Attachment C

Empirical Harvest-Related Landslide Sediment Delivery Reduction Model

Prepared By

Staff of the North Coast
Regional Water Quality Control Board
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Introduction and Context of this Report

This report describes the application of an empirical model used to develop enforceable receiving water limitations for sediment delivered from timber harvest-related landslides in two Humboldt County watersheds: Freshwater Creek and Elk River. The Empirical Harvest-Related Landslide Delivery Reduction Model (Landslide Reduction Model) described in this report is a more developed version of an empirical sediment budget approach originally offered by Dr. Leslie Reid of the Redwood Sciences Laboratory, and then further refined and recommended for use by the Independent Scientific Review Panel.

By applying the Landslide Reduction Model, staff of the North Coast Regional Water Quality Control Board (Regional Water Board) have developed receiving water limitations for watershed-wide Waste Discharge Requirements (WDRs) to be issued by the Regional Water Board. The receiving water limitations are a numeric interpretation of existing narrative water quality objectives contained in the Regional Water Board's *Water Quality Control Plan for the North Coast Region* (Basin Plan, 2005). The WDRs will apply specifically to discharges of waste from Pacific Lumber Company (PALCO) Timber Harvesting Plan (THP) activities[1] in the Elk River and Freshwater Creek watersheds, both of which have been cumulatively impacted by sediment discharges and are listed as sediment impaired under Section 303(d) of the Clean Water Act. PALCO is the majority landowner in these watersheds, owning approximately 75% of four planning watersheds in Elk River[2] and 78% of three planning watershed in Freshwater Creek.[3]

The receiving water limitations developed in this report will support the proposed WDRs by providing a scientific basis by which the Regional Water Board may allow new timber harvest-related discharges to continue while providing for the recovery of the beneficial uses of water in Elk River and Freshwater Creek, as required by law (Federal Water Pollution Control Act, 2002; California Water Code, 2005; Basin Plan, 2005). The issuance of the proposed watershed-wide WDRs prior to the completion of the Total Maximum Daily Load (TMDL) development process is a near-term strategy for permitting new discharges of waste associated with PALCO's ongoing land management activities in these sediment-impaired watersheds. Once TMDLs are complete, staff may broaden or refine the scope of the WDRs to retain them as a part of TMDL implementation.

This report covers, in brief, pertinent background information regarding the problem of harvest-related landsliding in the Elk River and Freshwater Creek watersheds, the history of numerical model development aimed at addressing this problem (including the recommendations of a blue ribbon science panel), the derivation of the Empirical Harvest-Related Landslide Sediment Delivery Reduction Model (the final form of the model used), and the rationale for staff's

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[1] The proposed WDRs regulate, "Timber Harvesting Plan (THP) activities" approved by the California Department of Forestry and Fire Protection (CDF).

[2] In Elk River, the planning watersheds to be subject to the WDRs include the Upper North Fork, Lower North Fork, Upper South Fork and Lower South Fork Elk River planning watersheds, based on CALWATER watershed maps available from the Natural Resources Conservation Service (version 2.2.1)

[3] In Freshwater Creek, the planning watersheds to be subject to the WDRs include the Cloney Gulch, Little Freshwater, and Upper Freshwater Creek planning watersheds, based on CALWATER watershed maps available from the Natural Resources Conservation Service (version 2.2.1)

specific application of the model to develop enforceable receiving water limitations for the proposed WDRs.

Work Conducted by California Licensed Professionals

The work described in this report constitutes the practices of geology and civil engineering, according to the California Professional Engineers Act (California Business and Professions Code §§ 6700-6799, 2005), the Geologist and Geophysicist Act (California Business and Professions Code §§ 7800-7887, 2005), and associated rules and regulations. The work has been performed by a team of California licensed professional engineers and geologists on staff at the Regional Water Board. These individuals include, but are not limited to, David Kuszmar, PE No. C65460 and Mark Neely, CEG No. 1582, whose professional stamps and signatures appear on page 2 of this document.

Analysis Objective and Margin of Safety

The purpose of the following analysis is to develop, using the best available methods and data, enforceable receiving water limitations for timber harvest-related discharges from PALCO lands in the sediment-impaired Elk River and Freshwater Creek watersheds. The final recommended limitation must adequately address cumulative impacts, and be reasonably expected to allow for watershed recovery from existing impaired conditions. Where the quality of available data has been questionable, or where simplifying assumptions have been necessary to generate results, staff has made conservative choices. These choices provide the analysis with a built-in margin of safety that generally corresponds to a greater consideration for public health, safety, and water quality protection.

Method Refinement

The model applications and analysis results outlined in this report, and the resulting receiving water limitations included in watershed-wide WDRs, are subject to future modifications and revisions based on additional watershed data and analyses and public review. Staff encourage all stakeholders, agencies, and qualified experts to participate in the processes of model refinement and WDRs revision.

Typically, methods developed in Academia or research go through four steps including 1) methods development, 2) peer review, 3) potential modification and implementation with calibration, and 4) validation through time. In the case of the Landslide Reduction Model, methods development and significant peer review has already occurred as described in the next sections (ISRP 2002 & 2003), with input from the public, agencies, and experts in related topics. The model described in this report is the result of recommendations from those reviews. Further refinements have been made in response to comments received during public review of the watershed-wide WDRs under the California Environmental Quality Act. Responses to comments received during that review process were issued along with this report on September 2, 2005. Implementation of the WDRs will occur upon their adoption by the Regional Water Board, and the Landslide Reduction Model can only be validated through time.

Background and Model History

The winter of 1996/1997 brought to the North Coast the second wettest December on record since 1887, and a particularly significant rainfall event on New Year's Eve, based on rainfall data available from the National Weather Service in Eureka, CA. Local watersheds, including Elk River, Freshwater Creek, and others in Humboldt County, which had been heavily logged during the previous decade, responded to the storm with widespread landsliding and erosion. This response, when added to logging-related impacts that had already been endured by these watersheds leading up to the 1996/1997 events, led to extensive instream sedimentation and to the degradation of the beneficial uses of water.

In 1997, identification and evaluation of negative cumulative impacts due to intense land management activities in Elk River and in Bear, Jordan, Stitz and Freshwater Creeks (collectively referred to as the "Five Watersheds") led State regulatory agencies to require the primary landowner and timber operator in these watersheds, PALCO, to produce reports aimed at addressing sediment problems in the watersheds and at protecting receiving waters from any further impacts (Cumulative Watershed Effects Meeting Minutes, California Department of Fish and Game, et al., 1997). Among the reports and analyses required were sediment budgets and inventories, documenting levels of sedimentation and the distribution of sediment delivery sources.

Over the following two years, PALCO provided the agencies with sediment inventory reports for each of the Five Watersheds, most of which were prepared by Pacific Watershed Associates (PWA), a natural resources consulting firm then based in Arcata, CA.[4] Sediment inventory data presented in the reports, which were based on a combination of aerial photo reviews and field surveys, showed that, in general, a significant percentage of the volume of sediment delivered to receiving waters during the air photo period between 1994 and 1997 came from landslides initiating from recently logged areas.

At the request and under the direction of licensed professionals on the Regional Water Board staff, scientists at the USDA Forest Service Pacific Southwest Research Station's Redwood Sciences Laboratory (RSL) in Arcata, CA prepared analyses of the data in PWA's reports for Bear Creek (Reid, 1998a) and for North Fork Elk River (Reid, 1998b). These analyses, authored by Dr. Leslie Reid, highlighted the strong relationship between recent logging and increases in landslide-delivered sediment in these watersheds. Furthermore, based on these relationships and the data available in PWA's reports, the analyses offered simple empirical models (each based on the same general approach) that could be used to determine future rates of timber harvesting that would adequately protect the beneficial uses of water from future harvest-related landslides, achieve water quality objectives, and allow for watershed recovery from cumulative impacts. Specifically, the approach identifies the rate of sediment production expected on recently harvested areas, based on past observations, and compares that to the rate of sediment production expected on older, forested areas.

[4] Pacific Watershed Associates prepared "Sediment Source Investigation and Sediment Reduction Plan(s)" for Bear Creek (1998a), North Fork Elk River (1998b), Jordan Creek (1999a) and Freshwater Creek (1999b). A similar report for Stitz Creek was prepared by Natural Resources Management Corporation (1998). Staff notes that none of these reports bears the seal or signature of a California licensed geologist, although principals of the firm have provided verbal assurance that the reports were prepared under the responsible charge of licensed individuals.

In June 2002, and again in February 2003, the Regional Water Board directed that a blue-ribbon science panel, which came to be known as the Humboldt Watersheds Independent Scientific Review Panel (ISRP), be convened to provide input on key issues related to water quality protection in the Five Watersheds. Each of two reports generated by the ISRP (ISRP, 2002 & 2003), both of which were certified by a multi-disciplinary team of California licensed professionals, focused on specific questions assigned to the ISRP by the Regional Water Board with significant input from representatives of state and federal agencies, industrial timberland and non-industrial timberland owners, residents, and environmental organizations.

As part of its first phase of work, the ISRP was asked to review available approaches for addressing discharges from timber harvesting such that the beneficial uses of water in the Five Watersheds might be recovered. Among these was the approach developed by Dr. Reid. The ISRP found that Dr. Reid's approach, referred to in their reports as the "empirical sediment budget approach," was superior to the other methodologies it reviewed, including processed-based, modeled sediment budget approaches, given the kinds and amounts of data presently available in the Five Watersheds. They stated that the empirical sediment budget's use of sediment production ratios, rather than absolute values, alleviated much of the difficulty associated with estimating background sediment production rates for the watersheds. Acknowledging criticisms of the empirical sediment budget approach (primarily that it did not properly consider areas that were off-limits to harvesting because of high landslide potential), the ISRP identified means of addressing those issues. In Appendix C of its first report (ISRP, 2002), the ISRP provided a detailed discussion and derivation of a refined version of Dr. Reid's initial work in which they prescribed how to account for sediment production from areas with different landslide hazards.

For its second phase of work, the ISRP was asked to conduct additional technical reviews of, among other topics, PALCO's Habitat Conservation Plan (HCP) / Sustained Yield Plan (SYP) process at providing water quality protections, and determining rates of recovery. The ISRP presented its findings in a second report (ISRP, 2003), wherein it emphasized the earlier conclusion that a model is only as good as its input data and that an empirical sediment budget approach, such as that originally described by Dr. Reid (Reid, 1998a and 1998b) and further refined by the ISRP (2002), is most consistent with the quality and quantity of data that are currently available or likely to become available in the near future for these watersheds.

The Empirical Harvest-Related Landslide Sediment Delivery Reduction Model (Landslide Reduction Model) described below is a more developed version of the empirical sediment budget approach originally offered by Dr. Reid, and then further refined and recommended for use by the ISRP. Staff's application of the Landslide Reduction Model is the source of the results and recommendations presented in later sections of this report.

Empirical Sediment Budget Approach

Significant portions of the following discussion have been extracted directly from Appendix C of the ISRP's first report (2002). Where necessary, symbolic nomenclature and the definitions of some terms have been changed to allow for consistency with later sections of this report regarding model application.

The empirical sediment budget approach for modeling sediment production in a watershed is based on stratifying the watershed into land classes and applying rate coefficients that quantify the rate of sediment produced from each land class. The sediment production from a watershed can be represented as the sum of contributions from each distinct land class.

$$S = \sum c_i a_i \tag{1}$$

where:

S is the rate of sediment production per unit area ($L^3/L^2/T$)

c_i is the sediment production rate coefficient for land class i ($L^3/L^2/T$)

a_i is the dimensionless fraction of watershed area comprising land class i

Modeling watershed sediment production in this manner allows for the subdivision of the landscape into logical land class categories based on physical processes governing erosion and other pertinent factors. Consequently, the model can be tailored to differences that exist within and among watersheds. Likewise, the model may be used to describe comprehensive sediment budgets or individual components of a sediment budget, where those components are of particular interest to the analyst.

Sediment production in a watershed is strongly dependent on spatial landscape variability, climate, and the stochastic occurrence of storm and seismic events. To be able to discern changes in the sediment production rate due to land management and other anthropogenic influences, it is thus helpful to remove the variable effects of natural processes by defining sediment production relative to a background or reference rate. Equation (1) can be re-written to define this reference rate.

$$R = \sum r_i a_i \tag{2}$$

where:

R is the reference rate of sediment production per unit area ($L^3/L^2/T$)

r_i is the reference sediment production rate coefficient for land class i ($L^3/L^2/T$)

Dividing Equation (1) by Equation (2) gives

$$\frac{S}{R} = S_R = \sum \left(\frac{c_i}{R}\right) a_i = \sum w_i a_i \tag{3}$$

where:

S_R is the dimensionless rate of sediment production relative to reference conditions

w_i is the normalized, and therefore dimensionless, sediment production rate coefficient for land class i

Where values of w_i are known, a critical threshold for sediment production may be assigned for S_R (expressed as a percentage of the reference rate of sediment production), and Equation (3) may be solved for values of a_i that do not exceed that threshold, provided that values of a_i are controllable. Such an exercise (i.e., assigning a value for S_R) is described in the following sections of this report in the context of defining a receiving water limitation.

Rationale for Considering Potential Sediment Source Categories to be Applied in the Empirical Sediment Budget Approach

In determining which elements of the sediment budget might be appropriate candidates for application of the empirical sediment budget approach, staff considered available sediment source inventories and sediment budget data from PWA (1998b and 1999b) and PALCO (2003, 2004, 2005a and 2005b). Appropriate candidates are those source categories that meet the following criteria:

1) The source category represents a relatively significant fraction of the watershed's total sediment load,
2) Data are available to discern the difference between natural and anthropogenic sources with some degree of confidence, and
3) The source category is not already reasonably being controlled through some regulatory or non-regulatory means.

Summaries of available sediment source inventories and budget data for PALCO's ownership in Elk River and Freshwater Creek are provided in Tables 1 and 2 below. The numbers reported vary significantly by time interval considered, and by methods used to model the individual elements of the sediment budgets. The data in the tables have been modified from their original forms in order to make the units and source categories comparable. Detailed source data for Tables 1 and 2 are available from staff upon request.[5]

[5] It should be noted that PALCO has provided staff only very limited access to the data used to develop the sediment budgets in Elk River and Freshwater Creek. Without the underlying data, staff cannot readily confirm or validate the sediment delivery estimates in each of the source categories. However, through TMDL development, staff will have the opportunity to examine all sediment source categories in more depth, using data previously supplied as well as newly developed information in cases where data have not previously been supplied. As a result of this examination, staff expects to see changes in the sediment production estimates for several of the source categories in the sediment budgets, especially where those categories are divided between natural ("background") and anthropogenic (management-related) sources.

