SECTION III: REFERENCE AND CURRENT CONDITIONS

GEOLOGY AND GEOMORPHOLOGY

Overview and Background

The landscape of the Quartz Creek analysis area has been formed by glacial, alluvial and mass wasting processes acting on a substrate of relatively diverse volcanic bedrock types. Soil formation and development is limited by the relatively young geologic formations, the inherent slope instability caused by elastic rebound and increased topographic relief, and the differential weathering of the various geological deposits and formations. Hard, ridge-capping basalt flows overlie older, less indurated and more easily eroded volcaniclastic and sedimentary tuffaceous rocks that weather and produce unstable, erodible soils in the eastern half of the Quartz Creek and Mill Creek watersheds. This protective cover is generally absent in the western half of the analysis area.

A variety of erosional processes have acted to move sediment within the watershed areas. These include glacial and glacio-fluvial processes that have been very important in the main McKenzie River corridor, and various forms of mass soil movement in the steep canyons and side slopes of, especially, the Quartz Creek and Elk Creek watersheds. Fluvial erosion has been a long term control on developing steep slopes since the latest phase of geologic uplift occurred several million years ago. Rates of channel downcutting, controlled by bedrock resistance, has shaped the stream-side landscape by producing steep inner gorge slopes and narrow tributary canyons. Fluvial erosion also continues to play an important short-term role by dispersing and relocating sediment deposited by episodic landslide events and by rapidly transporting sediment through the tributary fluvial system to the McKenzie River.

The effects of historic land management in watersheds of the Quartz Creek watershed analysis area has been varied. Some watersheds, such as Elk Creek, have received very little human disturbance, and processes there remain visually low and virtually unaltered. In other areas, including much of Mill Creek and portions of Quartz Creek, past land management has been relatively intense and observed erosional processes have increased. In steep managed lands, both timber harvesting and road construction are associated with apparent increases in landslide frequencies and rates of fluvial and surface erosion. In more moderate and gentle terrain, mass movement features associated with land management are less common and smaller, and surface erosion is less apparent. In these areas, it is likely that fine sediment production from roads, and small scale bank erosion and bank failure along stream channels are the most significant sources of increased sediment production and delivery.

Reference Conditions

Disturbance regimes

The geologic materials of the analysis area, and the geologic uplift that rejuvenated the topography several million years ago, continue to strongly shape and control watershed processes and condition. Both large- and small-scale disturbances have been an integral part of the watershed's evolution, and the aquatic and terrestrial community has adapted to this disturbance regime. The landscape has evolved over millions of years, and through that time it has experienced catastrophic change and, in all probability, long intervening periods of relative stability.

Flood events of magnitude approximating the estimated 100-year recurrence event occurred in 1964 and 1996 (Table G1). These flood events, and the geomorphic processes they triggered, provide a glimpse into the nature and magnitude of mass wasting, erosion and channel modification that could be expected in the undisturbed watershed. Post-flood studies underway at sites in other locations such as the HJ Andrews suggest that significant erosion and sediment delivery can be expected to occur during very large storms, even in the undisturbed landscape. It is important to recognize that mass soil movement is the main process that has sculpted the analysis area, particularly the steeper tributary basins. This process can be expected to continue in the future, and it will result in periods when landsliding is occasionally widespread causing drastic changes in riparian and aquatic ecosystems.

Table G1. Flood events of McKenzie River tributaries (from Blue River Watershed Analysis 1997)

Year of Flood	Recurrence Interval –South Fork McKenzie[1]	Recurrence Interval - Lower Blue River[2]
December, 1945	25 years	Unknown
January, 1953	8 years	Unknown
December, 1955	16 years	Unknown
December, 1964	130 years	100 years
January, 1965	Unknown	12 years
January, 1971	15 years	Unknown
January, 1972	Unknown	8 years
December, 1977	Unknown	8 years
February, 1986	8 year	4.5 years
February, 1996	Unknown	Similar to 1964

[1] USGS gauging station, near Cougar Dam [2] USGS gagging station, Blue River below Tidbits Creek

The watershed response to episodic events is controlled by the magnitude of the disturbance event and the time between successive events. For example, when a hillslope fails by landsliding, the most unstable materials are transported down slope or downstream. They may come to rest on the hillslope or in a stream channel. The origination site of the slope failure is now more stable than before, but soil forming processes and geomorphic processes gradually begin to render the slope unstable. As soils develop through time on the landslide scar, and as hillslope creep and surface erosion processes gradually moves sediment from upland areas onto these steep swales and hillslopes, the sensitivity of the hillside to a large landslide triggering event will gradually increase.

Thus, when a large triggering disturbance event occurs in a watershed, the most susceptible sites are likely to fail. These sites are often located at, or associated with, steep zero order basins, inner gorge slopes, slope-breaks, zones of weathered bedrock, fault zones and zones of emergent groundwater on steep slopes. Subsequent events that occur close in time will trigger fewer and smaller hillslope responses. Large events separated by long-time intervals are each likely to generate more substantial geomorphic change. Large events separated by short-time intervals will produce less change but may keep the aquatic ecosystem in a continually degraded, under productive state.

Other large-scale disturbances have affected the watershed. The terrain has experienced glacial, near-glacial, and peri-glacial conditions and this influence persists in the main valley bottoms of the McKenzie River and Quartz Creek. Other flood generated impacts, such as terrace and flood plain formation, riparian removal, alluvial fan development, and severe channel erosion, are natural watershed effects that can be expected to occur in the future.

Large wildfires have denuded portions of the watershed. Historic fire suppression has probably reduced the short-term risk of a stand-replacing fire. Studies from nearby watersheds indicate the large stand-replacing fires occurred rarely, perhaps only every 300 years (P. Weisberg pers. comm., Connelly and Kertis 1992). The return interval for large fires are now considered to be over 500 years (Teensma 1987) making wildfire now a less important geomorphic process. However, uncontrolled wildfire in other forests of the western United States over the last decade shows that it is possible to achieve complete burns, and intensities can even be greater than under natural conditions due to decades of fire suppression. Thus, it is possible that wild fire will strip the watershed vegetation at some time in the future and expose the underlying soil mantle to dramatically increased rates of mass movement, surface erosion and sediment delivery.

Major events that reset the geomorphic and aquatic system would have been separated by relatively long periods of recovery lasting from decades to several centuries. Sedimentation rates from landslides and erosion would rapidly diminish as vegetation recovers on both the exposed source areas and the

depositional zones. Channel structure, riparian and aquatic function, and species populations would also recover as organic debris and sediment is accumulated and complex habitat is developed.

This process of episodic disturbance, and intervening recovery, is the background in which species have adapted over long periods of time. It works as long as: 1) the disturbance is not excessive compared to the survival needs of the species; 2) disturbance is a relatively short-term phenomenon, compared to habitat recovery; and 3) there are adjacent or nearby populations in relatively undisturbed ecosystems that can migrate and repopulate the recovered habitat. In the undisturbed landscape of western Cascades, this pattern of watershed and ecosystem disturbance and recovery was randomly distributed through time and space, creating watersheds across the landscape in different stages of recovery and productivity..

Terrain analysis

The earliest complete set of aerial photos reviewed for this analysis are from 1959. At that time, there were 11 clear-cut units in the upper Quartz Creek watershed (USFS ownership) covering approximately two square miles of land. A significant core road network had already been constructed in lower, middle, and upper hillslope positions. Private lands in the lower and middle watershed had already been significantly modified by timber harvest and road construction. Another 11 harvest units, and most of the presently existing road network, had already been completed in the Mill Creek block. Only the Elk Creek watershed remained relatively uncut by 1959

Although 1959 cannot be used as a reference condition, there were still large areas of the analysis area that had not yet been entered. Viewing the relatively unbroken canopy of these areas in the 1959 photos does little to portray the range and potential magnitude of erosional processes that are likely to have occurred. Aerial photos present one view of the watershed, but this view is limited, and using a "point-in-time" to represent reference conditions is also problematic.

Pre-European settlement conditions can better be inferred by quantitative slope modeling, studies from other nearby watersheds, and interpretation of present day topography and landforms. Physical observations of terrain as well as field observations of recent flood damage and storm impacts suggest that debris sliding and mass movement processes are an important sediment production mechanism in most of analysis area. Post-storm aerial reconnaissance of the Oregon Cascades, including both Quartz Creek and its adjacent watersheds (Pacific Watershed Associates 1996) noted a number of landslides triggered by the February 1996 storm event. Similarly, studies from the nearby HJ Andrews Experimental Forest have identified landsliding as the most significant sediment production mechanism in the region.

To identify which portions of the landscape are most susceptible to mass movement, slope maps were prepared for the entire watershed analysis area (Maps 6a-6d). These four maps outline areas of steep, dissected terrain throughout the watershed analysis area. The land within the watershed analysis area was first divided into seven discrete mapping units or "blocks," based on geographic location and general topographic characteristics. The land blocks are referred to as:

1. Upper Quartz Creek	Map 6a
2. Deathball Mountain – Thors Hammer	Map 6b
3. Ennis Creek	Map 6c
4. Mt Hagan – Doris Creek	Map 6c
5. Elk – Cone Creek	Map 6c
6. Lookout Ridge	Map 6b
7. Mill Creek – Castle Rock	Map 6d

The terrain analysis consisted of several elements, but focused on the identification of slopes exceeding 65 % gradient. These are areas where mass wasting processes are most likely to be initiated. Along stream channels, these slopes are known as inner gorge slopes. The steep slopes were then divided into areas that were most likely and least likely to cause sediment delivery to the stream channel network, either through direct landsliding or through debris torrenting processes. Steep slopes were divided into those marked "i", potential initiation sites, and those marked "u", upland sites on the map. Initiation sites were those that displayed relatively continuous steep slopes indicating they could deliver sediment to the stream channel system. Upland sites were equally as steep, but the probability of sediment delivery to a channel was minimal. These upland sites are generally separated from the stream network by broad benches or low gradient areas which would effectively eliminate the possibility of sediment delivery, or they may represent rock falls and talus slopes beneath outcrops of resistant bedrock typically found around the basin's upland margins.

Upper Quartz Creek Block. This block can be divided into several topographically distinct units (Map 6a). Steep slopes constitute only 36% of the block (Table G2) but sub-watersheds within this block display distinctly different surface morphologies, and these have been further subdivided based on slope gradient (Tables G2-G5). Map 6a depicts the classification of upper Quartz Creek watershed areas according to slope gradient and the potential for sediment delivery from areas that fail by mass wasting processes.

