CHAPTER 4
Upslope Conditions – A Plan for Water Quality

Redwood forest habitat on the northern hillslopes of the Lower Van Duzen River Basin in 2008, where numerous clear cuts and skid trails are still clearly visible. Photo by S. Steinberg.

Catchment Areas

One of the very unique capabilities of GIS (ArcInfo) is the ability to use large scale (1:24,000) stream blue line data and high resolution (10 meter) digital elevation model (DEM) grid data to define the shape and quantify the area of true watersheds or rainfall catchment areas. Knowing the location of a monitoring site and the elevation of the associated hillsides, an analyst can program GIS software to define all of the upslope area that contributes water and runoff to that particular point in the stream (Figure 4-1). Therefore, having spatially recorded the locations of all 11 monitoring sites within the project boundary and having DEM grid data for the entire area, it is possible to define the shapes and sizes of each catchment area associated with each monitoring site (Figure 4-2). One of the most obvious advantages to this type of calculation, besides being able to delineate the shapes of the catchment areas, is to be able to analyze the relationship between turbidity (and suspended sediment) and upslope conditions that potentially influence these dependent variables on a per unit area basis.

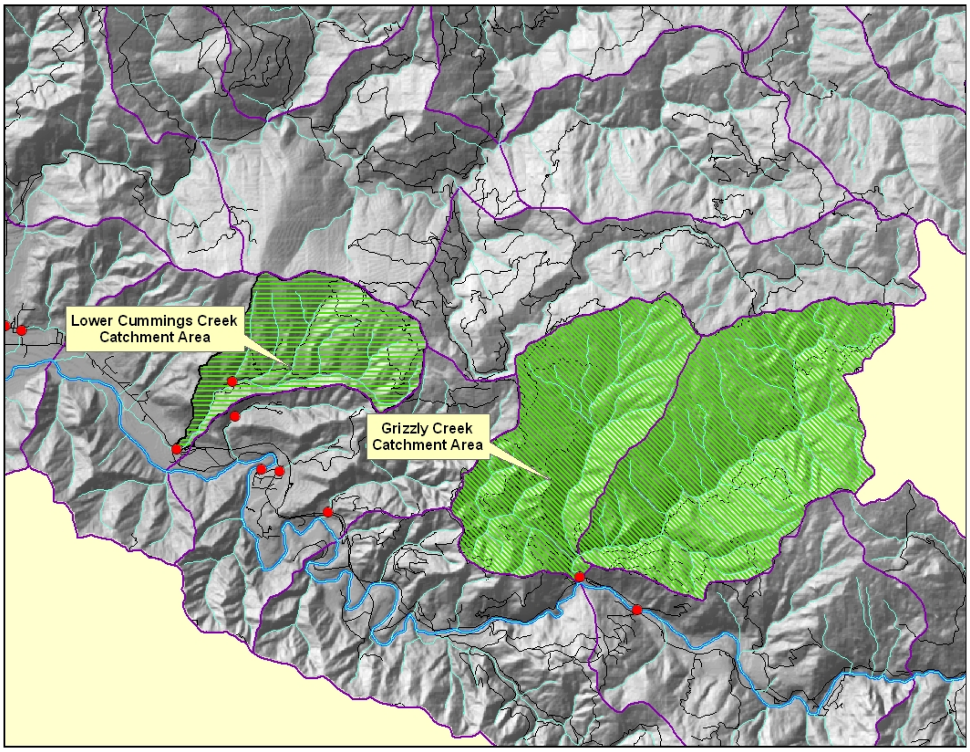

Figure 4-1. Examples of catchment area shapes and sizes (in green) derived using GIS software. Left: Lower Cummings Creek, Right: Grizzly Creek.