Table 1. Summary of Available Freshwater Creek Sediment Source Inventories and Sediment Budget Data

Time Period	1955-1997 (PWA)[1]		1995-1997 (PWA)[1]		1988-1997 (WA)[2]		1988-1997 (ROWD)[3]	
(units)[4]	($yd^3/mi^2/yr$)	% Total	($yd^3/mi^2/yr$)	% Total	($yd^3/mi^2/yr$)	% Total	($yd^3/mi^2/yr$)	% Total
Non-road related landslides	99	23%	146	15%	84	13%	90	12%
Torrent track scour	4	1%	27	3%				
Bank erosion & Streambank slides	18	4%	59	6%	126	19%	140	19%
Scour of filled channels	17	4%	26	3%				
Low order valley fill incision	52	12%	75	7%	29	4%	27	4%
Surface erosion from disturbed areas	85	19%	351	35%	10	1%	10	1%
Soil creep					94	14%	102	14%
Road-related erosion[5]	159	37%	313	31%	327	49%	357	49%
Total	434	100%	997	100%	670	100%	726	100%

Notes:

1 - Data from Table 21 of Sediment Source Investigation for the Freshwater Creek Watershed (PWA 1999b).

2 - Data estimated visually from Figure 3-7 of Appendix E in PALCO's Freshwater Cr. Watershed Analysis Final Report, v.2 (PALCO 2003).

3 - Data estimated visually from Figure 3.2 in PALCO's ROWD for Freshwater Creek (PALCO 2005a)

4 - Where necessary, units converted using a bulk desnity of 1.2 tons/yd^3.

5 - Road-related erosion is a combination of landslides, surface erosion, gullying and washouts.

Table 2. Summary of Available Elk River Sediment Source Inventories and Budget Data

	(North Fork only)		(North Fork only)		(North & South Forks)		(North & South Forks)	
Time Period	**1955-1997 (PWA)[1]**		**1995-1997 (PWA)[1]**		**1988-2000 (WA)[2]**		**1988-2000 (ROWD)[3]**	
(units)[4]	($yd^3/mi^2/yr$)	% Total	($yd^3/mi^2/yr$)	% Total	($yd^3/mi^2/yr$)	% Total	($yd^3/mi^2/yr$)	% Total
Non-road related landslides	316	51%	741	51%	183	23%	153	23%
Torrent track scour	21	3%	207	14%				
Bank erosion & Streambank slides	37	6%	40	3%	243	30%	222	33%
Scour of filled channels	103	17%	112	8%				
Low order valley fill incision								
Surface erosion from disturbed areas	43	7%	102	7%	6	1%	5	1%
Soil creep					76	9%	63	9%
Road-related erosion[5]	96	16%	263	18%	298	37%	225	34%
Total	617	100%	1,466	100%	806	100%	668	100%

Notes:

1 - Data from Table 9 of Sediment Source Investigation for the North Fork Elk River Watershed (PWA 1998b).

2 - Data from Table B-17 (medium estimates) of PALCO's Elk River-Salmon Creek Watershed Analysis Public Review Draft (PALCO 2004).

3 - Data estimated visually from Figure 3.2 in PALCO's ROWD for Elk River (2005b).

4 - Where necessary, units converted using a bulk desnity of 1.2 tons/yd^3.

5 - Road-related erosion is a combination of landslides, surface erosion, gullying and washouts.

Staff notes that the sediment source inventories and sediment budget data presented in PALCO's Reports of Waste Discharge (ROWDs) for Freshwater Creek and Elk River (PALCO 2005a and 2005b, respectively) do not agree in all cases with the data presented in PALCO's Watershed Analysis documents (PALCO 2003 and 2004, respectively), although the data are from the same inventories. The difference is larger between the Elk River data sets than between the Freshwater Creek data sets. The source(s) of these discrepancies is unknown.

Regardless of some differences between available sediment budget data, Tables 1 and 2 suggest that road-related erosion and non-road related landsliding represent significant fractions of the sediment budgets for Freshwater Creek and Elk River. Other prevalent elements of the sediment budgets include: bank erosion and streamside landsliding, surface erosion from disturbed areas, and soil creep. Available methods for estimating rates of sediment delivery from soil creep generally assume that it is a natural process unaffected by land management activities. While the validity of this assumption, as well as different estimates of soil creep rates will be further examined during TMDL development, staff do not currently consider this source category an appropriate candidate for use in the empirical sediment budget approach. However, the other four categories listed above are comprised of both natural and anthropogenic components that might lend themselves to applications of the empirical sediment budget approach, provided that all other necessary criteria are met. Toward this end, separate evaluations of each category are provided below.

Road-related Erosion

Tables 1 and 2 suggest that road-related erosion, which includes road-related landslides, surface erosion, gullying, and washouts, accounts for 31-49 percent of the total sediment budget for Freshwater Creek, and 16-37 percent of the total sediment budget for Elk River. Clearly, this sediment source category represents a significant fraction – if not the most significant fraction – of each watershed's total load. However, staff has already issued ownership-wide cleanup and abatement orders (CAOs) for controllable sediment sources on PALCO's lands in North and South Forks Elk River (Regional Water Board, 2002 & 2004, respectively), and will soon issue a similar order for the Freshwater Creek watershed. These orders are expected to reduce road-related erosion from existing and potential sources. Furthermore, the proposed WDRs contain requirements for the development of Erosion Control Plans (ECPs) for each THP to be covered under those permits. The ECPs, coupled with a variety of other road-improvement activities required under PALCO's HCP (USFWS & CDF, 1999), are expected to capture and correct controllable sediment discharges sources that otherwise don't appear in the source inventories used to guide corrective work under the CAOs. Therefore, because controls are already (or soon will be) in place, application of the empirical sediment budget approach to road-related erosion appears to be unnecessary at this time, although future monitoring results may be used to revisit this determination.

Surface Erosion from Disturbed Areas

The sediment budgets developed by PWA and PALCO differ on the magnitude of surface erosion from non-road disturbed areas in Freshwater Creek and Elk River. For instance, PWA's data (PWA, 1999b) suggest that this source category accounts for 19-35 percent of the total sediment budget in Freshwater Creek, while PALCO's data (PALCO, 2003) suggest that it accounts for only 1 percent. Based on an examination of Table 1, PALCO presumably attributed to soil creep (a natural source) much of what PWA considered surface erosion from disturbed areas (an anthropogenic source). Whatever the actual amount of sediment attributed to this source category may be, modern logging practices under PALCO's HCP are expected to reduce it substantially. PALCO's HCP requires special treatment of areas of exposed soils, stream buffer widths, and limitations designed to trap sediment before it reaches the streams, and other THP erosion control measures. Furthermore, PALCO generally uses cable and helicopter yarding methods on steep grounds (i.e., greater than 40 percent slopes), rather than tractor-based yarding. According to Figure 4.6 in each of PALCO's ROWDs (PALCO 2005a and 2005b), the company has done very little broadcast burning in Freshwater Creek and Elk River in recent years.

It is important to note that the effectiveness of all these measures for controlling surface erosion from disturbed areas remains largely untested. However, given uncertainty in the data regarding the true significance of this source category in the sediment budget, and given the promising measures in place designed to help control surface erosion on disturbed areas, staff do not recommend applying the empirical sediment budget approach to this source category at this time. Staff will revisit the importance of surface erosion from disturbed areas in these watersheds during TMDL development, and make adjustments to future versions of the WDRs as appropriate.

Bank Erosion and Streambank Landsliding

Data summarized in Tables 1 and 2 suggest that bank erosion and streambank landsliding account for anywhere between 3-33 percent of the total sediment loads in Freshwater Creek and Elk River. PALCO's sediment budgets attribute higher yields to this source category than do PWA's sediment budgets. Because these elements of the sediment budget are driven largely by stream stage and flow, few direct measures can be taken to control them. However, reductions in peak flow increases due to canopy removal and reductions in streambed aggradation from other controllable sediment sources in the watersheds may be expected to indirectly minimize rates of bank erosion and streambank landsliding.

The proposed WDRs contain receiving water limitations that are designed to reduce increases in peak flows. Furthermore, provided that PALCO's HCP, the Regional Water Board's CAOs and ECPs, and other regulatory measures in place are successful in reducing sediment contributions from other significant elements of the sediment budgets, reductions in bank erosion and streambank landsliding are expected. This presumption, along with the fact that differences between natural and anthropogenic sources of bank erosion cannot be reasonably discerned using available data, deters staff from consideration of bank erosion for applications of the empirical sediment budget approach at this time. However, given that there is significant uncertainty regarding the significance of bank erosion and streambank landsliding in the overall sediment budget, and given that the indirect methods of controlling these processes remain untested, staff will revisit this source category during TMDL development, and make adjustments to future versions of the WDRs as appropriate.

Non-road Related Landsliding

The last significant source category reported in the Freshwater Creek and Elk River sediment budgets is non-road related landsliding. Tables 1 and 2 suggest that this source category accounts for 12-23 percent of the overall sediment load to Freshwater Creek, and 23-51 percent of the overall load to Elk River, for all reported time periods. Detailed landslide inventory data available for recent winters in these watersheds allow for documented landslides to be reasonably categorized according to natural or anthropogenic sources.

Landslide avoidance strategies aimed at reducing rates of controllable non-road related landsliding required by the HCP are currently in place on PALCO's lands. These strategies include the use of landslide hazard (or hazard potential) maps for THP design, the preparation of geologic reports by licensed consultants for individual THPs, and agency review of THPs, sometimes by licensed professional geologists and engineers.[6] The effectiveness of these measures is largely unknown. While methods associated with geologic field reviews and avoidance strategies based on hazard maps have undoubtedly improved over recent decades, harvest-related landsliding is predictable, but not unavoidable. PALCO's ROWDs contend that landslide data from the winter of 2003 clearly demonstrate that the current avoidance strategies are working. However, staff do not agree that the 2003 data alone provide reasonable certainty that harvest-related landslides will be controlled for the foreseeable future.

Therefore, until the effectiveness of current landslide avoidance strategies has been sufficiently demonstrated through adequate monitoring and testing, this source category meets the three criteria (listed on page 9) that qualify it as an appropriate candidate for the empirical sediment budget approach.

Derivation of the Landslide Reduction Model

The Landslide Reduction Model derived below represents a particular use of the empirical sediment budget approach, tailored specifically for applications in the Elk River and Freshwater Creek watersheds. Building on previous work by Reid (1998a and 1998b) and the ISRP (2002 and 2003), Regional Water Board staff have developed two versions of the model (i.e., the 'refined' and the 'simplified' versions), both of which focus on a single key component of the watershed sediment budget (open slope or non-road related landslides), based on the rationale provided in the section above.

To derive the final form of the model, staff considered land class categories based on differences in silvicultural methods (clearcut vs. partial cut methods), and on landslide hazard differences using three available hazard zonation schemes.

Land class categories based on yarding methods were not initially considered because silviculture and hazard zone were expected to be greater factors in harvest-related landsliding. Future applications of the Landslide Reduction Model could be made to consider differences in yarding methods, should the additional effort be deemed worthwhile, but staff do not currently recommend it.

Land class categories based on site preparation practices were also not considered because detailed data for site preparation treatments are not available in the Discharger's harvest history database.

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[6] For a complete and detailed description of the various landslide avoidance and mitigation strategies employed by PALCO on its lands, please refer to its Reports of Waste Discharge for Freshwater Creek (PALCO, 2005a) and Elk River (PALCO, 2005b).

Staff's preliminary applications of the Landslide Reduction Model revealed that landslide hazard zones (otherwise referred to as harvest restriction zones) were generally a stronger influence on rates of sediment delivery due to harvest-related landsliding than silviculture (i.e., clearcut vs. partial cut) in the three watersheds. This fact, coupled with several technical challenges that arise upon attempting to apply the model using silvicultural land classes, led staff to conclude that the hazard zone version of the model was superior and appropriate for use in the WWDRs.[8]

The refined version of the model considers four land classes, including combinations of two timber harvesting categories ("recently harvested" vs. "unharvested" areas) and two landslide hazard categories ("high hazard" vs. "low hazard" zones). The simplified version of the model considers only the timber harvesting categories, and does not recognize different hazard zones. Each version of the model is described in detail below.

<u>The Refined Model</u>

Given the four land classes selected for the refined Landslide Reduction Model, the following terms may be defined, and units chosen for any time interval of *n* years:

Table 3. Definition of terms related to land classes in the refined Landslide Reduction Model.[9]

No.	Land Class Description	Area (acres)	Sediment Production (yd^3)
1	Unharvested Area + Low Hazard Zone	A_1	P_1
2	Unharvested Area + High Hazard Zone	A_2	P_2
3	Recently Harvested Area + Low Hazard Zone	A_3	P_3
4	Recently Harvested Area + High Hazard Zone	A_4	P_4

If inventory data from one landslide event are to be considered in the model for a given watershed, every acre in the watershed falls into one (and only one) of the land classes listed in Table 1, the total watershed area, A_{total} (acres) may be defined as[10]

$$A_{total} = A_1 + A_2 + A_3 + A_4 \qquad (4)$$

[8] Staff recommend that future applications of the Landslide Reduction Model consider land classes based on combinations of hazard zone and silviculture, provided that sufficient data become available through monitoring to support such a model, and provided that technical challenges that arise may be overcome.

[9] Application of the model requires that values of *A* and *P* are known for each land class, preferably based on historical measurements.

[10] Note: Inventory data from multiple landslide events may also be considered in the model for a given watershed, provided that something is known about the comparability of those events. In such a case, Equation (4) will remains valid as written, but A_H will sum to the total watershed area times the number of events considered, and every acre in the watershed will fall into one of the land classes listed in Table 1 for each event considered. That said, the rest of the derivation provided below follows for either the single or multiple event application.

And the dimensionless proportion of the watershed comprised of high hazard areas, a_H is

$$a_H = \frac{A_2 + A_4}{A_{total}} \qquad (5)$$

The fraction of the watershed associated with each of the four land classes may thus be defined as follows:

Unharvested fraction of low hazard areas	=	$(1-N_L) \bullet (1-a_H)$	(6a)
Unharvested fraction of high hazard areas	=	$(1-N_H) \bullet a_H$	(6b)
Harvested fraction of low hazard areas	=	$N_L \bullet (1-a_H)$	(6c)
Harvested fraction of high hazard areas	=	$N_H \bullet a_H$	(6d)

where:

N_H is the proportion of high hazard zones harvested within the last *n* years.

N_L is the proportion of low hazard zones harvested within the last *n* years.

