Appendix F. Sediment Delivery Studies and Modeling Efforts

CONTENTS

INTRODUCTION

This appendix presents a description of the sediment delivery studies and the sediment modeling efforts conducted by Simpson Resource Company (Simpson). These projects were undertaken to estimate future long-term sediment delivery volumes to watercourses from roads and landslides within the Plan Area. The empirically-based model was designed to comparatively evaluate average long-term sediment delivery from roads and landslides under different management scenarios. The structure of the model enables Simpson to examine a wide range of management scenarios to identify the most efficient and effective prescriptions that will sufficiently reduce future management-related sediment delivery to meet the needs of aquatic resources of concern.

Model Data Base

Simpson conducted two extensive sediment delivery studies. One study involved the compilation of landslide inventories to evaluate landslide-related sediment delivery. Average long-term sediment delivery volumes from shallow and deep-seated landslides were evaluated for three pilot watersheds covering roughly 10% of the Plan Area: Salmon Creek, Little River, and Hunter Creek. Delivery rates were based on standard interpretations of aerial photographs with a limited amount of field verification. Sediment delivery from deep-seated landslides was also estimated in the Upper Mad River pilot watershed based on published data. The impact of harvesting on landslides and landslide-related sediment delivery was evaluated from the landslide inventory data collected in the pilot watersheds, from published reports, and complemented by professional judgment where data were lacking. A summary of the results of the landslide inventory and associated analysis is included as Appendix F1.

The second data collection effort was a field-based road inventory of 518 miles of road in five pilot watersheds to evaluate future sediment sources and sediment delivery related to the road network. The road-related sediment source inventories employed standard road inventory protocols developed by Pacific Watershed Associates, which have been used on forest and ranch lands throughout the north coast. The inventories were designed to quantify potential future sediment delivery from road-related landslides, watercourse crossing failures, and “other” sites (such as problems with ditch relief culverts and related gullies) associated with Simpson’s road network. As part of Simpson’s modeling effort described in this appendix, the road inventory data were summarized and applied to the Simpson ownership within the 11 HPAs to develop potential road-related sediment delivery estimates. These data were also instrumental in developing site-specific erosion prevention measures as well as general road-related erosion prevention measures that were incorporated into the Plan. A summary of the road inventory data is included as Appendix F2.

Simpson used the road-related sediment source data and landslide-related sediment data to parameterize a simple sediment delivery model for the Plan Area. This model was subjected to Monte Carlo simulation analyses to evaluate changes in forecast variables given ranges of uncertainty in the model’s parameters. The use of empirically-based sediment inventory methods and Monte Carlo simulation enabled Simpson to comparatively analyze average long-term sediment delivery under a variety of management scenarios and conservation measures. It was through this comparative analysis that Simpson developed the accelerated road-related erosion prevention strategy (see Section 6.3.3) and appropriate slope stability conservation measures (see Section 6.3.2) that are expected to meet the needs of the aquatic resources of concern. A description of the Plan Area model and the Monte Carlo simulation results are included as Appendix F3.

Limitations of the Model

The model quantified only those sediment sources and processes that were considered to be among the most prolific sediment contributors and that may be affected by management prescriptions. The conservation measures developed from the model focused on those prescriptions that were expected to have the greatest benefit to the covered species, provide the highest confidence of success, and are logistically and economically feasible. Conversely, prescriptions that were expected to result in only a marginal benefit, provide low confidence of success, and that are logistically or economically infeasible were avoided.

The model is best suited for comparative analysis of road and landslide related sediment delivery, and it is not intended to be a comprehensive sediment budget. Although the model does not address all possible forms of management-related sediment delivery, such as legacy skid trail erosion, in-unit hillslope erosion, and stream bank erosion, conservation measures and BMPs have been developed, following the advice of experts both within the government and within the private sector, to address those potential sediment inputs.

The model does not differentiate between fine- and coarse-grained sediment. While the effectiveness monitoring and the adaptive nature of the conservation measures will be based only on sediment delivery and potential sediment delivery volume, the conservation measures as a whole are expected to have a significant effect on fine-grained sediment contributions. This is particularly true of the road-related and harvest-related-ground-disturbance conservation measures described in the Plan.

Finally, the sediment model does not address cumulative watershed effects (CWEs). It is not site specific, and it does not integrate past, current, and reasonably foreseeable projects. Instead, the sediment model is spatially-averaged over the Simpson ownership within the 11 HPAs and time-averaged over the next 50 years. This does not reflect actual sediment delivery processes, which are prone to occur in more of an episodic nature and vary locally, depending mostly on climatic conditions. However, the significance of this limitation is reduced by the adaptive management mechanisms in the Plan that are expected to provide appropriate elasticity for the conservation measures within individual HPAs to meet the needs of the aquatic resources of concern.

Although Simpson's modeling approach may overestimate sediment delivery in some places and underestimate it in other places, it is thought to be reasonably accurate overall. Therefore, Simpson believes the model is adequate for evaluating the most efficient and effective prescriptions to limit management-related sediment delivery in order to meet the needs of the species of concern, keeping in mind that some of the initial prescriptions are subject to adaptive management.

Appendix F1. Assessment of Long-term Landslide Sediment Delivery under Existing and Proposed Plan Conditions

CONTENTS

Tables

F1.1 INTRODUCTION

The following chapter outlines the methodology, assumptions, limitations, and results of a modeling exercise designed to estimate approximate long-term landslide delivery rates from the road and skid trail network and from hillslopes to watercourses in several pilot watersheds within the Plan Area. The modeling is also intended to estimate long-term sediment delivery under various silviculture options.

The purpose of this exercise was to evaluate the potential impacts of forest practices on landslide-related sediment delivery and to assist in evaluating the most effective and efficient slope stability measures. Such evaluations are the focus of Appendix F3, which takes the models and results developed in this chapter and applies them to the Plan Area to develop property-wide sediment delivery estimates.

A general discussion of landslide types and processes is summarized in Appendix B. A general discussion of the potential impact management activities can have on these processes is summarized in Section 5.

Estimates of landslide delivery rates are based primarily on landslide data collected from the historical set of aerial photographs. Historical rates of landslide delivery from grading activities (i.e., roads, skid trails, landings, etc.) and from hillslopes were estimated separately. A simple model was developed to estimate management-related landslide delivery rates in harvest areas that are attributable to silvicultural treatment. Landslide rates for the pilot watersheds were applied to the remainder of the Plan Area based on professional experience.

A mechanistic modeling approach was considered. However, due to the inherent variability in many of the input parameters that can affect slope stability, the difficulty in obtaining the precise data required for any mechanistic model, temporal and spatial variability of the parameters, and limitations in the slope stability models, Simpson does not believe that accurate results could be obtained from such a model.

The information provided in this appendix is specific to sediment production and delivery from shallow and deep-seated landslides associated with roads and silvicultural treatment. Sediment production and delivery from other processes, such as surface erosion, channel bank erosion, or erosion of watercourse crossings are not addressed in this appendix, although the potential for such sediment causing effects is addressed elsewhere in the Plan.

F1.1.1 Approach

Total sediment delivery from landslides is the sum of natural landslide sediment and management induced landslide-related sediment. Management induced landslide related sediment includes sediment derived from cut slopes and fill slopes of roads (including skid trails and landings) and from harvest units (as influenced by silvicultural treatment). This relationship is illustrated by the following equation:

Equation 1: $SED_{tot} = SED_{background} + (SED_{road} + SED_{harvest})$

Landslide delivery volumes were estimated based on empirical evidence that related management activities to increased erosion rates. These models are based largely on the results of preliminary mass wasting assessments (MWAs) conducted on several pilot watersheds within Simpson property. The impact of harvesting on sediment delivery was estimated from landslide inventory data collected throughout north coastal California and Oregon published scientific literature, and complemented by professional judgment where data were lacking.

Average long-term sediment delivery volumes from shallow and deep-seated landslides were estimated for both current management practices and those under the proposed Plan measures for three pilot watersheds: Salmon Creek, Little River, and Hunter Creek. Sediment delivery from deep-seated landslides was also estimated in the Upper Mad River pilot watershed.

F1.1.2 Limitations

It should be recognized that estimating landslide rates across all of Simpson ownership property with its diverse terrain and types of landsliding is a complicated process. Sediment delivery rates are temporal and spatially variable. The sediment delivery volumes presented here are long-term averages using empirically determined associations between sediment delivery and land management. The model is based on best available data.

Short-term sediment delivery rates may be higher or lower than the average presented here due to land-use and metrological events. Sediment delivery will be higher than average following major events and lower during relatively dry periods. Moreover, the post harvest impact immediately after harvesting is expected to be higher than average, diminishing as vegetation becomes reestablished. Sediment delivery is also not spatially characterized by the models presented herein. Local differences in geology, terrain, land use, and climate may result in locally different rates of sediment delivery to watercourses.

Ranges in model parameters have been provided in an attempt to evaluate ranges in sediment delivery due to uncertainties in estimates or measurements of the parameters. These ranges were useful in the Monte Carlo simulation exercise reported in Appendix F3.

The sediment delivery volumes presented here are intended as a means for evaluating the relative effects of different management scenarios on landslide sediment delivery to develop a physically based approach to prescription development. The results from this modeling effort are considered approximate and are not intended as detailed sediment budget of each watershed.

F1.2 MODEL DESCRIPTION

The following sections provide a detailed description of the data and analytical methods used to determine sediment delivery volumes for both shallow and deep-seated landslides. The impact of harvesting on shallow landslide processes was considered separately from the impact of harvesting on deep-seated landslides because of the difference in landslide processes and the availability and quality of existing data. Each of the following sections also includes a description of the limitations and assumptions used in the development of the model, and the limitations that should be understood during the application of the model output.

F1.2.1 Shallow Landslides

Shallow landslides are characterized by debris slides, debris flows, channel bank failures and small to large hillslope failures. These landslides are typically rainfall-activated, relatively fast-moving, shallow (less than 10 feet deep), and generally incorporate only the overlying surficial mantle of soil, colluvium, and weathered bedrock (see Appendix B).

F1.2.1.1 Methods

Average long-term sediment delivery from shallow landslides was calculated from preliminary landslide sediment delivery data collected in the MWAs of five pilot watersheds: Salmon Creek, Ryan Creek, Little River, Hunter Creek, and Tectah Creek. Sediment delivery from road-related landslides was estimated directly from the aerial photograph-based landslide inventory. Sediment delivery from hillslope landslides was estimated by applying a simple model that relates the relative impact of different harvest scenarios to landslide rates. The landslide inventories for Ryan Creek and Tectah Creek are incomplete at present; therefore, only the results from shallow, road-related failures in these areas were used as a supplement to the analysis.

F1.2.1.2 Total Sediment Delivery

Historical rates of sediment delivery from shallow landslide processes operating in each of the five pilot watersheds were estimated from an analysis of the historical set of aerial photographs (Table F1-1). Landslide were mapped from the historical set of aerial photographs and, with the exception of Ryan Creek and Tectah Creek, their location entered into the geographic information system (GIS) database for further analysis. The age of the slide was reported as the year of the photograph the slide was first observed. The input of landslide data from Ryan Creek and Tectah Creek into the GIS is pending.

Table F1-1. Landslide inventory photo record.

Pilot Watershed	Acreage	Photo Years
Salmon Creek[a]	7,889	1997, 1991, 1978, 1958, 1954
Ryan Creek	7,590	1997, 1990, 1984, 1978, 1966
Little River	28,755	1997, 1987, 1978, 1966, 1948
Hunter Creek	10,126	1997, 1984, 1972, 1958
Tectah Creek[b]	12,675	1997

Notes
a: 1958 photos used where 1954 photos were unavailable
b: Landslide inventory for earlier years incomplete at present

Pertinent data associated with each landslide were recorded into a database for further analysis. This included landslide type, estimated size (ft^2), estimated depth (ft), sediment delivery ratio (%), slope form (convergent, divergent, planar) and location (headwall swale, inner gorge, midslope), any association with graded areas (road, skid trail, landing, railroad tracks, etc.), and level of harvest (clearcut, partial cut, forested, grassland).

Limited field verification of mapped landslides was undertaken in all pilot MWA areas except Ryan Creek. Additional fieldwork in all watersheds is pending. Sediment delivery from each of the pilot watersheds is summarized in Tables F1-2 and F1-3.

In Tables F1-2 and F1-3, the road category is the sum of landslide sediment derived from all graded areas including roads, skid trails, landings, railroad tracks, etc. It is assumed that any landslide that initiates at, or adjacent to, a graded area is a result of that grading. The Non-Road category is the sum of all landslide-derived sediment that is not associated with grading. The % Historical Road category is the percentage of the total sediment for the period of the air photo record that is road-related (including all graded areas), whereas the % 1997 Road category is the percentage of 1997 sediment that is road-related. The % Historical Road can be higher or lower than the % 1997 Road depending on road construction history. The % 1997 Road is considered a better estimate of the current relative impact of roads on shallow landslide sediment delivery.

Table F1-2. Shallow landslide sediment delivery volumes.

Watershed	Acres	Years of Record	Landslide Delivery (cy)			% Historical Road[1]	% 1997 Road
			Total	Road[1]	Non-Road		
Salmon Creek	7,889	58	156,732	41,650	115,082	26%	17%
Ryan Creek	7,590	46	27,903	9,240	18,663	33%	56%
Little River	28,755	64	139,457	28,491	110,966	20%	40%
Hunter Creek	10,126	54	494,523	306,751	187,772	62%	39%
Tectah Creek	12,675	n/a	104,121	550	84,982	n/a	18%

1 Road includes all graded areas including roads, landings, skid trails, railroad tracks and other graded areas.

Table F1-3. Long-term shallow landslide delivery rates.

Watershed	Cy/ac/yr			$T/mi^2/yr$[b]		
	Total	Road[c]	Non-Road	Total	Road[c]	Non-Road
Salmon Creek	0.34	0.09	0.25	295	80	217
Ryan Creek	0.08	0.03	0.05	69	22	46
Little River	0.08	0.02	0.06	65	13	52
Hunter Creek	0.90	0.57	0.34	781	485	297
Techtah Creek[a]	--	--	--	--	--	--

Notes
a: Pre-1997 landslide data unavailable at present
b: Assumes a unit weight of soil of 100 pcf.
c: Road includes all graded areas including roads, landings, skid trails, railroad tracks and other graded areas.

F1.2.1.2.1 Confidence of Landslide Volume Estimates

The accuracy of identifying and characterizing landslides in aerial photographs is variable and depends, in part, on the size of the slide, thickness of the vegetative cover, and timing and quality of the photographs. Large landslides, or landslides mapped in recently harvested areas or through thin canopy, are identified with relatively high accuracy. However, small streamside failures, which are often numerous, are difficult to identify because of thick riparian canopy. Therefore, aerial photo analysis will only allow for a partial identification of the total number of landslides in the Plan Area. As a result, the number of slides inventoried for use in landslide delivery should be considered a minimum representation of the actual number of slides that are present in the area. To illustrate this point, the Oregon Department of Forestry's (ODF) evaluation of storm impacts and landslides for 1996 (Robison et al. 1999) revealed that air photo inventories may underestimate sediment production from landslides by as much as 50 percent. The error is greatest in mature forests with thick canopy and less apparent in recently harvested areas.

Field verification of air photo measurements was conducted in Hunter Creek and to a lesser extent in Salmon Creek, Little River, and Tectah Creek. Where field verification is complete, air photo estimates of sediment production are generally within 30 percent of field measurements. This relatively high level of accuracy may be partly explained by data indicating that small slides, potentially undetected in the aerial photograph record, do not deliver large volumes of sediment to streams and are not a large component of the total sediment budget. This leads to the conclusion that the majority of sediment is probably delivered by large slides that have a high likelihood of detection in the air photo record. It should be noted, however, that Simpson has accounted for uncertainty in landslide sediment delivery rates in its modeling efforts. Appendix F3 contains a description of four assumption variables that address such uncertainties: Delivery From Road-Related Landslides, Little River Sediment Multiplier, Hunter Creek Sediment Multiplier, and Salmon Creek Sediment Multiplier.

Table F1-4 summarizes the expected range of shallow landslide sediment delivery volumes relative to measured aerial photograph volumes. The range is based on limited field reconnaissance and verification of slides in Salmon Creek, Little River and Hunter Creek, and professional judgment. The range in landslide delivery volumes incorporates uncertainties in slide identification and volume estimates. The higher range in Salmon Creek and Little River compared to Hunter Creek is a result of the expected higher incidence of small stream bank failures that were apparent during field reconnaissance of the watershed but may not be apparent in the air photos.

Table F1-4. Assumed range in landslide delivery volumes relative to air photo estimates.

Watershed	***Lower Bound***	***Most Likely***	***Upper Bound***
Salmon Creek	80%	100%	150%
Ryan Creek	80%	100%	150%
Little River	80%	100%	150%
Hunter Creek	70%	100%	130%
Tectah Creek	--	--	--

F1.2.1.3 Road -Related Landslide Sediment

Landslide delivery volumes from road-related landslides were calculated directly from the air photo inventory. Failures were identified as road, landing, skid trail or “other” related landslides. “Other” related landslides included failures originating from railroad fill and building pads. It was assumed that any landslide on or adjacent to one of these road features occurred as a result of the construction of that feature. Cutbank failures were not inventoried unless they overtopped the road and delivered sediment directly to a watercourse.

The classification of failures related to grading activities is relatively straightforward in harvested areas or areas with thin canopy. Some small roads may have been classified as skid trails; likewise, some large skid trails may have been classified as roads. Identification of roads or skid trails in areas of thick canopy is speculative at times and therefore it is possible that some failures in these areas may have been misclassified. Landslide delivery volumes from roads are summarized in Tables F1-2 and F1-3.

F1.2.1.4 Harvest-Related Landslide Sediment

Harvesting can potentially impact landslide rates through reduced root reinforcement and changes in the hydrologic regime (See Section 5). Determining the contribution of sediment from harvest areas is a much more difficult endeavor than estimating sediment contribution from roads. Unlike roads, the simple existence of a slide within in a harvest unit is insufficient to make a causal link between that particular slide and the harvesting activity. This is because natural landslides may occur within harvest units therefore determining the casual mechanism of failure of any given in unit slide often requires in-depth field review. Although many studies have addressed the impact of roads on sediment production, there are few comparable studies in the region that have quantitatively evaluated the impact of harvesting (i.e., tree removal alone) on sediment production and delivery rates, and those studies that have been completed give widely varying results.

With respect to sediment delivery, the relative impact of timber harvesting on landsliding is probably best evaluated using an empirical approach that compares landslide delivery rates from harvested areas to forested ground. Unfortunately, few studies of this kind have been conducted in northern California.

The difficulty in evaluating the impact of harvesting is further compounded by the fact that different harvest methods are expected to have different implications for slope stability. For example, a selection harvest is not expected to have the same impact on slope stability as clearcutting. Similar problems exist with differences in terrain and geology. For example, the reduction of root strength in cohesionless soils is expected to have a greater impact on shallow landsliding than harvests in soils with relatively high cohesion. Further, it is possible that some harvests may have impacts on slope stability offsite. For example, it has been hypothesized that in some areas, extensive upslope harvesting may have an impact on downslope areas through alterations in the hillslope hydrology (see Section 5).

In this study, the harvest contribution of non-road-related, shallow, landslide-derived sediment was estimated using a relatively simple empirical model that applies a regional average ratio between harvest-related sediment (timber removal alone) and natural "background" sediment [herein referred to as *"harvest ratio"* (HR)] to the non-road-related component of shallow landslide sediment measured in each pilot watershed (see Equation 3).

The average clearcut HR was estimated from published and unpublished studies, including total maximum daily load (TMDL) studies, Pacific Lumber Company (PALCO) sediment source assessments, the ODF study, and from preliminary results from Simpson's Hunter Creek pilot MWA (these studies will be discussed in detail later in this appendix). HRs for other silvicultural prescriptions are not reported. Therefore, adjustments to the clearcut HR were required to account for differences in silvicultural prescriptions and expected differences in mass wasting rates as a result of inherent sensitivity of the hillside as delineated by the mass wasting prescription zones (MWPZs).

Simpson has assumed that sediment delivery from harvest areas can be reasonably estimated based on the following equation:

Equation 2: $\mathbf{SED_{harv} = SED_{nonroad} / (HR_{clearcut} * N_{partcut\ (y)} * N_{terrain})}$,

where SED_{harv} is the rate of sediment delivery resulting from timber removal alone, $SED_{nonroad}$ is the rate of non-road-related sediment delivery measured from the historical set of aerial photographs, $HR_{clearcut}$ is the clearcut harvest ratio, $N_{partcut\ (y)}$ is a factor to account for different silvicultural techniques (y) other than clearcutting, and $N_{terrain}$ is a factor to account for terrain differences.

The model assumes that the rate of harvesting has remained relatively constant over time. In addition, the model assumes a direct spatial link between harvesting and slope failure. In other words, the analysis assumes that vegetation retention has only a local effect on slope stability. Any offsite impact of harvesting (such as changes in downslope hillslope hydrology from upslope harvesting, or increased stream flow from upstream harvesting) is assumed to be negligible and was not modeled.

While Simpson recognizes that upslope harvesting may have an impact on downslope harvest areas, there is little data at present to model this process. Nonetheless, Simpson believes the model provides a reasonable and simple method to evaluate the relative impact of different silvicultural methods. As more data are collected and the understanding of the impact of harvesting increases, the model can be revised.

F1.2.1.5 Harvest Ratio

HR is defined as the ratio between the average long-term rate of sediment delivery (cy/acre/yr) derived from harvest blocks (includes harvest-derived sediment and background sediment) compared to uncut or advanced second growth forested ground (background sediment):

Equation 3: $\mathbf{HR(n) = (SED_{harvest}(n) + SED_{background})/SED_{background}}$,

where n is the type of silviculture applied, $\mathbf{SED_{background}}$ is the measured volume of sediment generated from undisturbed or advanced second growth forests, $\mathbf{(SED_{harvest}(n) + SED_{background})}$ is the measured volume of sediment generated from failures originating in harvest blocks, and $\mathbf{SED_{harvest}}$ is the volume of extra sediment above background that is generated as a result of harvesting. This value cannot be directly measured because it is generally not possible to distinguish between individual natural and harvest-caused landslides within harvest blocks.

The model assumes that the impact of harvesting is uniform and constant across the landscape. It is likely, however, that HRs are quite variable, depending on terrain, geology, hydrology and vegetation type. Moreover, the period during which a slope is most prone to shallow instability is a function of the magnitude of the hydrologic event and the decay time to a critical root cohesion value low enough to allow for landsliding, and the duration of time spent below the critical root strength (SWS 1999; Ziemer and Swanston 1977). With the amount of data available at present, however, it is not possible to tailor the HR to individual watersheds or sub-watersheds.

As a first approximation, a regional long-term average clearcut HR ($HR_{clearcut}$) was estimated based on published and unpublished reports. HRs for other silvicultural strategies are not presented in the literature. Therefore for the purpose of this model, the clearcut HR was then modified to account for other silvicultural prescriptions (e.g., 85 percent overstory retention, selection, hardwood retentions, etc.) based on what data was available, review of deterministic models and professional judgment.

F1.2.1.5.1 <u>*Clearcut Harvest Ratio*</u>

An average clearcut harvest ratio was estimated from a review of published and unpublished landslide inventories, including TMDL studies, the ODF study on the impacts of 1995 and 1996 storms (Robison et al. 1999), PALCO Sediment Source Investigations (PWA 1998a, 1998b, 1999a, 1999b), PALCO Freshwater Creek Watershed Analysis (PALCO 2001a), and Simpson's preliminary Mass Wasting Assessment for Hunter Creek. The results of these studies are summarized in Table F1-5. Results from the other pilot watersheds are pending.

Based on the foregoing, the historical average **long-term** increase in sediment delivery from clearcut areas ranges between 1.25 and 4.0 times background (most likely equal to 2.0). The results from Freshwater and Hunter Creek were weighted more heavily than the other studies because these were the most rigorous in evaluating the impact of clearcut harvesting, and because they are more representative of geologic and terrain conditions on Simpson lands. In addition, each of these cases includes periods of record in which extensive clearcut harvesting occurred a few years prior to intense triggering storms.

It is important to note the clearcut harvest ratio likely presents a 'worst' case scenario for a long term average given that the ratio is based on data originating from areas recently subjected to very intensive land use dominated by the effects of recent large storm events (i.e., Hunter Creek and Freshwater Creek). Recent work by Schmidt et al. (in press) on root cohesion and susceptibility to shallow landsliding found that 100-year-old industrial forests had lower root strength and inferred higher landslide rates in comparison to natural forests. However, these results should be viewed with caution since the lower root strength in the 100-year-old industrial forests is attributed to forestry practices a century ago that did not include replanting of conifer, therefore allowing the site to regenerate with hardwood. Conceptual modeling by Schmidt et al. (in press) suggests that if the site is replanted with conifer immediately following harvesting root cohesion values can return to pre-harvest levels within 16 years.

It is important to note that the HR used for modeling is intended to be a long-term average over the 50-year period of the harvest. Short-term impacts may be higher or lower depending on the occurrence of triggering hydrologic events and the rate of vegetation regrowth.

F1.2.1.5.2 Partial Cut Harvest Ratios

Because partial cutting retains understory vegetation and leaves a substantial live root mass, it has less impact on root strength and slope stability than clearcutting. Further, harvesting in redwood or hardwood forests, which maintain a viable root network and generally sprout vigorously after cutting, should have less impact on slope stability.

Few studies have been conducted that evaluate the impact of different residual stand densities on slope stability and shallow landslides. The ODF study of the effects of the 1995-96 storms revealed that comparatively few landslides originated in partially cut areas (Robison et al., 1999). Similarly, little change in landslide rates was documented in partial cuts in the *Draft Freshwater Creek Watershed Analysis* (PALCO 2001).

