Module A

Sedimentation Assessment

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SEDIMENTATION ASSESSMENT

1.0 INTRODUCTION

This Sedimentation Assessment combines the Mass Wasting Assessment and the Surface Erosion Assessment. The latter assessment covers both hillslope erosion and road erosion.

1.1 MASS WASTING ASSESSMENT

The purposes of the Mass Wasting Assessment are to identify the landslide processes that are active in the East and West Dickey Watershed Administrative Units (E/W Dickey WAU), and to evaluate which of those processes have been accelerated by forest practices. To accomplish these tasks, this module generally followed the methodology described in Version 3.1 of the *Standard Methodology for Conducting Watershed Analysis* (the Watershed Analysis Manual; Washington Forest Practices Board [WFPB] 1996). Deviations from the Watershed Analysis Manual methodology are explained in Section 3.0.

Through the use of text description and maps (Appendix A-1), the module report addresses the nine critical questions listed by the WFPB (1996):

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

All of the forms and maps recommended by the Watershed Analysis Manual (WFPB 1996) for the mass wasting module were either used, modified, or excluded as noted in Table A-1.

.Table A-1 Location of Mass Wasting Assessment module products.

Watershed Analysis Manual product title		Corresponding product(s) used in this report	
Form A-1	Mass wasting inventory data	Appendix A-2	Mass wasting and surface erosion inventory data
Form A-2	Mass wasting map unit	Appendix A-3	Geomorphic terrain descriptions
Form A-3	Mass wasting summary table	Table A-3	Summary of mass wasting events
Form A-4	Summary of mass wasting and delivery potential (optional)	Synthesis document: Text discussion in Sections 4.0 and 5.0	
Map A-1	Landslide inventory	Map A-1	Mass wasting and surface erosion events
Map A-2	Mass wasting map units and potential hazard ratings	Map A-2	Geomorphic terrain units

1.2 SURFACE EROSION ASSESSMENT

The purposes of the Surface Erosion Assessment, which encompasses assessments of hillslope erosion and road erosion, are several-fold. To understand hillslope surface erosion, the analyst must identify the surface erosion processes that are active in the E/W Dickey WAU, and to evaluate which of those processes have been accelerated by forest practices. To understand the importance of road-derived sediment in the E/W Dickey WAU, the analyst must quantify natural background volumes of sediment introduced to the channel network through creep processes, quantify the volumes of fine sediment derived from road erosion and delivered to the channel network, and then compare these volumes to evaluate the potential for impacts to water quality and other components of fish habitat. To accomplish these tasks, the module generally followed the methodology described in Version 3.1 of the Watershed Analysis Manual (WFPB 1996). Deviations from the Watershed Analysis Manual methodology are explained in Section 3.0.

Through the use of text description and maps (Appendix A-1), the module report addresses the 11 critical questions listed by the WFPB (1996):

Hillslope Erosion

1. What is the hillslope erosion potential?
2. Are contributing activities present?
3. Is sediment delivered to streams?
4. What areas are sensitive to forest practices?

Road Erosion

1. What are the roads' erosion potentials?
2. Are contributing activities present?
3. Is sediment delivered to streams?
4. What roads are sensitive to forest practices?
5. What is the potential effect of sediment on public resources?
6. What is the baseline sediment level?
7. What are the amounts and types of sediment contributions from forest practices?

All of the forms and maps recommended by the Watershed Analysis Manual (WFPB 1996) for the surface erosion module were either used, modified, or excluded as noted in Table A-2.

Table A-2 Location of Surface Erosion Assessment module products.

Watershed Analysis Manual product table		Corresponding product(s) used in this report	
Form B-1	Hillslope field/photo assessment	Appendix A-2	Mass wasting and surface erosion inventory data; text discussion in Sections 4.0 and 5.0
Form B-2	Roads calculations spreadsheets	Appendix A-4	Roads calculations spreadsheets
Form B-3	Roads field forms	Appendix A-4	Road erosion field form B-3 (present only in reviewer's copy)
Form B-4	Surface erosion summary	Table A-7	Summary of road erosion results and road density
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		Map A-3	Road types by traffic and surface material
		Map A-4	Road types by topography and construction style, and road segments
		Map A-5	Road erosion hazard

2.0 GEOLOGIC OVERVIEW

The E/W Dickey WAU lie within the coastal lowlands near the very northwest tip of the Olympic Peninsula, Washington State (see E/W Dickey Watershed Analysis Vicinity Map in the Introduction section of this watershed analysis). The core of the Olympic Mountains is uplifting at rates of approximately 1 km per million years (1 mm/year) (Pazzaglia and Brandon, in review), and evidence suggests that uplift has actively occurred for at least the past 15 million years, since the late Miocene (Brandon et al., in review). During this time, coastal areas of the Olympic Peninsula, such as where the E/W Dickey WAU lie, appear to have remained at or near present day sea level (Pazzaglia and Brandon, in review).

The E/W Dickey WAU are underlain by Eocene- and Miocene-aged sedimentary rock assemblages that are typical of the peripheral rocks that encircle the Olympic Mountains. Sand- and siltstone are the most common components of the sedimentary portion of the peripheral rock assemblages (Tabor and Cady 1978). They are broadly of volcanic origin, formed of material eroded from an arc of island volcanoes that existed off the coast of North America during the middle Tertiary. These lithologies outcrop above an elevation of about 1,000 ft along the northern and eastern margins of the E/W Dickey WAU (see Map A-2, Geomorphic Terrain Units, GMU 58 and 59). (Note: Snavely and others [1993] did not map glacial deposits in this area above 400 to 800 ft; however, outcrop examination by one of the authors [Dieu] suggests that 1,000 ft is a more characteristic value of the upper extent of glacial deposits in the E/W Dickey WAU.)

The very northern edge of the E/W Dickey WAU may be underlain by Eocene-aged metamorphic rocks such as argillite (essentially metamorphosed siltstone). The contact between the Olympic peripheral rocks and the east-west trending slivers of older metamorphic rocks that underlie the very northern edge of the Olympic Peninsula crosses the West Dickey WAU boundary when the boundary is superimposed onto a large-scale geologic map of Washington, but the actual field location of the contact is unknown.

During the Pleistocene, the northern edge of the Olympic Peninsula was repeatedly overrun by ice during advances of the continental glaciation. Most recently, during the Vashon Stade (18,000-12,000 years ago), the Juan de Fuca lobe advanced southwest from Canada, across the Strait of Juan de Fuca, and extended as far south as the central area of the E/W Dickey WAU. To an elevation of about 1,000 ft, the hillslopes along the northern and eastern edge of the E/W

Dickey WAU are coated in glacial till (see Map A-2, Geomorphic Terrain Units, GMU 34b and 35). A series of low-lying, parallel ridges occur in low relief areas where the advancing ice plowed over pre-existing till and outwash deposits (see Map A-2, GMU 34a). These features are drumlins, classic glacial features formed by mechanical, not fluvial, processes. Drumlins are observed around the world wherever ice has advanced over expanses of low relief areas of unconsolidated glacial deposits, but they are rare on the Olympic Peninsula, perhaps because of the paucity of low relief land.

