Appendix C4. Assessment of Erosion and Sedimentation in Class III Watercourses: A Retrospective Study

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C4.1 INTRODUCTION

California forest practice rules during the period of this study (1992-1998) required that Class III watercourses (typically first order streams that do not support aquatic life) be delineated as equipment exclusion zones and that ground disturbance be minimized, but they did not require retention of existing forest canopy. Concerns have been raised that complete removal of trees from Class IIIs will result in destabilizing these headwater areas resulting in an upslope extension of the channel and increased risk of shallow rapid landslides. The mechanisms that could trigger these potential effects may not be fully mitigated by the existing forest practice regulations: loss of root strength in the soil column that could increase mass wasting, decrease bank stability and increased incident precipitation and storm runoff that could increase mass wasting and fluvial erosion processes in Class III watercourses. There is some evidence suggesting the latter from Caspar Creek (Lewis 1998). The net effect is that there could be significant increases in sediment production from watercourses even though Class I and II watercourses may have ample buffer retention. Because the majority of a channel network is made up of the first order channels, the overall impact of destabilized Class IIIs may be quite large even though increased sediment delivery in any given Class III is small. There is also the concern that if a debris torrent is triggered from one of these Class III areas, there will be no opportunity for delivering LWD into the channel below if no trees are retained in the uppermost reaches of these watercourses. The role of LWD in erosion and sedimentation processes in Class III channels is also potentially significant. LWD provides sediment storage sites, controls channel grade by preventing channel bed erosion, and deflects and concentrates stream flow thereby both protecting banks from erosion and magnifying fluvial bank erosion processes.

However, there are few empirical data available to assess the magnitude of these potential problems in northern California forestlands. To begin with, the proportion of first order streams that are designated as Class IIIs in current timber harvest plans (THPs) has not been quantified. Since any headwater channel that is judged to support "aquatic life" must be classified as a Class II, an unknown but increasingly higher proportion of first order channels are receiving protection as Class II watercourses. Although the forest practice rules have not changed, this trend has occurred primarily due to the southern torrent salamander. The transition began at Green Diamond in 1992 when its biological staff began demonstrating to the foresters that many first order channels supported torrent salamanders. The rest of the California north coast region followed suit when the torrent salamander was petitioned to be state listed in 1995. The species was not listed, but a mandatory training program to learn to identify the habitat of the salamander was instituted for all registered professional foresters that wished to submit THPs within the range of the species. Region wide, this had a dramatic effect on watercourse classification and in some areas there are few Class IIIs at the head of a Class II watercourse. The channel begins as a Class II, because it has intermittent habitat for torrent salamanders.

In addition to not knowing the extent of Class IIIs in THPs, there are no data on the changes that result in these watercourses following timber harvest. In particular, it is important to know the degree to which channel extension or head-cutting is occurring along with some quantification of the amount of sediment that is being generated from the existing channel banks due to bank erosion or channel scour. It is also important to know if destabilized Class IIIs are contributing to increases in shallow rapid landslides.

Past protection of Class III watercourses during timber harvest was a combination of both compliance and effectiveness of the forest practice rules as they were implemented through the THP process. Therefore, completed THPs were used as the basis for the selection and assessment of the condition of Class IIIs. A retrospective approach was used to randomly select completed THPs from across the ownership, and quantify the number and extent of both Class II and III watercourses that were identified by the RPF prior to harvesting. The selected watercourses were visited, and data were gathered on the physical condition of the Class III watercourse. Since this was a retrospective study and it was not possible to utilize controls, subtle changes in Class IIIs following timber harvest could not be quantified. Rather the objective was to assess the extent to which major changes occurred in Class IIIs that were responsible for substantial increases in management related sediment production. Specifically, the objectives were to: 1) collect data to characterize and describe Class III channels following clearcut harvest under the past Forest Practice Rules and Green Diamond's spotted owl HCP; and 2) explore potential relationships between key response variables that correlate strongly with sediment production (e.g. bank erosion and number of landslides) and other important stream variables. There also was the opportunity to compare pre-harvest characteristics of Class III watercourses that were assessed as part of the Little River monitoring study to a sub-set of the streams from the retrospective study that were located within or adjacent to the Little River HPA. Unfortunately, this was not a pre and post-treatment assessment of the same streams, but it did allow for general comparisons of characteristics before and after harvest.

It is important to reiterate that this was a retrospective study and comparisons to untreated control streams (i.e., unharvested Class III watercourses in advanced second growth or virgin old growth) were not possible. Therefore, conclusions from the study were limited in scope. The primary objectives were to provide a description of key variables of Class III watercourses sampled and quantify gross changes that might have occurred following clearcut timber harvesting. A stratified random sampling design was followed, so it was appropriate to draw inferences to the total sampling universe. However, since the sampling was tied to recent harvesting (1992-1998), the inferences need to be restricted to that portion of the total ownership that has experienced significant harvesting in recent years. Despite these limitations, the study has significant value simply because there is so little known about the characteristics of Class III watercourses or the impact of timber harvest on them.

C4.2 METHODS

C4.2.1 Site Selection

The Class III retrospective survey was conducted across all of Green Diamond's property with the exception of some of outlying areas (e.g. South Fork Mountain, Supply and Goose Creeks) where logistical constraints would have drastically reduced the efficiency of the project. All of Green Diamond's ownership within the Mad River was included in the study, including lands outside the HPAs. A stratified random sampling of Class III watercourses was employed throughout the remaining tracts (management units) of the ownership. All Class IIIs in completed THPs from 1992-1998 were classified as either a “run-through” or “within” (Figure C4-1). A “run-through” refers to a Class III watercourse where the beginning of the channel is outside the harvest unit, but if the channel was initiated within the boundaries of the harvest unit, it was designated “within.” The number of Class IIIs was then randomly sampled at frequency of 2:9 within streams and 1:9 run-throughs. The sampling was weighted toward within streams in order to focus on channel extension of Class IIIs. The original THP map for each selected unit was reviewed as well as aerial photos to ensure that selected units were true clearcuts. Units that had non-clearcut prescriptions (i.e. seed tree removal, selection harvest or commercial thinning) were not included in the sample. In addition, a minimum apparent channel length of 200 feet on the THP map was required to be included in the sample. However, in the field, the actual channels varied from minimums of 113 and 58 feet, and maximums of 1146 and 1295 feet for run-through and within channels, respectively.

