyed (m)	261	282	200	453	100
% Canopy Shade	44.6	37.2	21.9	25.3	58
% Pool Area	31.1	54.7	44.2	68.5	35.8
# of Pools	14	17	9	23	2
Channel Widths/Pool	3.5	2.4	3.85	2.53	4.7
LWD/Channel Width	3	2.16	1.3	2	3.5
% of Pools w/Wood Cover	85.7	94	89	95.6	50
Mean % Wood Cover in Pools	17.1	27.9	13.3	25.7	4
% Boulder Cover	12.4	0.41	13.1	0.03	60
Dominant Substrate	Cobble	Gravel	Cobble	Gravel	Boulder
Sub-Dominant Substrate	Gravel	Cobble-Sand	Gravel	Sand	Cobble
Mean Wetted Width (m)	3.85	3.77	3.55	4.69	5.73
Mean Channel Width (m)	5.33	6.91	5.79	7.77	10.36
Mean Wet Width Pools (m)	3.81	3.91	3.42	4.94	6.1
Mean Residual Depth Pools (m)	0.31	0.48	0.37	0.59	0.8
Mean Residual Depth Pools with Wood (m)	0.31	0.48	0.37	0.6	0.96
Mean Residual Depth Pools w/o Wood (m)	0.27	0.41	0.38	0.53	0.63
Mean % Surface Fines	18.4	29.2	11.9	37.4	16
Mean Volume of LWD (cubic m)	0.23	N/A	0.5	0.18	0.85

	Segment Number				
	P4.3 (GMU 4)	P5.1 (GMU 4)	S6 (GMU 4)	P7 (GMU 5)	G8 (GMU 6)
Distance Surveyed (m)	165	200	247	207	181
% Canopy Shade	78.9	78.4	83.5	87.6	89.6
% Pool Area	11.5	21.7	26.1	85.4	51.9
# of Pools	6	8	8	13	6
Channel Widths/Pool	3.3	3.75	4.71	1.68	3
LWD/Channel Width	5.9	4.2	3.4	8	3.3
% of Pools w/Wood Cover	100	87	100	100	100
Mean % Wood Cover in Pools	35	15.6	14.1	44.6	10.6
% Boulder Cover	7.1	28.6	19.2	0	33.6
Dominant Substrate	Cobble	Cobble	Cobble	Sand	Boulder
Sub-Dominant Substrate	Boulder	Boulder	Boulder	Gravel	Cobble
Mean Wetted Width (m)	3.7	4.01	3.75	6.58	7.04
Mean Channel Width (m)	8.2	6.71	6.65	9.45	10.06
Mean Wet Width Pools (m)	3.25	3.47	4.46	6.75	8.23
Mean Residual Depth Pools (m)	0.37	0.46	0.4	0.63	0.71
Mean Residual Depth Pools with Wood (m)	0.37	0.46	0.4	0.63	0.71
Mean Residual Depth Pools w/o Wood (m)	N/A	0.48	N/A	N/A	N/A
Mean % Surface Fines	6.1	5.6	8.3	47.2	5.45
Mean Volume of LWD (cubic m)	0.14	0.34	0.35	0.89	0.27

Table 4F-1. Habitat Metrics By Channel Segment (continued).

	Segment Number				
	G9 (GMU 6)	G10 (GMU 6)	G20 (GMU 6)	G36 (GMU 6)	P11 (GMU 6)
Distance Surveyed (m)	100	200	119	132	244
% Canopy Shade	53.75	76.1	82.7	73.7	88.7
% Pool Area	9.2	2.9	18.2	28.5	18.1
# of Pools	2	2	4	8	8
Channel Widths/Pool	5.3	10.4	5.7	3.62	2.63
LWD/Channel Width	2.3	1.9	3.7	2.6	3.5
% of Pools w/Wood Cover	0	0	100	75	63
Mean % Wood Cover in Pools	0	0	18.2	6.9	13.8
% Boulder Cover	53.7	68.9	55.6	39.6	57.2
Dominant Substrate	Boulder	Boulder	Boulder	Cobble	Boulder
Sub-Dominant Substrate	Cobble	Cobble	Cobble	Boulder	Cobble
Mean Wetted Width (m)	5.49	5.69	4.06	3.13	5.06
Mean Channel Width (m)	9.45	9.6	5.18	4.57	11.58
Mean Wet Width Pools (m)	4.57	5.03	3.88	3.31	4.42
Mean Residual Depth Pools (m)	0.67	0.63	0.23	0.53	0.41
Mean Residual Depth Pools with Wood (m)	N/A	N/A	0.23	0.6	0.47
Mean Residual Depth Pools w/o Wood (m)	0.67	0.63	N/A	0.32	0.32
Mean % Surface Fines	26	8.54	10	5.7	15.8
Mean Volume of LWD (cubic m)	0.64	0.56	0.9	0.41	0.38

	Segment Number				
	P12 (GMU 6)	P15.2 (GMU 6)	P16 (GMU 6)	S7 (GMU 6)	P28 (GMU 9)
Distance Surveyed (m)	183	183	390	125	146
% Canopy Shade	90.2	76.6	62.7	67.5	21.1
% Pool Area	22.8	41.2	14.5	43.2	53.3
# of Pools	8	12	6	14	7
Channel Widths/Pool	2.08	1.43	3.2	1.47	4.8
LWD/Channel Width	5.4	1.7	4.9	2	4.42
% of Pools w/Wood Cover	38	91	17	71	100
Mean % Wood Cover in Pools	7.5	7.3	0.8	2.8	7.1
% Boulder Cover	69.3	64.5	54	64.1	10
Dominant Substrate	Boulder	Boulder	Boulder	Boulder	Cobble
Sub-Dominant Substrate	Cobble	Cobble	Cobble	Cobble	Sand
Mean Wetted Width (m)	4.12	4.86	6.14	4.2	4.5
Mean Channel Width (m)	10.97	10.67	10.36	6.1	5.49
Mean Wet Width Pools (m)	4.07	4.11	6.2	4.1	4.57
Mean Residual Depth Pools (m)	0.37	0.46	0.49	0.39	0.39
Mean Residual Depth Pools with Wood (m)	0.41	0.44	0.53	0.38	0.39
Mean Residual Depth Pools w/o Wood (m)	0.34	0.66	0.48	0.43	N/A
Mean % Surface Fines	8.7	8.2	3.2	4.9	35.4
Mean Volume of LWD (cubic m)	0.34	0.5	0.26	0.65	0.15

	Segment Number				
	G11 (GMU 13)				
Distance Surveyed (m)	280				
% Canopy Shade	53.6				
% Pool Area	46.4				
# of Pools	12				
Channel Widths/Pool	3.33				
LWD/Channel Width	1.8				
% of Pools w/Wood Cover	83.3				
Mean % Wood Cover in Pools	11.7				
% Boulder Cover	1.8				
Dominant Substrate	Gravel				
Sub-Dominant Substrate	Cobble				
Mean Wetted Width (m)	4.35				
Mean Channel Width (m)	7.01				
Mean Wet Width Pools (m)	4.17				
Mean Residual Depth Pools (m)	0.48				
Mean Residual Depth Pools with Wood (m)	0.49				
Mean Residual Depth Pools w/o Wood (m)	0.48				
Mean % Surface Fines	10.7				
Mean Volume of LWD (cubic m)	0.69				

Table 4F-2. Habitat Condition Calls By Channel Segment.