As the ice retreated, the meltwaters ran through all the lower valleys that permitted flow to travel toward the south and southwest. Thus, most of the broad valley bottoms have thick deposits of glacial outwash, predominantly formed of gravel and sand (see Map A-2, Geomorphic Terrain Units, GMU 37). The modern-day stream channels have incised into the outwash deposits and formed smaller flood plains. Where valley orientation permitted impounding by the ice sheet, glacial lakes were formed (see Map A-2, GMU 46). Stream channels, such as the headwaters of the East Dickey, have incised into these glacial lake deposits. In areas along the West Dickey, large lakes were impounded not by ice, but rather by sediment. A lake extended north from the confluence of the East and West Dickey rivers. Its water was drained or it filled with sediment sometime during the Holocene. Dickey Lake has remained a stable landscape feature to the modern day.

3.0 METHODS

3.1 MASS WASTING AND HILLSLOPE SURFACE EROSION

Mass wasting and hillslope surface erosion were assessed using different methods than those proposed by the Watershed Analysis Manual (WFPB 1996). Described below, the methods used involved only a small deviation from the standard mass wasting assessment but a rather large deviation from the standard hillslope surface erosion assessment. These alternate methods led to several fewer map products, a more consistent understanding of the landform controls on both processes, and greater historical knowledge of hillslope surface erosion. As will become apparent in Section 4.1.2, these methods more exactly determine the landforms sensitive to erosion and the triggering mechanisms that disturb them than does examination of soil maps and systematic review of the recent harvest units.

A complete mass wasting and surface erosion inventory was accomplished using 1:12,000 scale (approximately) aerial photographs from 1953, 1964, 1977, 1990, and 1996 (color). These were mapped at 1:24,000 on Mylar printed with the Rayonier hydrolayer and road layer, and overlain on US Geological Survey (USGS) quadrangle maps (Map A-1, Mass Wasting and Surface Erosion Events). Several data were recorded about each observed event: Event Number; Event Type (LS = landslide and SE = surface erosion); Years Observed; Delivery; Land Use or Origin; Landslide Type; Geomorphic Shape; and Aspect (Appendix A-2, Mass Wasting and Surface Erosion Inventory). The site of each event was examined in the subsequent years of photography, and it was noted if it was revegetating (B = better), enlarging (W = worse), or remaining the same (year followed by no letter). The first photo year when a landslide had completely revegetated is noted with a dash on Appendix A-2. For example, surface erosion Event No. 34 was first identified on the 1964 photograph, had experienced partial revegetation on the 1977 photograph, remained unchanged on the 1990 photograph, and had completely revegetated on the 1996 photograph. So "64, 77B, 90, --" is recorded in the Years Observed column of Appendix A-2. This level of detail was collected because it provides information about the severity of surface erosion after a mass wasting event, and about the recovery time for both mass wasting and surface erosion events.

From the topography and the aerial photograph, a map of geomorphic terrains was developed (Map A-2) following the system developed by J. Sasich for the *Big Quilcene Watershed Analysis* (Sasich 1994), used by J. Sasich and J. Dieu for the *Sol Duc Pilot Watershed Analysis* (Sasich and Dieu 1995), and used by J. Dieu and B. Shelmerdine for the *North Fork Calawah Watershed Analysis* (Dieu and Shelmerdine 1996). The geomorphic terrains, also called Geomorphic Mapping Units (GMU), delineate areas of similar bedrock or environment of deposition, degree of channel dissection, steepness, and process. The parameters of delineation, such as hillslope gradient of greater than or less than 65 percent, are chosen to best separate areas where mass wasting and surface erosion processes are more active from areas where they are less active. Thus, the watershed can be stratified into units that have distinct susceptibilities to, and rates or frequencies, of erosional processes, as well as distinct sensitivities to natural disturbances and management activities. Considered in this way, the watershed can be viewed as coarsely stratified by mass wasting and surface erosion hazard. The GMU that have significant surface erosion potential, for example, are delineated based on characteristics of sites where surface erosion has been noted in the inventory (i.e., landforms that look like sites where surface erosion events have occurred, but have not been observed to erode during the historic photo record, are also mapped). For mass wasting processes, GMU are similar to the Mass Wasting Map Units (MWMU) developed by other analysts, but are systematically used for each new watershed analysis (e.g., MWMU #1 may be a completely different landform in each watershed analysis, but GMU 34 will represent the same landform across western Washington).

Extensive field work contributes to the development of the GMU. This field work is the accumulation of field work accomplished for watershed analyses in the region (e.g., Sasich and Dieu 1995), of field review of individual forest practices applications within the E/W Dickey WAU and throughout the region, and of field work specifically pursued to obtain greater knowledge of the E/W Dickey Watershed.

In some WAU, a mass wasting and surface erosion hazard map must be created from the geomorphic map because of findings made during Synthesis. This was not found to be necessary for the E/W Dickey WAU, so Map A-2, Geomorphic Terrain Units, serves as an area of resource sensitivity (ARS) map for mass wasting and hillslope surface erosion hazards.

3.2 ROAD SURFACE EROSION

Evaluation of potential impacts from road erosion was done following the methods described in the Watershed Analysis Manual (WFPB 1996) with minor modification. There were five steps to the evaluation:

1. Natural or background inputs of fine sediment were estimated for each subbasin.

2. Maps were made that delineate road surfacing and traffic and topography and construction style.

3. The 2000, 5000, and 9000 mainline roads, the 5200 secondary road, and selected segments of the remaining roads (representative of the types delineated on the maps made in Step #2), were surveyed for erosion and delivery.

4. The volume of sediment that is eroded from the road prism and the fraction of this that is delivered to stream channels were estimated for each surveyed road segment.

5. Total road erosion inputs per subbasin were calculated by extrapolating the values of the representative road segments and adding the values for the 2000, 5000, 5200, and 9000 roads.

Step 1: Natural Background Inputs

Natural background inputs can be estimated by a simple cross-sectional area, calculated from soil depth and stream channel length and then multiplied by a creep rate. When following the standard methodology, soil depths are assigned by soil type. In a somewhat different approach, soil depths were assigned to each GMU with consideration of both average depths for the soil types present and field observations of the GMU. Thus, built into the calculations is an evaluation of slope gradient, the degree of dissection, and the mass wasting history factors that also influence soil depths. Soil creep rates were assigned to each GMU: 2 mm/year for GMU with slopes that are usually > 30 percent; 1 mm/year for GMU with slopes that are usually < 30 percent. The creep rates and 30 percent threshold are from the standard methodology; however, slope assignment by GMU rather than directly by topography simplifies the Geographic Information Systems (GIS) work and may more accurately determine areas with distinct creep rates by averaging the overall gradient of a slope rather than so rigorously separating areas of distinct creep rates by the 30 percent threshold. GIS provided a spreadsheet containing stream length per GMU per subwatershed, and the calculations were completed on this spreadsheet (Table A-4.1 in Appendix A-4). Soil depths and creep rates assigned to each GMU are evident in Table A-4.1. As suggested by the WFPB (1996), a specific gravity for soil of 1.5 was used in the calculations.