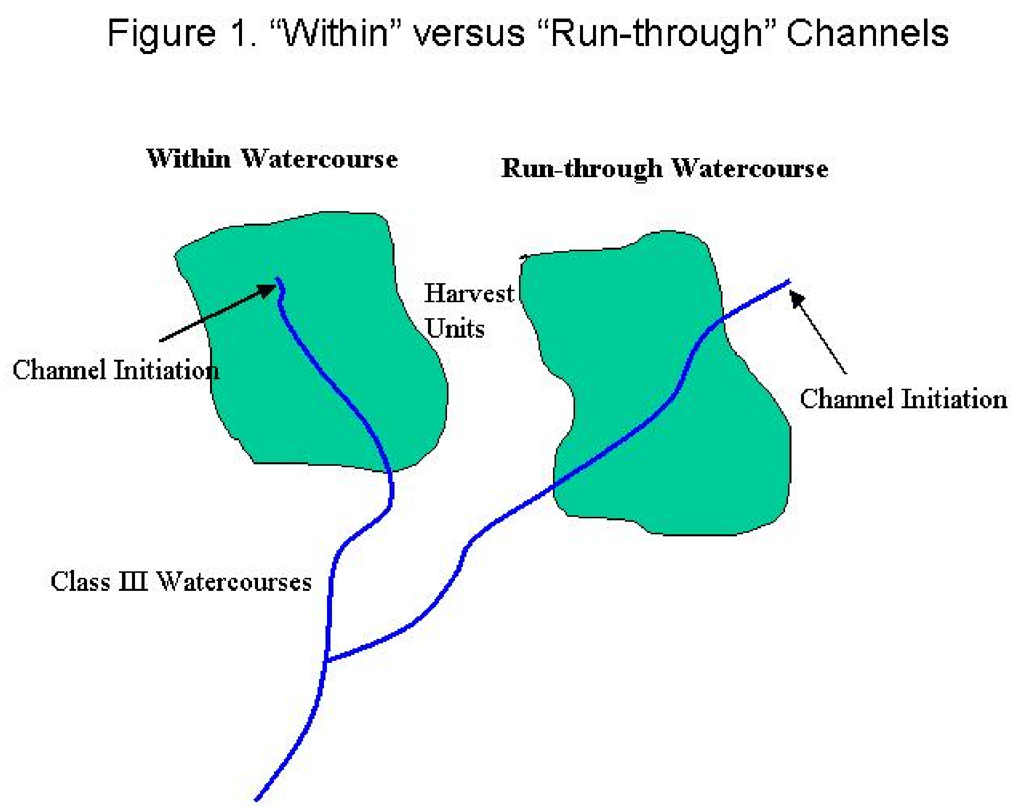


Figure C4-1. "Within" versus "run-through" channels.

Bedrock geology underlying each study site was determined based on USGS geologic maps and characterized as “consolidated” or “unconsolidated” by Oscar Huber (retired geologist, CDF). Consolidated bedrock geology included the Franciscan series (undifferentiated, melange, sandstone with siltstone, rocks and schist), Galice and ultramafic rocks. The undifferentiated Wildcat Group, Hookton and Falor Formations, Alluvium, Quaternary marine terraces and coastal plain sediment were considered unconsolidated bedrock geology.

THPs were not selected before 1992, because of a property-wide shift in the designation of Class II versus III watercourses. Prior to that year, many small intermittent channels were classified as Class IIIs that would have been designated a Class II after 1992. (This shift resulted from the recognition of southern torrent salamander habitat as noted above.) THPs were not selected after 1998 to insure that Class IIIs had experienced at least one winter of storms.

C4.2.2 Field Protocol

Before going into the field, Green Diamond delineated the Class III drainage as mapped on the original THP map. Assessment of the watercourse began at the lowest point on the channel within the THP unit. If the lowest end was within a riparian protection zone or habitat retention area (HRA), then Green Diamond began the channel measurements at the uppermost edge of the standing timber. Measurements were taken systematically up the channel at 10-foot intervals based on a random start within the first 10-foot interval. At each 10-foot sampling interval, the active channel width, maximum depth, was measured, and it was determined if there was evidence of an exposed active channel (channel bed exposed by fluvial processes). The linear length of exposed bank within 15 feet of the channel on both banks also was measured. If the exposed bank was part of an earth flow or slide, the entire limit of the exposed ground was measured. Game trails and animal burrows were not included in measurements of exposed banks, but their occurrences were noted. Watershed drainage area at the downstream end of study sites was also determined.

At every 50-foot interval, the bank angle perpendicular to the channel on the left and right banks was measured. At every 100-foot interval, the mean understory vegetation height was measured, and percent overstory canopy closure was determined using a densiometer. The channel gradient was measured with a clinometer at the beginning of the layout and at all major gradient breaks in slope throughout the remaining channel layout. Large woody debris (LWD) greater than 6 inch diameter with no minimum length requirement was measured (length and average diameter) wherever it occurred throughout the channel. It was recorded if the LWD was hardwood or conifer (if not clear which, “hardwood” was recorded, which provides a more conservative estimate of the longevity of the LWD), and it was noted if the LWD was acting as a control point. (A control point was any in-channel feature retaining sediment and/or preventing head-cutting.) The location and type of all other control points (roots, boulders, bedrock, etc.) were recorded in addition to LWD, and the size (with the exception of bedrock) and the vertical drop below the control point were measured. The area and location of any significant (generally greater than 3 feet in length) bank erosion were measured, and the predominant channel substrate, presence and flow of water, changes in predominant vegetation, and the occurrence of any aquatic vertebrates were noted.

Green Diamond photo documented the site, looking upstream at the beginning of the layout, both directions in the middle, and downstream at the end. In addition, any major gradient breaks in the channel that precluded visibility, any significant mass wasting, large scours, or other major features that affected the channel were photo documented.

The in-channel survey was continued until the Class III channel ended at a headwall, or at the harvest unit boundary, if the channel was a run-through. Green Diamond assessed the channel for evidence of head cutting by looking for evidence of recent scour or bank erosion at the initiation of the channel. In addition, Green Diamond compared the mapped initiation of the channel from the THP map relative to the current initiation of the channel. Green Diamond surveyed the associated road system within the sub-basin and sketched the drainage area onto a topographic map. Green Diamond recorded any stream piracy or diversions associated with the road system and include it in the drainage area. On the topographic map, Green Diamond recorded road failures, inner gorge slides or other larger scale sediment delivery features within the sub-basin. Data collected are summarized in Table C4-1.

An ongoing monitoring program in the Little River watershed utilizing a BACI (before-after-control-impact) experimental design allowed for a partial comparison of pre-treatment (advanced second growth with no recent timber harvesting activities) Class III watercourses to some of the post-treatment streams from this retrospective study. The same protocols described above were applied to the pre-treatment assessment of 26 Class III watercourses in the Little River, which were compared to 29 post-treatment (retrospective) watercourses located within or adjacent to the Little River watershed.

Table C4-1. Summary of continuous and categorical variables measured on surveyed Class III watercourses.[1]

Continuous	Categorical
Width and depth of active channel	Exposed active channel
Length of surveyed channel	Exposed banks
Channel gradient	Channel initiation (run-through vs. within)
Bank slope	Bedrock geology
Number of years (winters) since harvest	Type of harvest (tractor vs. cable)
Drainage area above the channel	Burn history
Height of ground vegetation	
Total canopy closure	
LWD: #, length, diameter and volume	
Bank erosion: number and area	
Slides: number and area	

Note
1 Exposed active channel and exposed banks were assessed as a categorical variable at each 10-foot sample interval, but summarized as a percentage of the total samples intervals measured. Response variables are highlighted.

C4.2.3 Data Analysis

Green Diamond selected four variables that best reflected potential sediment delivery to the lower portions of a watershed as the primary response variables for analysis. These variables were cross-sectional area (product of the active channel depth and width measurement), percent exposed active channel, frequency of sites with bank erosion and number of slides relative to channel length. Forward stepwise regression was performed using function step.glm (generalized linear model) in the computer program S-Plus. Step.glm added variables from the pool of potential explanatory (independent) variables, one at a time, until the model AIC (Akaike's Information Criterion) would not decrease if another variable was entered. The variable chosen for inclusion at each step was the variable that provided the greatest improvement of the modeled likelihood among variables that were not yet in the model. This addition amounted to adding the variable at each step with the most significant likelihood score statistic. Significance of terms in the final model was assessed using an approximate F-test based on the drop-in-deviance likelihood ratio. GLM R^2 values were calculated, which are equivalent in interpretation (amount of the variation in the dependent variable explained by the independent variable) to R^2 values from regression based on a normal distribution.

Response variables ‘bank erosion’ and ‘number of slides’ were modeled using a Poisson regression that included an “offset” to relate the count to the length of sampled stream segment. ‘Percent exposed active channel’ was modeled using binomial regression. ‘Cross-sectional area’ of the channel was modeled using Normal regression theory, but was first transformed by computing the natural log of the variable. To meet assumptions of normality, cross-sectional area and percent exposed active channel were also transformed (natural log for area and square root for percent scour) before performing t-tests or analysis of covariance (ANCOVA). For stepwise regression, geology was treated as a categorical variable with two levels: ‘unconsolidated’ and ‘consolidated’.

