EROSION PROCESSES

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Characterization

The two primary components of erosional processes found within the South Fork Coos Watershed are mass movement and surface erosion.

Erod Table 1: Classification of Mass Movement Types by Type of Material (based on classification by Varnes 1978 presented in Ritter 1986 with additional information from Swanson et al 1982, and Coch 1995)

Type of Mass Movement			Type of Material and Rate of Movement:		
(**Mass Movement** is the downslope displacement of regolith and rock. Fall, slide and slump events are popularly referred to as **landslides**.)			Bedrock	Primarily Coarse Fragments	Primarily Fine Material (Soils)
Falls - Material travels through the air and lands at the base of the slope. A fall is called a topple when the movement is through a forward arc around a hinge point at the base of the block.			**Rock Fall** (extremely rapid)	**Debris Fall** (extremely rapid)	**Earth Fall** (extremely rapid)
Slides - Slope failure initiated along a well-defined slippage plane Material moves in contact with the underlying surface.	**Rotational** - Plane of sliding is often deep and movement of material is along a concave contact surface. Mass of material moves as a unit or breaks into a few cohesive blocks. Movement often associated with water at the slip plane reducing resistance to failure or with loss of buttressing at the toe of the slope. Other terms include rotational slip, rotational slump. Some authors differentiate these features into small-sporadic deep-seated landslides and large-persistent deep-seated landslides based on size, origin, and permanence on the landscape.		**Rock Slump** (extremely slow to moderate)	**Debris Slump** (extremely slow to moderate)	**Earth Slump** (extremely slow to moderate)
	Translational - Alternately called planar. Plane of sliding is generally shallow and approximately parallel to the ground surface. Usually occurs following prolonged or intense rainfall and has been associated with activities that overload or over steepen the slope. (In this watershed, translational slides are far more common than rotational.)	Few units - Mass of material moves as a unit or breaks into a few cohesive blocks	**Rock Block Slide** (moderate)	**Debris Block Slide** (slow to very rapid)	**Earth Block Slide** (slow to very rapid)
		Many units - Mass of material breaks into many units or mixed as it moves	**Rock Slide** (very slow to extremely rapid)	**Debris Slide** (very slow to rapid)	**Earth Slide** (very slow to rapid)
Flows - Displaced mass moves as a plastic or viscous liquid, in which the velocity is greatest at the surface and decreases downward in the flowing mass. Rapid movement is facilitated by water acting as a lubricant or less commonly by a cushion of air trapped between the moving mass and the underlying surface. Most flows rise naturally as the final stage of a movement that began as a slide. Usually occurs following prolonged or intense rainfall.			**Rock Flow** an alternate term is rock fragment flow (extremely rapid)	**Debris Flow** (very rapid)	**Earth Flow/ Mud Flow** (slow to rapid)
				Debris avalanche* (Very rapid to extremely rapid) **Debris torrent**** (extremely rapid)	
Creep - The down slope movement of regolith driven by gravity and aided periodically by the heave mechanism. Heaving is a disrupting force acting perpendicular to the ground surface by expansion of material. Examples are soil particles displaced by shrinking and swelling (typically clays) and by freezing and thawing (typically silts).				**Soil creep** (Extremely slow)	

* The general term **avalanche** is used for the most rapidly falling sliding and flowing mass movements (Coch 1995). The term **debris avalanche** appears not to have a consistently applied definition. Coch (1995) defines debris avalanche as extremely rapid movements of rocks and sediment characterized by a semicircular head with an elongated tongue of debris running down the slope, and as a chute cut down the slope terminating in piles of debris at the toe of the slope. Ritter (1986) explains that a debris avalanche may be generated from a debris flow, if the mass is wet, as a long narrow flow that extends well beyond the toe of the slope. The definition used in this watershed analysis is from Swanson and others (1982). They use debris avalanche as a general term for rapid shallow (1 to 2 meter deep) mass movement that encompasses the processes classed as debris flows, slides, and rapid earth flows.

** Swanson and others (1982) define a **debris torrent** as a rapidly moving slurry of soil, alluvium and large organic debris that occur in response to intense storms and are commonly triggered by debris avalanches entering a channel from adjacent hillslopes. As the debris avalanche moves down the channel, it becomes a debris torrent as it scours the streambank and bed. Runoff from intense storms can also initiate a debris torrent by mobilizing material previously deposited in the channel by erosional processes and windthrow.

Mass Movement: The mass movement processes most often found in the South Fork Coos are landslide failures such as debris flows, debris slides, and slumps. Debris torrents affect steep channels. Rock falls/rock slides are locally important. Soil creep is on going process on most of the landscape. Erod Table 1 defines and classifies mass movement types.

Surface Erosion: Surface erosion is the wearing away of soil and rock by weathering agents such as wind and water. Surface erosion results from sediment availability and transport capacity. Soil erodibility is strongly related to soil texture. Coarse and fine soil particles generally have lower erodibilities than intermediate textures. Coarse or large particles are more difficult for water to move while fine soils such as clays possess enough cohesiveness to hamper movement. Intermediate classes generally have high silt contents that lack cohesion in wet conditions. Tables Erod-2 and Erod-3 display the soil types typical for the geologic features in the watershed. Erosion Appendix Table 1, in the Erosion Processes Appendix, lists the soils found within the South Fork Coos Watershed and gives an estimate of susceptibility to surface erosion based on K-Factor values. K-Factor is a measure of the inherent erodibility of a soil. The Natural Resource Conservation Service identifies K values in their soil surveys. The Soil Survey of Coos County, Oregon (Haagen 1989) and the unpublished soil survey data set for Douglas County (USDA unpubl.) contain the K values for the soils in this watershed.

Geology and Geologic Hazards: Table Erod-2 displays the geological formations and Table Erod-3 displays the superficial geological units within the South Fork Coos River Watershed (Beaulieu & Hughes 1975, Niem & Niem 1990). These features have erosional hazards associated with them based on properties such as texture, permeability, and mineral content.

Table Erod-2 Descriptions of Primary Geologic Formations in the South Fork Coos Watershed

Unit	Formation (Symbol)	Rock type	Structure and bedding	Soils	Associated Hazards
Sandstone of Tertiary Age	Bateman (Teb) Tyee (Tet) Flournoy (Tef)	Hard, thick to thin bedded sandstone with minor siltstone. Flournoy and Tyee both have increasing siltstone content high in the member.	Rhythmic to deltaic bedding; gentle to moderate dips, jointed and faulted locally	Loamy sand and sandy loam; very thin soils on steeper slopes with abrupt transition to bed-rock	Rapid erosion, flash flooding, rapid mass movement, stream bank erosion
Siltstone of Tertiary Age	Elkton (Tee)	Soft to moderately hard siltstone and shale with minor sandstone	Same as above, but finer jointing	Silty loam and silty clay loam; very thin locally even on gentle slopes	Rapid erosion, mass movement, streambank erosion
Basalt of Tertiary Age	Roseburg volcanic member (Terv)	Dense to rubbly basalt	Massive, thick, variable stratigraphic position	Silty clay loam, silt loam; extremely variable in thickness	Flash flood, mass movement

Table Erod-3 Descriptions of Superficial Geologic Units in the South Fork Coos Watershed

Superficial Geologic Units (Symbol)	Distribution	Material and bedding	Soils	Associated erosion hazards	Other land use suitability characteristics
Marsh and Peat (mpt)	Estuarine wetlands with vegetative cover	Horizontally bedded sand, silt, and clay rich in organic material	Silty loam, silty clay, muck		Caving, liquefaction, settling, flooding, high ground water
Quaternary alluvium (Qal)	Flood plains of rivers and major streams	Sand, silt, clay and gravel depending on environment and source; cross-bedded	Sandy and loamy sand, silty loam, silty clay loam	Siltation, streambank erosion	Caving, flooding, ponding, settling, high ground water
Quaternary Fluvial terrace (Qft)	Dissected former flood plains "elevated" above present flood plain by stream down cutting	Sand, silt, clay and gravel depending on the source; cross-bedded	Silt loam, silty clay loan	Streambank erosion	Ponding, high water table
Quaternary Marine terrace (Qmt)	Flat coastal uplands, lifted by tectonism, and mantled with marine deposits	Compact, horizontally bedded, deeply weathered silt, sand, and clay; pan development locally	Silt loam, silty clay loan, sandy loam, sand, silt	Streambank erosion	Locally thin, poor drainage in places, failure in deep cuts.
Quaternary Landslide debris (Qls)	Large, persistent, deep-seated landslides that occurred 100s-1,000s of years ago during seismic events or as the result of extreme rainfall events or channel incision. These features predate and are independent of management activities; Slump features on deep cohesive soils.	Mixed soil and debris	Colluvium.	Slumping, streambank erosion, chronic sedimentation	

<u>Landform and Slope Stability</u>: The sandstone units can be stratified into two types based on landform characteristics and associated slope failures. The marine basalt unit exhibits similarities to the second sandstone type (Burroughs et al 1973, Townsend et al 1977). These are shown in Table Erod-4 below.