Step 2: Development of Maps

After completing initial field work and evaluating aerial photography, and while working closely with landowner road engineers from Rayonier, the Washington Department of Natural Resources (DNR) and Crown Pacific, two maps were developed. Distinct traffic levels (e.g., mainline, inactive) and surfacing (e.g., > 6 inches of gravel, 2 to 6 inches of gravel) were delineated on Map A-3, Road Types by Traffic and Surface Material. Mainline roads receive frequent, heavy log-truck and dump-truck traffic, secondary roads receive occasional log-truck and dump-truck traffic, inactive roads receive frequent light-vehicle traffic, and abandoned roads receive occasional light-vehicle traffic, if any. In general, mainline and secondary roads have unvegetated treads, inactive roads have unvegetated or only lightly vegetated tire tread surfaces but may have vegetation on the road crown, and roads classified as abandoned have highly variable amounts of vegetation, from light grass to large trees. "No erosion" roads, those that have revegetated so completely that their erosion processes are like those of the normal forest floor, were also delineated on Map A-3.

The topographic position (e.g., ridgetop, midslope, stream-adjacent) of each road segment was delineated on Map A-4, Road Types by Topography and Construction Style, and Road Segments Surveyed. Construction style was delineated only for midslope roads on slope gradients of < 35 percent, because midslope roads are where construction style has a significant impact on delivery. Specifically, railroad grades tend to cut across topography, which severely limits opportunities to place cross drains, while modern roads tend to follow topography, which allows cross drains to be placed on convex slopes where delivery to the channel network is unlikely. Few railroad grades were built on slope gradients of > 35 percent in the E/W Dickey WAU, so this topographic type of midslope road is not delineated by construction style.

Step 3: Selection and Inventory of Road Segments

Erosion surveys of road segments were conducted in three ways. First, the 2000, 5000, and 9000 mainline roads and the 5200 secondary road were completely surveyed by Art Lambson, contractor to Rayonier. This was done because erosion rates of mainlines, and to a lesser extent of secondary roads, are so great that even small errors in delivery caused by extrapolation from surveys of other road segments can cause large errors in the final results. Second, representative road segments of about 1 mile of other road types were surveyed. Road segments surveyed were carefully selected to best represent a road type created by the combination of characteristics on Maps A-3 and A-4 (e.g., an inactive, stream-adjacent road), but road types whose erosion rates could be easily derived from another survey were not surveyed. For example, because of the similarity between inactive and abandoned roads in most factors except traffic, erosion from an abandoned, stream-adjacent road can be derived using the survey from an inactive, stream-adjacent road survey by changing the Traffic Factor from 1 to 0.05. Third, many abandoned roads were briefly visited. A short segment of each of these was walked to evaluate the condition of the drainage structures and to evaluate if the road represented any significant source of sediment. The objective of these surveys was to develop an overall picture of the condition of abandoned roads throughout the basin so as to accurately portray the hazard they represent.

Road erosion inventories and the abandoned road surveys were done on a modified version of Road Erosion Field Form B-3 from the WFPB (1996). Photocopies of the actual field inventory forms are attached to copies of this report which were submitted to the DNR for peer review; others may request photocopies from Dieu.

Step 4: Calculation of Erosion Rates for Reference Roads

We created a spreadsheet that is somewhat modified from that provided at the DNR Watershed Analysis Certification Training (Calculations in Appendix A-4). The major difference is that we calculated *tons/drainage structure/year* instead of *tons/acre/year*. (Drainage structures include ditch outs, cross drains, water bars, culverts, and bridges.) This is a useful way to calculate, for example, the long, continuous surveys for mainlines because *tons/drainage structure/year* allow an engineer to see easily where additional cross drains will be most effective at reducing the overall delivered erosion from a road. For the shorter surveys of representative segments, the same spreadsheet was used for consistency, but the *tons/drainage structure/year* values were added and then divided by the total road length to acquire a *tons/mile/year* value to be extrapolated to unsurveyed segments of the same road type.

Details of the calculation methods are provided in Appendix 4, Calculations for Sediment Yield from Roads. All constants used in the road calculations are taken from the Watershed Analysis Manual (WFPB 1996).

Step 5: Final Calculation by Subbasin

The E/W Dickey WAU has been divided into 16 subbasins; these are clearly delineated and labeled on Map A-1, Mass Wasting and Surface Erosion Events.

The continuous mainline and secondary road erosion surveys were split into subbasins by determining where the subbasin boundaries lie with respect to individual drainage structures. As subbasin boundaries are, by definition, high points in the topography, each individual drainage structure clearly lies within a subbasin. The *tons/drainage structure/year* values for each drainage structure in a subbasin were added to get a total value for the 2000, 5000, 5200, and 9000 roads (Appendix A-4, Table A-4.3).

For the remaining road segments, GIS provided the total length of each road type in each subbasin. Road types are a combination of attributes delineated on Maps A-3 and A-4. The different road attribute combinations present in each subbasin are presented in Table A-4.4 of Appendix A-4. Table A-4.4 was used to calculate the total erosion from roads within each subbasin other than from the mainline and secondary roads that were continuously surveyed. This was accomplished by extrapolating from the representative surveyed segment (or from the value calculated by modifying a factor used in the calculation of an appropriate survey) for a distinct road type to all miles of the road type by using the *ton/mile/year* value.

Finally, the results in Table A-4.4 (Appendix A-4) were added to the totaled values obtained from the mainline and secondary roads to arrive at the total delivered road erosion value for each subbasin. The volume of road-derived sediment was compared to the natural background sediment for each subbasin. From this comparison, a hazard call was established for each subbasin, and certain road segments were identified as being the greatest contributors of fine sediment. Map A-5, Road Erosion Hazards, is an ARS map that shows those road segments that are producing the majority of the road-derived fine sediment and the subbasins that received High or Moderate hazard calls.

4.0 RESULTS

4.1 MASS WASTING AND HILLSLOPE SURFACE EROSION

Mass wasting events have been very rare in the E/W Dickey WAU, and only a small percentage of the occurrences have delivered sediment to the channel network. No mass wasting hazards have been identified in the WAU. Hillslope surface erosion events have been rare, and many were triggered by historic logging practices; however, clearcut harvest of southern-aspect small inner gorges has triggered surface erosion resulting in delivery to the channel network, in both historic and current times. Although erosion from a single, southern-aspect, small inner gorge contributes minor amounts of sediment compared with natural inputs and road-derived sediment, there are areas of the E/W Dickey WAU where concentrations of these small inner gorges occur. These have been mapped as GMU 35 and 59, and assigned High hazard calls.