C4.3 RESULTS

There were 899 THP units operated within the study area from 1992-1998. To find units that meet the criteria of having a Class III watercourse located within a clearcut block, 553 harvest units were initially selected using a stratified random sampling design. From these units, 110 Class III watercourses were identified that appeared to have met the criteria for inclusion in the survey. On field inspection, some of these Class III watercourses had to be to be eliminated (e.g. trees were retained in the Class III to meet habitat retention guidelines under Green Diamond’s spotted owl HCP), which resulted in 100 channels ultimately being assessed across Green Diamond’s ownership (Figure C4-2). Forty-seven of the channels were run-throughs (channel initiated outside the harvest unit) and 53 were within channels (initiated within the harvest unit). Because the selection of Class IIIs was dependent on recent (1992-1998) harvesting activities, the number of channels assessed per HPA was not necessarily proportional to the area of the HPA. In addition, the number of Class III watercourses associated with each unit varied across the study area. The majority of harvest units within most of the study area had no or only one Class III watercourse within or adjacent to the unit, while the majority of units had multiple Class III watercourses in the two most southerly HPAs (Table C4-2). The greatest number of channels (25) was assessed in the Mad River HPA, followed by Smith River (20), North Fork Mad River (14), Little River (13), Humboldt Bay (11), Eel River (6), the area in the Mad River that is outside the Plan Area (3), and two each for Redwood Creek, Coastal Lagoons, Coastal and Interior Klamath HPAs. Of the 100 watercourses selected to be assessed as Class IIIs based on the original THP, 16 were judged to have at least a small portion that was a Class II watercourse based on Green Diamond’s current more thorough and conservative approach to evaluating streams for the presence of headwater amphibians or their habitat.

The mean length and cross-section area of run-through channels were greater than within channels (Table C4-3), as might be expected because they were generally lower in the watershed and had greater drainage area. However, the mean cross-sectional areas were not significantly different ($t = 1.81$, d.f. = 96, $P = 0.073$) between run-through and within channels.

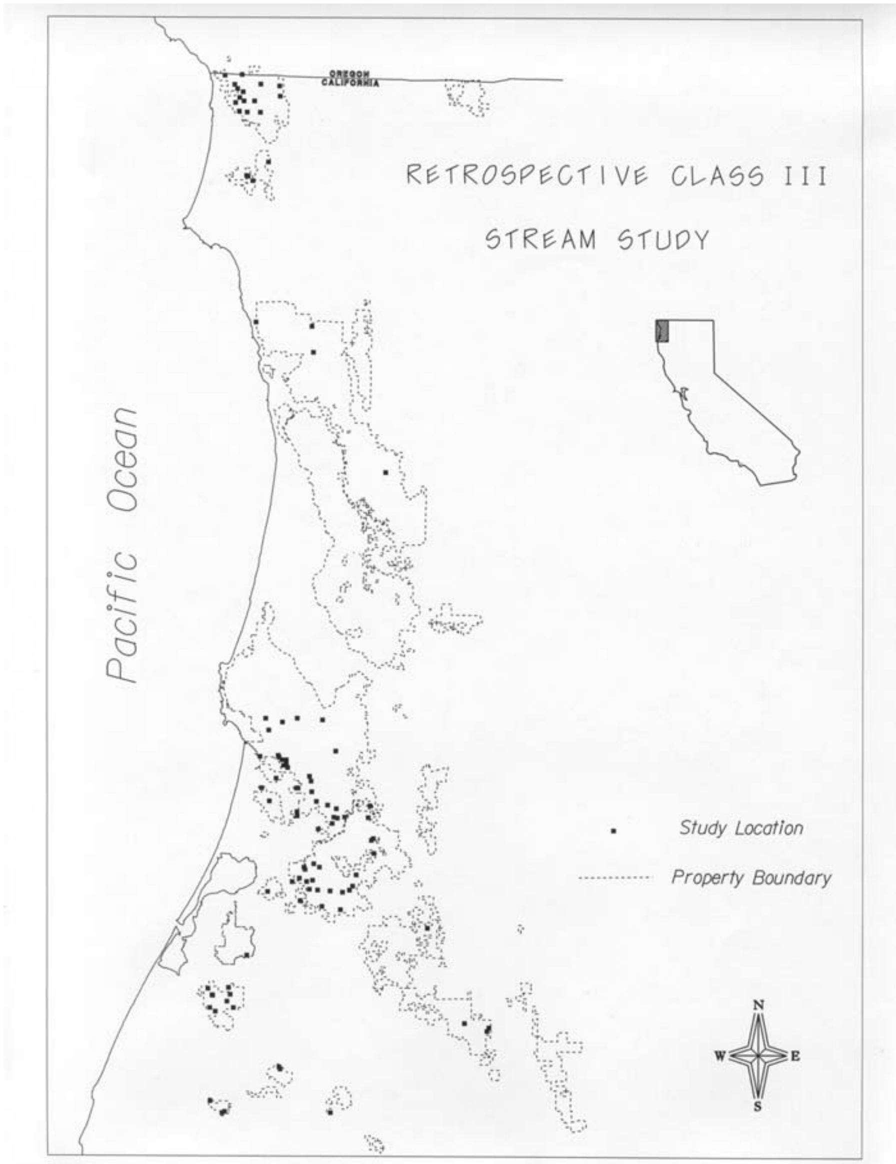


Figure C4-2. Location of Class III channels assessed on Green Diamond's ownership.

Table C4-2. Summary of harvest units operated from 1992-1998 within each Hydrographic Planning Area and the number of units with no or only one Class III watercourse within or adjacent to the harvest unit.[1]

Hydrographic Planning Area	Harvest Units	Percentage with no Class III	Percentage with one Class III
Smith River	141	36.2	24.1
Blue Creek	53	34.0	35.8
Coastal Klamath	152	38.1	31.6
Interior Klamath	145	39.3	27.6
Redwood Creek	51	62.7	21.6
Coastal Lagoon	11	27.3	27.3
Little River	38[2]	5.3[2]	15.8[2]
NF Mad River	61	23.0	29.5
Mad River	126	17.5	26.2
Humboldt Bay	42	14.3	16.7
Eel River	42	11.9	16.7
Area outside the Plan Area	64	43.8	28.1
Total	899	32.0	26.2

Notes
1 Summary includes all units whether or not there were any type of watercourses associated with the harvest unit.
2 Harvest units in this HPA were developed and operated by a previous owner.

Table C4-3. Summary of Class III watercourse characteristics.[1]

Variables	Run-through		Within		Total	
	N	mean (SE)	N	mean (SE)	N	mean (SE)
Drainage area (acres)	47	10.5 (2.48)	53	5.6 (0.66)	100	7.9 (1.24)
Channel length (ft)	47	451.5 (31.62)	53	346.1 (34.46)	100	395.6 (24.02)
Channel width (ft)	47	2.55 (0.147)	53	2.69 (0.234)	100	2.62 (0.140)
Channel depth (ft)	47	0.33 (0.029)	53	0.25 (0.002)	100	0.29 (0.019)
X-section area (ft^2)	47	0.96 (0.146)	53	0.67 (0.083)	100	0.81 (0.083)
Channel gradient (%)	47	31.5 (1.79)	53	35.2 (1.81)	100	33.4 (1.28)
Bank slope (%)	47	47.4 (2.481)	53	43.0 (2.61)	100	45.1 (1.81)
Exposed bank (%)	47	0.66 (0.113)	53	1.00 (0.343)	100	0.84 (0.189)

Note
1 Cross-sectional area of the channel represents the product of the active channel depth and width measurement. RT = run-through channels and Within = within channels.

