Soil

Soil is composed primarily of sand, silt, and clay particles that have been physically or chemically weathered from a parent material and are intermixed with decomposing bits of plant and animal materials. DNR (1996) defines soil as "the material at the earth's surface capable of supporting plants. It is the ecosystem element located at the interface of the climatic, geologic, hydrologic, and biologic ecosystem elements. It is a dynamic, natural, three-dimensional body composed of weathered mineral and organic material that provides plants with air, water, root anchorage, and nutrients."

Biological and climatic factors control the rate of physical and chemical weathering and the differentiation of soil into distinct horizons. Most often, soils contain three horizons, known as A, B, and C. The 'A' horizon is closest to the surface, includes a large amount of organic material, and is most affected by biological factors such as invading plants and animals and climatic factors such as temperature and precipitation. The 'B' horizon lies below the A horizon and has less organic material, has more and larger fragments of parent material, and frequently contains re-deposited material derived from the A horizon. The lowest layer is the 'C' horizon. It is compact and largely consists of decomposed or shattered regolith or parent material. Each horizon has unique qualities which influence a soil's productivity, erosion potential, and susceptibility to compaction and displacement. These qualities determine how a particular soil might affect several associated environmental attributes including, but not limited to, fish habitat, water quality, water quantity, and tree growth rates.

Why Are Soils Important?

Healthy soil is a critical component of the forest ecosystem. Not only does it serve as the basis for plant growth, it also provides habitat for numerous insects and fungi, creating an environment where organic matter can be recycled back into the ecosystem. Ultimately, human survival depends on the conservation of both the body and fertility of soil (Kohnke and Franzmeier 1995). As a medium for plant growth, soil serves four functions: 1) it anchors roots, 2) it supplies water, 3) it provides air to plant roots, and 4) it furnishes minerals for plant nutrition (Kohnke and Franzmeier 1995). DNR forest management relies on the productivity and conservation of soil to support a healthy ecosystem and yield desired forest products (DNR 1997a).

What Are the Criteria for Managing Soil Productivity and Forest Roads?

DNR's criteria for maintaining soil productivity are based on best management practices described in the *Forest Practices Rules* (DNR 2001) and DNR's 1997 *Habitat Conservation Plan* (HCP). These soil-related best management practices focus on limiting soil compaction, displacement, and disturbance, minimizing surface erosion, and preventing management-related mass wasting, or landslides. *Forest Practices Rules* related to soil compaction, displacement, and disturbance include, but are not limited to: equipment limitation zones designed to keep ground-based equipment out of sensitive areas[1], ground-based logging including rutting and displacement of soils[2], and minimizing the construction of new roads.[3] Landowners (including DNR as trust land manager) must comply with the State Environmental Policy Act (SEPA) requirements

[1] Defined in Chapter 222-16-010 Washington Administrative Code [WAC]
[2] Chapter 222-30-070 Washington Administrative Code [WAC]
[3] Chapter 222-24-010 Washington Administrative Code [WAC]

when proposing forest practices activities on potentially unstable slopes and certain potentially unstable slopes which are classified as Class IV and require preparation of an environmental checklist for these activities.[4]

What Are the Indicators Used to Assess Soil Conditions and Sediment Delivery from Roads?

One internationally-recognized indicator of soil conditions is the percent of a watershed harvested (Montreal Process 1995). Another indicator is the number of times a forest is harvested over a projected time frame. In this section, the level and frequency of harvesting is used to assess management effects on soil conditions. From these indicators, DNR can make inferences about impacts to soil properties, including productivity, compaction, erosion, and displacement. Soil management interpretations for the OESF and descriptions of the original assessments for compaction, erosion, and displacement can be found in Appendix G. Additionally, this section addresses sediment delivery to streams from road surface erosion and landslides.

SOIL PRODUCTIVITY

Soil productivity refers to the soils' fertility or capacity to grow vegetation. Soil is the medium that supports most plants in upland environments (DNR 1997a). Therefore, land use activities that affect soil productivity also affect plants. In general, more productive soils support more biomass (tree volume, wood production), providing important ecological and social benefits, and ultimately, more revenue for the trust beneficiaries. Additionally, high levels of soil productivity support biodiversity, regulate water and nutrient movement and filter out undesirable elements before they reach plants or water features.

Reductions in soil productivity can result from increased compaction and/or accelerated erosion. Timber removal and road construction, maintenance, and use can affect both the degree of compaction and the rate of erosion. The type of timber removal (for DNR, variable retention harvest versus variable density thinning) and the number of timber harvest entries may also influence soil compaction and erosion.

Removal of vegetation exposes soil more directly to elements that may cause erosion such as wind and precipitation. The resulting soil loss may reduce future site productivity due to the increased potential for accelerated soil erosion, compaction, and displacement.

COMPACTION

Compaction is the loss of pore space within a soil profile due to an external force that pushes particles closer together. Compaction typically occurs when heavy machinery or objects such as logs fall on or move over the soil, but it can also result from mineral soil being exposed to the impact of raindrops. Small roots are in the uppermost two to four inches of the soil profile, which is the area most affected by harvesting and road construction. These small roots gather nutrients and water and can be damaged or broken when soil is excessively compacted.

Space between the soil pores is essential to the survival of plants. Water and air enter the soil through pore spaces, where tree roots absorb water, carbon dioxide (CO_2), and nutrients to sustain plant growth. Because compaction reduces pore space, the availability of water, carbon dioxide, and nutrients also is reduced. Moderate or high levels of soil compaction can reduce infiltration rates, increasing the potential for overland flow and accelerated surface erosion. Compaction also can impede root

[4] Chapter 222-16-050 (1)(d) Washington Administrative Code [WAC]

growth (Heilman 1981) limiting the ability of plants to absorb water and nutrients. In some soils, compaction ultimately can decrease overall productivity (Cafferata 1992; Grier and others 1989), although several recent studies have indicated that high levels of compaction do not substantially affect tree growth in newly planted stands (Ares and others 2007). Compaction can be beneficial in some soils as it increases water holding capacity, unsaturated water flow, and soil-root contact (Ares and others 2007).

SURFACE EROSION AND MASS WASTING

Erosion is the movement of soil particles through particle detachment, transport, and deposition (Megahan 1991). Erosion can be caused by gravity, wind, water, or other forces that detach or move soil particles. Erosion potential refers to a soil's resistance to detachment and transport (Dyrness 1967). The forms of surface erosion include rainsplash, sheet, rill, gully, and dry ravel. Mass-wasting (such as in the form of landslides) is the down-slope movement of loose soil and rocks by the force of gravity without the direct aid of a transporting medium such as water, ice, or wind (Nelson 2003).

Erosion potential often is dependent on slope, soil texture, and vegetative cover (DNR 2001). Although it is a natural process, erosion can be a management concern for two reasons. First, soil loss affects productivity and can reduce the capacity for a particular site to grow trees. Second, the transported soil (or sediment) particles can have detrimental effects on down-slope resources. Sediment transported through surface erosion processes can deposit in streams, lakes, and wetlands and adversely affect water quality and fish habitat. Sediment transported through mass wasting processes such as landslides can have similar effects on aquatic resources but can also pose a threat to public or privately-owned infrastructure (roads and bridges), private property, and public safety. The type and particle size distribution of a given soil affects its erosion potential, which, in turn, determines the potential risk of impacts to water quality and fish.

DISPLACEMENT

Displacement is the localized movement of soil that results from an external force applied to the soil surface. The most common forest activities that result in soil displacement include log yarding using heavy, ground-based equipment such as skidders, bulldozers, or excavators. Displacement potential is a measure of the susceptibility of a particular soil to rutting. Ruts can intercept shallow groundwater, concentrate surface flow, and potentially initiate rill and gully erosion.

SEDIMENT DELIVERY FROM ROADS

The forest road network is composed of a variety of temporary and permanent roads. Temporary roads typically are constructed and intended for use during the life of an approved forest practices activity, while permanent roads are maintained year-round (dependant on weather-related closures) for many purposes. Access to forested state trust lands is provided through a network of federal, state, and private forest roads, as well as county roads, state, and interstate highways. Forest roads are necessary for carrying out land management activities (such as timber harvesting, replanting, and fire control) and also provide access for public use (DNR 2001).

Mass wasting, or landslides, associated with roads can be a major source of sediment to water resources as well as their riparian buffers (Beschta 1978; Swanson and Dyrness 1975). Typical causes of mass wasting events are described in Text Box 3-5. Traffic-generated surface erosion from road surfaces, along with cutbanks, and ditches represent sources of road-related sediment input to streams. Increased sediment delivery to streams after road construction is well-documented in research and literature in the Pacific Northwest (Bilby and Wasserman 1989; Donald and others 1996; Megahan and Kidd 1972; Reid and Dunne 1984; Rothacher 1971; Sullivan and Duncan 1981). Road runoff from heavy precipitation events can be routed directly to the stream network at stream crossings or by road-induced gullies (Wemple and others 1996). Rates of sediment delivery are highest in the first few years following construction (Megahan and Kidd 1972) and correlate closely with traffic volume (Reid and Dunne 1984; Sullivan and Duncan 1981). Road density—as measured by (linear) miles per square mile—is proposed as an index of several effects of roads in a landscape, specifically the potential for sediment delivery to streams.

Text Box 3-5. Landslides 101

The topography, geology, and climate of the Olympic Experimental State Forest (OESF) predispose the area to mass wasting or the downward movement of soil, rock, and debris caused by gravity. Steep terrain, structurally weak parent materials, and abundant rainfall combine to make the area prone to landslides. Generally, landslides[5] can be divided into two categories: deep-seated and shallow-rapid. This section will describe each type, discuss the differences and similarities between the two, and explain the factors that contribute to their occurrence.