Table Erod-4: Landform and Associated Slope Failures (Burroughs *et al.* 1973, Townsend *et al.* 1977).

Geologic material	Type of failure	Activity most affected	Remarks
Bedded sediments: Flournoy, Bateman, and portions of the Tyee formation	Debris avalanches, debris flows, and debris torrents originating in headwalls are the most common slope failures. Also, rock slides and rock falls.	Roads and clearcut timber harvest Side cast road construction on very steep and extremely steep slopes risks overloading marginally stable slopes.	Very steep and extremely steep slopes with sharp ridges. Many slopes have a uniform gradient from ridge top to slope toe. Headwalls (fan-shaped concave features) high in the drainage, and high dissection density. Very shallow to moderately deep, skeletal soils. Headwall gradients typical 80% or greater. Typical headwall soils are Umpcoos, Digger, Jason and Rockland. Typical ridge top soils are Preacher and Blachly. Bohannan is a typical steep sideslope soil. (Type I sites)
Bedded sediments: Portions of the Tyee formation, primarily the upper thinner beds that have more silt than sand Bedded sediments: Elkton formation	Rotational slumps, translational slides and earth flows (Tyee) Slumps and earth flows (Elkton) Most unstable areas are steep, concave slopes at head of drainages; convex portions of ridges and edges of benches, or areas where water accumulates.	Roads Road failures frequently involve poorly consolidated or poorly drained road fills. Failures are also associated with embankments greater than 12 to 15 feet on any red clayey soil (for example: Honeygrove, Blachly or Jory)	Very deep soils, unconsolidated bedrock materials and steep slopes. Side slope gradients are 10% to 80%. Ridges are rounded and longer side slopes may be broken by benches. Dissection density less than on type I sites. Headwalls and small patches of exposed rock are rare. Typical ridge top soils are Honeygrove, Preacher, and Blachly. Bohannan is typically found on smooth steep side slopes. Preacher is typically found on benches. Digger and Jason soils are generally associated with steep side slopes at the head of drainages. Soils on gentle slopes have developed over centuries and therefore are deep with a high (50-70%) clay content. Fine sediment inputs to streams are naturally high from the plateau areas due to the deep fine textured soils and to associated slump features. Little mass wasting on the flatter benches (except from the convex edges), but instead soil creep is dominant mechanism for delivery of soil to hollows and draws. (Type II sites)
Submarine basalt: Volcanic member of Roseburg formation	Slumps	Roads	Moderately deep to very deep soils and highly fractured bedrock materials, otherwise, the same as above. (Type II sites)

The overall shape of the landscape, with V-shaped first and second order draws, and narrow bottom valleys makes for efficient delivery of sediment. Steeper drainages tend to produce more sediment and have a greater response to management activities in part because of the importance of mass wasting on steep land. Production of sediment was observed to be low from drainages with a mean slope less than 35% even after road construction, clearcutting and broadcast burning (Swanson et al 1987).

Current Conditions

We conducted a probabilistic analysis on the South Fork Coos Watershed using the infinite slope model (Map Erod-1). The analysis provides an estimate of the probability of slope failure and is not intended to give a calculated factor of safety, nor is it a deterministic analysis of risk. The probability of failure was broken down into five categories based on ranges of factors of safety. The acres by category are shown in Table Erod-5. Sensitivities in the model identify areas of greater probability for slope failure. The model is most sensitive to variables such as soil and root cohesion (strength). During the analysis phase, tree age data was unavailable for lands in private ownership therefore, the map shows federally managed lands only. The stand ages for BLM land come from the FOI data base.

Table Erod-5: BLM Acres by Landslide Probability

Probability (map color code)		Acres
None	(green)	11,614
Low	(blue)	10,032
Moderate	(yellow)	3,596
Moderately High	(orange)	3,004
High	(red)	3,491

The Timber Production Capability Classification (TPCC) Map of the South Fork Coos Watershed is another representation of the current condition of the soils in the Watershed with respect to risk of mass movement[1]. The TPCC was mapped only to BLM land and is displayed on Map Erod-2. The TPCC fragile gradient classes for Coos Bay District are FGR1, FGR2, and FGNW. FGR1 sites are predominantly on 50 to 70% slopes and FGR2 sites are on predominantly 70 to 80% slopes. These sites are classified

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[1] The first TPCC manual was prepared in 1974 partly in response to the March 1972 Church Subcommittee Report on Clearcutting on Federal Lands. Policy guidelines that came out of the Subcommittee Report included:

> *Clear-cutting should not be used as a cutting method on Federal land areas where: a. Soil, slope or other watershed conditions are fragile and subject to major injury. b. There is no assurance that the area can be adequately restocked within five years after harvest.*

The implementation of these two policy guidelines are reflected in the 2-part structure of the TPCC classification. The first part is a classification of site robustness/ fragility with respect to timber removal. The second part is a classification of site conditions that may restrict reforestation success. The TPCC is a land classification system that allows for stratifying the land for calculating allowable sale quantity. The land is classified through TPCC based on the physical and biological capability of the site to support and produce forest products on a sustained yield basis, using operational management practices. "TPCC is not designed for, nor is to be used to make management decisions on economic, or multiple-use considerations. Resource allocation is a function of the Bureau Planning System" (USDI 1986). Consequently, TPCC is used to identify all of the sites that can support a sustainable yield of wood. The Resource Management Plan identifies those lands, which are classified as capable of producing a sustain yield of wood products, that will actually be included in the land area allocated to meet the timber production objectives.

During the 1986/87 TPCC mapping project, sustainability of timber production was determined in the context of the timber management plan in place at that time, and in context of the state of the art of applied logging engineering and silvicultural practices in 1986. The assumptions used to assess sustainability were management for timber production through repeated clearcut harvest on 40-year rotations using appropriate logging technology, followed by broadcast burn site preparation, planting, and timely application of treatments to insure seedling survival and growth. Reduction of forest yield was interpreted to occur if the site productivity was expected to drop by one site class as the result of the management regime described above (F. Price, Tioga TPCC Forester in 1986/87). Land was classified nonfragile if the land was expected to produce a sustainable yield of wood products without special harvest or restrictive measures beyond those that are a standard part of timber sale contracts in 1986. Lands were classified fragile-restricted (FGR1 and FGR2) if special harvest or restrictive measures (for example partial log suspension, full log suspension, directional falling, aerial logging, or low impact alternative site preparation) were required to insure long-term sustainable harvest of wood products (USDI 1986). Lands classified as FGNW are not expected to produce sustainable yields of wood products if managed for timber production objectives following the assumptions described above. Therefore, FGNW lands are not included in the land base used to calculate the allowable sale quantity. The FGNW classification does not preclude treatments to obtain non-timber management Forest Plan objectives.

"fragile" because special harvest and/or restrictive measures, beyond the standard timber sale contract language, are necessary to protect the ability of these sites to product a sustainable yield of wood products. Matrix lands classified through TPCC as nonproblem, non-fragile, fragile-restricted (includes FGR1 and FGR2) are in the land base used to calculate the allowable sale quantity (USDI 1986; USDI 1995)[2]. FGNW sites are very fragile and are usually on steep, shallow, rocky soils that are prone to landsliding when denuded by clearcutting or by stand replacement fire. Some FGNW mapping units contain exposed rock, which though stable, do not support tree growth. FGNW mapping units sometimes contain small areas of non-fragile or fragile-restricted land due to the practical limitations of delineating and managing those inclusions. The BLM excludes FGNW sites from the timber base when calculating an allowable sale quantity (USDI 1986) and the management direction is to minimize disturbance of these sites (USDI 1995). The TPCC data do not compare directly with the result of the infinite slope model. The TPCC map was produced using a combination of photo interpretation, and site visits. The TPCC fragile gradient classification is an assessment of the risk to site productivity posed by shallow rapid slides and flows if the site were to be clearcut harvest using appropriate special harvest and/or protective measures. In contrast, the infinite slope model estimates of probability are based on current conditions, which considers among other things the presence of live roots providing strength to the soil mass[3].