Choosing unharvested areas (areas not harvested within the last *n* years) as an approximate reference or background condition for landslide sediment production in the watershed, reference rates of sediment production may be calculated for each hazard category using

$$R_L = \frac{P_1}{A_1 n} \quad \text{and} \quad R_H = \frac{P_2}{A_2 n} \qquad (7a), (7b)$$

where:

R_L is the reference rate of sediment production per unit area in low hazard zones (yd^3/acre/yr)

R_H is the reference rate of sediment production per unit area in high hazard zones (yd^3/acre/yr)

Likewise, rates of landslide sediment production from recently harvested areas (i.e., areas harvested within the last *n* years) may be calculated for each hazard category using

$$S_L = \frac{P_3}{A_3 n} \quad \text{and} \quad S_H = \frac{P_4}{A_4 n} \qquad (8a), (8b)$$

where:

S_L is the rate of sediment production per unit area recently harvested in low hazard zones (yd^3/acre/yr)

S_H is the rate of sediment production per unit area recently harvested in high hazard zones (yd^3/acre/yr)

Finally, the dimensionless ratio of sediment production per unit area of recently harvested to unharvested areas may be expressed for each hazard category as

$$L_L = \frac{S_L}{R_L} \quad \text{and} \quad L_H = \frac{S_H}{R_H} \qquad \text{(9a), (9b)}$$

where:

L_L is the ratio of sediment production per unit area between recently harvested and unharvested areas in low hazard zones

L_H is the ratio of sediment production per unit area between recently harvested and unharvested areas in high hazard zones

By comparing values of *S*, *R*, and *L* between the hazard categories, one can determine whether land classes have been chosen appropriately and, if so, the degree to which increases in non-road related landsliding may be attributed to timber harvesting activities. Such comparisons may also shed light on potential inaccuracies in the data used to run the model, and other problems. Properly selected land classes should meet each of the following criteria, or else the fundamental premise upon which the Landslide Reduction Model is based (i.e., increases in timber harvesting and operations in high hazard zones lead to increases in sediment production from non-road related landslides) have not been validated:

$$L_L \geq 1.0 \quad \text{and} \quad L_H \geq 1.0$$
$$R_H \geq R_L \quad \text{and} \quad S_H \geq S_L$$

Higher values of *L* suggest stronger relationships between timber harvesting and non-road related landslide sediment production.[11] Likewise, provided that the criteria above have been met, greater differences between values of *R* and *S* in the each of the hazard category suggest that the hazard map being used effectively captures the importance of high hazard zones in terms of increased sediment delivery rates.

Given the definitions described above, and accounting for hazard zones, the total rate of sediment production in the watershed, *S* (yd^3/acre/yr) is given by

$$S = R_H L_H N_H a_H + R_H(1-N_H)a_H + R_L L_L N_L(1-a_H) + R_L(1-N_L)(1-a_H) \qquad (10)$$

Likewise, the total reference sediment production rate in the watershed, *R* (yd^3/acre/yr) is given by

$$R = R_H a_H + R_L(1-a_H) \qquad (11)$$

Dividing Equation (10) by Equation (11) yields a version of Equation (3) that has been tailored to reflect sediment production from each of the land classes defined for the refined model (Table 3). This equation describes the total rate of sediment production in the watershed relative to reference conditions.

[11] In some cases, L_L may be greater in value than L_H. This condition does not necessarily invalidate the model's fundamental hypotheses.

$$\frac{S}{R} = S_R = \frac{R_H L_H N_H a_H + R_H (1-N_H) a_H + R_L L_L N_L (1-a_H) + R_L (1-N_L)(1-a_H)}{R_H a_H + R_L (1-a_H)} \qquad (12)$$

Expanding parenthetical terms in both the numerator and denominator of Equation (12), then grouping them based on the presence of the coefficients N_H and N_L leads to

$$S_R = \frac{R_H a_H + R_L - R_L a_H}{R_H a_H + R_L - R_L a_H} + \frac{R_H L_H a_H - R_H a_H}{R_H a_H + R_L - R_L a_H} \cdot N_H + \frac{R_L L_L - R_L L_L a_H - R_L + R_L a_H}{R_H a_H + R_L - R_L a_H} \cdot N_L \qquad (13)$$

At last, rearranging Equation (13) and recombining common terms leads to

$$S_R = 1 + \frac{R_H a_H (L_H - 1)}{R_H a_H + R_L (1-a_H)} \cdot N_H + \frac{R_L (L_L - 1)(1-a_H)}{R_H a_H + R_L (1-a_H)} \cdot N_L \qquad (14)$$

Equation (14) is the final form of the refined Landslide Reduction Model. Given known values of P and A for each land class based on past observed data, and setting S_R as the critical receiving water limitation, Equation (14) may be solved for paired values of N_H and N_L. Using the transformations below, any solution pair of N_H and N_L can then be converted into future allowable annual harvest acreages in both hazard categories that will not exceed the receiving water limitation, thus making the limitation enforceable.

Allowable annual harvest in high hazard zones (acres/yr) $= \frac{(A_{total})(a_H)}{n} \cdot N_H$ (15a)

Allowable annual harvest in low hazard zones (acres/yr) $= \frac{(A_{total})(1-a_H)}{n} \cdot N_L$ (15b)

The Simplified Model

In cases where values L, S and R suggest that increases in sediment production on recently logged areas are not substantially different between hazard zones, or when there are insufficient historical data to effectively discern the influence of hazard zones on landslide sediment production, the equations above can be condensed to describe a simplified version of the Landslide Reduction Model.

If hazard categories in the refined model are not considered, there are only two land classes: "recently harvested" and "unharvested" areas. Staying with the terms already defined in Table 3 for purposes of this discussion, the total area associated with unharvested portions of the watershed is equal to the sum of the unharvested areas in the low and high hazard zones. The balance of terms for the simplified model may be defined in a similar fashion for any time interval of n years, resulting in the following set of definitions:

Table 4. Definition of terms related to land classes in the simplified Landslide Delivery Potential Model.

Land Class Description	Area (acres)	Sediment Production (yd^3)
Unharvested Area	A_1+A_2	P_1+P_2
Recently Harvested Area	A_3+A_4	P_3+P_4

The fraction of the watershed associated with each of the two land classes may thus be defined as follows:

Unharvested fraction of the watershed = $1\text{-}N_T$ (16a)

Harvested fraction of the watershed = N_T (16b)

where:

N_T is the proportion of the watershed harvested within the last *n* years.

Choosing unharvested areas (areas not harvested within the last *n* years) as an approximate reference or background condition for landslide sediment production in the watershed, the reference rate of sediment production per unit area in the watershed, R_T (yd^3/acre/yr) may be calculated using

$$R_T = \frac{(P_1 + P_2)}{(A_1 + A_2) \cdot n} \tag{17}$$

Likewise, the rate of sediment production per unit area recently harvested in the watershed, S_T (yd^3/acre/yr) is given by

$$S_T = \frac{(P_3 + P_4)}{(A_3 + A_4) \cdot n} \tag{18}$$

Without hazard zones, a single value of L_T explains differences in sediment production between recently harvested and unharvested areas according to

$$L_T = \frac{S_T}{R_T} = \frac{(P_3 + P_4)/(A_3 + A_4)}{(P_1 + P_2)/(A_1 + A_2)} \tag{19}$$

where:

L_T is the dimensionless ratio of sediment production per unit area between recently harvested and unharvested areas in the watershed

Given the definitions described above, the total rate of sediment production in the watershed, S (yd^3/acre/yr) is given by

$$S = R_T L_T N_T + R_T (1 - N_T) \tag{20}$$

The total reference sediment production rate in the watershed, R (yd^3/acre/yr) is given by

$$R = R_T \qquad (21)$$

Dividing Equation (20) by Equation (21) yields a version of Equation (3) that has been tailored to reflect sediment production from each of the land classes defined for the simplified model (Table 4). This equation describes the total rate of sediment production in the watershed relative to reference conditions.

$$\frac{S}{R} = S_R = \frac{R_T L_T N_T + R_T(1 - N_T)}{R_T} \qquad (22)$$

Equation (22) can be rearranged into

$$S_R = 1 + (L - 1) \cdot N_T \qquad (23)$$

Equation (23) is the final form of the simplified Landslide Delivery Prevention Model. Given known values of *P* and *A* for each land class based on historical data, and setting S_R as the critical receiving water limitation, Equation (23) may be solved for N_T. Using the transformation below, the value of N_T can then be converted into a future allowable annual harvest acreages that will not exceed the receiving water limitation, thus making the limitation enforceable.

$$\text{Allowable annual harvest in the watershed (acres/yr)} = \frac{A_{total}}{n} \cdot N_T \qquad (21)$$

Model Application

The discussion below describes staff's application of the refined and simplified Landslide Reduction Models to PALCO's lands in Elk River and Freshwater Creek. The general process of model application involves several decisions, each of which is described in the sections below:

- The selection of appropriate drainage areas,
- The definitions of "recently harvested" and "unharvested" areas,
- The selection of appropriate sets of raw data,
- The processing of those raw data to generate model input parameters,
- The selection of an appropriate critical receiving water limitation,
- The validation of appropriate hazard maps, and finally,
- The selection of the most appropriate model application result.

Data Difficulties and Licensing Issues

It is important to note that PALCO has not provided staff direct access to the electronic Geographic Information System (GIS) database used to generate the raw data files. Rather, the company elected (with staff's consent) to run queries of its GIS database based on staff's requests, and to provide staff with reports of the query results. This system of information exchange eventually proved to be problematic in terms of limiting staff's ability to validate data received. Staff's overall confidence in the raw data provided by PALCO varies between the data types, as described in further detail below.

Regarding the preparation of technical reports by California licensed professionals, staff notes that PALCO's final ROWD documents (received October 13, 2004) and PALCO's corrected final ROWD documents (received January 16, 2005) were both submitted under the stamps, seals and signatures of a California licensed geologist, a California licensed civil engineer, and a Registered Professional Forester.[12] The multiple versions of the landslide databases,[13] however, were typically submitted under separate cover from the main ROWD document, were corrected and reissued at least once after January 16, 2005, and are not explicitly mentioned in the statement certified by the licensees. In discussions, PALCO staff has suggested that all landslide data and analyses were collected and prepared under the responsible charge of appropriately licensed individuals, though staff currently does not have official documentation of this fact.

It is with these limitations in mind that staff have made necessary decisions associated with the parameters and datasets described below.

Selection of Appropriate Drainage Areas

Applications of the Landslide Reduction Model are best suited to drainage areas where the following statements can be supported by available information:

1) All areas in the watershed have been, and will continue to be subject to the same natural and management-related influences (e.g., rainfall events and logging practices),
2) All areas have been and will continue to respond similarly when tested by natural and management-related influences, and
3) There are sufficient amounts of data available for each land class to produce stable model results.

Based on the statements listed above, staff selected Freshwater Creek, North Fork Elk River, and South Fork Elk River as the most appropriate drainage areas for applications of the Landslide Reduction Model. Lack of sufficient data to populate all land classes in smaller drainages proved the most limiting factor in watershed selection. The primary differences between the North and South Fork Elk River drainages include differences in slope, land use history, and history and timing of observed water quality impacts. The geologic formations underlying the watersheds also differ.

For purposes of the rest of this discussion, the term "North Fork Elk River" refers to all areas in the Upper and Lower North Fork Elk River planning watersheds (PALCO's ownership = 14,099 acres) and "South Fork Elk River" refers to all areas in the Upper and Lower South Fork Elk River planning watersheds minus Railroad[14] Gulch (PALCO's ownership = 6,176 acres).

[12] Licensees include: John Oswald, Certified Engineering Geologist No. 2291, Frederick Lee Charles, Registered Professional Civil Engineer No. C58853, and Stephen Horner, Registered Professional Forester No. 2441.

[13] PALCO's first submission of its landslide databases was received on September 2, 2004. The fifth and final versions of the databases were received on March 8, 2005, with some final, minor corrections received on June 3, 2005.

[14] Railroad Gulch is tributary to Mainstem Elk River, not South Fork Elk River, as the CALWATER watershed maps suggest. Consequently, for purposes of this analysis and the WWDRs, Railroad Gulch (~742 acres) is not considered part of South Fork Elk River.

"Freshwater Creek" refers to all areas in Cloney Gulch, Little Freshwater, and Upper Freshwater Creek planning watersheds (PALCO's ownership = 15,520 acres).

<u>Definition of Recently Harvested and Unharvested Areas</u>

A key decision in applying the Landslide Reduction Model lies in defining the temporal threshold between "recently harvested" and "unharvested" areas (or rather, choosing the model parameter *n*). Because these designations are used as surrogates at individual landslide locations for attributing yards delivered to either "harvest-related" or "natural" ("background") sources, the outcome of this choice is important to the final model results.

The model parameter *n* is expressed in terms of years since harvest. It represents the length of time over which timber harvest operations are likely to affect an area's susceptibility to landsliding. Conceptually, the removal of trees during logging operations results in loss of root strength and hydrologic function for some period of time, and heavy equipment operations (if applicable) result in increased exposure of disturbed ground to direct rainfall and concentration of runoff. These effects correspond to an increased likelihood of landsliding on recently logged areas, should those areas be exposed to a significant hydrologic or seismic event. After *n* years, it is assumed that root strength, hydrologic function, and the growth of protective vegetation over disturbed areas has returned to the harvested area, thus protecting it from significant triggering events to a degree that approximates pre-harvest conditions.

Clearly, this conceptual model is an oversimplification of a complex natural process. First, the loss and recovery of root strength and hydrologic function do not follow a uniform step function in time, but rather decline in an exponential manner over time over a period of several years (Burroughs and Thomas 1977, O'Loughlin and Watson, 1979 (as cited by Sidle, 1985)). Hammond, et al. (1992) cites Zeimer (1981a&b) and O'Loughlin (1974) studies of measurements indicating the period of minimum root strength ranges from about 3-5 years to about 10-20 years following harvest, depending on climate and the associated root decay and vegetative regrowth. PWA's sediment source investigations for Elk River (PWA 1998b) and Freshwater Creek (PWA 1999b) suggest that an *n*-value of 15 years empirically explains much of the differences observed between historical landslide sediment delivery rates from recently harvested areas and the rates from unharvested areas. Because the data were summarized based upon *n* equal to 15 years, and stated acknowledgement of this value being within the range of reasonableness, subsequent data analyses also reflected this same time period for recovery from reduced stability due to harvesting (Reid 1998a and 1998b, and ISRP 2002). At this time, and based upon pertinent studies and previous analyses, staff recommend an *n*-value of 15 years for applications of the Landslide Reduction Model in Elk River and Freshwater Creek.