Deep-seated landslides are mass soil movements where the slip plane (or rupture surface) is far below the ground surface (refer to Figure 3-5). Oftentimes, landslides with slip planes below the rooting depth of trees (6 to 10 feet) are considered deep-seated. The most common types of deep-seated landslides in the OESF are earth slumps and earthflows. These landslides are characterized by slow, chronic movement (on the order of inches to feet per year) commonly triggered by seasonal or inter-annual fluctuations in precipitation, stream undercutting, and large magnitude earthquakes. Because the rate of slope movement is typically slow, the slide mass involved in a deep-seated landslide often appears intact and can be covered with large, mature trees. These landslides can range in size from less than an acre to many hundreds of acres. Deep-seated landslides are characterized by benchy, hummocky, and/or broken ground, extensive seepage, ponded water, ground cracks, and tipped, swept, or otherwise deformed trees. Due to the slow, progressive nature of deep-seated slope movement, the absolute age of these landslides is often unknown (Salo and Cundy 1987).

Deep-seated landslides are common in areas dominated by glacial deposits, but they can also be found in areas underlain by bedrock. Most often, deep-seated landslides form when mechanically weak materials overlie more competent (strong) materials. Where glacial sediments dominate, these landslides commonly form where coarse sands and gravels lie atop less permeable clays or silts. Water moving downward through the sand/gravel layers becomes perched atop the clay or silt layer, creating a zone of weakness that may serve as a slip plane or rupture surface.

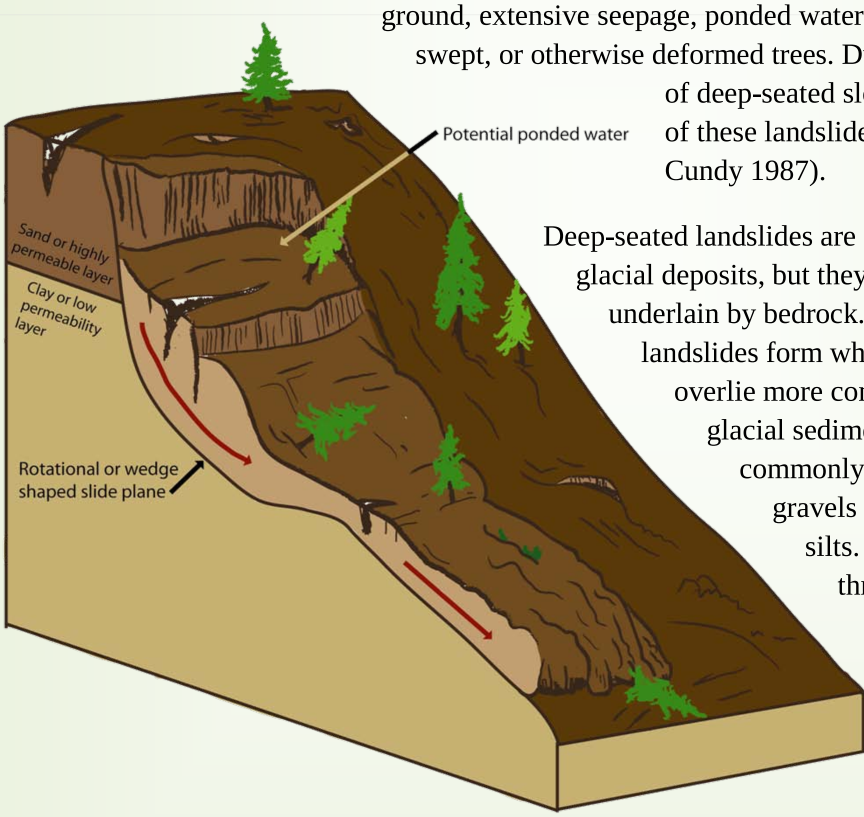


Figure 3-5. Deep-Seated Landslide (modified from DMG 1997)

[5] **Landslides** result from the downslope movement of soil, rock, and debris under the force of gravity. They can occur on any terrain given the right conditions of soil, moisture, and the angle of slope. Integral to the natural process of the earth's surface geology, landslides serve to redistribute soil and sediments in a process that can occur as abrupt collapses or slow, progressive movement.

Unlike their deep-seated cousins, the slip plane of a **shallow-rapid landslide** (Figure 3-6) is relatively close to the ground surface. Landslides with slip planes less than six feet below the ground surface are considered shallow. As the name implies, these landslides move relatively quickly, sometimes as much as 30 miles per hour. Shallow-rapid landslides include debris avalanches, debris slides, debris flows, and debris torrents. Debris flows and debris torrents occur when a landslide mass enters a high-gradient stream channel. Upon entering the stream, the landslide mass becomes more liquid and, as a result, more mobile. The mobile slurry of sediment, wood, and water flows down the stream, and may scour the channel bed and banks, increasing in volume as it progresses. Debris flows and torrents may travel a mile or more from their point of initiation and have the potential to have devastating effects on roads, bridges, and structures that lie within their travel path. Shallow-rapid landslides are commonly triggered by high-intensity rain or rain-on-snow events but like deep-seated landslides, they can also result from stream undercutting and large magnitude earthquakes.

While the underlying geology strongly influences deep-seated landslide formation, the occurrence of shallow-rapid landslides is more directly related to topography and weather patterns. Shallow landslides generally originate in steep (greater than 70 percent or 35 degrees), convergent topography that concentrates shallow groundwater. Landforms with these characteristics are commonly known as bedrock (or colluvial) hollows, convergent headwalls, and inner gorges. These landforms have a higher incidence of shallow landslides relative to more gently sloping terrain. When shallow landslides occur, they are typically triggered by intense rainstorms or storms known as rain-on-snow events. During these storms, large amounts of water enter the soil, increasing soil pore water pressures. If the water pressure forcing the soil particles apart exceeds the particles' capacity to stick together, the soils structure fails and a landslide results.

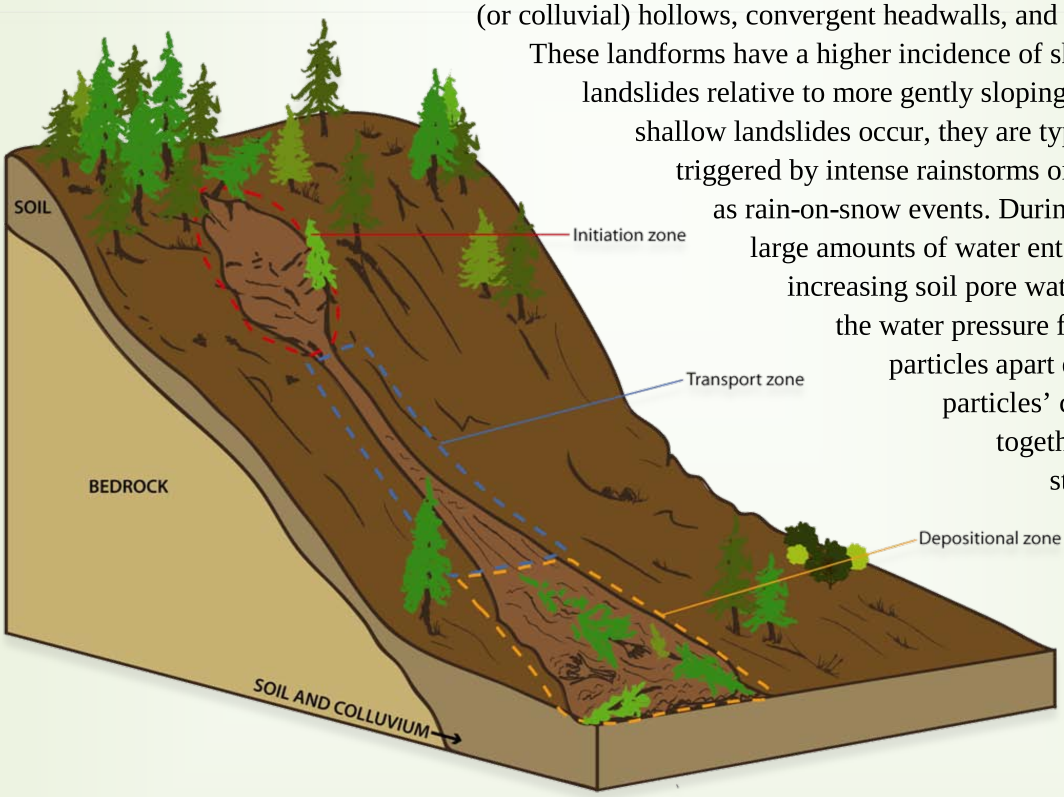


Figure 3-6. Debris Flow (a form of shallow-rapid landslide; modified from DMG 1997)

What Are the Current Soil Conditions?

Soil characteristics are variable throughout the planning unit because of the diversity of soil forming factors. The type of parent material (glacial sediments or bedrock from which a soil develops) largely determines the susceptibility of the resulting soil to land use impacts. Most of the parent material on the Olympic Peninsula consists of uplifted marine sedimentary rocks, continental and alpine glacial deposits, and marine basalts. Mineral weathering is common in areas with high annual precipitation. Water infiltrating the soil dissolves the underlying parent material and accelerates the rate of soil development.

In addition to parent material; climate, elevation, topography, and slope steepness influence soil development and help explain the variability of soils within the OESF. These factors influence slope stability and the movement and distribution of soil and water. In general, soils in lower topographic positions are deeper because rock and debris from upslope mass-wasting accumulates at the toe slope or base of slopes and in valleys (Henderson and others 1989).