The BLM manages 32,736 acres of land in the South Fork Coos Watershed. Of this, 6,038 acres (18.4%) are either rock outcrops or classified as FGNW and therefore withdrawn from timber production in 1986/87. These areas are scattered throughout the Watershed with concentrations of withdrawn ground in the south central portion of the Watershed.

<u>Interaction of roads and hillslope processes</u>: The following discussion on the interaction of roads and streams is from Jones and others (2000) unless noted otherwise. Road location on the landscape, specifically slope position, strongly influences the types and frequencies of interactions between roads and streams. Roads near ridges have little direct effect on streams. Roads intersect streams at angles close to perpendicular on midslope and lower slope positions. Roads on the lower slope and valley floor parallel major streams and cross tributary streams. Consequently, road-stream crossings are concentrated on the mid and lower slope positions. These are points of interaction between the road and stream systems. Streams are conduits for the gravitational transport of water, sediment and debris. A road segment can affect water flow and sediment transport in a stream by acting as a barrier, a net source, a net sink, or as a corridor for water and sediment. Roads act as corridors for water flow on the road surface and in the roadside ditch, and as corridors for lateral rerouting material in slides and debris flows. Roads act as sources of water to streams through culverts, gullies and ditches that empty directly into streams. Roads act as sinks by intercepting sediment, and landslides, and as sources for the same. A road segment's ability simultaneously to act as barrier, corridor, source or sink results in the capacity to modify the magnitude and direction of water, sediment and debris movement and to transform water flows into debris flows. Roads thereby can alter the distribution on the landscape of debris flow starting points and stopping points, and can alter the composition of material delivered to streams. For example, a road segment crossing a stream can intercept debris flows preventing delivery of fine sediment, coarse material and wood to a low gradient channel below. Alternately, many debris flows in channels are either initiated or augmented by road associated slope failures. May (1999) found Coast Range debris flows initiated at roads had an order of magnitude greater volume of sediment compared with non-road related failures. In other cases, a debris

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[2] This discussion is specific to site fragility as it relates to erosion issues. As a point of clarification, the TPCC has a reforestation component and certain lands classified as "woodland" due to reforestation issues are also excluded from the land base used to calculate the allowable sale quantity (USDI 1986).

[3] Sensitivity analysis showed that when a denuded condition was assumed, that is no live roots, then the infinite slope model estimated a probability of slope failure more closely matching the TPCC.

flow can take out a road at a stream crossing adding the road fill material to its mass. The impact of midslope roads on landslide rates is greatest where slopes are stable enough that slope failures in clearcuts are unusual, but where low investment in road construction and maintenance results in a high frequency of road related landslides (Swanson et al 1987).

Wemple (1998 cited in Jones et al 2000) found that midslope roads are net sources of sediment to streams, whereas lower slope and valley bottom roads are net sinks. Consequently stream segments, below a midslope road, are more likely to be affected by debris flows than a similar stream segment that does not have a road above it (Snyder 1999 cited in Jones et al 2000). Also, a stream below a valley bottom road may be less affected by debris flows compared with a similar stream without parallel road. While this reduces fine sediment delivery to valley bottom streams, it also reduces delivery of the large wood and boulders needed in structure deficient streams.

Reference Conditions

Geologically, the Coast Range was created by a combination of regional uplift and erosional processes dominated by landslide activity. The heaviest precipitation in the Coast Range falls on the coastal side and feeds numerous west flowing rivers like Coos River. This higher rainfall plus steeper gradients have caused more active headward erosion of the west flowing rivers, compared with the lesser east flowing streams. This resulted in the crest of the Coast Range being pushed well east of the central axis of uplift for the range. The combination of high rainfall and unstable minerals in the bedrock geologic units has produced a thick soil mantle on all but the steepest slopes (Irwin; Hotz 1979). Erosional forces encountering more resistant bedding planes are responsible for the plateaus and benches found in the Tyee and Elkton formations. The slope of these essentially flat features corresponds to the north dipping slope of the underlying sedimentary bedding planes. The South Fork Coos River gorge is the result of the river cutting down as the land is uplifted. Rock falls, from the cliffs in the gorge reaches, deposited large boulders at the toe of the slopes and in the channel. Some of these boulders were 15 to 30 feet tall (Farnell 1979). Tectonic uplift, along with a progressive lowering of sea level, has resulted in a series of marine and alluvial terraces at the west end of the Watershed. The oldest is the 1,600-foot high marine terrace on top of Blue Ridge. Large alluvial terraces are down stream from Dellwood along the South Fork and main stem of Coos River. The youngest alluvial terraces probably date from 550 years ago while the oldest were lain down in the Middle Pleistocene (Haagen 1989). Landslides are a crucial component to the delivery of gravel and coarse woody debris to stream systems. Alluvial landforms are created when the sediment production exceeds the transport capacity of streams (Lewin 1992 cited in Rot et al 2000). Some flats and benches in the Watershed are the result of slumps, or when found next to small mountain streams down stream from steep reaches and headwalls, are debris torrent depositions.

Erosion is a product of the interaction of landscape characteristics and processes. Among these are fire, rain, wind, topography, lithology and vegetation. The amount, timing and relative importance of different types of erosion are not fixed. Rather erosional patterns change spatially in response to topographic, soil, and vegetation distribution attributes, and temporally in response to vegetation maturity and successional stage, and climatic variation (Benda et al 1999). Surface erosion may be increased by other processes like debris avalanches and windthrow that expose mineral soil and/or locally increase slope steepness. Debris avalanches may be triggered by windthrow or by local slope steepening caused by soil creep, slumping or earthflows. Soil creep can be a precursor to mass movement, for example by loading headwalls, or can cause trees to tip increasing the risk of windthrow (Swanson et al 1982).

Under undisturbed conditions, overland flow of water, even during heavy rainstorms, is rare on forest soils in the Douglas-fir Region. Overland flow, when it does occur, is associated with special circumstances such as when soils are extremely shallow and easily saturated, or when soils are frozen (Fredriksen; Harr

1979). The thick forest canopy, heavy understory vegetation, the duff layer, and the naturally high infiltration rates of the top soils all contribute to minimizing overland flow and associated surface erosion. Overland flow can be locally common on severely disturbed sites (Swanson et al 1987).

Much surface erosion from steep forest soils is the result of particle by particle movement as dry ravel, and displacement by rain drop impact or by freeze-thaw. Ravel occurs primarily on 60%+ slopes, even under natural forest cover. Burning greatly accelerates the rate of ravel by removing the live and dead organic matter that binds soil particles together (Swanson et al 1987). In the Oregon Cascades, the highest surface erosion rates are associated with dry ravel (Swanson et al 1982).

Debris torrents generally begin in first and second order streams and come to rest in lower third order and upper fourth order draws. Long runout debris torrents typically begin high in the drainage in long straight channels with gradients generally exceeding 80% and come to rest either where the channel makes an abrupt turn or where the channel gradient flattens out to 3 to 11%. A short runout debris torrent typically begins lower in the drainage and enters the main channel from a tributary with >60% gradient. A 27-year case study in a Coast Range watershed suggests the greatest extent of stream length directly affected by debris torrents are the second and third order draws (Swanson; Lienkaemper 1978, Swanson et al 1987).

The effect of a debris flow on a stream depends on the size of the stream and the volume of the flow. Debris flow deposits in a small channel can block fish passage whereas a debris flow entering a large stream is likely to be dissipated down stream in a wood laden flood wave (Swanson et al 1987).

<u>Wildfires and climatic conditions influences on erosion processes</u>: Soil denuding low intensity wildfires that did not kill roots resulted in periods of elevated surface erosion but had little effect on mass movement potential. High intensity stand replacement wildfires resulting in an increased rate of landslide activity in addition to surface erosion within the impacted area. High intensity fire also consumed the organic matter that helped resist erosion by binding soil particles together. Dry ravel between rain events delivers colluvium to channels adding sediment and bed load. The loss of live vegetation reduces evapotranspiration. This leads to longer periods of seasonally increased soil water resulting in prolonged seasonal soil creep, slump and earthflow movements. Blowdown caused by fire generated wind, and fallen fire-killed timber resulted in pit and mound microtopography, and accumulations of woody debris on slopes and in stream channels (Swanson 1981).