4.1.1 Mass Wasting Inventory

Six of the twelve mass wasting events inventoried in the E/W Dickey WAU were triggered from road edges (fillslope failures). Only one of these appeared to deliver to fish-bearing water (Table A-3). Three natural events (i.e., without anthropogenic influence) were inventoried from the historic aerial photography; only one of these appeared to deliver to fish-bearing water. Three events initiated within areas of recent clearcut harvest, apparently because of root strength loss; none of these delivered to the channel network.

Table A-3 Summary of mass wasting events.

Landslide origin	Total	Delivered	Debris slide	Debris flow
Fillslope failure	6	1	4	2
Clearcut harvest	3	1	1	2
Natural	3	0	3	0
Total	**12**	**2**	**8**	**4**

Mass wasting events occurred by two failure mechanisms. Eight of the twelve events were debris slides whose momentum rapidly dissipated as the slides traveled downhill. As most of these events occurred within small inner gorges or other concave landforms, which helped focus the slides' momentum, it appears that the gradients were insufficient to allow the development of larger mass wasting events. Four events evolved into debris flows (Nos. 29, 40, 43, and 65 on Map A-1, Mass Wasting and Surface Erosion Events); two of these were road fillslope failures and two were related to clearcut harvest. Only No. 65 was a large event (Map A-1), and it was the only debris flow to directly deliver to fish-bearing water.

The inventoried mass wasting events were spread throughout the E/W Dickey WAU, although events were somewhat concentrated in the northeast corner of the watershed where the East Dickey abuts the Hoko and Sol Duc drainages (four events in the East Dickey Mainstem Headwaters Subbasin and two events in the Skunk Creek Subbasin), and in the southwest corner of the watershed where a small area of higher, unglaciated hills exists (three events in the West Dickey Lower Mainstem Subbasin) (Map A-1, Mass Wasting and Surface Erosion Events).

Recovery rates (i.e., stabilization and revegetation) after mass wasting events are very high in the E/W Dickey WAU (Appendix A-2). Many events were completely revegetated by the next inventoried photo year. Others were somewhat vegetated by the next inventoried photo year and were completely revegetated in the inventoried photo year after that. The single exception to this is Event No. 17, a natural debris slide that appeared quite fresh on the 1953 aerial photos but has only slowly revegetated since that time (Map A-1, Mass Wasting and Surface Erosion Events). Event No. 17 has not been visited in the field, but it seems likely that the slide exposed somewhat more competent bedrock than is the norm in the E/W Dickey WAU. It may be a small cliff face, as occasionally occurs in the adjacent Hoko WAU.

This past winter (1996-97), a modest storm event triggered a small debris flow from the 21E Road in the Ponds Creek Subbasin. This event was evaluated by two of the authors (LaManna and Dieu), who observed that the failure initiated from a fillslope, traveled downhill on a modest slope (50 percent), and reached the road that lay 200 ft below. It appears that logs contained within the debris flow formed a dam against several trees on the fillslope of the lower road, diverting the debris flow onto the lower road where it deposited, covering perhaps 150 ft of the lower road to a depth of 3 ft. This event appears to have been caused by a recently built water bar that concentrated ditch water onto oversteepened fill and piles of sidecast ditch spoils. It was unclear whether the berm of sidecast ditch spoils had been cut through at the location of the water bar, but examination of the remainder of the road segment suggested that the operator had installed the water bar without providing a drainage path across the fill, exacerbating the concentration of water. The basic scenario of this mass wasting event (i.e., a mistake causes a small failure that is easily stopped or diverted because of the low hillslope gradient) is typical of the few landslides that do occur in the E/W Dickey WAU.

4.1.2 Surface Erosion Inventory

Fifty-seven significant surface erosion events in the E/W Dickey WAU were observed during the aerial photo inventory. A total of 19 surface erosion events were triggered by direct soil disturbance during logging. Fifteen of these events were badly scarred swing landing tracks, two occurred because of downhill yarding, and two occurred during normal yarding practices (i.e., other than downhill) (Table A-4). Eleven surface erosion events were caused by the placement of excessive sidecast material on a sufficiently steep slope for ravel to occur. Nine of these occurred during road building; two occurred when overburden was sidecast from gravel pits. Four events were recorded when unusually large cutslopes were created during road building. One event occurred because excessive road drainage was not diverted before it reached a landing, causing a gully to form beyond the landing. The other 22 surface erosion events could not be clearly assigned to an operational occurrence, but rather appear to have happened simply because of clearcut harvest.

Table A-4 Summary of surface erosion events.

Forest practice	Total	Delivered
Swing landing track	15	8
Downhill yarding	2	0
Yarding	2	2
Fillslope sidecast	9	4
Gravel pit sidecast	2	0
Cutslope	4	0
Landing gully	1	0
Clearcut harvest	22	21
Total	**57**	**35**

4.1.2.1 Historical Practices

As mentioned previously, the hillslope surface erosion assessment has been conducted following methodology other than that prescribed in the Watershed Analysis Manual (WFPB 1996). Following the customary assessment techniques, only logging practices conducted in the past 5 years are assessed; no historical perspective of surface erosion is provided as it is for mass wasting processes. However, it is important to distinguish between historical and modern practices because disturbance caused by historical practices do not represent a hazard that we should be concerned about in modern times. Therefore, this discussion about historical causes of surface erosion is provided because it is interesting (to the authors at least), not because these triggers are environmentally hazardous today.

Fifteen of the 57 surface erosion events were the scars from swing landing tracks. Railroad logging, which continued into the 1960s in the E/W Dickey WAU, utilized a technique known as a swing landing to transfer logs from some distance away to the rail line so as to avoid building additional rail. Logging was accomplished by yarding logs to a spar pole with a steam donkey; typically in the E/W Dickey WAU, about 25 acres were accessed from a spar pole. These logs were then "swung" to another spar pole, and sometimes to a third pole, *en route* to the rail line. Yarding logs to a spar pole caused little ground disturbance. Yarding 25 acres of timber from the first spar pole to the second caused extensive ground disturbance down a single track. Where a third spar pole was used, 50 acres of logs were yarded down a single track. Eight out of 15 swing landing tracks delivered sediment to the channel network (Table A-4); these eight tracks crossed small stream channels. Swing landing tracks usually revegetated with red alder before the next inventoried aerial photo year (which explains why only 15 were mapped as areas of active erosion despite the common use of swing landings). This practice was not observed on photo years subsequent to 1964.

Downhill yarding is another historic logging practice. Although it was seldom practiced in the E/W Dickey WAU, it was an occasional cause of ground disturbance (two inventoried events, neither of which delivered sediment to the channel network).