	Segment Number									
	G2	G3	G4	G5	P4.2	S1.2	S3	GMU 2	S1.1	S2
Summer/Winter Rearing										
Percent Pool	Poor	Poor	Poor	Fair	Good	Fair	Good	Fair	Fair	Good
Pool Frequency	Fair	Fair	Poor	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Debris Pieces/Channel Width	Good	Good	Good	Fair	Good	Good	Good	Good	Fair	Good
% Wood Cover in Pools	Fair	Fair	Fair	Poor	Good	Fair	Good	Fair	Fair	Good
Habitat Condition Call	*Fair*	*Fair*	*Fair*	*Fair*	*Good*	*Fair*	*Good*	*Fair*	*Fair*	*Good*
Winter Rearing										
Substrate	Fair	Fair	Fair	Fair	Good	Fair	Poor	Fair	Poor	Fair
Off - Channel	Good	Good	Good	Fair	Fair	Good	Fair	Good	Good	Good
Habitat Condition Call	*Fair/Good*	*Fair/Good*	*Fair/Good*	*Fair*	*Fair/Good*	*Fair/Good*	*Fair*	*Fair/Good*	*Fair*	*Fair/Good*
Upstream Adult Migration										
Holding Pools	Good	Good	Good	Fair	Good	Fair	Good	Good	Fair	Good
Access to Spawning	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Habitat Condition Call	*Good*	*Good*	*Good*	*Fair/Good*	*Good*	*Fair/Good*	*Good*	*Good*	*Fair/Good*	*Good*
Spawning and Incubation										
Gravel Quality	Good	Good	Good	Good	Fair	Good	Good	Good	Good	Fair
Fines in Gravel	Fair	Fair	Fair	Poor	Good	Fair	Poor	Fair	Fair	Poor
Redd Scour	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Gravel Quantity	Fair	Good	Fair	Fair	Poor	God	Good	Fair	Fair	Good
Habitat Condition Call	*Fair*	*Fair/Good*	*Fair*	*Fair*	*Fair*	*Fair/Good*	*Fair*	*Fair*	*Fair*	*Fair*

	Segment Number									
	GMU 3	G7	P4.3	P5.1	S6	GMU 4	P7	GMU 5	G8	G9
Summer/Winter Rearing										
Percent Pool	Fair/Good	Fair	Poor	Poor	Poor	Poor	Good	Good	Good	Poor
Pool Frequency	Fair/Good	Poor	Fair	Fair	Poor	Poor/Fair	Good	Good	Fair	Poor
Debris Pieces/Channel Width	Fair/Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
% Wood Cover in Pools	Fair/Good	Poor	Good	Fair	Fair	Fair	Good	Good	Fair	Poor
Habitat Condition Call	*Fair/Good*	*Fair*	*Fair/Good*	*Fair*	*Fair*	*Fair*	*Good*	*Good*	*Fair/Good*	*Poor*
Winter Rearing										
Substrate	Poor/Fair	Good	Fair	Good	Good	Good	Poor	Poor	Good	Good
Off - Channel	Good	Fair	Poor	Fair	Fair	Fair	Good	Good	Poor	Poor
Habitat Condition Call	*Fair*	*Good*	*Fair*	*Fair/Good*	*Fair/Good*	*Fair/Good*	*Fair*	*Fair*	*Fair*	*Fair*
Upstream Adult Migration										
Holding Pools	Fair/Good	Good	Fair	Fair	Fair	Fair	Good	Good	Good	Poor
Access to Spawning	Good	Good	Good	Good	Good	Good	Good	Good	Fair	Fair
Habitat Condition Call	*Good*	*Good*	*Fair/Good*	*Fair/Good*	*Fair/Good*	*Fair/Good*	*Good*	*Good*	*Fair/Good*	*Poor/Fair*
Spawning and Incubation										
Gravel Quality	Fair/Good	Good	Fair	Fair	Good	Fair/Good	Fair	Fair	Poor	Fair
Fines in Gravel	Poor/Fair	Fair	Good	Good	Good	Good	Poor	Poor	Good	Poor
Redd Scour	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Gravel Quantity	Fair/Good	Good	Fair	Poor	Good	Fair	Good	Good	Poor	Poor
Habitat Condition Call	*Fair*	*Fair/Good*	*Fair*	*Fair*	*Good*	*Fair/Good*	*Fair*	*Fair*	*Poor/Fair*	*Poor/Fair*

Table 4F-2. Habitat Condition Calls By Channel Segment (continued).

	Segment Number									
	G10	G20	P11	P12	P15.2	P16	S7	G36	GMU 6	P28
Summer/Winter Rearing										
Percent Pool	Poor	Poor	Poor	Fair	Good	Poor	Good	Fair	Fair	Good
Pool Frequency	Poor	Poor	Fair	Fair	Good	Fair	Good	Fair	Fair	Fair
Debris Pieces/Channel Width	Fair	Good	Good	Good	Fair	Good	Good	Good	Good	Good
% Wood Cover in Pools	Poor	Fair	Fair	Fair	Fair	Poor	Poor	Fair	Fair	Fair
Habitat Condition Call	*Poor*	*Fair*	*Fair*	*Fair*	*Fair/Good*	*Poor/Fair*	*Fair/Good*	*Fair*	*Fair*	*Fair/Good*
Winter Rearing										
Substrate	Good	Good	Good	Good	Good	Good	Good	Good	Good	Fair
Off - Channel	Poor	Poor	Poor	Fair	Poor	Fair	Poor	Poor	Poor	Fair
Habitat Condition Call	*Fair*	*Fair*	*Fair*	*Fair/Good*	*Fair*	*Fair/Good*	*Fair*	*Fair*	*Fair*	*Fair*
Upstream Adult Migration										
Holding Pools	Poor	Poor	Fair	Fair	Fair	Good	Fair	Good	Fair	Fair
Access to Spawning	Fair	Poor	Fair	Poor	Poor	Poor	Fair	Fair	Fair	Fair
Habitat Condition Call	*Fair/Poor*	*Poor*	*Fair*	*Poor/Fair*	*Poor/Fair*	*Fair*	*Fair*	*Fair*	*Poor/Fair*	*Fair*
Spawning and Incubation										
Gravel Quality	Good	Poor	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Fines in Gravel	Good	Good	Fair	Good	Good	Good	Good	Good	Good	Poor
Redd Scour	Poor	Poor	Poor	Fair	Poor	Fair	Poor	Fair	Poor	Fair
Gravel Quantity	Poor	Poor	Fair	Fair	Poor	Fair	Poor	Poor	Poor	Good
Habitat Condition Call	*Fair*	*Poor*	*Fair*	*Fair*	*Poor/Fair*	*Fair*	*Poor/Fair*	*Fair*	*Poor/Fair*	*Fair*

	Segment Number		
	GMU 9	G11	GMU 13
Summer/Winter Rearing			
Percent Pool	Good	Fair	Fair
Pool Frequency	Fair	Fair	Fair
Debris Pieces/Channel Width	Good	Fair	Fair
% Wood Cover in Pools	Fair	Fair	Fair
Habitat Condition Call	*Fair/Good*	*Fair*	*Fair*
Winter Rearing			
Substrate	Fair	Poor	Poor
Off - Channel	Fair	Fair	Fair
Habitat Condition Call	*Fair*	*Poor/Fair*	*Poor/Fair*
Upstream Adult Migration			
Holding Pools	Fair	Fair	Fair
Access to Spawning	Fair	Poor	Poor
Habitat Condition Call	*Fair*	*Poor/Fair*	*Poor/Fair*
Spawning and Incubation			
Gravel Quality	Fair	Good	Good
Fines in Gravel	Poor	Good	Good
Redd Scour	Fair	Fair	Fair
Gravel Quantity	Good	Good	Good
Habitat Condition Call	*Fair*	*Good*	*Good*

4F.5.2 ENTRENCHED MAINSTEM (GMU 2)

Fish-Bearing Channel Segments: G2, G3, G4, G5, P4.1, P4.2, S1.2, S3

Channel segments in this GMU occur in the lower half of the mainstems of Goat, Piper, and Squeezer Creeks. A variety of sizes classes of all salmonids found in the analysis area occur in these channel segments, suggesting that all life requisites are supported, at sparse to moderate densities. Spawning gravel is available, found on bars, behind obstructions, and in pool tailouts. Spawning gravel quality is generally fair in terms of fine sediments and stability. Incubation success is expected to be fair for both fall and spring spawning species. Rearing habitat is provided by primary pools and side channels. Most pools are formed by scour associated with woody debris and secondarily by bedform. Primary pool frequency is moderate and residual depths tend to be greater than 0.5 meters. Large substrate particles (> 12 in.) are generally infrequent and cobble and gravel are the dominant substrates. Winter rearing habitat is provided through pool depth 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 GMU.

4F.5.3 LOW GRADIENT POOL RIFFLE (GMU 3)

Fish-Bearing Channel Segments: S1.1, S2

Channel segments in this GMU are unique to the lower reaches of Squeezer Creek. All size classes of bull trout and brook trout were encountered in this GMU, at relatively high densities. Cutthroat trout were infrequent and when encountered, were greater than 6 in. in length. Hence, this GMU likely supports all life requisites for bull and brook trout and supports rearing for larger cutthroat. Spawning gravels are frequently available, but stability is questionable. Observed fine sediment concentrations in the substrate are generally moderate in channel segment S1.1 and high in segment S2. Incubation success is expected to be moderate for fall spawners, but poor for spring spawners due to the potential for redd scour. Rearing habitat is provided by primary pools, wood cover, low energy glides, and periodic side channels. Pool frequency is fair and pools are of sufficient residual depth for winter rearing. Pool formation is primarily a function of channel form with woody debris functioning secondarily. 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. Even though winter rearing habitat may be compromised by the paucity of large substrate particles, this situation is likely ameliorated by the water column remaining relatively ice-free due to the influence of groundwater upwelling (see Channel Condition Module) in this GMU. No migration barriers occur in this GMU. Fish population estimates indicate that channel segments in this GMU are very important in providing rearing habitat to juvenile bull and brook trout.