Table G2. Distribution and frequency of steep slopes in the upper Quartz Creek block, Quartz Creek watershed analysis area

Upper Quartz Creek sub-watershed areas	"u" - Steep slopes; delivery unlikely (slopes > 65%) (acres)	"I" – Possible landslide initiation sites with delivery (slopes > 65%) (acres)	Total area in steep slopes (>65%) (acres)
Upper western	195	36	231
Western	104	1,806	1,910
Upper eastern	235	0	235
Eastern	194	971	1,165
Total	728	2,813	3,541
% of total	7%	28%	36%

Most of the far upper basin consists of relatively gentle uplands with a limited number of steep slopes typically confined to bedrock exposures and adjacent talus slopes (Table G3). This area is conveniently contained on the Sardine Buttes topographic quadrangle. Only 18% of this 2,588 acre upper watershed area is classified as having steep slopes and 98% of the steep slopes are not considered as having the potential to develop debris torrents or debris landslides that could enter stream channels.

Table G3. Distribution and frequency of steep slopes in the upper Quartz Creek (area contained on Sardine Butte USGS topographic quadrangle)

Slope category	Area (acres)	% of total	% of all steep slopes
Steep (>65%)	466	18%	100%
U (steep, no delivery)	455	18%	98%
I (steep, potentialdelivery)	11	<1%	2%
Moderate & gentle (<65%)	2,122	82%	–
Total Acreage	**2,588**	**100%**	–

Indian Creek, the largest of the upper Quartz Creek tributaries on USFS lands, contains some of these upper hillslope areas, but in its middle and lower reaches it becomes more deeply dissected. Approximately 35% of the 2,952-acre Indian Creek watershed is composed of steep slopes. Nearly 60% of these steep slopes were classified as having the potential to develop debris torrents (based of the presence of steep stream channels or swales) or debris slides that could deliver sediment to streams (Table G4).

Table G4. Distribution and frequency of steep slopes in the Indian Creek sub-watershed, Quartz Creek

Slope category	Area (acres)	% of total	% of all steep slopes
Steep (>65%)	1,038	35%	100%
U (steep, no delivery)	429	15%	41%
I (steep, potential delivery)	609	21%	59%
Moderate & gentle (<65%)	1,914	65%	–
Total Acreage	**2,952**	**100%**	–

Lytle Creek is a steep, 676-acre tributary that enters the main stem of Quartz Creek on the east bank (Map 6 a). Nearly 50% of the slopes were classified as exceeding 65% gradient, and virtually all the steep slopes appear to have the potential for mass wasting which could directly enter the channel or torrent from steep swales down to the junction with Quartz Creek (Table G5).

Table G5. Distribution and frequency of steep slopes in the Lytle Creek sub-watershed, Quartz Creek			
Slope category	**Area (acres)**	**% of total**	**% of all steep slopes**
Steep (>65%)	327	48%	100%
U (steep, no delivery)	0	0%	0%
I (steep, potential Delivery)	327	48%	100%
Moderate & gentle (<65%)	349	52%	--
Total Acreage	**676**	**100%**	--

West of the main stem of Quartz Creek several small watersheds have their headwaters on USFS lands and then drain across private timber company lands before entering Quartz Creek downstream from federal lands. These tributaries form the steep headwaters to Fawn Creek. Approximately 62 % of the 660 acres on federal lands in these headwaters areas are comprised of lands steeper than 65 %, and virtually all of these steep slopes were judged to have the potential for downstream sediment delivery (Table G6).

Table G6. Distribution and frequency of steep slopes in the Fawn Creek tributaries of Upper Quartz Creek			
Slope category	**Area (acres)**	**% of total**	**% of all steep slopes**
Steep (>65%)	412	62%	100%
U (steep, no delivery)	0	0%	0%
I (steep, potential delivery)	412	62%	100%
Moderate & gentle (<65%)	251	38%	--
Total Acreage	**663**	**100%**	--

Deathball Mountain –Thors Hammer Block. This block is located in the lower, eastern portion of the Quartz Creek watershed (Map 6b). Some area of the block drain east to the South Fork McKenzie River basin and, although shown on Map 6b, are not included in the data analysis. The topography in this land block is generally steep and dissected. There are two distinct radial drainage patterns flowing in all compass directions from the peaks of Deathball Mountain at elevation 4,600 feet and from Thors Hammer at elevation 3,000 feet down to main channel of lower Quartz Creek at 1,000 feet elevation.

Topographic analysis reveals that over 60 % of the land base in this 5,330-acre block is composed of slopes steeper that 65 %, and that 88 % of these steep slopes have the potential for both sediment production and delivery into to steep channel sideslopes or swales that could torrent to lower elevation areas (Table G7). Although the headwaters of these steep upland channels are within the National Forest, their lower reaches flow through private timber company land.

Table G7. Distribution and frequency of steep slopes in the Deathball Mountain – Thors Hammer Blocks, lower eastern Quartz Creek watershed, McKenzie River			
Slope category	**Area (acres)**	**% of total**	**% of all steep slopes**
Steep (>65%)	3,266	61%	100%
U (steep, no delivery)	379	7%	12%
I (steep, potential delivery)	2,887	54%	88%
Moderate & gentle (<65%)	2,064	39%	--
Total Acreage	**5,330**	**100%**	--

Ennis Creek Block. This block consists of 1,984 acres of ridge top and hillslopes in the lower, western portion of the Quartz Creek watershed. Roughly one-third of the block drains west to Ennis Creek , a direct tributary to the McKenzie located downstream from Quartz Creek, one-third drains east to lower Quartz Creek ,and one-third flows north directly to the McKenzie River (Map 6c).

Terrain analysis indicates that approximately 54 % of the Ennis Block is comprised of steep hillslopes (Table G8). Of the steep slopes, 95 % were judged to have the potential to delivery sediment to a stream either through debris sliding or torrenting. Deep channel incision on the north- and east-facing slopes suggests that many of these channels have been sculpted by mass wasting and torrenting processes.

Table G8. Distribution and frequency of steep slopes in the Ennis Block, lower western Quartz Creek watershed, McKenzie River

Slope category	Area (acres)	% of total	% of all steep slopes
Steep (>65%)	1,075	54%	100%
U (steep, no delivery)	49	2%	5%
I (steep, potential Delivery)	1,026	52%	95%
Moderate & gentle (<65%)	909	46%	–
Total Acreage	**1,984**	**100%**	–

Mt Hagan – Doris Creek Block. This block actually consists of three units which includes the 495-acre Mt Hagan area and two isolated 40-acre blocks located just upstream from Finn Rock (Map 6c). All the units are located on the north side of the McKenzie River with a south- and southeast-facing exposure. The terrain consists of low- and moderate-gradient ridge top areas separated by very steep hillslope areas which lead to deeply incised swales and small stream channels that drain to the McKenzie River.

Visually, the hillslope channels appear to be dominated by debris torrenting processes that have intermittently scoured the colluvial debris from steep bedrock lined channels in the upper hillslope channels. These channels then discharge debris onto the terraces along the McKenzie River and produce alluvial fans where the tributary valleys become unconfined and channel gradients diminish. Just over 70 % of the land base in this block is composed of steep slopes. 55 % of the steep slopes have the potential for sediment delivery (Table G9). The steep slopes with no expected delivery are in the upper hillslope positions and they terminate in a broad bench that parallels the McKenzie River at an elevation of about 1,000 feet above the river. This is probably either a bedrock bench or a remnant strath terrace.

Table G9. Distribution and frequency of steep slopes in the Mt. Hagan – Doris Creek Blocks, Minor watersheds (McKenzie River slopes)

Slope category	Area (acres)	Pct of total	Pct of all steep slopes
Steep (>65%)	408	71%	100%
U (steep, no delivery)	178	31%	44%
I (steep, potential delivery)	230	40%	56%
Moderate & gentle (<65%)	167	29%	–
Total Acreage	**575**	**100%**	–

Elk Creek – Cone Creek Block. This block is one of the steepest and least disturbed watersheds in the analysis area. It consists of 3,465 acres of very steep forested slopes with deeply incised drainages separated by long, narrow ridges (Map 6c). Approximately 64 % of the slopes in these watershed areas are classified as steep. Over 90 % of these steep slopes are continuously steep to the basal stream channels (Table G10). Although the three main channel systems are deeply incised into the landscape (Map 6c), the side slopes which drain into these channels are typically long and uniform with only moderate incision of small, steep feeder channels and swales. The long planar slopes between these swales suggests these hillslopes may be more controlled by soil creep and surface erosion than by debris torrenting. Intermediate hillslope benches, suggestive of slumping and ancient or recent landsliding, are not as common in this block as in other blocks.

Table G10. Distribution and frequency of steep slopes in the Elk – Cone Creek Blocks, Minor watersheds (McKenzie River slopes)

Slope category	Area (acres)	% of total	% of all steep slopes
Steep (>65%)	2,226	64%	100%
U (steep, no delivery)	131	4%	6%
I (steep, potential delivery)	2,095	60%	94%
Moderate & gentle (<65%)	1,239	36%	–
Total Acreage	**3,465**	**100%**	–

Lookout Ridge Block. This block is located on the north side of the McKenzie River valley just east of the town of Blue River. It is a relatively long, narrow strip of land extending from the McKenzie River up to the ridge separating the McKenzie from the Blue River drainage (Map 6b). It contains some of the lowest McKenzie River valley glacial features, where valley glaciers actually breached the ridge crest between the two drainages at Saddle Dam.

In general, slopes in the Lookout Ridge block are not as steep as those in the blocks of Quartz Creek or in downstream areas. Only 33% of the hillslopes in the 3,465-acre block are classified as steep and over half of the steep slopes have been classified as "upland" slopes with minimal potential for sediment delivery to a stream channel (Table G11). The slopes with the greatest potential for sediment delivery are those immediately adjacent to the McKenzie River, but these are relatively undissected and do not exhibit numerous signs of recent landsliding or torrenting.

Table G11. Distribution and frequency of steep slopes in the Lookout Ridge Block, Minor watersheds (McKenzie River slopes)

Slope category	Area (acres)	% of total	% of all steep slopes
Steep (>65%)	492	32%	100%
U (steep, no delivery)	269	18%	55%
I (steep, potential delivery)	223	15%	45%
Moderate & gentle (<65%)	1,030	68%	
Total Acreage	**1,522**	**100%**	–

Mill Creek – Castle Rock Block. This block consists of hillslopes on both the south side (Castle Rock) and north side (Mill Creek) of the McKenzie River (Map 6d). In spite of the fact that slopes immediately below Castle Rock are extremely steep, average slope gradients in the block are significantly lower than in the other blocks. In addition, stream channels drain onto wide sections of the McKenzie River terrace and flood plain before entering the river. This allows for some filtering and deposition of sediment that may be generated by upland hillslope processes. Debris torrents that extend from steep upslope areas and travel to the McKenzie are very unlikely.