When relating landslide occurrence to changes in vegetation crown cover, studies in Idaho revealed that landslide frequency increases only slightly as overstory crown cover is reduced from 100 percent to 11 percent. However, a notable increase in landslides occurs when crown cover is reduced below 11 percent (Megahan et al. 1978). The Idaho study may not be applicable to the north coast area because of differences in geology and vegetation; nonetheless, it illustrates that in some areas, even a rudimentary root network can increase soil stability on a hillside. The relatively low impact that partial cuts have on landslide occurrence is also supported by the preliminary data from the Simpson MWA pilot watersheds.

Modeling studies of shallow landslides and the effects of different silvicultural systems on root strength suggest that partial cutting results in substantially greater residual root strength and a substantially lower probability of slope failure compared to a clearcut scenario (Krogstad 1995; Schmidt et al. in review; Sidle 1991, 1992; Ziemer 1981a, b). For example, Sidle (1992) reports “A 75 percent partial cut reduced the maximum probability of failure more than five times compared with clearcut simulation." Ziemer (1981a) suggests that under shelterwood removal silviculture, where 70 percent of the original stand is harvested followed by removal of the remaining trees 10 years later, root reinforcement dropped to about 70 percent of its uncut value at 2 to 3 years post harvest, then rose to about 10 percent above the uncut value after about 7 years after harvest as the residual trees quickly expand. About 15 years after the residual trees were harvested, root reinforcement again dropped to about 50 percent of the uncut value. Under a light selection harvest where 20 percent of the trees were cut every 10 years, root strength would decrease by about 3 percent 2 years after harvest, then increase to about 7 percent above the uncut strength as a result of rapid expansion of the roots of the remaining trees. It is important to recognize that the foregoing modeling results are for maximum short-term impact. Long-term impact over complete rotations (i.e., 50 years) would be substantially less.

Table F1-5. Summary of clearcut harvest ratios.

Study	Clearcut Harvest Ratio ($HR_{clearcut}$)
Early Oregon and Washington Studies (summarized in Sidle et al. 1985)	1.9 – 8.7[a]
Oregon Department of Forestry (ODF): 1996 Storm Impacts in Oregon	0.3 – 5.1[b]
Amaranthus et al. (1985)	6.8[c]
North coast TMDL Studies	N/A[d]
PALCO: Bear Creek Sediment Source Assessment (source data from PWA 1998b)	11.5[e]
PALCO: Jordan Creek Sediment Source Assessment (source data from PWA 1999b)	3.0[f]
PALCO: Elk River Sediment Source Assessment (source data from PWA 1999a)	2.3[g]
PALCO: Draft Freshwater Watershed Analysis (source data from PALCO 2001 and PWA 1999)	2.3[h]
Simpson: Hunter Creek (unpublished)	1.0 – 1.7(max)

Notes

a: Includes older harvest practices. Impact of skid trails may not have been factored out. Uncertain whether landslide rates include delivered sediment volume or mobilized sediment volume.

b: Evaluates short-term impact of a large storm, likely not representative of long-term average. Ratios based on delivered sediment volume.

c: Includes older harvest practices.

d: Landslide rates are not normalized by harvest acreage; it is not possible to compute HR from these data.

e. Very high HR value reflects extraordinarily large debris slides that occurred in 1996/1997 in unusual storms on steep terrain shortly after harvest, and may therefore represent worst case scenario. Not all harvest areas in source data are clearcuts, most areas have some history of tractor harvest, and landslide rates are calculated for a 22-year period (1975-1997). Ratio calculated for delivered landslide volume. See also section 4 below.

f. Value represents the period 1975-1997. Not all harvest areas in source data are clearcuts and most areas have some history of tractor harvest. Ratio calculated for delivered landslide volume. See also section 4 below.

g. Value represents the period 1969-1997 (28-year period of record). Not all harvest areas in source data are clearcuts and most areas have some history of tractor harvest. Ratio calculated for delivered landslide volume. See also section 4 below.

h. Value represents the period 1969-1997 (28-year period of record). Not all harvest areas in source data are clearcuts and most areas have some history of tractor harvest. Ratio calculated for delivered landslide volume. The same ratio (to two significant digits) was computed for the period 1988-1997 in a comparison of landslide rates (not sediment delivery volume) in clearcuts and advanced second growth forest. See also section 4 below.

Modeling studies have also shown that understory vegetation often represents an important component of total root cohesion and that the retention of the understory canopy can substantially reduce the probability of slope failure (Schmidt et al. in review; Krogstad 1995; Sidle 1992). Because shallow landslides might opportunistically exploit gaps in the root network when partial harvesting is employed, uniform spacing of trees to minimize “gaps” that might develop in the root network between trees is important to provide the greatest root strength benefit (Burroughs and Thomas 1977; Schmidt et al. in review).

Based on the foregoing, it is appropriate to make adjustments in the clearcut HR to account for different stand densities and overstory retention resulting from partial harvest silviculture. Although the effect of tree roots is highly variable, it was assumed that on a regional level, the impact of harvesting can be related to overstory retention as a surrogate for the completeness of the root network and total root strength. The basic assumption is the more trees retained, the greater the root reinforcement.

Table F1-6 lists assumed corrections factors to the average long-term clearcut HRs for different levels of overstory retention. Vegetation retention assumes uniform or "square spacing" of conifers. Table F1-7 outlines overstory retention under pre- and post-Plan conditions, and forms the basis for estimating sediment delivery. For simplicity, it was assumed that all slopes within the riparian management zone (RMZ) are greater than the critical slope gradient (i.e., > 60 percent for Salmon Creek, > 65 percent for Little River, and >70 percent for Hunter Creek). Although this would overestimate the acreage of ground within the prescription zone, it is not expected to have a large impact on the estimate of sediment delivery. This is because at least 80 percent of the total volume of sediment delivered from streamside landslides is generated from landslides originating on slopes greater than the critical slope gradient.

Table F1-6. Assumed correction factors for different stand densities: overstory retentions compared to clearcut harvesting on shall landslide sediment delivery.

	Expected multipliers for landslide delivery rates relative to clearcutting		
Stand Density	***Lower***	***Most Likely***	***Upper***
85% to 100% Overstory Retention	100%	100%	100%
70% to 85% Overstory Retention	90%	90%	100%
50% to 70% Overstory Retention	60%	70%	80%
Selection Harvest	50%	60%	70%
Hardwood and Understory Retention	25%	35%	45%
Understory Retention	0%	10%	20%
Clearcut	0%	0%	0%

F1.2.1.6 Adjustments for Slope Position

Adjustments are needed to account for expected differences in the impact of harvesting on different MWPZs. MWPZs are broken down into Steep Streamside Slopes (RMZ and SMZ), Headwall Swales (SHALSTAB areas) and "Other" areas. The impact of harvesting is expected to be different in each of these areas. The impact of harvesting is likely slightly less than average along streamside slopes because some of the failures in this area are attributed to undercutting of the hillside by bank erosion and thus are likely to occur independent of vegetation cover. This is not to say that vegetation has no effect on hillslope stability in these areas, but rather the *relative* importance of vegetation in controlling overall hillslope stability along streamside slopes is less compared to the regional average.

Similarly, the impact of harvesting also appears to be slightly greater than average in headwall swale areas. The reported impact of clearcut harvesting in headwall areas in Freshwater Creek was 5.0 times background. The measured impact in Hunter Creek does not appear to be as large. Assumed correction factors for MWPZs are listed in Table F1-8.

Table F1-7. Summary of modeled streamside slope vegetation retention under existing and proposed Plan conditions.

	HPA Group[1]	*Slope Distance (feet)*[2]	*Slope Gradient*	*Name*		*Overstory Retention*	
				Existing	**Plan**	**Existing**	**Plan**
CLASS 1	ALL	0-70	ALL[4]	WLPZ	RSMZ	70%	100%
	ALL	70-100	ALL[4]	WLPZ	RSMZ	70%	85%
	ALL	100-150	ALL[4]		RSMZ	0%	85%
	HUM	150-200	>60%		SMZ	0%	Selc
	KOR, SR	150-200	>65%		SMZ	0%	Selc
	CKLM	150-475	>70%		SMZ	0%	Selc
CLASS 2-2	ALL	0-30	ALL[4]	WLPZ	RSMZ	~70%	100%
	ALL	30-75	ALL[4]	WLPZ	RSMZ	~70%	85%
	ALL	75-100	ALL[4]		RSMZ	0%	85%
	HUM	100-200	>60%		SMZ	0%	Selc
	KOR,SR	100-200	>65%		SMZ	0%	Selc
	CKLM	100-150	>70%		SMZ	0%	Selc
CLASS 2-1[3]	ALL	0-30	ALL[4]	WLPZ	RSMZ	~70%	85%
	ALL	30-70	ALL[4]	WLPZ	RSMZ	~70%	75%
SHALSTAB	ALL	N/A	ALL[4]		SHALSTAB	0%	Selc

Codes

1 HUM Humboldt Bay and Eel River Hydrographic Planning Areas (HPAs)
KOR Mad River, Little River, Redwood Creek, Coastal Lagoons and Interior Klamath HPAs
CKLM Coastal Klamath and Blue Creek HPAs
SR Smith River HPA

2 Assumes 50% sideslopes to calculate horizontal distances
Assumes valley bottom width of 30' for Class 1, 20' for Class 2-2, and 10' for Class 2-1
Watercourse and Lake Protection Zone (WLPZ) distance assumes cable yarding

3 There is no Class 2-2 SMZ in Smith River

4 Assumes all slopes within the RMZ and SHALSTAB areas are greater than the critical slope gradient. This would overestimate the amount of ground in a prescription zone but is unlikely to have a large impact on associated sediment delivery. This is because at least 80% of landslide-derived sediment is from failures on slopes greater than the critical slope gradient.

Table F1-8. Assumed adjustments in the harvest ratio to account for different MWPZs.

	Multiplier Relative to Average		
Mass Wasting Prescription Zone	***Lower***	***Most Likely***	***Upper***
Streamside Slopes (WLPZ, RMZ)	80%	80%	100%
Headwall Swales (SHALSTAB)	100%	150%	150%
Other Areas	100%	100%	100%

F1.2.2 Deep-Seated Landslides

Deep-seated landslides are features with a basal slip plane that extends below the surficial mantle of weathered earth material and into bedrock. They include translational/rotational landslides and earthflows. Translational/rotational slides are characterized by a somewhat cohesive slide mass. In contrast, earthflows are characterized by slow progressive deformation or creep of the slide mass in a semi-viscous, plastic state. Combinations of the two are common. Most deep-seated failures move incrementally, with catastrophic failure being relatively rare.

F1.2.2.1 Methods

Most deep-seated landslides deliver sediment to the stream system by streamside erosion (bank erosion and streamside landslides). Sediment is delivered primarily along watercourses bounding the toes of and, to a lesser extent, by drainage from the interior of the slides. There are few studies, however, that have estimated sediment delivery rates from deep-seated landslides on a landscape scale.

Estimated average long-term deep-seated landslide delivery volumes were estimated for Simpson ownership within four pilot watersheds: Salmon Creek, Little River, Upper Mad River and Hunter Creek. It is assumed that sediment delivery from deep-seated landslides can be estimated by multiplying the length of stream channel bordering the toe and lateral margins of the slides by the average depth of the failure (approximate height of banks/gully walls) and average movement rate (Equation 4).

Equation 4: SED_{tot} **= Stream Length * Slide Depth * Rate of Slide Movement**

Because of the lack of data, estimates of sediment delivery from deep-seated landslides should be viewed as approximate. Moreover, because some of the sediment from deep-seated slides is a result of small shallow landslides (i.e., debris flows, debris slides, and channel bank failures) occurring along the toe of the larger landslide, it is likely that some “double counting” of sediment will occur when the results of deep-seated landslides are combined with shallow landslide volumes. At present, however, there is little data to differentiate between the two sediment sources.

The impact of harvesting on sediment delivery from deep-seated landslides was evaluated based on a review of published and unpublished reports, and using professional judgment.

F1.2.2.1.1 *Landslide Acreage*

Deep-seated landslides in Salmon Creek, Little River, and Hunter Creek were mapped from the historical set of aerial photographs using standard methodologies. Pertinent data associated with each mapped landslide were recorded into a database for further analysis. This information included landslide type (i.e., translational landsliding and earthflows), certainty of identification, and inferred level of activity. Limited field verification of mapped landslides was undertaken in Hunter Creek. Additional fieldwork in the other watersheds is pending.

The Upper Mad River pilot watershed is located upstream of Boulder Creek and encompasses the Boulder Creek Planning Watershed. Identification of deep-seated landslides in the Upper Mad River pilot watershed was initially based on published reconnaissance-level landslide mapping by the California Department of Water Resources (CDWR) (1982). The Mapping by CDWR revealed that roughly a third of the watershed is underlain by deep-seated failures. However, discussions with Simpson forestry staff revealed that the mapping of deep-seated landslides in pilot watershed by CDWR likely underestimates the landslide acreage and that as much as 60 percent of the watershed may be underlain by deep-seated landslides. For the purpose of this study it was assumed that 60% of the pilot watershed is underlain by deep-seated landslides.

CDWR (1982) did not differentiate between the two different classes of deep-seated landslides (translational landslides and earthflows). Review of aerial photographs and discussions with Simpson staff indicate that roughly 70 percent of the deep-seated landslides in Upper Mad River pilot watershed are earthflows.

Landslide acreage for each of the studied watersheds is summarized in Table 9. With the exception of the Upper Mad River pilot watershed, low and mid-range values were based on measured acreage for definite and probable landslides. For Little River and Salmon Creek, upper range values included acreages for questionable landslides. For Hunter Creek, questionable landslides were not mapped; therefore, upper range values were estimated. For Upper Mad River pilot watershed, the lower range was based on CDWR (1982) mapping; mid- and upper ranges were estimated based on qualitative field and air photo observations by Simpson staff.

F1.2.2.1.2 *Landslide Activity*

The range of landslide activity is classified as historically active, dormant, or relic. A slide with documented movement within the past 0 to 100 years (roughly the time frame of modern harvesting practices) is classified as a historically active landslide. In the field, these slides are recognized by some or all of the following features: recent scarps or cracks (>6 inches), leaning second growth trees, or sag ponds and/or offset road prisms (see appendix B for a more complete discussion). Slides with very low rates of movement that do not show signs of obvious movement within the past 50 to 100 years are classified as dormant or relic. It is assumed that harvest activities have the greatest relative impact on the more active slides and that impacts on dormant or relic slides are negligible.

It is usually not possible to accurately evaluate the level of deep-seated landslide activity using air photos alone. Therefore, estimates of slide activity were based on limited field observations, discussions with Simpson staff, review of completed geologic reports for timber harvesting plans (THPs), and professional opinion. Slide activity for each pilot watershed and landslide type is summarized in Table F1-9.

Table F1-9. Deep-seated landslide acreage, stream channel length, and level of activity.

Watershed		Range	TRANSLATIONAL/ROTATIONAL LANDSLIDE Slide Acres	Watercourse Length (miles)	Activity % of Slide Class: *Historically Active*	*Dormant/ Relic*	EARTHFLOW LANDSLIDE Slide Acres	Watercourse Length (miles)	Activity % of Slide Class: *Historically Active*	*Dormant/ Relic*
Salmon Creek		Lower	2880	11.7	5%	95%	61	0.6	5%	95%
		Most Likely	2880	11.7	10%	90%	91	0.6	15%	85%
		Upper	3447	14.5	20%	80%	91	1.1	25%	75%
Little River		Lower	6271	30.7	5%	95%	119	0.9	5%	95%
		Most Likely	6271	30.7	5%	95%	119	0.9	15%	85%
		Upper	7595	39.6	15%	85%	347	2.4	25%	70%
Upper Mad River[1]	**Conifer**	Lower	320	1.6	20%	80%	746	3.7	?	?
		Most Likely	575	2.8	20%	80%	1343	6.6	20%	80%
		Upper	815	4.0	30%	70%	1902	9.4	?	?
	Grassland/ Hardwood	Lower	594	3.1	65%	35%	1385	7.2	?	?
		Most Likely	1069	5.5	65%	35%	2493	12.9	65%	35%
		Upper	1514	7.8	75%	25%	3532	18.2	?	?
Hunter Creek		Lower	338	3.8	5%	95%	0	0	N/a	N/a
		Most Likely	338	3.8	5%	95%	0	0	N/a	N/a
		Upper	500	5.7	15%	85%	0	0	N/a	N/a

1: 49% of the ground in Upper Mad River pilot watershed is grassland or native oak and is not proposed to be harvested. Moreover, disproportionate percentage of the landslides in the watershed are located in these areas. Therefore, the conifer ground has been delineated out separately from grassland and oak.

About half of the Upper Mad River pilot watershed (49 percent) is grassland or native hardwood. Fifty one percent of the area is conifer. Simpson staff report that deep-seated landslides underlie about 60 percent of the pilot watershed, and that the slides, and particularly the more active earthflows, are preferentially located in the grassland and hardwood areas (65 percent versus 35 percent). As a result, sediment delivery from grassland/hardwood areas is significantly higher in comparison to conifer areas, and is considered the dominant source of sediment.

Sediment delivery from grassland/hardwood areas was evaluated separately from conifer ground. This is because 1) timber harvesting is not expected to occur in the grassland/hardwood areas and therefore there would be no management-derived sediment from harvesting occurring in these areas, and 2) the grassland/hardwood areas deliver a disproportionate amount of sediment to watercourses because of the high proportion of active earthflows, substantially overwhelming management-derived sediment generated from the conifer ground.

F1.2.2.1.3 Stream Channel Length

Sediment delivery from deep-seated landslides is assumed to correlate to the length of all watercourses bounding the toes and lateral margins of these features. This may slightly underestimate the length of stream channels delivering sediment from earthflows because it would not account for sediment eroded from streams draining the interior of the slide. Work by Kelsey (1977) indicates that well-developed gully systems on active earthflows could produce more sediment than erosion along the toe of the slide. However, this is in contrast to work presented by Nolan and Janda (1995) that suggests that less than 10 percent of the measured sediment leaving earthflows was delivered by fluvial processes operating in the small tributaries in the interior of the slide.

The length of streams bordering the toe and lateral margins of large landslides in Salmon Creek, Little River, and Hunter Creek were measured from watercourse maps available in Simpson's GIS database. Upper, mid-, and lower range values were based on the degree of certainty of landslide identification. The length of watercourses bounding the toe of large landslides in the Upper Mad River pilot watershed is not available at present and therefore was approximated based on average stream lengths measured in the other three pilot watersheds. Estimated stream lengths bordering landslides for all four pilot watersheds are summarized in Table F1-9.

F1.2.2.1.4 Slide Depth

The depth of deep-seated landslides is variable across the landscape depending on landslide size, local terrain, and processes. Swanston and others (1995) reported shear depths along earthflows and block glides in Redwood Creek to be between 12 and 40 feet. Past studies in the Eel River Basin found an average height of earthflow toes of 30 feet (SWS 1999; USACE 1980; USDA 1970).

Professional experience suggests that the depth of deep-seated translational landslides can vary considerably, from between 10 to greater than 100 feet. In general, translational landslides are much deeper than earthflows. An average slide depth subject to toe erosion of 40 feet was assumed for translational landslides, and 25 feet for earthflows. Upper and lower bounding depths were estimated at 10 feet deeper and 10 feet shallower, respectively.

F1.2.2.1.5 *Slide Movement Rates*

Deep-seated slide movement is highly variable and episodic, depending on storm history, underlying geology, and slide process. At present, very limited data are available for estimating average long-term movement rates of deep-seated landslides in northern California. In this preliminary analysis, the average creep rates on the west side of Redwood Creek was used.

Swanston and others (1995) monitored several sites in the Redwood Creek Basin to quantify natural creep and earthflow rates. A concerted effort was made to avoid areas of current, clearly definable active earthflows; however, Simpson's review suggests that several of these sites appear to have been on slides that may have been classified as historically active under the Plan's slope stability measures.

Progressive earthflows on the east side of Grogan Fault in Redwood Creek that are underlain by pervasively sheared sandstone and mudstone have movement rates from 3.0 to 131 mm/yr. These rates are assumed to be representative of active earthflows on Simpson property. Sites dominated by block slides displayed movement rates ranging between 2.5 and 16.4 mm/yr. These rates are assumed to be representative of active translational landslides on Simpson property. Progressive creep rates on the west side of the Grogan Fault in Redwood Creek that are underlain by sheared and foliated schists range between 1.0 to 2.5 mm/yr. These rates are assumed to be representative of natural soil creep and of dormant earthflows and translational landslides.

Regional data sources on active grassland earthflows report much higher average movement rates of 2.4 to 4 m/yr [Van Duzen River Basin (Kelsey 1980)] and 4 m/yr [Eel River Basin (Scott 1973, referenced in SWS 1999)]. It is doubtful that these rates are representative of all earthflows, because in these studies there was a bias toward monitoring the most active slides. Moreover, the rates are for earthflows in open grassland areas and not representative of forested slides where rates are much lower to support a timber stand.

Limited field reconnaissance of the deep-seated landslides in Hunter Creek, Little River, and Salmon Creek revealed that most of the large slides are dormant or relic, and have very low rates of movement. Where movement is observed, it is typically manifested by small discontinuous ground cracks along the head of slide blocks. Lobate toes or zones of accumulation are rarely present.

Estimated deep-seated landslide rates are summarized in Table F1-10. High and low range values are based primarily on data presented by Swanston and others (1995). Most likely values are from published data and were modified based on professional judgment. Most of the slides on Simpson property do not appear to be as active as those studied in the professional literature, as is indicated by the simple fact that most roads crossing large landslides are not disturbed by slide movement. Therefore, the most likely rate of movement on forested slides is assumed to be lower than the published average. Because few measurements of deep-seated landslides in northern California exist, these rates should be viewed as very approximate. Additional research is required to refine these numbers and to increase the confidence in their accuracy.

Table F1-10. Average deep-seated landslide slip rates.

Slide Type	Activity	Average Slip Rate (mm/yr)		
		Lower	*Most Likely*	Upper
Translational/Rotational Landslide	Historically Active	2.5	4	16.4
	Dormant/Relic	0.5	2	2.5
Earthflow Landslide	Historically Active	3.0	20	130
	Dormant/Relic	0.5	2	2.5

F1.2.2.1.6 *Harvest-Derived Sediment*

Published work concerning the effects of timber harvesting (i.e., logging) on deep-seated landslide activity is sparse. Deep-seated landslides can theoretically be affected by hydrologic changes associated with reduced evapotranspiration and reduced canopy interception during rainstorms (California Department of Conservation 1997). Descriptions of conditions affecting deep-seated landslides have been discussed briefly by Swanston and Swanson (1977), Sidle and others (1985), and Miller and Sias (1998), but few studies exist that quantitatively address how timber harvesting affects deep-seated landslide stability.

Short-term increases in ground displacement following clearcutting have been documented on an active earthflow in southwestern Oregon (Swanston et al. 1988; Swanston 1981). Swanson and others (1988) report substantial short-term increases in ground displacement rates beginning the second year after harvesting, with movement rates returning to background rates in the third year following harvest. Post-harvest rates are reported to be more than two to four times the pre-harvesting rate (Swanston 1981). The short-term nature of the increase was probably the result of dry conditions and the small regolith blocks involved in accelerated displacement. In contrast, work by Pyles (1987) on the Lookout Creek earthflow in the central Cascades in Oregon concluded that timber harvesting was unlikely to induce a large increase in movement, primarily because the slide was well-drained.

Miller and Sias (1998) modeled the effect of timber harvest on groundwater conditions and slope stability of a large, deep-seated landslide in glacial lacustrine sediments adjacent to a large river channel in the western Washington Cascades. They predicted that timber harvest in the groundwater recharge area of the landslide would produce very small decreases in the factor of safety, suggesting that harvest would contribute to landslide movement only if the landslide were at or near the threshold of stability. This suggests that active deep-seated landslides are most likely to be affected by harvest-induced changes in groundwater, while inactive and dormant slides are less likely to be affected.

There may be some impact from clearcut harvesting on sediment delivery from deep-seated landslides; however, to what extent is difficult to quantify at present. For the purpose of this study it was assumed that harvesting will have an impact only on historically active slides and negligible impact on dormant or relic features, and that the level of impact will be proportional to the level of harvest. It was assumed that clearcutting the entirety of the slide will increase the rate of slide movement by a factor of two on historically active slides, diminishing linearly to pre-harvesting rates in 30 years. Based on this assumption, the average increase in deep-seated slide movement over the 50-year period of the Plan would be 1.3 times background if the slide were entirely clearcut.

It is assumed that the impact of harvesting on deep-seated slide activity is a function of percentage of canopy retained on a slide, which in turn is expected to be directly related to evapotranspiration rates. In this analysis, it was assumed harvesting will take place on the entirety of a slide. This is considered a worst-case scenario because many slides exceed the maximum 40-acre size of clearcuts under current California Forest Practice Rules, and harvest blocks would rarely have boundaries that coincide with slide boundaries. It is unlikely that all of a slide would be harvested at any given time; therefore, the impact of the harvest is expected to be less than modeled.

Under current conditions, vegetation retention results primarily from the required 70 percent overstory canopy retention along Class I and Class II WLPZs under Simpson's Owl HCP. The amount of vegetation retained on any given slide is quite variable, depending on the density and class of watercourses transecting or bordering the slide, existing stand density and composition, and silviculture prescriptions. Additional retention has often been provided on the more active slides in the interest of slope stability. On average, however, it is estimated that a minimum of 5 percent to 10 percent of the total canopy cover is currently retained on deep-seated landslides. Therefore, the sediment delivery under existing management conditions is estimated to be about 1.28 times background.

Under proposed Plan prescriptions, vegetation retention on historically active slides will be primarily from RMZ, slope management zone (SMZ), and SHALSTAB areas. Additional protection is provided by 25-foot no-cut zones along historically active toes and scarps (see Section 5.2). The proposed Plan prescriptions are estimated to be 15 percent effective in reducing the management component of sediment delivered from deep-seated landslides relative to existing conditions.