Once a value of n = 15 years has been selected, sediment delivery rates associated with each land class are calculated by attributing all landslides that initiated from unharvested areas (i.e., areas not harvested within the last 15 years) to natural or background conditions, and attributing landslides occurring in recently harvested areas (areas harvested within the last 15 years) over and above the background landslide rates to timber harvesting.

<u>Selection of Appropriate Sets of Raw Data</u>

The Landslide Reduction Model requires the following spatially-referenced raw data for given time intervals of interest:

- Harvest history data
- Landslide hazard distribution data
- Landslide inventory data

Given the necessary raw data, values for the model input parameters A_i (the areas associated with each land class *i*) and P_i (the amount of sediment delivered by landslides in each land class *i*) may be calculated for a given interval of *n* years. The large majority of raw data used by staff to generate results from the Landslide Reduction Model were provided by PALCO as part of its ROWD. All raw data are available on CD from Regional Water Board staff upon request. All processed data used to perform model runs for this analysis appear in Appendix A to this report, and are also available on CD, along with relevant maps.

Harvest History Data

The harvest history information provided by PALCO (which consists of annotated maps and tabular data) are both spatially and temporally referenced. Each harvested acre has a known geographic location, silvicultural method, yarding method (in most cases), THP number, and the year of harvest. Based on a similar data set available from the California Department of Forestry and Fire Protection (CDF), PALCO's harvest history data appear to be complete and accurate for years dating back to 1986.

While staff's final application of the model requires spatially referenced harvest history information back to 1982, data for the years 1982-85 are generally not available electronically from either PALCO or CDF. In Freshwater Creek and North Fork Elk River, the absence of these data in the raw data set is not expected to significantly affect model results, because relatively little harvesting took place in the watersheds during this time,[15] and because many areas were re-entered in subsequent years, thus allowing them to be recognized by the model as harvested areas after all. However, in South Fork Elk River, harvest history data between 1982 and 1985 are crucial for accurate model results, because harvest rates in the watershed during these years were relatively high, and later re-entry was relatively infrequent. To fill this data gap, staff supplemented PALCO's South Fork Elk River harvest history data by evaluating archived THP files and hand-drawn harvest history maps available in CDF's Santa Rosa office. These sources revealed several hundred harvested acres that had not previously been known by staff or reported by PALCO in its ROWDs.[16]

[15] PWA (1999b) estimates an average rate of harvest in Freshwater Creek of 167 acres/yr for this time period, based on air photo data. Similarly, PWA (1998b) estimates an average rate of harvest in North Fork Elk River of 72 acres/yr.

[16] Specifically, staff discovered two Elk River Timber Company THPs covering an area of 1,105 acres in Tom Gulch, tributary to South Fork Elk River: THPs 1-82-462 HUM and 1-83-487 HUM. After it was logged, the land was acquired by PALCO as part of the Headwaters Deal in 1999.

In summary, staff have very high confidence in the accuracy of the final versions of PALCO's harvest history data and maps,[17] and have supplemented them where necessary to produce a complete set of raw data that can be used with confidence in applications of the Landslide Reduction Model. No further changes or data processing steps are necessary.

Landslide Hazard Distribution Data

Landslide hazard information provided by PALCO is spatially referenced and available for two 15-year intervals of interest (1982-1997 and 1988-2003) in tabular form. The rationale for the intervals chosen is explained in the next section. The distributions, reported in terms of acres associated with each land class, were prepared separately for Freshwater Creek, North Fork Elk River, and South Fork Elk River using three different hazard zonation schemes, or hazard maps. These maps delineate high landslide hazard categories, or what PALCO refers to as restriction categories in its Reports of Waste Discharge (PALCO, 2005a and 2005b), according to the following criteria:

- *Hazard Map #1: MWAC Only*

  High hazard zones include all areas that qualify as Mass Wasting Areas of Concern (MWAC), as spelled out in Section 6.3.3.7 of PALCO's HCP (USFWS & CDF, 1999). These areas are defined using a numeric scoring system to rate several factors related to landslide predisposition, including: geologic unit, soil type, slope, and landform. If the total of the combined factors exceeds a certain numeric threshold, the area is considered an MWAC.

- *Hazard Map #2: MWAC + Steep Slopes*

  High hazard zones include all areas that qualify as MWAC, as well as all areas of steep slopes (steeper than 50%) leading to Class I and Class II watercourses until the break-in-slope (defined as a slope less than 50% for more than 100 feet) or until a distance of 400 feet has been reached. These steep slope provisions are spelled out in Sections 6.3.4.1.2 and 6.3.4.1.3 of PALCO's HCP (USFWS & CDF, 1999).

- *Hazard Map #3: MWAC + Steep Slopes + Riparian Management Zones (RMZs)*

  High hazard zones include all areas that qualify as MWAC, or that meet the terms of the steep slope provisions described above, as well as all areas that lie within Riparian Management Zones (RMZs), as spelled out in Sections 6.3.4.1.2 and 6.3.4.1.3 and 6.3.4.1.4 of PALCO's HCP (USFWS & CDF, 1999). RMZ widths for Class I, Class II, and Class III watercourses are 170, 130, and 30 feet, respectively.

[17] The final version of PALCO's harvest history database for Freshwater Creek and Elk River was received by staff on January 7, 2005. The final Freshwater Creek harvest history map was received by staff on September 2, 2004. The final Elk River harvest history map was received on October 1, 2004.

While there are numerous hazard maps that might be used to categorize a watershed into land classes based on landslide delivery potential,[19] the hazard maps above were chosen primarily because: 1) they were readily available in PALCO's GIS database, 2) they were relatively easy to validate for accuracy, 3) they recognized areas already explicitly identified and treated specially under PALCO's HCP interim requirements, 4) they were fully compatible with PALCO's new HCP Watershed Analysis and Adaptive Management prescriptions, and 5) they could be verified, refined and improved based on geologic field investigations that are routinely conducted by PALCO during THP design.

With few exceptions, all high hazard zones recognized in the hazard maps described above have been strictly off-limits to logging on PALCO lands since 1999, based on HCP interim prescriptions. However, in Freshwater Creek, the large majority of these areas have recently been re-opened to logging under new Watershed Analysis prescriptions, though some limitations do still apply (PALCO, 2002). Similar prescriptions for Elk River are soon to be put in place. The refined Landslide Reduction Model is able to account for sediment delivered from these sensitive areas separately from the rest of the landscape by using land classes that have been defined according to HCP-derived conventions.

The final version of the raw data supplied by PALCO for the three specified hazard maps (received June 3, 2005) contained significant, unexplained errors. Specifically, the total recently harvested acreage in each watershed for the given time intervals was not consistent between the hazard maps. In an effort to correct this discrepancy, staff made an assumption that the source of the problem was strictly calculation-driven, and not associated with faulty GIS data, and asked PALCO to verify that assumption. PALCO has not done so. As a result, staff assumes that the hazard distribution data used as input for the Landslide Reduction Model are accurate, although this assumption cannot currently be verified.

Staff were required to apply a second correction to PALCO's data upon discovering that the hazard distributions PALCO reported for its lands in the South Fork Elk River drainage included all of its lands in the Mainstem Elk River drainage as well. Because the PALCO's Mainstem holdings (1,875 acres) are not the subject of staff's application of the Landslide Reduction Model, staff scaled PALCO's data to make the total number of acres in the distribution equivalent to the number of acres in PALCO's South Fork Elk River ownership (6,176 acres), assuming a proportional distribution of hazard zones between the two adjacent drainage areas. The data were then scaled a second time to account for the additional 1,105 recently harvested acres discovered by staff in South Fork Elk River that had not previously been reflected in PALCO's harvest history database. These scaling exercises, the details of which are available from staff upon request, introduce unknown errors of unknown magnitude the Landslide Reduction Model, and may affect model results.

In summary, the accuracy of the final version of PALCO's landslide hazard distribution data is questionable. Staff were required to apply one correction to the data from North Fork Elk River and Freshwater Creek, and two corrections to the data from South Fork Elk River in order to make the data usable. The first correction is assumed to have made the data accurate. The

[19] Staff is familiar with hazard potential maps made recently available for both Freshwater Creek and Elk River by California Geological Survey (2002 and 2003, respectively). These maps may indeed be appropriate candidates for consideration in future applications of the Landslide Reduction Model and/or future versions of the WDRs.

second correction may have introduced errors that are carried into applications of the Landslide Reduction Model in the South Fork Elk River watershed. Model results for the refined version of the model in this drainage may thus have been compromised.

Landslide Inventory Data

The landslide information provided by PALCO (which consists of annotated maps and tabular data) are both spatially and temporally referenced. Each inventoried landslide is known by approximate geographic location, land use history (e.g., road-related vs. non-road related), landslide type, estimated volume displaced, estimated volume delivered, and various other attributes.[20] Specifically, PALCO submitted landslide inventories for Freshwater Creek and Elk River as identified on the 1997 and 2003 aerial photo sets, along with its ROWDs.

The earlier (1997) landslide inventories were developed by PWA as part of its early sediment budget work in these watersheds (PWA, 1998 and 1999). The inventories were generated using a combination of aerial photo analyses (calibrated by field measurements) and complete road surveys. Methods are described in PWA's original reports for Freshwater Creek and North Fork Elk River (PWA 1999b and 1998b, respectively).[21] Sediment volumes reported by PWA for 1997 landslides in each of the three watersheds represent total volumes delivered over three winter periods, beginning with the winter of 1994/1995 and ending with the winter of 1996/97. For purposes of this analysis, staff assumes that the volumes delivered during this three-year period may be wholly attributed to the winter of 1996/97, especially considering the magnitude of the New Years storm event of that winter. The effect of this assumption on model results cannot be easily quantified without yearly data for landslide delivery volumes, and accompanying hazard distribution data for those same years, neither of which are currently available.

The later (2003) landslide inventories were developed by PALCO's geologic staff based on analysis of 2003 aerial photos, calibrated by field measurements. Methods are described in Appendix G of each of PALCO's ROWDs (PALCO, 2005a & 2005b). According to Appendix G, PALCO's 2003 landslide inventory data span a total of six winter periods, ending with the winter of 2002/03. However, staff has learned from PALCO's geologic staff that the 2003 inventories contain only those landslides thought to have occurred during the winter period of 2002/03, as interpreted from the 2003 aerial photos. Assuming that this extraction of a single year's landslides from a three-year photo record was executed with some degree of precision, staff have available data from two landslide inventories, each of which is keyed to winter periods during which record storms were observed. Further details regarding the characterization of the New Years storm of 1997 and the December 27-28, 2002 storm as landslide triggering events can be found in PALCO's ROWDs (PALCO, 2005a and 2005b).

By combining landslide delivery and hazard distribution data from the 1997 and 2003 inventories, staff applied the Landslide Reduction Model to develop an enforceable receiving

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[20] Staff note that non-discrete landslide-related erosional processes such as soil creep or surface erosion of disturbed areas where there are no obvious landslide scars, are not considered landslide features in PALCO's landslide inventories. As a result, these processes are not accounted for in staff's applications of the Landslide Reduction Model.

[21] Staff note that there is no report that describes PWA's 1997 landslide inventory data for South Fork Elk River.

water limitation based on recent observed watershed responses to two significant testing events – an approach consistent with staff's original data requests to PALCO.[22]

PALCO submitted the fifth and final version of its landslide inventory databases for 1997 and 2003 on March 8, 2005, although some minor corrections and other clarifications were later required. Once errors and omissions in the first four versions of the databases were resolved, staff processed the raw data in each inventory by first sorting them by land use association, and extracting all non-road related slides, including reactivated slides. These landslides were then categorized according to each of the four land classes considered in the refined version of the Landslide Reduction Model. Once the delivered volumes associated with each of the land classes were available for each inventory, the 1997 and 2003 data were combined into a single input data set for each watershed, to be coupled with similarly combined hazard distribution data for each watershed.

While processing the landslide data, as described above, staff encountered several instances where changes to PALCO's raw data were necessary to correct errors, omissions, or other apparent discrepancies. Where staff made such changes to PALCO's data, staff highlighted the affected spreadsheet cells in blue, both in the raw data (with comments) and in the processed data (without comments), which is provided in Appendix A to this report. Full, annotated versions of the corrected raw data files are available on CD from Regional Water Board staff upon request.

As an important final note, there are two circumstances under which staff found it appropriate to alter reported delivery volumes for individual landslides, as evidenced by the processed data. The first circumstance involves a February 2003 report prepared for PALCO by PWA (PWA, 2003), pursuant to CAO Order No. R1-2002-0114 (Regional Water Board, 2002). This particular report provides field measured sediment delivery volumes for several landslides originally inventoried in PWA's 1997 aerial photo analysis for North Fork Elk River. Staff incorporated these improved, field-measured volumes, into the processed data for the 1997 North Fork Elk River landslide inventories.

Secondly, in cases where available data suggest that an inventoried harvest-related landslide was a deep-seated feature, half of the volume delivered from the feature was attributed to recently harvested land classes, and half to unharvested land classes for the applicable hazard zone. This change in the processed data is based on the assumption that deep-seated features (i.e., features originating below the influence of changes in root strength) may not be wholly attributable to harvesting, but may be partially affected by other complex natural processes including changes in groundwater. While acting on this assumption does not constitute the most conservative approach for handling sediment delivery volumes associated with deep-seated features, staff believes it does constitute the most reasonable approach, given the debatable relationship between recent timber harvesting and the occurrence of deep-seated landslides.

[22] Staff note that additional landslide inventory data for the years 1998-2002 are available for Elk River, but have not been factored into staff's applications of the Landslide Reduction Model because they are not associated with a known landslide-triggering event. These additional data will be the subject of future analyses and model applications as appropriate during TMDL development.

Selection of an Appropriate Critical Receiving Water Limitation

TMDLs and their associated load allocations have not yet been established for Freshwater Creek and Elk River. As such, to help determine an appropriate threshold for harvest-related landslide sediment delivery, staff reviewed fifteen US EPA approved Total Maximum Daily Loads (TMDLs) for sediment for the North Coast. Figure 1 demonstrates the ranges of total load allocations expressed as percentages of the natural loads in these north coast TMDLs. Ten of these analyses set the load allocations at or near 125% of the natural load.[23] Based upon these TMDLs, and until Elk River and Freshwater Creek loads allocations are established, staff recommends that the critical receiving water limitation be consistent with these completed analyses and should be set at 125% of natural conditions. For the purposes of the Landslide Reduction Model, this translates to a limitation in harvested-related landslide sediment delivery of 125% of "background" landslide sediment delivery, or a value of 1.25 for S_R, the dimensionless rate of sediment production relative to reference conditions.