Green Diamond conducted a forward stepwise regression analysis to determine which of the independent variables explained variation in mean channel cross-sectional area. The first variable to enter the model was drainage *area* (F = 20.80, d.f. = 1,92, P < 0.001, improvement R^2 = 0.237, model coefficient = 0.044), followed by underlying bedrock geology (F = 8.23, d.f. = 1,92, P = 0.005, improvement R^2 = 0.061, model coefficient = -0.455) indicating greater channel width in unconsolidated bedrock geology), stream gradient (F = 9.16, d.f. = 1,92, P = 0.003, improvement R^2 = 0.051, model coefficient = -0.016) and number of rock controls (F = 3.93, d.f. = 1,92, P = 0.051, improvement R^2 = 0.027, model coefficient = 0.937). The full model explained 37.5% of the variation in cross-sectional area of channels among streams. The cross-sectional area of channels with consolidated underlying geologic materials was significantly less when corrected for drainage area than channels in unconsolidated geology (consolidated area: n = 74, $\bar{x}$ =

0.61, SE = 0.048; unconsolidated area: n = 24, $\bar{x}$ = 1.41, SE = 0.273; ANCOVA: F = 13.52, d.f. = 1,95, P < 0.001). This relationship between drainage area and cross-sectional area of the active channel is illustrated in Figure C4-3.

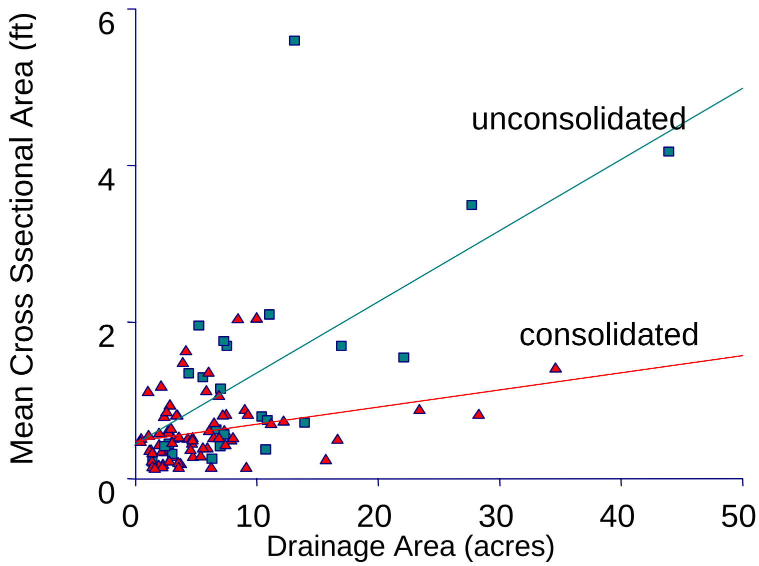


Figure C4-3. Mean cross sectional area (ft^2) of channels versus drainage area in consolidated and unconsolidated bedrock geology. Triangles represent consolidated geology and squares unconsolidated geology. Regression equation for consolidated geology: Y = 0.477 + 0.022*drainage, R^2 = 0.096; unconsolidated geology: Y = 0.447 + 0.091*drainage, R^2 = 0.409.

Consistent with being higher in slope position, within channels had somewhat higher mean stream gradient ($\bar{x}$ = 35.2, SE = 1.82) compared to run-through channels ($\bar{x}$ = 31.5, SE = 1.79), although the differences were not statistically significant (t = 1.44, d.f. = 98, P = 0.153). In addition, the distribution of stream gradients indicated that both types of Class III channels had a similar wide range of stream gradients (Figure C4-4). There was no difference in channel gradient or bank slope between consolidated and unconsolidated bedrock geologies with drainage area as the covariate (ANCOVA: stream gradient – F = 0.51, d.f. = 1,97, P = 0.478; bank slope – F= 1.02, d.f. = 1,97, P = 0.315). The mean number of LWD pieces per 100 feet of Class III channel was 4.80 (SE = 0.318), while mean volume was 226.6 (SE = 25.02) cubic feet per 100 feet of channel. However, the distribution in the number and volume of LWD (Figure C4-5) indicated that most channels had relatively low amounts with a small proportion of channels having high amounts of LWD. Of the LWD associated with these channels, 85.0% (SE = 2.59) was determined to be conifer.

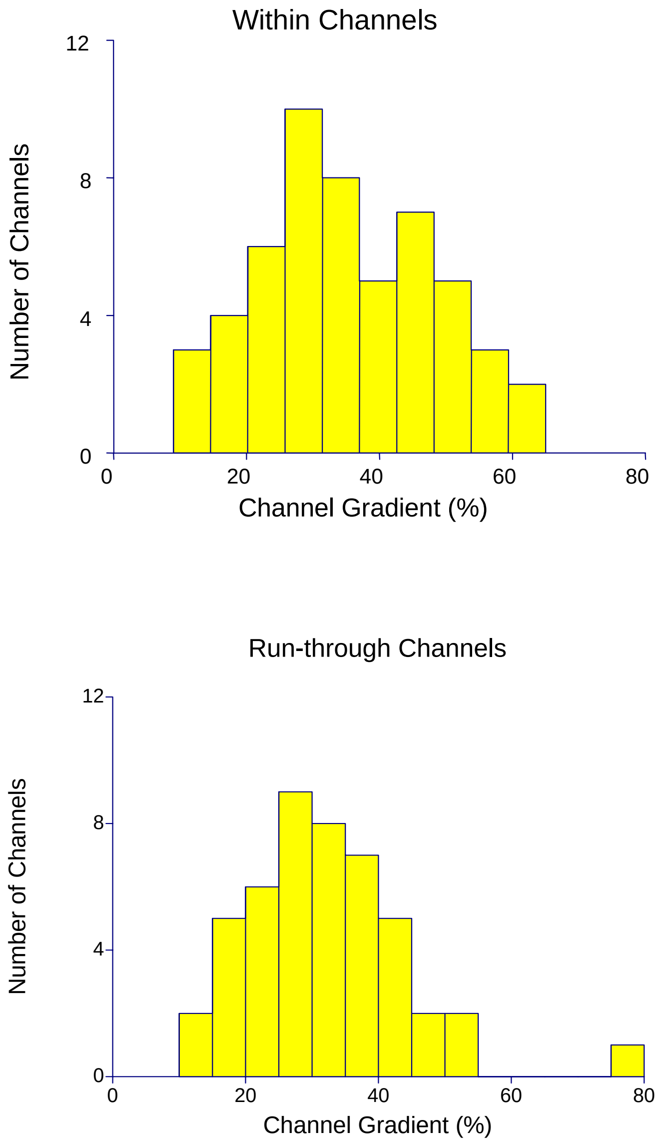
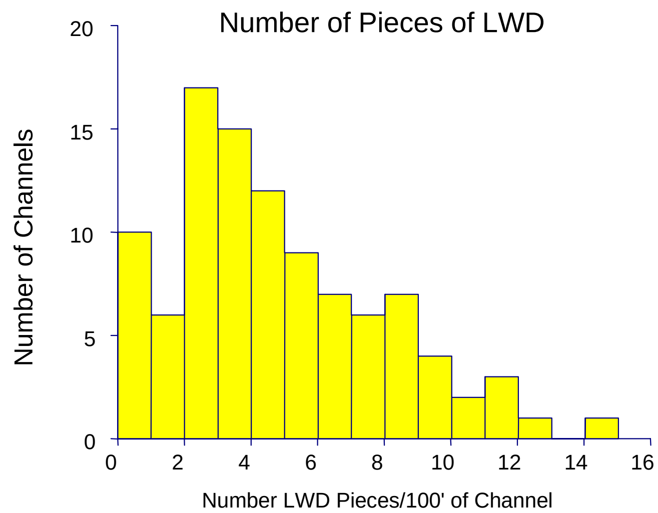


Figure C4-4. Distribution of stream gradients for "within" and "run-through" Class III watercourses.