F1.2.3 Results

This section presents the results of a modeling effort designed to estimate average long-term landslide sediment delivery volumes to watercourses from the historical road network and from various silvicultural treatments. As previously mentioned, the information presented below is specific to sediment delivery from shallow and deep-seated landslides; sediment delivery from other processes, such as surface erosion, channel bank erosion, or erosion of watercourse crossings is not addressed in this appendix. The results represent long-term totals for each pilot watershed.

Average long-term sediment delivery volumes from shallow and deep-seated landslides were estimated for both existing and proposed Plan conditions for three pilot watersheds: Salmon Creek, Little River, and Hunter Creek. Sediment delivery from deep-seated landslides was also estimated in the Upper Mad River pilot watershed. Work in Ryan Creek and Tectah Creek was used to examine the effects of road building on landslides, but could not be used to examine the effects of silviculture at the time of the statistical analysis. Results from shallow-seated landslides are reported separately from deep-seated landslides.

F1.2.3.1 Shallow Landslide Results

Road-related and non-road-related shallow landslides were evaluated separately from one another. Shallow landslide data was gathered primarily from aerial photograph interpretation. Landslides that occur near roads were assumed to have been triggered by road construction (i.e., grading activity). Landslides in harvest areas were not assumed to be caused by harvest effects (e.g., loss of root reinforcement). Instead, the proportion of landslides in harvest areas that were likely triggered by harvest effects is estimated using the harvest ratio HR(n) (see Equation. 3). A spatial analysis of non-road- related landslides assesses the proportion of slides that originate in different Plan MWPZs. Finally, the expected sediment reductions resulting from the Plan's mass wasting prescriptions pertaining to harvest effects were estimated.

F1.2.3.1.1 Road-Related Landslides

Estimated shallow landslide delivery volumes from shallow landslides resulting from all grading activities are summarized in Tables F1-11 and F1-12. The data are presented in two forms. In Table F1-11, the average sediment delivery from shallow landslides is summarized for the entire (long-term) photoperiod. However, these values may not be representative of recent conditions because of improvements in road management and increased road densities. The relative impact of grading is most likely best represented by a more recent (1997) photoperiod, covering a roughly 7- to 12-year time span (Table F1-12). A summary of the relative percentage of each grading activity to the total volume of shallow landslide sediment delivered to watercourses is summarized in Table F1-13.

Table F1-11. Shallow landslide delivery from the long-term period of record.

Watershed	Period of Record (years)[1]	# of Shallow Landslides	Sediment Delivery (cy)				
			Total	Road and Landing	Skid Trail	Other[2]	Non-Grading[3]
Salmon Creek	58	756	156732	40398	1174	78	115082
Ryan Creek	46	1260	27903	6893	1248	1100	18663
Little River	64	419	139457	20230	2546	5714	110966
Hunter Creek	54	598	494523	216584	90167	0	187772
Tectah Creek	--	--	--	--	--	--	--

Notes
1. Landslides visible in the earliest set of air photos are assumed to have occurred within the previous 15 years based on the level of revegetation
2. Other includes failures along the old railroad lines and failures from non-harvesting-related grading activities.
3. Non-grading summarizes sediment not generated from grading activities

Table F1-12. Shallow landslide delivery from the 1997 photoperiod.

			Sediment Delivery (cy)				
Watershed	**Period of Record (years)**	**# of Shallow Landslides**	**Total**	**Road and Landing**	**Skid Trail**	**Other[1]**	**Non-Grading[2]**
Salmon Creek	6	329	55515	9241	333	0	45941
Ryan Creek	7	152	10014	3967	527	1100	4420
Little River	10	34	14525	5844	0	0	8681
Hunter Creek	13	301	29497	9729	1680	0	18088
Techtah Creek	?[3]	631	104121	18589	550	0	84982

Notes
1. Other includes failures along the old railroad lines and failures from non-harvesting-related grading activities.
2. Non-grading summarizes sediment not generated from grading activities
3. This period of record is uncertain because only one set of aerial photographs (1997) was examined

Table F1-13. Percentage of each grading activity relative to total shallow landslide delivery.

		Long-Term Period of Record			1997 Photoperiod		
Watershed	**Acreage**	Roads and Landings	Skid Trails	Other[1]	Roads and Landings	Skid Trails	Other[1]
Salmon Creek	7889	26%	1%	0%	17%	1%	0%
Ryan Creek	7590	25%	4%	4%	40%	5%	11%
Little River	28755	15%	2%	4%	40%	0%	0%
Hunter Creek	10126	44%	18%	0%	33%	6%	0%
Tectah Creek	12675	-	-	-	18%	1%	0%

Note
1 Other includes failures along the old railroad lines and failures from non-harvesting-related grading activities.

Roads and Landings

The data suggest that roads and landings (combined) are responsible for the majority of landslide-derived sediment that is generated from grading activities. Skid trail failures, in comparison, are infrequent. For the long-term period of record, landslide-derived sediment from roads and landings ranges between 15 percent and 44 percent of the total sediment delivered from shallow landslides. As expected, the impact of roads is greatest in the steeper gradient watersheds (e.g., Hunter Creek) and less in the lower gradient watersheds (e.g., Little River). In the 1997 photoperiod, road and landing failures comprise 17 percent to 40 percent of the shallow landslide delivery.

A decrease in the relative importance of road-related failures was observed in Salmon Creek and Hunter Creek, which have inherently high rates of landsliding, even though road densities have increased in both watersheds. The decrease in road-related failures (both volume and size) in these watersheds may be attributed to improvements in forest practices and the implementation of Forest Practice Rules over the past 25 years. Because of these regulations, new roads are more likely to be located on more stable ridge tops that have much lower rates of landsliding rather than less stable mid to lower slope areas, and constructed using end-haul construction techniques when steep slopes cannot be avoided. New roads and reconstructed (repaired) roads also have restrictions on fill depth, compaction of fill, more frequent cross drain and waterbar spacing, and increased culvert sizes. Steep ground is commonly cable yarded rather than tractor yarded, resulting in much less ground disturbance.

An increase in road and landing failures was observed in Ryan Creek and Little River; however, both of these watersheds have inherently low rates of slide activity. In both of these watersheds, it is believed the relative importance of shallow landslide processes to the total sediment budget is less than in the steeper watersheds such as Hunter Creek and Salmon Creek. In Little River, and to a lesser extent in Ryan Creek, it is also difficult to draw definitive conclusions on changes in sediment delivery over time because of the relatively small sample size in the 1997 photoperiod (see Table F1-2), and because much of the observed sediment from that period was generated from just a few slides.

Preliminary results show that mean landslide volumes for road and landing failures have decreased over time from 400 cy/slide in the long-term photoperiod to 275 cy/slide in the 1997 photoperiod. Additional work would be required to further evaluate whether the reduction is a result in improved road management or simply a product of storm history.

Skid Trails

Skid trail-related failures comprise a substantially smaller portion of the total volume of sediment delivered from landslides compared to roads and landings (Table 14). In the long-term period of record, skid trail failures comprise between 1 percent and 18 percent of the total volume of sediment delivered from shallow landslides. Additional unquantified sediment would be generated from surface erosion of the skid trail. The majority of this impact resulted from the early failures in the Hunter Creek watershed. Excluding Hunter Creek, the measured long-term impact of skid failures averages less than 2 percent of the total shallow landslide delivery volume.

In the 1997 photoperiod, skid trails comprise 0 percent to 6 percent of the landslide sediment delivered to watercourses. Mean landslide delivery volumes for skid trail failures have decreased from a long-term average of 275 cy/slide to a recent short-term average of 57 cy/slide. Again, the decrease in the size of slide may be due to changes in forest practices, such as a greater reliance on cable yarding rather than tractor yarding, or be a product of storm history. Skid trail failures were also substantially smaller than road failures, probably because skid trails tend to have smaller fill prisms.

Comparison of Road and Skid Trail Failures

One of the goals of this analysis was to gain insight into the relative importance of road failures compared to skid trail failures. In other words, how important are road failures to the total sediment delivery compared to skid trail failures? This is an important question when allotting resources to address legacy problems.

Comparing Table F1-14 summarizes the relative importance of road failures normalized against skid trail failures. This simple ratio was generated by dividing the volume of sediment delivered from road failures by the volume of sediment delivered from skid trail failures. The data is based on total landslide sediment delivered and has not been normalized against length of road or skid trail.

Table F1-14. Summary of sediment delivery from road and landing failures normalized against skid trail failures.

	Long-Term Period of Record		1997 Photoperiod	
Watershed	Road and Landing	Skid trail	Road and Landing	Skid trail
Salmon Creek	34.4x	1x	27.7x	1x
Ryan Creek	5.5x	1x	7.5x	1x
Little River	7.9x	1x	∞	1x
Hunter Creek	2.4x	1x	5.8x	1x
Tectah Creek	--	1x	33.8x	1x
AVERAGE[1]	**3.1X**	**1X**	**13.4X**	**1X**

Note
1 Average is calculated from the sum of all inventoried landslides with no weighting given to watershed area.

The ratio of road-derived sediment to skid trail-derived sediment is quite variable between watersheds. Much of this variably is likely attributed to relative differences in road and skid trail densities in each watershed. Nonetheless, the data do indicate for all watersheds there has been a sustainable decrease in sediment delivery from skid trails in comparison to road and landing failures (Table F1-14). One possible explanation for the measured reduction is the stricter forest practice rules that limit tractor yarding on slopes steeper than 65 percent. By avoiding tractor operations on such slopes, the potential for new skid trails to trigger slides has been greatly reduced, as documented in Table F1-14.

It is important to point out that the results in Table F1-14 are based on sediment volumes. A similar analysis based on frequency (number) of landslides would reveal that roads generate two to four times as many landslides as skid trails for both the long-term period of record and 1997 photoperiod, respectively. The difference between the analysis based on sediment volume and frequency of slides is a product of larger landslides occurring on roads compared to skid trails.

The results based on frequency of landslides are consistent with the results of the California Department of Forestry and Fire Protection's (CDF's) Hillslope Monitoring Program (1999), which documented 4.5 times as many large debris slides occurring on roads and landings compared to skid trails. Sediment volumes were not presented in the CDF report. The Hillslope Monitoring Program was based on a comprehensive field evaluation of erosion features identified on 292 random road transects (53 miles), 26 skid trail transects (33 miles), and 291 landing transects.

There are several possible explanations for the lower rate of skid trail failures compared to road failures. First, the majority of shallow landslides occur on slopes over 60 percent to 65 percent. This is ground that under the Forest Practice Rules must be cable or helicopter yarded rather than tractor yarded. By avoiding such steep slopes, the potential for future skid trails to trigger shallow landslides has been greatly diminished. Because Simpson began to employ cable yarding techniques on much shallower slopes than many of the other timber companies, the effect of skid trails may be much less than for other areas. Roads, on the other hand, often cannot avoid steep ground.

In addition, the landslide inventory suggests a reduction in skid trail failures compared to road and landing failures over time. One explanation for this is that many of the legacy skid trails that were located on steep slopes have since failed and comparatively few skid trails are constructed on steep slopes under present management practices. Many of the skid trail failures observed in the 1997 set of aerial photographs are associated with legacy skid trails. To address the potential for future skid trail failures, Simpson proposes to exclude tractor operations on slopes greater than 45%.

The lower rate of skid trail failures in relation to road failures may also be a product of the differences in the amount of ground disturbance required to cut a skid trail vs. a road. The average width of a skid trail is about 10 feet compared to a 20+ width for roads. A 10-foot-wide skid trail contouring across a 65 percent side slope would displace 0.7 cy of earth per foot of skid trail, resulting in a 1.8-foot-deep fill prism. A skid trail descending the same hillside at a steep gradient would generate much less fill. In comparison, a 20-foot-wide haul road contouring across the same slope on balanced cut and fill would generate four times as much sidecast, with a fill prism of over 4 feet. Moreover, thicker fill prisms on roads often exist at watercourse and swale crossings, which is where many of the larger fill failures originate.

F1.2.3.1.2 Harvesting-Related Sediment

Estimates of sediment delivery from shallow landslides are based primarily on a review of aerial photographs. The harvesting components (tree removal alone) of shallow landslide sediment delivery volumes were estimated for three pilot watersheds (Salmon Creek, Little River, and Hunter Creek) by applying non-road-related shallow landslide sediment delivery volumes measured from aerial photographs to several empirical models that relate management activities to increased erosion rates. Harvesting-related sediment delivery was estimated for existing and proposed Plan conditions. The results of this modeling effort are summarized in Tables F1-15 and F1-16.

Table F1-15. Non-road-related shallow landslide sediment delivery per mass wasting prescription zone under existing conditions.

			MWPZ			
WATERSHED	**ACRES**	**RSMZ Cy/yr %**	**SMZ cy/yr %**	**SHALSTAB cy/yr %**	**NONE cy/yr %**	**TOTAL cy/yr %**
Salmon Creek	7889	798	2	268	916	1984
		40.2%	*0.1%*	*13.5%*	*46.2%*	
Little River	28755	768	31	195	740	1734
		44.3%	*1.8%*	*11.2%*	*42.7%*	
Hunter Creek	10126	235	697	1190	1355	3477
		6.8%	*20.1%*	*34.2%*	*39.0%*	

Table F1-16. Non-road-related shallow landslide sediment delivery under existing and proposed Plan conditions.

WATERSHED	ACRES	BACKGROUND		HARVESTING		TOTAL NON-ROAD		Reduction in Management Component
				Existing Conditions	Proposed Plan	Existing Conditions	Proposed Plan	
		Cy/yr	Cy/ac/yr	Cy/yr	Cy/yr	Cy/yr	Cy/yr	%
Salmon Creek	7889	1174	0.15	810	523	1984	1698	35%
Little River	28755	1054	0.04	680	424	1734	1478	38%
Hunter Creek	10126	1693	0.17	1785	1109	3477	2802	38%

In Salmon Creek and Little River, non-road-related sediment delivery in the RMZ prescription areas is significantly greater than in SMZ or SHALSTAB areas. This contrasts notably with Hunter Creek, where the majority of sediment was generated from failures within SHALSTAB and SMZ areas. There are several possible reasons to account for the higher rate of sediment delivery in the Hunter Creek SMZ and SHALSTAB areas compared to either Salmon Creek or Little River. First, the majority of sediment in Hunter Creek is generated by very large slides that extend well outside the RMZ and therefore are not assumed to be controlled by conditions within the RMZ. Similar large slides are not as prevalent in either Little River or Salmon Creek, possibly because slopes are generally not as steep. Second, the watercourse mapping in Hunter Creek is relatively old and many Class III drainages in that drainage would be reclassified as Class II watercourses under current rules. In the analysis, this results in fewer RMZ slides than probably actually exist. Lastly, the terrain in Hunter Creek is much steeper than in either Little River or Salmon Creek, which results in a greater percentage of SHALSTAB areas.

The data also reveal that a significant volume of sediment (39 percent to 46.2 percent) is generated from failures located outside of any MWPZ. This might be partly explained by the inherent limitations of the existing 10-m digital elevation models (DEMs) used to generate slope gradients in the GIS. The DEM tends to underestimate slope gradients, especially in deeply incised drainages. Because this analysis relies on aerial photo interpretation and topographic and map data, fewer prescription zones may have been mapped compared to field-based mapping, potentially resulting in an underestimate of associated sediment delivery. Nonetheless, the results illustrate the inherent difficulties in identifying landslide hazard areas solely from a remote analysis. A greater level of prediction would be achieved based on site-specific field review.

Based on the HR equation (Equation 3) background, sediment delivery from shallow landslide processes averages between 0.04 and 0.17 cy/ac/year (see Table 16). The higher sediment delivery in Salmon and Hunter creeks likely results from steep streamside slopes (Salmon Creek) and headwall swale areas (Hunter Creek). Background sediment delivery rates in Little River are relatively low in comparison because of the relatively shallow slopes found throughout most of the watershed.

Harvesting (tree removal) over a 50-year period is estimated to be responsible for 39 percent to 51 percent of the total non-road-related shallow landslide sediment delivered to watercourses under existing conditions (1.6 to 2.1 times increase relative to undisturbed or advanced second growth forests). Implementation of the proposed Plan measures is expected to reduce the harvesting-related component of sediment by at least 35 percent to 38 percent. Significantly more sediment savings will be achieved by road upgrades (see Appendix F2).

F1.2.3.2 Deep-Seated Landslide Results

Estimated annual sediment delivery volumes from deep-seated landslides are summarized in Table F1-17. These estimates are based on the deep-seated landslide sediment source model presented earlier in this report. Average long-term sediment delivery from deep-seated landslides is estimated to range between 0.02 cy/ac/yr in Hunter Creek, where few landslides are present, to 0.44 cy/ac/yr in the Upper Mad River pilot watershed, where much of the watershed is underlain by deep-seated landslides, many of which are considered active.

In the Upper Mad River pilot watershed, sediment delivery rates are significantly higher in the oak and grassland areas compared to conifer ground. This is attributed to the much higher percentage of earthflows located in this terrain. In general, the open grassland and hardwood areas are less stable than the conifer ground, and many grassland areas are too active to support viable conifer forest. The impact of harvesting in the grassland areas is negligible because few trees grow in these areas.

For the purpose of this study it is assumed that the impact of harvesting is directly proportional to the amount of vegetation retained on a historically active slide. Based on this assumption, harvesting (tree removal) is estimated to be responsible for an increase of from 1.02 to 1.17 times the amount of sediment delivered by deep-seated landslides in conifer areas under existing conditions (harvesting is generally not proposed in grassland and hardwood areas). This may be an overestimate of the impact of harvesting, because it assumes that the slide block is located wholly within a harvest unit. More often, only a portion of a slide is cut at any given time.

Table F1-17. Deep-seated landslide sediment delivery under existing and proposed Plan conditions.

WATERSHED		ACRES	BACKGROUND		HARVESTING		TOTAL NON-ROAD (Background + Harvesting)		Assumed Reduction in Management Component
					Existing Conditions	Proposed Plan	Existing Conditions	Proposed Plan	
			cy/yr	cy/ac/yr	cy/yr	cy/yr	cy/yr	cy/yr	%
Salmon Creek		7889	706	0.09	42	35	748	741	15%
Little River		28755	1722	0.06	56	48	1778	1770	15%
Upper Mad River	Conifer	4658	767	0.16	135	115	902	882	15%
	Grasslands/ hardwoods	4475	3309	0.74	0	0	3309	3309	N/a
Hunter Creek		10126	204	0.02	5	5	209	209	15%

The variability in landslide delivery between watersheds is primarily a function of the percentage of the watershed underlain by historically active landslides, particularly earthflows. Data indicate that sediment delivery rates on earthflows are much higher than for translational/rotational rockslides. Implementation of the proposed Plan measures is assumed to reduce the management component of sediment by at 15 percent.

Roads can affect the stability of deep-seated landslides by removing toe support and by concentrating and diverting runoff. However, at present there is little data on Simpson property to address the significance of roads on deep-seated landslide sediment delivery. Moreover, there are very few published studies that have addressed this question. This analysis does not separately address sediment delivery related to road construction on deep-seated landslides. It was assumed that any sediment delivered by deep-seated landslides as a result of roads is already indirectly addressed in either the shallow landslide section of this report or in the road inventory section presented in Appendix F2.

F1.2.3.3 Summary of Results

Road-related shallow landslides occurring in the most recent photoperiods range from 17 percent to 40 percent in the five watersheds investigated, with a watershed mean value of about 30 percent. The extent to which the Plan measures are expected to reduce road-related shallow landslides is discussed in Appendix F2.

Harvest-related shallow landslides were estimated to constitute 39 percent to 51 percent of non-road-related shallow landslides for the three watersheds investigated. The proposed Plan measures (MWPZs and associated prescriptions) are expected to reduce harvest-related shallow landslides by 36 percent to 44 percent. Shallow landslides occurring outside of MWPZs account for 39 percent to 46 percent of sediment delivery.

Timber harvest on deep-seated landslides is calculated (based on estimates) to increase sediment delivery to streams by 2 percent to 17 percent. Plan measures for harvest on deep-seated landslides are expected to be only 15 percent effective, resulting in small declines in harvest-related sediment delivery from deep-seated landslides. However, management-related sediment from deep-seated landslides is not considered to be a large component of the total volume of sediment delivered by landslides.

Appendix F2. Road-Related Sediment Source Inventory of High and Moderate Priority Sites

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F2.1 INVENTORY METHODS

Since 1997, over 40 mi^2 of Simpson's forest lands have been inventoried for on-going and potential sediment sources that have the potential to deliver eroded sediment to stream channels. The inventories, funded by the CDFG Restoration Grant Program and by Simpson Resource Company, identified road-related sediment sources in the biologically high priority watersheds through a two-step process of air photo analysis and field inventories. An analysis of historic aerial photos was conducted to identify all the roads that were ever constructed in each of the inventoried watersheds, whether they were maintained and driveable, or abandoned and overgrown with vegetation. When possible, historic photographs from a number of years (perhaps one or two flights per decade) were selected to "bracket" major storms in the watersheds. This analysis led to the construction of detailed land use history maps for the watershed, specifically including road location and road construction history.

Field inventories and site analyses were employed to identify and quantify future road-related sediment sources and to develop defensible plans for erosion prevention in each of the five watersheds. From north to south these included Rowdy Creek (17.1 mi^2), McGarvey Creek (7.0 mi^2), Redwood Creek (11.0 mi^2), Little River (35.0 mi^2) and Salmon Creek (6.8 mi^2). The two most important factors used to evaluate the risk of road-related sediment delivery in these basins included: 1) an assessment of the probability of erosion or failure at all "susceptible" points along the alignment (termed "erosion potential") and 2) an estimation of the volume of potential sediment delivery to a stream (if no preventive work is done). The data that were collected were then employed to develop a defensible, cost-effective plan for mitigating or preventing road-related sediment delivery in each basin.

For the detailed field assessment, acetate overlays were attached to 9" x 9" aerial photographs and used to record site location information as it is collected in the field. A computer database (data form) was then completed for each site of potential sediment delivery identified in the field. Only sites of future sediment delivery were included in the inventory. Detailed inventories of all maintained and abandoned road systems were used to identify and determine future contributions of sediment to the stream system, and to define cost-effective treatments.

The most common sediment source sites generally included watercourse crossings, potentially unstable road and landing fills, and "hydrologically connected" road segments which exhibit surface erosion and sediment delivery. Once sites were identified and quantified, prescriptions for erosion control and erosion prevention were developed for each major source of treatable erosion that, if left untreated, would likely have resulted in sediment delivery to a stream. Prescriptions developed during the field inventory included types of heavy equipment needed, equipment hours, labor intensive treatments required, estimated costs for each work site and quantitative estimates of expected sediment savings.

F2.2 ROAD-RELATED SEDIMENT SOURCES

Three geomorphic processes are responsible for sediment delivery from roads. These include: 1) chronic surface erosion from bare soil areas, 2) landslides (mostly from the fill slope, but also including some cutbank failures), and 3) watercourse crossing failures (mostly gullying from washouts and diversions, but also including other types of crossing erosion). In sediment source inventories that have been performed on Simpson road networks in north coast watersheds over the last five years, these processes were found to deliver sediment to streams in different amounts and with differing efficiencies (Table F2-1).

F2.2.1 Chronic Erosion

In general, *chronic erosion* delivers sediment every winter, whether or not there are any large storms. The volume of fine sediment which is delivered to streams from the road system is a function of the type and amount of traffic on the road system, as well as the length of road and road ditches which drain directly to streams. Sediment delivery from chronic road erosion is generally greatest on roads that are open and used during the winter, and where ditches are connected to the streams. Roads which are abandoned and overgrown, and those where there is very little "connectivity" typically contribute far less sediment from chronic surface erosion than those which are well connected and used for commercial hauling.

In the inventories of Salmon Creek and Rowdy Creek, it was found that 12% and 21% of the road networks, respectively, are directly connected to the stream system through road side ditches. On average, over 30% of the inventoried road systems on Simpson lands were found to be hydrologically connected to the stream system. These road surfaces and ditches are delivering both runoff and fine sediment directly to streams. Although this represents a threat or risk to the aquatic system, it is not one which results in catastrophic sediment inputs.

F2.2.2 Episodic Sediment Sources

The other two types of sediment delivery that derived from road-related landslides and watercourse crossing erosion are more episodic in nature (Table F2-1). Episodic mass wasting and watercourse crossing failures most commonly occur during large storm events. The more extreme the hydrologic event is, the more frequent and larger are the failures from these two sediment sources. These episodic sediment sources delivery relatively large quantities of sediment (including both fine and coarse grain sizes) to stream channels. Future episodic sediment sources represent a risk or threat to the aquatic system that tends to be more substantial as the storm size increases. All else equal, the risk is often greatest on old and/or abandoned roads which have culverts that may be unmaintained and/or undersized for the design (100-year) flow event. Newly constructed roads also exhibit increased risk of sediment production for the first several years following construction.

Table F2-1. Sources and magnitude of road-related sediment delivery in selected Simpson watersheds, north coastal California[1]

Site location	Process	Sediment delivery for road-related erosion sites: Delivery range for sites (%)	Delivery range for sites (yds^3)	Average delivery (yds^3)	Percent of road-related sediment delivery (range)[2]
1. chronic surface erosion from bare soil areas (road surfaces, ditches and cutbanks)[3]	Surface erosion	NA	NA	NA	<5% - 15%
2. road-related landslide erosion	Mass wasting				15% - 80%
fill slope failures		5-100%	5 - 2,500	220	
landing failures		5-100%	5 - 2,000	385	
cut bank failures		50-100%	10 - 150	80	
hillslope landslides[4]		25-100%	10 - 10,000	3,500	
3. watercourse crossing erosion	Fluvial erosion				35% - 80%
watercourse crossing washouts		100%	5 - 3,000	225	
stream diversions (gullies)		80-100%	5 - 2,800	400	

[1] Data based on inventories of Salmon Creek and Rowdy Creek road systems; sediment delivery from stream diversions based on data from Jordan Creek (lower Eel River).