Tables G12 and G13 itemize the land base and slope classification for the Mill Creek - Castle Rock land block (they are report here in separate tables). Excluding the flat, broad McKenzie River valley, these contributing watershed areas total just over 4,000 acres. In total, steep slopes account for less than 20 % of the watershed areas. Only 12 % of the Castle Rock hillslopes are steep, and these are almost exclusively confined to the upper elevations below Castle Rock peak. None of these slopes are expected to deliver sediment directly to the McKenzie through mass wasting processes.

On the north side of the river valley, the Mill Creek sub-block drains the slopes from Lookout Ridge to the McKenzie River. The western 2/3 of the area contains unusually low-gradient hillslopes. Isolated steep slopes exist primarily along the ridge crest and along a single long, narrow bench on the valley margin. These areas have likely been modified by past valley glacial activity and broad, hillslope-slumping processes. The eastern 1/3 of the Mill Creek sub-block is drained by a deeply incised, unnamed stream channel and contains most of the steep slopes in the unit. Those slopes immediately adjacent the channel were identified as the most likely locations for debris sliding that could enter the stream and be transported to downstream areas. Overall, the Mill Creek sub-block contained only 20 % of its areas in steep slopes, and 60 % of these potential landslide initiation sites are not expected to affect adjacent or downslope stream channels.

Table G12. Distribution and frequency of steep slopes in the Mill Creek Block (McKenzie River slopes)

Slope category	Area (acres)	% of total	% of all steep slopes
Steep (>65%)	568	20%	100%
U (steep, no delivery)	341	12%	60%
I (steep, potential delivery)	227	8%	40%
Moderate & gentle (<65%)	2,347	80%	–
Total Acreage	**2,915**	**100%**	–

Table G13. Distribution and frequency of steep slopes in the Castle Rock Block (McKenzie River slopes)

Slope category	Area (acres)	% of total	% of all steep slopes
Steep (>65%)	142	12%	100%
U (steep, no delivery)	142	12%	100%
I (steep, potential delivery)	0	0%	0
Moderate & gentle (<65%)	1,025	88%	–
Total Acreage	**1,167**	**100%**	–

Debris torrent channels

Land blocks in the Quartz Creek watershed and in the western half of the Minor watershed area show evidence of being modified repeatedly by debris landsliding and debris torrenting. Steep, deeply incised swales and small stream channels have dissected the hillslopes draining these areas. These channels have probably developed over several thousands of years by repeated mass wasting events.

The location, frequency and density of possible debris torrent channels were plotted on the slope maps (Maps 6a – 6d). Dots have been used to designate those steep channels and channel reaches where it appears that debris torrents have been active or where slope gradients of the channels are sufficiently steep to allow a debris landslide to propagate downstream as a torrent. These channel segments would be debris torrent source areas. Not all channels have continuous marking. Thus, if channel gradients diminish and they do not appear to be steep enough to allow for debris torrent initiation, the channel segment is not marked.

Table G14 summarizes the data from all the land blocks and sub-blocks that have been described above. Approximately 42 mi^2 of terrain are included in the analysis. Just under 80 miles of potential torrent channel was measured from the maps, for an average torrent channel density of 1.9 mi/mi^2. The steeper more deeply incised drainages consistently showed densities from 2.0 to 3.0 mi/mi^2, while the more gentle blocks had torrent channel densities between 0.2 and 0.5 mi/mi^2. The sub-watersheds with the highest torrent channel densities were Lytle Creek at 3.5 mi/mi^2, and Fawn Creek at over 4.5 mi/mi^2, both in the upper Quartz Creek block.

Table G14. Length and density of mapped potential torrent source channels, Quartz Creek and Minor watershed analysis area

Designated land block	Block Area (mi^2)	Potential torrent source channel length (miles)	Potential torrent channel density (mi/mi^2)
Upper Quartz Creek	15.5	34.9	2.3
Deathball Mtn – Thors	8.3	18.9	2.3
Ennis Blocks	3.1	8.1	2.6
Mt Hagan – Doris Block	0.9	2.7	3.0
Elk – Cone Creek Block	5.4	11.7	2.2
Lookout Ridge	2.4	0.7	0.3
Mill Creek Block	4.6	2.3	0.5
Castle Rock Block	1.8	0.3	0.2
Total	**42.0**	**79.6**	**1.9**

Volumetrically, mass soil movement appears to represent the single most significant contributor to watershed erosion and sediment delivery. Debris torrents and stream side debris slides have a high likelihood of delivering both sediment and large organic debris to high-order stream channels, where it becomes an integral and necessary component of aquatic habitat for a variety of species. This process is perhaps the most important geomorphic process

regulating ecosystem function within the large-scale fluvial systems, such as Quartz Creek. The contribution of large organic debris to the aquatic system may be as important as the delivery of sediment. Organic debris can be delivered by several mechanisms, including debris slides, debris torrents, bank erosion and direct toppling from the riparian zone.

Sediment sources

Although no sediment source inventory, sediment budget, or comparable investigation has been completed for either Quartz Creek or the Minor Tributaries watersheds, extensive long-term analysis of erosion and sedimentation processes has been the focus in the nearby HJ Andrews Experimental Forest. Information from this site, as well as existing soil mapping data and field observations of the analysis area, provides some insight into the likely importance of various sediment production mechanisms.

Soils mapping data were used to portray the inherent natural stability of various portions of the landscape (Map 7). The stability rating is based on the relative stability of the soil mapping units and includes mass soil movement by slumps, slides and deep seated failures (Legard and Meyer 1973). The classification is based largely on visible evidence of the frequency of recent and past failures associated with various soil units as they occur throughout the region.

Table G15 describes the spatial data visible in Map 7. Clearly, soil mapping data suggests that the great majority of the landscape in the Quartz Creek and Minor Tributaries watersheds analysis area is stable in the undisturbed state. Over 75 % of the soils are classified as stable or very stable. Those land areas with potentially the most unstable soils are Mill Creek (46 %) and Castle Rock (25 %). These two areas are perhaps the most resilient to the geomorphic effects of large storms (i.e., debris sliding and debris torrenting) but may exhibit slump and earthflow processes (see Map 6d). Land blocks and watershed areas exhibiting soils with the greatest inherent stability include Cane and Coffee Creek tributaries of the Deathball Mountain block and the Elk – Cone Creek block (Table G15). Some of the steepest lands are underlain by the most resistant and stable bedrock units and, in the undisturbed state, this is where they derive their natural stability. These steep terrain types are relatively stable, but still prone to shallow–rapid landslide processes during extreme storm events.

Table G15. Natural stability of soils in selected watersheds of the Quartz Creek and Minor watersheds analysis area (from SRI)

Watershed	Natural stability rating (acres)				
	Very stable	Stable	Moderately stable	Unstable	Total
Cane – Coffee Ck.	14	2950	130	60	3154
Wycoff – Sugar Ck.	11	997	360	0	1368
West lower Quartz Ck.	0	266	67	24	357
Upper Quartz Ck.	241	2255	409	0	2905
Lytle – Indian	325	3448	413	21	4207
Fawn – Buck	13	1684	95	345	2137

Table G15. Natural stability of soils in selected watersheds of the Quartz Creek and Minor watersheds analysis area (from SRI)

Watershed	Natural stability rating (acres)				
	Very stable	Stable	Moderately stable	Unstable	Total
Elk Ck – Cone Ck	0	2786	496	0	3282
Mill Creek	318	1229	1267	948	3762
Swamp – Castle Rock	239	478	9	628	1354
Total	**1161**	**16093**	**3246**	**2026**	**22526**
Percent of total (%)	**5%**	**71%**	**14%**	**9%**	**100%**

The soil mapping data classifies 86 % of the upper Quartz Creek watershed as either very stable or stable. These same relationships were inferred from the topographic terrain analysis (Table G2) where 19 % of the area was classified as having moderate or gentle slopes and a general absence of torrent features.

This simple analysis, using the soil mapping data, provides a glimpse of possible watershed processes under reference conditions. But its use is limited because it relies on regional information and has not been specifically developed or ground-truthed for the Quartz Creek analysis area. For example, debris slide origination points are most commonly associated with certain geologic types, geomorphic locations, topographic positions and slope gradients, as well as soil characteristics. With a digital elevation model to generate hillslope gradients, topographic data can be modeled to segregate the landscape into zones of comparable expected landslide frequency under reference watershed conditions. Such a model would provide another approximation of the potential for mass wasting processes.

Clearly, absolute landslide frequencies will vary under a more complicated set of variables and conditions. As a result, more complicated models can be used to derive predicted rates of landslide occurrence. However, simple GIS spatial analysis programs can begin to assist in the process of categorizing the watershed analysis area into different stability zones, based on a variety of factors which have been determined, in the field, to be associated with landslide occurrence. This zonation can then be used to predict the frequency and location of potential sites of natural slope instability, and to evaluate the observed effects of past land management practices throughout the watershed analysis area.

In addition to debris landslides and debris torrent processes, small debris slides and stream bank failures are also thought to be fairly common mechanisms of sediment production along tributary channels and along main channels that are flowing through their own alluvium. Isolated bank failures, typically located on the outside of meander bends or where large organic debris had deflected flow against the stream bank, were observed on channels in the Quartz Creek, Elk Creek and Mill Creek watersheds. In steep boulder bed channels and where channel banks are lined with boulders or bedrock, stream bank erosion will be relatively unimportant. Although believed to be relatively common both in the

managed and reference watershed condition, these small failures probably contribute a relatively small cumulative volume of sediment to the stream channel system[1]. In an undisturbed riparian setting, they are probably more important in their function of introducing mature, whole trees to the stream channel.

Deep-seated landslides, including forested earthflows and block slides, are also found in the nearby H.J. Andrews Experimental Forest. They occur on gentler slopes than debris slides, and they form in areas of poor drainage, abundant near-surface groundwater and deep soils. Deep-seated slides often involve much larger volumes of material than debris slides, but they occur less frequently and deliver only a small fraction of their volume to the stream channel each time they fail or move. Unlike debris slides, they usually do not fail all at once. Deep-seated landslides were observed to occur locally in the Quartz Creek analysis area, but there has been no inventory to determine their frequency or importance in watershed sediment production.

Several other erosion processes can have a significant effect on watershed erosion rates, and aquatic habitat, during certain conditions. Unlike mass movement processes, which might occur on 1 % of the landscape during a given century, the widely dispersed processes of surface erosion, soil creep, root throw, animal burrowing, and solution transfer, occur on nearly 100 % of the watershed area. Surface erosion by rilling and sheet wash in the undisturbed forest is thought to be very low on all but the most severely disturbed sites due to rapid infiltration and low runoff (Harr 1977, Swanson et. al. 1987). Surface erosion by dry ravel, raindrop impact and freeze-thaw can be locally important on steep slopes. Root throw and burrowing can also be effective "soil moving" processes over long time periods, especially on steep slopes, but they probably account for relatively low volumes of annual sediment delivery to the stream system.