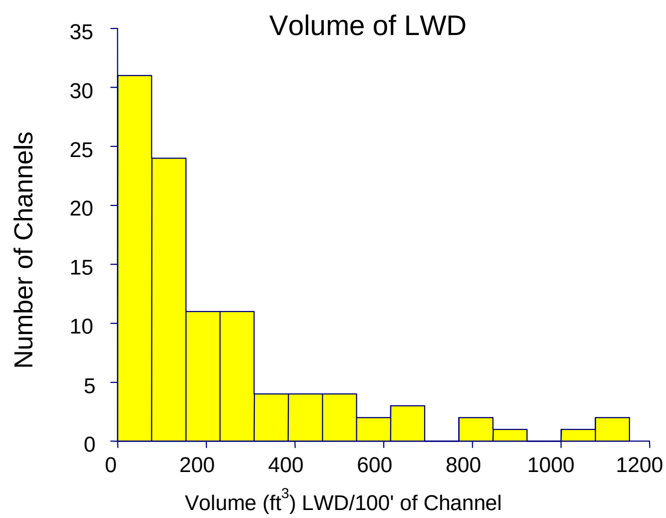


Figure C4-5. Distribution among surveyed Class III watercourses of the number and volume of LWD per 100 feet of channel.

The mean number of total control points per 100 feet of Class III channel was 0.93 (SE = 0.121) with most (>75%) of the controls being formed by LWD (Figure C4-6). Roots and rocks (large rock or bedrock) were particularly rare in forming control points in these Class III channels.

Mean percent exposed active channel (EAC – percent of 10-foot sample intervals with evidence of an exposed active channel) for within and run-through channels was 23.3 (SE = 2.88) and 24.6 (SE = 2.55), respectively. The difference was not statistically different (t = 1.097, d.f. = 97, P = 0.275) so the two channel types were combined for additional analysis. The distribution of mean percent EAC channel (Figure C4-7) was highly skewed to the left with most channels showing little or no EAC. Green Diamond conducted a forward stepwise regression to further explore the relationship between EAC and other independent variables measured. The first variable to enter the model was the total number of channel control points (F = 41.427, d.f. = 1,93, P < 0.001, improvement R^2 = 0.232, model coefficient = 0.474), followed by mean height of riparian ground vegetation (F = 6.75, d.f. = 1,93, P = 0.011, improvement R^2 = 0.047, model coefficient = 0.220), and underlying bedrock geology (F = 5.33, d.f. = 1,93, P = 0.023, improvement R^2 = 0.036, model coefficient = -0.498). The full model explained 31.5% of the variation in EAC of channels among streams. Green Diamond expected channel scour to be positively correlated with stream gradient, but it did not enter the stepwise regression model. To graphically explore the relationship, Green Diamond produced a scatter plot of EAC and gradient (Figure C4-8), which further illustrates the lack of correlation between these two variables.

The preponderance of LWD as channel controls and the apparent positive correlation between channel controls and EAC prompted us to graphically look at the relationship between LWD controls and EAC (Figure C4-9). Although there is considerable variation, it is apparent that there was a positive relationship between the number of LWD controls and percent EAC.

Sites along the banks of the Class III channels with bare mineral soil that were the result of undercutting or sloughing were termed bank erosion. Relative to the axis of the channel, these sites were longer (mean length = 9.6 feet, SE = 0.81) than wide (mean width = 5.3 feet, SE = 0.47). Among the 100 channels surveyed, there were 107 total sites with bank erosion. Most sites (57%) had no bank erosion, while a few streams had relatively frequent bank erosion (Figure C4-10). Green Diamond conducted a forward stepwise regression to further explore the relationship between bank erosion and other independent variables measured. The only variables to enter the model were underlying bedrock geology (F = 8.05, d.f. = 1,93, P = 0.006 improvement GLM R^2 = 0.258, model coefficient = -0.787) (greater bank erosion in unconsolidated geology), followed by total canopy closure (F = 7.75, d.f. = 1,93, P = 0.007, improvement GLM R^2 = 0.086, model coefficient = -0.030) (less bank erosion with greater canopy closure) and volume of LWD (F = 3.21, d.f. = 1,93, P = 0.077, improvement GLM R^2 = 0.026, model coefficient = 0.001) (greater bank erosion with more LWD). The full model explained 37.1% of the variation in bank erosion among streams.

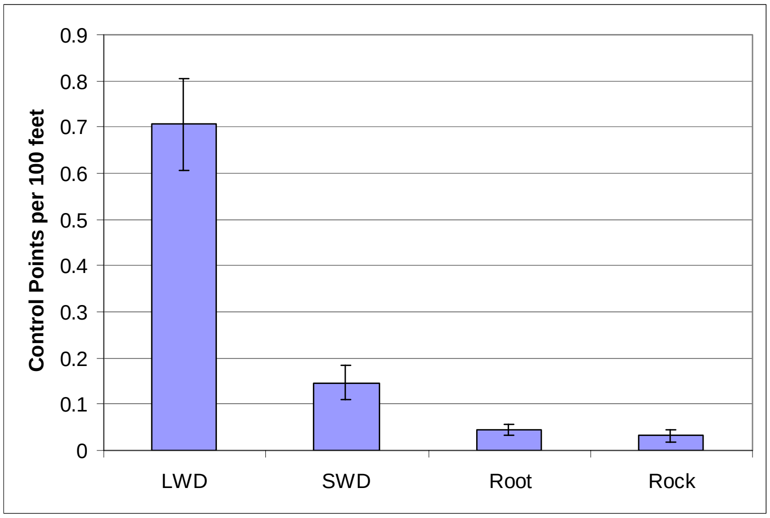


Figure C4-6. **Mean number of control points per 100 feet of channel with standard error bars. LWD = control points formed from large woody debris (>6 inches), SWD = control points formed from collections of small woody debris (<6 inches), root = control points formed by tree roots and rock = control points formed from large rocks or bedrock.**

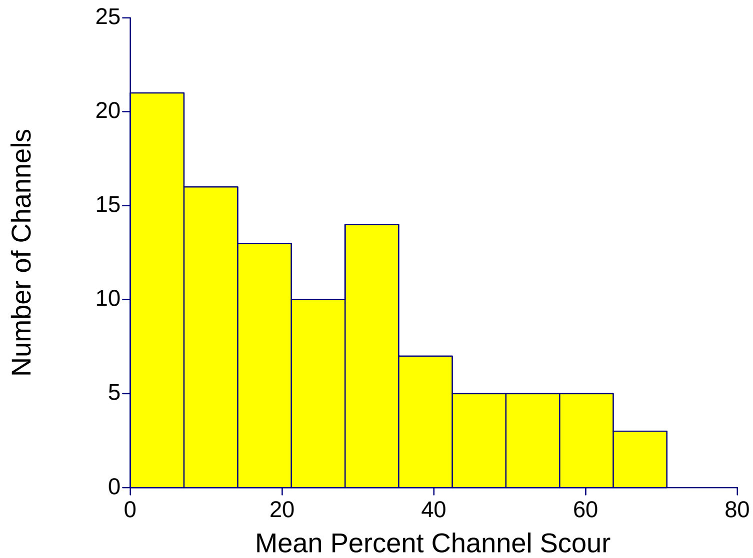


Figure C4-7. **Distribution of mean percent exposed active channel (EAC) among surveyed Class III watercourses.**