[2] Typically, watersheds with geologies like Salmon Creek and Rowdy Creek are dominated by fluvial processes, where road-related fluvial erosion (washouts and gullying at watercourse crossings) is expected to account for up to 85% of future sediment delivery. Road-related mass wasting is comparatively less in these watersheds. In steep, potential unstable watersheds on the north coast, such as those of the lower Eel River and Mattole, mass wasting may account for up to 65% of future road-related sediment delivery. In these watersheds, fluvial processes are relatively less important.

[3] Sediment delivery from road-related surface erosion occurs where the road is hydrologically connected to the stream system. Delivery volumes are based on contributing length of road reach, use levels, surface erosion rates and duration of analysis. Does not include surface erosion from non-road sources.

[4] Small to large hillslope slides triggered by road cuts, road fills or by altered hydrology (diversion or discharge)

F2.3 RESULTS

For this analysis, a total of 518 miles of forest road from five watersheds were included in the assessment. The watersheds spanned a number of the geologic types and geographical terrains of Simpson's north coast property. Just over 2,800 inventoried sites were judged to have a high or moderate priority for erosion prevention or erosion control treatment (Table F2-2). The average frequency of sediment delivery sites ranged from 3 sites/mile (Rowdy Creek) to over 7 sites/mile (Little River). Sub-watersheds in these basins displayed even greater variability in their potential for erosion and sediment delivery.

The field inventory employed standard inventory protocols developed by PWA and employed on forest and ranch lands throughout the north coast. Watercourse crossings represented the most common and volumetrically most important of the future sources of road-related sediment in most Simpson watersheds (Table F2-2). As future sediment sources, watercourse crossings were followed in importance by road-related landslides (mostly fill slope failures), and by "other" sediment sources (including ditch relief culverts and gullies). Non road-related landslides were not included in the road inventories (see Appendix F1).

Treatment costs were developed for all high and moderate priority sites in each of the five watersheds. These treatment costs were then analyzed according to each of the three main sediment sources (watercourse crossings, landslides and "other" sites). The breakdown of costs for erosion prevention treatments for these three sediment sources is depicted in Tables F2-3, F2-4 and F2-5, respectively. Total costs to treat all watercourse crossings (including both road upgrading (storm-proofing) and road decommissioning) is expected to exceed $9 million. Treatment of road-related landslide sites and "other" sites in these sample watersheds are expected to require $1.3 million and $0.5 million, respectively.

Basic treatment priorities and prescriptions were formulated concurrent with the identification, description and mapping of potential sources of road-related erosion and sediment yield.

Treatment priorities were evaluated on the basis of several factors and conditions associated with each potential sediment delivery site:

1) *Delivery volume* - the expected volume of sediment to be delivered to streams,

2) *Erosion potential* - the potential for future erosion (high, moderate, low),

3) *Access and access costs* - the ease and cost of accessing the site for treatments,

4) *Treatment costs* - recommended treatments, logistics and costs,

5) *Treatment immediacy* - the "urgency" of treating the site, and

6) *Treatment cost-effectiveness ($ spent per yd^3 "saved").*

Table F2-2. Analysis of inventoried road-related erosion sites in the Plan Area with high treatment priorities.

Watershed name	Assessment area (mi^2)	Road length analyzed (mi)	High and moderate priority sites (#)			Future sediment delivery from watercourse crossings				Future sediment delivery from landslides				Future sediment delivery from "other" sites			
			#	#/mi	#/mi^2	# of sites	yds^3	Yds^3/mi	yds^3/mi^2	# of sites	yds^3	yds^3/mi	yds^3/mi^2	# of sites	yds^3	yds^3/mi	yds^3/mi^2
Salmon Creek	6.8	36	183	5	27	153	43,472	1,208	6,393	19	7,023	195	1,033	11	364	10	54
Rowdy Creek	17.1	135	373	3	22	302	111,386	825	6,514	60	8,906	66	521	11	149	1	3
McGarvey Creek	7.0	63	383	6	55	195	110,115	1,748	15,731	181	49,330	783	7,047	7	84	1	12
Redwood Creek (PPZ)[1]	11.0	64	355	6	32	207	75,873	1,186	6,898	98	48,807	763	4,530	50	2,076	32	189
Little River[2]	35.0	220	1,533	7	44	939	248,390	1,129	7,097	315	60,994	277	1,743	279	6,454	29	184
Total	76.9[3]	518	2,827	5.5	37[3]	1,796	589,236	1,137	7,662[3]	673	175,060	338	2,276[3]	358	9,127	18	119[3]

[1] The Redwood Creek PPZ sediment source inventory is presently in progress. This data reflects only the inventoried roads on the west side of Redwood Creek.
[2] The Little River sediment source inventory is presently in progress. The data reflects all inventoried sites entered in the Access database as of 1/08/2001.
[3] Does not include data for Little River assessment area.

Table F2-3. Analysis of inventoried watercourse crossings in the Plan Area with high and moderate treatment priorities.

Watershed name	Assessment area (mi^2)	Road length analyzed (mi)	High and moderate priority sites (#)			Future sediment delivery From watercourse crossings				Estimated Cost ($)[1]			Uncorrected cost effectiveness ($/$yds^3$)	Cost per site ($/site)
			#	#/mi	#/mi^2	# of sites	yds^3	yds^3/mi	yds^3/mi^2	$	$/mi	$/$mi^2$		
Salmon Creek	6.8	36	183	5	27	153	43,472	1,208	6,393	677,454	18,818	99,626	15.58	4,428
Rowdy Creek	17.1	135	373	3	22	302	111,386	825	6,514	1,456,251	10,787	85,161	13.07	4,822
McGarvey Creek	7.0	63	383	6	55	195	110,115	1,748	15,731	1,249,891	19,840	178,556	11.35	6,410
Redwood Creek (PPZ)[2]	11.0	64	355	6	32	207	75,873	1,186	6,898	986,364	15,412	89,670	13.00	4,765
Little River[3]	35.0	220	1,533	7	44	939	248,390	1,129	7,097	`4,695,622	21,344	134,161	18.90	5,001
Total	76.9[4]	518	2,827	5.5	37[4]	1,796	589,236	1,138	7,662[4]	9,065,582	17,501	117,888[4]	15.38	5,048

[1] Costs include low boy transportation, heavy equipment, labor, materials, and supervision. Costs are listed as though both high and moderate priority sites are to be treated. In reality, especially on decommission roads, all sites are treated at once. Additional costs have been included for endhauling and the use of dump trucks at upgrade watercourse crossing sites. It was assumed that for crossings greater than 200 yds^3 approximately 60% of the total volume excavated will have to be endhauled from the site during culvert installation or replacement.
[2] The Redwood Creek PPZ sediment source inventory is presently in progress. This data reflects only the inventoried roads on the west side of Redwood Creek.
[3] The Little River sediment source inventory is presently in progress. The data reflects all inventoried sites entered in the Access database as of 1/08/2001.
[4] Does not include data for Little River assessment area.

Table F2-4. Analysis of inventoried landslides in the Plan Area with high and moderate treatment priorities.

Watershed name	Assessment area (mi^2)	Road length analyzed (mi)	High and moderate priority sites (#)			Future sediment delivery from landslides				Estimated Cost ($)[1]			Cost effectiveness ($/$yds^3$)	Cost per site ($/site)
			#	#/mi	#/mi^2	# of sites	yds^3	yds^3/mi	yds^3/mi^2	$	$/mi	$/$mi^2$		
Salmon Creek	6.8	36	183	5	27	19	7,023	195	1,033	66,953	1,860	9,846	9.53	3,524
Rowdy Creek	17.1	135	373	3	22	60	8,906	66	521	56,933	422	3,329	6.39	948
McGarvey Creek	7.0	63	383	6	55	181	49,330	783	7,047	263,447	4,182	37,635	5.34	1,456
Redwood Creek (PPZ)[2]	11.0	64	355	6	32	98	48,807	763	4,437	339,331	5,302	30,848	6.95	3,463
Little River[3]	35.0	220	1,533	7	44	315	60,994	277	1,743	572,758	2,603	16,364	9.39	1,818
Total	76.9[4]	518	2,827	5.5	37[4]	673	175,060	338	2,276[4]	1,299,422	2,504	16,898[4]	7.42	1,931

[1] Costs include low boy transportation, heavy equipment, labor, materials, and supervision. Costs are listed as though both high and moderate priority sites are to be treated. In reality, especially on decommission roads, all sites are treated at once.
[2] The Redwood Creek PPZ sediment source inventory is presently in progress. This data reflects only the inventoried roads on the west side of Redwood Creek.
[3] The Little River sediment source inventory is presently in progress. The data reflects all inventoried sites entered in the Access database as of 1/08/2001.
[4] Does not include data for Little River assessment area.

Table F2-5. Analysis of inventoried "other" sites in the Plan Area with high and moderate treatment priorities.

Watershed name	Assessment area (mi^2)	Road length analyzed (mi)	High and moderate priority sites (#)			Future sediment delivery from "other" sites				Estimated Cost ($)[1]			Cost effectiveness ($\$/yds^3$)	Cost per site ($/site)
			#	#/mi	#/mi^2	# of sites	yds^3	yds^3/mi	yds^3/mi^2	$	$/mi	$\$/mi^2$		
Salmon Creek	6.8	36	183	5	27	11	364	10	54	5,445	151	801	14.96	495
Rowdy Creek	17.1	135	373	3	22	11	149	1	3	8,376	62	490	56.21	761
McGarvey Creek	7.0	63	383	6	55	7	84	1	12	5,177	82	740	61.63	740
Redwood Creek (PPZ)[2]	11.0	64	355	6	32	50	2,076	32	189	63,224	988	5,748	30.45	1,264
Little River[3]	35.0	220	1,533	7	44	279	6,454	29	184	403,104	1,832	11,517	62.46	1,403
Total	76.9[4]	518	2,827	5.5	37[4]	358	9,127	18	119[4]	485,326	937	6,311[4]	53.17	1,314

[1] Costs include low boy transportation, heavy equipment, labor, materials, and supervision. Costs are listed as though both high and moderate priority sites are to be treated. In reality, especially on decommission roads, all sites are treated at once.
[2] The Redwood Creek PPZ sediment source inventory is presently in progress. This data reflects only the inventoried roads on the west side of Redwood Creek.
[3] The Little River sediment source inventory is presently in progress. The data reflects all inventoried sites entered in the Access database as of 1/08/2001.
[4] Does not include data for Little River assessment area.

Requiring proposed work to meet pre-established cost-effectiveness criteria is critical to developing a defensible and objective watershed protection and restoration plan. The cost-effectiveness of treating a restoration work site is defined as the average amount of money spent to prevent one cubic yard of sediment from entering or being delivered to the stream system. The cost-effectiveness of treating each of the sediment sources in each of the five Simpson watersheds is listed in the summary data tables. Cost-effectiveness values average \$15/yd^3 for watercourse crossings, \$7.50/yd^3 for road-related landslides, and \$53/yd^3 for "other" sites. "Other" sites are often less cost-effectively treated because of their relatively small delivery volume.

F2.4 LIMITATIONS AND ASSUMPTIONS IN SEDIMENT DELIVERY AND TREATMENT COST ANALYSES

The sediment production and delivery figures developed for Simpson lands in the five sampled watersheds have been extended to the remainder of the ownership (see Appendix F3). It is assumed that the sediment delivery volumes developed for the five watersheds are reasonable estimates of future sediment delivery from existing roads in the absence of future treatments (such as road upgrading and decommissioning, as described in the Plan).

As would be expected with a forward-looking sediment source assessment, the predictive data generated from such a field inventory of road systems have certain inherent limitations and uncertainties. The resulting data also display variability that is derived from a number of sources. Finally, some assumptions have necessarily been employed to derive "reasonable" values for future erosion and sediment delivery.

Sources of variability or uncertainty in the estimates are described below. Data are presented for four subject areas: 1) general procedures, 2) inventory volumes, 3) sediment delivery volumes, and 4) estimated treatment costs. The sources of variability are generally outlined in Table F2-6. The effects of these findings are expressed in Table F2-2 or have been incorporated in the final sediment delivery estimates for the Plan Area (Appendix F3).

F2.4.1.1 Assumptions Employed in General Road Sediment Analysis

1. All sediment delivery numbers generated for and applied to the remainder of the Simpson ownership assume that the sample data from the detailed inventories in the five watersheds correctly represents Simpson properties and road conditions. The broad range of geologic types represented by the five watersheds lends support to this assumption. Additional field inventories to be conducted in the first five years after implementation of the Plan will be examined to confirm these assumptions and estimates.

Table F2-6. Accounting for variability in sediment delivery and work estimates.

No.	Source of variability or potential error	Result	Possible action, solution or accounting	Proposed Analysis	Results and Findings
1	Not all inventoried sites will erode or fail	Overestimate of delivery volume and work requirement	Develop a reducing factor which assumes some sites will not fail in the analysis period	Determine how many sites on abandoned roads have failed (frequency) since abandonment. Go to past inventories to determine failure frequency (#/mi) landslides). Use P-L 4 watershed data of past delivery. Determine past erosion on inventoried watercourse crossings	Landslide delivery frequency & failure rates for PL 4-basin inventory: Past frequency = 1.09 - 2.47 slides/mile Past delivery = 760 - 3,300 yds^3/mi Future = 180 - 1,410 yds^3/mi (estimate appears reasonable) 53% of crossings on abandoned roads show sediment delivery (currently overestimated frequency - see below).
2a	Not all sites of future sediment delivery have been identified	Underestimate of future sediment delivery volumes and work estimate	Develop an inflating factor which assumes some new sites will develop and deliver that were not previously identified	Determine how well future failure sites can be identified. With RX get close to 100%. With LS maybe 75%? Give a range and work estimates from that range.	Past frequency = 1.1 - 2.5 slides/mile Future frequency = 1.2 - 2.6 slides/mile (some slides don't fail; some slides aren't recognized - generally balances)
2b	More sites have been identified than will fail	Overestimate for future sediment delivery volumes	Develop a reducing factor which assumes that not all sites that were identified will actually fail and delivery sediment.	Based on experience and field evidence on inventoried roads, estimate what percent of the mapped sites actually fail.	Past LS frequency = 1.1 - 2.5 slides/mile Crossing failure (erosion) frequency on abandoned roads = 53%
3	Erosion from stream diversions not fully accounted for (crossing volume used as surrogate)	Underestimate of delivery volumes and cost-effectiveness calculation	Review volumetric data for all diversions and compare against crossing volumes to develop corrected sediment savings estimate	Review crossing data from 4 P-L watersheds (determine # w/Dp and # diverted and average yield); review RNP Professional Paper findings; review USFS Furniss data; Compare all delivery data to watercourse crossing volumes.	31% of crossings have DP; range = 24% - 81%; Delivery from PL diversions averages 75% of crossing volume (range = 29% -130%). USFS estimates (KNF) 2x - 3x sediment delivery from 1997 diversions; RNP yields up to 10x

Table F2-6 (Continued). Accounting for variability in sediment delivery and work estimates.

No.	Source of variability or potential error	Result	Possible action, solution or accounting	Proposed Analysis	Results and Findings
4	Not all watercourse crossings will completely erode	Overestimate of delivery volumes	Develop a reducing factor, based on drainage area	Look at eroded watercourse crossings on abandoned roads. Look for crossings over 50% eroded and define minimum drainage area; Look at upgrade data for distribution of watercourse crossing drainage areas	53% of crossings have past delivery 68 % are 1% - 25% eroded 16 % are 25% - 50% eroded 9 % are 50% - 75% eroded 7 % are 75% - 100% eroded
5	Watercourse crossing erosion assumes 1:1 side slopes	Under estimate of long term delivery volumes	Develop a range of delivery volumes based on 0.5:1, 1:1 to 1.5:1 side slopes	Develop a range of delivery volumes based on 0.5:1, 1:1 to 1.5:1 side slopes.	There is an average 35% reduction or increase in volumes
6	Road surface erosion and delivery not included in delivery volume estimates	Underestimate of delivery volumes; treatment costs already included in estimates	Connectivity is already known for most inventoried areas; delivery volumes could easily be estimated	Define average connectivity numbers for inventoried roads and apply average erosion volumes for watercourse crossings.	Average connectivity = 33%; Range = 6% - 74% (Little River); Total sediment delivery = 123% of site erosion; Range = 102% - 146%
7	GIS does not identify all roads that could contribute to sediment delivery	Underestimate of delivery volumes, costs and work requirements	Include an inflation factor for unmapped roads; data already exists for this	Look at GIS road densities and actual road densities for Simpson watersheds. Determine unmapped road density.	Actual road mileage is an estimated 110% to 125% of GIS road mileage (mean = 120%)
8	New and upgraded roads have smaller and fewer sites with lower risk of failure	Estimates are for older roads; over time, unit volumes will decrease as roads are treated	Acknowledge risk is still present and determine new volumes for treated roads	Look at upgraded roads and new roads for reduction in watercourse crossing volumes and risk of failure. Estimate reduced risk and reduced volumes (no diversions, smaller volumes and less frequent failure).	NA
9	New and upgraded roads are not hydrologically connected (connection is minimized)	Current delivery estimate does not include road surface erosion	Measure or estimate new connectivity and estimate delivery volumes	Determine new connectivity and sediment delivery for upgraded roads (Assume an average connectivity of 100 feet for upgraded roads)	Past connectivity = 33% Future connectivity = 7% (Based on 100 feet per crossing @ 3.5 crossings/mile - 32.5 yds^3/mile/decade))

Table F2-6 (Continued). Accounting for variability in sediment delivery and work estimates.

No.	Source of variability or potential error	Result	Possible action, solution or accounting	Proposed Analysis	Results and Findings
10	Unknown if property-wide road building rate is greater or less than road closure (decom) rate	Total volume of deliverable sediment could be increasing or decreasing	Could be easily analyzed and projected into the future based on known road management plans	Not relevant	NA
11	Poor or inaccurate inventory will dramatically affect costs and sediment saving estimates	Could increase or decrease costs; reduced sediment savings (increased discharge)	Use trained inventory crews; employ peer review procedures for erosion assessment and erosion prevention prescriptions	Apply multiplier estimate for low, medium and high expertise and accuracy	Estimated that inventory crews, if contracted or held as long term employees, will achieve proficiency. Initial inaccuracy may increase costs by 5% - 15% for 3 years. Inefficiency may be reduced through technical oversight.
12	Inexperienced operators will increase costs and reduce effectiveness (sediment savings)	Increased costs; reduced sediment savings	Employ only trained, experienced operators; Train operators specifically for road work	Apply multiplier estimate for low, medium and high operator expertise	Estimated that equipment operators, if contracted or held as long term employees, will achieve proficiency. Initial inaccuracy may increase costs over skilled crews by 15% - 35% for first 3 years. Inaccuracy may be largely eliminated through technical training and oversight.
13	"Fluff factor" not included in excavation or endhaul volumes	Will increase costs for endhauling somewhat	Build in inflation factor for volume increases during excavation	Assume a 20% expansion factor for endhauling. Determine how much of total treatment costs in each watershed are for endhauling and increase costs by 20%	Endhauling the extra material (volume accounted for in the expansion of compacted soil) is estimated to increase endhauling costs by 24% and total project costs by 2%.
14	Unit costs (and total costs) for work will increase over time	Less work is done for fixed dollar amounts	Build in inflation factor to annual expenditure levels for road work	Inflation factor will be worked into overall cost and production estimate (see Plan text). Could tie it to fuel prices and general inflation rate	Not calculated

2. It is assumed that there are 10% to 25% more roads (mean 15*%)* than are documented in the Simpson GIS (based on field mapping projects already undertaken on Simpson lands). Most of these roads are abandoned and overgrown. Road-related erosion and sediment delivery will need to be adjusted to account for this.

3. Road inventories on Pacific Lumber Company lands have been used in place of Simpson inventories to determine some erosion and delivery estimates (e.g., past landslide frequency (slides/mile)) because PWA inventories in Simpson watersheds do not contain systematic data on past erosion and sediment delivery volumes. Inventories of Simpson roads contain data only on future and on-going sediment sources and only describe sediment delivery from High and Moderate priority sites.

F2.4.1.2 Assumptions Employed in Developing Sediment Production (Erosion) Volumes

F2.4.1.2.1 Future Landslide Volumes

Field inventories on Simpson and other industrial properties indicate that past landslide frequencies (1.1 to 2.5 slides/mile) are similar to future (predicted) landslide frequencies (1.2 to 2.6 slides/mile) that have been mapped in the recent field inventories. This appears reasonable for roads that are becoming more "seasoned" through time and lends support to the overall field estimate for the magnitude of future sediment delivery that could be derived from road-related landslides. Future (predicted) landslide volumes were estimated based on comparable features which have already failed in the vicinity of potentially active slides, as well as the location and physical dimensions of the potential slide as inferred from scarps and cracks within the road bed or on the fill slope. In almost all cases, there had to be physical evidence of a potential failure (scarps, cracks, etc) before a road or landing fill was classified as a potential road-related failure. Not all these sites will fail, but similarly, a limited number of other sites that have not yet developed overt signs of potential failure may end up failing and delivering sediment to the stream system.

F2.4.1.2.2 Future Watercourse Crossing Erosion Volumes

Watercourse crossing fill volumes can be measured fairly accurately in the field by employing simple measurements and applying double end-area calculating formulas. Initially, watercourse crossing washout volumes (predicted erosion) were geometrically calculated by assuming the stream would eventually cut through the fill exposing a natural channel bottom width and typically exhuming 1:1 (100%) sideslopes through the fill. Thus, in Table F2-2 it was assumed that if a culvert "failed" during a large storm event, the watercourse crossing fill would completely washout. This may be a reasonable assumption for crossings of large streams, or when it was standard practice to abandon roads between harvest rotations and leave them unmaintained for 50 years or longer. However, this is no longer a standard practice, and it cannot be assumed that all under-designed watercourse crossings will completely fail if they are not upgraded or decommissioned.

To determine what a reasonable erosion volume might be, a number of abandoned crossings were inventoried and characterized. Crossings on abandoned roads were studied because crossings on maintained roads are quickly repaired after storm events and data on erosion is no longer available. For abandoned crossings with no diversion potential, data from 707 inventoried watercourse crossings indicates that 53% show significant erosion. Generally, the older the crossing, and the larger the stream, the more erosion it exhibits. Table F2-7 outlines the erosion data for watercourse crossings on roads which have been abandoned for 10 to 50 years.

Table F2-7. Measured erosion of watercourse crossings on abandoned roads in the Plan Area.

Crossings showing erosion[1] (% of total number)	Amount of erosion (% of entire fill crossing)
36.0	1% to 25%
8.5	25% to 50%
4.8	51% to 75%
3.7	75% to 100%
53.0	_ = 14%

[1] A total of 707 abandoned watercourse crossing (none with diversion potential) were analyzed. Watercourse crossings had been abandoned for 10 to 50 years.

Based on field inventories, a more reasonable assumption of the actual frequency and volume of watercourse crossing erosion during a given 50 year period (assuming no upgrading or decommissioning treatments are undertaken) is outlined in Tables F2-8 and F2-9.

Table F2-8. Predicted watercourse crossing erosion in the Plan Area for a 50 year time period.

Crossings showing erosion (% of total number)	Amount of erosion (% of entire fill crossing)
40 %	10%
30 %	30%
20 %	50%
10 %	90%
Average erosion	32%

Table F2-9. Analysis of inventoried watercourse crossings in Plan Area with high and moderate treatments priorities.

Watershed name	Assessment area (mi^2)	Road length analyzed (mi)	Potential future sediment delivery from high and moderate priority watercourse crossings					Future sediment delivery (yds^3) using three calculation methods		
			# of sites	yds^3	yds^3/mi	yds^3/mi^2	Unit delivery volume (yd^3/site)	Complete crossing washout (yd^3)	Expected delivery 40% erode 10% 30% erode 30% 20% erode 50% 10% erode 90%	Abandoned xings 36.0% erode 13% 8.5% erode 38% 4.8% erode 63% 3.7% erode 88%
Salmon Creek	6.8	36	153	43,472	1,208	6,393	284	43,472	13,905	6,166
Rowdy Creek	17.1	135	302	111,386	825	6,514	369	111,386	35,660	15,813
McGarvey Creek	7.0	63	195	110,115	1,748	15,731	565	110,115	35,256	15,634
Redwood Creek (PPZ)[2]	11.0	64	207	75,873	1,186	6,898	367	75,873	24,310	10,780
Little River[3]	35.0	220	939	248,390	1,129	7,097	265	248,390	79,627	35,310
Total	76.9[4]	518	1,796	589,236	1,137	7,662[4]	328	589,236	188,508	83,592

[1] Costs include low boy transportation, heavy equipment, labor, materials, and supervision. Costs are listed as though both high and moderate priority sites are to be treated. In reality, especially on decommission roads, all sites are treated at once. Additional costs have been included for endhauling and the use of dump trucks at upgrade watercourse crossing sites. It was assumed that for crossings greater than 200 yds^3 approximately 60% of the total volume excavated will have to be endhauled from the site during culvert installation or replacement.
[2] The Redwood Creek PPZ sediment source inventory is presently in progress. This data reflects only the inventoried roads on the west side of Redwood Creek.
[3] The Little River sediment source inventory is presently in progress. The data reflects all inventoried sites entered in the Access database as of 1/08/2001.
[4] Does not include data for Little River assessment area.

The prediction of future watercourse crossing erosion on Simpson lands is based largely on a calculation of erodible fill volumes and an analysis of past erosion and delivery volumes from watercourse crossings on roads that have been abandoned for 10 to 50 years. Other than some data collected after singular flood events in northern California and Oregon, this is the best long term data set that is available for watercourse crossing erosion.