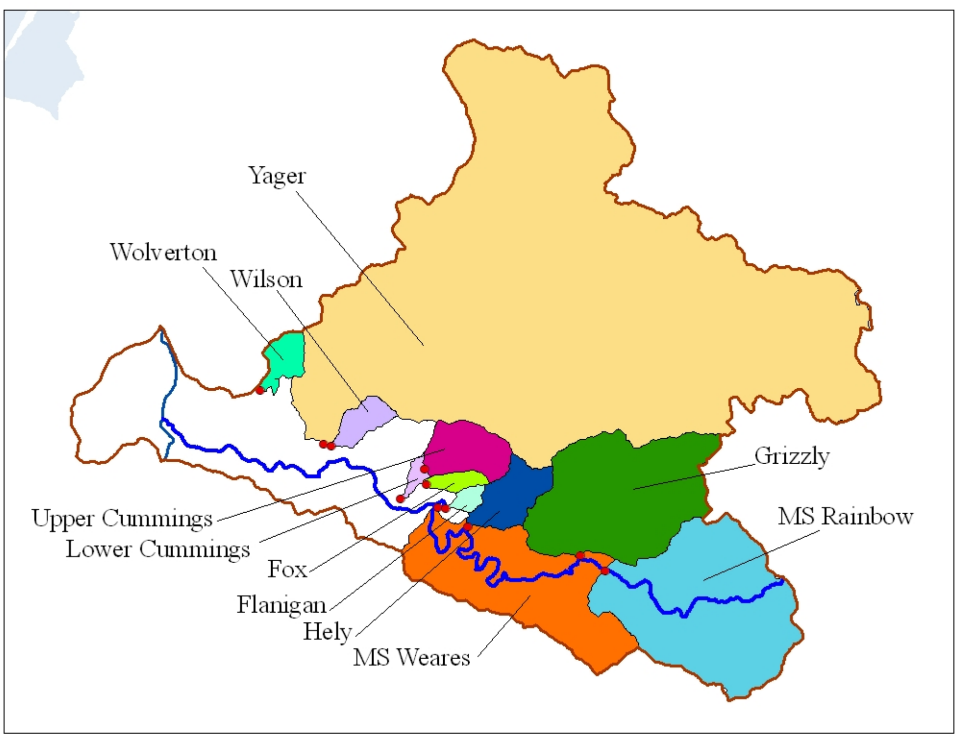

Figure 4-2. Catchment areas associated with the 11 monitoring sites (red dots) in the Lower Van Duzen River Basin.

Note that Yager Creek Catchment area is disproportionately larger than any of the other areas, and actually comprises about 14 planning watersheds within its boundary. Grizzly Creek comprises two planning watersheds, Grizzly Creek and Stevens Creek. MS Weares is larger than it appears in the map (Figure 4-2), as it also encompasses the areas of Hely Creek, Grizzly Creek, and MS Rainbow, all of which are either part of (MS Rainbow) or drain into (Hely Creek and Grizzly Creek) the main stem Van Duzen River, and all flow through the sample site at MS Weares.

Road Density

As described earlier in Chapter 3, road density can have profound impacts on the integrity of a watershed. Newly edited road data (see Chapter 3) were used to calculate road densities for all monitoring site catchment areas (Figure 3-8, Table 3-2). Catchment areas described above can also be thought of as true watersheds for the streams and monitoring sites that are used to derive them and road densities can be calculated on a per catchment area basis (Figure 4-3) similar to a planning watershed basis, as was described in Chapter 3. Within the lower basin, road densities averaged 7.8 miles per square mile of catchment surface (Table 4-1). This value is considerably higher than the average value calculated for the 22 planning watersheds (6.24 miles per square mile), which is probably because Yager Creek counts as only a single catchment area, but as 14 separate planning watersheds, several of which registered relatively low density values, thereby giving Yager a greater influence on the overall average.

The highest road density was recorded for Wilson Creek (10.385), closely followed by Fox Creek (9.327), Lower Cummings Creek (9.226), Upper Cummings Creek (8.926), Hely Creek (7.945), and Flanigan Creek (7.886) all of which registered above average densities. Yager Creek, the largest catchment area in total area, registered the lowest road density (5.695), which according to the Bull Creek Study (USDA 1996, Chapter 3), would still receive a ranking of extremely high, as do all of the catchment areas within the lower basin (Figure 4-4).

The Yager Creek catchment area is unique to this study in several ways, an obvious characteristic being its size which is orders of magnitude larger than many of the other much smaller catchment area. Yager Creek represents the drainage system for two dramatically different sub basins, Lawrence Creek which drains primarily a redwood forest system and merges with Yager Creek at the junction between Corner Creek and Blanton Creek planning watersheds. Immediately above this junction, Yager Creek drains forested hillslopes, but at higher elevations the primary landcover is grazing and grassland (Chapter 3, Figure 3-16).