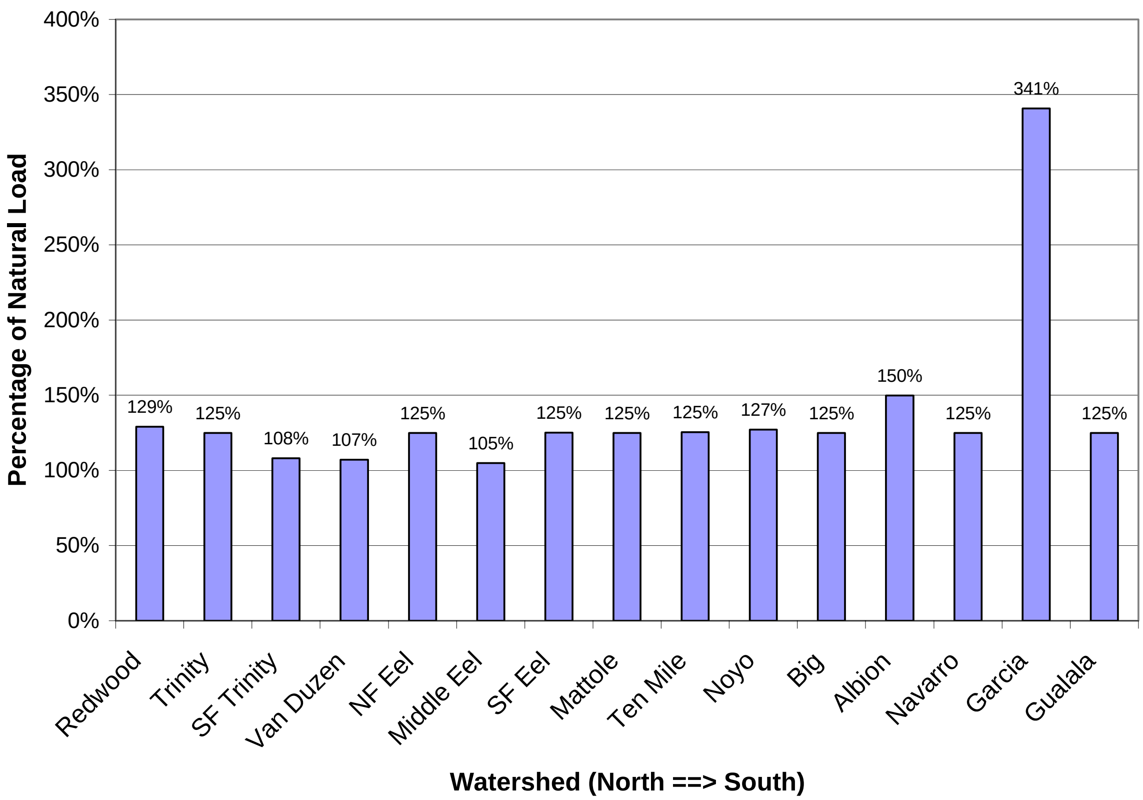

Figure 1. Total load allocation expressed as a percentage of the natural load for 15 EPA established TMDLs on the northcoast.

[23] Three of the TMDL documents included original load allocation analyses (Noyo River, Redwood Creek, and Trinity River), upon which seven other TMDLs depended when setting their load allocations.

Selected Model Applications and Results

The results of the Landslide Reduction Model, as applied to PALCO lands in the Freshwater Creek, North Fork Elk River, and South Fork Elk River watersheds, based on available harvest history, hazard distribution, and landslide inventory data, as explained above, are provided in Appendix B and summarized here.

Freshwater Creek

The most appropriate model result for an enforceable receiving water limitation in Freshwater Creek utilizes Hazard Map #2 in the refined Landslide Reduction Model. The selected result corresponds to a maximum annual harvest rate of 144 acres/yr in low hazard zones, a minimum annual harvest of 38 acres/yr in high hazard zones, or any combination of acres between the hazard zones that satisfy the following relationship:

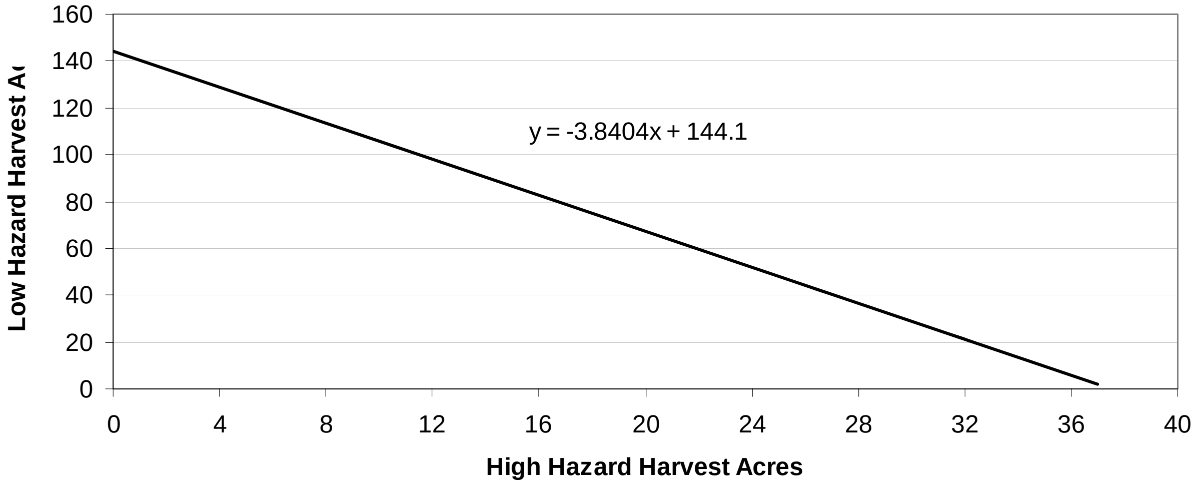

Figure 2. Relationship of high and low hazard acres available for harvest based on results of refined Landslide Reduction Model utilizing Hazard Map #2 in Freshwater Creek.

North Fork Elk River

The most appropriate model result for an enforceable receiving water limitation in North Fork Elk River utilizes Hazard Map #3 in the refined version of the Landslide Reduction Model. The selected result corresponds to a maximum annual harvest rate of 266 acres/yr in low hazard zones, a minimum annual harvest rate of 21 acres/yr in high hazard zones, or any combination of acres between the hazard zones that satisfy the following relationship:

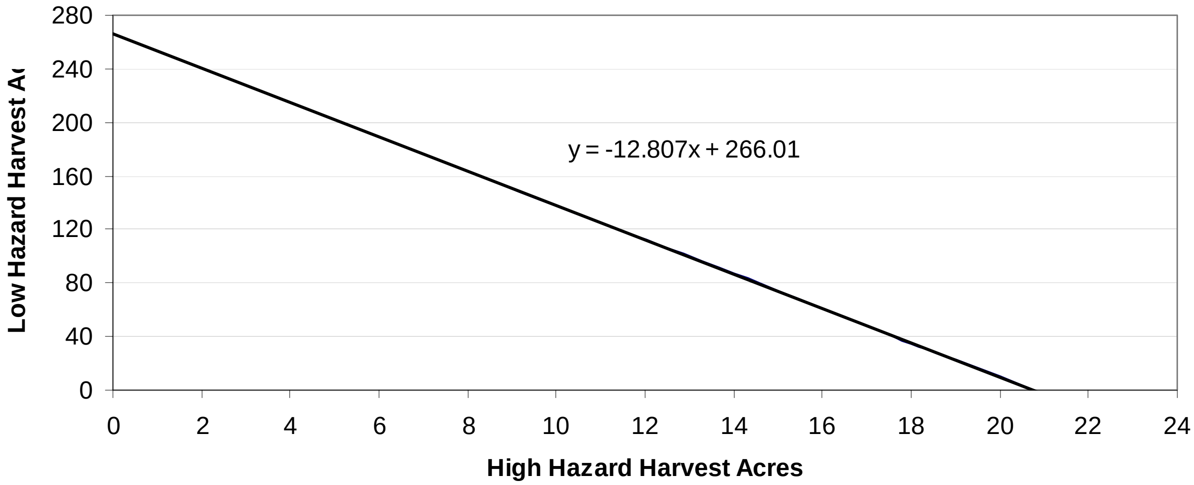

Figure 3. Relationship of high and low hazard acres available for harvest based on results of refined Landslide Reduction Model utilizing Hazard Map #3 in North Fork Elk River.

South Fork Elk River

The most appropriate model result for an enforceable receiving water limitation in South Fork Elk River utilizes the simplified Landslide Reduction Model. The selected result corresponds to a maximum annual harvest of 113 acres, regardless of hazard zone.

Discussion of Model Limitations, Assumptions, and Suggestions for Future Improvements

As with any model development and application effort, data issues, judgement calls, and design decisions, such as those enumerated in this report, require that certain limitations be accepted and certain assumptions be made that will inherently introduce potential error or bias into the eventual model results. In the interest of open science and to highlight opportunities to make model refinements and to relax certain assumptions, staff have compiled the following list of key model limitations and assumptions. Where possible, staff have provided information regarding the affect of each model limitation and assumption and staff's confidence in making the assumption, and have suggested where there may be room for refining and improving the model for future applications.

Model Limitations

***Limitation No. 1*:**
Forest cover limits the detection of smaller landslide features on aerial photographs, especially where those features are located in older forest stands.

Effect on results:
The most likely effect of landslide detection problems associated with air photo inventories used to generate PALCO's landslide databases is an underestimate of background sediment production. This effect would result in overly conservative limits on allowable sediment discharge. However, because the Landslide Reduction Model relies not on absolute sediment production estimates, but rather relative estimates between recently harvested and unharvested

land classes, the model results may be insulated from errors as large as those reported in the scientific literature, because those errors would appear in both the numerator and denominator of the relative estimate, thus canceling themselves to some degree. The actual effect of detection problems on the model results cannot be known, given the available data. However, if background sediment production rates are underestimated to any degree, the result will be a greater margin of safety built into the model results.

Possible Future Improvements:
Site specific information regarding detection limits as a function of stand age for aerial photo analyses in Freshwater Creek and Elk River should be developed, in order to assess the potential need for correction factors to be applied to volume estimates used as model inputs.

***Limitation No. 2*:**
Criteria for quantities of data necessary to populate each land class in the Landslide Reduction Model constrain current model applications to large drainage areas.

Effect on results:
By applying the model on drainage areas as large as Freshwater Creek, and North and South Fork Elk River, the model assumes sediment production rates that likely do not honor the spatial variability of these rates between sub-watersheds. Also, by leading to receiving water limitations that apply to large areas, localized concentrations of sediment generating activities (i.e., timber harvest operations) could lead to water quality degradation at smaller scales.

Possible Future Improvements:
Given sufficient amounts of relevant data from past and future significant triggering events, applications of the Landslide Reduction Model should focus on sub-watersheds.

Assumptions

***Assumption No. 1*:**
Setting the critical receiving water limitation for discharges from harvest-related landslides at 125% of background will allow for the recovery of beneficial uses of Elk River and Freshwater Creek.

Support for assumption:
This assumption is based upon load allocations of established TMDLs for ten north coast watersheds.

Confidence:
Medium

Effect on results:
Using a lower load allocation would yield more conservative results, would provide greater assurances of watershed recovery, and would have the effect of lowering allowable annual harvesting in each watershed. Using a higher load allocation would have the opposite effect, and would possibly impede watershed recovery.

Possible Future Improvements:
The development of TMDLs for Freshwater Creek and Elk River, which are currently under construction, will lead to watershed-specific load allocations that should be used in the place of the assumed critical receiving water limitation of 125%.

***Assumption No. 2*:**

Rates of sediment production from areas not harvested in the last 15 years (*n*=15) can be used to approximate natural landslide production rates.

Support for assumption:
PWA's sediment source investigations for Elk River (PWA 1998b) and Freshwater Creek (PWA 1999b) suggest that an *n*-value of 15 years empirically explains much of the differences observed between historical landslide sediment delivery rates from recently harvested areas and the delivery rates from unharvested areas. This number is generally within the range of values found in the scientific literature for the recovery of pre-harvest slope stability conditions through root strength and hydrologic function.

Confidence:
Medium

Effect on Results:
This assumption treats the site recovery of a recently harvested area as a uniform function that reaches pre-harvest slope stability levels (i.e., background status) in 15 years. This introduces potential errors in two ways: first, due to the assumed shape of the recovery curve, and second, due to the assumed completion of site recovery (i.e., the resumption of pre-harvest slope stability) after a finite period of time. For the watersheds in which the Landslide Reduction Model is being applied, staff expects the results of these errors to pull the model results in both directions, thus dampening the effect of the uncertainty. We note, however, that if the actual recovery period is more than 15 years, then this assumption will lead to overestimates of background sediment production from landslides, and thus have the effect of allowing more annual harvesting in the watersheds than is necessary for water quality protection.

Possible Future Improvements:
Age distributions for available landslide inventories in these watersheds should be evaluated against landslide occurrence, to determine if adjustments to the assumed shape and length of the recovery function would decrease potential levels of error or bias in future model applications.

***Assumption No. 3*:**

Sediment delivery from deep-seated landslide features mapped in recently harvested areas is equally attributable to harvest activities and natural conditions.

Support for assumption:
Generally speaking, deep-seated landslides are not as susceptible to changes in root strength and ground disturbance as shallow landslide features. Rather, the mediator in deep-seated landslide initiation is water, either as surface water destabilizing the toe of the feature, or as subsurface water influencing pore pressures and groundwater dynamics within and adjacent to the slide mass. As such, harvesting effects on deep-seated features include changes in hydrologic function due to tree removal, but do not necessarily include the loss of root strength in the shallow soil layer. Attributing half the volume of deep-seated features in recently harvested areas to management, and half to natural conditions is not the most conservative possible approach for handling these features in the Landslide Reduction Model. However, considering the model's sensitivity to large features (as deep-seated landslides tend to be), and given the complex and debatable relationship between recent harvesting and the occurrence of deep-seated landslides, staff believe this assumption is the most reasonable at this time.

Confidence:
Medium

Effect on results:
Attributing more than half the volume of harvest-related deep-seated landslide features to management causes would yield more conservative results, would provide greater assurances of watershed recovery, and would have the effect of lowering allowable annual harvesting in each watershed. Attributing less than half the volume to management would have the opposite effect.

Possible Future Improvements:
Alternative options for handling sediment inputs from deep-seated features in the model should be explored and considered based upon further review of the scientific literature and upon careful examination of the deep-seated features inventoried in Elk River and Freshwater Creek.

***Assumption No. 4*:**

Harvest-related landslide volumes delivered during the 1995-1997 and 2003 photoperiods are wholly attributable to single hydrologic events.