4.1.2.2 Modern Practices

Clearcut harvest without obvious operational ground disturbance appears to have triggered almost half of the inventoried surface erosion events (22 out of 57 total events). Twenty-one of the harvest-related events occurred within small inner gorges; one occurred in a concave area that was not an inner gorge landform. Twenty-one harvest-related events appear to have delivered small quantities of sediment to the adjacent stream channel. All 22 of the harvest-related surface erosion events had south, southwest, or southeast aspects. This phenomenon was so dramatic that both sides of the inner gorges trending north to south on south-aspect slopes were observed to erode, but only the south-aspect sides of east to west trending inner gorges eroded.

Numerous field observations of small inner gorges by one of the authors (Dieu) demonstrate that some inner gorges are contributing small amounts of sediment to the channel network via shallow surface erosion and small slump processes even when they are under full canopy. At low elevations (i.e., areas with infrequent snow cover), small inner gorges with northern aspects actually appear to yield less sediment after clearcut harvest because revegetation by thick brush occurs very quickly. This was observed to be most dramatic on a single inner gorge in the E/W Dickey WAU that was divided by a property line. The portion of the inner gorge that lay within a recent clearcut on DNR land was extremely well-vegetated, while the portion on Rayonier land that was surrounded by mature forest with limited understory vegetation was actively eroding along much of its length.

However, dramatic revegetation of northern-aspect inner gorges does not occur on southern aspects. Field observations show that many southern-aspect inner gorges remain poorly vegetated and actively erode for approximately a decade after harvest. The common explanation (e.g., among US Forest Service personnel) for slow revegetation is that southern aspect slopes are droughty during the summer. However, Dieu's repeated observations of two of these features over the past 3 years suggest that vegetation begins to establish during the spring and summer months, and then is lost again during the winter months as surface ravel occurs. Therefore, the intensity of winter storms may be playing a role in the development of surface erosion on southern-aspect slopes after clearcut harvest. While the precise triggering mechanisms remain in question, it is apparent that clearcut harvest of southern-aspect inner gorges is a small but real surface erosion hazard.

Eighteen other events were triggered by practices that remain in use today. Midslope roads are still built in a manner that creates a cutslope (four events) and a fillslope of sidecast material (nine events). Overburden is still sidecast from gravel pits (two events). Yarding through non-fish-bearing waters across small inner gorges is still permitted by Standard Forest Practices, although forest engineers are often sensitive to these situations and design harvest units so that yarding is away from streams instead of across them (two events). And it is possible that excessive drainage could trigger gully erosion from a landing (one event). From a practical viewpoint, these surface erosion events triggered by modern operational techniques have been very rare in the E/W Dickey WAU, and few events have delivered (Table A-4). None of the cutslopes, gravel pit sidecast, and the landing gully events appear to have delivered to the channel network. Delivery of sidecast material to the channel network during road building, which is in direct violation of Standard Forest Practices, has not been observed on photographs taken after 1977. Damage caused by yarding across small inner gorges has been rare, although certain delivery was observed on the 1990 photos. This latter trigger of surface erosion appears to be the only operational disturbance worthy of concern. Field observations of numerous forest practices in the E/W Dickey WAU confirm that delivered surface erosion occurring at a scale finer than can be detected on aerial photos is also not occurring.

4.1.3 Geomorphic Terrains

The E/W Dickey WAU has been divided into eight geomorphic terrains or GMU. These are displayed on Map A-2, Geomorphic Terrain Units. Five of the GMU can be broadly categorized as glacial depositional, two as fluvial erosional and one as fluvial depositional. More detailed descriptions of each GMU can be found in Appendix A-3.

GMU 34a, 34b, and 35, all glacial moraine landforms, cover much of the total E/W Dickey WAU. GMU 34a is identical with GMU 34 mapped in the neighboring Sol Duc and North Fork Calawah watersheds. It is mapped in areas where glacial till was deposited on low-lying hills. GMU 34b, a landform not previously observed during watershed analysis on the northwestern Olympic Peninsula, delineates areas of moraine that were deposited on nearly flat surfaces and then pushed by subsequent ice advances into drumlins (low, linear mounds that trend parallel to ice motion). GMU 34b occurs in the large, nearly flat area that surrounds Dickey Lake, and to a lesser extent in the headwaters of Skunk Creek. GMU 35 is mapped to delineate from steeper hillslopes (greater than 40 percent) that are covered with glacial till from GMU 34a. Small areas of this GMU occur along the northern and eastern edges of the watershed where modest ridges separate the Dickey from the Sol Duc and Hoko drainages and the East Dickey Mainstem Headwaters Subbasin from the Middle Dickey Subbasin.

The other two GMU of glacial depositional origin are very low-relief landforms. GMU 37 delineates areas where water flowed during glacial retreat. These areas are usually underlain by outwash deposits. GMU 37 as mapped, except where covered over by later lake deposits, portrays the anastomosed channel network that flowed south by southwest across the E/W Dickey WAU (Map A-2, Geomorphic Terrain Units). GMU 46 delineates areas where glacial lakes, either dammed by ice during glaciation or developed in depressional areas that remained after glacial retreat, existed or still exist. Wentworth Lake is the only remnant of the largest of these, which covered much of the lower West Dickey and the lower reaches of Squaw Creek. Dickey Lake extended far to the north in early times, and a sizable lake covered much of the No-name 1 Slough Subbasin. Smaller lakes existed in the East Dickey Mainstem Headwaters and Skunk Creek subbasins, and other small lakes, such as Big Joe's Lake and Thunder Lake still remain.

GMU 58 and 59 are the two fluvial erosional terrains. These GMU are used to delineate areas of hillslopes which have not been glaciated and which are of sufficiently low gradient to either infrequently or never experience mass wasting processes. In the E/W Dickey WAU, these GMU delineate hillslopes of sedimentary rock, covered by colluvial soils, whose slope gradients are usually less than 65 percent. GMU 58 is weakly dissected (i.e., there is a low channel density and the channels are not deeply cut into the adjacent hillslope); GMU 59 is strongly dissected (i.e., there is a high channel density and the channels are deeply cut into the adjacent hillslope). These terrains are present above 1,000 ft of elevation along the northern and eastern boundaries and along the southern portion of the western boundary of the E/W Dickey WAU (Map A-2, Geomorphic Terrain Units).

GMU 60 delineates the wide Holocene-age flood plains in the E/W Dickey WAU. Many of these reaches of the channel network have down-cut through glacial deposits and then experienced sufficient channel meander to establish a sizable flood plain. Some areas of GMU 60 are the lower valley bottoms that dissect the colluvial hillslopes in the southwest corner of the E/W Dickey WAU (Map A-2, Geomorphic Terrain Units). Throughout the E/W Dickey WAU, larger channels that are not adjacent to GMU 60, as mapped, either remain in contact with the upper surface of the glacial deposits they flow through (e.g., the lower reaches of Skunk Creek remain in contact with the glacial outwash plain) or have entrenched into the glacial deposits and not meandered sufficiently to develop a sizable flood plain (e.g., the East Dickey Middle Mainstem).