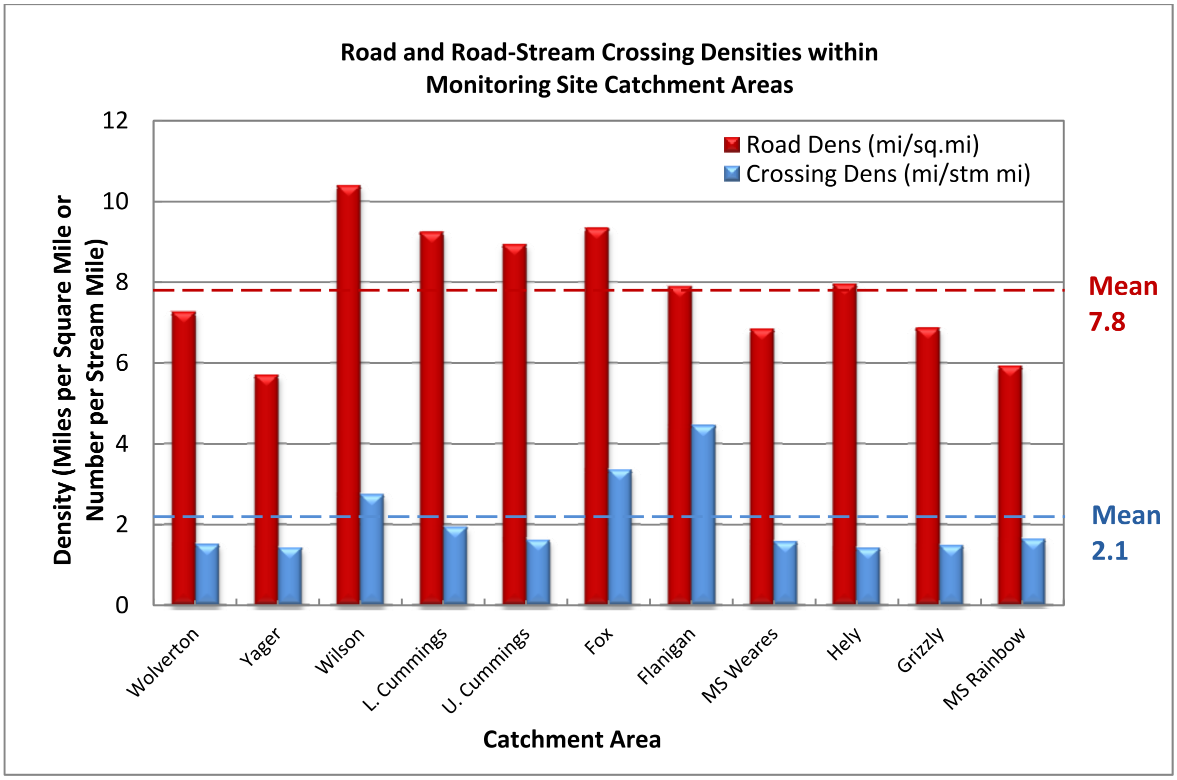

Figure 4-3. Road and road-stream crossing densities calculated for the 11 monitoring site catchment areas within the Lower Van Duzen River Basin. Results are given as either miles of road per square mile of watershed, or number of stream crossings per mile of stream.

As a substantial portion of the Yager Creek catchment area is grassland (Chapter 3, Figure 3-16), it is logical that road densities are lower than in some of the other areas that are either predominately or wholly dominated by timberlands. The primary issue here is that most of the roads in the lower basin are related to timber harvest (logging roads, skid roads, etc.), and thus, as a large part of the Yager Creek area is grassland, road densities would naturally be lower. Nonetheless, a road density of 5.7 miles per square mile of area is still considered to be extremely high, using criteria developed by the Forest Service (USFS 1996). Moreover, many of the planning watersheds within the Lawrence Creek sub basin (e.g., Bell Creek, Shaw Creek, Corner Creek, Cooper Mill Creek, and Blanton Creek) exhibit road densities much higher than the average for the Yager Creek catchment area as a whole.

Table 4-1. Summary Statistics of baseline data for catchment areas that correspond to the 11 monitoring sites within the Lower Van Duzen River Basin turbidity monitoring project.