Processes that result in slow rates of soil delivery to the steep, high-energy channels of the analysis area probably have little negative effect on aquatic habitat. Soil mantle creep and solution processes may be volumetrically more important than surface erosion, but their influence on, or ability to degrade, aquatic habitat structure and complexity is probably minimal. Annual rates of material transfer are generally considered be low and their contribution to total sediment load represents a subtle component of the sediment budget.

Exposure of large areas of the watershed through wildfire was, in all likelihood, an episodically important sediment production mechanism. Average recurrence intervals of 200 years have been reported as typical for central western Cascade

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[1] The exception may be in the Mill Creek area, where relatively gentle topography appears to have resulted in lower rates of debris sliding. Here, small stream side landslides may be a more important component of the overall sediment budget.

Mountain forests (Swanson 1981). Such fires would have increased the susceptibility of the landscape to mass soil movement and dramatically raised short-term surface erosion rates. The greater the erodibilty of the landscape, the greater the erosional consequences or response of the watershed would have been. Swanson (1981) has estimated a five-fold increase in sediment yield may occur in steep unstable terrains following intense wildfires, with subsequent recovery periods of 20 to 30 years.

Soils mapping data can be used to portray the inherent natural erodibility of various portions of the landscape in the Quartz Creek watershed analysis area (Map 8). The mapped rating is based on the expected erodibility and soil loss once vegetation and organic material has been stripped from the surface such as from landslides or fire. The values range from minor sheet and rill erosion in the "slight" category, to large soil losses from numerous small or large gullies or heavy sheet erosion in the "extreme" classification (Table G16). Such a view qualitatively segregates the watershed analysis area into zones of relative erodibility and watershed response to soil exposing events such as wildfire and widespread landsliding.

Table G16. Surface erosion potential of disturbed soils in selected watersheds of the Quartz Creek and Minor Tributaries watersheds (from SRI).

	Soil erosion potential rating (acres)					
Watershed	**Slight**	**Low**	**Moderate**	**Moderate to extreme**	**Extreme**	**Total**
Cane – Coffee	14	0	52	216	2807	3089
Wycoff – Sugar	8	0	93	330	921	1352
West lower Quartz	0	0	24	0	333	357
Upper Quartz	216	0	426	70	2186	2898
Lytle – Indian	262	0	471	331	3126	4190
Fawn – Buck	0	0	446	185	1501	2132
Elk Ck - Cone Ck	0	0	129	15	3128	3272
Mill Creek	0	0	2804	434	524	3762
Swamp - Castle Rock	6	0	870	286	189	1351
Total	**506**	**0**	**5315**	**1867**	**14715**	**22403**
Percent of total (%)	**2%**	**0%**	**24%**	**8%**	**66%**	**100%**

In contrast to the natural stability ratings (Table G15), most of the soils exhibit an extreme or moderate/extreme potential for surface erosion once they are exposed following disturbance (Table G16). Thus, 74 % of the area--over 16,500 acres--are classified as exhibiting significant potential for surface erosion and only 2 % of the area contains soils with a slight or low erosion potential. Some watershed areas contain an abundance of extremely erodible soil units. Over 90 % of the Cane–Coffee Creek sub-watershed on federal land has an extreme erosion potential, as does over 95 % of the Elk--Cone Creek watershed. In contrast, 75 % of the Mill Creek watershed area contains soils with only a moderate potential for accelerated surface erosion.

When determining reference conditions, it is important to recognize that the condition of riparian and aquatic habitat of Quartz Creek and its tributary sub-basins has varied through time. The picture of a closed, old-growth canopy

across the hillsides, together with a mature, closed riparian canopy, as seen in the earliest aerial photography of the area, depicts a point in time following relative watershed stability and quiescence. This picture of "steady-state" processes and continual high quality habitat would have been punctuated by periods of relatively great upheaval.

Up to the turn of the century, variation in the watershed conditions through time was largely a function of episodic natural disturbances, including wildfire and flood. Some events were likely to have been extreme. It is almost certain that widespread mass wasting during large flood events or following extreme wildfire incursions would have introduced substantial quantities of sediment and organic debris to the channel system. High flows and increased sedimentation resulted in channel changes and the development of new organic structure in the streams. On occasion, large portions of the riparian zone of high order stream channels would have been swept clean.

Recovery would have been an incremental process. Initially, water temperatures may have increased in the open riparian zone and sedimentation may have reduced the quality of aquatic habitat. In the years succeeding the flood, increased mass wasting from stream side areas and erosion of bare landslide scars would have maintained relatively elevated levels of annual sedimentation. Debris jams would have enlarged or sealed with fine material. Over time, sediment storage and pool development near organic debris would begin to add complexity to the aquatic habitat.

During the lengthy intervening periods of stability, riparian areas would have matured and eventually have been dominated by large conifers. The riparian forest would have provided shade and cool water temperatures. Channel structure would have been controlled by the occasional introduction of individual pieces of large woody debris from the riparian zone, or the localized entry of pulses of sediment and woody debris from isolated debris torrents originating from the upland areas during moderate storm events.

Although no studies have been performed, the geomorphic evidence of prehistoric floods and sedimentation events, as described above, is exposed in a number of locations in the Quartz Creek analysis area. For example, high flood plains and overflow channels attest to the occurrence of past flood events exceeding those of historical times. The junctions of many tributary watersheds show substantial alluvial fan development and/or hummocky debris torrent deposits suggestive of multiple episodes of sedimentation. It is unknown when, or over what time frame, these deposits accumulated but their presence indicates past episodes of flooding, mass movement and sedimentation as great or greater than those of historical events. Likewise, without further study, it is not possible to determine if these sedimentation events occurred concurrently in many different tributaries, or were isolated in time and space from each other.

In summary, little direct, quantitative information exists regarding historic conditions that have been responsible for the evolution of the morphology the analysis area. It is assumed, based on the existing evidence, that the analysis area has experienced episodes of moderate and extreme disturbance, both fire and flooding, followed by extended periods of relative quiescence and recovery. Aquatic and riparian function, and the species that depend on these conditions, have evolved and thrived under these conditions. What is not known is the relative magnitude of these disturbances, their timing or frequency of occurrence, and the extent to which such events produced temporally synchronous watershed response such as widespread landslides throughout the watershed, as opposed to locally isolated tributary or main stem landslides and sediment input.

Current Conditions

The current condition of the Quartz Creek analysis area is a result of a complex mixture of both natural disturbance events and land management activities. Erosional patterns in the managed watershed areas have changed significantly from the erosional model developed to describe pre-European reference conditions. Yet, much of the watershed processes that occur under reference conditions apply to the current condition of the watershed. All geomorphic processes, although modified in frequency and magnitude by recent land and resource management practices, are still operative.

Land management and sediment production

Land management in the Quartz Creek analysis area has generally consisted of timber harvesting and road construction in the wildland portions of the watershed, and highway construction, residential development and limited commercial development primarily within the McKenzie River corridor. Development along the terraces and flood plains of the McKenzie River, especially early road construction and road maintenance activities, has locally resulted in increased bank erosion and the introduction of sediment into the river system. Volumetrically, it is unlikely that this amount of sediment has had a serious, long-term negative impact on channel processes. More important than increased erosion, from view of the aquatic ecosystem, has been the permanent removal of portions of the riparian corridors and the terrestrial and aquatic habitat it once contained, as well as the permanent loss of a source of large woody debris.

Road-related erosion. Map 9 depicts the road network that currently exists within the Quartz Creek watershed analysis area. Roads within private lands, including an extensive network of logging roads in the middle Quartz Creek watershed, have generally been omitted. Road densities in the upper Quartz Creek watershed average about 4.5 mi/mi^2, moderately high compared to Forest Service lands elsewhere. Road densities are somewhat lower in the Mill Creek

area--about 3 mi/mi^2 --and even lower in the relatively undisturbed Elk Creek watershed--about 1.5 mi/mi^2.

Based on data in the Soil Resource Inventory (Legard and Meyer 1973) soil units within the analysis area were categorized in several ways to illustrate the changes in sediment production which have occurred, or are likely to occur, in response to various land management practices. For example, Map 8 portrays soil units according to their relative potential for surface erosion when disturbed. This would indicate the erodibility of the soils when disturbed by any process, including landsliding, burning, harvesting and road construction.

The surface erosion potential map (Map 8) does not portray actual sediment production, but the potential for erosion from sites that are disturbed. Thus, although much of the Elk Creek watershed exhibits an extreme potential for surface erosion, the minimal amount of human disturbance in that watershed has limited accelerated sediment production.

In contrast, the upper Quartz Creek watershed also exhibits considerable terrain in the extreme erosion potential category, and substantial harvesting and road construction would indicate that past surface erosion in this area is likely to have been significantly increased over pre-disturbance conditions. Most present–day surface erosion in these areas likely originates from the road surface and adjacent exposed cutbanks and ditches.

Finally, much of the McKenzie River corridor and the Mill Creek area is underlain by soils which exhibit only a moderate potential for surface erosion when disturbed. Although there has been considerable road construction and harvesting in this area, unit surface erosion rates are assumed to have increased to a lesser degree than in the Quartz Creek watershed. Field observations suggest these general conclusions are valid.

Road construction accelerates sediment production in several ways. Soils exposed during and following construction activities are prone to increased rates surface erosion, especially as compared to surface erosion rates within an undisturbed, vegetated forest (Table G17). Soils in the Cane and Coffee Creek basins, and in the Elk and Cone Creek watersheds, exhibit comparatively high susceptibility to road fill surface erosion.

Table G17. Predicted surface erosion potential of exposed sidecast and road fill materials in selected watersheds of the analysis area (SRI).

Watershed	Surface erosion potential of sidecast and road fill materials (acres)				
	Low	Moderate	Moderate to high	High	Total
Cane – Coffee	143	79	2807	60	3089
Wycoff – Sugar	281	59	921	90	1351
West lower Quartz	0	0	290	67	357
Lytle – Indian	469	887	2565	270	4191
Fawn – Buck	20	178	1846	88	2132
Elk Ck – Cone Ck	9	131	2646	487	3273

Table G17. Predicted surface erosion potential of exposed sidecast and road fill materials in selected watersheds of the analysis area (SRI).