4.1.4 Mass Wasting and Hillslope Surface Erosion Hazard

Mass wasting events have been extremely rare in the E/W Dickey WAU. Twelve events were observed on aerial photographs that covered the period from 1953 to 1996 across the entire 52,756 acres of the watershed. Only two events appear to have delivered sediment to the channel network. No hazard from mass wasting has been identified in the E/W Dickey WAU.

Surface erosion events have been somewhat more common than mass wasting events, and a higher percentage of these events have delivered sediment to the channel network (Table A-4). Many events occurred because of soil disturbance during historic logging practices (e.g., swing landing tracks). Other events were triggered by modern practices, but have occurred only occasionally or did not cause delivery of sediment to the channel network or both (e.g., gravel pit sidecast and road cutslopes). Fillslope sidecast has occurred more often (nine events), and has delivered (four events), but has not been observed since the 1977 photographs, suggesting that compliance with Standard Forest Practices is occurring. Therefore, it is only the vegetation removal and/or disturbance of southern-aspect small inner gorges that stands out as a modern triggering mechanism that has the possibility of delivering volumes of fine sediment to the channel network in sufficient quantities to degrade water quality and spawning gravel.

In the relative comparison of volumes of fine sediment derived from hillslope erosion in southern-aspect small inner gorges and derived from other sources such as road erosion and natural background processes, the volume of fine sediment derived from hillslope erosion of a single small inner gorge is very small. Within a subbasin, natural background sedimentation rates and road erosion rates may each account for the addition of hundreds of tons of fine sediment to the channel network each year. Hillslope erosion of a single small inner gorge appears to be on the order of a few hundred pounds to 1 to 3 tons; negligible volumes when compared to the other inputs. However, although the small inner gorges are scattered throughout the E/W Dickey WAU, they are concentrated in certain small areas of the landscape. These small areas, if clearcut without protection of the small inner gorges, have the potential to deliver sediment to the fish-bearing tributary to which they are headwaters in sufficient quantity to cause habitat degradation. As an example, if a single clearcut occurs across five small inner gorges, then a release of several tons to tens of tons of sediment could occur over the next decade, mostly concentrated in the first 2 years. While this quantity is still negligible on the scale of the subbasin, it is significant to the immediate fish-bearing tributary, especially if the tributary is Geomorphic Channel Unit (GCU) 7, small pool-riffle channels with gravel substrate and spawning habitat which typically have very low gradients and abundant fine sediment. The substrates of GCU 2, 3, and 4 are sensitive to the input of fine sediment, but they are large channels which presumably handle small volumes without perceptible substrate degradation. In other GCU, the hazard is restricted to degradation of water quality by excess turbidity.

The small areas where concentrations of small inner gorges occur were carefully delineated within GMU 35 and 59. Protection of southern-aspect small inner gorges from clearcut harvest, and by default from yarding disturbance, in GMU 35 and 59 will alleviate the hillslope surface erosion hazard present in the E/W Dickey WAU.

4.2 ROAD EROSION

The comparison of fine sediment inputs to the channel network of the E/W Dickey WAU from natural processes and from roads demonstrates that channels in 11 out of 16 subbasins are receiving volumes of road sediment that may be degrading water quality and spawning/rearing habitat. In each of the 11 subbasins, greater than 80 percent of the total road inputs are derived from the mainline and secondary roads, specifically the 2000, 5000, 5200, and 9000 roads. Aggressive road maintenance on these four roads will reduce volumes of fine sediment derived from road erosion to levels associated with low hazard throughout the two WAU.

4.2.1 Natural Background Results

Natural background rates, in tons/year for each of the 16 subbasins, are presented in Table A-7. Values range from a high of 739 tons/year in the East Dickey Lower Mainstem Subbasin to 134 tons/year in the Upper Thunder Creek Subbasin. The wide range of natural background rates reflects the ranges in several characteristics of the subbasins. Obviously, the acreage of each subbasin is reflected in the natural background rates (e.g., 4,378 acres in the East Dickey Middle Mainstem vs. 1,261 acres in Upper Thunder Creek). Geology may provide some influence, although both subbasins are dominated by GMU 34a and 37, but channel density is much lower in the East Dickey Lower Mainstem (see Map E-1 in the Stream Channel Assessment [Module E] and Table A-4.1 in Appendix A-4). Generally, subbasin size and channel density are more strongly controlling the natural background rates than is geology. The influence of geology is moderated in the E/W Dickey WAU because the watershed is dominated by low-gradient, deep glacial deposits that were assigned the same creep rate and similar soil depths for the natural background calculations.

4.2.2 Survey Results

As described in detail in Section 3.0, three different types of road erosion surveys were conducted in the E/W Dickey WAU. Certain mainline and secondary roads were continuously surveyed. Representative segments of inactive and mainline roads were surveyed so that these results could be extrapolated to the extended road network. Abandoned roads were examined to understand how they were different from inactive roads, to verify that they were not causing significant sediment production by a process not observed on inactive roads (i.e., numerous culverts becoming plugged and causing the road ballast to erode) and to validate that the longest-abandoned of these could be classified as "No Erosion" roads.

4.2.2.1 Continuous Surveys of the 2000, 5000, 5200, and 9000 Roads

The estimates of surface erosion are presented in tons/drainage structure/year for the entire lengths of the 2000, 5000, 5200, and 9000 roads in the E/W Dickey WAU in Appendix A-4, Table A-4.3. These results are summarized by road and subbasin in Table A-5. The 5000 Road contributes large volumes of fine sediment to the channels of the Dickey Lake, No-name 2 Slough, and Squaw Creek subbasins, and a lesser, but significant, volume to the Middle Dickey. The 5200 Road contributes a substantial volume of sediment to the channels of Upper Thunder Creek, and lesser volumes to the subbasins of No-name 3 Slough and the West Dickey Lower Mainstem. The 9000 Road contributes very large volumes of sediment to the channels of the Middle Dickey and No-name 1 Slough subbasins, a large volume to the East Dickey Mainstem Headwaters Subbasin, and a lesser volume to the Dickey Lake Subbasin.