4F.5.4 MODERATE GRADIENT AVULSING (GMU 4)

Fish-Bearing Channel Segments: G6, G7, P4.3, P5.1, S4, S5, S6

Channel segments in this GMU occur in the middle reaches of Goat and Squeezer Creeks and in the lower portion of Piper Creek. All size classes of bull trout and brook trout, and most size classes of cutthroat trout, were encountered in this GMU, at relatively sparse to moderate densities. Therefore, this GMU 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. 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. Even though pool frequency is not optimal, groundwater upwelling likely prevents anchor ice formation in most habitat units. No likely migration barriers were observed in this GMU, but increased gradients and water velocities may impede upstream migration by smaller-bodied salmonids (brook trout and cutthroat trout) to some degree.

4F.5.5 BRAIDED FLOODPLAIN (GMU 5)

Fish-Bearing Channel Segments: P7, P15.1, P15.3

This GMU, with all channel segments occurring in the middle reaches of Piper Creek, supports sparse to moderate densities of most size classes of brook trout, bull trout, and cutthroat trout. Spawning gravels are abundant throughout this GMU and are found in bars, pool tailouts, and associated with wood debris. Concentrations of fine sediment, however, are high and spawning gravel stability was rated as fair. Incubation success is expected to be poor for both fall and spring spawners. Rearing habitat is provided by primary pools, wood cover, low energy glides, and numerous side channels. Pool frequency is good 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, which is a rare occurrence. LWD is common and functions individually and in jams, in small to large sizes, 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. Large substrate particles are rarely found, but winter rearing is provided through numerous deep pools and side channels. Groundwater upwelling is also expected to benefit the quality of winter rearing habitat in this GMU. No migration barriers were found in this GMU, but log jams may periodically impede upstream movement by fish, especially during low-flow periods.

4F.5.6 GLACIAL TROUGH/INCISED MAINSTEM (GMU 6)

Fish-Bearing Channel Segments: G8, G9, G10, G13, G14, G20, G21, G36, P5.2, P11, P12, P15.2, P15.4, P16, S7, S8

Channel segments in this GMU occur in the mid to upper reaches of Goat Creek, Piper Creek, and Squeezer Creek. Except for the lower half channel segment G8, only bull trout (all size classes, moderate to sparse densities) are found in this GMU in Goat Creek. In Piper Creek, this GMU supports sparse to moderate densities of all size classes of cutthroat trout, sparse densities of all size classes of bull trout, and very sparse densities of brook trout. In the fish bearing channel segments of Squeezer Creek, this GMU supports moderate to sparse densities of most sizes of bull, brook and cutthroat trout. Observations of relative abundance and distribution of fish species indicate that this GMU is important to the maintenance of the cutthroat trout population in the Piper Creek watershed. Field surveys indicate that in Goat Creek, this GMU may partially support an isolated, resident population of bull trout (see discussion of GMU 13). Spawning habitat is limited in this GMU 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 relatively 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. Several channel segments in this GMU exhibited cascades and falls, usually as a result of bedrock outcrops and/or boulder accumulations, that pose as impediments or barriers to upstream fish migration.

4F.5.7 GROUND MORAINE INTERMITTENTS (GMU 7)

Fish-Bearing Channel Segments: G59, G60, (P13?)

Channel segments in this GMU rarely support fish and intensive surveys to collect habitat and fish population data were not conducted. A population of cutthroat trout is reported to exist in segments G59 and G60 and cutthroat may use the lower portion of segment P13 for spawning in the spring (when surface flows and subsequent connectivity to Piper Creek occurs). Field reconnaissance of these segments indicates that spawning gravels are available in limited quantities, but high concentrations of fine sediment indicate that incubation success is expected to be poor. Rearing habitat is provided primarily through dam pools formed by LWD obstructions and bedform. Riparian vegetation contributes to channel stability and bank integrity in fish-bearing segments. Winter rearing habitat is expected to be provided by deeper dam pools, where present, and groundwater upwelling may play a role in keeping portions of stream segments ice-free. Migration barriers are evident through the intermittent flow patterns exhibited by this GMU.

4F.5.8 SCARP-SLOPE HEADWATERS (GMU 8)

Fish-Bearing Channel Segments: None Identified

Channel segments within this GMU were not evaluated since no fish-bearing segments exist in the analysis area. These channels do not connect with fish-bearing channel segments and ephemeral use is not expected.

4F.5.9 CIRQUE HEADWATERS (GMU 9)

Fish-Bearing Channel Segments: P17, P24, P27, P28, P30, P39

Fish-bearing channel segments in this GMU occur exclusively in the upper reaches of Piper Creek and support only cutthroat trout at moderate to low densities. Channel segments in this GMU occur in a large-scale stair-step pattern (see Channel Condition Module). Field evaluation indicates that the higher gradient portions of these channels are expected to express fish habitat characteristics (and subsequent vulnerabilities) of GMU 6. In the lower gradient portions, surveys indicate that spawning gravels are common, but fine sediment concentrations are high in some areas. Incubation success is expected to be impacted. Rearing habitat is provided by primary pools and infrequent side channels. Pools are formed primarily by boulders and bedrock, and secondarily by LWD. Woody debris functions in jams and as individual pieces of small to moderate sizes. Pool frequency is generally fair and pools are of sufficient residual depth to support winter rearing for resident fish. Winter rearing habitat is also provided to a moderate degree by accumulations of large substrate particles periodically available throughout the segments. Riparian vegetation can be important for channel stability and bank integrity in portions of these segments, primarily in areas exhibiting multiple channels. Because of steeper gradient sections interspersed throughout these channel segments, upstream passage in this GMU can be difficult for smaller resident trout.

4F.5.10 HEADWATERS WITH AVALANCHE (GMU 10)

Fish-Bearing Channel Segments: None Identified

Channel segments within this GMU 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.5.11 FANS (GMU 11)

Fish-Bearing Channel Segments: G12

The one known fish-bearing channel segment in this GMU is in upper Goat Creek, hence the only fish species supported is bull trout. This segment was not surveyed for habitat metrics, but may provide limited spawning and rearing habitat. Habitat formation and maintenance processes are expected to be similar to GMU 4. Habitat vulnerabilities to modifications of upland input processes are also expected to be similar, but not to the same degree because of relatively diminished stream power.

4F.5.12 TROUGH-WALL CASCADES (GMU 12)

Fish-Bearing Channel Segments: G37

The only portion of this GMU that supports fish is the lower third of segment G37, in upper Goat Creek. This reach is the upstream limit of fish distribution in the watershed and snorkel surveys did not detect any fish. Presumably, this area could support bull trout at very low densities. Channel gradients range from 12% to 26%. Dominant substrates are 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. Habitat maintenance and formation processes are similar to GMU 6, but are magnified due to increased stream power. Barriers to upstream migration occur throughout this GMU.

4F.5.13 UPPER GLACIAL TROUGH ALLUVIAL (GMU 13)

Fish-Bearing Channel Segments: G11

This GMU consists of one unique channel segment found in the upper Goat Creek drainage, G11. Low densities of bull trout have been found in this channel segment. In October, 1996 two small, freshly-excavated redds were found in upper portion of this segment. The lower-most 100 m of this segment was dry. The redds were not of sufficient size to have been constructed by an adfluvial adult bull trout. Since bull trout are the only species that have been detected in upper Goat Creek, these observations tend to support the hypothesis that this channel segment partially supports a population of resident bull trout. Spawning gravels are abundant in this GMU, and exhibit low to moderate accumulations of fine sediment. Gravels also appear to be relatively stable. Therefore, incubation success is expected to be good. Rearing habitat is provided by primary pools, wood cover, low energy glides, and periodic side channels. Pool frequency is fair and pools are of sufficient residual depth for winter rearing. Pool are formed primarily by woody debris with channel form functioning secondarily. LWD of various sizes functions individually and in jams to provide habitat features. Riparian vegetation, in the form of shrubs and trees, is locally important in portions of this segment for channel stability and for the formation of undercut banks. Even though winter rearing habitat may be limited by low frequencies of large substrate particles, primary pools and side channel habitats likely provide enough habitat area to support existing population levels. The previously mentioned dewatered portion of channel segment G11 constitutes a seasonal migration barrier during periods of low flow (late summer/early fall).