Watershed	Surface erosion potential of sidecast and road fill materials (acres)				
	Low	Moderate	Moderate to high	High	Total
Mill Creek	322	430	1472	1538	3762
Swamp – Castle Rock	239	286	818	9	1352
Total	**1732**	**2112**	**15551**	**3010**	**22405**
Percent of total (%)	**8%**	**9%**	**69%**	**13%**	**100%**

Loose sidecast on steep slopes is also susceptible to mass movement processes, particularly where construction has occurred on steep stream-side slopes without employing end-hauling techniques to remove spoil materials (Table G18). Based on their physical characteristics, some soils are more prone to these processes than are others. Map 10 depicts the susceptibility of sidecast soils to mass wasting processes.

Table G18. Failure susceptibility of road fill and sidecast materials in selected watersheds of the Quartz Creek and Minor watersheds analysis area (from SRI)

Watershed	Road fill failure potential (acres)						
	Low	Moderate	High	Low-moderate	Low – high	Moderate to high	Total
Cane – Coffee	92	269	72	0	130	174	737
Wycoff – Sugar	11	839	16	60	270	173	1369
West lower	0	266	67	0	0	24	357
Upper Quartz	287	25	102	2106	8	377	2905
Lytle – Indian	1080	270	16	2676	144	21	4207
Fawn – Buck	13	1391	11	371	7	345	2138
Elk Ck - Cone Ck	125	97	2969	5	9	77	3282
Mill Creek	423	1610	133	645	4	948	3763
Swamp–Castle Rock	1333	3376	628	482	151	370	6340
Total	**3364**	**8143**	**4014**	**6345**	**723**	**2509**	**25098**
Percent of total (%)	**13%**	**32%**	**16%**	**25%**	**3%**	**10%**	**100%**

The distribution of soils that are "sensitive" to these road construction activities reveals that road construction has at least a moderate likelihood of increasing, or having increased, sediment production for large portions (93 %) of the watershed analysis area. On average, soil materials display a wide range of stability ratings for road sidecast construction. Potentially negative effects can often be avoided or mitigated by employing special construction techniques in areas where sidecast would otherwise be placed on steep or potentially unstable hillslopes near streams. Fortunately, some of the most sensitive sites (e.g., the Elk Creek and Cone Creek watersheds) have experienced very limited road construction. The risks are uniformly high for road fill failures in this area. Over 90 % of soils in the Elk Creek – Cone Creek land block display an extreme susceptibility for road fill and sidecast failures.

Field reconnaissance suggests that road construction has indeed been locally important in increasing sediment production to tributary streams in Quartz Creek through both fill failure and surface erosion of side cast materials. The magnitude of this increase is unknown. However, both processes (mass wasting and surface erosion of road fill materials) are assumed to deliver sediment to

stream channels and to adversely affect aquatic resources (Legard and Meyer, 1973).

The final indicator of accelerated surface erosion selected from the SRI database is the "silt and clay sediment yield potential." This indicator suggests "the potential for sedimentation and pollution from silt and clay particles carried in suspension following timber harvest, road construction, or other activities. This is a measure of the silt and clay content and texture of the soils, and suggests the potential for increased turbidity and resultant damage that fine sediment can cause to fish and fish habitat.

Map 11 shows that much of the Quartz Creek watershed is susceptible to the production of fine sediment pollution from human disturbances. Soils susceptible to fine sediment production as especially prevalent in the Cane and Coffee Creek watersheds, the Fawn and Buck Creek watersheds, and in the upper Quartz Creek watershed (Table G19). Chronic production and delivery of fine sediment to the stream system is an important management-related sediment source that should be evaluated through road inventories and assessments, primarily because of the known fisheries values in Quartz Creek and in downstream areas.

Table G19. Potential yield of fine sediment from land use activities in selected watersheds of the Quartz Creek and Minor watersheds analysis area (from SRI)

Watershed	Fine sediment yield potential (acres)					
	Low	Low - Moderate	Moderate	Moderate - High	High	Total
Cane – Coffee	157	0	166	2766	0	3089
Wycoff – Sugar	334	35	66	917	0	1352
West lower Quartz	0	262	0	0	67	329
Upper Quartz	79	95	16	2708	0	2898
Lytle – Indian	263	582	249	3096	0	4190
Fawn – Buck	20	6	178	1928	0	2132
Elk Ck – Cone Ck	9	2569	207	4	483	3272
Mill Creek	322	238	705	2497	0	3762
Swamp – Castle Rock	248	174	286	643	0	1351
Total	**1432**	**3961**	**1873**	**14559**	**550**	**22375**
Percent of total (%)	**6%**	**18%**	**8%**	**2%**	**65%**	**100%**

Fine sediment production from road ditches and road surface runoff is a common and chronic problem in heavily managed, forested watersheds (Reid, 1981; Wemple, 1994). The magnitude of the problem is dependent on road density, the level of connection between the road drainage and the stream system, the level of use of the road (especially for commercial traffic), road maintenance practices (grading and spoil disposal), and a variety of site factors (road slope, soil characteristics).

Field observations in Quartz Creek suggest that this source of sediment production is still locally important in portions of the basin where roads and surface drainage systems are fairly old and have not yet been upgraded. Some newer roads, or rebuilt roads, are outsloped to disperse runoff. Other, old roads

including portions of the 2816 Road where it climbs fairly steeply in upper portions of Quartz Creek, were observed to still retain long lengths of active ditch.

Clearly, these sources of fine sediment are part of the "current conditions" in the analysis area and they continue to contribute to increased levels of chronic sediment production. Until inventories are completed to evaluate the magnitude of the problem, and maintenance and reconstruction efforts are undertaken to "disconnect" the road surface and ditches from the stream network through outsloping and the installation of rolling dips and ditch relief culverts, road-related fine sediment will continue to be produced and delivered to streams in the Quartz Creek analysis area.

Roads also contribute increased levels of fluvial sediment production during flood events. When culverts plug or their capacity is exceeded, stream crossing fills will either partially or completely wash out or stream flow will be diverted down the road and across adjacent hillslopes. Washouts are most likely to occur where culverts are undersized or prone to plugging and the soil materials in the fill are fine grained and erodible. Undersized culverts are most commonly associated with older roads that were constructed considerably before present-day standards. Many of these crossings have not yet washout out, or they have been repaired without completely upgrading or "storm-proofing" the drainage facility. These sites are waiting to fail and deliver eroded sediment to the channel system.

Stream crossing washouts and fillslope failures are likely to be more common on abandoned roads and closed roads if the stream crossing fills were not "pulled" at the time of road abandonment or closure. During our review of selected aerial photography, approximately four miles of abandoned logging road were identified in the analysis area (this total does not include short abandoned ridge spurs once used for yarding but which have little potential for future sediment production)(Table G20). These roads were constructed prior to 1959 and have been abandoned for at least two or three decades. Erosion along these old routes may have already occurred, with little left to prevent or repair.

Table G20 List of several abandoned roads in the Quartz Creek watershed analysis area.

Road location	Constr. before:	Length (mi.)	Comment
Millpond off Highway 126; 100 Spur	1959	1.2	Old logging road climbs along riparian zone and potentially steep side slopes of small tributary stream from Millpond to ridge near 101 spur road (Abandoned road pre-date the 100 road system) (section 22) T16S R4E
1501 Spur	1959	0.7	Old switchback spur road accesses steep slopes below 1501 road about 0.75 miles east of Hwy 15 junction (section 13) T16S R4E

Table G20 List of several abandoned roads in the Quartz Creek watershed analysis area.

Road location	Constr. before:	Length (mi.)	Comment
2620 Spur	1959	1.9	Old spur roads through inner gorge and stream side riparian slopes of lower Cone Creek and its tributary. Leaves 2620 road near Cone Creek bridge (sections 19 & 20) T165 R4E

Table G21 lists the road construction history, as derived from aerial photo analysis, for different parts of the Quartz Creek analysis area. It clearly indicates that much of the road system was constructed decades ago. For example, in upper Quartz Creek 88 % of the current road network had been built by 1972, over 25 years ago. Nearly 40 % of the network had been built by 1959 (the date of the earliest aerial photos we reviewed). Inspection of drainage structures in this area suggests that some structures have been replaced probably as they failed, but many of the original culverts are still in place. Visual inspection of channel characteristics also suggests that some of these structures are undersized for both the 50- and 100-year design flood. Road construction histories for Mill Creek are similar, with 81% of the road network having been built by 1972. Roads in Elk Creek are more recent and less likely to be under-designed. The main bridge over Cone Creek dates to 1977 and most road construction likely post-dates bridge installation.

Table G21. Percent of roads constructed before given dates in the analysis area.

Watershed	1959	1967	1972	1990	Road miles surveyd
Upper Quartz Creek	38	29	21	12	63
Mill Creek	56	2	23	19	30
Elk Creek	33	2	0	67	7
Total (miles and %)	**43**	**19**	**20**	**18**	**100**

Road construction history is based on a preliminary analysis of aerial photography from 1959, 1967, 1972, and 1990. Not all roads in the analysis area have been included.

Stream diversions are another potentially significant source of accelerated sediment production and yield associated with current conditions in most roaded forests. When a culvert plugs or its capacity is exceeded, stream flow backs up and eventually spills onto the road surface. It then either flows over the fill and back into the channel or it flows some distance down the ditch or road surface until it finds an another route down slope. This process is termed a stream

Geotechnical Engineer, at the Willamette National Forest has developed an inventory form that identifies both culvert capacity and diversion information, but surveys for Quartz Creek have not been conducted and are not currently scheduled. Although we did not conduct a field inventory, evidence of several past diversions that had been repaired were noted during our reconnaissance. Observations suggest that a large number of stream crossings currently exhibit a diversion potential. The combined occurrence of undersized culverts and diversion potential represents a significant risk of future storm-triggered road-related sediment production in the analysis area.

Mass movement. Road construction and timber harvesting are also generally considered to be associated with increased frequencies of landslides in steep forested watersheds (Swanson and Dyrness, 1975). No field or aerial photo inventories of landslides have been conducted for any part of the analysis area, so the relative contribution of accelerated mass wasting to total sediment production is unknown. Similarly, the specific associations between land management practices and mass wasting processes have not been investigated.

Both the terrain analysis and the SRI data suggests that much of the analysis area is susceptible to increased landslides following land management (Map 12), but the nature of the failures and the magnitude of increased sediment production and delivery has not been quantified. Most all the watershed areas (80 %) which are described in Table G22 show predicted increases in mass wasting following land management, but less than 5 % of the sampled area display "greatly increased" mass movement activity.

Table G22. Expected mass movement resulting from land management activities in selected tributary watersheds (from SRI).