Table A-5 Summary of road erosion derived from the 2000, 5000, 5200, and 9000 roads.[1]

Subbasin	2000 Road	5000 Road	5200 Road	9000 Road	Total
Dickey Lake	---	667	---	73	740
East Dickey Lower Mainstem	505	---	---	---	505
East Dickey Mainstem Headwaters	---	---	---	827	827
East Dickey Middle Mainstem	---	---	---	---	—
Gunderson Creek West	739	---	---	---	739
Lower Thunder Creek	904	---	---	---	904
Middle Dickey	---	235	---	1,052	1,287
No-name 1 Slough	---	---	---	1,034	1,034
No-name 2 Slough	---	359	---	---	359
No-name 3 Slough	---	---	165	---	165
Ponds Creek	---	---	---	46	46
Skunk Creek	---	---	---	---	—
Squaw Creek	---	848	---	---	848
Stampede Creek	---	---	---	---	—
Upper Thunder Creek	113	---	257	---	370
West Dickey Lower Mainstem	---	---	57	---	57
Total	**2,261**	**2,109**	**479**	**3,032**	**7,881**

1. In tons/drainage structure/year.

4.2.2.2 Representative Surveys of Other Road Segments

A survey of a representative inactive road segment was conducted for each of the six topographic and construction classifications: flats (i.e., those roads that lie on glacial outwash and glacial lake deposits that are not stream-adjacent); midslope roads on slopes greater than 35 percent; midslope roads on slopes less than 35 percent that were originally constructed for truck traffic; midslope roads on slopes less than 35 percent that were originally constructed as railroad grades; ridgetop roads; and stream-adjacent roads (Map A-1, Road Types by Topography and Construction Type, and Road Segments Surveyed). These data were used to calculate the fine sediment derived from road erosion and delivered to the channel network in tons/mile/year. These results were modified to derive road erosion values for topographically equivalent roads classified as abandoned. Erosion values of secondary roads were derived by the modification of data from both inactive and 2000 mainline surveys. The road erosion values that were extrapolated to all unsurveyed road segments are presented in Table A-6.

Table A-6 Values in tons/mile/year extrapolated to unsurveyed road segments.

	No erosion	Abandoned	Inactive	Secondary
Flats	0.00	1.29	**2.66**[1]	21.50
Midslope, > 35 percent	0.00	2.66	**6.23**	---
Midslope; < 35 percent, no railroad	0.00	4.79	**6.87**	13.41
Midslope, < 35 percent, railroad	0.00	.91	**1.18**	2.05
Ridgetop	0.00	3.30	**5.12**	26.36
Stream-adjacent	0.00	2.29	**3.81**	21.50

1. **Bold** values are calculated from actual surveys; non-bold values are derived.

Although the proportion of a road that delivers sediment to the channel network (usually referred to as percent delivery) varies widely across the topographic and construction classes, the inactive roads are, as a group, contributing small volumes of fine sediment from each mile of road. This reflects the vigorous growth of vegetation along fillslopes and cutslopes, and some road treads, in the E/W Dickey WAU; delivery may vary, but sediment production is ubiquitously low on inactive roads in the watershed.

Abandoned roads experience less traffic and tend to be better vegetated than inactive roads. Therefore, it seems reasonable that the abandoned road erosion values derived from the inactive surveys are very small. Any inaccuracy caused by deriving the abandoned road values from the inactive road surveys is insignificant in the subbasin totals for road erosion because abandoned roads are contributing so little compared with mainline roads.

The road erosion values derived for the secondary roads reflect increased tread width and traffic as expected, but may not be very accurate values because road maintenance is greater on secondary roads. Specifically, secondary roads should have less cutslope vegetation than do inactive roads, leading to higher erosion than estimated by the derived values, but there may be more cross drains on secondary roads, leading to lower delivery. Although values of 10 to 30 tons/mile/year will significantly affect the subbasin total, so that it is usually important to have real survey data for at least representative segments of secondary roads, there are very few miles of secondary roads in the E/W Dickey WAU (excepting the 5200 Road which was completely surveyed). Therefore, any inaccuracies in the road erosion values presented in Table A-6 can cause only small affects in the subbasin totals.

4.2.2.3 Surveys of Abandoned Roads

One of the authors (LaManna) randomly picked 20 abandoned road segments on Map A-4, Road Types by Traffic and Surface Material. He field-checked each of these by walking down 200 to 400 yards to verify that it truly was an abandoned road, to document differences between these roads and inactive roads, and to determine if there were catastrophic sediment sources, such as culvert wash-outs. Two other authors (Cahill and Dieu) conducted similar field surveys on abandoned roads that they happened upon in the field.

Several conclusions can be drawn from observations made on these field visits. One, abandoned roads vary considerably in quantity of tread vegetation, from a little grass on the crown of the road to large trees across the entire road tread (the latter type of abandoned road has been classified as No Erosion). Where tread surfaces are bare, they are well-armored with coarse aggregate, usually sandstone. Two, the amount of incision into the road prism at culvert outfalls is generally less than 2 ft deep. Three, although slight slumping of old road prisms is not uncommon, complete washouts and slides of road prisms are rare. Four, many of the road segments that were long ago abandoned are actually places of net deposition of sediment. Through natural forest sedimentation processes (e.g., bioturbation and creep), and through cutslope ravel as the oversteepened surface lays back to the natural angle of repose, sediment is building up on the abandoned road tread.

4.2.3 Road Erosion by Subbasin

The total sediment yield from roads to channels is summarized in Table A-7. These values are the sums, per subbasin, of the continuously surveyed roads, presented in Table A-5, and of the representative surveys or derived values presented in Table A-6 as they have been extrapolated to the miles of each road type. The actual calculations are presented in Table A-4.4 in Appendix A-4.

Table A-7 Summary of road erosion results (tons/year) and road density (mi/mi²).

Subbasin	Road density	Road erosion yield	Natural background yield	Percent of background	Hazard call
Dickey Lake	4.51	840	380	221	**High**
East Dickey Lower Mainstem	5.03	720	739	97	**High**
East Dickey Mainstem Headwaters	4.53	913	425	215	**High**
East Dickey Middle Mainstem	4.53	123	604	20	**Low**
Gunderson Creek West	5.20	810	143	566	**High**
Lower Thunder Creek	4.62	1,015	431	235	**High**
Middle Dickey	5.23	1,402	578	243	**High**
No-name 1 Slough	4.19	1,076	227	454	**High**
No-name 2 Slough	5.85	428	275	156	**High**
No-name 3 Slough	5.82	267	371	72	**Moderate**
Ponds Creek	5.63	202	551	37	**Low**
Skunk Creek	4.64	102	483	21	**Low**
Squaw Creek	5.44	982	641	153	**High**
Stampede Creek	4.74	30	154	19	**Low**
Upper Thunder Creek	5.50	404	134	301	**High**
West Dickey Lower Mainstem	5.16	167	712	23	**Low**
Total or (Average)	**(5.02)**	**9,481**	**6,858**	**(138)**	**High**

The total road erosion for each subbasin varies from 30 tons/year in Stampede Creek to 1,402 tons/year in the Middle Dickey. As with the natural background rates, acreage has some influence on the total road erosion, particularly because road density is fairly uniform across the E/W Dickey WAU (see Table A-7). However, it becomes apparent, when comparing the mainline and secondary road erosion totals from Table A-5 (which do not include the limited miles of secondary roads other than the 5200 Road) with the total road erosion values from Table A-7, that erosion from mainline and secondary roads in the E/W Dickey WAU is producing a very high proportion of the total road-derived sediment. In fact, in the subbasins where mainline and secondary roads contribute more than 200 tons/year (Table A-5), the contribution of these roads to the total road erosion values (Table A-7) varies from 62 to 96 percent; the median value is 89 percent. These astonishing results are reflected across the entire E/W Dickey WAU, where 83 percent of the total road-derived sediment is contributed by the mainline and secondary roads.