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 Goat Creek and Piper Creek analysis area. Important channel segments were rated as primary or secondary habitat for life phases for both resident species (cutthroat trout, brook trout, presumed resident bull trout) and migratory species (adfluvial bull 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 life history strategy (resident or migratory). A rating of secondary indicates that the channel segments are, or will likely be, utilized by the given life history strategy 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.

The MDFWP has conducted bull trout spawning site inventories in index portions of Goat, Piper, and Squeezer Creeks since 1982. The results of their surveys are displayed in Table 4F-3.

Table 4F-3. Bull Trout Spawning Site Inventory (number of redds identified - 1982 to 1996)

Stream	1982	1983	1984	1985	1986	1987	1988	1889	1990	1991	1992	1993	1994	1995	1996
Goat	33	39	31	40	56	31	46	34	27	31	17	64	66	32	52
Piper	0	0	1	NA	NA	NA	NA	25	NA	18	NA	NA	NA	10	29
Squeezer	41	57	83	24	55	64	9	67	42	101	115	106	91	149	117

Using data available from spawning site inventories collected in 1985, redd density was plotted in 500 meter increments to assess the relative utilization of channel segments for spawning activity by adfluvial adult bull trout. The data are displayed in Figures 4F-2, 4F-3, and 4F-4 for Goat Creek, Piper Creek, and Squeezer Creek, respectively. Data compiled for bull trout spawning site selection by segment were then clustered by GMU to ascertain of any discernable pattern of selection for GMU was expressed. Table 4F-4 displays these results.

Table 4F-4. Bull Trout Redd Density By GMU (1985 Survey Data)

GMU	Total Length (m) All Segments	Total Redds (1985)	Spawning Site Density (Redds/km)
1	511	0	0
2	10649	76	7.1
3	2168	31	14.3
4	4458	59	13.2
5	1595	5	3.1
6	2617	17	6.5

The above data were subjected to a use-verses-availability analysis (Neu et al 1974). At p=0.1, use of GMUs 3 and 4 was found to be significantly greater than expected. These findings suggest that spawning bull trout exhibit selection for some combination of specific habitat attributes expressed in GMUs 3 and 4. It is postulated that the combination of significant groundwater upwelling

Figure 4F-2. Distribution of Bull Trout Redds in Goat Creek (1995 Data).

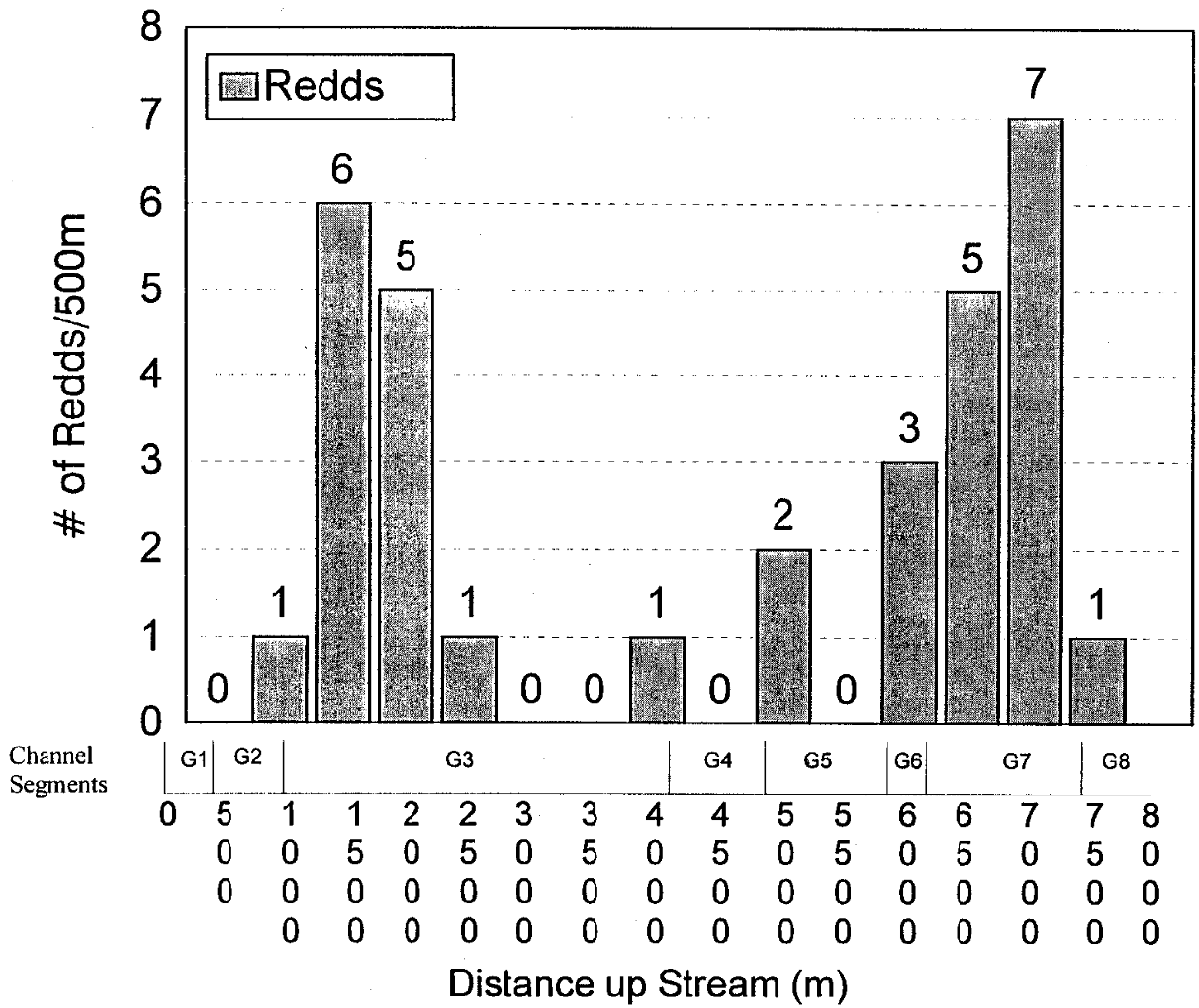
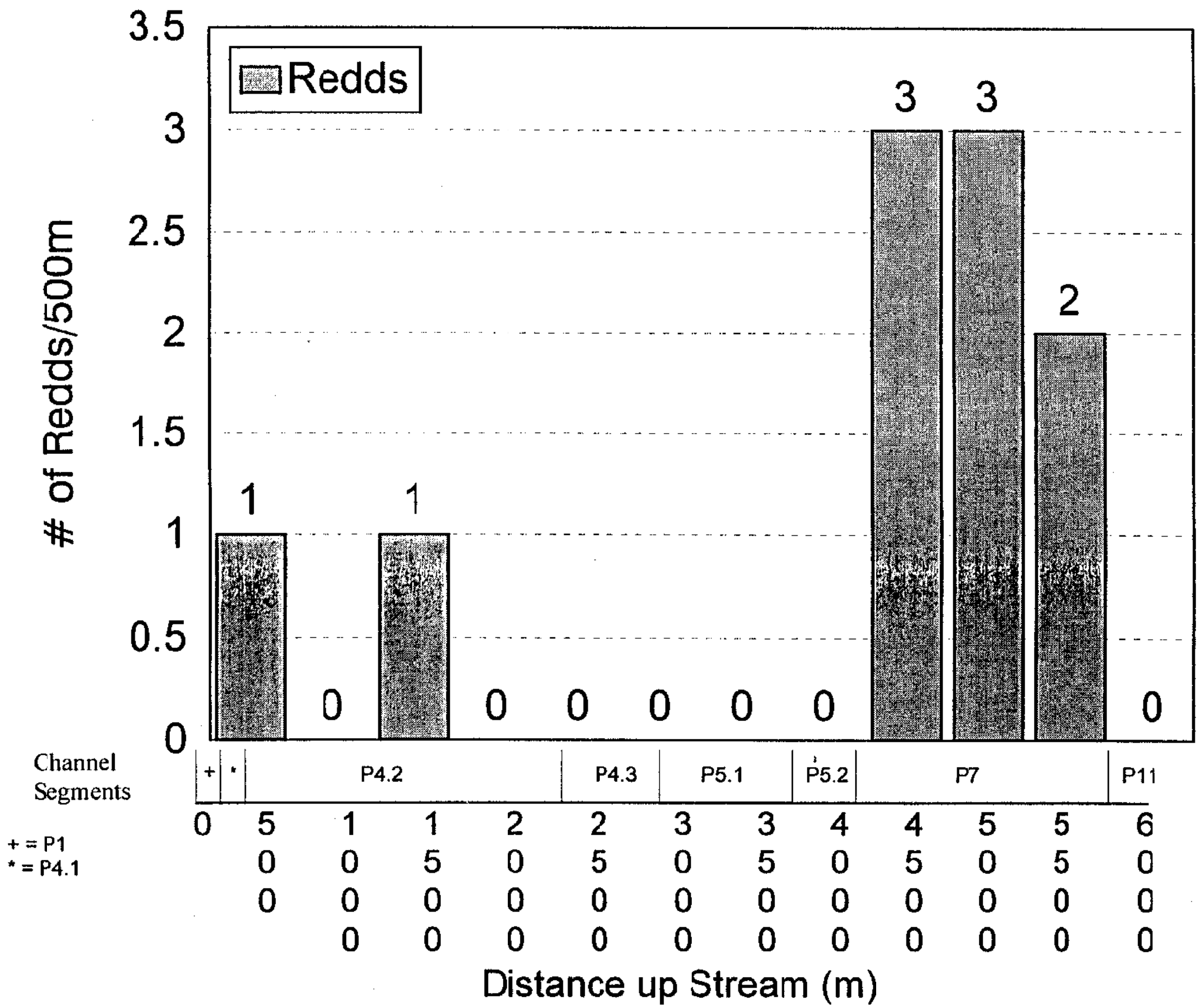