Support for assumption:
This assumption is based on knowledge of the extreme magnitudes and intensities of the New Years 1997 storm, and the December 27-28, 2002 storm, and upon the colloquial understanding that these particular storms were responsible for most of the landslides in these watersheds for the photo periods specified.

Confidence:
Medium

Effect on results:
The effect of this assumption on model results cannot be easily quantified without yearly data for landslide volumes delivered during each storm of each year in each photoperiod. However, staff expect the effect to be modest, because the Landslide Reduction Model is indifferent to whether the "events" considered are individual storm events, entire winters, or collections of winters.

Possible Future Improvements:
Landslide inventory data for all available recent years and photo periods should be examined to determine the degree which Landslide Reduction Model results are sensitive to the choice of the design "event" in terms of individual storms, entire winters, or entire collections or winters (i.e., photo periods). All available inventory data, not just those associated with the 1997 and 2002 storms should be considered in this exercise.

Conclusion

The purpose of the modeling work described in this report was to develop, using the best available methods and data, enforceable receiving water limitations for timber harvest-related discharges from PALCO lands in the sediment-impaired Elk River and Freshwater Creek watersheds. In staff's professional opinion, the final recommended limitations (i.e., the selected model application results) adequately address cumulative impacts, and are reasonably expected to allow for watershed recovery from existing impaired conditions. Where the quality of available data has been questionable, or where simplifying assumptions have been necessary to generate results, staff has made conservative choices. These choices provide a built-in margin of safety for the recommended limitations that generally corresponds to a greater consideration for public health, safety, and water quality protection.

The recommended receiving water limitations support the proposed watershed-wide WDRs by providing a scientific basis by which the Regional Water Board may allow new timber harvest-related discharges to continue while providing for the recovery of the beneficial uses of water in Elk River and Freshwater Creek. The issuance of the proposed watershed-wide WDRs prior to the completion of the Total Maximum Daily Load (TMDL) development process is a near-term strategy for permitting new discharges of waste associated with PALCO's ongoing land management activities in these sediment-impaired watersheds. Once TMDLs are complete, staff may broaden or refine the scope of the watershed-wide WDRs, and the models used to support them, as a part of TMDL implementation

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List of parameters Associated with the Landslide Reduction Model

a_i - the dimensionless fraction of watershed area comprising land class *I*
c_i - the sediment production rate coefficient for land class *i* ($L^3/L^2/T$)
L_L - the ratio of sediment production per unit area between recently harvested and unharvested areas in low hazard zones
L_H - the ratio of sediment production per unit area between recently harvested and unharvested areas in high hazard zones
n - the number of years since harvesting (T). It represents the length of time over which timber harvest operations are likely to effect an area's predisposition to landsliding.
N_H - the proportion of high hazard zones harvested within the last *n* years.
N_L - the proportion of low hazard zones harvested within the last *n* years.
N_T - the proportion of the watershed harvested within the last *n* years.
r_i - the reference sediment production rate coefficient for land class *i* ($L^3/L^2/T$)
R - the reference rate of sediment production per unit area ($L^3/L^2/T$)
R_L - the reference rate of sediment production per unit area in low hazard zones (yd^3/acre/yr)
R_H - the reference rate of sediment production per unit area in high hazard zones (yd^3/acre/yr)
S - the rate of sediment production per unit area ($L^3/L^2/T$)
S_H - the rate of sediment production per unit area recently harvested in high hazard zones (yd^3/acre/yr)
S_L - the rate of sediment production per unit area recently harvested in low hazard zones (yd^3/acre/yr)
S_R - the dimensionless rate of sediment production relative to reference conditions
w_i - the normalized, and therefore dimensionless, sediment production rate coefficient for land class *i*

Appendix A

Processed Landslide Inventories and Hazard Zonation Data for PALCO Lands in the Freshwater Creek, North Fork Elk River, and South Fork Elk River watersheds

(Data Processed by Regional Water Board Staff)

Hazard Zonation Data for PALCO Lands - Hazard Map #1
(All values are in units of acres)

Freshwater Creek

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	227	360	587
	> 15	647	515	1162
Subtotal		**875**	**875**	**1749**
Low	<= 15	3268	6089	9357
	> 15	11377	8557	19934
Subtotal		**14645**	**14645**	**29290**
Grand Total		**15520**	**15520**	**31039**

Freshwater Creek

Model Inputs	1997	2003	Combined	
A1	11377	8557	19934	low hazard, unharveste
A2	647	515	1162	high hazard, unharvest
A3	3268	6089	9357	low hazard, recently ha
A4	227	360	587	high hazard, recently h

North Fork Elk River

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	390	527	917
	> 15	501	364	865
Subtotal		**891**	**891**	**1782**
Low	<= 15	4700	6285	10985
	> 15	8509	6923	15432
Subtotal		**13208**	**13208**	**26417**
Grand Total		**14099**	**14099**	**28199**

North Fork Elk River

Model Inputs	1997	2003	Combined	
A1	8509	6923	15432	low hazard, unharveste
A2	501	364	865	high hazard, unharvest
A3	4700	6285	10985	low hazard, recently ha
A4	390	527	917	high hazard, recently h

Hazard Zonation Data for PALCO Lands - Hazard Map #1
(All values are in units of acres)

South Fork Elk River

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	258	125	383
	> 15	89	223	312
Subtotal		**348**	**348**	**696**
Low	<= 15	2993	2175	5168
	> 15	2835	3654	6488
Subtotal		**5828**	**5828**	**11656**
Grand Total		**6176**	**6176**	**12352**

South Fork Elk River

Model Inputs	1997	2003	Combined	
A1	2835	3654	6488	low hazard, unharveste
A2	89	223	312	high hazard, unharvest
A3	2993	2175	5168	low hazard, recently ha
A4	258	125	383	high hazard, recently h

Hazard Zonation Data for PALCO Lands - Hazard Map #2
(All values are in units of acres)

Freshwater Creek

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	227	360	587
	> 15	647	515	1162
Subtotal		**875**	**875**	**1749**
Slope	<= 15	219	500	719
	> 15	694	413	1106
Subtotal		**912**	**912**	**1825**
Low	<= 15	3049	5589	8638
	> 15	10684	8144	18827
Subtotal		**13733**	**13733**	**27465**
Grand Total		**15520**	**15520**	**31039**

Freshwater Creek

Model Inputs	1997	2003	Combined	
A1	10684	8144	18827	low hazard, unharvested
A2	1341	928	2269	high hazard, unharvested
A3	3049	5589	8638	low hazard, recently harves
A4	446	859	1305	high hazard, recently harve

North Fork Elk River

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	390	527	917
	> 15	501	364	865
Subtotal		**891**	**891**	**1782**
Slope	<= 15	314	432	745
	> 15	588	470	1058
Subtotal		**902**	**902**	**1804**
Low	<= 15	4386	5854	10240
	> 15	7921	6453	14374
Subtotal		**12307**	**12307**	**24613**
Grand Total		**14099**	**14099**	**28199**

North Fork Elk River

Model Inputs	1997	2003	Combined	
A1	7921	6453	14374	low hazard, unharvested
A2	1089	834	1923	high hazard, unharvested
A3	4386	5854	10240	low hazard, recently harves
A4	704	959	1663	high hazard, recently harve

Hazard Zonation Data for PALCO Lands - Hazard Map #2
(All values are in units of acres)

South Fork Elk River

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	258	125	383
	> 15	89	223	312
Subtotal		**348**	**348**	**696**
Slope	<= 15	54	35	89
	> 15	52	71	123
Subtotal		**106**	**106**	**212**
Low	<= 15	2939	2140	5079
	> 15	2783	3582	6366
Subtotal		**5722**	**5722**	**11444**
Grand Total		**6176**	**6176**	**12352**

South Fork Elk River

Model Inputs	1997	2003	Combined	
A1	2783	3582	6366	low hazard, unharvested
A2	141	294	435	high hazard, unharvested
A3	2939	2140	5079	low hazard, recently harves
A4	313	159	472	high hazard, recently harve

Hazard Zonation Data for PALCO Lands - Hazard Map #3
(All values are in units of acres)

Freshwater Creek

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	227	360	587
	> 15	647	515	1162
Subtotal		**875**	**875**	**1749**
Slope	<= 15	219	500	719
	> 15	694	413	1107
Subtotal		**913**	**913**	**1825**
RMZ	<= 15	789	1747	2536
	> 15	2706	1748	4454
Subtotal		**3495**	**3495**	**6990**
Low	<= 15	2260	3842	6102
	> 15	7978	6396	14373
Subtotal		**10238**	**10238**	**20475**
Grand Total		**15520**	**15520**	**31040**

Freshwater Creek

Model Inputs	1997	2003	Combined	
A1	7978	6396	14373	low hazard, unharvested
A2	4047	2676	6723	high hazard, unharvested
A3	2260	3842	6102	low hazard, recently harves
A4	1236	2606	3842	high hazard, recently harve

North Fork Elk River

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	390	527	917
	> 15	501	364	865
Subtotal		**891**	**891**	**1782**
Slope	<= 15	314	432	745
	> 15	588	470	1058
Subtotal		**902**	**902**	**1804**
RMZ	<= 15	1123	1523	2646
	> 15	1774	1374	3148
Subtotal		**2897**	**2897**	**5794**
Low	<= 15	3263	4331	7594
	> 15	6147	5079	11226
Subtotal		**9410**	**9410**	**18820**
Grand Total		**14099**	**14099**	**28199**

North Fork Elk River

Model Inputs	1997	2003	Combined	
A1	6147	5079	11226	low hazard, unharvested
A2	2863	2208	5070	high hazard, unharvested
A3	3263	4331	7594	low hazard, recently harves
A4	1827	2482	4309	high hazard, recently harve

Hazard Zonation Data for PALCO Lands - Hazard Map #3
(All values are in units of acres)

South Fork Elk River

Hazard	Harvest	1997	2003	Combined
MWAC	<= 15	258	125	383
	> 15	89	223	312
Subtotal		**348**	**348**	**696**
Slope	<= 15	54	35	89
	> 15	52	71	123
Subtotal		**106**	**106**	**212**
RMZ	<= 15	500	359	859
	> 15	498	638	1136
Subtotal		**997**	**997**	**1995**
Low	<= 15	2440	1782	4221
	> 15	2285	2943	5228
Subtotal		**4725**	**4725**	**9450**
Grand Total		**6176**	**6176**	**12352**

South Fork Elk River

Model Inputs	1997	2003	Combined	
A1	2285	2943	5228	low hazard, unharvested
A2	639	933	1571	high hazard, unharvested
A3	2440	1782	4221	low hazard, recently harves
A4	813	519	1331	high hazard, recently harve

Freshwater Creek 1997 Landslide Inventory Data

Freshwater Creek 1997 - Unharvested Open Slope Landslides

			Restriction Status			Harvest Activity	Landuse	Vol. Disp.	Vol. Deliv.		Volume Delivered			
SLIDEID	Data-base	Drainage	Haz #1	Haz #2	Haz #3	Age Group	Association	(yd3)	(yd3)		Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
F0078	Road	Little Freshwater	0	0	1	0	A	422	404		0	0	404	
F0223	Aerial	Little Freshwater	0	0	0	0	OS	40	0		0	0	0	
F0224	Aerial	Little Freshwater	0	0	0	0	OS	37	0		0	0	0	
F0288c	Aerial	Graham Gulch	0	0	1	0	OS	14933	1941		0	0	1941	
F0339	Aerial	Mainstem	0	1	1	0	OS	154	20		0	20	20	
F0340	Aerial	Upper Freshwater	1	1	1	0	OS	370	370		370	370	370	
F0342	Aerial	Little Freshwater	0	0	1	0	OS	19	12		0	0	12	
F0395	Aerial	Upper Freshwater	0	0	0	0	OS	280	246		0	0	0	
F0408	Aerial	Upper Freshwater	0	0	0	0	OS	222	196		0	0	0	
F0409	Aerial	Upper Freshwater	0	0	0	0	OS	2710	1030		0	0	0	
F0493	Aerial	Mainstem	0	0	0	0	OS	40	20		0	0	0	
11	Count						Total Unharvested Volume (yd3) =		4,239	P1	**3,869**	**3,849**	**1,492**	Low Hazard
										P2	**370**	**390**	**2,747**	High Hazard

Freshwater Creek 1997 - Recently Harvested Open Slope Landslides

SLIDEID	Data-base	Drainage	Haz #1	Haz #2	Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)	Vol. Delivered Haz #1 (yd3)	Vol. Delivered Haz #2 (yd3)	Vol. Delivered Haz #3 (yd3)
F0220	Aerial	Graham Gulch	0	1	1	1	OS	368	0	0	0	0
F0221	Aerial	Graham Gulch	0	0	1	1	OS	67	0	0	0	0
F0236	Aerial	Little Freshwater	0	0	0	1	OS	65	0	0	0	0
F0238	Aerial	Little Freshwater	0	0	0	1	OS	27	0	0	0	0
F0240	Aerial	Little Freshwater	0	0	0	1	OS	368	0	0	0	0
F0241	Aerial	Mainstem	0	0	0	1	OS	64	0	0	0	0
F0242	Aerial	Little Freshwater	0	0	0	1	OS	475	0	0	0	0
F0245	Aerial	Little Freshwater	0	0	1	1	OS	30	0	0	0	0
F0246	Aerial	Little Freshwater	0	0	0	1	OS	30	0	0	0	0
F0247	Aerial	Little Freshwater	0	0	0	1	OS	29	0	0	0	0
F0248	Aerial	Little Freshwater	1	1	1	1	OS	31	0	0	0	0
F0249	Aerial	Little Freshwater	0	0	0	1	OS	116	0	0	0	0
F0256	Aerial	Mainstem	0	0	0	1	OS	98	0	0	0	0
F0257	Aerial	Mainstem	0	0	0	1	OS	61	0	0	0	0
F0258	Aerial	Mainstem	0	0	0	1	OS	146	0	0	0	0
F0299	Aerial	Graham Gulch	0	0	1	1	A	105	14	0	0	14
F0303b	Aerial	Little Freshwater	0	0	0	1	OS	1944	778	0	0	0
F0316	Aerial	Little Freshwater	0	0	1	1	A	187	75	0	0	75
F0317	Aerial	Little Freshwater	0	0	0	1	A	1133	1077	0	0	0
F0318	Aerial	Little Freshwater	1	1	1	1	OS	130	26	26	26	26
F0319	Aerial	Mainstem	0	0	0	1	OS	248	32	0	0	0
F0320	Aerial	Little Freshwater	0	1	1	1	OS	2133	1707	0	1707	1707
F0321	Aerial	Little Freshwater	1	1	1	1	OS	185	24	24	24	24
F0323	Aerial	Little Freshwater	0	0	0	1	OS	250	50	0	0	0