4.2.4 Road Erosion Hazard

Hazards calls for fine sediment derived from road erosion take into account the volume of fine sediment entering the channel network of a subbasin as compared with the natural background sediment yield, the sensitivity of the GCU within the subbasin, and water quality. With the creation of the new Water Quality Module (WFPB 1996), the sensitivity of other water bodies such as lakes and wetlands are also considered. Basic (default) hazard calls are established as follows: High hazard is concluded when road erosion exceeds or is close to 100 percent of the natural background yield (i.e., more than doubles the sediment input to the channel network); Moderate hazard is concluded when road erosion is between 50 and 100 percent of the natural background yield; and Low hazard is concluded when road erosion is less than 50 percent of natural background yield. However, careful consideration of such issues as confidence in the assessment and sensitivity of the GCU within a subbasin may cause a Moderate call to be adjusted to either a High or a Low call. High hazard calls remain so regardless of GCU sensitivity because of concern for water quality degradation.

Hazard calls for the 16 subbasins in the E/W Dickey WAU are presented in Table A-7. Without exception, they appear to be directly derived from the default evaluation described above, but GCU sensitivity was carefully considered during synthesis. The rational for each hazard call as it relates to the GCU is documented in the Synthesis chapter. Each subbasin that receives more than 200 tons/year of fine sediment derived from the mainline and secondary roads (Table A-5) has received a High hazard call. Low and Moderate hazard calls occur in subbasins with little or no mainline or secondary road contributions. Eleven out of sixteen subbasins have received Moderate or High hazard calls. As road erosion exceeds natural background yield by 138 percent for the entire E/W Dickey WAU (Table A-7), the assignment of two-thirds of the subbasins to Moderate or High hazard does not seem surprising.

The goal of management prescriptions is to reduce road erosion inputs of the fine sediment to Low hazard levels. For 10 of the 11 subbasins, because of the presence of GCU 3 and 7, which have high sensitivity to fine sediment, road erosion rates must reach 50 percent or less of natural background rates. In No-name 2 Slough Subbasin, which contains only GCU with low sensitivity to fine sediment, road erosion rates must reach 100 percent or less of natural background rates. Although High hazard is a single category, High hazard calls can be prioritized. The High hazard call for Upper Thunder Creek has an elevated priority over other High hazard calls because Thunder Lake is vulnerable to sediment inputs (refer to the Water Quality Assessment [Module G] for details).

Road erosion hazard is specifically assigned to the 2000, 5000, 5200, and 9000 roads because these roads are such a huge percentage of the total road sediment yield in the E/W Dickey WAU. Concentration of road maintenance efforts on these four roads will be a cost-effective, time-efficient way to reduce road-derived fine sediment inputs to levels that represent Low hazard to water quality and fish habitat. Other roads are not included in the Road Erosion Causal Mechanism Report because maintenance efforts will have only small affects on the road erosion totals for each subbasin.

4.2.5 Road and WAU Characteristics Causing High Sediment Production and Delivery

High annual precipitation causes high erosion rates, especially where soil is bare, such as unvegetated cutslopes, and where unpaved roads receive traffic. Precipitation factors alone have large impacts on the final road erosion values. Precipitation is not factored into the natural background calculations, so WAU with high annual precipitation are likely to be found to have some road erosion hazard even if roads are maintained to Standard Forest Practices. In the E/W Dickey WAU, this affect is somewhat offset by the phenomenal growth of vegetation on all exposed soil surfaces that do not receive frequent traffic.

Geology, like climate, is a also a double-edged sword. Roads throughout much of the E/W Dickey WAU are built on low-gradient landforms, causing fillslopes and cutslopes to be short and easily vegetated. Delivery from miles of road is limited by their ridgetop position. Historically, logging roads were built wherever it was cheapest to do so; in steeper landscapes, ridgetop roads are fairly rare because they were costly to build, but in low-gradient, glaciated terrain ridgetop was a practical location. However, the local sandstone used for much of the road ballast and topping is poorly indurated and, locally, quite silty. This results in high sediment production when roads experience active haul. The glacial deposits contain hard Canadian-province rock that better withstands haul, but well-sorted deposits of glacial outwash are difficult to locate. It can be said that geology increases sediment production, but limits delivery, in the E/W Dickey WAU.

5.0 CONCLUSIONS

The E/W Dickey WAU natural background inputs of sediment are predominantly via creep and bank erosion processes. There are essentially no natural inputs via mass wasting processes except slumping associated with bank erosion. Mass wasting events triggered by forest practices have been very rare, and the volumes of sediment from these events that have reached the channel network are extremely small compared with the much higher natural background inputs. Hillslope surface erosion triggered by forest practices has been more common. Historic logging practices such as swing landing tracks account for many of the observed events. The only modern forest practice that is triggering significant hillslope surface erosion is the clearcut harvest of southern-aspect small inner gorges. Where inner gorges occur in concentrations, in GMU 35 and 59, sediment inputs to the channel network are sufficiently high to cause concern for the quality of spawning gravel and water in the immediate tributary to which they are headwater. However, hillslope surface erosion inputs are very small compared with natural inputs, and the effects are almost certainly undetectable at a subbasin scale. Road erosion, particularly from the mainline and secondary roads, is contributing more fine sediment to the channel network than are natural processes. It is likely that water quality degradation, due to increased turbidity, and aquatic habitat degradation, due to the embedding or burial of spawning gravel, is affecting salmonid fish productivity in the E/W Dickey WAU. Thus, only two causal mechanism reports have been written for this Sedimentation Assessment. One addresses clearcut harvest of the southern-aspect small inner gorges that are concentrated in GMU 35 and 59; the other addresses road erosion from the mainline and secondary roads.

6.0 CONFIDENCE

Confidence in the results presented in this module report is very high. Five aerial photo years were completely inventoried for all mass wasting and hillslope surface erosion events. Most of the land in the E/W Dickey WAU was clearcut harvested during this historic photo record, so confidence is very high that mass wasting is not a significant sedimentation process on this landscape. This conclusion is supported by the observations of numerous people familiar with the watershed.

For the same reasons, confidence is very high that the only modern forest practice that is a significant trigger of hillslope erosion has been correctly identified. In addition, extensive field experience in the local area by one of the authors (Dieu) validates these findings.

Confidence is very high for the validity of the road erosion results because of the continuous surveys of mainline and secondary roads and because of the careful stratification and selection of representative segments of other roads to be surveyed for the extrapolated results. As is always the case in watershed analyses, there is lower confidence in the accuracy of the natural background and road erosion calculations, but confidence is high that the significant sources of road erosion inputs have been correctly identified. Although distinctions between Inactive, Abandoned, and No Erosion roads have little effect on the subbasin totals, there is low confidence for the accuracy of this destinction for any given spur road on Map A-4.

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