Figure 4F-3. Distribution of Bull Trout Redds in Piper Creek (1995 Data).



combined with the availability of spawning gravels of a sufficient size and quantity are the primary elements driving this selection.

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 resident trout, the following channel segments were deemed important: Primary Spawning - Segments G3, G4, G11, P5.1, P11, P12, P16; Secondary Spawning - Segments G5, P7, P15.2, S6, S7. For migratory trout: Primary Spawning - Segments G3, G6, G7, P4.2, P7, S1.1, S2, S3, S4, S5, S6, S7; Secondary Spawning - Segments G5, S1.2.

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-5, was also used to assess the relative importance of channel segments for rearing habitat. Using module diagnostics as prescribed resulted in habitat condition calls of either fair or good for all channel segments evaluated, except for segments G9 and G10 - both in GMU 6. Poor rearing habitat calls for these segments is primarily the result of low pool frequencies, to be expected in some segments of this GMU because of increased gradients and high stream power.

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.

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 resident trout, the following channel segments were deemed important: Primary Rearing - Segments G4, G5, G20, P7, P11, P15.2, P16, S4, S6, S7; Secondary Rearing - Segments G3, G10, G11, G59, P4.2, P4.3, P12, P17, P28, S5. For migratory trout: Primary Rearing - Segments G5, G7, G8, P7, P11, S1.1, S2, S3, S4, S6, S7; Secondary Rearing - Segments G3, G6, G9, G10, P12, P15.2, S5.

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

Table 4F-5. Relative Fish Densities By Channel Segment

Segment	Bull Trout 0 - 3"	Bull Trout 3 - 6"	Bull Trout 6 - 9"	Bull Trout 9 - 12"	Brook Trout 0 - 3"	Brook Trout 3 - 6"	Brook Trout 6 - 9"	Brook Trout 9 - 12"	Cutthroat Trout 0 - 3"	Cutthroat Trout 3 - 6"	Cutthroat Trout 6 - 9"	Cutthroat Trout 9 - 12"	Rainbow Trout 0 - 3"	Rainbow Trout 3 - 6"	Rainbow Trout 6 - 9"	Rainbow Trout 9 - 12"
G2 (GMU 2)	S	S			M	M							S	S	S	
G3 (GMU 2)	S	S	S	S	M	M	S		S	S	S			S		
G4 (GMU 2)			S		S	S	S		M	M	S	S				
G5 (GMU 2)	S	S			S	M		S	S	S	S					
P4.2 (GMU2)		S			S				S	S	S					
S1.2 (GMU 2)							S									
S3 (GMU 2)	M	N	N	M	M	M	M	M								
S1.1 (GMU 3)	N	N	M		M	M	N				S	S				
S2 (GMU 3)	N	N	M	M	M	M	S	S			S	S				
G7 (GMU 4)	S	M	M		S	S	S									
P4.3 (GMU 4)						S	S			S						
P5.1 (GMU 4)		S			S	S	S		S	M	S				S	
S6 (GMU 4)	S	M	M	S	M	M	M	S		S	S					
P7 (GMU 5)	S	M			S	S	S		S	M	S					
G8 (GMU 6)	S	M	S												S	
G9 (GMU 6)	S	S		M												
G10 (GMU 6)	S	M	S	S												
G20 (GMU 6)	S	S	S	S												
G36 (GMU 12)			S													
P11 (GMU 6)	S	S	S			S			S	M	M	S				
P12 (GMU 6)	S	S		S					S	M	S					
P15.2 (GMU 6)		S		S					S	M	M	S				
P16 (GMU 6)									S	M	M	S				
S7 (GMU 6)	M	M	S	S	S	M	S				S	S				
P28 (GMU 9)										M	S					
G11 (GMU 13)		S	S													

S = Sparse (1 to 10 fish/100 m)
M = Many (11 to 50 fish/100m)
N = Numerous (>50 fish/100m)

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 was 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 Goat Crek and Piper Creek 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 likelyihood of groundwater influence were evaluated to designate channel segments as primary, or secondary winter rearing habitat. For resident trout, the following channel segments were deemed important: Primary Winter Rearing - Segments G3, G36, P4.2, P7, P15.1, P15.3, P16, P27, S1.2, S4, S5, S6, S7; Secondary Winter Rearing - Segments G4, G20, G59, P5.1, P12, P17, P28. For migratory species: Primary Winter Rearing - Segments G3, G6, G7, P7, P15.1, S2, S3, S4, S5, S6, S7; Secondary Winter Rearing - Segments G9, P5.1, P12, P15.3, S1.1.

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-6 displays relative fish habitat vulnerabilities to modification of important input processes necessary for the creation and maintenance of habitat features within the Goat Creek and Piper Creek 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, however. Analysts determined that, in these instances, important habitat features (primarily spawning habitat) were more sensitive to modifications of the given input factor than suggested by channel sensitivity ratings.

Table 4F-6. Fish Habitat Vulnerability To Changes In Input Process.

Geomorphic Unit	Coarse Sediment	Fine Sediment	Peak Flows	LWD	Catastrophic Events	Riparian Vegetation	CMZ
Swan Floodplain (GMU 1)	Moderate	Low	Moderate	Moderate	Low	Low	Moderate
Entrenched Mainstem (GMU 2)	Moderate	Moderate	Moderate	High	Low	Moderate	Moderate
Low Gradient Pool-Riffle (GMU 3)	High	High	Moderate	High	Low	High	Moderate
Moderate Gradient Avulsion (GMU 4)	High	Moderate	Moderate	High	Moderate	High	High
Braided Floodplain (GMU 5)	High	High	Moderate	High	Low	Moderate	High
Glacal Trough/Incised Mainstem (GMU 6)	Low	Low	Moderate	Moderate	Moderate	Low	Low
Ground Moraine Intermittents (GMU 7)	Low/High*	Low/High*	Moderate	Moderate	Low	Moderate/High*	Low
Scarpe Slope Headwaters (GMU 8)	Moderate	Low	Low	Moderate	Low	Low	Low
Cirque Headwaters (GMU 9)	Moderate	Moderate	Low	Moderate	Moderate	Low/High^	Low/Moderate^
Headwaters with Avalanche (GMU 10)	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Low
Fans (GMU 11)	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate
Trough-Wall Cascades (GMU 12)	Low	Low	Low	Low	Low	Low	Low
Upper Galcial Trough Alluvial (GMU 13)	High	Moderate	Moderate	High	Moderate	Moderate	Moderate

* - High vulnerability rating applies only to fish-bearing portions of channel segments
^ - Higher vulnerability rating applies to unique channel segments of low gradient (< 3%) and small substrates (sand, gravel, small cobble)

4F.8 CONFIDENCE

Confidence is high for fish distribution in stream segments and low for distribution in high elevation lakes. Comprehensive electrofishing and snorkel surveys were conducted in channel segments throughout the analysis area in 1994 and 1996 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. Findings of fish distribution from these recent surveys were found to be analogous to surveys conducted in the early 1980's. Surveys of fish presence were not conducted for most of the high mountain lakes in the analysis area. Due to the propensity of recreationists to practice "bucket biology", it is likely that some of these lakes have been stocked without the knowledge of MDFWP. This issue is not of critical importance to this analysis however, since these lakes have a very low probability of being affected by land management. The primary concern is the potential for the introduction of additional exotic species into the watersheds.