F2.4.1.2.3 *Average Erosion*

The watercourse crossing erosion data for abandoned roads is not unlike those that have been collected after a single large storm event (Figure 1). Furniss (2000) reported that hydraulic exceedence was not a major failure mechanism for watercourse crossings in large floods. Calculated peak flow and culvert capacity did not predict watercourse crossing failure where sediment and woody debris were the ultimate cause of failure and subsequent erosion.

It was thought that there would be a relationship between the degree of watercourse crossing erosion (washout) and the drainage area above the crossing (discharge), especially for the 53% of Simpson watercourse crossing fills that have already experienced some erosion. However, the observed relationship is weak and by itself, drainage area was not a good predictor of observed watercourse crossing erosion volumes.

Several other factors were considered in the evaluation of predicted sediment delivery from eroded watercourse crossings.

When watercourse crossings erode from overtopping, they typically develop head cuts and gullies across the road prism. Field observations suggest most gullies develop 1:1 side slopes. Initially some gullies will have steeper sides, and over time others (especially those in poorly consolidated, non-cohesive soils) will lay themselves back to a gentler angle. To account for the potential variability in watercourse crossing erosion volumes caused by variable side slope morphology, PWA employed a range of sideslope steepness values from 0.5:1 to 1.5 :1. This resulted in a potential ±35% range for watercourse crossing erosion volumes where gullying develops.

Erosion volumes calculated for watercourse crossing failures are “compacted” volumes. When excavation treatments (especially for decommissioning) are calculated, an expansion factor of 20% has been applied to these numbers. This expansion volume is not considered in developing estimates of future erosion volumes, only in developing cost estimates for heavy equipment treatments where soil is to be excavated and hauled in dump trucks.

F2.4.1.2.4 *Future Erosion Volumes from “Other” Sediment Sources*

“Other” sources of road-related erosion typically involve gullying at the outlets of ditch relief culverts and other road surface drainage structures. The calculation and estimation of future sediment delivery volumes from these sediment sources is largely a process of estimating the potential for continued enlargement of the existing gullies which remain active or appear to have the potential to enlarge.

Figure 1. Stream crossing erosion from single storm overtopping

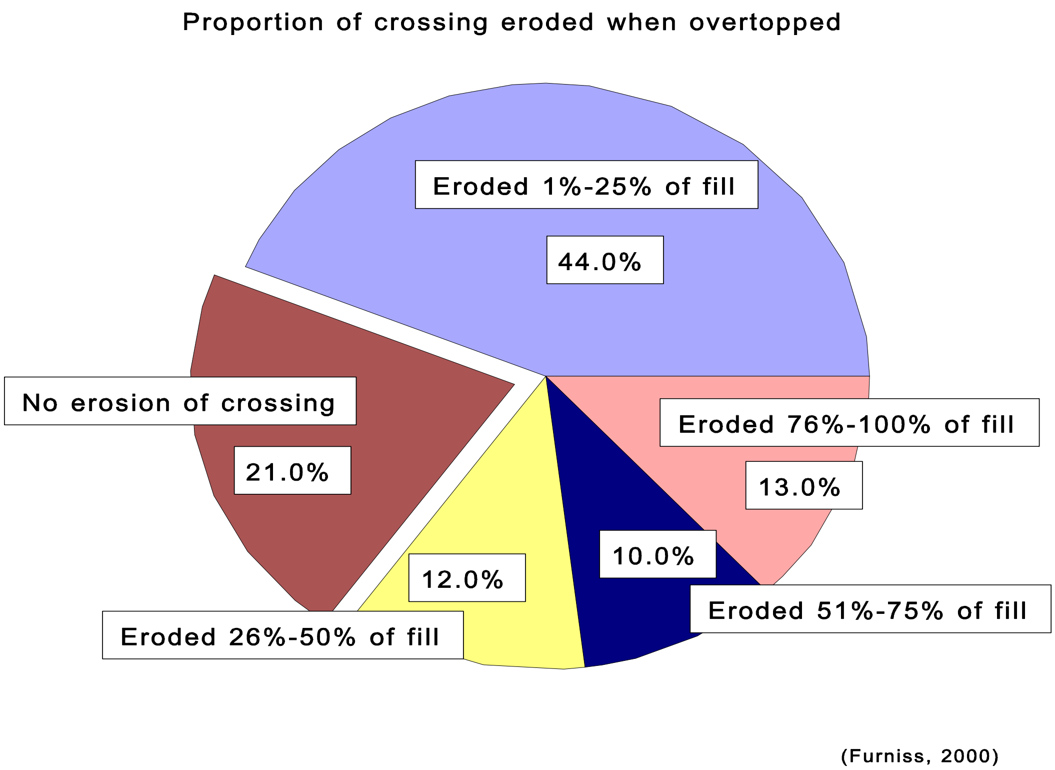


Figure F2-1. Watercourse crossing erosion from a single storm overtopping.

F2.4.1.3 Assumptions Employed in Developing Sediment Delivery Volumes

It should be clearly stated that this analysis of road erosion in the five Simpson watersheds does not include an assessment of fine sediment contributions from road surface erosion. Only "site" data has been included. Volumetrically and ecologically, over the course of one or more decades of road use and log hauling, this sediment source can be a highly important source of impact to the aquatic system. Importantly, the treatments (and the resultant cost tables), have been developed under the assumption the road surface drainage is "disconnected" from the natural drainage network, to the extent that is feasible. Thus, although the fine sediment erosion volumes are not included in the analysis, the treatments required to eliminate chronic sediment delivery from the road systems have been included in the final cost tables.

F2.4.1.3.1 Future Landslide Delivery

Field inventories on Simpson and other industrial properties indicate that past landslide frequencies (1.1 to 2.5 slides/mile) are similar to future (predicted) landslide frequencies (1.2 to 2.6 slides/mile) that have been mapped in the recent field inventories, but that future (predicted) landslide delivery volumes (180 to 1,410 yd^3/mile) are 25% to 40% of past volumes (760 to 3,300 yd^3/mile). Future delivery volumes are estimated in the field based on physical measurements of potentially unstable fill materials (typically bounded by scarps and/or cracks) and sediment delivery rates. Sediment delivery rates (% of the slide mass that would be delivered to a stream if the fillslope failed) were estimated in the field by applying a reasonable delivery percentage that considers what other nearby slides have done, as well as specific site characteristics that typically influence slide run-out distances (e.g., slope gradient, distance to stream, slope shape, moisture, etc.).

A second method (analysis of sequential air photos) has been employed to determine road-related mass wasting and sediment delivery from the Simpson road network (Appendix F1). Air photo analysis is good at identifying moderate and large size features that break the forest canopy and deliver sediment to streams. Small slide features that cannot be seen on aerial photos are less likely to delivery substantial volumes of sediment to streams, but their potentially high frequency may still make them important to the aquatic system.

In three watersheds of the lower Eel River where there is good data on past mass wasting using both air photo analysis and field inventories, there was an additional 6% to 38% sub-canopy sediment delivery (average increase = 15%) from small features that could not be seen in the 1:12,000 aerial photos. The number of landslides in these project areas increased by 75% when the field inventory data was added to the air photo analysis, but the delivery volumes increased by only 15% (on average). Clearly, field inventories of road erosion pick up many smaller road-related landslides that do not show up on air photos. This suggests that if air photo analysis of past landsliding is used to estimate future sediment delivery from landsliding, landslide delivery volumes should be increased by 10% to 30% (average 15%) over the photographically-derived rate.

F2.4.1.3.2 *Future Sediment Delivery from Watercourse Crossings*

It has been assumed that 100% of all sediment that is eroded from a watercourse crossing is delivered to the stream network. It is further assumed that field inventories will identify all watercourse crossings and that no significant crossings will be overlooked in the inventory process. Based on past experience, these are valid assumptions.

F2.4.1.3.3 *Future Sediment Delivery from "Other" Sites*

In the analysis of sediment delivery from "other" sites, it has been assumed that 60% to 100% of the eroded sediment (mean = 75%) is delivered to the stream system. Most of the "other" sites consist of gullies that are well connected and integrated with the natural stream channel network. In general, connected gullies are very efficient at delivering eroded sediment.

F2.4.1.4 Assumptions Employed in Developing Erosion Prevention Treatment Costs

F2.4.1.4.1 *Covered Costs*

Costs for implementing erosion prevention work (road upgrading and road decommissioning) incorporate all relevant expenses, including equipment, labor and materials as well as technical oversight, monitoring and reporting. Costs for treatments in each of the five watersheds includes equipment mobilization (moving) costs, road opening costs (especially for overgrown roads), heavy equipment costs for treating sites and for addressing road drainage, endhauling costs, laborer costs for culvert installations, mulching and seeding, rock costs, culvert materials (including couplers and downspouts), planting and mulching materials, and professional costs for treatment layout, equipment oversight, supervision, documentation and reporting.

The costs that are summarized in Tables F2-3, F2-4 and F2-5 were developed from the detailed cost analyses for each road and each site in the five watershed erosion assessments, employing the assumptions listed above. The costs are based on competitive equipment rental and labor rates for the watershed areas. Based on recent road upgrading work, it has also been assumed that watercourse crossings exceeding 200 yd^3 in volume will require that 60% of the crossing volume be endhauled (because it is too wet to reuse) during the rebuilding process. The cost tables have been reworked to account for this added work effort.

F2.4.1.4.2 *Costs not Covered*

As the cost tables were developed for the five Simpson watersheds, and as experience in implementing road upgrading and road decommissioning has increased, additional cost categories have been added to better reflect actual on-the-ground expenses. It has become apparent that volume calculations which are based on in-place geometric shapes of fills (e.g., watercourse crossing fills) need to be increased to account for the expansion of the soil materials as they are excavated and loaded into trucks. Simpson has estimated that the increase in volume due to fluffing or expansion of excavated material will increase overall project costs by 2% over that which is stated in the cost tables. This increased cost is largely the consequence of increased endhauling requirements (these cost are added in Table F2-10).

Table F2-10. PWA treatment costs, as itemized and adjusted from Tables F2-3, F2-4, and F2-5.

Category Range	Watercourse crossings ($/mi)	Landslides ($/mi)	"Other" ($/mi)	Cost ($/mi)	Other costs (multiplier)	Total costs ($/mi)
Average	17,500	2,504	940	20,940	0.2	25,000
Minimum	15,000	420	60	15,480	0.2	18,000
Maximum	21,000	5,300	1,800	28,100	0.2	40,000

F2.4.1.4.3 *<u>Additional Undefined Cost Variables</u>*

Several cost elements cannot easily be estimated. These include: 1) operator experience and skill, and 2) the skill and experience of the road erosion inventory crews that ultimately identify problems and define treatment prescriptions. The data contained in the summary cost tables (Tables F2-3, F2-4 and F2-5)) assume that the inventory crews and the equipment operators are skilled, accurate and efficient in their work.

Technically and practically well trained inventory crews can have a large effect on the overall cost-effectiveness of the erosion prevention work that is undertaken. Poor problem identification or quantification can result in inaccurate or misguided prescriptions that either under or over estimate to scope of the necessary work. In addition, problems which are "missed" or mis-identified may end up resulting in environmental damage if necessary work is not correctly prescribed and undertaken. Similarly, well trained and experienced operators can save thousands of dollars in how they approach and conduct the prescribed work. A poor operator can doom a project to being significantly over budget.

As a result, it is anticipated that for the first three years of the road implementation program on Simpson lands, inventory crews and equipment operators will be training and improving in their skills and efficiency. As a result, equipment costs could be as much as 15% to 35% higher than listed in the data tables. Increased program costs associated with untrained inventory crews could similarly add up to 5% to 15% additional implementation costs. It should be noted that no estimates have been included in the cost tables to cover the actual erosion inventories of Simpson roads. Listed costs are only for the implementation of prescribed treatments (usually road upgrading and road decommissioning) as derived from the five sampled watersheds. Most of these increased costs could be eliminated by implementing an organized training and technical oversight program for quality assurance and quality control covering at least the first three years of the program.

The sediment data for the 76.9 mi^2 assessment area on Simpson property is summarized in Table F2-11. Sediment delivery from watercourse crossing erosion is expressed both as an uncorrected volume (assuming complete washout of untreated crossings at sometime during the term of the Plan) and as a corrected erosion and delivery volume. The "corrected" erosion volume assumes that watercourse crossings erode at frequencies and in proportion to the observed erosion characteristics listed in Table F2-9. In this manner, 50-year erosion and delivery volumes for untreated, under designed watercourse crossings would equal approximately 32% of the fill volume, on average.

Total (corrected) sediment delivery from the three main sediment sources is nearly equally divided between watercourse crossings and road-related landslides (~350 yd^3/mile) with only 3% (on average) attributable to "other" sediment sources (mostly gullies at ditch relief culverts). A range of potential sediment delivery volumes has also been developed based on the field inventory data (Tables F2-3, -4, and -5).

Average treatment costs for erosion prevention work, principally road upgrading and road decommissioning, is summarized in Table F2-10. Unit treatment costs are broken down by site type (crossing, landslide and "other") and then summed as a single unit cost ($/mi). These have then been adjusted to account for the 2% increase in costs expected to result from additional endhauling where soil "expands" (or fluffs) during excavation. The range in treatment costs ($18,000 to $40,000/mile) assumes that operators are well trained and experienced in all implementation measures. These figures are in line with actual road upgrading and decommissioning costs encountered in recent erosion prevention projects.

Table F2-11. Summary data for inventoried erosion and sediment delivery volumes for 5 watersheds covering 76.9 mi^2.

Sediment Source	**Sample size (number of sites of future sediment delivery, inventoried**	**Average potential sediment delivery (uncorrected assumes complete washout and failure) (yds^3/mi)**	**Range of potential sediment delivery volumes (among 5 inventoried watersheds) (yds^3/mi)**	
			Low	**High**
Watercourse Crossings (uncorrected)	1,796	1,140	825	1,750
Watercourse Crossings (corrected)	1,796	364	264	560
Landslides	673	340	65	780
"Other"	358	20	0	30
Total site data (corrected)	**2,827**	**724**	**329**	**1,370**

F2.5 SUMMARY

Pacific Watershed Associates (PWA) conducted sediment source inventories in five watersheds on Simpson's ownership. The inventories were designed to quantify the potential future sediment delivery associated with road-related landslides, watercourse crossing failures and "other" sites associated with Simpson's road network. The results from these inventories for high and moderate priority treatment sites are shown in Table F2-2.

PWA also assessed the cost required to stabilize the potential sediment associated with these sites (Tables F2-3). Although the summary data tables do not include potential sediment derived from road-related surface erosion, the costs outlined in Tables F2-3, F2-4 and F2-5 do include monies to address such sources of sediment. That is, although the sediment delivery from road surface erosion has not been quantitatively described in the following inventory data tables, the treatment costs to address these sediment sources have been included in the cost tables. Thus, Simpson's Road Implementation Plan has this additional important benefit to the species covered by the Plan.

The PWA sediment inventory data were used extensively in the development of the sediment production model that is discussed in Appendix F3. The data were particularly helpful in developing sediment delivery estimates over the 50-year life of the Plan. A rather key result, based on PWA's investigations, is that much of the potential sediment associated with watercourse crossings may not deliver within the next 50 years even if left untreated (Table F2-9). The PWA data were also used to estimate the magnitude of the potential sediment issues associated with Simpson's road network which led to the development of an appropriate strategy to accelerate erosion control and erosion prevention efforts over the first 15 years of the Plan.

Appendix F3. Plan Area Sediment Delivery Estimates: A Model and Results

CONTENTS

Figures

Tables

F3.1 INTRODUCTION

A sediment delivery model was developed to:

- Consolidate information from the landslide assessment (Appendix F1) and road sediment source inventory (Appendix F2);
- Combine the findings from the above mentioned studies to produce an approximate sediment delivery estimate for the Plan Area;
- Compare sediment delivery for the “No Plan” versus Plan scenarios;
- Evaluate the statistical efficiency and effectiveness of the various conservation measures; and
- Assess the variation in sediment delivery due to the “uncertainty” or “ranges” associated with key assumption variables using Monte Carlo simulation techniques;

F3.2 A CONCEPTUAL SEDIMENT DELIVERY MODEL

A simple conceptual model was developed to integrate the various sources of data and to produce a partial sediment summary for the Plan Area (see Figure F3-1 below). The model does not include all sources of sediment. It only attempts to model the sediment produced from shallow and deep-seated landslides (see Appendix F1) and high and moderate priority sites associated with roads (see Appendix F2). These are (1) sources of sediment not directly addressed by the implementation of best management practices (BMPs), (2) sources of sediment that were studied in sufficient detail such that empirical models could be constructed, and (3) potential sediments that could be effectively addressed by the conservation measures proposed pursuant to this Plan to mitigate the impacts of the covered activities.

The sources of sediment not directly addressed in this simple model include sediment produced from surface erosion and sediment produced from stream bank erosion. It should be noted, however, that the Road Implementation Plan includes measures to address and correct potential surface erosion associated with high and moderate priority treatment sites. Thus, this potentially prolific source of fine sediment will be treated and its impacts to aquatic species largely eliminated by the end of the 50-year term of the Plan.

This simple property-wide model is based on expected 50-year (long-term) average sediment delivery rates. (The model was developed to assess property-wide sediment delivery issues. The model does not have a spatial component and, therefore, is not able to make site-specific sediment delivery predictions.) It is recognized that the annual variation in such rates may be large and lead to annual sediment delivery amounts that are much greater or much smaller than the averages contained within this model. A model that accounts for such variation would have been unwieldy (if not impossible) to construct and problematic to parameterize given the nature of the sediment delivery studies described in Appendices F1 and F2.

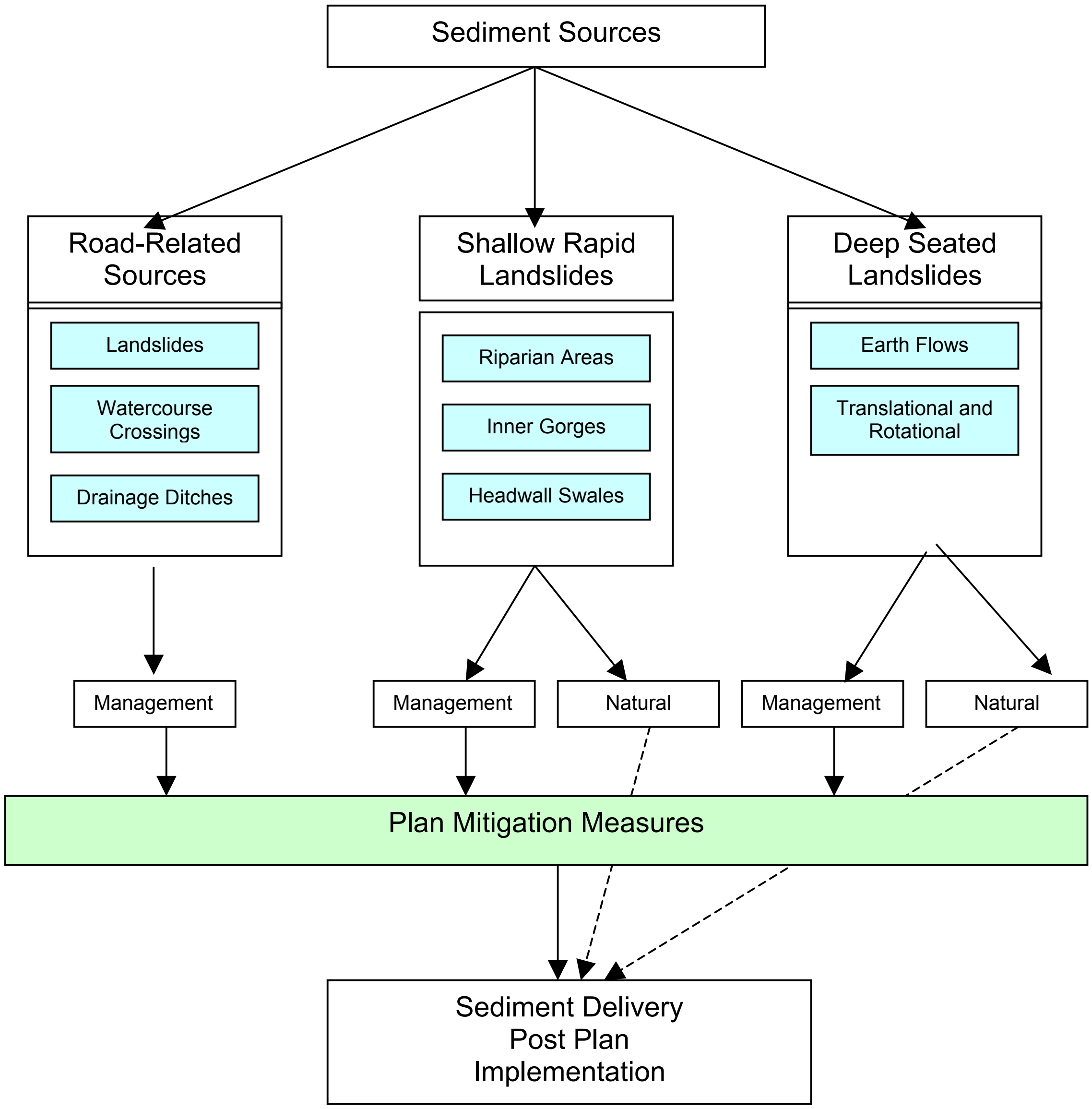


Figure F3- 1. Conceptual model of integration of data for partial sediment summary for Plan Area.

In any event, even if such a model could be constructed, its computed 50-year averages would be comparable to the output generated by the simple model described herein. Thus, the management options and conservation measures that evolve from the use of the model described in this appendix are entirely appropriate provided they are implemented over the 50-year term of the Plan to produce the desired results.

This conceptual model was used as the basis for developing a spreadsheet model that integrated the various data sets compiled for the Plan.

F3.3 ROAD-RELATED SEDIMENT SOURCE DATA

The road sediment source inventory conducted by PWA covered five watersheds: Salmon Creek, Rowdy Creek, McGarvey Creek, Redwood Creek, and Little River. The following table (Table F3-1) shows how the information from these watersheds (see Appendix F2 for watershed specific details) was combined to produce estimates for the Plan Area. The basic idea was to use an estimate of Plan Area road length (4,311 miles) as a multiplier to produce potential sediment totals for the Plan Area. For example, the current GIS estimate of road miles in the Plan Area is 4,311. Plan Area potential sediment from road-related landslides would be determined as follows:

$$1{,}456{,}862 \text{ yd}^3 = 4{,}311 \text{ miles} \times 338 \text{ yd}^3/\text{mile}$$

(Note: The spreadsheet model carries many digits beyond the decimal point so the math may not appear to "work out" properly in the equation above or the table below.) Only potential sediment from high and moderate treatment priority sites is used in the analysis, as it is these sites that are targeted for repair under the Road Implementation Plan.

As part of the sediment inventory, PWA provided Simpson with treatment costs (Table F3-2) that were used as the basis to determine the amount of sediment that could be stabilized using $2.5 million as specified under the Road Implementation Plan—approximately 204,000 cubic yards. An important consideration in this calculation is the efficiency that is realized by appropriately prioritizing the work and focusing on concentrations of high and moderate priority treatment sites. Such prioritization will allow Simpson to stabilize approximately 48% of the potential sediment during the first 15 years of the Plan with the $2.5 million annual commitment.

Several of the variables associated with the road sediment source inventory were assigned an appropriate range for purposes of conducting the Monte Carlo simulation exercise. These variables and their ranges are listed below in the VARIABLE RANGES section of this appendix. An example is the range associated with the miles of road contained within the Plan Area. Simpson recognizes that some roads have not been mapped and are not contained in Simpson's GIS. To account for this understatement of Plan Area road miles, an assumption called the "road miles blow up factor" was devised. This factor was assigned a triangular distribution with a minimum increase of 10%, a most likely increase of 15%, and a maximum increase of 25%. The mean of this distribution, 16.7%, was used in the calculations to produce Tables F3-1 and F3-2. That is,

$$4{,}311 \text{ miles} = 116.7\% \times 3{,}695 \text{ miles},$$

where 3,695 miles is the length of roads according to Simpson's GIS.

Table F3-1 Potential road-related sediment delivery from high and moderate treatment priority sites.[1]

	Road Length (mi)	Potential Sediment Delivery From Watercourse Crossings		Potential Sediment Delivery From Landslides		Potential Sediment Delivery From "Other sites"		Total Potential Sediment Delivery	
		yd^3	yd^3/mi	yd^3	yd^3/mi	yd^3	yd^3/mi	yd^3	yd^3/mi
Inventory Total from Five Watersheds	518	589,236	1,138	175,060	338	9,127	18	773,423	1,493
Estimate for the Plan Area	4,311	4,903,664	1,138	1,456,862	338	75,956	18	6,436,482	1,493

1 The inventory totals were extracted from Table F2-2 in Appendix F2. The Plan Area sediment delivery estimates are based on the inventoried rates (cubic yards per mile) multiplied by an estimate of the total miles of roads within the Plan Area.

Table F3-2. Calculation of the sediment stabilization effort for the Plan Area.[1]

	Watercourse Crossings	Landslides	Other	Total
Total sediment (yd^3)	4,903,664	1,456,862	75,956	6,436,482
Cost/yd^3	$15.69	$7.57	$54.24	$14.31
Total cost	$76,938,495	$11,028,445	$4,119,829	$92,086,769
48% of total sediment	2,329,708	692,148	36,086	3,057,943
Cost/yd^3	$13.45	$6.49	$46.49	$12.26
41% of total cost	$31,331,250	$4,491,054	$1,677,696	$37,500,000
Sediment stabilization effort (yd^3)	155,314	46,143	2,406	203,863
Cost/yd^3	$13.45	$6.49	$46.49	$12.26
Annual cost	$2,088,750	$299,404	$111,846	$2,500,000

1 The cost per cubic yard figures in this table is slightly larger than those shown Table F2-3. These cost adjustments were made to account for an underestimate in the basic data as described in Table F2-6.