Mass movement following a fire can transport tremendous amounts of sediment and wood debris to stream channels. Reeves (1996) observed that mass movement following fire can deposit so much material that two or three meters of sediment and coarse debris can still remain in the channel 100 years after the event. Many terrace-like features next to mountain streams are depositions of debris avalanche transported material that were subsequently cut down through by streams. The accelerated erosion associated with intense fire combined with normal background levels may cause a fivefold increase in sediment yield, and the recovery to pre-fire sediment yields may take 20 to 30 years (Swanson 1981). In the Coast Range, very large stand replacement fires have a return rate of about 240 years (Ripple 1994)[4]. Based on that return rate, the Watershed experienced elevated sediment levels 8% to 12% of the time when periods long enough to include stand replacement fires are considered. Smaller fires and less severe fires would have caused additional smaller spikes of fire associated sediment. Most fires were clustered in time with periods of few fires in between (Tioga Appendix: Fire History).

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[4] Climatic changes would affect fire frequency. Sediment cores used to reconstruct fire and vegetation patterns in a Coast Range site for a 9,000-year period suggests fire return intervals of 110± 20 years for the period 9,000 to 6,850 years ago, and 160± 20 years for period 6,850 to 2,750 years ago. The sediment cores indicate a fire return rate for the last 2,750 years comparable with Ripple's findings (Long *et al.* 1998).

Intense precipitation increases landslide rates. In recent history, major storm events resulted in numerous landslides. Data from NOAA Cooperative Weather Stations show intense rain storms (at least 4 inches in 24-hours) have a return frequency of 5+ years. Cumulative rain falls of 9-inches or more over several days correlate to higher incidents of landslides and torrents (USDI 2000). High intensity rainfalls saturate the soil filling the spaces between the soil particles. This is pronounced in concave features on the landscape like headwalls. When the soil pore spaces are filled, the soil particles float apart and away from roots. This overcomes the resistance to soil movement normally provided soil cohesion and root mass. Under these conditions, landsliding is common on the effected landscape and occurs without regard to vegetive cover condition.

Large Slump Features on the Landscape: Geology maps show several large slumps, which form prominent features in the Watershed (Wiley 1995; Wiley et al 1994; Beaulieu & Huges 1975). These features are likely the result of earthquakes occurring hundreds to thousands of years ago. Geology and anthropology studies suggest that periodic earthquakes of sufficient intensity to cause flooding through rapid subsidence or tsunamis occurred along the Pacific Coast. Data from Bradley Lake, 5 km south of Coquille indicate three earthquake subsidence episodes occurring 300, 1,000 and 1,600 years ago (Hall 1995, Nelson et al 1994, cited in Hall 1995, Clarke & Carver 1993, Atwater 1987). At least 8 events during the last 5,000 years are evident in the marshes of South Slough on Coos Bay (Orr et al 1992). This suggests earthquakes of sufficient size to alter the landscape occur on average every 600-700 years.

Synthesis & Interpretation

Natural and human caused changes in erosion: Management for agricultural and forest products have caused increases in surface erosion and mass wasting compared with erosion rates associated with the unmanaged fully forested condition. Experimental manipulation of vegetation in small drainages and studies of erosion processes indicate that debris slides and road surfaces are dominant sources of elevated sediment delivery on managed forest landscapes (Swanson et al 1987). Conversion of land inside the Watershed to agricultural purposes began in the 1850s (Mahaffy 1865) and logging began in the 1880s (Beckham 1990). Early logging involved using livestock to move logs to the rivers for water transport to the mills. Later, logs were moved to the river by cable using steam donkeys and later gasoline donkeys. Logs could be moved from one to two miles using relay donkeys every half mile (Anonymous 1911). This avoided road construction costs and associated erosion hazards. Log drives above tide water from 1880s to the 1940s were discrete events separated by periods of inactivity[5]. The first splash dam was built in 1940 in Section 30, T25S.,R10W. and washed out the following year. A second dam was built 1941 in section 32, T.25S.,R10W., and it too washed out in 1942. A third dam, which became known as the Lower Dam, was built in 1942 and operated for 15 years[6]. The Tioga Dam or Upper Dam was built in Section 7, T26S.,R9W., in 1943 and operated from 1944 to 1957. An access road was also built down Tioga Creek from the Winkler Mast Homestead to the dam site in 1943. The operation of the upper dam depended on a regular supply of logs necessitating the operation of several logging contractors (Farnell 1979, Beckham 1990).

Log drives and later splash dam operations resulted in impacts to stream side vegetation elevating

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5 Logs were brought out on freshets from McKnight's Landing in 1882 and 1884. Logs were hauled to tide water on Coos River by rail from Daniels Creek and Blue Ridge after 1898. There appears to have been no significant log drives above tide water on Daniels Creek. Winter freshets were used to drive logs from Smith Basin (sections 11, 14, 15, 23, & 25, T.25S.,R11W.) from 1906 to 1916. Winter freshets were used to drive 100 logs from the Ferrin Camp area (section 27, T.25S.,R10W.) from 1908 to 1911 (dates not clear from text), and another operator drove 1,200,000 board feet of logs and pilings in 1909/10. Except for a drive in 1925/26, little additional logging occurred above tidewater on the South Fork Coos River until 1934 (Farnell 1979, Beckham 1990).

6 Beckman (1990) noted that the Lower Dam lacked sufficient head of water to carry logs over the exposed bedrock stream bottoms of the wider reaches of the South Fork Coos.

streambank erosion. Log drives ceased in 1957 ending associated direct impacts to stream banks. However, log drives required and caused changes to the channel that reduced the South Fork Coos River's channel roughness, which in turn reduced the river's ability to retain woody structure and sediment. Operating the splash dams required blasting boulders to remove obstructions in the South Fork Coos channel. Some of these boulders were 15 to 30 feet high. After the boulders were blasted and other "improvements" made, 4,000,000 board feet could be taken from the Tioga Dam down Coos River in a single splashing. On some freshets, 200,000 board feet per hour could be moved down the river. Some logs were up to 120 feet long (Farnell 1979).

Road construction and logging on steep ground back away from water access began in earnest after World War II. Early road construction and logging were done as inexpensively as possible with little regard for environmental consequences. The most impacting practices during the 1950s and 1960s, with respect to sediment delivery, were:

- sidecast road construction on steep ground through headwalls and above streams.
- cat logging next to and through streams exposing bare soil and compacting the soil reducing the water infiltration and by that facilitating sheet and sometimes gully erosion.
- poorly rocked or natural surfaced roads near streams.
- road placement next to streams that later necessitated mid-slope road construction to access ridges.
- downhill logging to stream bottom road systems. This practice became increasingly uncommon after the 1950s.
- culverts that were too few, undersized, poorly placed and unmaintained.
- Poor or deferred road maintenance, and road maintenance practices like debris sidecasting, aggressive ditch cleaning and cut bank scaling.
- ground lead logging on steep ground.

The Tioga Appendix: Sediment Budget & Dynamics Investigation included a review of old aerial photographs to document the changes in the channels and sediment storage and correlated those observations with changes on the landscape. The 1943 aerial photos of Tioga Creek show early successional vegetation in valley bottoms, indicating naturally occurring recent debris torrents before active management in the area. The 1950 aerial photos show stream side road construction, downhill yarding and large pulses of sediment delivered to the Lower Tioga Creek. The 1953/54/55 stream survey (summary in Tioga Appendix: In Stream Gravel & Coarse Woody Debris) shows an array of material from small gravel through boulders on the lower 4.3 miles of Tioga Creek. From 4.3 to 5.9 miles were reaches of exposed bedrock. From there up to the end of the survey 12.4 miles above the mouth, was again an array of substrates. These early surveys document large log jams in Tioga Creek from 6.1 to 8.7 miles above the mouth on the main stem, and smaller jams from 11.1 to 12 miles. The upper extent of logging was at 10.1 miles above the mouth then. The 1960s aerial photos show cat logging on the landscape, loss of riparian vegetation to logging, to road construction and to debris torrents. The photos also show formation of bars in Tioga Creek indicating a sediment delivery rate exceeding transport capacity. A comparison of the 1964 and 1965 aerial photographs suggests the 1964 flood had little effect on the Tioga Creek channel. A decrease in sand bars and stream down cutting between 1965 and 1970 indicated a shift from excessive delivery of sediment to a loss of ability to store sediment. This is visible on 1976 aerial photos. The 1970 stream survey showed bedrock, bedrock pools and boulders occupying most all of the lower 6 miles (Tioga Appendix: Sediment Budget & Dynamics Investigation). The loss of gravel from the mouth up is analogous to the way that the heads of gullies progressively move upslope over time by eroding from the exposed face at the head of the gully.