Except as noted below, confidence is high for habitat condition calls and habitat vulnerability ratings for all GMUs. 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 GMUs. Data were share by analysts and consensus was reached on hazard, sensitivity, and vulnerability calls during synthesis. Confidence is low for GMU 7 since only cursory field evaluation was conducted for the two fish-bearing channel segments (G59 and G60). Confidence is moderate for habitat condition and vulnerability ratings for GMU 9 since rigorous data collection was conducted in only one fish-bearing segment of this GMU (P28). However, field reconnaissance of other channel segments in GMU 9 indicates that the analyzed segment is likely representative of fish habitat and subsequent vulnerabilities found in this GMU.

Confidence is high for channel segment importance ratings (i.e. Primary or Secondary) for spawning and summer rearing habitat for migratory species (i.e. bull trout), and for summer rearing for resident species. Records of bull trout spawning distribution in the analysis area are available for the past 15 years. Extensive habitat analyses and population surveys have been conducted in the analysis area in the summers of 1993 and 1996 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 for both resident and migratory species, and for spawning habitat for resident species. 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 trout. Therefore, only habitat analyses and diagnostics were used to determine the relative importance of channel segments.

4F.9 AREAS OF SPECIAL CONCERN

The following areas within the analysis area are of special interest regarding monitoring and/or research needs.

Previously, it was postulated that a population of resident bull trout may exist in the upper reaches of Goat Creek. If these fish are indeed stream resident, this will be the first non-adfluvial population documented in the Swan Valley. The MDFWP may wish to conduct analyses to determine if this population is indeed unique. If so, special management measures may be necessitated.

It has been reported than channel segments G59 and G60 contain a stock of resident cutthroat trout. Since these segments are marginally connected to mainstem Goat Creek, this population of cutthroat may have remained reproductively isolated from undesignated stocks of cutthroat previously planted in the Swan Valley, thus resulting in a genetically unmixed population of westslope cutthroat trout. If this is the case, individuals from this population could be used as founders to establish pure populations of westslope cutthroat in suitable as yet unoccupied habitats elsewhere in the Swan River basin.

Significant densities of brook trout are found to exist in channel segments used by adfluvial bull trout for spawning. Hybridization between brook trout and bull trout commonly results in sterile offspring and life history differences between the species tend to favor populations of brook trout (Leary et al 1991). Of 226 fish, thought to be juvenile bull trout, collected in Swan Valley tributaries (Elk, Goat, Lion and Lost Creek) in 1993, 13 were found to be bull trout/brook trout hybrids (Fredenberg 1997). Since Goat and Squeezer Creeks are considered to be some of the most important bull trout spawning streams in the Swan River basin, hybridization with resident brook trout could result in significant impacts to the Swan River valley bull trout population as a whole. Managers may wish to investigate the current and potential risks from hybridization and, if deemed significant, proceed with management options to control brook trout populations.

Findings of this module suggest that the specific geomorphic character of any given stream segment is an pivotal factor in determining habitat characteristics and subsequent utilization by distinct species and size classes of fish. For example over 90 percent of the channel segments designated as primary spawning habitat for bull trout are found in the Ground Moraine and Mountain Front GMU Super Groups (see Channel Condition Module). Since channel segments within GMUs are found to exhibit similar sensitivities to physical input processes, and since these sensitivities can be predicted, it logically follows that fish habitat and utilization of said habitats can be predicted from some scheme of geomorphic classification. A useful tool for managers would be the extrapolation of the results of this watershed analysis so that protective management measures could be applied to channel segments exhibiting relatively similar characteristics, both in terms of channel formation processes and fish habitat attributes. A ecological classification scheme, based partially on the work of Sirucek and Bachurski (1995), has been developed for channel types occurring in the Swan River valley by Whitehorse Associates (1996). This ecological classification will be use to test the hypothesis that fish habitat and populations are similar within specified "geomorphic guilds". If analysis of collected data tends to support the above hypothesis, results from this watershed analysis can be applied to channel segments elsewhere in the Swan River basin.

4F.10 LITERATURE CITED

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SECTION 5

CAUSAL MECHANISM REPORTS

CAUSAL MECHANISM REPORT - A1

Sensitive Area:	Landform Unit #4 (Oversteepened toe slope) Landform Unit #6 (Inner gorges) Landslide Hazard Map (Figure 4A-1)
Sub-basins:	Piper, Goat, Squeezer
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	HIGH
Resource Vulnerability:	LOW TO HIGH
Rule Call:	PREVENT OR AVOID

SITUATION SENTENCE:

Input	**Coarse and fine sediment**
Time Frame	**from past and potential future**
Watershed Process	**landslides on steep slopes incised by streams**
Unit Location	**mapped as Landform Unit 4 and 6**
Activity	**due to removal of rooting strength from timber harvest or road construction or addition/concentration of water from road drainage or skid trails from ground-based or cable-yarding**
Conditions	**within 100 feet (slope distance) of stream channels where the slope gradient is greater than 80% or greater than 60% if evidence of seepage or slope movement exists**
Channel Effects	**leading to accumulation of coarse and fine sediment**
Location	**in any fish-bearing segment rated Low, Moderate or High vulnerability**
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 substrate for resident trout and adfluvial bull trout.**

TRIGGERING MECHANISMS:

1) Road construction that removes trees along streambank or locally increases slope gradient (e.g., sidecast material, cutslopes)
2) Road drainage addition/concentration from culverts, waterbars, dips, etc.
3) Cable or ground-based yarding skid trails that concentrate water
4) Timber harvest

ADDITIONAL COMMENTS:

Most of the area mapped as Landform Unit #6 does not meet the criteria of greater than 80% gradient or greater than 60% with evidence of water seepage or slope movement, so field verification is essential for determining whether a hazard exists. Field verification of the entire map unit was not feasible during the analysis, but can be done by an experienced forester. The mapped areas that do not meet the criteria are typically part of Landform Unit #7- a low hazard.

While timber harvest may be possible in the verified landform unit without increasing the risk of slope failure, the exact amount and nature of the timber harvest can only be determined through field investigation by specialists with training and experience in evaluating landslide hazards.

CAUSAL MECHANISM REPORT - A2

Sensitive Area:	Landform Unit #1a (Steep rocklands) Landslide Hazard Map (Figure 4A-1)
Sub-basins:	Piper, Goat, Squeezer
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	MODERATE
Resource Vulnerability:	LOW TO HIGH
Rule Call:	MINIMIZE or PREVENT OR AVOID

SITUATION SENTENCE:

Input	**Coarse and fine sediment**
Time Frame	**from past and potential future**
Watershed Process	**rockfalls, snow avalanches, and debris flows on steep slopes typically with planar(flat) to concave cross-sectional slope forms (convergent topography)**
Unit Location	**mapped as Landform Unit 1a**
Activity	***due primarily to natural processes, but possibly increased by*** **non-full bench road construction and/or locating roads within avalanche/debris flow paths**
Conditions	**within glacial-derived bowls (cirques) prone to avalanche initiation and along avalanche/debris flow paths where the hillslope gradient is greater than 80 percent**
Channel Effects	**leading to accumulation of coarse and fine sediment**
Location	**in any fish-bearing segment rated Moderate or High-vulnerability**
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 substrate for resident trout and adfluvial bull trout.**

TRIGGERING MECHANISMS:

1) Road construction that is not full-benched (i.e., roads constructed with material placed or sidecast on the fill slope)
2) Locating roads within avalanche/debris flow paths

ADDITIONAL COMMENTS:

The lack of trees within this landform unit makes timber harvest an unlikely triggering mechanism. Additionally, little potential exists in much of the mapped landform unit for delivery of sediment to fish-bearing streams.