	Mass Movement from Management (acres)			
Watershed	**Unchanged**	**Increased**	**Greatly increased**	**Total**
Cane – Coffee	164	2937	60	3161
Wycoff – Sugar	47	1321	0	1368
West lower	0	290	67	357
Upper Quartz	319	2586	0	2905
Lytle – Indian	784	3423	0	4207
Fawn – Buck	106	2031	0	2137
Elk Ck - Cone Ck	140	2660	483	3283
Mill Creek	1857	1906	0	3763
Swamp - Castle Rock	250	1104	0	1354
Total	**3667**	**18258**	**610**	**22535**
Percent of total (%)	**16%**	**81%**	**3%**	**100%**

A variety of mass movement processes were observed to be relatively common in the Quartz Creek watershed. Cutbank failures in certain geologic units create increased erosion rates but do not always contribute to sediment delivery to stream channels. Fillslope failures are also common, especially where roads have been constructed on steep slopes and in inner gorge areas. These failures are typically small (<100-200 yds^3) but they can have a high rate of sediment

delivery. Fillslope failures are most common within the first 10 to 20 years following road construction and are typically triggered by moderate or large storm events. Many of the most susceptible sites on existing roads have already failed.

Roads constructed across steep headwater swales have caused several large debris slides that incorporated original ground beneath the road and torrented down steep stream channels all the way to Quartz Creek. A review of historic aerial photography revealed at least three large debris torrents originating from roads, including one in the headwaters of Lytle Creek and one in the headwaters of Doe Creek. The Doe Creek torrent traveled approximately three miles down the channel before coming to rest in the main stem of Quartz Creek.

In the upper Quartz Creek watershed, a review of available aerial photography revealed that a number of in-unit debris slides and torrents have developed since harvesting. Seven such slides were identified, but the causal links were not investigated further. Additional slope failures likely occurred in the 1996 storm event, but post-storm aerial photography was not available for this analysis. On adjacent heavily managed lands downstream from USFS property, recent debris sliding appears to be more common. At least seven debris torrents reached the floor of the main valley as a result of the 1996 storm and flood event. It is unknown if these torrents were management-related or if they developed from single or multiple initiation sites farther up the tributary channels.

In the terrain analysis described earlier, mass wasting was inferred to be the dominant overall sediment production mechanism operating during reference watershed conditions. Although no sediment source inventories exist, mass movement is still deemed to be the most important component of the current sediment budget. Physical controls on landslide development are complex, but it has been shown in nearby watersheds that harvesting and road construction are generally associated with increased frequencies of mass soil movement, especially in certain slope classes, geomorphic positions, soil and bedrock units. It is to be expected that increased rates of landsliding and surface erosion have resulted from forest management activities.

Policies and procedures

A number of current policies and procedures on the Forest have implications for sediment production and delivery under current watershed conditions. These are briefly described below.

Land Allocation: Land management under the Northwest Forest Plan provides a means of estimating future landscape disturbances from human activities and qualitatively assessing watershed impacts. For example, the late- successional reserve established in the Elk Creek watershed will allow an evaluation of the current road network for possible decommissioning. Similar land designations

for the western side of upper Quartz Creek may provide even greater opportunities for managing sediment production from both roads and forested lands. Under current management conditions, roads in inner gorge hillslope positions of Quartz Creek and its tributaries (e.g., Road 2618-330 and Road 2618-340) are likely to generate substantial accelerated sediment production from fill slope failures and fluvial processes during future storm events. Maintenance requirements on these routes are also high (Dick White, pers. comm.).

In contrast, managed lands on the eastern side of the watershed are currently classified for continued intensive timber management. Although no harvesting is planned for the near future (Karen Geary, pers. comm.) roads will be retained and slopes will be managed for timber. Landscape disturbances will remain high and sediment production under the current designation will also be elevated.

Much of the remainder of federal lands in the watershed analysis area have been designated as an adaptive management area (AMA). These are located along the McKenzie River corridor and in the Mill Creek watershed area. Under adaptive management, land managers have the ability to design and employ experimental or innovative approaches to achieving their ecological, economic and social objectives. The AMA contains a variety of landform types, slope classes and soil units that make it well suited for experimentation and monitoring. Opportunities exist for managing sediment production in this area through the application of a variety of site-specific land management and soil conservation measures, and to test and evaluate the effectiveness of these practices through scientific analysis.

Road maintenance: Maintenance of forest road systems is a fundamental component of road management and environmental protection. Maintenance consists of a variety of actions taken to keep the road open and in good repair, as well as a host of measures designed to minimize the erosional impact of the road on the watershed and its streams. Poorly maintained roads are likely to exhibit increased frequencies of stream crossing washouts and fillslope failures than well-maintained roads. Watershed erosion rates, especially during storm events, can be dramatically affected by past and on-going maintenance activities.

Under current conditions, funding for road maintenance has dropped dramatically, without a concurrent drop in the mileage of roads needing inspection and treatment (Dick White, pers. comm.). Funding for annual road maintenance on the three ranger districts of McKenzie, Blue River and Lowell once exceeded $2 million but now averages about $400,000 for the same road network. Currently three equipment operators and one foreman are responsible for the maintenance of over 2,000 miles of forest roads, including roads in the analysis area.

Within the Blue River Ranger District, as of 1998, there are 48 miles of Level 1 (closed) roads, and 579 miles of Level 2 (4-wheel drive) roads, out of a total road base of 736 miles. The McKenzie Ranger District has 82 miles of Level 1 road, and 412 miles of Level 2 road out of a total of 653 miles.

Forest-wide standards and guidelines require the inspection and maintenance of all roads (FW-094 through FW-102 of the Forest Plan 1990). However, budget constraints have made this a virtually impossible undertaking. Lower standard roads are generally the first to experience significantly reduced levels of inspection and maintenance. Maintenance efforts are typically aimed at identifying vehicle passage problems on Level 3 (and higher) roads and at the identification and repair of road-related problems which are resulting in ecological damage (K. Johanson, pers. comm.). Old culverts are upgraded as they fail or have problems, and when funding is available through timber sales or through a capital investment project. Maintenance funding is generally not sufficient to accomplish needed culvert upgrading and replacement work.

Road closure and decommissioning: Sediment production from roads can be controlled through storm-proofing and maintenance, or through hydrologic decommissioning (Harr and Nichols, 1993). Decommissioning generally entails removing those elements of a road that obstruct or re-route hillslope drainage or that present slope stability hazards (FEMAT 1993). It involves removing culverts and stream crossing fills, sub-soiling road surfaces, outsloping, surface drainage improvements, and the excavation of potentially unstable fill material. Most of the road is left intact so that future reconstruction is possible.

Road decommissioning includes putting a road in storage (storm proofing with dips, berms, waterbars, etc.) for later use, or in some cases, the road is obliterated and permanently removed. Obliteration restores the hydrologic function of the soil by lifting compacted subsoils, removing fills and culverts and enhancing vegetative growth (Willamette NF ATM Guide, June, 1995).

Streams: Channel Condition, Fisheries and Riparian Zones

Overview

Streams systems are highly visible to the public and are often viewed as indicators of watershed health. The stream channel, the fish habitat, and the riparian zones are inter-related as the riparian zone affects and is affected by the stream channel. Both riparian zones and channel conditions determined fish habitat. Riparian zones in addition, have been recently recognized for their own intrinsic values. They have been defined as three-dimensional zones of influence between terrestrial and aquatic ecosystems (Gregory and Ashkenas 1990). Riparian zones also provide special moist habitats for plant and animal species, refugia and travel corridors for upland animal species, and even corridors for migrations of some plant species. Finally riparian zones and the streams within them offer esthetic, recreational, and resource values directly related to humans (Malanson 1993).

In the Willamette National Forest, the riparian acreage may be small compared to the total forest area, but the impact and value is proportionally greater as shown in Table S1.

Table S1: Proportion of forest resource uses located in riparian areas of the Willamette National Forest[1].

Forest use or type	Percent of forest total
Area of Class I, II, III, and lake riparian (Class IV not avail.)	6
Fisheries	100
Bird species feeding	70
Mammal species with primary habitat	58
Big game winter range	12
Plant species	75
Developed recreation	85
Dispersed recreation	75
Wilderness recreation	48
Biological potential timber yield	5

[1]Revised from Gregory and Ashkenas 1990.

Reference Conditions of Streams and Riparian Vegetation

Reference conditions cannot be quantitatively described for streams in the analysis area as no survey data exists. However, conditions may be inferred using current data from streams in the analysis area or nearby that have not sustained impacts from forest harvesting, road building, or other human activities. Also an experienced stream technician can infer what a reference condition is like by observing how stream behavior and how they recover over time following disturbances. Many of the comments contained in the stream surveyor notes can be a source of inference about condition.

Elk Creek is the sub-watershed of the analysis area that has both survey data and undergone the least amount of human disturbance. A partial cut was performed along the ridge top along the western-most boundary. Roads are limited, entering the watershed near the ridge tops along the east side and along the west boundary. While limited harvesting has occurred in the federal portions of Elk Creek watershed, a stand replacing disturbance event occurred about 120-150 years ago based on known ages of stands just to the west in Hagan Research and Natural Area and based on our examination of aerial photos. It should be noted that the stream surveyors thought the stand in the upper watershed was only 50-years old, but we believe they significantly underestimated the age of the stand.

Despite the relatively limited degree of human disturbances to the Elk Creek watershed, the channel habitat of Elk Creek does not show significantly different or better conditions when stream survey data are compared with survey data from other watersheds in the analysis area. These other watersheds have sustained a range of human activities including forest harvesting and road building. In addition, when the 1996 post-flood data for Elk Creek are examined and compared with the 1990 pre-flood data, the range of natural variation of stream channel condition appears to be quite large.

The 1990 and 1996 stream surveys of Elk Creek show a large degree of change in the channel condition. In 1996 versus 1990, Elk Creek had a lower count of woody debris and a decrease in pool area. Wood counts in Elk Creek were between 20 % and 50 % lower in 1996 versus 1990. A confounding effect is that the surveys after 1994 changed the criteria for whether a piece of woody debris was counted or not. Before 1994, the minimum diameter a log had to have in order to be counted was 12 inches and was measured at the largest end of the log. After 1994, the 12-inch minimum diameter was measured at 25 feet from the largest end. This change would. by itself, reduce the number of logs that would be counted as woody debris pieces.

Pool area in Elk Creek in 1990 varied between 34 % and 45 %. The 1990 pool area of Elk Creek was somewhat greater than the other streams--for example: Quartz 15 %, Indian 10%, Lytle 4 %, Buck 20 %, Mill Creek 19 %. However

following the February 1996 flood, Elk Creek had considerably less pool area, averaging only 12 % above river mile 0.3. The cause of the decrease in pool area was not explained in the survey notes. It is possible the difference in pool area was due to surveyor bias. Some bias is expected as these surveys are mostly visual estimates. Bias between surveys is evident in a comparison of the 1993 and 1997 surveys of Mill Creek. It is also possible that the apparent decrease in pool area in Elk Creek was due to the noted bank instability and mass wastes. The high entrenchment ratio of 2.7 in Reach 3 in 1996 suggests bed load mobility and deposition in that reach. This could cause some pool filling. However, the surveyors' report for 1996 did not mention any pool filling.