Other road-related assumption variables that were assigned distributions (see Table F3-13) include:

- Delivery from road-related landslides
- Delivery from road-related watercourse crossings
- Delivery from road-related “other” sites
- Cost to fix watercourse crossing sites
- Cost to fix landslide sites
- Cost to fix “other” sites
- Road upgrade effectiveness factor

F3.4 WATERSHED SEDIMENT SUMMARIES AND PLAN AREA SEDIMENT DELIVERY ESTIMATES

Sediment delivery summaries for the Hunter Creek, Salmon Creek, Litter River, and Upper Mad River pilot watersheds are shown in Tables F3-3, F3-4, F3-5, and F3-6, respectively. These tables are based on the results of an assessment of long-term landslide sediment presented in Appendix F1. The sediment delivery summaries show how sediment is partitioned among three sources of sediment—roads, shallow landslides, and deep-seated landslides—contained in the conceptual model. (Note: The Upper Mad River watershed summary only shows sediment delivery estimates for deep-seated landslides.) The purpose of this section is to explain how these data were combined to derive appropriate sediment delivery estimates for the Plan Area.

Tables F3-3, F3-4, F3-5, and F3-6 are largely restatements of results presented in Appendix F1 (see Tables 15, 16, and 17) in a format that conveniently summarizes the modeled sources of sediment delivery and shows the reduction in sediment delivery that is expected to occur as a result of implementing the Plan's conservation measures. The road-related sediment delivery estimates, as discussed in detail below, are based on data presented in Appendices F1 and F2.

The data from these four pilot watersheds were combined to derive sediment delivery estimates for the Plan Area. This was accomplished by developing factors (or weights) that represent how much of the Plan Area is similar to each of the pilot watersheds. Such Plan Area factors were developed by examining the landslide processes acting within each of the unstudied sub-watersheds based on a review of terrain maps, geologic maps, available landslide maps, discussions with Simpson foresters, and observations made by a Registered Geologist during a year 2000 helicopter flyover of the Simpson property. The percentages of each pilot watershed were then assigned to each sub-watershed based on the criteria listed above. The results of this Delphi technique exercise are summarized in Table F3-7. The last row of Table F3-7 shows the Plan Area factors. This row was determined by multiplying the sub-watershed acreages by the pilot watershed percentages and then summing the results. Note that there are separate factors for shallow landslides and deep-seated landslides.

To illustrate the use of the Plan Area factors in Table F3-7 (see the last row of the table), consider the calculation of the expected sediment delivery that will come from Plan Area RMZs prior to implementation of the Plan (Pre-Plan estimates). To do this, the data from these three representative watersheds will be combined to develop an estimate for 394,675 timberland acres. From Tables F3-3, F3-4, and F3-5, the sediment delivery estimates for RMZ areas are 235 yd^3/yr, 798 yd^3/yr, and 768 yd^3/yr for the Hunter Creek, Salmon Creek, and Little River watersheds, respectively. The total acres within each of these watersheds, also shown in the tables, are 10,126 acres, 7,889 acres, and 28,755 for the Hunter Creek, Salmon Creek, and Little River watersheds, respectively. The appropriate equation, therefore, is

$$13{,}200\ yd^3/yr = 394{,}675\ \text{acres} * [0.312*(235\ yd^3/yr \div 10{,}126\ \text{acres}) \\ + 0.105*(798\ yd^3/yr \div 7{,}889\ \text{acres}) \\ + 0.583*(768\ yd^3/yr \div 28{,}755\ \text{acres})]$$

Table F3-3. **Hunter Creek sediment delivery summary. SMZ buffer widths are based on a cumulative sediment delivery volume of 80%. The sediment numbers in the table represent the total annual sediment delivery expected from the watershed. Note that natural and management related sediment delivery estimates are provided for both the pre- and post-Plan conditions.**

							Pre-Plan			Post-Plan		
	Sediment Split (roads vs. harvest)	Sediment Split	Mgt vs. Natural Sediment Under Current Practices	Effect of Plan Measures	Percent Acres in Zone	Acres in Zone	Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)	Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)
Roads	54.8%	100.0%	100.0%	96.1%			4,465	0	4,465	173	0	173
Hillslope Shallow Landslides (extracted from Tables 15 and 16 in Appendix F1)	42.7%											
RMZs		6.8%	19.0%	95.4%	14.7%	1,489	235	191	45	193	191	2
SMZs		20.1%	50.0%	58.6%	3.5%	356	697	349	349	493	349	144
SHALSTAB		34.2%	60.0%	60.0%	13.1%	1,324	1,190	476	714	762	476	286
Other		39.0%	50.0%	0.0%	65.4%	6,621	1,355	677	677	1,355	677	677
Deep Seated Landslides (extracted from Table 17 in Appendix F1)	2.6%											
DSL Total		100.0%	2.6%	15.0%	3.3%	338	210	205	5	209	205	5
Total Sediment Delivery (Note that Total Acres is shown in one column)						10,126	8,153	1,898	6,255	3,184	1,898	1,287

Table F3-4. **Salmon Creek sediment delivery summary. SMZ buffer widths are based on a cumulative sediment delivery volume of 60%. The sediment numbers in the table represent the total annual sediment delivery expected from the watershed. Note that natural and management related sediment delivery estimates are provided for both the pre- and post-Plan conditions.**

	Sediment Split (roads vs. harvest)	Sediment Split	Mgt vs. Natural Sediment Under Current Practices	Effect of Plan Measures	Percent Acres in Zone	Acres in Zone	Pre-Plan			Post-Plan		
							Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)	Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)
Roads	23.6%	100.0%	100.0%	96.1%			842	0	842	33	0	33
Hillslope Shallow Landslides (extracted from Tables 15 and 16 in Appendix F1)	55.5%											
RMZs		40.2%	23.8%	99.8%	8.8%	698	798	608	190	608	608	0
SMZs		0.1%	50.0%	60.0%	0.3%	21	2	1	1	1	1	0
SHALSTAB		13.5%	60.0%	60.0%	3.0%	234	268	107	161	172	107	64
Other		46.2%	50.0%	0.0%	54.2%	4,279	916	458	458	916	458	458
Deep Seated Landslides (extracted from Table 17 in Appendix F1)	20.9%											
DSL Total		100.0%	5.6%	15.0%	33.7%	2,657	748	706	42	741	706	35
Total Sediment Delivery (Note that Total Acres is shown in one column)						7,889	3,574	1,880	1,693	2,471	1,880	591

Table F3-5. Little River sediment delivery summary. SMZ buffer widths are based on a cumulative sediment delivery volume of 60%. The sediment numbers in the table represent the total annual sediment delivery expected from the watershed. Note that natural and management related sediment delivery estimates are provided for both the pre- and post-Plan conditions.

	Sediment Split (roads vs. harvest)	Sediment Split	Mgt vs. Natural Sediment Under Current Practices	Effect of Plan Measures	Percent Acres in Zone	Acres in Zone	Pre-Plan			Post-Plan		
							Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)	Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)
Roads	40.4%	100.0%	100.0%	96.1%			2,377	0	2,377	92	0	92
Hillslope Shallow Landslides (extracted from Tables 15 and 16 in Appendix F1)	29.4%											
RMZs		44.3%	23.1%	99.4%	13.3%	3,815	768	590	177	592	590	1
SMZs		1.8%	50.0%	60.0%	0.3%	74	31	16	16	22	16	6
SHALSTAB		11.2%	60.0%	60.0%	2.5%	725	195	78	117	125	78	47
Other		42.7%	50.0%	0.0%	65.5%	18,830	740	370	370	740	370	370
Deep Seated Landslides (extracted from Table 17)	30.2%											
DSL Total		100.0%	3.2%	15.0%	18.5%	5,311	1,779	1,722	56	1,770	1,722	48
Total Sediment Delivery (Note that Total Acres is shown in one column)						28,755	5,889	2,776	3,113	3,340	2,776	564

Table F3-6. **Upper Mad River sediment delivery summary. The sediment numbers in the table represent the total annual sediment delivery expected from the watershed. Note that natural and management related sediment delivery estimates are provided for both the pre- and post-Plan conditions. This is a "partial" summary because only sediment from deep seated landslides is included in the table.**

							Pre-Plan			Post-Plan		
	Sediment Split (roads vs. harvest)	Sediment Split	Mgt vs. Natural Sediment Under Current Practices	Effect of Plan Measures	Percent Acres in Zone	Acres in Zone	Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)	Sediment Delivery (cu yds/yr)	Natural Sediment (cu yds/yr)	Mgt Sediment (cu yds/yr)
Roads												
Hillslope Shallow Landslides												
RMZs												
SMZs												
SHALSTAB												
Non-Protected Areas												
Deep Seated Landslides (extracted from Table 17 in Appendix F1)	100.0%											
DSL Total		100.0%	14.9%	15.0%	41.2%	1,918	902	767	135	882	767	115
Partial Sediment Delivery (Note that Total Acres is shown in one column)						4,658	902	767	135	882	767	115

Table F3-7. Factors used to derive Plan Area sediment delivery estimates from the four pilot watersheds. The factors in this table represent that portion of the Plan Area that can be adequately characterized.

Road Planning Watershed	Acres	HPA Group	Shallow Landslide Division			Deep-Seated Landslide Division			
			SC	LR	HC	SC	LR	HC	MR
South Fork Winchuck	7,859	SR	50%	50%		100%			
Dominie	4,024	SR	50%	50%		100%			
Rowdy	8,342	SR	50%	50%		100%			
Little Mill	4,888	SR	50%	50%		100%			
Wilson	6,370	CKLM		50%	50%			100%	
Goose	10,250	CKLM			100%			100%	
Hunter	11,656	CKLM			100%			100%	
Terwer	21,592	CKLM			100%			100%	
Hoppaw	5,172	CKLM		100%				100%	
Waukell	2,815	CKLM		100%				100%	
McGarvey	4,867	CKLM		100%				100%	
Omagar	5,903	CKLM		50%	50%			100%	
Ah Pah	10,037	CKLM		50%	50%			100%	
Bear	6,199	CKLM		50%	50%			100%	
Surper	6,493	CKLM		50%	50%			100%	
Tectah	12,385	CKLM		25%	75%		25%	75%	
West Fork Blue	5,634	CKLM			100%			100%	
Blue	9,760	CKLM		50%	50%		75%		25%
Pecwan	15,692	KOR		50%	50%		75%		25%
Mettah	9,077	KOR		25%	75%		25%	75%	
Joe Marine	8,105	KOR		50%	50%		75%		25%
Roach	19,847	KOR		25%	75%		25%	75%	
Tully	12,727	KOR		25%	75%		25%	75%	
Panther	9,689	KOR		100%			75%		25%
Dolly Varden	13,543	KOR		100%			75%		25%
Noisy	9,719	KOR		100%			75%		25%
McDonald	2,040	KOR		100%			100%		
NF Maple	12,154	KOR		100%			100%		
Maple	18,236	KOR		100%			100%		
Coastal Tribs	7,756	KOR		100%			100%		
North Little River	6,846	KOR		100%			100%		
East Little River	7,658	KOR		100%			100%		
South Little River	11,535	KOR		100%			100%		
Lindsay	8,740	KOR		100%			100%		
Dry	9,487	KOR		50%	50%			100%	
Canon	13,566	KOR		100%			100%		
Basin	5,341	KOR		100%			100%		
Long Prairie	17,435	KOR		100%			100%		
Gosinta	5,418	KOR		100%			100%		
Boulder	17,711	KOR	50%	50%					100%
Jacoby	3,608	KOR		100%			100%		
Salmon	6,258	HUM	100%			100%			
Ryan	7,702	HUM	100%			100%			
Eel Van Duzen	7,932	HUM	100%			100%			
Plan Area Factors			10.5%	58.3%	31.2%	11.4%	44.6%	35.7%	8.3%

SC: Salmon Creek; LR: Little River; MR: Mad River, HC: Hunter Creek
SR: Smith River, CKLM: Coastal Klamath; KOR: Korbel; HUM: Humboldt Bay

Table F3-8. Pre- and post-Plan sediment delivery for the Plan Area. Sediment delivery figures represent cubic yards/year. Also included is an estimate of the sediment stabilization effort that can be achieved with an annual expenditure of $2.5 million. Road-related sediment "saved" differs from the stabilization effort because not all sediment from watercourse crossings and "other" sites is expected to deliver.

	Roads	RMZs	SMZs	SHAL-STABs	DSLs	Subtotal of All Zones	Outside of Zone	Total
Sediment Delivery--Pre-Plan	77,779	13,200	8,748	17,451	24,442	141,621	27,220	168,841
Percent of Total Sediment	46.1%	7.8%	5.2%	10.3%	14.5%	83.9%	16.1%	100.0%
Sediment Delivery--Pre-Plan/Acre[1]	4.43	0.25	1.74	0.75	0.37	0.97	0.11	0.43
Sediment Delivery--Post-Plan	3,012	10,276	6,182	11,169	24,201	54,840	27,220	82,060
Percent of Total Sediment	3.7%	12.5%	7.5%	13.6%	29.5%	66.8%	33.2%	100.0%
Sediment Delivery--Post-Plan/Acre[1]	0.17	0.20	1.23	0.48	0.37	0.37	0.11	0.21
"Natural" Sediment	0	10,241	4,374	6,981	22,832	44,428	13,610	58,038
Sediment Stabilization Effort	203,863							
Sediment "Saved"	97,648	2,924	2,566	6,282	242	109,662	N/A	109,662
Percent of Total	89.0%	2.7%	2.3%	5.7%	0.2%	100.0%	N/A	100.0%
Management Related Sediment (%)	100.0%	22.4%	50.0%	60.0%	6.6%			
Effectiveness	96.1%	22.1%	29.3%	36.0%	1.0%			
Do they fail with wood?	No	Yes	Yes	Maybe	Maybe			

[1] Calculations for roads are based on an estimate of "roaded acres" of 17,540 acres.

This simple calculation illustrates how the data in Tables F3-3, F3-4, F3-5, and F3-6 were combined to produce the non-road numbers shown in Table F3-9. Sediment delivery for roads is the next topic to be covered.

To derive an estimate of the sediment delivery associated with roads for the Plan Area it was necessary to integrate the road-related sediment delivery data provided in Appendices F1 and F2. Data presented in Appendix F1 were used to estimate road-related sediment delivery associated with shallow landslides. Data presented in Appendix F2 were used to estimate delivery from watercourse crossings as well as "other" sites. The calculations for the Plan Area are as follows:

The estimate based on Appendix F1 data (38,202 yd^3/year) only includes road-related sediment delivered from shallow landslides. This estimate was deemed to underestimate the contribution from road-related shallow landslides (not all shallow landslides can be observed on aerial photos) so a triangular distribution was developed to (1) account for this underestimate and (2) provide a range of estimates used in the Monte Carlo simulation exercise. The triangular distribution set up for the road-related shallow landslide component is shown in the VARIABLE RANGES section of this appendix (see the "Delivery from road-related landslides" assumption variable in Table F3-13) but is repeated in Table F3-9 to demonstrate the calculations. In summary, it was estimated that the road-related shallow landslide component was most likely under-represented by 15%. Thus,

$$43{,}933 \text{ yd}^3\text{/year} = 115\% \times 38{,}202 \text{ yd}^3\text{/year}$$

The minimum under-representation was thought to be 10% whereas the maximum under-representation was thought to be 30%.

Table F3-9. Road-related sediment delivery for the Plan Area.

	Watercourse Crossings (yd^3/year)	Shallow Landslides (yd^3/year)	Other Sites (yd^3/year)	Total (yd^3/year)
Minimum	16,672	42,023	911	59,607
Likeliest	31,383	43,933	1,139	76,456
Mean	31,383	45,206	1,190	77,779
Maximum	46,094	49,663	1,519	97,277
Estimate based on Appendix F1		38,202		

The expected delivery from watercourse crossings was assessed by PWA and is described in Appendix F2. PWA does not expect that all the sediment associated with high and moderate priority treatment sites (the 4,903,664 yd^3 shown in Table F3-1) will deliver within the 50-year term of the Plan. Their likeliest estimate was 32%. On an annual basis this equates to 31,383 yd^3/year. The calculation is as follows:

$$31{,}383 \text{ yd}^3\text{/year} = 32\% \times (4{,}903{,}664 \text{ yd}^3\text{/50 years})$$

The range associated with this variable (see the “Delivery from road-related steam crossings” assumption in the VARIABLE RANGES section of this appendix) may have a minimum of 17% and a maximum of 47%, which produces the range of estimates shown in Table F3-9 (16,672 yd^3/year to 46,094 yd^3/year). Furthermore, since watercourse crossing sediment delivery is thought to be correlated with shallow landslide sediment delivery, these variables were assumed to have a correlation coefficient of 0.75 for the purposes of conducting the Monte Carlo simulation exercise. (Rainfall often initiates landslides and causes watercourse crossings to fail.)

PWA also assessed the potential sediment delivery from “other” sites. Their review resulted in the values reported in the table above. In this case, PWA expects that 60% to 100% (with the likeliest at 75%) of this sediment may deliver within the 50-year term of the Plan. The calculation of the likeliest value is as follows:

$$1{,}139\ yd^3/\text{year} = 75\% \times (75{,}956\ yd^3/50\ \text{years})$$

Delivery from these “other” sites was also thought to be correlated with delivery from shallow landslides and so these variables were assigned a 0.75 correlation coefficient for the purposes of conducting the Monte Carlo simulation exercise.

Based on the mean estimates provided in Table F3-9, the total expected sediment delivery for the Plan Area from roads is the sum of three components:

Total sediment delivery from roads = sediment delivery from landslides
+ sediment delivery from watercourse crossings
+ sediment delivery from “other” sites

$$77{,}779\ yd^3/\text{year} = 45{,}206\ yd^3/\text{year} + 31{,}383\ yd^3/\text{year} + 1{,}190\ yd^3/\text{year}$$

The 77,779 yd^3/year is an important estimate and is a key figure in Table F3-8.

In addition to the variables already mentioned, several other variables associated with the landslide data and road-related sediment source studies and were assigned appropriate ranges for purposes of conducting the Monte Carlo simulation exercise. These variables and their ranges are provided in the VARIABLE RANGES section of this appendix.

Taken together, the various sources of data and sediment delivery assessments were combined to produce sediment delivery estimates for the Plan Area (Table F3-8).

From an efficiency and effectiveness perspective, the Road Implementation Plan offers a very efficient and effective means for reducing sediment delivery to watercourses (Table F3-8). It is efficient because it “saves” the greatest amount of sediment (89.0%) without setting aside merchantable trees. It is effective (96.1% effectiveness shown in Table F3-8) because approximately 90% of the high and moderate priority sites will be treated at some time during the term of the Plan and will no longer contribute sediment to Plan Area watercourses. It should be noted, however, that the Monte Carlo simulation model actually allows the effectiveness to vary between 94.2%1 and 96.1% (see the assumption variable called Road Upgrade Effectiveness Factor in Tables F3-13 and F3-14).

Due to the model's flexible structure, Simpson was able to compare the efficiency, effectiveness, and economic consequences of a wide range of conservation measures. It should be emphasized, however, that the conservation needs of the covered species were deemed to be of paramount importance and scenarios (sets of conservation measures) that did not adequately meet these needs were rejected by the Plan developers.

F3.5 BENEFITS OF THE PLAN PROPOSAL

Currently, Simpson stabilizes sediment associated with problematic legacy road sites at an annual rate of about 82,000 cubic yards. Based on Simpson's anticipated harvest levels over the next 15 years, an appropriate average annual projected stabilization rate would be 81,545 cubic yards. (Note: This assumes that the relationship between harvest level and sediment stabilization effort remains constant over this period.) The expenditure of $2.5 million on an annual basis for the first 15 years of the Plan will result in the stabilization of 203,863 cubic yards of potential sediment on an annual basis over the first 15 years of the Plan. These figures are summarized in Table F3-10.

Table F3-10. A comparison of road-related sediment stabilization efforts with and without the Plan.

Year	No Plan Sediment Stabilization Program (cubic yards)	Plan Proposal Sediment Stabilization Program (cubic yards)
2002	81,545	203,863
2003	81,545	203,863
2004	81,545	203,863
2005	81,545	203,863
2006	81,545	203,863
2007	81,545	203,863
2008	81,545	203,863
2009	81,545	203,863
2010	81,545	203,863
2011	81,545	203,863
2012	81,545	203,863
2013	81,545	203,863
2014	81,545	203,863
2015	81,545	203,863
2016	81,545	203,863
Total	1,223,177	3,057,943
% of "pile of dirt"	19%	48%

1 A 94.2% road upgrade effectiveness factor implies that 85% of the high and moderate priority sites were appropriately treated during the term of the Plan.

Over the next 15 years, the two scenarios produce vastly different results. The “No Plan” scenario only stabilizes 19% of the total (i.e., 1,223,177 cubic yards divided by 6,436,482 cubic yards) whereas the Plan Proposal stabilizes 48% of the total—a 250% improvement relative to the “No Plan” scenario.

The two scenarios also have dramatically different sediment delivery rates over the next 50 years. For example, in year 15 (2016) the “No Plan” delivery rate from roads is 76% greater than the Plan Proposal delivery rate (44,754 cubic yards per year as compared to 25,463 cubic yards per year). The differences become even larger as time passes. By year 30 (2031) the “No Plan” delivery rate is 174% greater than the Plan Proposal delivery rate (23,627 cubic yards per year as compared to 8,635 cubic yards per year).

The Plan curves shown in Figure F3-2 show the road-related sediment component approaching 3,000 cubic yards during the last decade of the Plan. This implies that the Road Implementation Plan will be 96.1% effective in controlling sediment associated with high and moderate priority treatment sites.

Table F3-11 summarizes the differences between the No Plan and Plan Proposal scenarios in terms of the number of Coho generations that may benefit from an accelerated road repair program.

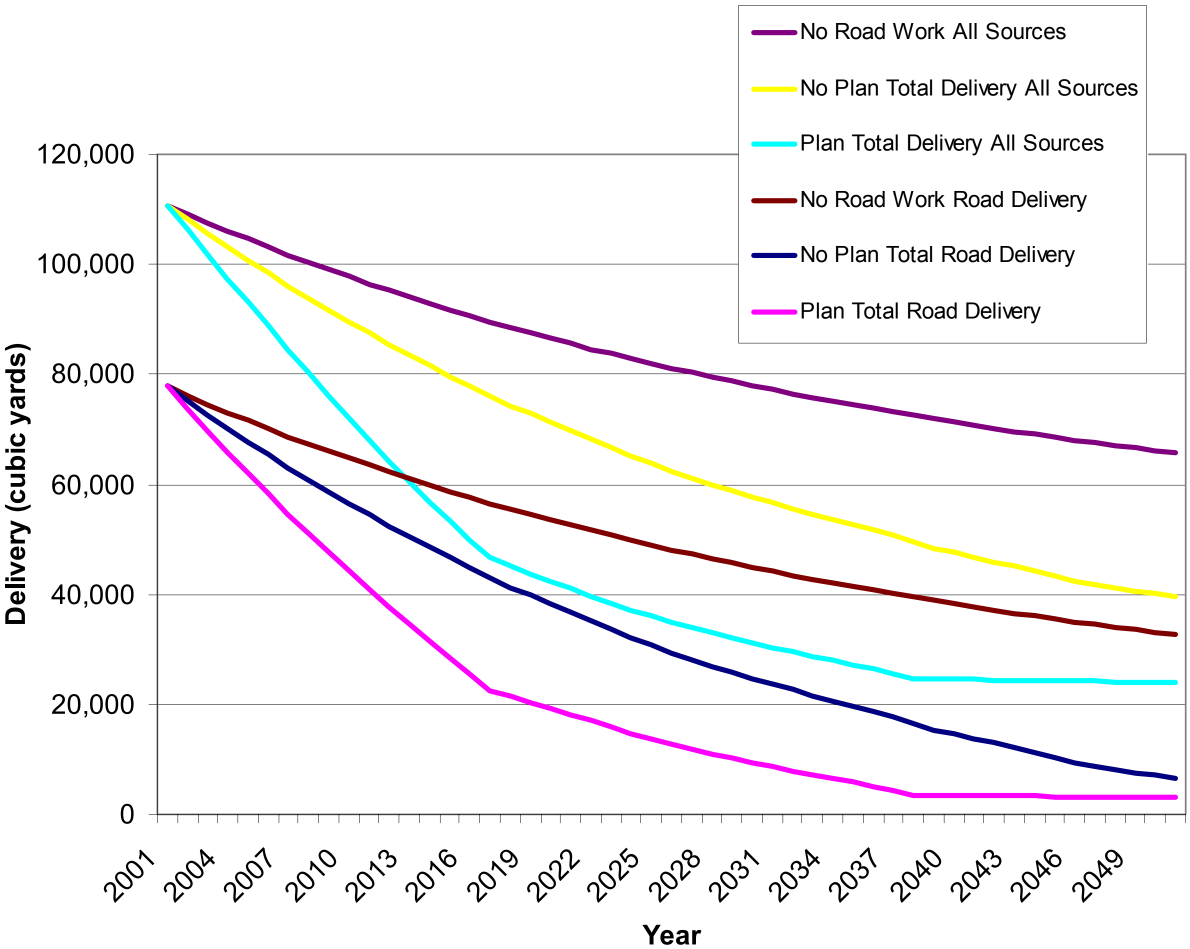
Table F3-11. Coho generations that benefit from the Plan’s accelerated road repair and sediment stabilization program.

Scenario	% Pile of Dirt Stabilized	Timeframe (years)	Difference in years	No. of Coho generations that benefit
No Plan	48%	38.0		
Plan Proposal	48%	15.0	23	7.7

This type of analysis shows that the Plan’s accelerated road repair and sediment stabilization program can provide benefits to approximately 7.7 generations (23 years divided by 3 years) of Coho salmon. Note that this is from road prescriptions alone. When coupled with the benefits of the other conservation measures, a greater number of fish generations benefit.