COMPACTION

The compaction potential rating refers to the susceptibility of a soil to compaction. The compaction potential ratings are based on moist soil surface behavior and the exact processes for assessing these conditions are included in Appendix G. The GIS analysis did not show any Type 3 watersheds with a low potential compaction rate, meaning that the majority of soils in each Type 3 watershed are somewhat susceptible to compaction, which could result in a reduction in water infiltration and a change in drainage patterns. Glacially derived and organic soils can be easily compacted, even those containing a variety of particle sizes and shapes (Henderson and others 1989). The acreages of Type 3 watersheds were used to find the area within each compaction class (medium, high, and unknown), and the percentage of each watershed administrative unit in each compaction potential class is shown in Table 3-53. The unknown classification was treated as a separate category and was not combined into the low or high class. The unknowns are not represented in the charts but are represented in the tables.

SURFACE EROSION

An erosion rating is developed to compare soils surface erosion potential and is based on the interaction of 1) certain soil properties including texture, structure, and porosity, 2) rainfall and storm intensity, and 3) slope. A data processing technique known as zonal statistics was used to calculate the mean area-weighted erosion potential (refer to Appendix G) of DNR-managed lands in the OESF for each Type 3 watershed. This averaged value represents a single erosion potential for each Type 3 watershed. These values were then aggregated by watershed administrative unit. The acreages of Type 3 watersheds were used to find the percent of total area for each erosion potential class (low, medium, high, and unknown), and the percentage of each watershed administrative unit in each erosion potential class is shown in Table 3-53. The unknown classification was treated as a separate category and was not combined into the low or high class. The unknowns are not represented in the charts but are represented in the tables.

DISPLACEMENT

Displacement potential is a measure of the susceptibility of a particular soil to rutting. Ruts can intercept shallow groundwater, concentrate surface flow, and potentially initiate rill or gully erosion. The acreages of Type 3 watersheds were used to find the area within each displacement potential class (low, medium, high, and unknown), and the percentage of each watershed administrative unit in each displacement potential class is shown in Table 3-53. The unknown classification was treated as a separate category and was not combined into the low or high class. The unknowns are not represented in the charts but are represented in the tables.

The Upper Clearwater and Middle Hoh watershed administrative units have the highest number of acres in the high erosion potential class. This is not surprising, given that these watershed administrative units are the largest of the 17 analyzed. However, the proportional distribution between the erosion potential classes reveals some important differences between the watershed administrative units. The Upper Clearwater has, on average, 72 percent of its acres with a high potential for erosion. Its high surface erosion potential is likely a result of the steep terrain found within the OESF. The Middle Hoh has only 57 percent of its acres with a high potential and three percent are moderate. Hoko, which has the third highest amount of acres with a high erosion potential, has a similar distribution as Upper Clearwater where 79 percent of the acres have a high potential for erosion.

RISK OF EROSION, COMPACTION, AND DISPLACEMENT

For the purpose of this assessment, when examining erosion, compaction, and displacement potentials, DNR considers the physical soil characteristics, slope gradient, soil drainage, and seasonal wetness. Using the information presented in Table 3-53, each watershed administrative unit was assigned a ranking based on the weighted scores for each soil risk rating (erosion, compaction, and displacement). The individual risk ratings for erosion, compaction, and displacement were then combined to derive an overall ranking (Table 3-54). Watershed administrative units with the lowest values, such as Hoko, Kalaloch Ridge, and Sekiu, have the highest overall risk while those with the highest values have the lowest overall risk (Lower Queets River, Sol Duc Lowlands).

Table 3-53. Erosion, Compaction, and Displacement Potential by Watershed Administrative Unit (Percent of DNR-Managed Lands)

Watershed Administrative Units ≥ 20% DNR-Managed Lands	Erosion				Compaction			Displacement			
	Low	Med	High	Unk	Med	High	Unk	Low	Med	High	Unk
Bogachiel	28%	37%	35%	0%	31%	69%	0%	0%	82%	17%	0%
Cedar	69%	25%	6%	0%	4%	96%	0%	10%	61%	29%	0%
Clallam River	24%	0%	76%	0%	16%	84%	0%	0%	40%	60%	0%
East Fork Dickey	82%	0%	18%	0%	17%	83%	0%	2%	85%	2%	0%
Goodman-Mosquito	43%	40%	17%	0%	19%	81%	0%	4%	72%	24%	0%
Hoko	21%	0%	79%	0%	9%	91%	0%	0%	30%	69%	0%
Kalaloch Ridge	12%	55%	33%	0%	4%	96%	0%	6%	10%	84%	0%
Lower Dickey	47%	42%	11%	0%	13%	87%	0%	3%	87%	10%	0%
Lower Hoh River	71%	24%	5%	0%	14%	86%	0%	2%	78%	20%	0%
Lower Queets River	94%	2%	3%	0%	16%	83%	0%	2%	83%	15%	0%
Middle Hoh	39%	3%	57%	1%	58%	41%	1%	2%	55%	42%	1%
Quillayute River	48%	41%	10%	0%	17%	83%	0%	1%	90%	9%	0%
Sekiu	35%	0%	65%	0%	1%	99%	0%	0%	35%	65%	0%
Sol Duc Lowlands	83%	0%	16%	1%	30%	69%	1%	0%	97%	2%	1%
Sol Duc Valley	65%	0%	35%	0%	32%	68%	0%	2%	70%	28%	0%
Twin Rivers-Deep Creek	86%	0%	11%	3%	0%	97%	3%	0%	86%	11%	3%
Upper Clearwater	13%	8%	72%	7%	44%	49%	7%	1%	31%	61%	7%

Table 3-54. Soil Erosion, Compaction, and Displacement Risk Rankings by Watershed Administrative Unit (1=highest risk, 17=lowest risk)

Watershed Administrative Units ≥ 20% Percent DNR-Managed Lands	Erosion	Compaction	Displacement	Totals
Hoko	1	5	2	8
Kalaloch Ridge	5	2	1	8
Sekiu	4	1	3	8
Clallam River	2	8	4	14
Cedar	12	3	9	24
Upper Clearwater	3	17	5	25
Middle Hoh	6	16	6	28
Goodman-Mosquito	8	12	8	28
Sol Duc Valley	9	14	7	30
Lower Dickey	10	6	14	30
Bogachiel	7	13	11	31
Lower Hoh River	14	7	10	31
Quillayute River	11	10	13	34
Twin Rivers-Deep Creek	16	4	15	35
East Fork Dickey	13	9	17	39
Lower Queets River	17	11	12	40
Sol Duc Lowlands	15	15	16	46

RISK OF SEDIMENT DELIVERY

For each Type 3 watershed, a GIS analysis was used to assign a sediment delivery potential based on proximity to the stream channel or riparian feature. Sediment delivery is inversely proportional to the distance to the stream feature; that is, the closer the stream, the greater the likelihood of sediment delivery. Due to omission errors and the current lack in the extent of DNR’s hydrographic dataset, the analysis may not be accurate. This analysis was performed using all stream types, which utilize different mapping techniques and are not consistently mapped across the planning unit. This method may cause the omission of streams that exist but are not mapped or could over-estimate the stream density in other areas. The distribution of values for the population of Type 3 watersheds was used to determine appropriate *z-scores* (distance in standard deviations from the mean) defining the breakpoints between the low, medium, and high sediment delivery categories. Type 3 watersheds with a z-score greater than 0.5 (greater than 379 feet) were classified as low, between -0.5 and +0.5 (199 to 378 feet) as medium, and less than 0.5 (0 to 198 feet) as high.

Table 3-55 shows the acres in each sediment delivery potential class for selected watershed administrative units, based on the analysis described above. All values have been rounded to the nearest integer. Only Type 3 watersheds and watershed administrative units with greater than 20 percent DNR-managed acres are presented because they represent areas most likely to be influenced by DNR’s management. The watershed administrative units were then ranked in descending order based on the percent in the high and medium sediment delivery categories.

The majority of Type 3 watersheds (195), totaling about 129,500 acres, were estimated to have a medium sediment delivery potential rating. Fifty-five Type 3 watersheds (~38,850 acres) were given a low sediment delivery potential rating, and 104 Type 3 watersheds (~44,300 acres) were placed into the high sediment delivery potential class. The ratings for the individual Type 3 watersheds were aggregated to establish a rating for each watershed administrative unit.

Watershed administrative units were ranked according to the proportion of their area with a high sediment delivery potential (Table 3-55). Note that this approach is not based on the total number of acres in the high sediment delivery potential class, but rather the percent of total area. While Kalaloch Ridge has the highest percentage of its area in the high sediment delivery potential class (88 percent) and ranks first, its total area is only 5,710 acres.

BACKGROUND AND ROAD USE SEDIMENT DELIVERY POTENTIAL

Road density was calculated for each watershed administrative unit where state trust lands comprise greater than 20 percent of the total area as discussed in the chapter's introduction. In the OESF, road density ranges from 1.9 to 5.2 miles per square mile, with an average road density of about 4.2 miles per square mile (Table 3-56).

Forest roads include those currently maintained and used, but does not include abandoned roads. Cederholm and others (1981) found that sedimentation in streams increases with road density, but the greatest increases were associated with newly constructed roads as opposed to vehicle traffic. However, the proportion of a watershed occupied by roads affects watershed hydrology and sediment delivery potential. Based strictly on road densities, Kalaloch Ridge, Sekiu, Cedar, and the Lower Hoh River watershed administrative units would be expected to have the highest sediment delivery potential because they have the highest overall road densities. Although the Upper Clearwater and Middle Hoh watershed administrative units have the most road miles overall, since the units are large, they have some of the lowest road densities.