If the pool area decrease in Elk Creek is an actual change, it suggests that these streams are very dynamic and the flood events of 1996 had significant impacts to the channel. Given this large change that channels may undergo due to what may be thought of as a "natural event" (i.e., a peak flow in a mostly unmanaged watershed), it is likely that current conditions of most streams are not outside the range of natural variation for most measures of channel condition.

Using data from streams under study at the HJ Andrews Experimental Forest, we can describe what the streams looked like with respect to in-channel woody debris and riparian vegetation.

The riparian forest structure for reference conditions are presented in Tables S2 and S3. These data document riparian forests of large stature, dominated by conifers, but containing scattered amounts of hardwoods. Even the younger stands such as the 130-year-old RS37, has an estimated average conifer stem diameter of 25 inches (assuming basal area were evenly distributed over all stems--otherwise some stems would be larger). It is fair to assume that some level of disturbance would have been operating in the riparian forest historically–either catastrophic floods or stand-replacing fires. As a result of these natural disturbances, some riparian forests would be expected to represent a younger seral stage than those represented here.

Table S2: Riparian forest structure statistics for reference stands near the analysis area[1].

Stand	Location	Elev. (m)	Dominant Tree spp.	Seral stage	Stand age (yr)	Area (ha)	Len. of record (yr)
RS25	Middle Santiam RNA	475	PSME, TSHE	Old-growth	380	1.13	12
RS37	SF Hagan Creek, Blue River RD	475	PSME, ACMA	Mature	130	1.0	5
RS38	Lower Lookout Cr., Andrews EF	500	PSME, THPL	Old-growth	—	2.44	0

Table S3: Stand attributes for riparian forest stands listed in Table S2[1].

Stand	Live stems (#/ha)			Live basal area (m^2/ha)		
	conifer	hardwood	Total	conifer	hardwood	total
RS25	358	4	362	127.3	0.3	127.6
RS34	323	6	329	83.2	0.2	83.4
RS35	218	108	326	48.7	3.1	51.8
RS37	125	105	230	41.7	8.5	50.2
RS38	249	421	670	49.8	8.9	58.7

[1]data in Tables S2 and S3 from S. Acker, OSU Department of Forest Science; manuscript in prep.

The amount of woody debris in channels of reference streams may have been very high compared to counts typically observed in streams today. Woody debris mass was quantified in a set of streams in minimally disturbed watersheds at the Andrews Experimental Forest. Lower Lookout Creek has had some logging and a road constructed along a short section of one bank, the other streams are essentially undisturbed by human activities. These data were converted to #/mile so as to be comparable to survey data of the Level II surveys performed by the Forest Service. The conversion required fairly reasonable assumptions about typical log size and the proportion of log that would have been lying in the bankfull channel and therefore counted as mass in the Andrews study. These data, once converted, produce log counts that range from just under 150 pieces per mile to over 500 pieces per mile (Table S4). It is believed that the 500 pieces per mile may somewhat over represent true log counts for two reasons. First, if logs in a particular stream average larger than the assumed size of 20-inch diameter and 40-foot length, the converted log count would be somewhat lower than that presented in Table S4. The forest along Lower Lookout Creek is old-growth and the in-channel logs probably average larger than the assumed size. Second, the Andrews study included logs as small as 10-cm diameter and the Level II surveys only count logs larger than 12 inches diameter and longer than 25 feet or twice bankfull width. Pieces less than 12 inches diameter are thought to be a relatively small amount of the total mass in the Andrews studies but, nevertheless, eliminating these would also reduce the converted log counts in Table S4 by a small amount.

Table S4: In-channel woody debris amount in, and inputs to, reference streams at the HJ Andrews Experimental Forest.

Stream	Reach length (m)	Chan. grad. (%)	Bank full width (m)	Amount of in-channel woody debris			Input rate	
				M^3/ha	Mg/ha	#/mile*	Mg/ha/yr	#/mile*
Water-shed 9	170	37	3.5	500	200	318	6.3	3.3
Water-shed 2	146	26	5.2	750	300	503	4.0	3.3
Mack Creek	332	13	11.9	570	228	366	5.0	9.0
Upper Lookout Creek	483	8	15.5	340	136	216	2.0	4.7
Lower Lookout Creek	350	3	24.0	230	92	146	8.8	32

data from (Lienkamper and Swanson (1987)
* #pieces per mile was derived by the analyst and assumes an average log mass of 1 Mg based on a log diameter of 20 inches, a length of 40 feet, and density of 0.4 g/cm^3 and that the proportion of the typical log in the bankfull channel is estimated by average log length/ bankfull width.

Current Conditions of Stream Channel and Fish Habitat

Quantitative surveys of fish habitat, called Level II surveys, have been performed by the Forest Service since 1990. Earlier examinations on record are dated to as early as 1975 but include only cursory descriptions of stream condition and fish densities. The surveys since 1990 have been summarized by stream in Tables S5 to S12 and the 1975 surveys are summarized in short paragraphs following the tables. Aerial photographs taken between 1959 and 1996 allowed an examination of channel condition of Quartz Creek. A "synoptic" survey was performed by the analysis team where channel conditions are assessed through an examination of patterns and characteristics visible during field visits. A series of photographs were taken during the synoptic surveys to document important elements of the channel and fish habitat. Significant findings from these various surveys are linked to the individual stream reaches on Maps 13 to 16. Following these tables is a discussion of what is known about these streams in context of the key questions.

Summaries of Forest Service Level II surveys of streams in the analysis area. Each table is followed by a annotation of the stream surveyors' field notes, by reaches. Note that these are not the watershed analysts' notes. Column headings are defined following Table S12. Refer also to Maps 13 through 16 for reach locations and additional information.

Table S5: Quartz Creek stream survey 1996 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large riparian conifers (%)	Canopy Cover (%)
1	0.0 - 4.5	2	--	10	7	6	40	46	Low	--
2	4.5 - 8.5	2	--	11	5	11	25	99	Low	--
3	8.5 – 10.7	5	1.8	28	7	81	5	46	69	86
4	10.7 – 12.4	13	2.3	10	9	92	20	10	64	59
5	12.4 – 13.9	13	2.3	15	6	82	8	15	71	79

Survey notes for Reaches 1 and 2 was performed by E. Dill, September, 1996--Level II protocols were not used; remainder of survey performed by Forest Service.

Quartz Creek 1996

R1 and R2: Lower portion is constrained by road in places and the channel showed evidence of down-cutting. There are low amounts of pool habitat. A mass waste was noted at river mile 2.14. There is very little woody debris in the channel and the riparian zone has been harvested of conifers. Floodplain is dominated by small red alder with scattered willow, bigleaf maple, ash, cottonwood, and small conifers. Cobble embeddedness is moderately high and insect production appears to be low. Rainbow trout, cutthroat trout, and sculpins were observed from the surface in many pools. Older roads constructed on the mid-portions of side-slopes, as opposed to those in the valley bottoms or those on ridge tops appear to pose the greatest risk of failure and sediment delivery to streams. The dike constructed across the floodplain for the Pond Road isolates the floodplain below it.

R3: 0.9% of banks were unstable. Two falls and one chute were noted but were not judged to be barriers to upstream migration. Inner riparian zone was 8-inch-diameter and smaller hardwoods. Snorkel surveys observed cutthroat trout throughout. Significant amounts of woody debris are the result of an enhancement project.

R4: No bank instability was noted. Three falls, one chute, eleven debris jams and two culverts were noted but none were judged to be barriers to upstream migration. Inner riparian zone consisted of mostly 8-inch-diameter and smaller hardwoods. Snorkel surveys observed cutthroat trout throughout.

R5: Less than 0.1 of banks were unstable. One falls, eight debris jams, and one culvert were noted, but none were judged to be barriers to upstream migration. The inner riparian zone consisted mostly of shrubs and seedlings less than 5-inches in diameter. Snorkel surveys observed cutthroat trout throughout.

Table S6: Indian Creek stream survey 1993 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large riparian conifers (%)	Canopy cover (%)
1	0.0-0.9	8	--	19	9	43	20	30	20	70
2	0.9-2.2	10	--	7	1	13	--	30	17	33
3	2.2-2.9	11	--	3	0	79	--	40	100	40

Indian Creek 1993
R1: Bank cutting noted at 3 of measured units. Unstable conditions occur at steep banks that have been logged near the stream. A six-foot high falls just below a culvert on Road 1825 is an upstream migration barrier. Cutthroat trout, rainbow trout, sculpin, and Pacific giant salamanders observed.
R2: Extensive logging along both banks creates unstable conditions--three mass wastes noted on right bank and bank cutting on left at start of reach. Inner riparian zone was mostly dense shrubby willow and cottonwood. Three barriers to upstream migration were noted. Snorkel surveys observed cutthroat trout, Pacific giant salamanders, and a tailed frog.
R3: Blowdown of the harvest buffer noted in the middle portion. One mass waste on left bank at top of blowdown section. Five debris jams noted. The culvert at end of survey on Road 160 was a barrier to fish passage. One cutthroat trout and several Pacific giant salamander larvae were observed during snorkeling surveys.

Table S7: Lytle Creek stream survey 1996 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large riparian conifers (%)	Canopy cover (%)
1	0.0-0.6	15	1.88	17	4	43	25	24	5	84

Lytle Creek 1996
R1: 3.9 % of the banks were noted as unstable and thought to be the result of the February, 1996 floods. Two falls over debris jams were judged to be fish passage barriers. The culvert under Road 2618 was also judged to be a fish passage barrier. Much of the in-stream wood recruited from recent blowdown. The inner riparian zone was mostly 8- to 21-inch-diameter alder with lesser amounts of bigleaf maple. Cutthroat trout were observed throughout during snorkeling surveys.

Table S8: Buck Creek stream survey 1996 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large riparian conifers (%)	Canopy cover (%)
1	0.0-0.8	8	1.48	22	2	139	30	31	0	40
2	0.8-1.5	8	1.62	17	0	222	43	21	76	33

Buck Creek 1996
R1: 0.3 % of banks were noted to be unstable. Four slope failures were noted; three occurred recently. Silt deposits were noted. Four debris jams were noted and were judged to be fish passage barriers. Significant amount of in-stream wood was the result of harvest operations that had occurred near the stream. The inner riparian zone was entirely 8-inch-diameter and smaller red alder. No snorkel surveys were conducted, however cutthroat trout were observed from surface sightings throughout the reach.
R2: 0.7 % of banks were noted to be unstable. Two toe-slope cuts were noted at river miles 1.03 and 1.12, respectively. A slide originating from a harvest unit on the right bank was noted at river mile 1.29. The inner riparian zone was 21-inch-diameter and smaller western hemlock and western red-cedar. Four debris jams, and two falls impeded fish passage, however fish were observed up to the base of the 25-foot falls at the end of the survey. Pacific giant salamanders were also noted. Above this, a 70-foot falls occurs--downstream of Road 330.