SLIDEID	Data-base	Drainage	Restriction Status Haz #1	Haz #2	Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)
F0324	Aerial	Little Freshwater	1	1	1	1	OS	33	16
F0325	Aerial	Little Freshwater	0	1	1	1	OS	437	153
F0326	Aerial	Little Freshwater	0	0	0	1	OS	4417	2208
F0335	Aerial	Mainstem	0	0	0	1	OS	621	236
F0336	Aerial	Mainstem	0	0	0	1	OS	103	65
F0337	Aerial	Mainstem	0	0	0	1	A	580	174
F0349	Aerial	School forest	0	0	0	1	A	147	15
31	Count						Total Recently Harvested Volume (yd3) =		6,649

	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
	16	16	16	
	0	153	153	
	0	0	0	
	0	0	0	
	0	0	0	
	0	0	0	
	0	0	0	
P3	**6,583**	**4,723**	**4,634**	Low Hazard
P4	**66**	**1,926**	**2,014**	High Hazard

Freshwater Creek 2003 Landslide Inventory Data

Freshwater Creek 2003 - Unharvested Open Slope Landslides

SLIDEID	Drainage	Restriction Status			Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)
		Haz #1	Haz #2	Haz #3				
172 (DS)	Little Freshwater	0	0	0	0	OS	1258	82
212	Little Freshwater	0	1	1	0	OS	59	8
213	Little Freshwater	0	1	1	0	OS	138	18
214	Little Freshwater	0	0	0	0	OS	536	70
267	Upper Mainstem	0	0	0	0	OS	325	42
268 (DS)	Graham Gulch	0	0	1	0	OS	4210	274
322 (DS)	Upper Mainstem	0	0	1	0	OS	3396	221
7	Count						Total Unharvested Volume (yd3) =	714

Volume Delivered

	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
	0	0	0	
	0	8	8	
	0	18	18	
	0	0	0	
	0	0	0	
	0	0	274	
	0	0	221	
P1	**714**	**688**	**194**	Low Hazard
P2	**0**	**26**	**520**	High Hazard

Freshwater Creek 2003 - Recently Harvested Open Slope Landslides

SLIDEID	Drainage	Haz #1	Haz #2	Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)
26	Little Freshwater	0	1	1	1	OS	109	109
78	Little Freshwater	0	0	1	1	OS	18	0
79	Cloney Gulch	1	1	1	1	A	1047	314
172 (DS)	Little Freshwater	0	0	0	1	OS	1258	82
205	Little Freshwater	0	0	0	1	OS	59	8
206	Little Freshwater	0	0	1	1	OS	244	0
211	Upper Mainstem	0	0	1	1	A	87	0
215	McCready Gulch	0	0	1	1	A	59	8
229	Upper Mainstem	0	0	0	1	OS	76	8
266	Upper Mainstem	0	0	1	1	OS	2954	384
268 (DS)	Graham Gulch	0	0	1	1	OS	4210	274
290	Upper Mainstem	0	0	0	1	OS	59	8
322 (DS)	Upper Mainstem	0	0	1	1	OS	3396	221
13	Count						Total Recently Harvested Volume (yd3) =	1,414

Volume Delivered

	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
	0	109	109	
	0	0	0	
	314	314	314	
	0	0	0	
	0	0	0	
	0	0	0	
	0	0	0	
	0	0	8	
	0	0	0	
	0	0	384	
	0	0	274	
	0	0	0	
	0	0	221	
P3	**1,100**	**991**	**105**	Low Hazard
P4	**314**	**423**	**1,309**	High Hazard

Freshwater Creek Sediment Yield Summary

Freshwater Creek 1997 & 2003 Combined - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are calculated from below)
P1	4582	4537	1685	Low Hazard
P2	370	416	3268	High Hazard
P3	7682	5714	4739	Low Hazard
P4	381	2349	3324	High Hazard

Freshwater Creek 2003 - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are linked!)
P1	714	688	194	Low Hazard
P2	0	26	520	High Hazard
P3	1100	991	105	Low Hazard
P4	314	423	1309	High Hazard

Freshwater Creek 1997 - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are linked!)
P1	3869	3849	1492	Low Hazard
P2	370	390	2747	High Hazard
P3	6583	4723	4634	Low Hazard
P4	66	1926	2014	High Hazard

North Fork Elk River 1997 Landslide Inventory Data

North Fork Elk River 1997 - Unharvested Open Slope Landslides

SLIDEID	Data-base	Drainage	Restriction Status Haz #1	Restriction Status Haz #2	Restriction Status Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)		Volume Delivered Haz #1 (yd3)	Volume Delivered Haz #2 (yd3)	Volume Delivered Haz #3 (yd3)	
404	Aerial	North Fork Elk River	1	1	1	0	OS	430	56		56	56	56	
457	Aerial	North Fork Elk River	0	0	0	0	OS	34	0		0	0	0	
458	Aerial	North Fork Elk River	0	0	0	0	OS	34	0		0	0	0	
459	Aerial	North Fork Elk River	0	0	0	0	OS	280	0		0	0	0	
585 (DS)	Roads	Scout Camp	0	1	1	0	OS	518	26		0	26	26	
590 (DS)	Aerial	North Fork Elk River	0	0	0	0	OS	152	29		0	0	0	
591	Aerial	North Fork Elk River	1	1	1	0	OS	1639	1033		1033	1033	1033	
598	Aerial	North Fork Elk River	1	1	1	0	OS	545	343		343	343	343	
742	Aerial	North Fork Elk River	1	1	1	0	OS	4236	1185		1185	1185	1185	
745	Aerial	North Fork Elk River	0	0	1	0	OS	332	126		0	0	126	
750	Aerial	North Fork Elk River	1	1	1	0	OS	81	0		0	0	0	
774	Aerial	North Fork Elk River	0	1	1	0	OS	841	1111		0	1111	1111	
12	Count						Total Unharvested Volume (yd3) =		3,909	P1	**1,292**	**155**	**29**	Low Hazard
										P2	**2,617**	**3,754**	**3,880**	High Hazard

North Fork Elk River 1997 - Recently Harvested Open Slope Landslides

SLIDEID	Data-base	Drainage	Haz #1	Haz #2	Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)
363	Aerial	North Fork Elk River	0	0	0	1	OS	74	10	0	0	0
364	Aerial	North Fork Elk River	0	0	0	1	OS	168	64	0	0	0
366	Aerial	North Fork Elk River	0	0	0	1	OS	1195	0	0	0	0
367	Aerial	North Fork Elk River	1	1	1	1	OS	35	22	22	22	22
368	Aerial	North Fork Elk River	0	0	0	1	OS	173	22	0	0	0
384	Aerial	North Fork Elk River	1	1	1	1	OS	84	0	0	0	0
385	Aerial	North Fork Elk River	0	0	1	1	OS	288	109	0	0	109
386	Aerial	North Fork Elk River	0	0	1	1	A	212	81	0	0	81
387	Aerial	North Fork Elk River	0	0	1	1	OS	777	101	0	0	101
388	Aerial	North Fork Elk River	0	1	1	1	OS	845	110	0	110	110
390	Aerial	North Fork Elk River	0	0	0	1	OS	71	0	0	0	0
392	Aerial	North Fork Elk River	0	0	0	1	OS	181	159	0	0	0
395	Aerial	North Fork Elk River	0	0	1	1	OS	11015	9693	0	0	9693
396	Aerial	North Fork Elk River	0	0	0	1	OS	295	0	0	0	0
405	Aerial	North Fork Elk River	0	0	0	1	OS	77	0	0	0	0
406	Aerial	North Fork Elk River	0	0	1	1	OS	4236	551	0	0	551
407	Aerial	North Fork Elk River	0	0	0	1	OS	1477	0	0	0	0
408	Aerial	North Fork Elk River	1	1	1	1	OS	555	0	0	0	0
409	Aerial	North Fork Elk River	0	0	0	1	OS	164	0	0	0	0
410	Aerial	North Fork Elk River	0	0	1	1	OS	120	16	0	0	16
413	Aerial	North Fork Elk River	0	0	0	1	OS	71	0	0	0	0
414	Aerial	North Fork Elk River	0	0	0	1	OS	115	15	0	0	0
415	Aerial	North Fork Elk River	0	0	0	1	OS	164	0	0	0	0

SLIDEID	Data-base	Drainage	Restriction Status Haz #1	Restriction Status Haz #2	Restriction Status Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)
417	Aerial	North Fork Elk River	0	0	0	1	OS	1106	0	0	0	0
418	Aerial	North Fork Elk River	0	0	0	1	OS	1718	0	0	0	0
419	Aerial	North Fork Elk River	0	0	0	1	OS	71	0	0	0	0
420	Aerial	North Fork Elk River	0	0	0	1	OS	701	0	0	0	0
422	Aerial	North Fork Elk River	0	0	0	1	OS	406	0	0	0	0
423	Aerial	North Fork Elk River	1	1	1	1	OS	371	0	0	0	0
424	Aerial	North Fork Elk River	0	0	0	1	OS	69	0	0	0	0
425	Aerial	North Fork Elk River	0	0	0	1	OS	71	0	0	0	0
426	Aerial	North Fork Elk River	0	0	0	1	OS	505	0	0	0	0
427	Aerial	North Fork Elk River	1	1	1	1	OS	37	0	0	0	0
428	Aerial	North Fork Elk River	0	0	0	1	OS	383	0	0	0	0
454	Aerial	North Fork Elk River	1	1	1	1	OS	41	0	0	0	0
455	Aerial	North Fork Elk River	1	1	1	1	OS	130	17	17	17	17
460	Aerial	North Fork Elk River	0	0	0	1	OS	1147	0	0	0	0
539	Roads	Scout Camp	1	1	1	1	OS	2015	1189	1189	1189	1189
585 (DS)	Roads	Scout Camp	0	1	1	1	OS	518	26	0	26	26
590 (DS)	Aerial	North Fork Elk River	0	0	0	1	OS	152	29	0	0	0
592	Aerial	North Fork Elk River	1	1	1	1	OS	343	0	0	0	0
599	Aerial	North Fork Elk River	0	0	0	1	OS	285	251	0	0	0
603	Roads	Scout Camp	0	1	1	1	OS	1185	83	0	83	83
729	Aerial	North Fork Elk River	1	1	1	1	A	190	120	120	120	120
744	Aerial	North Fork Elk River	0	0	1	1	A	492	0	0	0	0
746	Aerial	North Fork Elk River	0	0	0	1	OS	458	0	0	0	0
747	Aerial	North Fork Elk River	1	1	1	1	OS	81	51	51	51	51
748	Aerial	North Fork Elk River	1	1	1	1	OS	327	206	206	206	206
749	Aerial	North Fork Elk River	1	1	1	1	OS	134	0	0	0	0
754	Aerial	North Fork Elk River	0	0	1	1	OS	29604	5642	0	0	5642
755	Aerial	North Fork Elk River	0	1	1	1	OS	1952	733	0	733	733
756	Aerial	North Fork Elk River	0	0	0	1	OS	2450	89	0	0	0
757	Aerial	North Fork Elk River	0	0	1	1	OS	71	27	0	0	27
766	Aerial	North Fork Elk River	0	0	1	1	OS	295	102	0	0	102
767	Aerial	North Fork Elk River	0	0	0	1	OS	124	16	0	0	0
770	Aerial	North Fork Elk River	0	0	1	1	OS	303	191	0	0	191
771	Aerial	North Fork Elk River	0	1	1	1	OS	1383	871	0	871	871
772	Aerial	North Fork Elk River	0	0	0	1	OS	2805	1111	0	0	0
773	Aerial	North Fork Elk River	0	0	0	1	OS	120	114	0	0	0
59	Count						Total Recently Harvested Volume (yd3) =		21,821			

	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
P3	**20,216**	**18,393**	**1,880**	Low Hazard
P4	**1,605**	**3,428**	**19,941**	High Hazard

North Fork Elk River 2003 Landslide Inventory Data

North Fork Elk River 2003 - Unharvested Open Slope Landslides

SLIDEID	Drainage	Restriction Status Haz #1	Restriction Status Haz #2	Restriction Status Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)		Volume Delivered Haz #1 (yd3)	Volume Delivered Haz #2 (yd3)	Volume Delivered Haz #3 (yd3)	
68	NF Elk River	1	1	1	0	OS	890	712		712	712	712	
73	NF Elk River	0	0	0	0	OS	80	6		0	0	0	
75	NF Elk River	0	0	1	0	A	109	33		0	0	33	
109	Lake Cr	0	0	1	0	A	814	81		0	0	81	
133 (DS)	NF Elk River	0	1	1	0	A	714	19		0	19	19	
157	NF Elk River	0	1	1	0	OS	138	10		0	10	10	
162 (DS)	NF Elk River	0	0	0	0	A	407	21		0	0	0	
167	Bridge CK	0	1	1	0	A	59	4		0	4	4	
194 (DS)	Lake Cr	0	0	0	0	A	2879	140		0	0	0	
284	NF Elk River	1	1	1	0	OS	536	41		41	41	41	
285	NF Elk River	1	1	1	0	OS	536	41		41	41	41	
320	NF Elk River	0	1	1	0	A	896	90		0	90	90	
321	N. F. Elk	0	0	1	0	A	314	314		0	0	314	
13	Count					Total Unharvested Volume (yd3) =		1,510	P1	717	594	166	Low Hazard
									P2	793	916	1,344	High Hazard

North Fork Elk River 2003 - Recently Harvested Open Slope Landslides

70	Bridge CK	0	0	0	1	A	10990	0	0	0	0
121	West fork	0	0	0	1	A	143	1	0	0	0
133 (DS)	NF Elk River	0	1	1	1	A	714	19	0	19	19
136	NF Elk River	0	0	0	1	A	547	0	0	0	0
156	NF Elk River	0	0	0	1	OS	325	25	0	0	0
159	NF Elk River	0	0	0	1	OS	764	58	0	0	0
160	NF Elk River	1	1	1	1	A	300	120	120	120	120
161	NF Elk River	0	0	0	1	OS	59	4	0	0	0
162 (DS)	NF Elk River	0	0	0	1	A	407	21	0	0	0
164	WF Bridge Ck	0	1	1	1	A	524	0	0	0	0
166	Bridge CK	0	0	0	1	OS	138	10	0	0	0
193	Lake Cr	1	1	1	1	OS	59	4	4	4	4
194 (DS)	Lake Cr	0	0	0	1	A	2879	140	0	0	0
195	Lake Cr	0	0	0	1	OS	2954	223	0	0	0
197	NF Elk River	1	1	1	1	OS	912	456	456	456	456
198	NF Elk River	0	0	0	1	OS	213	43	0	0	0
199	NF Elk River	0	0	0	1	A	36	2	0	0	0
200	McWhinney Cr	1	1	1	1	OS	1303	1043	1043	1043	1043
201	Bridge Ck	0	1	1	1	OS	155	47	0	47	47