Beginning in 1969, the following changes in Federal land management practices resulted in a decrease of soil erosion and subsequent sediment entering the streams:

- NEPA passed in 1969 resulting in increased environmental awareness
- Shift from sidecast to full bench road construction started in the late 1960s/ early 1970s.
- Also in the 1970s, better equipment and aerial systems allowed for full log suspension when logging fragile ground.
- The 1975 TPCC was the first formal stratification of BLM land based on slope stability. Very fragile land was removed from the timber base. Recommendations restricting road construction and logging methods were applied to other fragile lands.
- District soils inventory, with management recommendations, was published in 1977 (Townsend *et. al*. 1977).
- The 1983 MFP required stream buffers on third order and larger streams (USDI 1983).
- The 1986/87 TPCC revision (USDI, 1986) resulted in more land removed from the timber base due to slope fragility.
- The Aquatic Conservation Strategy put forth by FEMAT (1993), and incorporated into planning and decision documents (USDA; USDI 1994, and USDI 1995).
- Best Management Practices are required under the Resource Management Plan (USDI 1995).

The State Forest Practices Act (SFPA), passed in 1971and followed by revisions over the years, has resulted in incremental improvements in road construction methods, and stream and riparian vegetation protection on private lands.

Weather cycles also affect sediment deliver. Wet and dry periods tend to run for 20 to 25 years, and correlate to shifts in global-scale ocean currents. Climate data for the Oregon coast goes back to 1896. These data showed dry periods for the water years from 1920 to 1945 and from 1975 to 1994. The years before 1920 and between 1945 and 1975 were wet periods. If the past can be used to predict the future, we should expect about 75% of the next 20 to 25 years to be wetter than average. We should also expect frequent floods, and for the winters to be cooler. The wetter, cooler trend will apply to the winter months but not necessarily to the summer months (Taylor 1999). During the last dry cycle on the Coos Bay District, 1976 and the first part of 1977 were drier than normal, with only 33.5 inches of rain in North Bend, Oregon during the 1976 calender year (Oregon Climate Service[7]). Intense storms resulting in landslides were largely limited to the years 1978 to 1983, with few mass wasting events occurring between 1983 and 1995. With the suspected entry into a new wet cycle, the winters of 1995/96 and 1996/97 have again been wet and brought intense rain storms with a corresponding increase in landsliding.

<u>Interaction of past management practices erosion processes and channel condition above tide water</u>:
Log drives and splash dam operations resulted in damage to stream side vegetation and elevated stream bank erosion. These direct effects ended following cession of splash dam operations in 1957. Activities to clear the channel of obstacles and hangups combined with the damage caused by pulses of water and logs abrading stream banks and channel have a continuing negative effect on the ability of the South Fork Coos River to retain and process sediments and retain large wood with consequences for channel condition and fish habitat. Rock falls and landslides deposited large boulders in the South Fork Coos River channel over 1,000s of years. These large boulders were removed to facilitate splash dam operations (Farnell 1979). Naturally occurring erosional processes will take a similarly long period to replace those boulders. Before the boulders were removed, they likely caused the river current to travel a more sinuous path, and this allowed small flood plains, gravel bars and backwaters to form. The loss of the boulders and other channel roughness features allows the river to flow a faster more direct path, which works against recruitment and retention of substrate and structure. The faster currents in the South Fork Coos channel may have also

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[7] Climate data can be found on the Oregon Climate Service website: http://www.ocs.orst.edu

caused the lower reaches of low gradient tributary streams also to experience faster currents with resulting down cutting. This is one possible explanation for the loss of substrate in the lower 4.3 miles of Tioga Creek, which was present during the 1953/54 stream survey and gone by the 1970 stream survey (surveys on file Coos Bay District Office).

The formation of bars and a delta on Tioga Creek that are visible on aerial photos taken in the 1950s and 1960s indicate that sediment delivery, exceeded transport capacity. The absence of those features and recovery of streamside vegetation, on the 1976 aerial photos, suggests that sediment delivery no longer exceeds transport capacity (Tioga Appendix: Sediment Budget & Dynamics Investigation). The loss of the delta and bars in the lower Tioga Creek may have been due, in part, to increased transport capacity caused the higher flow rates associated with the simplification of the South Fork Coos River channel. However, the reduction of sediment delivery caused by a decline in new road construction and improved management practices since the late 1960s allowed trees to establish on other bars in Tioga Creek and a cession of new bar formation.

<u>Interaction of past management, landslides, and coarse wood delivery</u>: The last log jam removals from low gradient streams in this Watershed to improve fish passage and reduce risk of damage to capital improvements was in 1981 (sect. 17, T.27S.,R.9W). The practice of salvaging small jams and individual pieces from streams declined through the 1980s and stopped when the Forest Plan went into effect in 1994. Removal of “potentially floatable debris” is still allowed when necessary to protect “downstream users’ improvements” (USDI 1995 pg D-2). Biologists for years were keenly aware of the fish passage problems that jams could cause. However, they only began to appreciate the sediment retention and processing functions, and habitat values provided by instream wood when simplified bedrock channel bottoms became a common stream feature in the 1970s. The operational shift from jam removal to jam retention was a slow process. The change over was complicated by an institutionalized concern for fish access to habitat (reinforced by bonafide instances of blockage), cases of property damage caused by debris in the streams, the desire to do good things for fish, and a fundamental change in the composition of logjams in clearcut influenced watersheds.

In unmanaged landscapes, log jams are composed of pieces delivered to streams from mature stands, as the result of fire, landslides and windfall. Based on observation in the intact reaches of Tioga Creek, log jams in the unmanaged landscape commonly had a moderately packed to loose architecture and each jam ranged from tens of feet to a few hundred feet long (Tioga Appendix: Upper Tioga Creek Stream & CWD Diagram, and Tioga Appendix: in Stream Gravel & Coarse Woody Debris). Larger jams were more often associated with extreme events like stand replacement fires or extreme storms. If these sorts of log jams had been typical in the 1970s, then the transition from removing log jams to address fish passage concerns to retaining log jams for habitat and hydrologic purposes would have been faster than it was. Those jams were not typical, because by the 1970s log jams contained a large component of tightly packed logging debris and ranged from several hundreds to thousands of feet long (Tioga Appendix: In Stream Gravel & Coarse Woody Debris). In BLM timber sale units sold before 1973, cull material and broken pieces that fell into draws during harvest operations were left in place. This practice was not an issue, with respect to slope stability on gentle to moderate slopes, but had consequences on steep slope failure prone first and second order draws. The removal of large stable pieces and deposition of floatable small cut ends, broken pieces and slash into these stream channels changed the size distribution of wood and increased the potential for debris torrents. In some cases, the debris temporarily blocked water flow in steep channels during storms and when the debris gave away the sudden downstream surge of water collected additional debris to form a debris torrent. In other cases, headwall failures resulted in slides or torrents that incorporated material from the logging debris laden draws and transported that material to the lower gradient stream channels below (Swanson; Lienkaemper 1978). This resulted in jams composed of tightly compacted short broken chunks and cull logs. In heavily logged watersheds, individual jams could expand to occupy a mile of more of the channel. This is illustrated by comparing log jam data from the 1950s to 1973 data:

The 1950s stream surveys documented 12 log jams on Tioga Creek from 6.1 to 12 miles above the mouth. The lowest jam was attributed to logging and a bridge and was 600 ft long. Between there and the upper extent of logging at 10.1 miles above the mouth were 5 more jams. Four were 300, 75, 450, and 600 feet long with the length of the fifth jam not recorded. The stream surveyor found 6 jams on the next 2 miles of Tioga Creek. These were in an unlogged part of the Watershed. One jam was 80 feet long and the rest ranged from 10 to 30 feet long. In comparison, the 1970 stream surveys resulted in a 1973 contract to remove 7 jams. One was a 500-foot long jam on Tioga that was viewed as a blockage. The other 6 jams ranged from more than a half mile to just under two miles long. Those 6 were viewed as limiting rearing habitat on low gradient tributary streams (on file Coos Bay Dist. Office).