Table S9: Mill Creek stream survey 1997 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment Ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large Riparian conifers (%)	Canopy Cover (%)
1	0.0-0.4	4	2.28	28	1	19	27	33	62	60
2	0.4-1.0	6	1.80	19	3	88	23	11	29	77
3	1.0-1.5	3	2.21	31	1	76	17	36	9	88
4	1.5-2.2	5	3.83	20	7	23	28	29	0	80
5	2.2-3.1	15	2.06	14	0	99	–	30	23	–
6	3.1-3.3	26	–	1	0	30	–	10	0	–

Mill Creek 1997

R1: Inner riparian zone consisted of mostly 8-inch-diameter and smaller red alder with lesser amounts of 21-inch diameter and smaller red alder and large cottonwoods. One step falls was noted at river mile 0.1 and judged to be a fish passage barrier to resident fish but not anadromous fish. Electrofishing surveys recovered cutthroat trout at two locations--one above and one below the step falls. Speckled dace were observed only below Highway 126 and below the step falls. By comparison with a survey in 1993, the 1996 flood caused scouring of banks, decrease in woody debris concentrations, and reduce channel sinuosity.

R2: Three areas of bank cutting and one small slide were noted. Wood occurs in small jams, creating complexity. The inner riparian zone was mostly 8-inch-diameter and smaller red alder. One chute at river mile 0.69, a falls at river mile 0.93 and a second falls at river mile 0.99 were judged to be fish passage barriers. No electrofishing was performed but salmonids were sighted throughout the reach.

R3: Six areas of unstable banks but no areas of slides were noted. Two debris jams were noted. The inner riparian zone was mostly 8-inch-diameter and smaller red alder. Large harvest units occurred on both sides of stream with buffers of 25 to 100 feet. Three falls over woody debris were noted at river miles 1.34, 1.36, and 1.43, respectively. A fourth falls over bedrock was noted at river mile 1.34. All four falls were judged to be fish passage barriers. No electrofishing was performed, however fish were present in reaches upstream. Most woody debris in last stages of decomposition.

R4: Four areas of unstable banks were noted. No areas of slides were noted. Woody debris concentrations were reduced from 1993. The inner riparian zone was a mix of shrubs and 8-inch-diameter and smaller red alder. A harvest unit spans the channel for the lower half the reach. Debris jams were noted at river miles 1.55 and 1.83. The second was judged to be a fish passage barrier as was the culvert at Road 720. Cutthroat trout and Pacific giant salamanders were observed during electrofishing at two locations above and below the culvert.

R5 and R6: no notes.

Table S10: Mill Creek stream survey 1993 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment Ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large Riparian conifers (%)	Canopy Cover (%)
1	0.0-0.4	3	–	8	0	47	–	100	–	–
2	0.4-1.1	5	–	7	0	87	30	30	–	78
3	1.1-1.4	9	–	21	0	80	35	20	–	50
4	1.4-2.1	6	–	9	5	68	45	100	–	40
5	2.1-2.9	15	–	8	0	160	0	20	–	67
6	2.9-3.1	30	–	1	0	8	–	5	–	63

Mill Creek 1993

R1: No mass wastes noted. However, potential for failures is high due to lack of bank vegetation. Evidence of scour and deposition. One debris jam noted. Inner riparian zone is 21-inch-diameter and smaller red alder and western hemlock. Snorkel surveys noted 2 chinook fry in addition to cutthroat, sculpin, and red sided shiners.
R2: Three areas of bank erosion noted. No mass wastes noted. Six debris jams were noted. Inner riparian zone consisted of 8-inch-diameter and smaller red alder with lesser amounts of western hemlock. No snorkel surveys were performed, however two salmonids were sighted.
R3: One mass waste and nine small debris jams noted. One bedrock falls noted. The inner riparian zone consisted of 8-inch-diameter and smaller red alder. Snorkel surveys observed cutthroat trout and rough-skinned newts.
R4: No unstable banks and no mass wastes were noted. Twelve small debris jams were noted. Large amounts of silt was noted in pools. Much of the reach passes through harvested units. The inner riparian zone consisted of 8-inch-diameter and smaller red alder. Snorkel surveys observed cutthroat trout and Pacific giant salamander larvae.
R5: Frequent erosion noted along banks, but no mass wastes. Large amounts of sand noted. The inner riparian zone consisted of vine maple and willow shrubs. No snorkel survey was conducted. One salmonid and one Pacific giant salamander were sighted.
R6: Large bank cutting along both banks was noted. No mass wastes were noted. Riffles contained very little pocket pool habitat due to low amounts of wood and mostly sand and gravel substrate. The inner riparian zone was mostly willow and alder shrubs. No snorkel survey was performed. No fish were sighted.

Table S11: Elk Creek stream survey 1996 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment Ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large Riparian conifers (%)	Canopy Cover (%)
1	0.0-0.3	1	1.35	37	0	17	10	40	53	70
2	0.3-0.9	5	1.80	14	6	35	8	50	0	80
3	0.9-2.3	8	2.70	10	2	48	30	29	72	60
4	2.3-3.3	12	1.80	11	2	104	11	28	14	50

Elk Creek 1996

R1: A network of channels in the delta formed at the confluence with a side channel of the McKenzie River provides historic chinook spawning and rearing habitat. The first 200 feet of stream channel also provide good anadromous spawning habitat. Three areas of cut banks were noted. No mass wastes were noted. The inner riparian zone consisted of 21-inch-diameter and smaller red alder and bigleaf maple. No snorkel surveys were conducted, however juvenile salmonids were sighted. An old water diversion structure noted at the end of the survey.
R2: Two areas of bank instability were noted. No mass wastes were noted. No energy absorbing jams were noted. The inner riparian zone consisted of 8-inch-diameter and smaller red alder and bigleaf maple. A small falls at river mile 0.81 was judged to be a fish passage barrier to resident trout at low flow. Cutthroat trout and one Pacific giant salamander were sighted. A diversion structure for domestic water supply was noted at river mile 0.45.
R3: Twenty-three unstable banks over the reach and one recent mass waste at river mile 1.61 were noted. The uniform nature of the forest stand suggests the occurrence of a stand-replacing fire in the last 80 years. The inner riparian zone was mostly 8-inch-diameter and smaller vine maple. Two falls over bedrock at river miles 2.1 and 2.33 were judged to be fish passage barriers. A third falls over woody debris at river mile 2.31 was also judged to be a barrier. Cutthroat trout were noted throughout the reach; also Pacific giant salamanders and a crawfish.
R4: Two areas of cut banks were noted, however other areas of channel instability were noted. Two mass wastes had occurred at river mile 2.8. The inner riparian zone was mostly shrub-sized vine maple with lesser amounts of bigleaf maple saplings. No fish were observed above the 10-foot falls at the junctions of Reaches 3 and 4. Pacific giant salamanders and a red-legged frog were observed.

Table S12: Elk Creek stream survey 1990 summary.

Reach	River mile	Channel gradient (%)	Channel entrench-ment Ratio	Pools (% area)	Side channels (% area)	Large woody debris (# / mi.)	Cobble embed-dedness (%)	Inner riparian width (ft)	Large Riparian conifers (%)	Canopy Cover (%)
1	0.0-1.1	2	--	34	5	86	--	50	35	25
2	1.1-1.8	4	--	45	4	65	--	50	50	--

Elk Creek 1990
R1: The inner riparian zone consisted of mostly 21-inch-diameter and smaller red alder with lesser amounts of bigleaf maple and vine maple. Cutthroat trout were sighted during the physical survey.
R2: The inner riparian zone consisted of 8-inch-diameter red alder and bigleaf maple. No comments regarding fish.

Definitions of column headings:
Channel entrenchment ratio: floodprone width / bankfull width. Values < 1.5 indicate an entrenched channel.
Inner riparian zone: the hardwood-dominated zone immediately adjacent to the stream.
Large riparian conifers (%): percent of reach length that was dominated by large conifers (>21 " DBH) in the outer riparian zone—an area outside the inner riparian zone but still within 100' of the stream.

The following paragraphs summarize the notes from the 1975 stream surveys.

Elk Creek: A survey of the lower portion (850 yards from Cone Creek to a major tributary) of Elk Creek reported relatively good fish habitat and excellent channel stability. They commented on the good spawning habitat with a nearly even mix of substrate sizes, 90 % canopy cover, a relatively high proportion of pools (pool to riffle ratio of 2.0), and high densities of cutthroat trout (between 60 and 100 per 100 yards of stream). However, they noted that the lower part had been "quite disturbed" in the past. The private lands along the stream had been logged and there was heavy deciduous growth. The federal land was unlogged and consisted of a mix of conifer and deciduous trees. The surveyors also noted recreational uses included fishing and bathing along the private lands. They also noted a fairly significant (i.e., 2 cfs) diversion for domestic water use "below the forks" (likely the same source noted in 1996). Water chemistry collected from the "Hiway Bridge," 5 September, 1975, 0930: air - 60, H_2O - 55, pH - 7.7, O_2 alkalinity - 28, hardness - 18, turbidity - 0".

Cone Creek: A survey of Cone Creek over the first 1.5 miles reported similarly good habitat as Elk Creek and excellent channel stability. The quantitative data are nearly identical to that reported for Elk Creek: pool to riffle ratio of 2.0, canopy cover of 90 %, nearly even mix of substrate sizes, and 50 to 80 cutthroat trout per 100 yards. The stream side vegetation was "mostly unlogged" and a mix of conifer and deciduous trees. They noted some erosion from roads and slumping of fills and cuts. Recreational use included fishing at the lower portion along the private lands.

Indian Creek: A survey of Indian Creek over the first 3 miles reported that the stream was damaged by logging, both from erosion from roads and logging activity and from "much slash in the stream channel." Comments also included "sparse cover near water," and "logging in progress along stream with logs dropped into and across stream: can expect even further degradation as a result." Cutthroat trout were noted.

Quartz Creek: A survey of Quartz Creek for 600 yards above the confluence with Indian Creek reported "...much bed shifting, mostly due to jams and accumulation of alluvial material behind: causes bank cutting. Severe erosion off road cuts and fills; some off log shows, since dragging has much disturbed surface on steep slopes." The debris jams were reported to have deep pools below--up to 7 feet. Many cutthroat trout were noted. The pool:riffle ratio was 1.25 and water temperature was 54 F and air temperature 62 F on August 26th.