Catchment Area	Summary Statistics (Catchment Areas) - Base Line Data			
	Catchment Number	**AREA (sq. meters)**	**AREA (sq. miles)**	**Road Length (meters)**
Wolverton Gulch	1	4733491	1.828	21340.25949
Yager Creek	2	347492400	134.167	1229711.18318
Wilson Creek	3	4570694	1.765	29494.43931
Lower Cummings Creek	4	11824930	4.566	67786.20107
Upper Cummings Creek	5	10419280	4.023	57787.54222
Fox Creek	6	2487554	0.960	209209.66040
MS Weares	7	167433900	64.646	46060.47559
Flanigan Creek	8	1687232	0.651	14416.16493
Hely Creek	9	9329660	3.602	8267.19884
Grizzly Creek	10	49107260	18.960	710593.5101
MS Rainbow Bridge	11	62645300	24.187	230498.57370
Average >>>		61066518.273	23.578	238651.383

Catchment Area	Road Length (miles)	Road Density (mi/sq.mi)	Road Density Rank	No. Road-Stream Crossings
Wolverton Gulch	13.26022	7.256	Extremely High	7
Yager Creek	764.10710	5.695	Extremely High	437
Wilson Creek	18.32699	10.385	Extremely High	14
Lower Cummings Creek	42.12039	9.226	Extremely High	23
Upper Cummings Creek	35.90751	8.926	Extremely High	17
Fox Creek	8.95779	9.327	Extremely High	7
MS Weares	441.54234	6.830	Extremely High	224
Flanigan Creek	5.13700	7.886	Extremely High	7
Hely Creek	28.62065	7.945	Extremely High	13
Grizzly Creek	129.99686	6.856	Extremely High	72
MS Rainbow Bridge	143.22517	5.921	Extremely High	73
Average >>>	148.291	7.841	Extremely High	81.273

Catchment Area	Crossings per sq.mi	Stream Length (meters)	Stream Length (miles)	Stream Density (miles.sq. mile)
Wolverton Gulch	3.830	7487.635	4.653	2.546
Yager Creek	3.257	494015.970	306.967	2.288
Wilson Creek	7.933	8227.277	5.112	2.897
Lower Cummings Creek	5.038	19098.171	11.867	2.599
Upper Cummings Creek	4.226	16939.432	10.526	2.616
Fox Creek	7.288	3357.411	2.086	2.172
MS Weares	3.465	229138.201	142.380	2.202
Flanigan Creek	10.745	2533.560	1.574	2.417
Hely Creek	3.609	14858.643	9.233	2.563
Grizzly Creek	3.797	78545.575	48.806	2.574
MS Rainbow Bridge	3.018	71617.180	44.501	1.840
Average >>>	5.110	85983.550	53.428	2.429

Table 4-1 (continued). Summary Statistics of baseline data for catchment areas that correspond to the 11 monitoring sites within the Lower Van Duzen River Basin turbidity monitoring project.

Catchment Area	Summary Statistics (Catchment Areas) - Base Line Data			
	Crossings per stream mile	Crossings Rank per Stream Mile	Meters of Road on Slopes > 35%	Road Density on Slopes > 35%
Wolverton Gulch	1.505	High	6594.287	2.242
Yager Creek	1.424	Moderate	330296.337	1.530
Wilson Creek	2.739	Very High	10423.718	3.670
Lower Cummings Creek	1.938	High	19674.408	2.678
Upper Cummings Creek	1.615	High	17208.626	2.658
Fox Creek	3.355	Very High	4681.731	3.029
MS Weares	1.573	High	247903.877	2.383
Flanigan Creek	4.446	Very High	946.961	0.903
Hely Creek	1.408	Moderate	16322.697	2.816
Grizzly Creek	1.475	Moderate	77474.114	2.539
MS Rainbow Bridge	1.640	High	68570.508	1.762
Average >>>	2.102	High	72736.115	2.383