The approach fish biologists used to gain fish passage through logging debris packed jams change over time. Early log jam removal consisted of moving all of the debris out of the stream. By the mid 1970s the fish biologists' approach was to rearrange rather than remove the jams. This was done by loosening packed debris that was causing the fish passage, so the stream could float that material away, while retaining large key pieces and retaining the gravels captured by the jam. By 1981, very large log jams consisting of tightly packed debris became less common. Visits to remaining logging debris packed jams showed the streams either cutting a new channel around the jams or down cutting below the jams (per. com. Bill Hudson, BLM fish biologist). The reduction in numbers of new jams is often attributed to the loss of large key pieces in the streams to attrition, logging and stream cleaning. However in areas where key pieces have survived or were recently recruited, there has not been a resurgence of large jams consisting of tightly packed logging debris. This suggests the practice of removing logging debris from draws on landslide prone landscapes after 1973, administrative withdraws of very fragile land in 1975, and improved logging practices have reduced the volume of logging debris entering low gradient streams.

Creek cleaning to reduce risk of debris torrents did have the unintended consequence of reducing the channel resistance to stream erosion in timber sale units sold after 1972 and yarded before 1980. BLM contract requirements to remove all logging debris over 6-inches in diameter from stream clearance areas and pile material above the stream high water mark began showing in fiscal year 1973 timber sale prospectuses[8]. The requirement became a regular feature in sales sold in fiscal year 1974, with some variation in the size limit for removal in later years. Some operators exceeded these requirements believing they were doing good work for the land and typically contract administrators did not discourage that behavior. On particularly steep ground, creek cleaning was combined with a gross yarding requirement to remove material that may roll into stream channels following logging. The consequence of this was the loss of embedded wood that provided step pool structures, resistance to debris torrents, and resistance to other less dramatic forms of erosion (Swanson; Lienkaemper 1978). However by about 1979, contact administrators began discouraging the timber sale contractors from using of chainsaws and other power equipment to remove wood from stream channels. The administrators stopped the removal of material embedded in the stream channel or bank. Instead, the contract administrators limited material removed from stream channels to that which was obviously logging debris that could be easily picked up and removed by hand.

[8] A review of timber sale prospectuses on file in the Umpqua Field Office indicates that stream cleaning for the purpose of removing logging debris from fish bearing streams was a requirement in timber sales sold at least as early as 1967. The beginning and extent of stream cleaning on private land is not known.

Vegetation and risk of landslides: Because of the differences in assumptions used to run the infinite slope model compared with those used to map the TPCC, the infinite slope model may be a better predictor of landslide potential on a fully forested unmanaged landscape and on lands where commercial thinning is practiced. The TPCC may be a better predictor of the response of the landscape to clearcut harvest done using 1980s technology. The TPCC would also be the better predictor of the land's response to stand replacement fire.

Areas that are already prone to sliding under forested conditions are at a greater risk of landsliding during the 10 to 15 years following clearcutting, based on observations in the Coast Range and H. J. Andrews (Swanson *et al.* 1977). Since landslide occurrence is strongly correlated with heavy precipitation events (Dyrness 1967), in-unit landslides may be avoided, if no intense rainstorms occur in the clearcut area during this period. Similarly the highest risk for road related landslide occurs during the first few intense storms following road construction. However, roads may still be at risk of landslides 20+ years after construction (Swanson *et al.* 1977). The shallower the soil, the more sensitive it is to harvest activities. Clearcutting on steep slide prone slopes with shallow soils increases the frequency of landslides, particularly debris avalanches. The deeper the soil the less effect root strength has on stability. A landslide inventory following a 5 to 10-year return period storm in the Coast Range showed all the "naturally" occurring slides and nearly all the management associated slides occurring on the same few soil types (Gresswell *et al.* 1976). An inventory of slides occurring before 1972 found a similar trend (Swanson *et al.* 1977). Gresswell and others (1976) also observed that 78% of the "natural" slides and 82% to 85% of the management associated slides occurred on 80% and steeper slopes.

Tree roots provide shear strength to a soil mass and add supplemental cohesion. Tree roots can also anchor the soil mass to the slope where roots penetrate into underlying fractured bedrock. Burroughs and Thomas (1977) examined Douglas-fir root strength and effect on slope stability and concluded that roots up to 1 cm in diameter are the most effective in increasing the stability of timbered slopes. They also found that the 1 cm and smaller Coastal Douglas-fir roots lost 82% of their strength per unit area within 30 months of tree felling. This fits with a post-storm landslide inventory that showed 65% of the landslides inside clearcuts occurred in units cut in the previous 3 years, 29% occurring in units cut in the 4 to 10 years before the storm, and 6% occurred in units cut more than 10 years before the storm (Gresswell *et al.* 1976). New tree growth replaces the lost tree roots in about 10 to 15 years after cutting[9].

Partial cut systems(thinning/ density management, and shelterwood) do not increase the risk of mass movement on slide prone ground because by their nature, live trees are retained on the site. The amount of live root mass, following a partial cut, is greater than would be suggested by the number of live trees alone. This is due to root grafts and the distribution of root mass in the ground. Eis (1972) found 45% of the selectively cut Douglas-firs were root grafted and half those stumps were still alive 22 years later. In addition, the roots of different trees in the stand are intertwined, unlike the tree crowns, which are spatially distinct. Consequently, thinning does not kill all the roots in the discrete areas of soil below the cut trees (Stout 1956 cited in Oliver & Larson 1990).

The idea that clearcutting precipitates landslides by causing a loss of root strength is not without controversies. These center around the issues of sampling method and the understanding of landslide causal mechanisms. The apparent connection between landslides and clearcutting is based in large part on aerial post storm landslide inventories, and on landslide histories done using aerial photos (Hockman-West,

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[9] For comparison, sources cited by Swanston and Swanson (1976) described loss of soil strength associated with rooting beginning 3 years following cutting and reaching minimum strength 15 years after cutting in Japan. Researchers in Alaska and British Columbia observed the minimum rooting strength occurring 3 to 5 years after cutting.

no date http://www.wildfirenews.com/forests/forest/research.html). These methods show where on the landscape slope failures have occurred, indicating slide prone soils and landforms. However, detractors argue that aerial observations and photos under sample slope failures on forested sites making these methods unreliable for correlating vegetation cover to landslide risk. Ground surveys for landslides have supported that argument, particularly for stands older that 100-years (Paul 1999). Skaugset (1999), in a presentation on an alternate landslide causal mechanism, argued that experimental results show the magnitude of excess pore water pressure generated during rain-induced slides and debris flows are sufficient to cause failure by static liquefaction, which would make root reinforcement moot. During follow-up questions, Skaugset speculated that if roots did play a part in providing soil strength under wet conditions then his research suggests that fine roots and root hairs are more important than the larger roots. Skaugset also speculated that the timing of peak rate of landsliding in clearcuts soon after cutting may coincide with macropore formation resulting from root decay. These macropores would channel water in the soil facilitating build-up of excess pore water pressure.

Roots of understory vegetation may provide shear strength to the soil mass and add supplemental cohesion in areas that are prone to sliding. The protection provided to a recently denuded site would depend on the understory species composition and density, and the intensity of the stand replacement event or site prep. To our knowledge, the relation between understory vegetation root strength/ mass and the risk of landslides on a steep forest setting has not been studied. However based on observation, residual vegetation in Coast Range plantations recovers rapidly following site prep if the site prep method sets back or kills the tops of the vegetation but not the roots. Examples are cool to moderate intensity broadcast burning, and manual cutting. Considering 3-year-old and younger trees are unable to fully occupy a site under normal conditions, the rapid recovery of the herb and shrub components may explain the drop in the rate of landsliding three years after clearcutting observed by Gresswell and others (1976). Intuitively, other site prep methods that do kill root systems, for example high intensity broadcast burning and some herbicides, may contribute to the risk of landslides following clearcut harvest on particularly steep slide prone sites. Under these conditions, forage seeding and/or the establishment of light seeded pioneer species will provide rapid recovery of fine root mass. However, it would take about 15 years before the trees and shrubs fully reoccupy the site and provide larger woody roots. This conjecture has yet to be tested by a controlled study, and may be moot if in fact Skaugset's line of reasoning, summarized above, is correct.