CAUSAL MECHANISM REPORT - A3

Sensitive Area:	Landform Unit #1b (Steep alpine lands) Landform Unit #3 (Deep-seated landslide) Landslide Hazard Map (Figure 4A-1)
Sub-basins:	Piper, Goat, Squeezer
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	MODERATE
Resource Vulnerability:	LOW TO HIGH
Rule Call:	MINIMIZE or PREVENT OR AVOID

SITUATION SENTENCE:

Input	**Coarse and fine sediment**
Time Frame	**from past and potential future**
Watershed Process	**snow avalanches, rockfalls, shallow landslides, and debris flows on steep slopes typically with planar (flat) to concave cross-sectional slope forms (convergent topography)**
Unit Location	**mapped as Landform Unit 1b and Unit 3**
Activity	**due to removal of rooting strength from fire, timber harvest or road construction, addition/concentration of water from road drainage or skid trails from ground-based or cable-yarding or poor road locations**
Conditions	**within 100 feet (slope distance) of stream channels where the slope gradient is greater than 80% or greater than 60% if evidence of seepage or slope movement exists or within snow avalanche/debris flow paths**
Channel Effects	**leading to accumulation of coarse and fine sediment**
Location	**in any fish-bearing segment rated Moderate or High-vulnerability**
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 substrate for resident trout and adfluvial bull trout.

TRIGGERING MECHANISMS:

1) Road construction that removes trees or locally increases slope gradient (e.g., sidecast material, cutslopes) along streams with steep slopes
2) Road locations within snow avalanche/debris flow paths
3) Road drainage addition/concentration from culverts, waterbars, dips, etc. onto steep slopes
4) Cable or ground-based yarding skid trails that concentrate water onto steep slopes
5) Timber harvest on steep slopes
6) Broadcast burning on steep slopes

ADDITIONAL COMMENTS:

Most of the area mapped as Landform Unit #1b and Unit #3 does not meet the criteria of greater than 80% gradient or greater than 60% with evidence of water seepage or slope movement, so field verification is essential for determining whether a hazard exists. Field verification of the entire map unit was not feasible during the analysis, but can be done by an experienced forester. Existing avalanche/debris flow paths can also be delineated by a forester. Specialists with experience identifying landslide hazards, however, may be helpful in verifying areas particularly if minor slope movement, water seepage or debris flow potential is suspected. If the mapped area does not meet the criteria for steep slopes or snow avalanche/debris flow path, it is considered a low hazard.

While timber harvest may be possible in the verified landform unit without increasing the risk of slope failure, the exact amount and nature of the timber harvest can only be determined through field investigation by specialists with training and experience in evaluating landslide hazards.

Based on observations following wildfire and timber harvest in the Washington Cascades, it should be noted that clearcut forest harvest along the ridges of slopes greater than 70% in this landform could cause an increase in snow avalanching. These ridges were not identified separately because of the difficulty in predicting exact locations and the lack of evidence to indicate that the likely small increase in snow avalanches would be detrimental to aquatic resources.

CAUSAL MECHANISM REPORT - A4

Sensitive Area:	Landform Unit #5 (Glacial moraine deposit) Landslide Hazard Map (Figure 4A-1)
Sub-basins:	Piper, Goat
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	MODERATE
Resource Vulnerability:	LOW TO HIGH
Rule Call:	MINIMIZE or PREVENT OR AVOID

SITUATION SENTENCE:

Input	**Coarse and fine sediment**
Time Frame	**from past and potential future**
Watershed Process	**slumps and shallow landslides on relatively steep slopes**
Unit Location	**mapped as Landform Unit 5**
Activity	**due to locally increased slope gradient (e.g., cutslopes, sidecast material) or addition/concentration of water from road drainage or skid trails from ground-based or cable-yarding**
Conditions	**within 100 feet (slope distance) of stream channels where the slope gradient is greater than 60% with evidence of seepage or slope movement**
Channel Effects	**leading to accumulation of coarse and fine sediment**
Location	**in any fish-bearing segment rated Moderate or High-vulnerability**
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 substrate for resident trout and adfluvial bull trout.**

<u>TRIGGERING MECHANISMS</u>:

1) Road construction that locally increases slope gradient (e.g., sidecast material, cutslopes) on slopes with shallow groundwater flow (seepage)
2) Road drainage addition/concentration from culverts, waterbars, dips, etc. onto steep slopes
3) Cable or ground-based yarding skid trails that concentrate water onto steep slopes

<u>ADDITIONAL COMMENTS</u>:

The primary danger associated with this landform is cutslope failure that blocks relief culverts and leads to gully erosion or failure of the road prism. Most of Landform Unit #5 does not meet the slope gradient criteria of greater than 60%, except where road construction has locally increased slope gradient with cut and fillslopes. Identifying areas with shallow groundwater flow can be difficult during the summer dry season and prior to excavation for road construction. Larger groves of western red cedar (*Thuja plicata*) can be used as potential indicators of near-surface groundwater flow. Monitoring of newly constructed roads in this landform unit following significant rainfall could also help identify potential problem areas.

CAUSAL MECHANISM REPORT - B1

Sensitive Area:	Areas prone to subsurface flow interception by road and skid trail cut- slopes
Sub-basins:	Piper, Goat, Squeezer
Input Variable:	Fine Sediment
Delivered Hazard:	LOW
Resource Vulnerability:	MODERATE TO HIGH
Rule Call:	STANDARD RULES

SITUATION SENTENCE:

Input	**Fine sediment generated**
Time Frame	**from past and potential future**
Watershed Process	**ditch erosion resulting from shallow groundwater interception**
Unit Location	**on hillslopes with impermeable soil layers**
Activity	**caused by road and *skid trail cutslope interception***
Conditions	**in areas with significant subsurface flow**
Channel Effects	**leading to accumulation of fine sediment**
Location	**in any Moderate or High-rated 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 substrate for resident trout and adfluvial bull trout.**

TRIGGERING MECHANISMS:

Road and skid trail construction on hillslopes with significant shallow groundwater flow.

ADDITIONAL COMMENTS:

Though this situation has not created a significant erosion problem in the drainages analyzed, it has the potential to cause problems elsewhere. These areas have not been mapped, but seem to occur on steeper slopes (Particularly near the toe of the slope) and in areas where glacial terraces meet residual hillslopes. One of these locations is where Plum Creek recently constructed new roads in Goat Creek (Section 11, T23N, R17W). Another indication of the potential for this situation is the presence of cedar or grand fir habitat types.

Where significant groundwater is intercepted by road and skid trail cutslopes, sedimentation can be reduced by trying to get this water re-infiltrated as quickly as possible. This was the action taken in the Section 11 roads.

CAUSAL MECHANISM REPORT - B2

Sensitive Area: High priority road sediment delivery locations mapped in Figure 4B-4a and 4B-4b and summarized in Appendix A, Table A-1

Sub-basins: Piper, Goat

Input Variable: Fine Sediment

Delivered Hazard: LOW

Resource Vulnerability: MODERATE TO HIGH

Rule Call: STANDARD RULES

SITUATION SENTENCE:

Input	**Fine sediment**
Time Frame	**from existing**
Watershed Process	**road surface erosion in areas**
Unit Location	**mapped in Figures 4B-4a and 4B-4b and prioritized in Appendix A, Table A-1.**
Activity	***due to old erosion control standards (BMP practices)***
Conditions	**proximate to stream channels is**
Channel Effects	**leading to accumulation of fine sediment**
Location	**in any Moderate or High-rated 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 substrate for resident trout and adfluvial bull trout.**

TRIGGERING MECHANISMS:

Stream crossings that are not up to current BMP standards.

ADDITIONAL COMMENTS:

Though the overall sediment hazard from roads is rated as low, a number of opportunities exist to further reduce sediment loading in Goat and Piper Creeks. These sediment sources are shown in

Figures 4B-4a and 4B-4b, and are prioritized in Table A-1 of Surface Erosion Appendix A. Of particular concern is a log stringer bridge over Scout Creek where the bridge is partially washed out and several yards of fill material are perched above the stream. Voluntarily addressing this and other high-priority sediment sources is highly recommended.

CAUSAL MECHANISM REPORT - D1

Figure 4D-1
Refer to Maps & Colors

Sensitive Area: Channel Segment P7 (GMU 5) and S2 (GMU 2)

Sub-basins: Piper and Squeezer

Input Variable: LWD Recruitment and Canopy Closure

Delivered Hazard: HIGH

Resource Vulnerability: HIGH

Rule Call: PREVENT OR AVOID

SITUATION SENTENCE:

Input	**Loss of long-term LWD and decreased shade**
Time Frame	**from past and potential future, causing a loss**
Watershed Process	**bank stability, LWD recruitment, and shade**
Unit Location	**mapped as P7 and S2 that have had**
Activity	**intensive (pre-SMZ law) timber harvest in the CMZ**
Conditions	**were reductions have already occurred**
Channel Effects	**leading to loss of in-channel LWD and decreased canopy closure**
Location	**in the lower 1/2 of channel segment P7 and all of S2**
Resource Effects	**which can 1) reduce the number of pools and channel complexity, 2) reduce the quality/quantity of summer/winter habitat for trout, and 3) increase stream temperature affecting... resident trout and adfluvial bull trout.**

TRIGGERING MECHANISMS:

1. Additional harvest with riparian zones removing trees within 75 feet of the bank for shade
2. Additional removal of recruitable trees within one tree height.