Table 3-55. Sediment Delivery Potential by Watershed Administrative Unit in Approximate Acres and Percent (1=highest delivery potential, 17= lowest delivery potential)

Watershed Administrative Units ≥ 20% DNR-Managed Lands	Acres			Percent			Sediment Delivery Potential Rank*
	Low	Medium	High	Low	Medium	High	
Bogachiel	27	6,515	4,486	0%	59%	41%	2
Cedar	517	2,007	1,221	14%	54%	33%	4
Clallam River	0	9,966	0	0%	100%	0%	10
East Fork Dickey	4,587	6,669	31	41%	59%	0%	14
Goodman Mosquito	1,193	9,075	2,265	10%	72%	18%	7
Hoko	1,071	8,373	0	11%	89%	0%	12
Kalaloch Ridge	0	682	5,038	0%	12%	88%	1
Lower Dickey	0	5,975	1,347	0%	82%	18%	5
Lower Hoh River	1,869	3,380	1,234	29%	52%	19%	11
Lower Queets River	13,108	1,275	0	91%	9%	0%	17
Middle Hoh	7,003	21,991	9,852	18%	57%	25%	9
Quillayute River	0	4,743	492	0%	91%	9%	6
Sekiu	546	2,067	825	16%	60%	24%	8
Sol Duc Lowlands	859	2,255	0	28%	72%	0%	13
Sol Duc Valley	6,597	5,365	576	53%	43%	5%	15
Twin Rivers-Deep Creek	198	162	0	55%	45%	0%	16
Upper Clearwater	1,278	39,002	16,934	2%	68%	30%	3

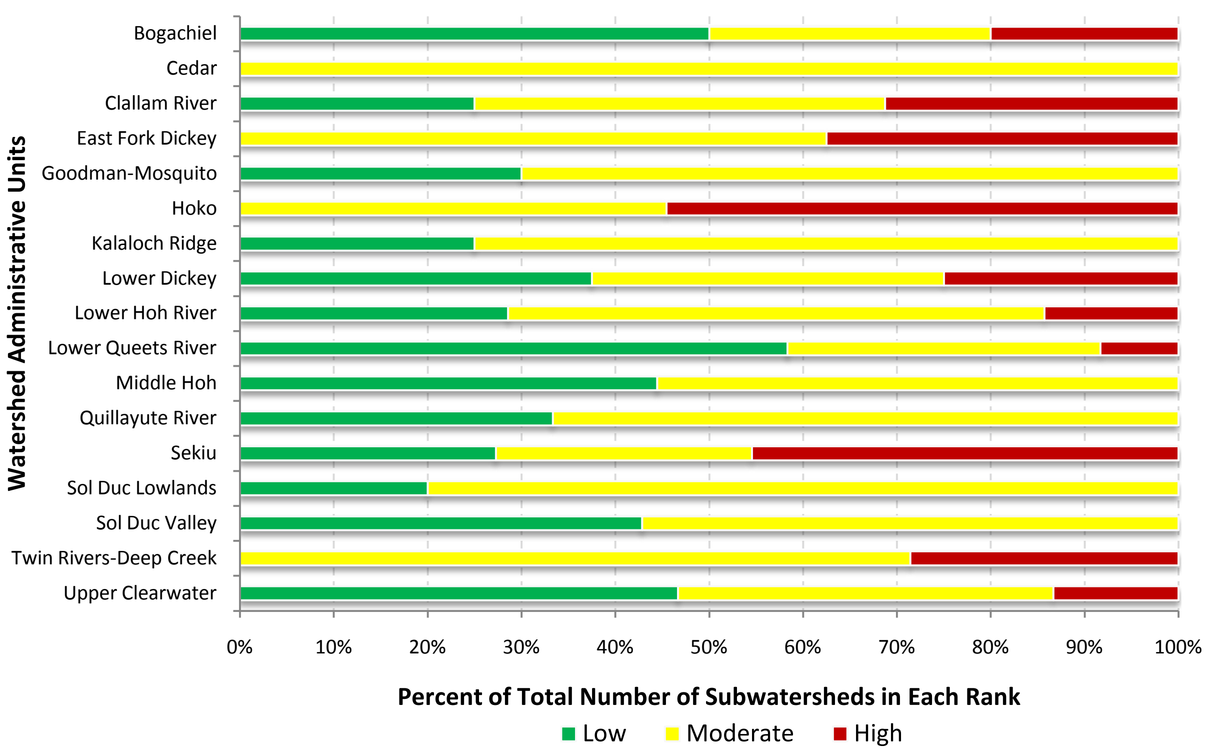
*by highest percent of high potential-if the value was 0 for high, then they were ordered by next highest values of medium potential.

DNR used the ratio of road miles to stream miles to identify areas that may be at higher risk for adverse impacts. Chart 3-65 shows the proportion of sub-watersheds (refer to Map 3-12) in each category by watershed administrative unit. A qualitative rating was then assigned based on the distribution of the entire data set: a low rating consists of values below the 25th percentile, moderate ratings are those in the two middle quartiles, and high ratings are those values above the 75th percentile. The Lower Queets River has the lowest expected impacts followed by Bogachiel and the Upper Clearwater because they have the greatest number of their sub-watersheds in the low category. The watershed administrative units expected to have the highest likelihood of sediment delivery because of their road miles to stream miles ratio include Hoko, Sekiu, and East Fork Dickey. Based on the ratios, Hoko has more than 50 percent of its sub-watersheds expected to have a higher likelihood of probable, significant, adverse, environmental impacts.

Table 3-56. Road Length and Density by Watershed Administrative Unit

Watershed Administrative Units	Acres	Miles	Miles/Mile^2
Kalaloch Ridge	6,102	49.5	5.2
Sekiu	4,048	31.2	4.9
Cedar	4,416	34.0	4.9
Lower Hoh River	7,618	58.0	4.9
Lower Queets River	15,757	111.9	4.5
Lower Dickey	7,733	53.7	4.4
Hoko	11,199	76.6	4.4
Quillayute River	7,384	50.2	4.3
East Fork Dickey	11,514	74.6	4.1
Clallam River	10,538	67.9	4.1
Goodman-Mosquito	13,070	83.0	4.1
Middle Hoh	39,127	245.7	4.0
Bogachiel	11,771	71.1	3.9
Sol Duc Lowlands	4,589	27.2	3.8
Upper Clearwater	57,225	329.5	3.7
Sol Duc Valley	14,263	74.8	3.4
Twin Rivers-Deep Creek	540	1.6	1.9

Chart 3-65. Proportional Distribution of Sediment Delivery Potential Ratings by Sub-Watershed within Watershed Administrative Units