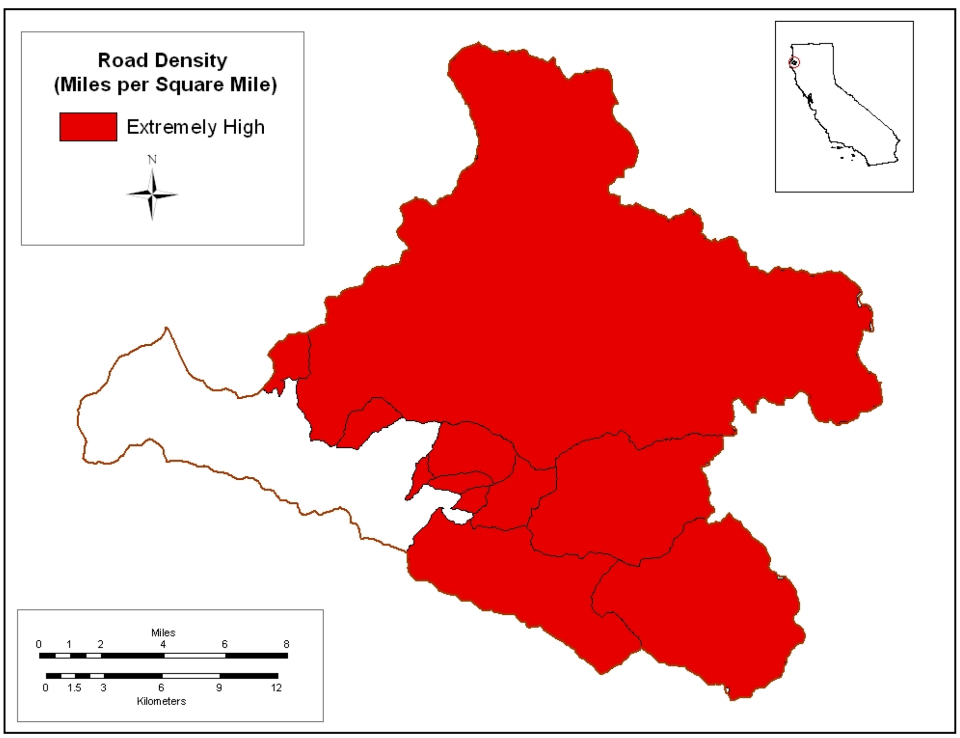

Figure 4-4. Ranking of road densities in 11 catchment areas that correspond to the monitoring sites used in the Van Duzen Watershed Project with the lower basin.

Road-Stream Crossings

The method of determining and calculating statistics for road-stream crossings is described in Chapter 3. Summary statistics for stream crossings, including crossing densities, were developed for each of the 11 catchment areas (Figure 4-3). Within the lower basin, road-stream crossing densities averaged 2.1 per stream mile for the 11 catchment areas. Similar to average road density, this value is also higher than the average stream crossing density for the 22 planning watersheds (1.56 crossings per stream mile) reported earlier (Figure 3-8, Table 3-2). Based on the ranking of stream crossing densities derived from an earlier study (Armentrout et. al. 1998), this represents an increase from High Density to Very High Density.

Similar to the situation described for road density, this difference is probably due to the Yager Creek catchment area absorbing 14 planning watersheds, many of which are outside of the timber harvest zone and therefore exhibit much lower densities, and also the co-relatedness between road density and road-stream crossings. Because of the vast differences in sizes of the catchment areas, even though data are presented on a per area or per stream length basis, it appears that calculating average summary statistics for these catchment areas may be of minimal value for understanding conditions throughout the study area. It may not be valid to compare watersheds that differ in area so dramatically, and in some cases this factor is as high as 100 fold or greater (e.g., Yager Creek versus Fox Creek or Flanigan Creek). Therefore averages of the catchment areas probably should not be considered further. However, because planning watersheds are similar in size (Figure 3-1, Table 3-2), comparisons and averages have much greater applicability.

Highest road-stream crossing density was register for Flanigan Creek (4.446 crossings per stream mile), followed by Fox Creek (3.355), Wilson Creek (2.739), Lower Cummings Creek (1.938), MS Rainbow Bridge (1.640), Upper Cummings (1.615), and Wolverton Gulch (1.505). Similar to road densities, Yager Creek catchment area registered the lower stream crossing density with 1.424 crossings per stream mile, undoubtedly due to the high proportion of grazing and grassland, as discussed previously. All catchment areas receive a ranking of moderate density or higher (Figure 4-5). Because of the lower density and also the very large size of the Yager Creek catchment area, the map gives the impression that most of the lower basin exhibits moderate road-stream crossing densities, which is not true of the Lawrence Creek sub basin. Lawrence Creek, which is part of the Yager Creek catchment area, has several planning watersheds (e.g., Blanton Creek, Bell Creek, Corner Creek, Cooper Mill Creek, Shaw Creek, and Booths Run) that exhibit road-stream crossing densities that receive a ranking of either high or very high (Figure 3-12, Table 3-2).