ADDITIONAL COMMENTS:

These areas were harvest before the Montana SMZ law removing the majority of the trees within the riparian area. Future management should restrict any further harvest and promote conifer regrowth growth within these areas. Current LWD is adequate, but long-term LWD has been reduced.

CAUSAL MECHANISM REPORT - D2

Sensitive Area:	GMUs 1 though 11, and 13 (2 though 5 and 13 for HIGH) LWD Vulnerability GMU 3 , 4, 7, and 9 (3, 4, and 7 for HIGH) Riparian Vegetation Vulnerability GMU 1 though 4, 9, 11, and 13 (4 and 5 for HIGH) CMZ Vulnerability
Sub-basins:	Piper, Goat, Squeezer
Input Variable:	Long-term LWD Recruitment, Riparian Vegetation, and CMZ
Delivered Hazard:	MODERATE
Resource Vulnerability:	MODERATE - HIGH
Rule Call:	MINIMIZE - PREVENT OR AVOID

SITUATION SENTENCE:

Input	**Lowered LWD recruitment, bank stability and channel movement within the CMZ**
Time Frame	**from 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 areas. 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 - D3

Sensitive Area:	Channel Segment G59 and G60, GMU 7
Sub-basins:	Goat
Input Variable:	Long-term LWD Recruitment and Riparian Vegetation
Delivered Hazard:	MODERATE
Resource Vulnerability:	MODERATE
Rule Call:	MINIMIZE

SITUATION SENTENCE:

Input	**Loss of long-term LWD and decreased bank stability**
Time Frame	**from past and potential future management activities**
Watershed Process	**causing loss of bank stability, loss of LWD recruitment potential**
Unit Location	**mapped as segments G59 and G60.**
Activity	**Harvest within the riparian area, reducing the number of available trees and loss of rooting strength**
Conditions	**within one tree height of the stream**
Channel Effects	**Leading to decreased LWD recruitment, lowered bank stability**
Location	**in fish bearing portion of the segments**
Resource Effects	**which can 1) reduce channel complexity for fish habitat, 2) reduce summer and winter rearing habitat by reducing pools and increasing fine sediments, and 3) reduce spawning areas for resident trout.**

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

ADDITIONAL COMMENTS:

These sections were not surveyed during the watershed analysis, but fish are reported to be in the segments. All future harvest should look at potential effects on the riparian area when developing the prescriptions. Streambank tree roots are essential for bank integrity, providing winter rearing habitat and minimizing bank erosion. LWD also creates side channels that are important for juvenile fish.

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CAUSAL MECHANISM REPORT - B1

Sensitive Area:	Road segments that deliver sediment to the stream network
Sub-Basins:	Beatrice Creek Boiling Springs Creek
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 ___ and ___ and prioritized in Appendix ___, Table ___.
Activity	due to old erosion control standards (BMP practices)
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.

CAUSAL MECHANISM REPORT - A1

Sensitive Area:	Steep slopes in glacial deposits adjacent to streams
Sub-Basins:	Beatrice Lower Murr Boiling Springs
Input Variable:	Coarse and Fine Sediment
Delivered Hazard:	MODERATE
Resource Vulnerability:	MODERATE (See Additional Comments for justification)
Rule Call:	MINIMIZE

SITUATION SENTENCE:

Input	Coarse and fine sediment
Time Frame	from potential future
Watershed Process	landslides on steep slopes adjacent to streams
Unit Location	mapped as Landform Unit ___
Activity	due to road construction and addition/concentration of water from road drainage
Conditions	within 100 feet (slope distance) of stream channels where the slope is greater than 80% or greater than 60% if evidence of seepage exists
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 cannel segments of GMU 4 in Beatrice Creek may potentially impede migration during base-flow peroids.

TRIGGERING MECHANISMS:

1) Road construction that removes trees along streambanks or locally increases slope gradient (eg. Sidecast material, cutslopes).
2) Road drainage addition, concentration from culverts, waterbars, dips, etc.

ADDITIONAL COMMENTS:

Discuss resource vulnerability modification

PRESCRIPTION(S):

CAUSAL MECHANISM REPORT - D1

Sensitive Area:	GMU 4
Sub-Basins:	Beatrice Creek Murr Creek
Input Variable:	Large Woody Debris
Delivered Hazard:	LOW (Segments____) MODERATE (Segments___) HIGH (Segments___)
Resource Vulnerability:	HIGH
Rule Call:	PREVENT OR AVOID

SITUATION SENTENCE:

Input	Large woody debris recruitment
Time Frame	from past and potential future
Watershed Process	timber harvest and road building along streams
Unit Location	mapped as wiithin GMU 4
Activity	
Conditions	
Channel Effects	
Location	
Resource Effects	

TRIGGERING MECHANISMS:

ADDITIONAL COMMENTS:

PRESCRIPTION(S):

CAUSAL MECHANISM REPORT - D2

Sensitive Area: GMU's with a moderate vulnerability to Large Woody Debris:

- GMU 1
- GMU 2
- GMU 3
- GMU 5
- GMU 6
- GMU 7
- GMU 8
- GMU 11

Sub-Basins: Beatrice Creek
Boiling Springs
Murr Creek

Input Variable: Large Woody Debris

Delivered Hazard: MODERATE (segments....)
HIGH (segments....)

Resource Vulnerability: MODERATE

Rule Call: MINIMIZE for MODERATE Delivered Hazard
PREVENT OR AVOID for HIGH Delivered Hazard

<u>SITUATION SENTENCE:</u>

Input ....

Time Frame ....

Watershed Process ....

Unit Location ....

Activity ....

Conditions ....

Channel Effects ....

Location ....

Resource Effects . . . .

TRIGGERING MECHANISMS:

ADDITIONAL COMMENTS:

Discuss Beatrice Creek road encroachment...

PRESCRIPTION(S):

CAUSAL MECHANISM REPORT - D3

Sensitive Area: GMU 10

Sub-Basins: Beatrice Creek

Input Variable: Large Woody Debris

Delivered Hazard: MODERATE (segments...)
HIGH (segments...)

Resource Vulnerability: HIGH

Rule Call: PREVENT OR AVOID

SITUATION SENTENCE:

Input . . . .

Time Frame . . . .

Watershed Process . . . .

Unit Location . . . .

Activity . . . .

Conditions . . . .

Channel Effects . . . .

Location . . . .

Resource Effects . . . .

TRIGGERING MECHANISMS:

ADDITIONAL COMMENTS:

PRESCRIPTION(S):

CAUSAL MECHANISM REPORT - D4

Sensitive Area: (Segments ...)

Sub-Basins: Boiling Springs

Input Variable: Solar Radiation

Delivered Hazard:

Resource Vulnerability:

Rule Call:

<u>SITUATION SENTENCE:</u>

Input . . . .

Time Frame . . . .

Watershed Process . . . .

Unit Location . . . .

Activity . . . .

Conditions . . . .

Channel Effects . . . .

Location . . . .

Resource Effects . . . .

<u>TRIGGERING MECHANISMS:</u>

<u>ADDITIONAL COMMENTS:</u>

<u>PRESCRIPTION(S):</u>

CAUSAL MECHANISM REPORT - D5

Sensitive Area: Channel Segment M1

Sub-Basins: Murr Creek

Input Variable: Riparian vegetation (shrubs)

Delivered Hazard: HIGH

Resource Vulnerability: MODERATE

Rule Call: PREVENT OR AVOID

SITUATION SENTENCE:

Input .... Rparian shrub growth

Time Frame .... due to past and present

Watershed Process .... livestock grazing

Unit Location .... in Channel Segment M1

Activity ....

Conditions ....

Channel Effects ....

Location ....

Resource Effects ....

TRIGGERING MECHANISMS:

ADDITIONAL COMMENTS:

PRESCRIPTION(S):

ADDITIONAL COMMENTS:

Note: discuss that though Murr Creek was a low hazad, there are opportunities to fix problems and these are identified in the appendix...

PRESCRIPTION(S):