Map 3-12. Sub-Watersheds within the OESF

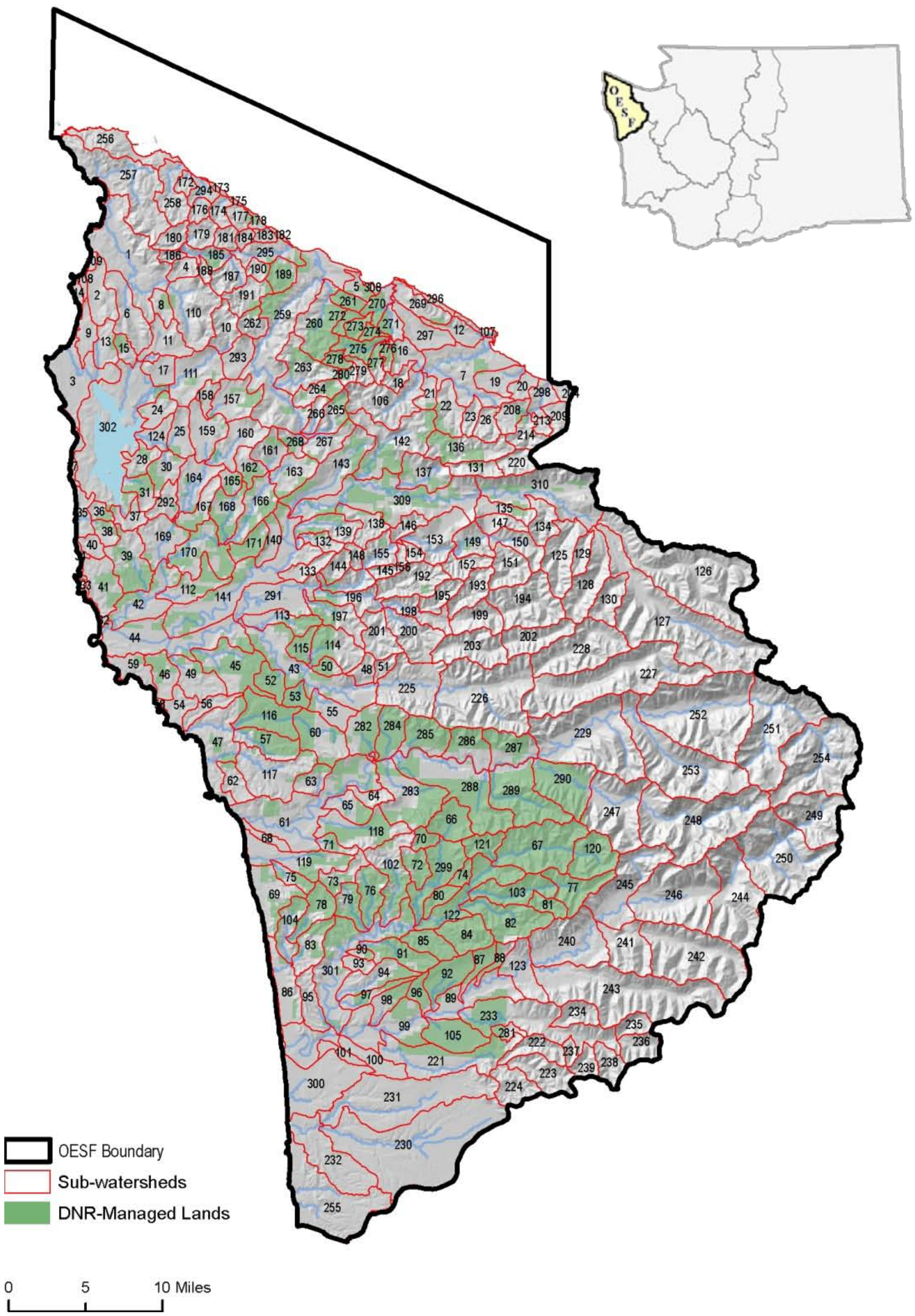
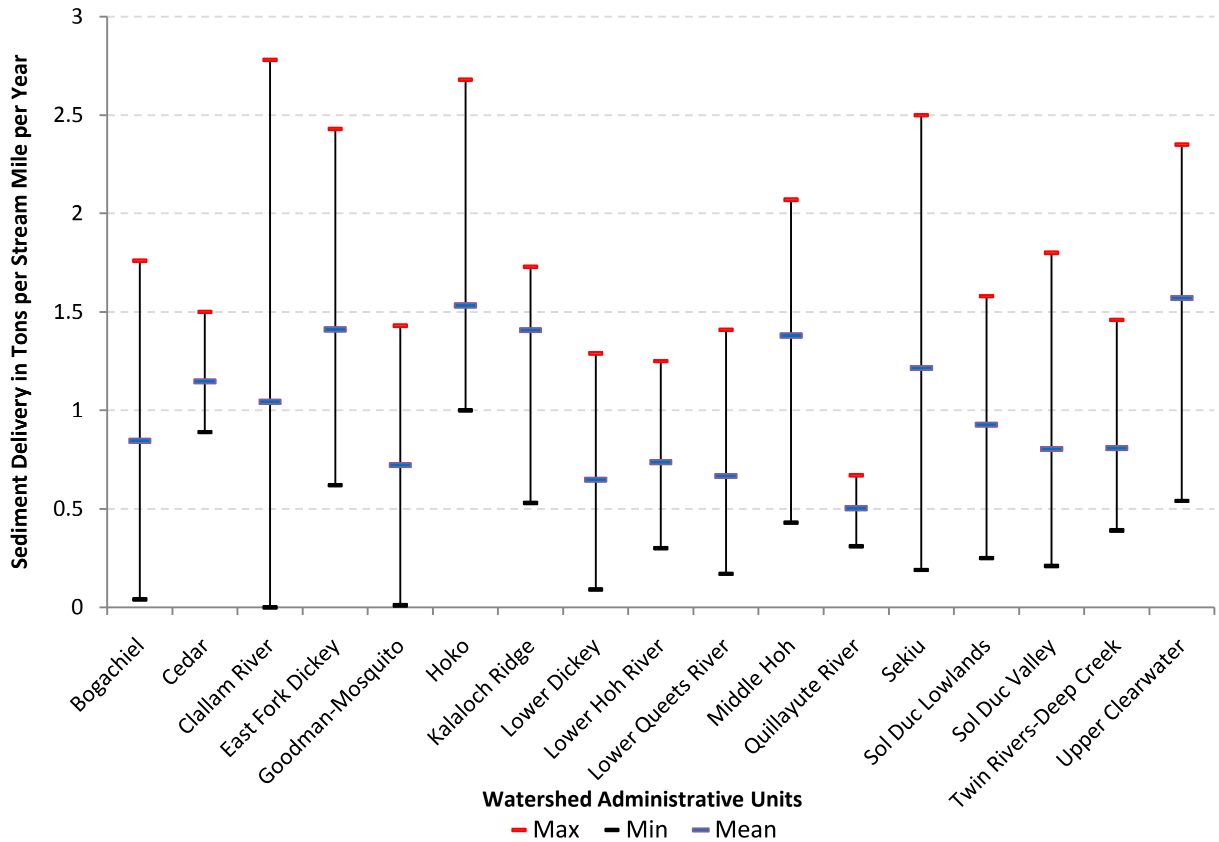


Chart 3-66. Road Sediment Delivery (Existing Road Network not including Road Traffic) for Sub-Watersheds (Grouped by Watershed Administrative Unit)



Using long-term erosion rates published for the Olympic Peninsula (Brandon and others 1998; Montgomery and Brandon 2002; Belmont and others 2007), combined with estimates of stream densities, DNR ranked sub-watersheds based on the estimated background sediment delivery expressed as tons per stream mile, per year. Estimates for current road sediment delivery (excluding sediment associated with road traffic) are reported in Chart 3-66. According to the Cooperative Monitoring, Evaluation, and Research (CMER) Committee (2010) standards, all sub-watersheds have a low delivery rating because none exceed six tons per stream mile per year. In fact, all of the sub-watersheds in the watershed administrative units with greater than 20 percent DNR-managed lands have less than three tons per stream mile per year. The averages for the watershed are between 0.5 and 1.5 tons per stream mile per year.

How Do the Alternatives Compare?

SOIL PRODUCTIVITY

In forested environments, productivity is often expressed as an index of the actual or potential tree growth for a given site. This expression, known as Site Index, is a species-specific measure of the average height of trees in a forest stand at a specific age (typically 50 or 100 years). Site indices are commonly grouped into Site Classes. The classes range from Site Class I (most productive) to Site Class V (least productive). The majority of DNR-managed lands in the OESF are Site Class III (for a further discussion, refer to *Forest Conditions*). Researchers suggest that low productivity sites are more susceptible to management-induced reductions in site productivity than high productivity sites, or the ability of these sites to recuperate after management is reduced. This analysis focuses on the amount of timber removed from low productivity sites, for this analysis it is defined as Site Class V.

Chart 3-67 shows the range of possible timber removals (at the end of each decade) from low productivity sites under both alternatives. In general, the mean volume of harvest in low productivity sites is less under the No Action Alternative. However, a range of projected harvest levels is presented, and the maximum exceeds the Landscape Alternative in periods three, four, seven, nine, and ten. The weighted mean total removals of the No Action Alternative suggest it would have less impact on site productivity than the Landscape Alternative.

In most cases, the level of timber removals is closely correlated with watershed size; in other words, the larger watershed administrative units tend have higher levels of timber removal. The Upper Clearwater and Middle Hoh watershed administrative units have much higher levels of timber removal because they are the largest of all (54,513 acres and 36,964 acres, respectively).

Timber removal levels are presented by alternative and watershed administrative units in Appendix G.

COMPACTION

This analysis shows the distribution of the percent of area harvested in any single decade in each Type 3 watershed over the 100-year model simulation for selected watershed administrative units (Charts 3-68 and 3-69). The higher the percentage of an area harvested, the greater the potential for probable, significant, adverse, environmental impacts to soils. The harvest levels are variable but the Landscape Alternative is almost always higher than the No Action Alternative. Three watershed administrative units stand out as having greater percentages of removal: the Hoko, Lower Queets River, and Sol Duc Valley had greater percentages of acres being harvested, many extending up to 50 percent of the acres within each Type 3 watershed in a single decade. Under the Landscape Alternative, harvest is distributed more evenly over the planning area.

Chart 3-67. Timber Removal (MMBF) from Low-Productivity (Site Class V) Acres in Each Decade for Watershed Administrative Units and Type 3 Watersheds with Greater Than 20 Percent DNR-Managed Lands