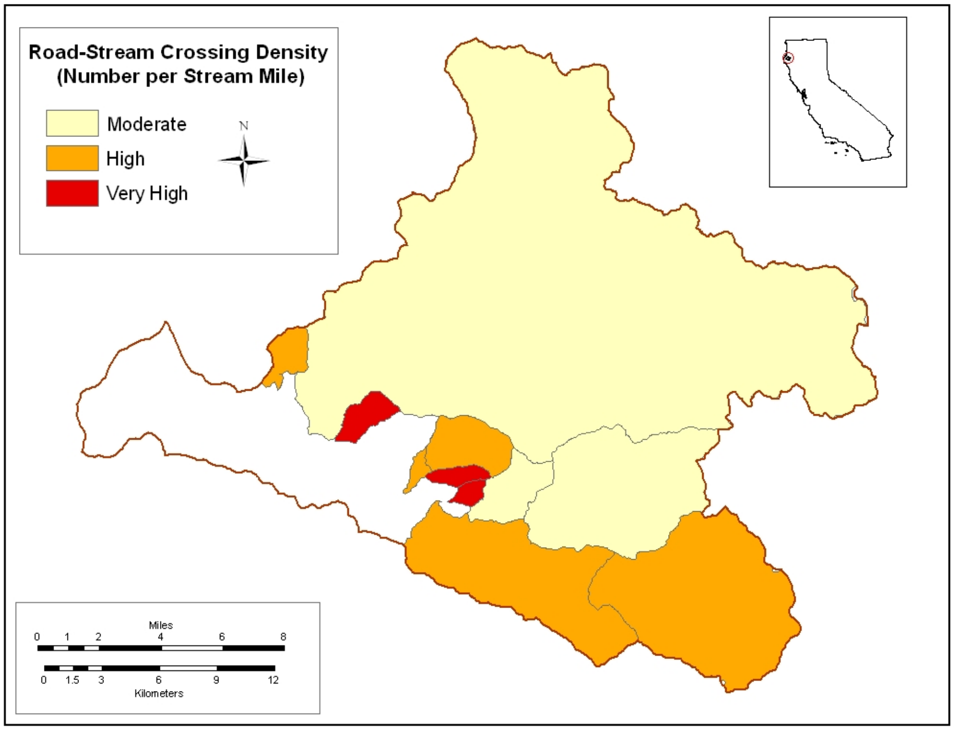

Figure 4-5. Ranking of road-stream crossing densities in 11 catchment areas that correspond to the monitoring sites used in the Van Duzen Watershed Project with the lower basin.

Topology and Vegetation Size Class

As discussed in Chapter 3, summary statistics were calculated for several critical topological features on a per-planning watershed basis, and also on a per-catchment area basis as well. Summary statistics quantify spatial data of interest in terms of proportion occupied by a given characteristic within each catchment area associated with a given monitoring site, such as that portrayed for road densities above.

The types of vegetation data available through various agencies and websites, and believed to be useful for characterizing and describing the conditions of these areas were also described and discussed in Chapter 3. The four northeastern planning watersheds discussed in Chapter 3 reside in the northeastern part of the Yager Catchment area, and are not substantially part of the forest timber harvest culture. However, in the case of catchment area analyses, it is not possible to separate the effects of these non-timber watersheds from the results of either summaries of upslope conditions or from the results of monitoring water quality, including turbidity and suspended sediment at the Yager Creek monitoring site. Summary statistics on tree size were calculated for each the 11 catchment areas described above (Table 4-2).

Table 4-2. Categories of tree size (DBH), presented as a proportion of each catchment area within the Lower Van Duzen River Basin (Imagery obtained from USFS 1999).

Catchment Area	Proportion of Watershed			
	Giant Trees	Very Large Trees	Large Trees	Medium-Large Trees
Wolverton Gulch	0.032	0.201	0.118	0.256
Yager Creek	0.013	0.037	0.058	0.300
Wilson Creek	0.022	0.201	0.078	0.116
Lower Cummings	0.002	0.048	0.266	0.480
Upper Cummings	0.001	0.033	0.291	0.493
Fox Creek	0.000	0.000	0.373	0.552
MS Weares	0.013	0.027	0.136	0.387
Flanigan Creek	0.000	0.146	0.431	0.388
Hely Creek	0.000	0.014	0.134	0.547
Grizzly Creek	0.005	0.023	0.104	0.396
MS Rainbow Bridge	0.000	0.015	0.132	0.332
Average >>>	0.008	0.068	0.193	0.386
Catchment Area	Proportion of Watershed			
	Small-Medium Trees	Small Trees	Saplings	Other (Grass, Ag., Urban)
Wolverton Gulch	0.110	0.055	0.097	0.133
Yager Creek	0.216	0.131	0.036	0.208
Wilson Creek	0.071	0.175	0.113	0.224
Lower Cummings	0.088	0.068	0.042	0.005
Upper Cummings	0.085	0.068	0.027	0.002
Fox Creek	0.031	0.030	0.003	0.011
MS Weares	0.153	0.076	0.015	0.191
Flanigan Creek	0.003	0.027	0.000	0.005
Hely Creek	0.234	0.068	0.002	0.001
Grizzly Creek	0.147	0.065	0.013	0.246
MS Rainbow Bridge	0.148	0.084	0.020	0.270
Average >>>	0.117	0.077	0.033	0.118