SLIDEID	Drainage	Restriction Status Haz #1	Restriction Status Haz #2	Restriction Status Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)
204	Bridge Ck	0	0	0	1	OS	143	0
225	NF Elk River	1	1	1	1	A	536	41
257	S Branch NF Elk River	0	0	0	1	A	127	13
259	NF Elk River	0	0	1	1	OS	138	10
260	NF Elk River	1	1	1	1	A	228	17
261	NF Elk River	1	1	1	1	A	325	25
282	NF Elk River	0	0	0	1	OS	95	76
283	NF Elk River	0	0	0	1	A	107	11
27	Count				Total Recently Harvested Volume (yd3) =			2,407

	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
	0	0	0	
	41	41	41	
	0	0	0	
	0	0	10	
	17	17	17	
	25	25	25	
	0	0	0	
	0	0	0	
P3	**701**	**636**	**626**	Low Hazard
P4	**1,705**	**1,770**	**1,781**	High Hazard

North Fork Elk River Sediment Yield Summary

North Fork Elk River 1997 & 2003 Combined - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are calculated from below)
P1	2009	749	195	Low Hazard
P2	3410	4670	5224	High Hazard
P3	20917	19029	2506	Low Hazard
P4	3310	5198	21722	High Hazard

North Fork Elk River 2003 - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are linked!)
P1	717	594	166	Low Hazard
P2	793	916	1344	High Hazard
P3	701	636	626	Low Hazard
P4	1705	1770	1781	High Hazard

North Fork Elk River 1997 - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are linked!)
P1	1292	155	29	Low Hazard
P2	2617	3754	3880	High Hazard
P3	20216	18393	1880	Low Hazard
P4	1605	3428	19941	High Hazard

South Fork Elk River 1997 Landslide Inventory Data

South Fork Elk River 1997 - Unharvested Open Slope Landslides

			Restriction Status			Harvest Activity	Landuse	Vol. Disp.	Vol. Deliv.		Volume Delivered		
SLIDEID	Data-base	Drainage	Haz #1	Haz #2	Haz #3	Age Group	Association	(yd3)	(yd3)		Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)
199	Aerial	South Fork Elk River	0	0	0	0	OS	74	0		0	0	0
287 (DS)	Roads	Tom Gulch	0	0	0	0	OS	416	21		0	0	0
317 (DS)	Roads	Tom Gulch	0	0	0	0	OS	6481	162		0	0	0
370	Aerial	Tom Gulch	1	1	1	0	OS	76	29		29	29	29
450	Roads	South Fork Elk River	1	1	1	0	OS	2667	0		0	0	0
510	Aerial	South Fork Elk River	0	0	0	0	OS	71	0		0	0	0
513	Aerial	South Fork Elk River	0	0	0	0	OS	71	0		0	0	0
514	Aerial	South Fork Elk River	0	0	0	0	A	418	368		0	0	0
515	Aerial	South Fork Elk River	0	0	1	0	OS	1606	1413		0	0	1413
523	Aerial	South Fork Elk River	1	1	1	0	OS	76	0		0	0	0
525	Aerial	South Fork Elk River	0	0	1	0	OS	37	5		0	0	5
530	Aerial	South Fork Elk River	0	0	1	0	A	120	0		0	0	0
12	Count						Total Unharvested Volume (yd3) =		1,998	P1	**1,969**	**1,969**	**551** Low Hazard
										P2	**29**	**29**	**1,447** High Hazard

South Fork Elk River 1997 - Recently Harvested Open Slope Landslides

SLIDEID	Data-base	Drainage	Haz #1	Haz #2	Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)
57	Roads	South Fork Elk River	0	0	0	1	A	568	455	0	0	0
187	Aerial	Tom Gulch	0	0	0	1	OS	167	22	0	0	0
192	Aerial	Tom Gulch	0	0	0	1	OS	168	22	0	0	0
207	Aerial	South Fork Elk River	0	0	0	1	OS	167	0	0	0	0
211	Aerial	Tom Gulch	0	0	0	1	OS	33	0	0	0	0
212	Aerial	Tom Gulch	0	0	0	1	OS	79	10	0	0	0
287 (DS)	Roads	Tom Gulch	0	0	0	1	OS	416	21	0	0	0
317 (DS)	Roads	Tom Gulch	0	0	0	1	OS	6481	162	0	0	0
330	Roads	Tom Gulch	0	0	0	1	OS	45000	0	0	0	0
364	Roads	Tom Gulch	0	0	0	1	OS	889	89	0	0	0
377	Aerial	Tom Gulch	0	0	0	1	OS	467	177	0	0	0
378	Aerial	Tom Gulch	0	0	0	1	OS	311	40	0	0	0
379	Aerial	Tom Gulch	0	0	0	1	OS	3858	2431	0	0	0
397	Aerial	Tom Gulch	0	0	0	1	OS	265	34	0	0	0
398	Aerial	Tom Gulch	1	1	1	1	OS	168	64	64	64	64
400	Aerial	Tom Gulch	0	0	0	1	OS	76	29	0	0	0
401	Aerial	Tom Gulch	0	0	0	1	OS	74	10	0	0	0
403	Aerial	Tom Gulch	0	0	0	1	OS	295	112	0	0	0
462	Aerial	South Fork Elk River	0	0	0	1	OS	177	67	0	0	0
463	Aerial	South Fork Elk River	0	0	0	1	OS	168	22	0	0	0
464	Aerial	South Fork Elk River	0	0	0	1	OS	34	0	0	0	0
465	Aerial	South Fork Elk River	1	1	1	1	OS	77	0	0	0	0
466	Aerial	South Fork Elk River	0	1	1	1	OS	77	0	0	0	0

SLIDEID	Data-base	Drainage	Restriction Status Haz #1	Restriction Status Haz #2	Restriction Status Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)
468	Aerial	South Fork Elk River	0	1	1	1	OS	1124	0	0	0	0
469	Aerial	South Fork Elk River	0	0	0	1	OS	37	0	0	0	0
470	Aerial	South Fork Elk River	1	1	1	1	OS	91	0	0	0	0
471	Aerial	South Fork Elk River	0	0	0	1	OS	69	26	0	0	0
476	Aerial	South Fork Elk River	1	1	1	1	OS	77	10	10	10	10
482	Aerial	South Fork Elk River	0	0	0	1	OS	177	112	0	0	0
508	Aerial	South Fork Elk River	0	0	0	1	OS	33	13	0	0	0
512	Aerial	South Fork Elk River	0	1	1	1	OS	295	0	0	0	0
524	Aerial	South Fork Elk River	0	0	0	1	OS	74	0	0	0	0
526	Aerial	South Fork Elk River	0	0	1	1	OS	319	41	0	0	41
527	Aerial	South Fork Elk River	0	0	0	1	OS	35	5	0	0	0
528	Aerial	South Fork Elk River	0	0	1	1	A	35	0	0	0	0
529	Aerial	South Fork Elk River	0	0	0	1	OS	31	0	0	0	0
535	Aerial	South Fork Elk River	0	0	0	1	A	531	467	0	0	0

37 Count

Total Recently Harvested Volume (yd3) = 4,441

	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
P3	**4,367**	**4,367**	**4,326**	Low Hazard
P4	**74**	**74**	**115**	High Hazard

South Fork Elk River 2003 Landslide Inventory Data

South Fork Elk River 2003 - Unharvested Open Slope Landslides

SLIDEID	Drainage	Restriction Status Haz #1	Restriction Status Haz #2	Restriction Status Haz #3	Harvest Activity Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)
191 (DS)	SF Elk River	0	0	0	1	OS	52360	2618
1	Count						Total Unharvested Volume (yd3) =	2,618

South Fork Elk River 2003 - Recently Harvested Open Slope Landslides

SLIDEID	Drainage	Haz #1	Haz #2	Haz #3	Age Group	Landuse Association	Vol. Disp. (yd3)	Vol. Deliv. (yd3)
152	SF Elk River	1	1	1	1	OS	764	58
153	SF Elk River	0	0	1	1	A	175	70
191 (DS)	SF Elk River	0	0	0	1	OS	52360	2618
223	SF Elk River	0	0	0	1	A	465	0
4	Count						Total Recently Harvested Volume (yd3) =	2,746

Volume Delivered

	Haz #1 (yd3)	Haz #2 (yd3)	Haz #3 (yd3)	
	0	0	0	
P1	**2,618**	**2,618**	**2,618**	Low Hazard
P2	**0**	**0**	**0**	High Hazard
	58	58	58	
	0	0	70	
	0	0	0	
	0	0	0	
P3	**2,688**	**2,688**	**2,618**	Low Hazard
P4	**58**	**58**	**128**	High Hazard

South Fork Elk River Sediment Yield Summary

South Fork Elk River 1997 & 2003 Combined - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are calculated from below)
P1	4587	4587	3169	Low Hazard
P2	29	29	1447	High Hazard
P3	7055	7055	6944	Low Hazard
P4	132	132	243	High Hazard

South Fork Elk River 2003 - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are linked!)
P1	2618	2618	2618	Low Hazard
P2	0	0	0	High Hazard
P3	2688	2688	2618	Low Hazard
P4	58	58	128	High Hazard

South Fork Elk River 1997 - Open Slope Landslides

Model Inputs	Haz#1 (yd^3)	Haz#2 (yd^3)	Haz#3 (yd^3)	(values in this table are linked!)
P1	1969	1969	551	Low Hazard
P2	29	29	1447	High Hazard
P3	4367	4367	4326	Low Hazard
P4	74	74	115	High Hazard

Appendix B

Landslide Reduction Model Results for Selected Applications to PALCO Lands in the Freshwater Creek, North Fork Elk River, and South Fork Elk River Watersheds

(Model Applications Performed by Regional Water Board Staff)

Empirical Harvest-Related Landslide Delivered Sediment Model

Watershed	Freshwater	(Freshwater or NF Elk or SF Elk)	**n**	15	years
Watershed Area	15520	acres	**S_R**	1.25	
LS Inventory	Combined	(1997 or 2003 or Combined)	**a_H**	0.115	
Hazard Map	2	(1 or 2 or 3)	**f_h**	0.09	

Hazard Category	Harvest Category	Model Inputs*	Area (acres)		Model Inputs*	Landlisde Volume Delivered (yd^3)
Low Hazard	Unharvested (> 15)	A_1	18827		P_1	4537
High Hazard	Unharvested (> 15)	A_2	2269		P_2	416
Low Hazard	Harvested (<= 15)	A_3	8638		P_3	5714
High Hazard	Harvested (<= 15)	A_4	1305		P_4	2349
			31039			13016

Refined Model

Intermediate Calculations

Category	Model Inputs	Model Parameter*	(yd3/acre)
Low, (> 15)	P_1/A_1	R_L	0.241
High (> 15)	P_2/A_2	R_H	0.183
Low (<= 15)	P_3/A_3	S_L	0.661
High (<= 15)	P_4/A_4	S_H	1.799

L-Factor Expressed by Logging and Hazard

L_L	(S_L/R_L)	**2.7**
L_H	(S_H/R_H)	**9.8**

Allowable Annual Harvest

Low Hazard Areas (max.)	**144**	acres/yr	$(N_H = 0)$
High Hazard Areas (min.)	**38**	acres/yr	$(N_L = 0)$

* Model Inputs and Intermediate Calculations are listed per interval of time over which the model inputs were reported.

Empirical Harvest-Related Landslide Delivered Sediment Model

Watershed	NF Elk	(Freshwater or NF Elk or SF Elk)	**n**	15	years
Watershed Area	14099	acres	**S_R**	1.25	
LS Inventory	Combined	(1997 or 2003 or Combined)	**a_H**	0.333	
Hazard Map	3	(1 or 2 or 3)	**f_h**	0.97	

Hazard Category	Harvest Category	Model Inputs*	Area (acres)		Model Inputs*	Landlisde Volume Delivered (yd^3)
Low Hazard	Unharvested (> 15)	A_1	11226		P_1	195
High Hazard	Unharvested (> 15)	A_2	5070		P_2	5224
Low Hazard	Harvested (<= 15)	A_3	7594		P_3	2506
High Hazard	Harvested (<= 15)	A_4	4309		P_4	21722
			28199			29647

Refined Model

Intermediate Calculations

Category	Model Inputs	Model Parameter*	(yd3/acre)
Low, (> 15)	P_1/A_1	R_L	0.017
High (> 15)	P_2/A_2	R_H	1.030
Low (<= 15)	P_3/A_3	S_L	0.330
High (<= 15)	P_4/A_4	S_H	5.041

L-Factor Expressed by Logging and Hazard

L_L	(S_L/R_L)	**19.0**
L_H	(S_H/R_H)	**4.9**

Allowable Annual Harvest

Low Hazard Areas (max.)	**266**	acres/yr	(N_H = 0)
High Hazard Areas (min.)	**21**	acres/yr	(N_L = 0)

* Model Inputs and Intermediate Calculations are listed per interval of time over which the model inputs were reported.

Empirical Harvest-Related Landslide Delivered Sediment Model

Watershed	SF Elk	(Freshwater or NF Elk or SF Elk)	**n**	15	years
Watershed Area	6176	acres	**S_R**	1.25	
LS Inventory	Combined	(1997 or 2003 or Combined)	**a_H**	0.235	
Hazard Map	3	(1 or 2 or 3)	**f_h**	#REF!	

Hazard Category	Harvest Category	Model Inputs*	Area (acres)		Model Inputs*	Landlisde Volume Delivered (yd^3)
Low Hazard	Unharvested (> 15)	A_1	5228		P_1	4587
High Hazard	Unharvested (> 15)	A_2	1571		P_2	29
Low Hazard	Harvested (<= 15)	A_3	4221		P_3	7055
High Hazard	Harvested (<= 15)	A_4	1331		P_4	132
			12352			11803

Simplified Model

Intermediate Calculations

Category	Model Inputs	Model Parameter*	(yd3/acre)
(> 15)	$(P_1+P_2)/(A_1+A_2)$	R_T	0.679
(<= 15)	$(P_3+P_4)/(A_3+A_4)$	S_T	1.294

L-factor Expressed by Logging Only

L_T	(S_T/R_T)	**1.9**

Allowable Annual Harvest

All Hazard Areas **114** acres/yr

* Model Inputs and Intermediate Calculations are listed per interval of time over which the model inputs were reported.