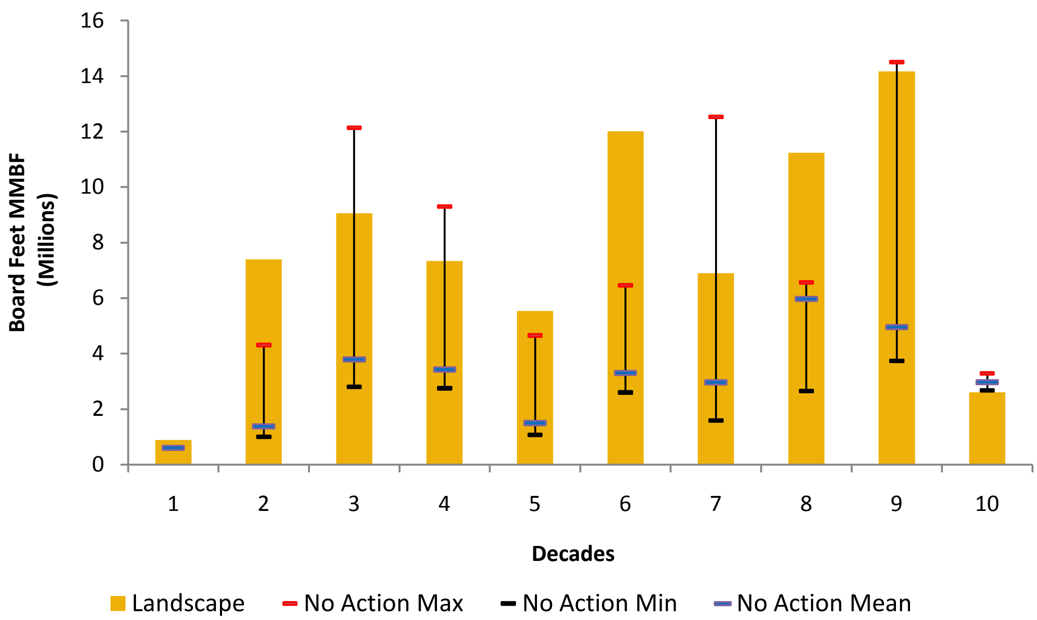
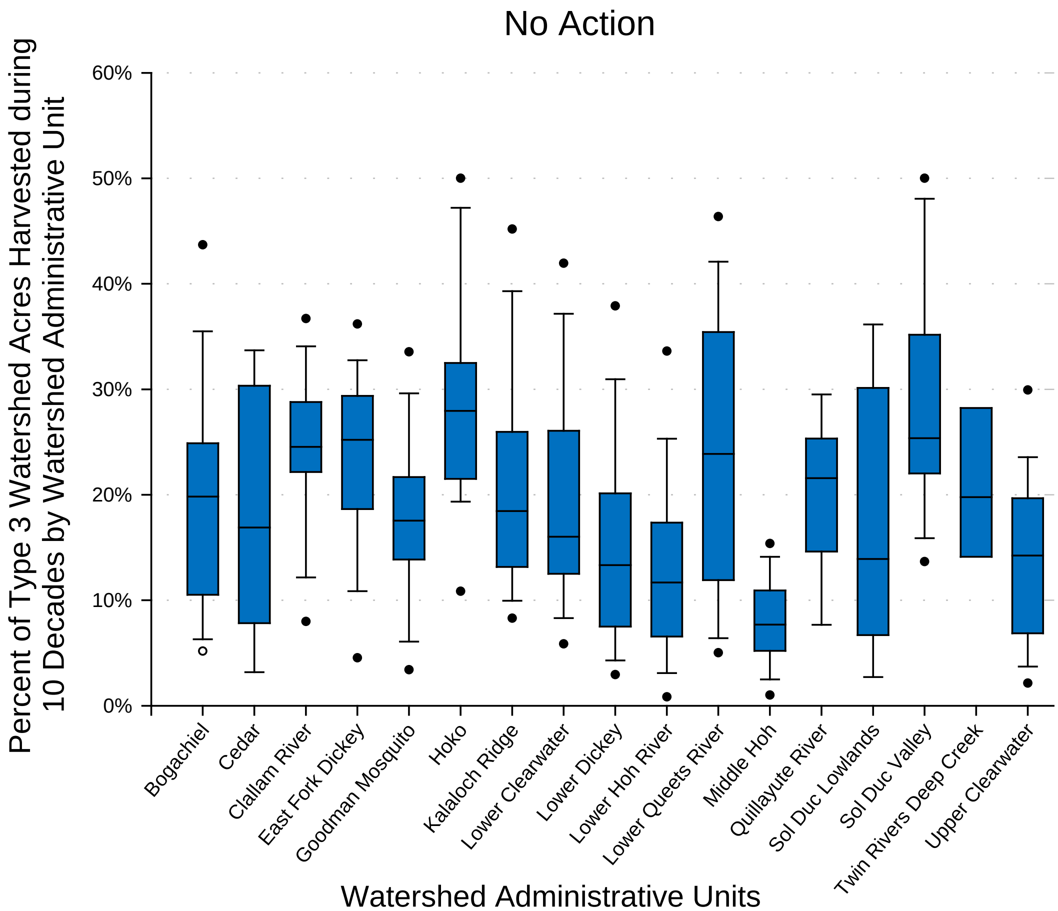


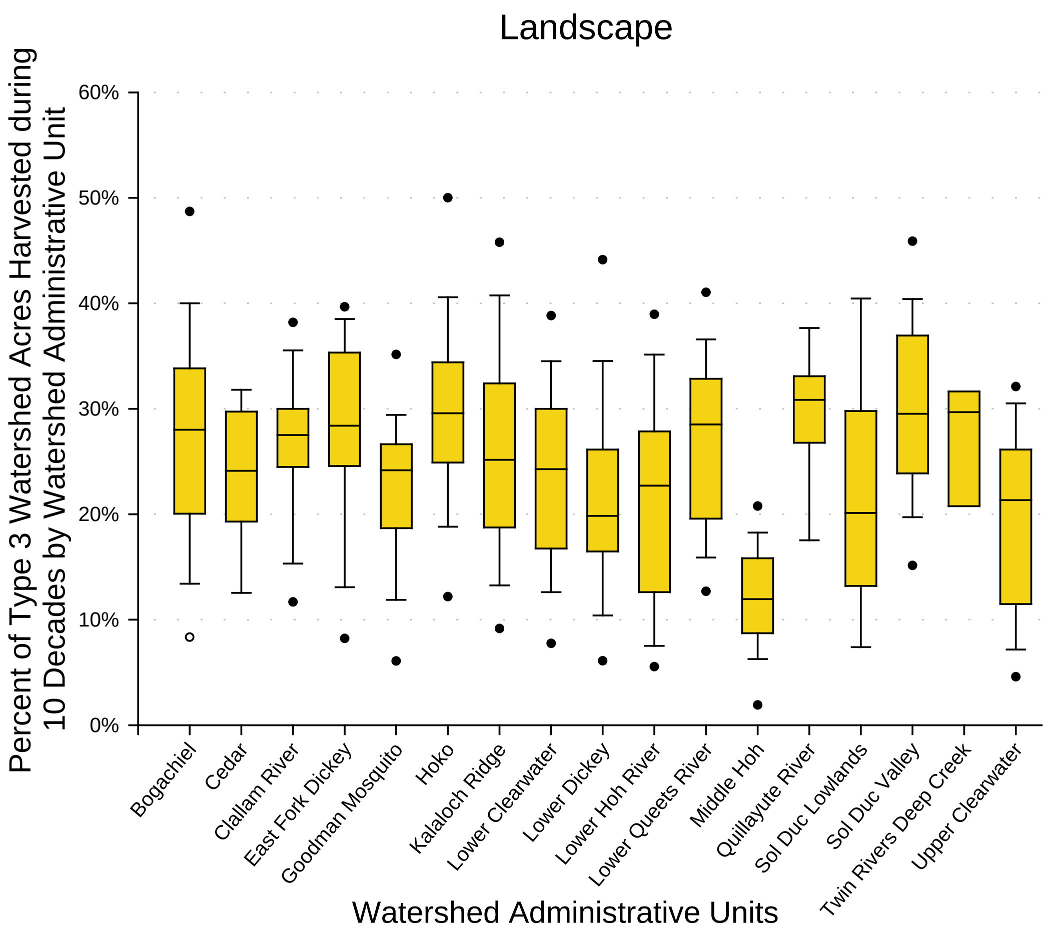
Chart 3-68. No Action Alternative: Percent of Each Type 3 Watershed Harvested for Selected Watershed Administrative Units



Harvest entries by alternative are shown in Chart 3-8 (*Forest Conditions*) which presents the total acres harvested by the number of harvest entries over the 100-year model simulation. There are 100,000 acres or 39 percent of the land base that have zero harvest entries under the Landscape Alternative versus 140,000 acres or 55 percent for the No Action Alternative. The Landscape Alternative has a greater area with multiple (two, three, four, or five) entries than the No Action Alternative.

Compaction is more likely to occur as the number of entries increases; thus the greater percentage of acres being entered multiple times under the Landscape Alternative may pose a higher risk for compaction (with additional implications for erosion) than the No Action Alternative. The No Action Alternative has the lowest risk for compaction because it has the highest acreage not receiving any harvest entries. Potential impacts to long-term soil productivity are directly related to the frequency and intensity of forest management activities (DNR 1996). Compacted soils often require several decades to recover (Cafferata 1992); therefore, frequent entries can lead to persistent, long-term soil compaction.

Chart 3-69. Landscape Alternative: Percent of Each Type 3 Watershed Harvested for Selected Watershed Administrative Units



SEDIMENT DELIVERY POTENTIAL

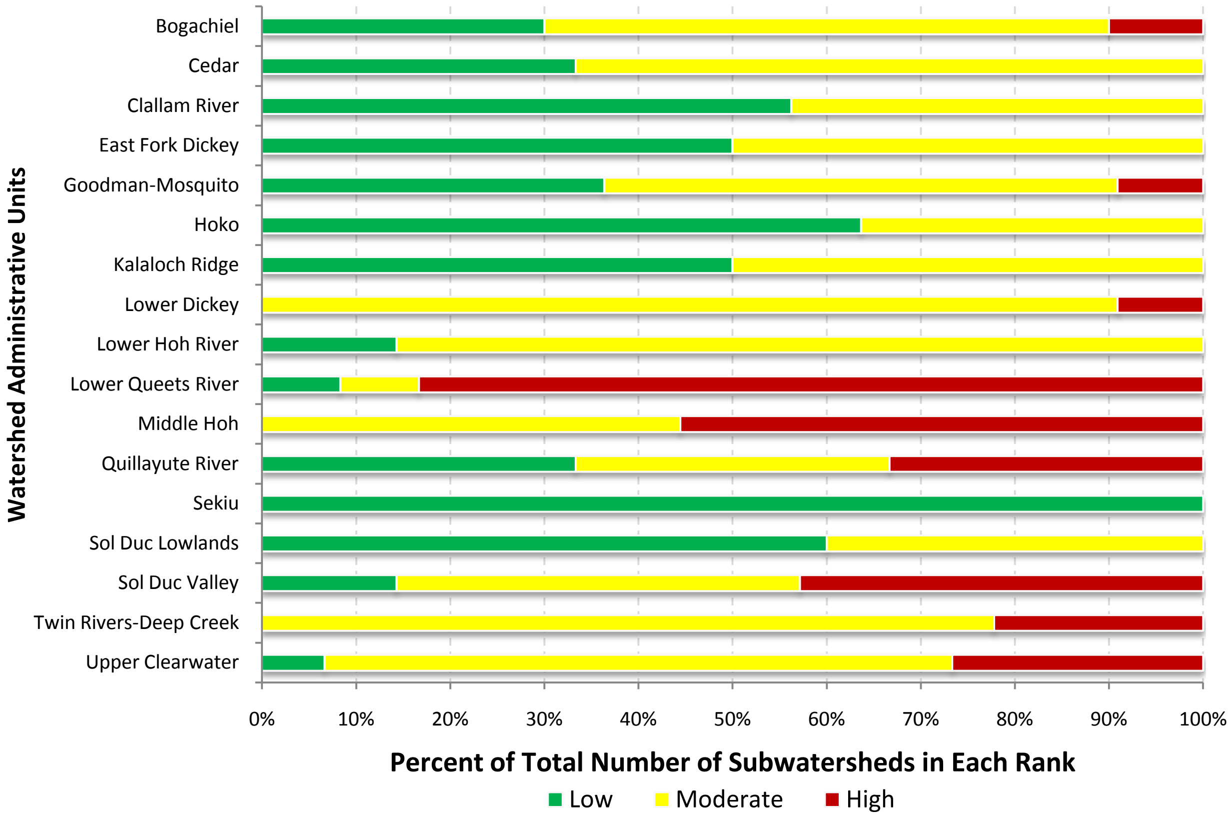
The Washington Road Surface Erosion Model[6] was used to assess road-related sediment delivery within each sub-watershed —both with and without traffic —to better understand the natural and anthropogenic sediment contributions. The Cooperative Monitoring, Evaluation, and Research Committee (CMER) standards specify ten tons of sediment per stream mile, per year within each sub-watershed as the maximum amount of sediment that may be delivered to a stream without causing a probable, significant, adverse environmental impact to water quality, stream morphology, and fish populations.

