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

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F2.1 INVENTORY METHODS

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

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

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

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

F2.2 ROAD-RELATED SEDIMENT SOURCES

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

F2.2.1 Chronic Erosion

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

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

F2.2.2 Episodic Sediment Sources

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

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

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

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

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

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

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

F2.3 RESULTS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

F2.4.1.1 Assumptions Employed in General Road Sediment Analysis

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

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

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

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

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

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

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

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

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

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

F2.4.1.2.1 *Future Landslide Volumes*

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

F2.4.1.2.2 *Future Watercourse Crossing Erosion Volumes*

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

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

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

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

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

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

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

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

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

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

[1] Costs include low boy transportation, heavy equipment, labor, materials, and supervision. Costs are listed as though both high and moderate priority sites are to be treated. In reality, especially on decommission roads, all sites are treated at once. Additional costs have been included for endhauling and the use of dump trucks at upgrade watercourse crossing sites. It was assumed that for crossings greater than 200 yds^3 approximately 60% of the total volume excavated will have to be endhauled from the site during culvert installation or replacement.

[2] The Redwood Creek PPZ sediment source inventory is presently in progress. This data reflects only the inventoried roads on the west side of Redwood Creek.

[3] The Little River sediment source inventory is presently in progress. The data reflects all inventoried sites entered in the Access database as of 1/08/2001.

[4] Does not include data for Little River assessment area.

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

F2.4.1.2.3 *Average Erosion*

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

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

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

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

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

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

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

Figure 1. Stream crossing erosion from single storm overtopping

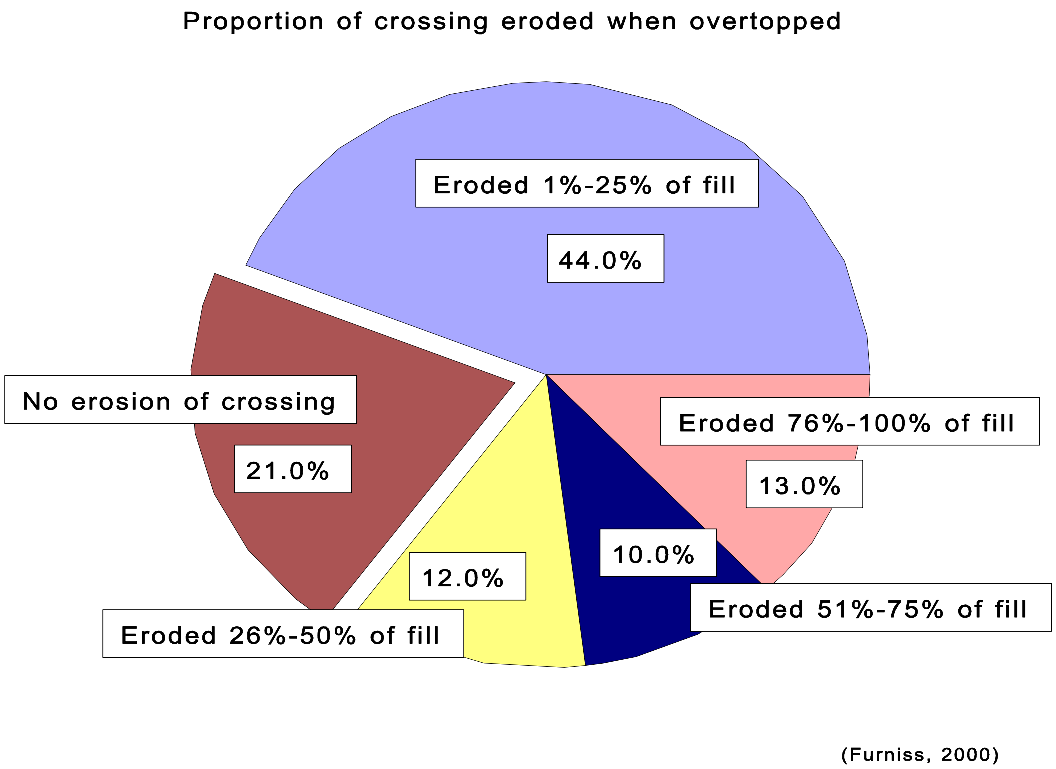

Figure F2-1. Watercourse crossing erosion from a single storm overtopping.

F2.4.1.3 Assumptions Employed in Developing Sediment Delivery Volumes

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

F2.4.1.3.1 Future Landslide Delivery

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

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

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

F2.4.1.3.2 Future Sediment Delivery from Watercourse Crossings

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

F2.4.1.3.3 Future Sediment Delivery from "Other" Sites

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

F2.4.1.4 Assumptions Employed in Developing Erosion Prevention Treatment Costs

F2.4.1.4.1 Covered Costs

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

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

F2.4.1.4.2 Costs not Covered

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

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

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

F2.4.1.4.3 *Additional Undefined Cost Variables*

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

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

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

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

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

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

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

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

F2.5 SUMMARY

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

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

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