Selection of waste areas: Endhauling, a technique used to dispose of excavated material generated by road construction or slide/flow debris which falls on the roadway, results in the placement of material on a site commonly called a waste area. The selection of suitable waste areas in the Watershed is difficult due to a lack of flat stable areas and the costs associated with long endhauls. Improperly sited waste areas can instigate or increase slope movement due to the loading of marginally stable sites.

Recruitment of Gravels, Cobbles, and Boulders: Bedrock dominated channels and a shortage of in stream gravel were identified as limiting habitat for many stream dwelling organisms by the late 1970s. This not only limits spawning habitat, but also limits habitat for aquatic invertebrates, and in channel water storage, which in turn affects summer low flows and water temperature. The processes that deliver gravel and larger lithic material to the streams also deliver fine sediment. Gravel production is not a limiting factor for streams below steep landslide prone areas with sandstone or basalt parent material. Observations show instream structures, with very rare exceptions, back fill with gravel in the one to two winters following installation. This indicates that retention of gravels is a greater problem than recruitment for reaches down stream from the Tyee and Flournoy formations. Low strength and rapid weathering of siltstone parent material do limit gravel production in the Elkton formation. Durability and retention of the gravels and cobbles, once they enter the stream, are the limiting factors in this Watershed regardless of parent material. Durability is an inherent characteristic unaffected by management. Table Erod-6 compares the parent materials with respect to sediment and gravel production.

Large boulders delivered by debris torrents down tributary streams and by rock falls from the stream side cliffs also provided structure to retain gravel and to retain wood in wide stream reaches that can in turn capture gravel. These cliff areas are along the more confined reaches of the main stem South Fork Coos River in and above sec. 22, T.25S.,R.11W., Williams River main stem up to sec. 22, T.27S.,R8W., and lower reaches of several tributaries to Williams River. These cliff features are massive sandstone beds overlaying siltstone. The presence of these cliffs and their propensity to produce large boulders is the result of the siltstone's lower resistence to erosion leading to the undermining of the overlying sandstone resulting in rockfall events. Most of the large instream boulders were removed from South Fork Coos River channel from Tioga Creek to Dellwood during the 1940s to improve conditions for water transport of logs (Farnell 1979, Beckam 1990).

Table Erod-6 Fine and Coarse Sediment Production by the Primary Geologic Formations in the South Fork Coos Watershed

Formation	Soils and sediment production	gravel production
Sandstone of Tertiary Age: Bateman (Teb) Tyee (Tet) Flournoy (Tef)	Weathers to form loamy sand and sandy loam soils. Surface erosion primarily transports sand particles a short distance from site of origin. The soils on steep landslide prone slopes typically have 35% to 50% sandstone gravels and cobbles. For example, Digger soils are found on 60 to 80% slopes and composed of 40% gravels and cobbles, 30% sand and the rest is silt and clay.	The most durable gravels produced inside this Watershed are from the sandstones in these formations. However, these sandstone gravels are soft and breakdown within a few years to decades to sand sized particles. The sand particles are much more durable being composed primarily of quartz. These sands are either settled out in deposition areas or swept out of the Watershed as bedload. The gravels breakdown as the result of abrasion experienced as bedload in fast moving streams with bedrock floors. Repeated wetting and drying cycles also causes the surfaces of the gravels derived from the softer beds to rapidly crumble into sand particles.
Siltstone of Tertiary Age: Elkton (Tee)	Weathers to form silty loam and silty clay loam soils. Surface erosion can result in the transport of silt particles as suspended sediment. The clay content puts these soils at risk of compaction, which would decrease water infiltration and increase the risk of surface erosion. Areas of deep cohesive soils are characterized by the dominance of slow mass movement processes of soil creep, rotational slump, and earth flows. These process can result in chronic fine sediment delivery where streams are at the toe of these landscape features. The soils derived from siltstone have few coarse fragments.	Gravels derived from the siltstone in this formation are hard to find in streams because siltstone weathers rapidly to silts and clays when exposed. Most all the gravel in streams in the Elkton formation are from the thin sandstone bed inclusions. Streams flowing through the Elkton formation that originated in the Bateman formation can have gravel derived from Bateman sandstone.
Basalt of Tertiary Age: Roseburg volcanic member (Terv)	Weathers to form silty clay loam, silt loam soils. Surface erosion can result in the transport of silt particles as suspended sediment. The clay content puts these soils at risk of compaction, which would decrease water infiltration and increase the risk of surface erosion.	The parent material is marine basalt and is long lasting in streams as cobbles and boulders. However, once this material is broken into gravel size material it decomposes rapidly. Marine basalts were extruded underwater. The hot basalt rapidly cooled when it contacted the water causing fracturing that structurally weaken the material.

<u>Erosional Processes and Recruitment of Coarse Woody Debris in Streams</u>: Large wood provides the in stream structure that retains gravel. Erosional processes also deliver large wood to streams. The most important processes for large wood recruitment are streambank erosion, other forms of individual tree mortality, intense storm event associated mass movement, and stand replacement fire associated timber fall and landslides. The relative importance of each of these processes depends on fire return rate, topography and lithology (Benda et al 1999). In the absence of debris torrents, large wood in first and second order draws is randomly located where it initially falls because these streams have insufficient flow to redistribute or transport large wood down stream. Third through fifth order streams are large enough to redistribute large wood and by that form distinct accumulations. In sixth order and larger streams, large wood is generally thrown on islands and banks where the wood has little influence on the stream except during high flow conditions (Swanson Lienkaemper 1978).

Fire associated toppling accounts for about 15% of large wood delivery in areas with a 500-year fire return rate and 50% of large wood delivery in areas with a 150-year fire return rate (Benda et al 1999). Based on the Tioga Creek Subwatershed fire history (Tioga Appendix: Fire History), this suggests that fire accounts for a higher proportion of instream wood in Burnt Creek and a lower proportion in Upper Tioga Creek when compared with the other drainages in that Subwatershed. The relative wood recruitment rates for the rest of the South Fork Coos Watershed, as affected by fire, are not known.

The amount of large wood recruitment associated with on going individual tree (or chronic) mortality is higher in areas of infrequent fire because the on going rates of mortality are applied against the large standing biomass of older forests. Further more when fire does occur, the pulse of large wood delivered to the streams is greater because of the greater standing biomass that accumulate between fires (Benda et al 1999). This suggests that in the Tioga Creek Subwatershed, the Upper Tioga Creek Drainage has the highest amount of chronic large wood recruitment and would have the highest pulse input of wood to streams following a stand replacement fire, whereas Burnt Creek would be lowest for both chronic and post fire recruitment.

Bank erosion associated large wood recruitment is greatest in actively migrating portions of the channel (for example Rosgen C stream type) and lowest where streambanks are confined by bedrock or boulders (entrenched channels like Rosgen A and B stream types) (Benda et al 1999). In the west end of the Watershed, large wood recruitment from along stream banks may be reduced, compared with pre management rates, by the loss of riparian trees in agricultural areas, and by diking arresting channel migration. The effects of log drives on stream banks between Dellwood and Tioga Creek, would have destabilized stream banks along flood plains and forested bars resulting in the lost of those features and their potential to provide wood to the river.

Shallow rapid landslide and debris flow associated large wood delivery rates are higher in the Tyee, Flournoy and Bateman formations, which are characterized by a steep highly dissected landscape, and lower on the Elkton formation. Large wood delivery to streams in the Elkton formation is less associated with landsliding and more associated with chronic tree mortality, and to soil creep and streambank erosion where those processes are active. In this Watershed, much of the Roseburg formation, volcanic member, is in a high marine terrace landform. Consequently, large wood delivery to streams on the steep edges of this landform is by landsliding, and on the relatively flat center of this landform by chronic mortality (Benda et al 1999, Beaulieu & Hughes 1975, Niem & Niem 1990).

<u>Management and Delivery of large wood, and Coarse and Fine Sediments</u>: Forest management activities can limit delivery of the large wood that provides the instream structure needed to retain gravels. Management activities can also alter the relative amounts of coarse and fine sediment delivered to streams by both being a source of erosion and by blocking delivery of material. Channels in and downstream from the Bateman, Tyee and Flournoy formations, and downstream from steep edges of the Roseburg volcanic formation are dependent on debris avalanches and torrents for the recruitment of instream material to provide for roughness and aquatic habitat components. Currently, roads intercept many landslides. The roads act as benches that slow or completely stop slope failure processes that are critical for the recruitment of coarse material. Oregon state guidelines do not allow the transfer of the landslide debris over the road prism and into the channel. Consequently the slide material, which would have entered the stream had there been no road, is removed from the site during post-storm cleanup thus eliminating a critical natural recruitment process.