Each sub-watershed was assigned a qualitative rating based on sediment delivery from the existing road network (without traffic) relative to CMER standards (Low=Below CMER threshold, Moderate=At CMER threshold, High=Above CMER threshold). The proportion of sub-watersheds in each category for selected watersheds administrative units is shown in Chart 3-70.

[6] The Washington Road Surface Erosion Model or WARSEM was developed by the Forest Practices Science Team for assessing sediment delivery in Washington State for a range of assessment levels (from a single road to a more complex network) which may be spatially explicit if GIS information is available. More information about WARSEM can be found at: http://www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesApplications/Pages/fp_warsem.aspx

Nine watershed administrative units currently contain sub-watersheds that exceed the CMER threshold for sediment delivery. Nearly 90 percent of the sub-watersheds within the Lower Queets River watershed administrative unit are estimated to have more than ten tons of sediment delivery per stream mile, per year, and therefore may be at the highest risk for probable, significant, adverse environmental impacts. The Middle Hoh and Sol Duc Valley follow with around 45 percent of their sub-watersheds in a high sediment delivery class. The lowest risk watershed administrative units for sediment delivery are expected to be Sekiu (which has only low sediment expected delivery rates) Hoko, and Clallam River. Overall, most sub-watersheds were assigned a moderate rating.

Chart 3-70. Estimated Road Sediment Delivery Influenced by the Existing Road Network* (Not including Road Traffic) for Selected Watershed Administrative Units



*The area extent of the road network is assumed to remain static between alternatives

Using the Washington Road Surface Erosion Model, sediment delivery potential was assessed in each sub-watershed resulting from log truck traffic associated with DNR timber removal. The haul route associated with each modeled harvest activity was used to assess the potential impacts of the alternatives. Chart 3-71 shows the number of sub-watersheds expected to have high road sediment delivery levels by alternative, at the end of each decade. The Landscape Alternative has a higher number of sub-watersheds with high traffic related road sediment delivery during all time periods.

Chart 3-71. Number of Sub-Watersheds with High Traffic-Related Road Sediment Delivery Rates by Alternative

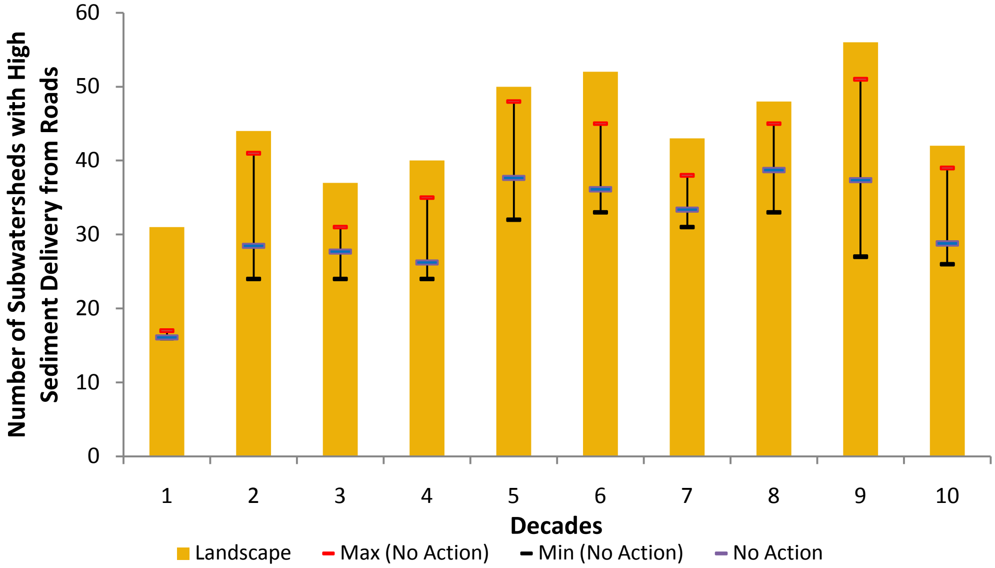


Chart 3-72. Total Road Sediment Delivery (tons/stream mile/year) for the High Sediment Delivery Class by Decade and Alternative for Selected Watershed Administrative Units

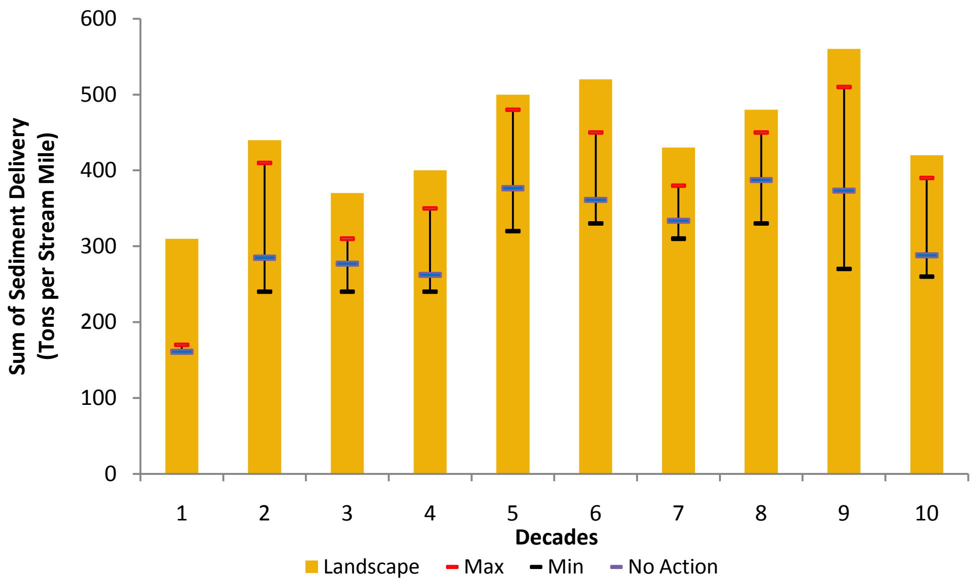


Chart 3-72 shows the total traffic related road sediment delivery by decade for those sub-watersheds in the high delivery category. The Landscape Alternative has both a greater number of sub-watersheds in the higher sediment delivery category, and a higher predicted total sediment delivery for these areas. However, relative to the total number of sub-watersheds in the OESF, few are expected to have high levels of sediment delivery.

A comparison of the sum of sediment delivery (road-related and traffic-related) per year in all sub-watersheds can be seen in Chart 3-73 for decades one, six, and nine which demonstrate the change over time for the short-, mid-, and long-term sediment delivery, respectively. The amount of sediment and variability increases noticeably for the No Action Alternative between decades one and six, but remains relatively constant thereafter. The mean value nearly doubles for the Landscape Alternative between decades one and six, but also remains relatively constant thereafter.

Chart 3-74 presents background sediment delivery rates which assess sediment movement caused by natural weathering of bedrock for watershed administrative units, not including additional delivery that may be caused by roads or traffic. Note the y-axis uses a logarithmic scale to improve readability. Road and traffic related sediment are a small fraction of the background sediment levels and would be unreadable using a linear scale. The amount of area being assessed in Chart 3-74 is much higher than in Chart 3-73 because it looks at all surface area, not just roads and associated man-made compaction sites (such as ditches and parking lots).

While the total road and traffic sediment inputs in a number of Type 3 watersheds exceed the "high" delivery class threshold of ten tons per stream mile per year, the rate of sediment input is relatively low compared to the background levels. Rates of erosion and sedimentation are highly dependent on climatic, topographic, and soil characteristics. DNR only hauls timber on forest roads about 180 days a year to limit the effects associated with wet-weather log haul. Precipitation is very high in the OESF, slope steepness is varied, and the area has relatively erodible soils. The combination of these factors results in extremely high levels of background sediment production, more than two orders of magnitude higher than expected contributions from roads (Chart 3-74).