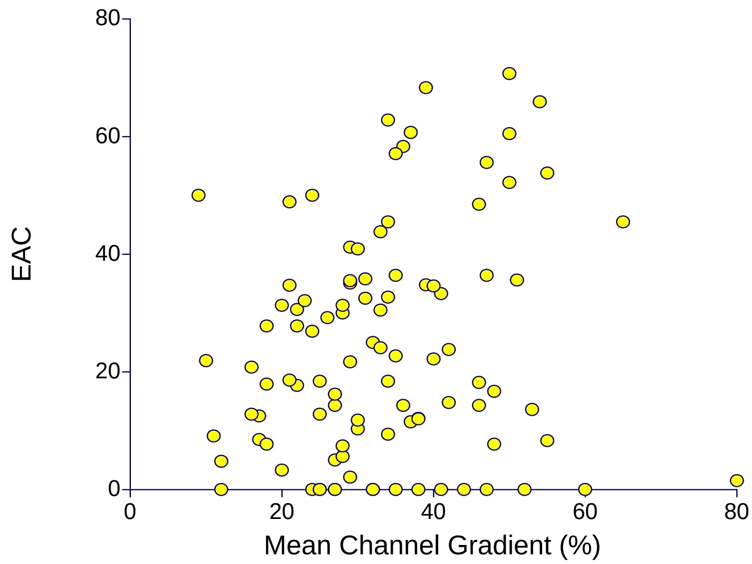


Figure C4-8. Mean channel gradient versus mean percent exposed active channel (EAC) for individual watercourses.

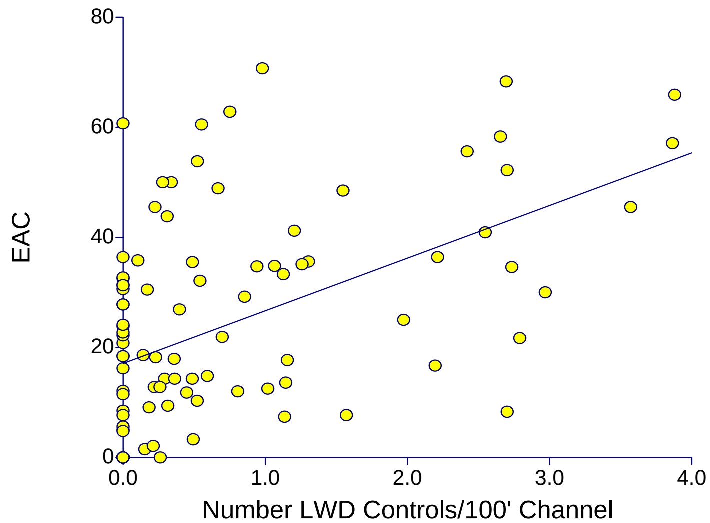


Figure C4-9. Number of LWD control points per 100 feet of channel versus mean percent exposed active channel. Trend line is the least squares regression line. Regression equation: Y = 0.010 + 0.026*EAC, R^2 = 0.245.

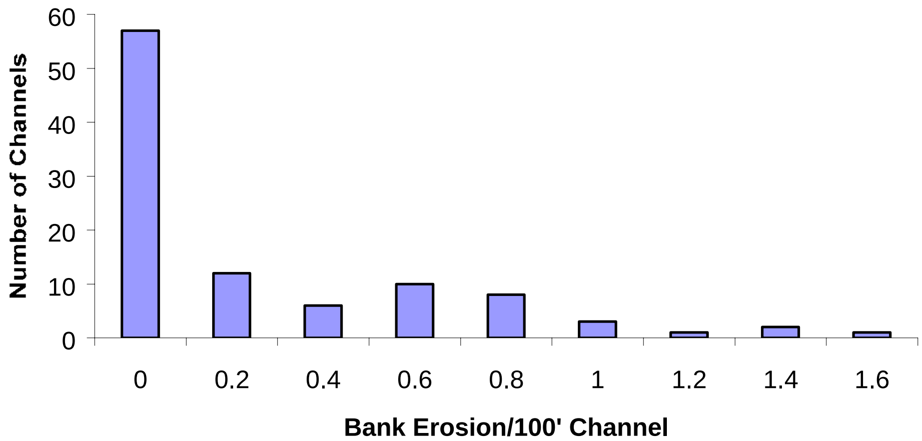


Figure C4-10. Distribution of sites with bank erosion among surveyed Class III watercourses. Each value in the figure represents the mean value from a given stream.

Twenty-four shallow rapid landslides were identified while surveying the 100 Class III watercourses. One slide was associated with a road and not included in further analysis, while all of the rest of the slides were associated with an inner gorge or steep streamside slope. There were no debris torrents associated with any of the channels surveyed. The distribution of landslides among surveyed channels (Figure C4-11) indicated that most (85%) had no slides with a few of the channels accounting for the majority of the slides. The cumulative frequency distribution of the length (maximum head scarp distance) of the landslides indicated that 80% of the slides were located within less than 20 feet of the channel (Figure C4-12). The results of a forward stepwise regression analysis of the relationship between landslides (number/100 feet of channel) and other independent variables measured indicated that the first variable to enter the models was stream gradient (F = 7.17, d.f. = 1,91, P = 0. 009, improvement GLM R^2 = 0.350, model coefficient = 0.027). This was followed by mean height of ground vegetation (F = 30.15, d.f. = 1,91, P < 0.001, improvement GLM R^2 = 0.093, model coefficient = -1.128), mean bank slope (F = 25.74, d.f. = 1,91, P < 0.001, improvement GLM R^2 = 0.072, model coefficient = 0.054), number of LWD controls (F = 14.56, d.f. = 1,91, P < 0.001, improvement GLM R^2 = 0.051, model coefficient = 0.473) and years since harvest (F = 14.57, d.f. = 1,91, P < 0.001, improvement GLM R^2 = 0.071, model coefficient = 0.322). The full model explained 63.6% of the variation in the number of slides among streams.

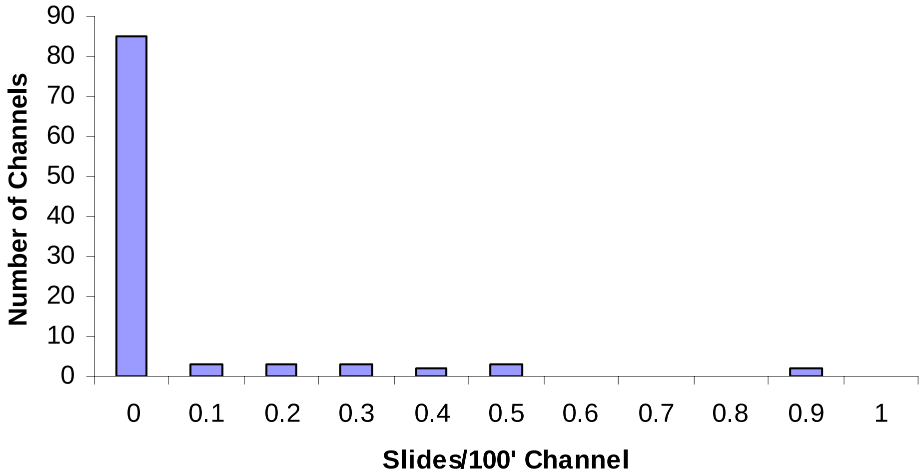


Figure C4-11. Distribution of landslides among surveyed class III watercourses. Each value in the figure represents the mean value from a given stream.