It is suspected that much of the pre-logging era gravel in the river, which was stored behind woody debris, flushed out of the system following salvaging of merchantable wood from the channel and stream cleaning intended to improve fish passage. Future sources of large woody debris were also lost when mature trees were removed from riparian zones. Removal of large trees from steep headwalls has resulted in a loss of potential large woody debris delivery by debris torrents. May (1999) also observed that landslides from Coast Range clearcut areas had a larger average volume and had runout zones affecting a greater length of streams than landslides from forested areas. May also observed that trees along the edges of the runout zones were important for recovery of those reaches that were scoured down to bedrock. Large trees that had fallen into the bed rock reaches were the only observed mechanism trapping sediment.

Fine Sediment Delivery to Creek Stream Systems: The constituent materials delivered to streams by mass movement (and by other erosional processes) range in size from clay particles to boulders. On entering a stream these materials are sorted by the flow. The silt and clay particles are almost entirely swept out of the stream system as suspended sediment during high winter flows. This suspended material increases turbidity and affects related habitat conditions, but is not well represented in the sediment of the channel bed and bars. The coarser material is either deposited on the flood plain or settles out on the channel bottom to be intermittently moved down stream as bedload. Channel geometry, and obstructions like large wood and boulders cause differences in flow rates that in turn result in storage of at least part of the bed load within the channel (Benda et al 1999). In A and B type channels, the gravels may be retained behind barriers, while much of the sand is moved out as bedload. In C channel reaches some sand size material, along with the gravel, is retained on flood plains, and behind barriers. Over time, weathering and abrasion will break down the bedload material into small particles. The Stream Channel Chapter in this document includes descriptions of stream channel types.

Road segments that intersect streams or are close to streams have potential to deliver surface erosion derived sediment to streams. Road segments that do not intersect streams, or are not connected to streams by ditchlines, culvert outflows or gullies or have more than 50 to 100 feet of filtering vegetation between them and a stream are usually not at risk of delivering sediment to streams. Roads connected directly to streams by ditches or cross drains function as extensions of the stream system. The road treads produce more fine silt and clay particles than the cut and fill slopes. This is due to traffic activity pumping fine-grain materials to the tread surface, and to the grinding action of the traffic reducing particle size. Water flowing on a road running surface and in the ditch pick up and transports fines (silt and clay) as suspended sediment. Sands and gravels (bedload) usually do not travel far in road side ditches due to low water volumes and velocities. Landslide material deposited on the road and in the ditch line is similarly sorted resulting in a disproportional transport of fines from the point of deposition. Excess fines from roads should only be a potential problem during and immediately following heavy rainstorms and only if the sediment actually reaches a stream. If water from the road surface and ditch line filters through 50 to 100 feet of vegetation before reaching a stream, most all of the sediment will drop out before reaching a stream.

Luce and Black (1999) in their examination of sediment production by Coast Range roads found the variability of sediment yields from road segment to road segment is high. Most road segments produce little sediment. Only a few road segments produce high yields of sediment. This suggests that managing sediment production on the few highest yielding road segments would be the most efficient approach to reducing road associated sediment delivery in a watershed. Based on Luce and Black's data, the following are indicators for identifying the high sediment yielding road segments in the Watershed:

- Sediment production increases with increased road segment length and gradient. Specifically, sediment production was proportional to the product of road segment length times the square of the road grade slope (LS^2). The nonlinearity of slope makes it an important consideration when assessing sediment potential.
- Soil texture has a strong influence on sediment production with the coarser textured soils yielding much less sediment than fine textured soils. For example, sediment production from aggregate surfaced

roads on silty clay loam soils was 9 times greater than sediment production from roads constructed on gravelly loam soils.

- Vegetation in the ditchlines and on the cut slope was an important component in preventing erosion. Sediment yields from older roads with undisturbed ditchlines are much smaller than sediment yields from newer roads or roads with disturbed ditchlines. Disturbance of the road surface alone through grading showed less effect. Sediment production was only weakly related to cut slope height. However, increases in sediment production were strongly related to vegetation removal from cut slopes.

The road segments in the Watershed that have the potential to be higher risks for delivering surface erosion derived sediment are:

- Long road segments that dip downhill to stream crossings (Luce and Black 1999). These occur typically on mid and lower slope positions. Based on observation, the steeper long segments that can potentially feed sediment to stream are most commonly found in midslope locations.
- Roads built on fine textured soils close to streams (Luce and Black 1999) on the moderate to steep areas in the Elkton formation, the Roseburg formation volcanic member, and on the upper part of the Flournoy formation where siltstone becomes more common (Beaulieu & Hughes 1975, Niem & Niem 1990). Risk of management associated sediment delivery is low in those areas in these formations where the average slope is less than 35% (Swanson et al 1987). Example areas are the marine terrace landform part of the Roseburg formation, and the plateau landform parts of the Elkton formation.
- Lower slope/ valley bottom roads that are close to and parallel with a stream where the fill slope and land between the road and streams lack sufficient vegetation to filter sediment, or where a gully has formed below the out fall of a cross drain connecting the ditch line to the stream (Washington Forest Practices Board 1992).
- Midslope roads that have rutted treads or have long flow paths on the tread where the water is delivered to a stream at a crossing.

Risk of surface erosion derived sediment delivery would be lessened by:

- Appropriately spaced cross drains intercepting ditch water above stream crossings and depositing that water where vegetation can slow and filter the water.
- Well vegetated fillslope, ditchline and cutslopes.
- Paved or well rocked running surface.
- Low traffic or by excluding traffic by blocking or gating.
- Installation of water bars on infrequently maintained roads
- Locate new roads so to minimize stream crossings

Swanson *et al.* (1980), in their discussion on how the method and time frame for measuring management impacts can substantially under or over estimate the change in the rate of landsliding, speculated that when landslide rates are evaluated using a period long enough to include stand replacement fire events, human activities may have affected the timing of sediment delivery more than the rate. This suggests that a large or a very large input of sediment during a single year or a short period of years followed by a recovery period may be more within the range of natural variation than chronic sediment delivery extending over decades. Chronic sediment delivery would be more typical in landscapes where practices like small staggered setting regeneration harvest units, road construction/ renovation, road maintenance, road decommissioning, culvert replacement/ removals occur in most years close to streams. A management approach of entering a watershed and accomplishing all identified forest management and restoration efforts then leaving that watershed alone would result in a sediment delivery pattern more in tune with natural patterns. Confining the timing of all activities in the watershed would not be necessary. Uplands and midslope locations in areas not likely to contribute sediment could be managed following more conventional timetables. On BLM lands, these areas are generally outside the Riparian Reserve.

<u>Roads, Management and Location on the Landscape</u>: Surface erosion and landsliding on upland sites may cause effects on capital improvements, site productivity and aesthetics at the location of the source of the material, the track followed by the material and the deposition site. However, if the products of erosion are not delivered to streams there is no sediment related effect on the stream system. Consequently extractive, conservative and restoration activities on sites that are not connected to streams or that cannot deliver material to streams will neither benefit nor harm streams with respect to sediment delivery. For example, closing a road on a ridge top, which is well away from a stream, may improve elk habitat and reduce road maintenance cost but will not help streams.

An ID Team completed the TMOs for Tioga Creek Subwatershed December 1997, and revised the TMOs in July 2000. As funding becomes available, we will make decisions on when and how we will close/ decommission each road by going through a NEPA analysis. Most roads proposed for closing are BLM controlled upper slope and ridge top roads. We need to complete field review of several roads designated for closure to assess the needs for potential culvert removal. Except where we build new roads to access timber sale units, we have few opportunities for additional road closures. Most all the new BLM road construction will be on ridge tops outside the Riparian Reserves. Most existing roads access private land in addition to BLM land and we have right-of-way agreements for those roads that predate the Forest Plan. These agreements limit our options to act unilaterally. Most the streamside roads in the Watershed, which are more likely to affect riparian and stream function, are privately controlled and therefore not subject to the Federal Forest Plan.

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