Assuming that larger trees impart greater stability to the watershed than smaller trees or no trees, areas with the largest proportion of Very Large Trees included Wolverton Gulch and Wilson Creek (both 20.1%), and Flanigan Creek (14.6%). Flanigan Creek also recorded the highest concentration of Large Trees (43.1%), which was followed by Fox Creek (37.3%), and Upper Cummings Creek (29.1%). Fox Creek had the highest frequency of Medium-Large Trees (55.2%), followed by Hely Creek (54.7%), and Upper Cummings Creek (49.3%). Comparing the two larger tree sizes (Large and Very Large) to the two smaller sizes (Small and Very Small) within each catchment area shows that Flanigan Creek registers the largest differential between large and small trees with a ratio of 57.7% to 3.0% (Figure 4-6). Other catchment areas showing a high differential of large to small trees included Fox Creek, Cummings Creek, and Wolverton Gulch. On the other hand, Hely Creek, Grizzly Creek, MS Weares, and Rainbow Bridge Catchments showed a reverse relationship with a high proportion of small trees to large trees. Because of the nature of catchment areas, MS Weares contains the areas of the mainstem that is sampled upstream, as well as several other streams that flow to its collection point. These areas include Hely Creek, Grizzly Creek, MS Rainbow Bridge, and Root Creek. Root Creek was not monitored for turbidity or sediment, and therefore can only be indirectly estimated based on samples collected at MS Weares.

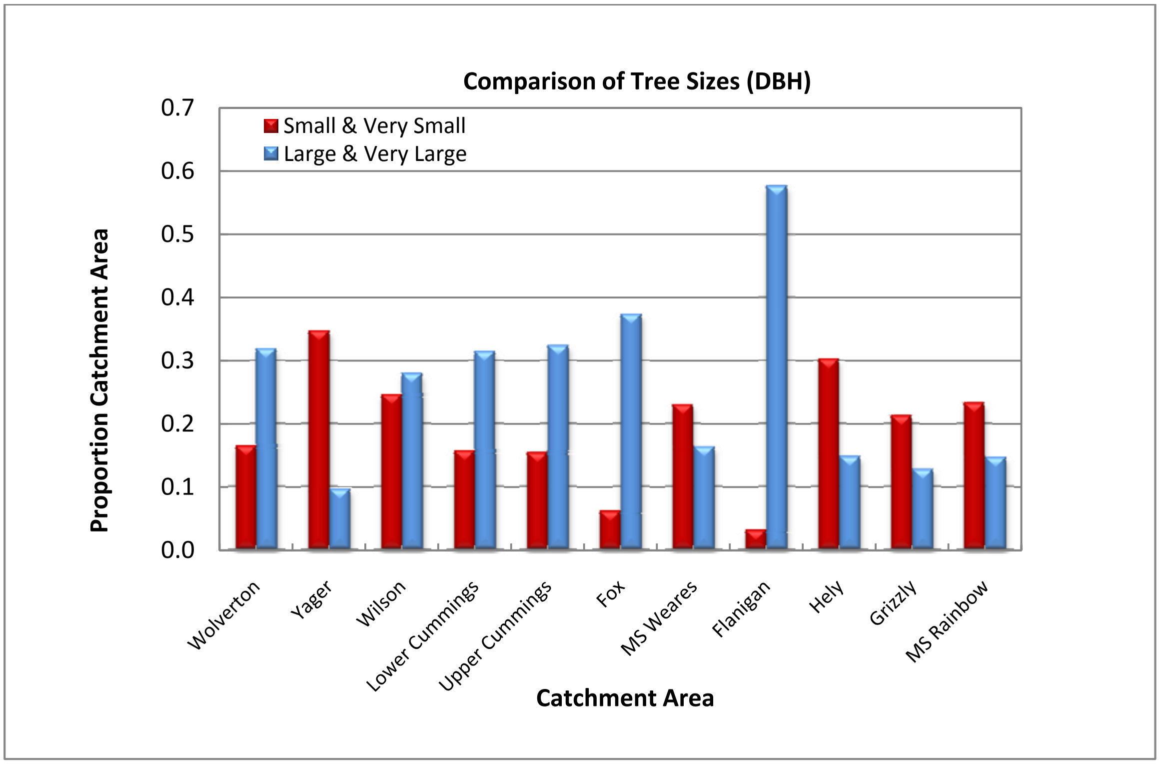

Figure 4-6. Tree sizes grouped into large versus small categories, presented as a proportion of each catchment area within the Lower Van Duzen River Basin in 1999.