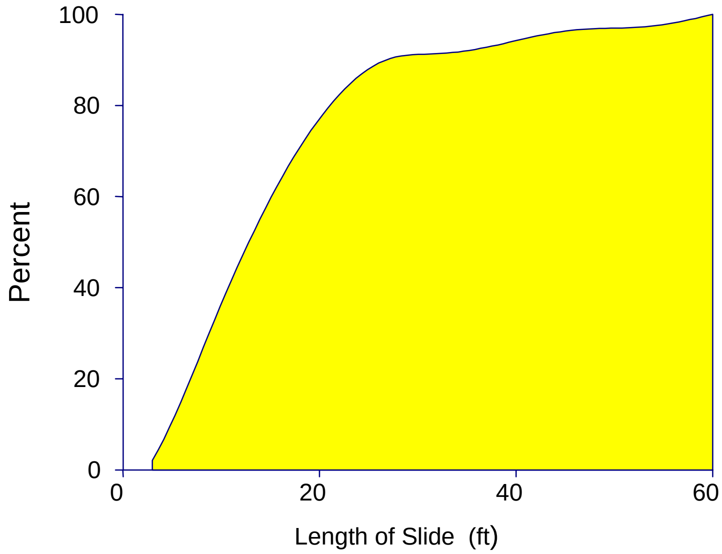


Figure C4-12. Cumulative frequency distribution of the length (maximum head scarp distance) of 23 inner gorge or steep streamside slope landslides associated with surveyed Class III watercourses.

Bank erosion or slides at the initiation of Class III watercourses are evidence of head cutting or channel extension. In the 53 within channels where this could be assessed, the only channel extension or head cutting observed was due to runoff from roads. This occurred in both in within and run-through channels and was typically associated with improper road drainage. There was no direct evidence for head cutting or channel extension due to hillslope processes. There was also no evidence of channel extension based on the mapped initiation of the channel in the THP map, but these maps were not considered very precise.

C4.3.1 Comparisons with Pre-treatment Steams

There were 26 Class III watercourses that were assessed as part of the Little River monitoring program. These were compared to 29 Class III watercourses in or adjacent to the Little River HPA that were assessed as part of this retrospective study. Although these streams were spatially and temporally separated, most characteristics were similar (Table C4-4).

Using ANCOVA with drainage area as a covariate, cross-sectional area and percent EAC (square root transformed) for pre and post-treatment streams were not significantly different (Cross-sectional area: $F = 0.31$, d.f. = 1,49, $P = 0.583$; Percent scour: $F = 2.72$, d.f. = 1,52 $P = 0.105$).

Table C4-4. Summary of pre- and post-treatment Class III watercourse characteristics.

Variables	Pre-treatment		Post-treatment	
	N	mean (SE)	N	mean (SE)
Drainage area (acres)	26	8.0 (1.40)	29	8.7 (3.60)
Active channel length (ft)	26	374.9 (51.81)	29	405.2 (50.54)
Active channel width (ft)	24	2.05 (0.156)	28	2.42 (0.231)
Active channel depth (ft)	24	0.28 (0.024)	28	0.26 (0.106)
Cross-sectional area (ft^2)	24	0.567 (0.063)	28	0.617 (0.063)
Channel gradient (%)	24	28.5 (2.10)	29	30.4 (2.19)
Bank slope	26	16.8 (1.21)	29	21.8 (1.41)
Percent exposed active channel	26	15.0 (2.47)	29	27.7 (4.26)
Bank erosion sites/100 ft	26	0.46 (0.127)	29	0.33 (0.084)
Slides/100 ft	26	0.03 (0.033)	29	0.05 (0.034)

C4.4 DISCUSSION

C4.4.1 Limitations

The preceding data are retrospective in nature and do not provide comparisons to untreated control streams (i.e. unharvested Class III watersheds in advanced second growth or virgin old growth.) Therefore, it is important to identify the type of conclusions that one should expect to be able to draw from the data. Most of the data were descriptive in nature, which allowed us to create an "image" of the characteristics of Class III watercourses sampled. Green Diamond followed a stratified random sampling design, so it was appropriate to draw inferences to the total sampling universe. However, since the sampling was tied to recent harvesting (1992-1998), the inferences should be restricted to that portion of the total ownership that has experienced significant harvesting in recent years. In addition to descriptive characterizations of these watercourses, the objective was to assess the extent to which major changes occurred in Class IIIs that were responsible for substantial increases in management related sediment production. Caution must always be used when attempting to establish treatment effects or cause and effect relationships using a retrospective study design, but this type of study can be useful in identifying major or gross changes that occurred in Class III watercourses following clearcut timber harvest. It should be noted that most knowledge concerning the impact of timber harvest on geologic or hydrological processes comes from studies that were retrospective in nature. Before-after-control-impact (BACI) experiments (Skalski and Robson 1992; McDonald et al. 2000)) are the only approach to definitively assess the impact of a treatment on a response variable, and there have been few studies that utilize such an experimental approach on landscape level geologic or hydrologic processes.

Despite these limitations, the pre-treatment data set from the Little River HPA indicates that there were not gross differences between treated and untreated control streams for this HPA. This suggests that the results of the retrospective study may be interpreted with greater confidence than might otherwise be possible for a retrospective study. However, it is also recognized that conclusions from this one region may not hold for other HPAs with steeper topography or unconsolidated geology.

C4.4.2 Channel Size

An expected feature of these first order channels associated with Class III watercourses was that they were generally steep with an overall mean channel gradient of 33.4%. However, there was also considerable variation in gradient with a range from 9-80%. The size of the active channel was also quite small with a mean cross-sectional area (product of the channel depth and width measurement) of 0.81 ft^2, which can also be represented by a mean volume (volume of substrate that was transported to produce the existing channel) of 8.07 ft^3/100 feet of channel. In addition, this was a maximum estimate since Green Diamond only measured the maximum depth of the channel at each 10-foot sampling interval. It was also important to note the influence that geology had on the size of Class III channels. Channels with unconsolidated underlying geology (i.e. most of the channels in the Humboldt Bay and Eel River HPAs), had channels approximately twice the cross-sectional area than channels in consolidated geology. Qualitative field observations further support that Class III watercourses were much larger in areas with unconsolidated geology. The suggestion that underlying geology is an important determinant of the size and hydrologic response of Class III watercourses is generally consistent with findings from the Freshwater Watershed Analysis. In Freshwater, Class III channels draining the extremely weak Wildcat Group enlarged significantly following initial harvest, while Class III watercourses in Franciscan Formation sandstones did not. Recent harvest, however, did not appear to have dramatic effects on Class III channels in either of the major bedrock formations (Freshwater Watershed Analysis, Stream Channel Module).

C4.4.3 Exposed Active Channel and Control Points

Observations of EAC can be interpreted as an indicator of fluvial erosion or deposition. The fact that the percentage of the bed showing EAC was correlated with control points suggests that fluvial erosion and deposition processes as expressed by EAC were associated with control points

Green Diamond has no information by which to judge the relative merits of the number of control points per unit length of stream channel identified from this study. A high proportion of control points were made up of LWD, but it was of interest to note that even collections of small woody debris (SWD) could serve as control points in these channels. LWD and SWD in the channel created plunge pools that were responsible for streambed scour immediately below the control point. Evidence for this was provided by the fact that the total number of control points was the first variable to enter the regression model (with a positive coefficient) with EAC as the dependent variable. It is generally thought that although control points may cause scour in short waterfalls immediately below the control point, they prevent overall channel down-cutting. Control points may also correlate with the abundance of roughness elements that cause lateral scour. With a retrospective study, Green Diamond was not able to detect subtle changes in mean channel bed elevation, and apparently, there were sufficient control points in all streams to prevent any major “unraveling” of the channels.

One of the potential effects of harvest is an increase in peak storm runoff in Class III channels. The potential for channel bed erosion (down cutting) is limited by erosion-resistant elements of the channel bed. Roots and rocks (large rock or bedrock) rarely formed control points. LWD was the dominant channel element forming control points in these Class III channels. This is consistent with the conceptualization of Class III channels as ephemeral streams with low sediment transport capacity; these would be expected to be colluvial channels with weak fluvial sorting of hillslope material and relatively fine bed texture. The fact that EAC occurred in only 25% of 10-foot channel measurements also demonstrates that fluvial processes were spatially intermittent in these Class III channels. Consequently, few bedrock or coarse sediment exposures in the channel bed may be expected and proportionately more might be expected in Class II channels or larger Class III channels as suggested by the stepwise regression for channel cross-section area.