Chart 3-73. Change in Sediment Delivery (Sum of Road-Related and Traffic-Related) over Time, by Alternative

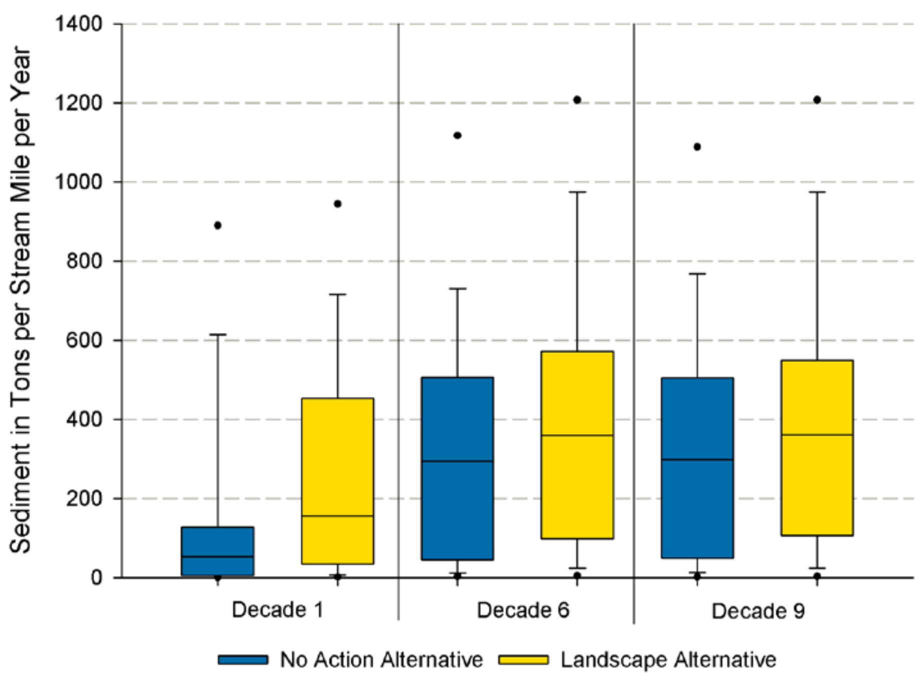
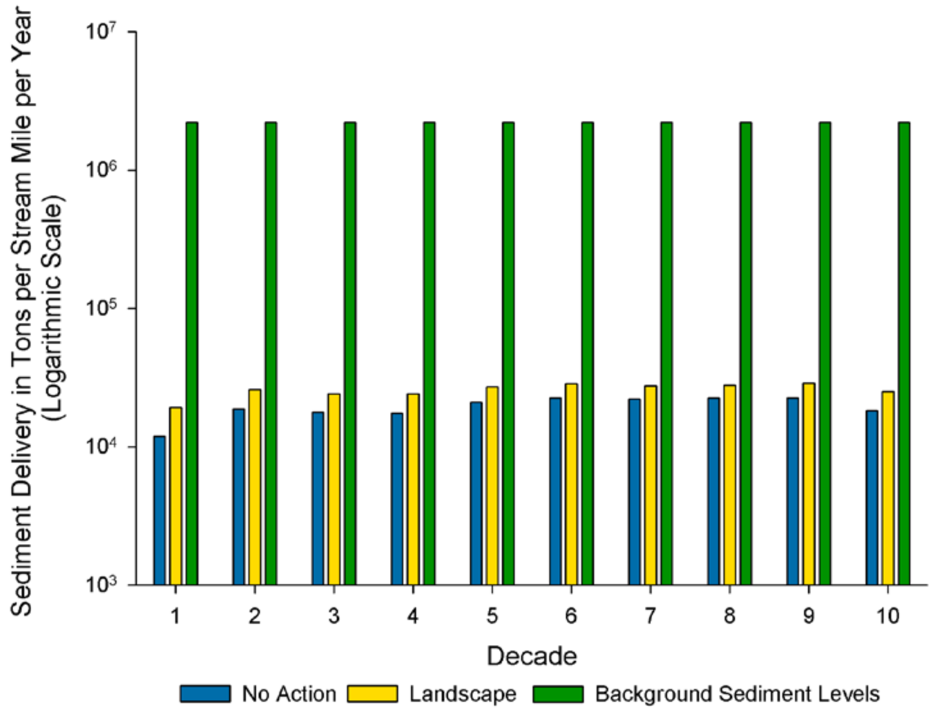


Chart 3-74. Comparison of Background Sediment Delivery Rates to Road Sediment Delivery Rates for the No Action and Landscape Alternatives



Direct, Indirect, and Cumulative Impacts to Soils

Potential impacts to soils were assessed using four criteria and indicators: 1) soil productivity, as measured by the projected timber harvests on low productivity soils; 2) the risk of compaction assessed by the level and type of harvest; 3) surface erosion; and 4) risk of sediment delivery. Based on Geographic Information System (GIS) soil data, current soil characteristics were combined to provide a relative ranking of the predisposition to soil impacts of each watershed administrative unit within the OESF. The Hoko, Kalaloch Ridge and Sekiu watershed administrative units have the highest combined relative risk of soil erosion, compaction, and displacement. Projections of harvest activities (including amount, type, and number of entries) were examined to identify potential impacts. Additionally, risk of sediment delivery was examined separately including both the current conditions and estimates based on timber removal projections.

Data regarding timber removals from low productivity sites in most watershed administrative units were shown for both alternatives (Chart 3-67). In general, the mean volume of harvest in low productivity sites is less under the No Action Alternative, which suggests it would have less impact on soil productivity than the Landscape Alternative.

The trends are similar for percentages of Type 3 watersheds being harvested under each alternative (Charts 3-68 and 3-69). The harvest levels are variable but the Landscape Alternative is projected to have a larger harvest area and a greater area with multiple entry harvests than the No Action Alternative (Chart 3-8, *Forest Conditions*). As a result, the Landscape Alternative presents a greater risk of probable, significant, adverse, environmental impacts.

Three watershed administrative units stand out as having greater percentages of timber removals; the Hoko, Lower Queets River, and Sol Duc Valley which consistently had greater percentages of acres being harvested in any single decade than the other watershed administrative units, extending up to 50 percent of the acres within a single Type 3 watershed.

Data from DNR's soils layer was used to identify those watershed administrative units with the greatest potential for surface erosion. Each watershed administrative unit's surface erosion potential can be compared to the amount and type of harvest under each alternative (Table 3-13, *Forest Conditions*). The Upper Clearwater is the largest watershed administrative unit and has the greatest number of acres in the high erosion potential class, putting it at the highest risk for surface erosion, relative to the other watershed administrative units. Its high surface erosion potential is likely a result of the steep terrain found within the OESF. Projected DNR management activities in the Upper Clearwater consist primarily of variable density thinning (accounting for more than 80 percent of all harvest activities under both alternatives) which should reduce the potential for management-related erosion.

The Hoko watershed administrative unit (10,564 acres) had the third highest average slope gradient and is the only watershed with a mean slope of more than 30 percent. A relatively high proportion of proposed management activities in this watershed administrative unit consist of variable retention harvests (50 and 45 percent for the No Action and Landscape Alternatives, respectively). Hoko has the highest combined risk of all watershed administrative units with respect to soil erosion, compaction, and displacement; however, background sediment delivery rates and the existing road network (not including road traffic) delivery rates were only moderate for the Hoko watershed administrative unit relative to other areas.

The analysis highlighted numerous sub-watersheds that have the potential to exceed the Cooperative Monitoring, Evaluation, and Research Committee (CMER) standards for sediment delivery. Under both alternatives, the watershed administrative units that have the greatest percent of Type 3 watersheds with the potential to exceed CMER standards are Hoko, Quillayute River, and East Fork Dickey. The Landscape Alternative has both a greater number of sub-watersheds in the high sediment delivery category, and a higher predicted total sediment delivery for these areas. However, relative to the total number of sub-watersheds in the OESF, few are expected to have high levels of sediment delivery. Furthermore, while the total road and traffic sediment inputs in a number of Type 3 watersheds far exceed the "high" delivery class threshold of ten tons per stream mile per year, the rate of sediment input is but a small fraction of the background levels.

Mitigation Measures

The existing management framework identifies mitigation techniques that will be applied to both alternatives. In the OESF, 25 foot riparian buffers are retained along streams and wetlands to protect against accelerated erosion and sedimentation and to provide shade, regulate microclimates, and recruit woody debris to improve in-stream habitat, which remains constant under both alternatives. For a further discussion of riparian functions refer to the *Riparian* section. Riparian buffers prevent sediment delivery to streams by providing an undisturbed forest floor to serve as a filter, and prevent accelerated streambank erosion by preserving streambank rooting strength.

DNR roads are constructed and maintained to protect water quality and riparian habitat by limiting sediment delivery to nearby waters. All new roads are constructed according to *Forest Practices Rules* and most existing roads are expected to meet these standards by 2016. Proper road design and maintenance, in addition to best management practices, are important steps toward reducing road-related sediment delivery (Coe 2004) and conditions are expected to improve over time as DNR strives to meet standards set forth in the state Forest Practices *Road Maintenance and Abandonment Plans* (RMAPs), which direct road construction, maintenance, and later abandonment. This analysis assumes that DNR's commitment to build and upgrade forest roads pursuant to Forest Practices' standards by 2016 avoids or mitigates probable, significant, adverse, environmental impacts. For a discussion on the recommended forest road construction and maintenance practices, DNR is incorporating by reference Appendix F of the 2001 *Final EIS on Alternatives for Forest Practices Rules*. If this goal is achieved, the standards proposed by Cooperative Monitoring, Evaluation, and Research (CMER 2010) will also be met.

Road maintenance is an essential part of land and resource management (refer to Appendix G for a summary of road maintenance in the OESF). Both the timing of construction operations and erosion control methods are important to reduce sediment delivery from roads (Ecology 2008). According to Arnaez and others (2004), the best means for reducing sediment is to design forest roads to fit the topography, apply well-established best management practices, and minimize the mobilization of sediment. These precautions, implemented at the site-specific project level, in addition to seasonal traffic restrictions, reduce the overall probability of increased surface erosion on any given site.

Forest Practices Rules will be followed for both alternatives. This analysis demonstrates there will be no probable, significant, adverse, environmental impacts beyond those analyzed in the 2004 *Sustainable Harvest Final EIS* (p. 4-104 to 4-108), incorporated here by reference.