Finally, with respect to total sediment delivery from all sources, the No Plan delivery rate in year 50 is comparable to the Plan Proposal’s delivery rate in year 15—a 35 year benefit (compare highlighted entries in Table F3-12).

Figure F3-2. Sediment delivery estimates over the term of the Plan. The "No Road Work" curves are based on the assumption that no money is spent repairing the high and moderate priority treatment sites over the next 50 years.



Note: Road-related sediment Includeds sediment from high and moderate priority sites only.

Table F3-12. Key sediment annual delivery rates at different points in time for both the "No Plan" and Plan Proposal scenarios.

	Year	Roads (1000 yd^3/yr)	Harvest Units (1000 yd^3/yr)	Natural (1000 yd^3/yr)	Total Delivery (1000 yd^3/yr)	Total as Compared to Background (i.e., Natural)	Roads Above Background
No Plan	0	78	33	58	169	2.9	1.3
No Plan	15	45	33	58	136	2.3	0.8
No Plan	50	7	33	58	**98**	1.7	0.1
Plan Proposal	0	78	33	58	169	2.9	1.3
Plan Proposal	15	25	24	58	**108**	1.9	0.4
Plan Proposal	50	3	21	58	82	1.4	0.1

F3.6 CALCULATION OF ACREAGE PLACED IN THE ADAPTIVE MANAGEMENT ACCOUNT

The acres within the Adaptive Management Reserve Account (AMRA) were established to address the risk associated with the management prescriptions for SMZs. Based on current GIS data, there are approximately 8,850 acres in SMZs. The acres contained within these zones will be managed using uneven-aged silviculture, defined within the Glossary of the Plan, as single tree selection. By applying single tree selection, Simpson will harvest approximately 65% of the conifer volume contained within these SMZs. Thus, approximately 35% of the volume will be retained within these zones to produce conservation benefits as the Plan is implemented over time. As proposed the prescriptions will represent approximately 3,100 acres (or 0.35 x 8,850 acres) of fully stocked timberland. To reduce the risk of potentially underestimating the protection needs of SMZs, Simpson will allow up to a 50% increase in the retained volume in SMZs. In terms of fully stocked acres, this will equate to 1,550 acres (0.50 x 3,100 acres = 1,550 acres) that can be applied to these zones. The opening AMRA balance t of 1,550 fully-stocked acres may increase or decrease in response to findings through the Effectiveness Monitoring programs outlined in Section 6.3.

F3.7 MONTE CARLO SIMULATION

The sediment delivery model for the Plan Area was subjected to a statistical procedure known as Monte Carlo simulation. This technique allows the analyst to assign ranges (or a probability density function) to key parameters (assumption variables) and to analyze the effects (the range of results) on forecast variables. The technique begins by randomly drawing parameter values from user-defined ranges and then the forecast variables are determined. This procedure is executed many times (10,000 for this exercise) and the results are saved so probability distributions can be displayed for the forecast variables. The ultimate purpose is to analyze how sensitive forecast variables are to changes in key parameters. The primary forecast variable in this exercise was an index of sediment "saved" (i.e., prevented from entering a watercourse) annually under the "No Plan" scenario as compared to the "With Plan" scenario. The benefit of using a tool like Monte Carlo simulation is that it allows the analyst to simultaneously vary a wide array of assumption variables to perform sensitivity analyses. Simplistic approaches to sensitivity analysis, like setting all assumption variables to their minimum or maximum values, may generate results in the forecast variables that are misleading because such an outcome is highly unlikely. Monte Carlo simulation produces forecast distributions that show which outcomes are most likely (the peaks in the distributions) and which outcomes are statistically unlikely (the tails of the forecast distributions).

F3.7.1 Monte Carlo Simulation Results and Variable Ranges

The complete output file from the Monte Carlo exercise is reproduced in Table F3-13. The table shows the results for the following six forecast variables:

1. Total Sediment Delivery
2. Total Sediment Stabilized
3. Road-Related Sediment Delivery
4. Road-Related Sediment Stabilized
5. No Plan Total Sediment Stabilized (compare to #2)
6. No Plan Road-Related Sediment Stabilized (compare to #4)

The first four forecast variables summarize results based on the implementation of the Plan measures. The last two forecast variables were included to provide some insight into what happens under the No Plan scenario. These No Plan forecast variables can be compared to their Plan counterparts to better understand the differences between the Plan and No Plan scenarios.

The table also includes a listing of 46 assumption variables and their ranges, some of which have been described above in this appendix. The entire output was reproduced here primarily to fully document the ranges associated with the assumption variables. The assumption variables listed in Table F3-13 are allowed to vary for a variety of reasons. The ranges associated with these assumption variables may be based on data, published literature, and/or professional judgment. Table F3-14 is included to indicate the basis for each of the assumption variables. Please review Appendix F1 and Appendix F2 for additional details.

Simpson assessed the differences in total sediment saved annually (over the next 15 years) under the No Plan scenario as compared to the Plan scenario. The appropriate forecast variables to inspect in Table F3-13 are “Total Sediment Stabilized” and “No Plan Total Sediment Stabilized”. A brief summary of these forecast variables is as follows:

Sediment Statistic	No Plan Total Sediment Stabilized (yd^3/year)	Plan Total Sediment Stabilized (yd^3/year)
Mean	42,575	114,973
Standard Deviation	1,534	4,801
Minimum	38,314	99,938
Maximum	47,093	129,822

These numbers indicate that the two scenarios are vastly different in a statistical sense. Note that the range of these two distributions does not overlap (i.e., the maximum No Plan value is less than the minimum of the Plan value). Thus, even considering the range (or uncertainty) of all the assumption variables, this key forecast variable shows that the Plan will result in significant sediment savings relative to the No Plan scenario.

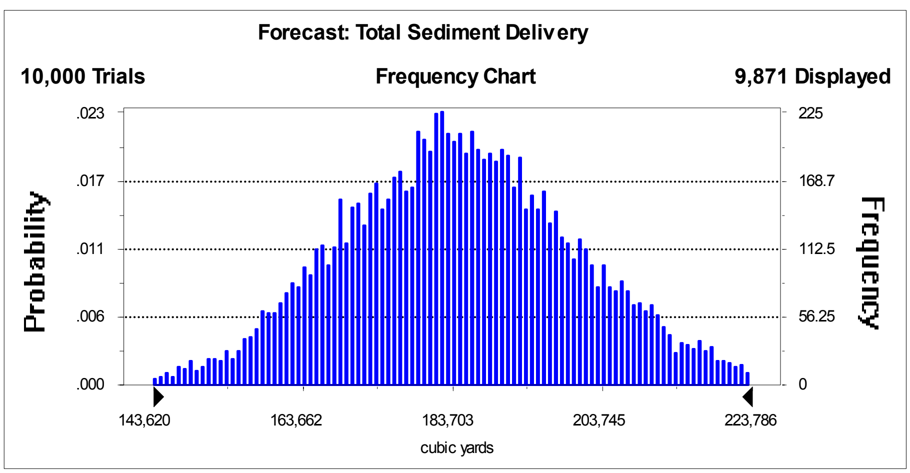
Table F3-13. Monte Carlo simulation results and assumption variable ranges. The program used to conduct the analysis is called Crystal Ball. The following is the unaltered output from that program.

Crystal Ball Report -- Option 1-SEL-b
Simulation started on 3/17/02 at 16:33:26
Simulation stopped on 3/17/02 at 16:38:31

Forecast: Total Sediment Delivery **Cell: K19**

Summary:
Display Range is from 143,620 to 223,786 cubic yards
Entire Range is from 131,750 to 263,258 cubic yards
After 10,000 Trials, the Std. Error of the Mean is 161

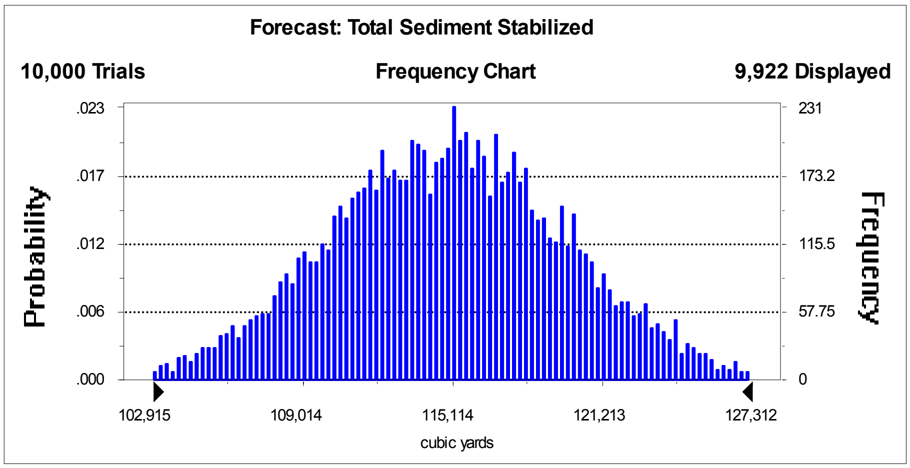
Statistics:	Value
Trials	10000
Mean	184,974
Median	184,520
Mode	---
Standard Deviation	16,070
Variance	258,234,756
Skewness	0.16
Kurtosis	3.01
Coeff. of Variability	0.09
Range Minimum	131,750
Range Maximum	263,258
Range Width	131,509
Mean Std. Error	160.70



Forecast: Total Sediment Stabilized **Cell: K25**

Summary:
Display Range is from 102,915 to 127,312 cubic yards
Entire Range is from 99,938 to 129,822 cubic yards
After 10,000 Trials, the Std. Error of the Mean is 48

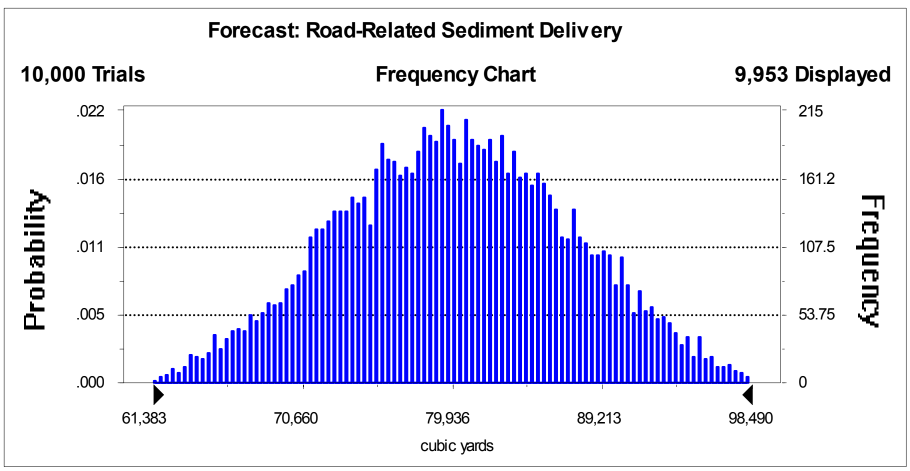
Statistics:	Value
Trials	10000
Mean	114,973
Median	115,016
Mode	---
Standard Deviation	4,801
Variance	23,047,670
Skewness	0.02
Kurtosis	2.77
Coeff. of Variability	0.04
Range Minimum	99,938
Range Maximum	129,822
Range Width	29,884
Mean Std. Error	48.01



Forecast: Road-Related Sediment Delivery **Cell: C19**

Summary:
Display Range is from 61,383 to 98,490 cubic yards
Entire Range is from 58,805 to 101,916 cubic yards
After 10,000 Trials, the Std. Error of the Mean is 73

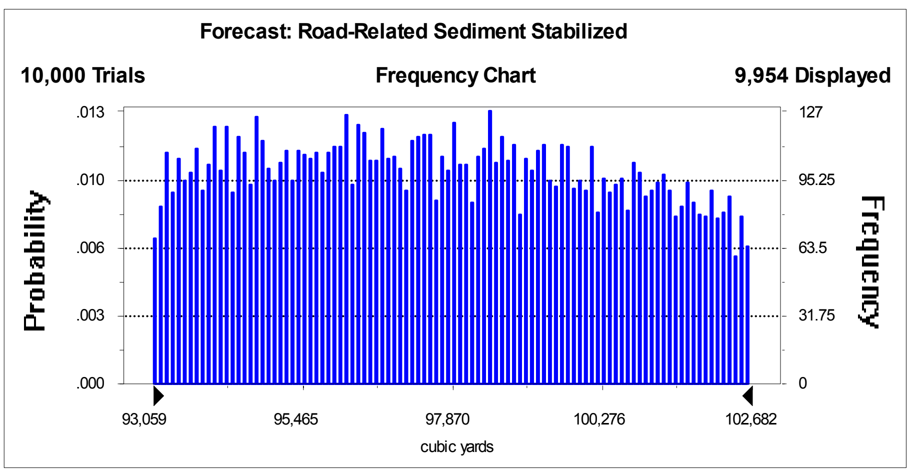
Statistics:	Value
Trials	10000
Mean	80,183
Median	80,142
Mode	---
Standard Deviation	7,258
Variance	52,676,578
Skewness	0.02
Kurtosis	2.61
Coeff. of Variability	0.09
Range Minimum	58,805
Range Maximum	101,916
Range Width	43,111
Mean Std. Error	72.58



Forecast: Road-Related Sediment Stabilized **Cell: C25**

Summary:
Display Range is from 93,059 to 102,682 cubic yards
Entire Range is from 93,026 to 102,745 cubic yards
After 10,000 Trials, the Std. Error of the Mean is 27

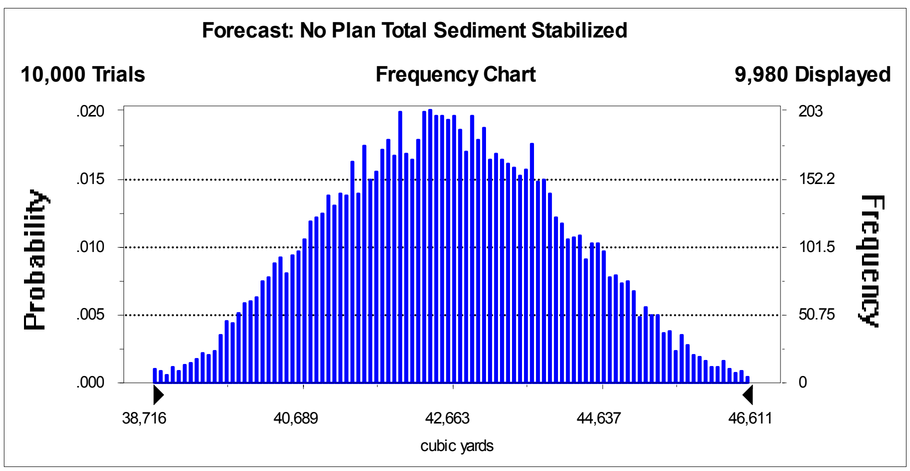
Statistics:	Value
Trials	10000
Mean	97,705
Median	97,638
Mode	---
Standard Deviation	2,695
Variance	7,261,524
Skewness	0.07
Kurtosis	1.86
Coeff. of Variability	0.03
Range Minimum	93,026
Range Maximum	102,745
Range Width	9,719
Mean Std. Error	26.95



Forecast: No Plan Total Sediment Stabilized **Cell: K3**

Summary:
Display Range is from 38,716 to 46,611 cubic yards
Entire Range is from 38,314 to 47,093 cubic yards
After 10,000 Trials, the Std. Error of the Mean is 15

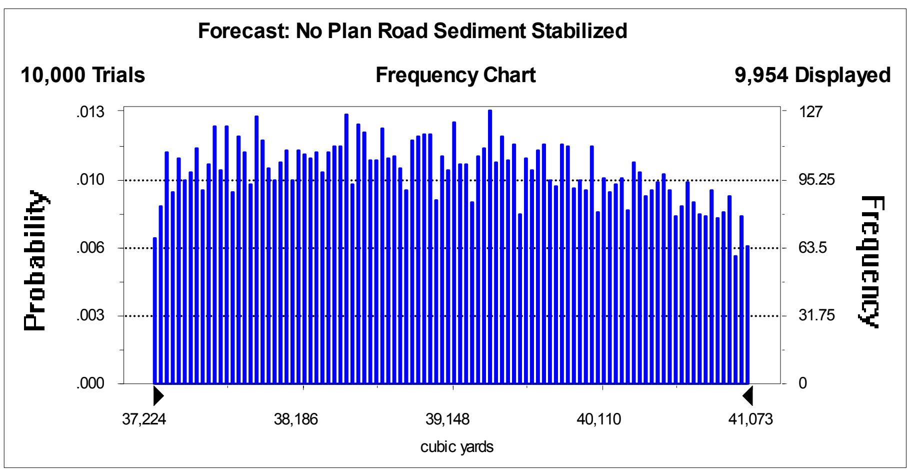
Statistics:	Value
Trials	10000
Mean	42,585
Median	42,569
Mode	---
Standard Deviation	1,534
Variance	2,353,559
Skewness	0.05
Kurtosis	2.52
Coeff. of Variability	0.04
Range Minimum	38,314
Range Maximum	47,093
Range Width	8,780
Mean Std. Error	15.34



Forecast: No Plan Road Sediment Stabilized **Cell: K1**

Summary:
Display Range is from 37,224 to 41,073 cubic yards
Entire Range is from 37,210 to 41,098 cubic yards
After 10,000 Trials, the Std. Error of the Mean is 11

Statistics:	Value
Trials	10000
Mean	39,082
Median	39,055
Mode	---
Standard Deviation	1,078
Variance	1,161,844
Skewness	0.07
Kurtosis	1.86
Coeff. of Variability	0.03
Range Minimum	37,210
Range Maximum	41,098
Range Width	3,888
Mean Std. Error	10.78



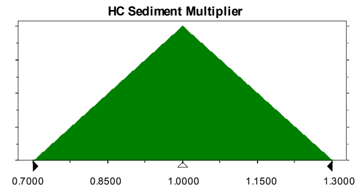
Assumptions

Assumption: HC Sediment Multiplier
[geology sediment model ver 7 best.xls]HC data - Cell: D26

Triangular distribution with parameters:

Minimum	0.7000
Likeliest	1.0000
Maximum	1.3000

Selected range is from 0.7000 to 1.3000

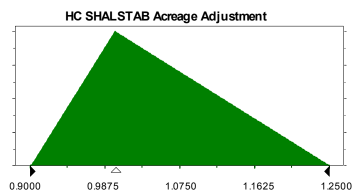


Assumption: HC SHALSTAB Acreage Adjustment
[geology sediment model ver 7 best.xls]HC data - Cell: G4

Triangular distribution with parameters:

Minimum	0.9000	
Likeliest	1.0000	
Maximum	1.2500	(=E4)

Selected range is from 0.9000 to 1.2500



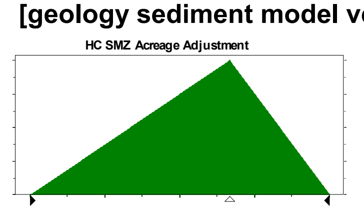
Assumption: HC SMZ Acreage Adjustment
[geology sediment model ver 7 best.xls]HC data - Cell: G3

Triangular distribution with parameters:

Minimum	1.0000	
Likeliest	2.0000	
Maximum	2.5000	(=E3)

Selected range is from 1.0000 to 2.5000

Assumption: HC SMZ Acreage Adjustment (cont'd)
[geology sediment model ver 7 best.xls]HC data - Cell: G3



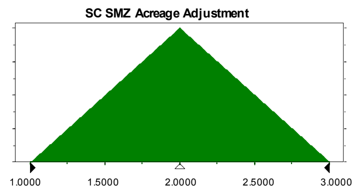
Assumption: SC SMZ Acreage Adjustment

[geology sediment model ver 7 best.xls]SC data - Cell: G3

Triangular distribution with parameters:

Minimum	1.0000	
Likeliest	2.0000	
Maximum	3.0000	(=E3)

Selected range is from 1.0000 to 3.0000



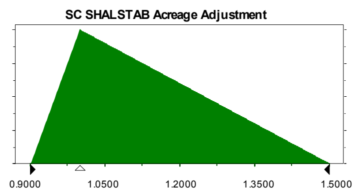
Assumption: SC SHALSTAB Acreage Adjustment

[geology sediment model ver 7 best.xls]SC data - Cell: G4

Triangular distribution with parameters:

Minimum	0.9000	
Likeliest	1.0000	
Maximum	1.5000	(=E4)

Selected range is from 0.9000 to 1.5000



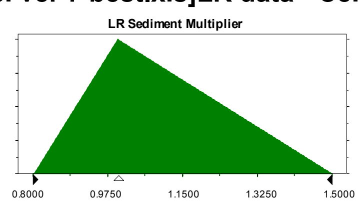
Assumption: LR Sediment Multiplier

[geology sediment model ver 7 best.xls]LR data - Cell: D26

Triangular distribution with parameters:

Minimum	0.8000
Likeliest	1.0000
Maximum	1.5000

Selected range is from 0.8000 to 1.5000



Assumption: LR SMZ Acreage Adjustment

[geology sediment model ver 7 best.xls]LR data - Cell: G3

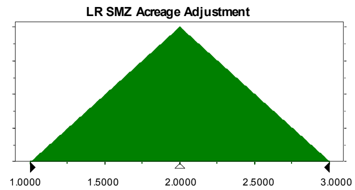
Triangular distribution with parameters:

Minimum	1.0000	
Likeliest	2.0000	
Maximum	3.0000	(=E3)

Selected range is from 1.0000 to 3.0000

Assumption: LR SMZ Acreage Adjustment (cont'd)

[geology sediment model ver 7 best.xls]LR data - Cell: G3



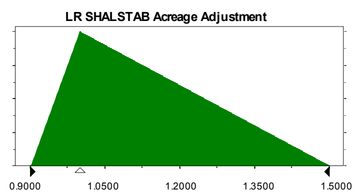
Assumption: LR SHALSTAB Acreage Adjustment

[geology sediment model ver 7 best.xls]LR data - Cell: G4

Triangular distribution with parameters:

Minimum	0.9000	
Likeliest	1.0000	
Maximum	1.5000	(=E4)

Selected range is from 0.9000 to 1.5000



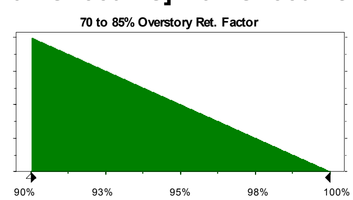
Assumption: 70 to 85% Overstory Ret. Factor

[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S7

Triangular distribution with parameters:

Minimum	90%
Likeliest	90%
Maximum	100%

Selected range is from 90% to 100%

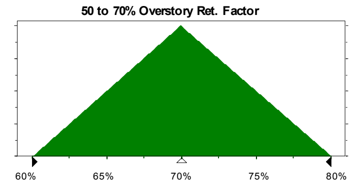


Assumption: 50 to 70% Overstory Ret. Factor
[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S8

Triangular distribution with parameters:

Minimum	60%
Likeliest	70%
Maximum	80%

Selected range is from 60% to 80%

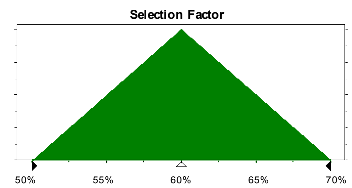


Assumption: Selection Factor
[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S9

Triangular distribution with parameters:

Minimum	50%
Likeliest	60%
Maximum	70%

Selected range is from 50% to 70%

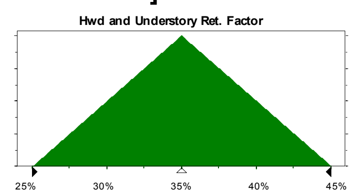


Assumption: Hwd and Understory Ret. Factor
[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S10

Triangular distribution with parameters:

Minimum	25%
Likeliest	35%
Maximum	45%

Selected range is from 25% to 45%

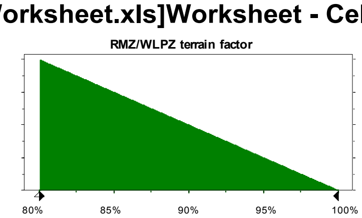


Assumption: RMZ/WLPZ terrain factor
[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S18

Triangular distribution with parameters:

Minimum	80%
Likeliest	80%
Maximum	100%

Selected range is from 80% to 100%

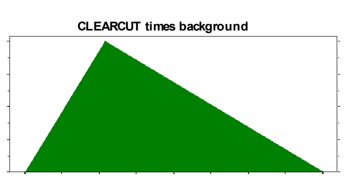


Assumption: CLEARCUT times background
[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: V3

Triangular distribution with parameters:

Minimum	1.25	(=T3)
Likeliest	2.00	
Maximum	4.00	(=U3)

Selected range is from 1.25 to 4.00



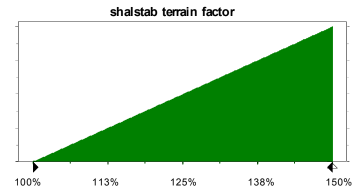
Assumption: shalstab terrain factor

[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S21

Triangular distribution with parameters:

Minimum	100%
Likeliest	150%
Maximum	150%

Selected range is from 100% to 150%



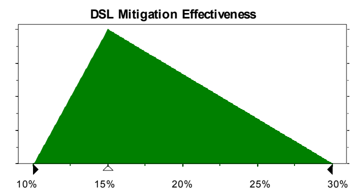
Assumption: DSL Mitigation Effectiveness

[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: P27

Triangular distribution with parameters:

Minimum	10%
Likeliest	15%
Maximum	30%

Selected range is from 10% to 30%



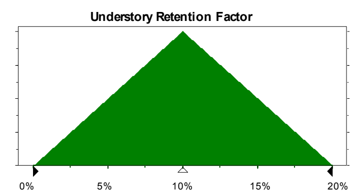
Assumption: Understory Retention Factor

[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S11

Triangular distribution with parameters:

Minimum	0%
Likeliest	10%
Maximum	20%

Selected range is from 0% to 20%



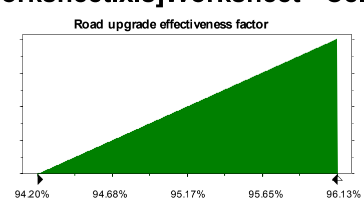
Assumption: Road upgrade effectiveness factor

[EROSION RATES by BUFFER - Worksheet.xls]Worksheet - Cell: S24

Triangular distribution with parameters:

Minimum	94.20%
Likeliest	96.13%
Maximum	96.13%

Selected range is from 94.20% to 96.13%



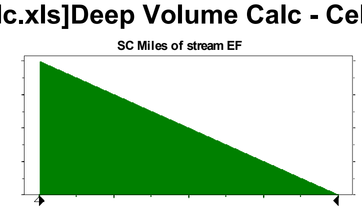
Assumption: SC Miles of stream EF

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E17

Triangular distribution with parameters:

Minimum	0.6
Likeliest	0.6
Maximum	1.1

Selected range is from 0.6 to 1.1



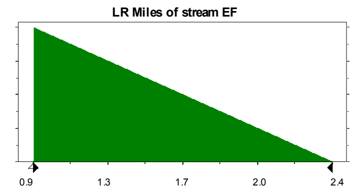
Assumption: LR Miles of stream EF

[Deep Volume Calc.xls]Deep Volume Calc - Cell: F17

Triangular distribution with parameters:

Minimum	0.9
Likeliest	0.9
Maximum	2.4

Selected range is from 0.9 to 2.4



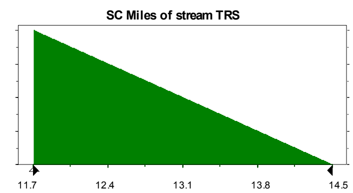
Assumption: SC Miles of stream TRS

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E18

Triangular distribution with parameters:

Minimum	11.7
Likeliest	11.7
Maximum	14.5

Selected range is from 11.7 to 14.5



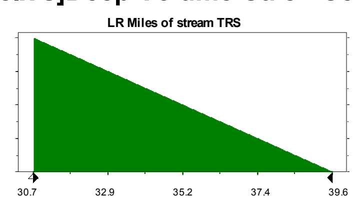
Assumption: LR Miles of stream TRS

[Deep Volume Calc.xls]Deep Volume Calc - Cell: F18

Triangular distribution with parameters:

Minimum	30.7
Likeliest	30.7
Maximum	39.6

Selected range is from 30.7 to 39.6



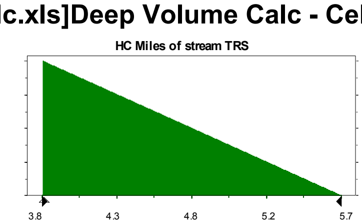
Assumption: HC Miles of stream TRS

[Deep Volume Calc.xls]Deep Volume Calc - Cell: G18

Triangular distribution with parameters:

Minimum	3.8
Likeliest	3.8
Maximum	5.7

Selected range is from 3.8 to 5.7



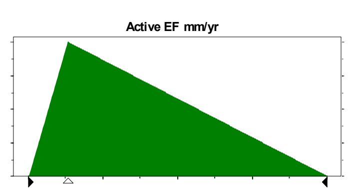
Assumption: Active EF mm/yr

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E2

Triangular distribution with parameters:

Minimum	3.00	(=J2)
Likeliest	20.00	(=K2)
Maximum	130.00	(=L2)

Selected range is from 3.00 to 130.00



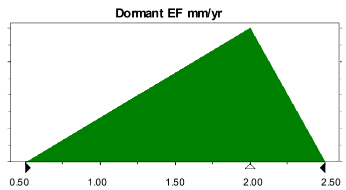
Assumption: Dormant EF mm/yr

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E3

Triangular distribution with parameters:

Minimum	0.50	(=J3)
Likeliest	2.00	(=K3)
Maximum	2.50	(=L3)

Selected range is from 0.50 to 2.50



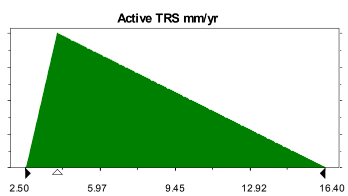
Assumption: Active TRS mm/yr

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E4

Triangular distribution with parameters:

Minimum	2.50	(=J4)
Likeliest	4.00	(=K4)
Maximum	16.40	(=L4)

Selected range is from 2.50 to 16.40



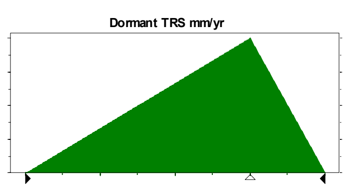
Assumption: Dormant TRS mm/yr

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E5

Triangular distribution with parameters:

Minimum	0.50	(=J5)
Likeliest	2.00	(=K5)
Maximum	2.50	(=L5)

Selected range is from 0.50 to 2.50



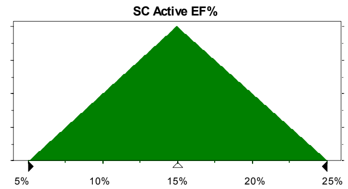
Assumption: SC Active EF%

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E11

Triangular distribution with parameters:

Minimum	5%	(=J19)
Likeliest	15%	(=J20)
Maximum	25%	(=J21)

Selected range is from 5% to 25%



Assumption: LR Active EF%

[Deep Volume Calc.xls]Deep Volume Calc - Cell: F11

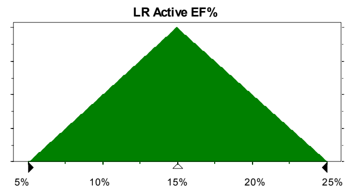
Triangular distribution with parameters:

Minimum	5%	(=K19)
Likeliest	15%	(=K20)
Maximum	25%	(=K21)

Selected range is from 5% to 25%

Assumption: LR Active EF% (cont'd)

[Deep Volume Calc.xls]Deep Volume Calc - Cell: F11



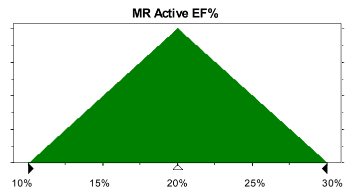
Assumption: MR Active EF%

[Deep Volume Calc.xls]Deep Volume Calc - Cell: H11

Triangular distribution with parameters:

Minimum	10%	(=M19)
Likeliest	20%	(=M20)
Maximum	30%	(=M21)

Selected range is from 10% to 30%



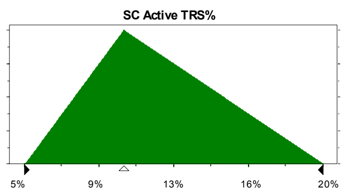
Assumption: SC Active TRS%

[Deep Volume Calc.xls]Deep Volume Calc - Cell: E14

Triangular distribution with parameters:

Minimum	5%	(=J25)
Likeliest	10%	(=J26)
Maximum	20%	(=J27)

Selected range is from 5% to 20%



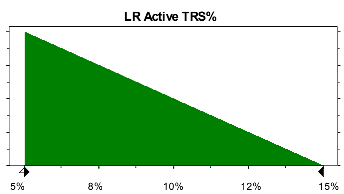
Assumption: LR Active TRS%

[Deep Volume Calc.xls]Deep Volume Calc - Cell: F14

Triangular distribution with parameters:

Minimum	5%	(=K25)
Likeliest	5%	(=K26)
Maximum	15%	(=K27)

Selected range is from 5% to 15%



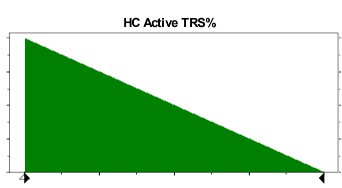
Assumption: HC Active TRS%

[Deep Volume Calc.xls]Deep Volume Calc - Cell: G14

Triangular distribution with parameters:

Minimum	5%	(=L25)
Likeliest	5%	(=L26)
Maximum	15%	(=L27)

Selected range is from 5% to 15%



Assumption: MR Active TRS%

[Deep Volume Calc.xls]Deep Volume Calc - Cell: H14

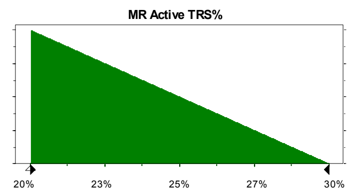
Triangular distribution with parameters:

Minimum	20%	(=M25)
Likeliest	20%	(=M26)
Maximum	30%	(=M27)

Selected range is from 20% to 30%

Assumption: MR Active TRS% (cont'd)

[Deep Volume Calc.xls]Deep Volume Calc - Cell: H14



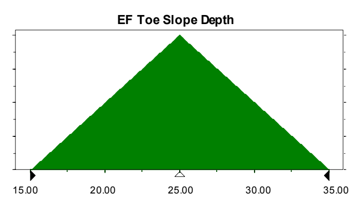
Assumption: EF Toe Slope Depth

[Deep Volume Calc.xls]Deep Volume Calc - Cell: B10

Triangular distribution with parameters:

Minimum	15.00	(=B14)
Likeliest	25.00	(=B15)
Maximum	35.00	(=B16)

Selected range is from 15.00 to 35.00



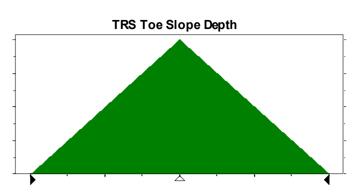
Assumption: TRS Toe Slope Depth

[Deep Volume Calc.xls]Deep Volume Calc - Cell: B11

Triangular distribution with parameters:

Minimum	30.00	(=B19)
Likeliest	40.00	(=B20)
Maximum	50.00	(=B21)

Selected range is from 30.00 to 50.00



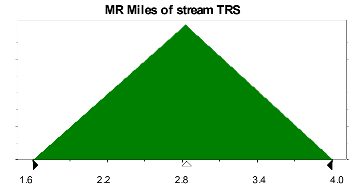
Assumption: MR Miles of stream TRS

[Deep Volume Calc.xls]Deep Volume Calc - Cell: H18

Triangular distribution with parameters:

Minimum	1.6
Likeliest	2.8
Maximum	4.0

Selected range is from 1.6 to 4.0



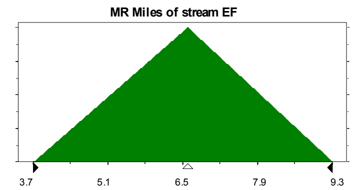
Assumption: MR Miles of stream EF

[Deep Volume Calc.xls]Deep Volume Calc - Cell: H17

Triangular distribution with parameters:

Minimum	3.7
Likeliest	6.6
Maximum	9.3

Selected range is from 3.7 to 9.3



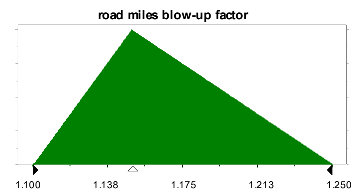
Assumption: road miles blow-up factor

[revised assessment summary ver 5.xls]data - Cell: I2

Triangular distribution with parameters:

Minimum	1.100
Likeliest	1.150
Maximum	1.250

Selected range is from 1.100 to 1.250



Assumption: Delivery from road-related landslides

[revised assessment summary ver 5.xls]removal and delivery - Cell: D22

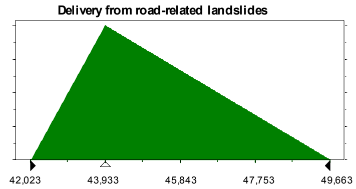
Triangular distribution with parameters:

Minimum	42,023	(=D24)
Likeliest	43,933	(=D25)
Maximum	49,663	(=D26)

Selected range is from 42,023 to 49,663

Correlated with:

Delivery from road-related other sites (F22	0.75
Delivery from road-related stream xings (B:	0.75



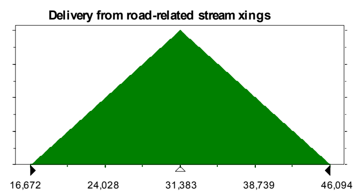
Assumption: Delivery from road-related stream xings
[revised assessment summary ver 5.xls]removal and delivery - Cell: B22

Triangular distribution with parameters:

Minimum	16,672	(=B24)
Likeliest	31,383	(=B25)
Maximum	46,094	(=B26)

Selected range is from 16,672 to 46,094

Correlated with:
Delivery from road-related landslides (D22) 0.75



Assumption: Delivery from road-related other sites
[revised assessment summary ver 5.xls]removal and delivery - Cell: F22

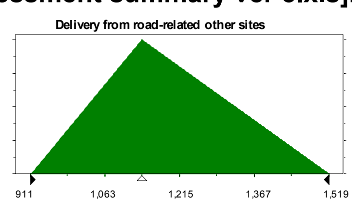
Triangular distribution with parameters:

Minimum	911	(=F24)
Likeliest	1,139	(=F25)
Maximum	1,519	(=F26)

Selected range is from 911 to 1,519

Correlated with:
Delivery from road-related landslides (D22) 0.75

Assumption: Delivery from road-related other sites (cont'd)
[revised assessment summary ver 5.xls]removal and delivery - Cell: F22

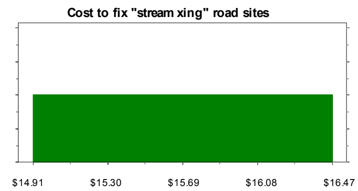


Assumption: Cost to fix "stream xing" road sites

[revised assessment summary ver 5.xls]removal and delivery - Cell: B5

Uniform distribution with parameters:

Minimum	$14.91
Maximum	$16.47



Correlated with:

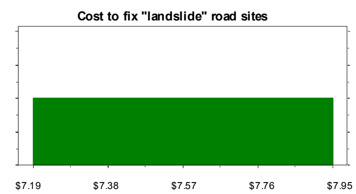
Cost to fix "landslide" road sites (D5)	0.75
Cost to fix "other" road sites (F5)	0.75

Assumption: Cost to fix "landslide" road sites

[revised assessment summary ver 5.xls]removal and delivery - Cell: D5

Uniform distribution with parameters:

Minimum	$7.19
Maximum	$7.95



Correlated with:

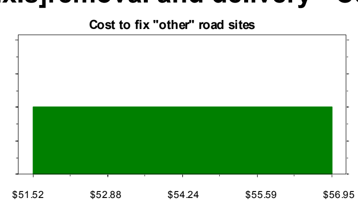
Cost to fix "stream xing" road sites (B5)	0.75

Assumption: Cost to fix "other" road sites

[revised assessment summary ver 5.xls]removal and delivery - Cell: F5

Uniform distribution with parameters:

Minimum	$51.52
Maximum	$56.95



Assumption: Cost to fix "other" road sites (cont'd)

[revised assessment summary ver 5.xls]removal and delivery - Cell: F5

Correlated with:

Cost to fix "stream xing" road sites (B5)	0.75

End of Assumptions

Table F3-14. The basis (i.e., data, literature, or professional judgment) used to determine the range of estimates for each assumption variable listed in Table F3-13. Much of the information pertaining to "hillslope" assumption variables was extracted from Appendix F1. For road-related assumption variables, information was taken from Appendix F2. The complete citations for the references used in this table are contained at the end of Appendix F1.

Variable No.	Assumption Variable	Hillslope or Road-Related	Basis Used To Determine Range	Comment
1	Hunter Creek Sediment Multiplier	Hillslope	Data and Professional Judgment	About 15% of the 1997 failures in Hunter Creek were field sampled to verify air photo interpretations and calibrate slide volumes and sediment delivery ratios. Range in landslide volumes estimated from 1) comparison of field and air photo measurements of landslide volumes and 2) professional judgment made from field reconnaissance and review of the historic aerial photographs.
2	Hunter Creek SHALSTAB Acreage Adjustment	Hillslope	Professional Judgment w/ limited supporting data	Range estimated from 1) comparison of the SHALSTAB map to aerial photograph interpretations of headwall swales and 2) field review of SHALSTAB areas on and off Simpson property.
3	Hunter Creek SMZ Acreage Adjustment	Hillslope	Professional Judgment w/ limited supporting data	The minimum is based on DEM measurements of slope gradient. Likeliest and maximum values have been increased to account for inherent underestimates of slope gradient by topographic maps and DEMs. The increase in SMZ acreage for likeliest and maximum values is estimated from 1) air photo observations, 2) limited field observations, and 3) discussions with Simpson forestry staff.
4	Salmon Creek Sediment Multiplier	Hillslope	Professional Judgment w/ supporting data	Limited field reconnaissance of the 1997 failures have been undertaken in Salmon Creek to verify air photo interpretations and calibrate slide volumes and sediment delivery ratios. Field reconnaissance has focused along steep streamside slopes. Range in landslide volumes is estimated from 1) comparison of field and air photo measurements of landslide volumes and 2) professional judgment made from field reconnaissance and review of the historic aerial photographs.
5	Salmon Creek SMZ Acreage Adjustment	Hillslope	Professional Judgment w/ limited supporting data	Range estimated from 1) comparison of the SHALSTAB map to aerial photograph interpretations of headwall swales and 2) field review of SHALSTAB areas on and off Simpson property.
6	Salmon Creek SHALSTAB Acreage Adjustment	Hillslope	Professional Judgment w/ limited supporting data	The minimum is based on DEM measurements of slope gradient. Mid and upper range have been increased to account for inherent underestimates of slope gradient by topographic maps and DEMs. The increase in SMZ acreage for likeliest and maximum values is estimated from 1) air photo observations, 2) limited field observations, and 3) discussions with Simpson forestry staff.

Table F3-14. (Continued)

Variable No.	Assumption Variable	Hillslope or Road-Related	Basis Used To Determine Range	Comment
7	Little River Sediment Multiplier	Hillslope	Professional Judgment w/ supporting data	Limited field reconnaissance of the 1997 failures have been undertaken in Little River to verify air photo interpretations and calibrate slide volumes and sediment delivery ratios. Field reconnaissance has focused along steep streamside slopes. Range in landslide volumes is estimated from 1) comparison of field and air photo measurements of landslide volumes and 2) professional judgment made from field reconnaissance and review of the historic aerial photographs.
8	Little River SMZ Acreage Adjustment	Hillslope	Professional Judgment w/ limited supporting data	Range estimated from 1) comparison of the SHALSTAB map to aerial photograph interpretations of headwall swales and 2) field review of SHALSTAB areas on and off Simpson property.
9	Little River SHALSTAB Acreage Adjustment	Hillslope	Professional Judgment w/ limited supporting data	The minimum is based on DEM measurements of slope gradient. Mid and upper range have been increased to account for inherent underestimates of slope gradient by topographic maps and DEMs. The increase in SMZ acreage for likeliest and maximum values is estimated from 1) air photo observations, 2) limited field observations, and 3) discussions with Simpson forestry staff.
10	Road Miles Blow-Up Factor	Road-Related	Data and Professional Judgment	Air photo analysis of Simpson and other property
11	Delivery From Road-Related Landslides	Road-Related	Data	Data from field inventories
12	Delivery From Road-Related Watercourse Crossings	Road-Related	Data	Data from field inventories
13	Delivery From Road-Related Other Sites	Road-Related	Data	Data from field inventories
14	Cost To Fix Watercourse Crossing Road Sites	Road-Related	Data	Field inventory, surveys, production rate estimates and standard cost rates
15	Cost To Fix Landslide Road Sites	Road-Related	Data	Field inventory, surveys, production rate estimates and standard cost rates
16	Cost to Fix Other Road Sites	Road-Related	Data	Field inventory, surveys, production rate estimates and standard cost rates

Table F3-14. (Continued)

Variable No.	Assumption Variable	Hillslope or Road-Related	Basis Used To Determine Range	Comment
17	70 to 85% Overstory Retention Factor	Hillslope	Professional Judgment w/ supporting data and literature	Adjustments to clearcut harvest ratio to account for different overstory retentions is based on professional judgment, supported by landslide inventories [e.g., ODF study on the impacts of 1995 and 1996 storms (Robison et al. 1999), PALCO Freshwater Creek Watershed Analysis (PALCO 2001a)], published literature (Megahan et al. 1978), shallow landslide modeling [e.g., (Krogstad 1995; Schmidt et al. in review; Sidle 1991; Sidle 1992; Ziemer 1981a, 1981b)], and experience.
18	50 to 70% Overstory Retention Factor	Hillslope	Professional Judgment w/ supporting data and literature	See # 17
19	Selection Factor	Hillslope	Professional Judgment w/ supporting data and literature	See # 17
20	Hardwood and Understory Retention Factor	Hillslope	Professional Judgment w/ supporting data and literature	See # 17
21	Road Upgrade Effectiveness Factor	Road-Related	Data and Professional Judgment	Data and observations from Simpson and other watersheds
22	RMZ/WLPZ Slope Position Factor	Hillslope	Professional Judgment w/ limited supporting data and literature	Adjustments in slope position (i.e., RMZ, SHALSTAB or other) are based on professional judgment supported by interpretations of regional landslide studies (PALCO Freshwater Creek Watershed Analysis (PALCO 2001a) and unpublished Hunter Creek landslide data) and professional experience.

Table F3-14. (Continued)

Variable No.	Assumption Variable	Hillslope or Road-Related	Basis Used To Determine Range	Comment
23	Clearcut Times Background	Hillslope	Professional Judgment and Literature	An average clearcut harvest ratio was estimated from a review of published and unpublished landslide inventories, including TMDL studies, the ODF study on the impacts of 1995 and 1996 storms (Robison et al. 1999), PALCO Sediment Source Investigations (PWA 1998a, 1998b, 1999a, 1999b), PALCO Freshwater Creek Watershed Analysis (PALCO 2001a), and Simpson's preliminary Mass Wasting Assessment for Hunter Creek. The results of these studies are summarized in Appendix F1, Table 5. A complete discussion of each study is included in Appendix F1 of this report. Range in clearcut ratio is based primarily on professional judgment.
24	SHALSTAB Terrain Factor	Hillslope	Professional Judgment w/ limited supporting data and literature	See #22
25	DSL Mitigation Effectiveness	Hillslope	Professional Judgment and data	The impact of harvesting on historically active deep-seated landslides is assumed to be a function of percentage of canopy retained. Landslides are mapped from the historic set of aerial photographs. The percentage of historically active slides is based on professional judgment (See #36, 37, 38, 39, 40, 41 and 42). Acreage of harvest on historically active slide determined from the GIS database. Analysis assumes clearcut harvesting on entirety of slide outside of prescribed retention areas (i.e. RMZ, SMZ, SHALSTAB, and active scarps and toes). Maximum and minimum based on professional judgment.
26	Understory Retention Factor	Hillslope	Professional Judgment	See # 17
27	Salmon Creek Miles of Stream Earth Flows	Hillslope	Data	Minimum and likeliest values based on length of streams on "Definite" and "Probable" landslides. Maximum value includes stream length on "Questionable" landslides. Certainty of landslide based on air photo observations.
28	Little River Miles of Stream Earth Flows	Hillslope	Data	See #27

Table F3-14. (Continued)

Variable No.	Assumption Variable	Hillslope or Road-Related	Basis Used To Determine Range	Comment
29	Salmon Creek Miles of Stream Translational/Rotational Landslides	Hillslope	Data	See #27
30	Little River Miles of Stream Translational/Rotational Landslides	Hillslope	Data	See #27
31	Hunter Creek Miles of Stream Translational/Rotational Landslides	Hillslope	Data	See #27
32	Active Earth Flow mm/yr	Hillslope	Literature and Professional Judgment	Maximum and minimum values based on range of measured rates of earthflow movement on the east side of the Grogan Fault in Redwood Creek (Swanson and others 1995). Likeliest value based on professional judgment supported by limited field review of slides on and off of Simpson property and professional experience.
33	Dormant Earth Flow mm/yr	Hillslope	Literature and Professional Judgment	Maximum and minimum values based on range of measured progressive creep rates on the west side the Grogan Fault in Redwood Creek (Swanson and others 1995). Likeliest value based on professional judgment supported by limited field review of slides on and off of Simpson property and professional experience.
34	Active Translational/Rotational Slides mm/yr	Hillslope	Literature and Professional Judgment	Maximum and minimum values based on measured rates of block glide movement in Redwood Creek (Swanson and others 1995). Likeliest value based on professional judgment supported by limited field review of slides on and off of Simpson property and professional experience.
35	Dormant Translational/Rotational Slides mm/yr	Hillslope	Literature and Professional Judgment	Maximum and minimum values based on measured progressive creep rates on the west side the Grogan Fault in Redwood Creek (Swanson and others 1995). Likeliest value based on professional judgment supported by limited field review of slides on and off of Simpson property and professional experience.
36	Salmon Creek Active Earth Flow %	Hillslope	Professional Judgment	Based on limited field reconnaissance of the watersheds, discussions with Simpson foresters and past experience.
37	Little River Active Earth Flow %	Hillslope	Professional Judgment	See #36

Table F3-14. (Continued)

Variable No.	Assumption Variable	Hillslope or Road-Related	Basis Used To Determine Range	Comment
38	Mad River Active Earth Flow %	Hillslope	Professional Judgment	See #36
39	Salmon Creek Active Translational/Rotational Slides %	Hillslope	Professional Judgment	See #36
40	Little River Active Translational/Rotational Slides %	Hillslope	Professional Judgment	See #36
41	Hunter Creek Active Translational/Rotational Slides %	Hillslope	Professional Judgment	See #36
42	Mad River Active Translational/Rotational Slides %	Hillslope	Professional Judgment	See #36
43	Earth Flow Toe Slope Depth	Hillslope	Literature and Professional Judgment	Depth based on professional judgment and experience, supported by published data on slide depth (e.g., Swanson and others 1995; SWS 1999; USACE 1980; USDA 1970).
44	Translational/Rotational Slide Toe Slope Depth	Hillslope	Literature and Professional Judgment	See #43
45	Mad River Miles of Stream Translational/Rotational Landslides	Hillslope	Data	See #27
46	Mad River Miles of Stream Earth Flows	Hillslope	Data	See #27