The abundance of LWD is significant in relation to the frequency of control points. Green Diamond has no data on the amount or distribution of LWD in Class II watercourses for comparison, but LWD surveys from the smallest Class I watercourses produced a mean of 5-6 pieces per 100 feet of channel in comparison to 4.8 for the Class III watercourses. However, these comparisons may not be appropriate, because the LWD surveys were conducted following different protocols. Green Diamond saw no evidence of transport of LWD in Class III watercourses. LWD was primarily composed of conifer in these Class III channels, which was generally not the case for Class I watercourses. However, this was consistent with the general observation of relatively few hardwoods such as red alder in upslope positions, while alder was a predominant component in many Class I watercourses.

Sites with bank erosion (bare mineral soil on the bank of the channel that was the result of undercutting or sloughing) were generally not large (about 50 ft^2) and did not occur in most channels. Relatively few channels were responsible for most of the bank erosion reported (Figure C4-10). Underlying bedrock geology (more bank erosion in unconsolidated geology), total canopy closure (less bank erosion with greater total canopy) and volume of LWD (more bank erosion with greater of amounts of LWD) were the only dependent variables that entered a stepwise regression analysis of bank erosion versus all appropriate independent variables measured. Increases in bank erosion in unconsolidated geology were expected, as was a decrease in bank erosion with increases in total canopy. (Canopy closure was coming from the regrowth of shrubs and trees since the streams were all in clearcuts with no tree retention.) However, the positive relationship between bank erosion and LWD was not as intuitive. Presumably, LWD directs flow into the banks of the channel thus increasing the sites with bank erosion.

C4.4.4 Slides and Debris Flows

There were relatively few total slides associated with these Class III watercourses and most of the slides occurred in just a few of the channels. In addition, the maximum head scarp distance for 80% of the slides was only 20 feet. It was also notable that there were no debris flows associated with any of these channels even though some had mean stream gradients as high as 80%. Number of LWD control points per 100 feet of channel (positive coefficient), stream gradient (positive coefficient), mean height of ground vegetation (negative coefficient), bank slope (positive coefficient), and number of years since harvest (positive coefficient) were the dependent variables that entered a stepwise regression analysis of the number of landslides versus all appropriate independent variables measured. The positive association between landslides and stream gradient as well as bank slope was predictable, given the importance of slope angle in slope stability. These two variables explained over 40% of the variation in landslides among streams and accounted for over two-thirds of the variation explained by the full regression model. A negative association with ground vegetation might be expected due to increased root strength, but this variable only explained 9% of the variation in the model. Positive correlation between years since harvest and landslide frequency may also be explained relative to root strength (initially declining following harvest), but the variable only explained 7% of the variation in the model making further speculation unwarranted. The potential reason for the positive association between inner gorge landslides and LWD control points was not so intuitive. Green Diamond believes that the apparent association was most likely created by landslides bringing LWD into the channel, and not that LWD in the channel had any direct effect on the rate of landslides. However, once again the variable contributed so little (5%) to explaining variation in the model that conclusions are unwarranted.

C4.5 CONCLUSIONS

This study suggests that there were no gross short-term effects of timber harvest on erosion in and near Class III channels for the period 1992-1998. There were few sites that experienced extensive bank erosion and less than 25% of 10-foot channel intervals contained exposed active channel (EAC). Furthermore, in the 100 sites examined, there were no debris flows. This is significant in that there were several potential triggering storms in 1996 and 1998 and there was above average (generally 120-140% of normal) total rainfall in all years except 1992 and 1994. In addition, 53% of the streams surveyed were harvested from 1996-1998 when the potential effects of increased incident precipitation (caused by reduced forest canopy) on soil erosion should have been greatest immediately following harvest. However, there is an expected lag effect of approximately 5 to 20 years associated with reduced root strength (Zeimer 1981; Sidle 1992), and a concomitant increased rate of landsliding (Sidle et al. 1985, p. 73-76). It may therefore be concluded that under the recent regime of harvest practices, Class III channels were not responding to harvest in the short-term by unraveling and causing the potential for major increases in sedimentation downstream. However, these results do not rule out the possibility that there were increases in sediment production from more subtle and chronic sources, or that a longer period of study might reveal changes not recognized in this investigation. The tendency for most of the sediment production from Class IIIs to be limited to a relatively few streams, particularly in regions with unconsolidated geology, suggest that effective mitigation can be provided by site specific geologic review where conditions warrant.

Since there were no controls, this study was not capable of assessing whether the observed erosion indicators differ significantly from either virgin old growth or advanced second growth forest stand conditions. In particular, it provides no clear evidence regarding whether predicted increases in peak runoff have induced significant increases in rates of fluvial erosion. This study was very similar to the retrospective study of the impact of timber harvest on water temperature in Class II watercourses (see Appendix C5), in that, potential short-term impacts of timber harvest were too subtle to be readily detected with a retrospective study design. That led to a BACI experimental design for Class II water temperature (see Appendix C5), and the BACI design has also recently been initiated for sediment production of Class III watercourses. The initial data set from the Little River HPA suggests that control-treatment comparisons may not show significant effects in that region.

The landslides recorded in this study that delivered sediment to Class III watercourses were associated with steeper stream gradients and bank slopes, shorter vegetation (a combination of silvicultural treatment, site preparation and time since harvest) greater time interval since harvest and more LWD in the channel. These findings were consistent with expectations regarding known triggering mechanisms for landslides (Sidle et al. 1985). The dominant predictor of landslide potential was the slope of the stream and its banks. Collectively it explained over 40% of the variation in landslides among streams and accounted for over two-thirds of the variation explained by the full regression model. However, it was much more difficult to determine potential management effects from this study. To begin with, the two variables that had management implications (height of ground vegetation and time since harvest) collectively only explained a small fraction of the variation of slides among streams. In addition, the height of ground vegetation could represent the influence of multiple management factors. Moreover, height of ground vegetation, had the opposite model coefficient as the direct measurement of time since harvest. It is likely that this retrospective study design is not capable of detecting management effects on landsliding. A more effective study design would include control streams, before-after data or both (BACI experiment).

Without reference or control streams for comparison, it was not possible to assess the quantity of LWD in Class III watercourses in the study area. However, LWD was the predominate element in the formation of channel bed grade control points. In addition, LWD was positively correlated with exposed active channels and bank erosion and, in some cases, with slides. Hence, there was evidence that LWD interacts with fluvial processes in Class III watercourses, but it was not possible to predict the impact of changes in the volume of LWD in Class III watercourses from this study.

C4.6 LITERATURE CITED

McDonald, T.L., W.E. Erickson and L.L. McDonald. 2000. Analysis of count data from before-after control-impact studies. Journal of Agricultural, Biological, and Environmental Statistics, 5(3): 262-279.

Sidle, R.C., 1992. A theoretical model of the effects of timber harvesting on slope stability. Water Resources Research, 28(7): 1897-1910.

Sidle, R.C., A.J. Pearce and C.L. O'Loughlin. 1985. Hillslope stability and land use. Water Resources Monograph Series 11.

Skalski, J.R. and D.S. Robson. 1992. Techniques for Wildlife Investigations, Design and Analysis of Capture Data. Academic Press, Inc. New York. 236 pp.

Ziemer, R. R. 1981. Roots and the stability of forested slopes. In: Timothy R. H. Davies and Andrew J. Pearce (eds.), Erosion and Sediment Transport in Pacific Rim Steeplands, Proceedings of the Christchurch Symposium, 25-31 January 1981, Christchurch, New Zealand. Int. Assn. Hydrol. Sci. Pub. No. 132: 343-361.