As discussed with respect to planning watersheds (Chapter 3), vegetation interpreted from satellite imagery can also be used to derive proportion of tree sizes within a given distance of all streams within the lower basin, such as within a 90-meter buffer zone on each side of the streams (Table 4-3). For the most part, tree sizes in these buffer zones tend to reflect size frequencies throughout the catchment areas. Catchment buffer zones with the highest frequency of Very Large Trees were again Wolverton Gulch (30.4%) and Wilson Creek (20.8%). The area with the highest frequency of Large Trees in the buffer zones was again Flanigan Creek (56.1%), followed by Fox Creek (35.1%), and Upper Cummings Creek (25.3%). Similar to total catchment areas, the highest frequency of Medium-Large Trees in the 90-meter stream buffer zones was registered for Fox Creek (54.9%), followed by Hely Creek (53.5%), and Upper Cummings Creek (51.1%).

It is noteworthy that in all cases, Lower Cummings Creek catchment area registered lower frequencies of large trees than Upper Cummings Creek, indicating that timber harvest has undoubtedly been more intense in the lower part of the watershed than in the upper part. It is also interesting that, similar to results registered for planning watersheds, frequencies of larger trees is higher within the 90-meter buffer zones around streams (Table 4-3) than out on the surrounding hillsides, as represented by the data on total catchment areas (Table 4-2). This differential again confirms some degree of observance of riparian zone no cut buffers as directed by State of California agencies.

Table 4-3. Categories of tree size (DBH) within 90 meters of streams at 1:24,000 scale, presented as a proportion of each catchment area within the Lower Van Duzen River Basin (Imagery obtained from USFS 1999). [1]

	Proportion of Watershed 90-m Buffer Zone			
Catchment Area	Giant Trees	Very Large Trees	Large Trees	Medium-Large Trees
Wolverton Gulch	0.058	0.304	0.118	0.246
Yager Creek	0.017	0.043	0.065	0.319
Wilson Creek	0.027	0.208	0.066	0.126
Lower Cummings	0.000	0.050	0.248	0.506
Upper Cummings	0.000	0.040	0.273	0.511
Fox Creek	0.000	0.000	0.351	0.549
MS Weares	0.016	0.026	0.126	0.366
Flanigan Creek	0.000	0.047	0.561	0.336
Hely Creek	0.000	0.008	0.115	0.535
Grizzly Creek	0.006	0.032	0.135	0.402
MS Rainbow Bridge	0.000	0.008	0.112	0.315
Average >>>	0.011	0.070	0.197	0.383
	Proportion of Watershed 90-m Buffer Zone			
Catchment Area	Small-Medium Trees	Small Trees	Saplings	Other (Grass, Ag., Urban)
Wolverton Gulch	0.131	0.070	0.029	0.045
Yager Creek	0.248	0.140	0.026	0.142
Wilson Creek	0.086	0.164	0.101	0.221
Lower Cummings	0.137	0.048	0.009	0.001
Upper Cummings	0.114	0.050	0.010	0.001
Fox Creek	0.034	0.060	0.000	0.006
MS Weares	0.177	0.105	0.018	0.167
Flanigan Creek	0.000	0.036	0.000	0.019
Hely Creek	0.216	0.125	0.000	0.000
Grizzly Creek	0.176	0.092	0.011	0.145
MS Rainbow Bridge	0.199	0.119	0.020	0.228
Average >>>	0.138	0.092	0.020	0.089

[1] Giant Trees: > 50 Inches (DBH); Very Large: 40-50 Inches; Large: 30-40 Inches; Medium-Large: 20-30 Inches; Small-Medium: 12-20 Inches; Small: 5-12 Inches; Saplings: 1-5 Inches; Other: Grassland, Agriculture, Urban, Barren.

Landcover / Landuse

Using EPA satellite imagery data on landcover, provides a slightly different perspective on vegetation and overall conditions within the watersheds, such as vegetation types and rural or urban landuse (Table 4-4). Most of the developed land within the lower basin is concentrated around the towns of Alton, Hydesville, Carlotta (Hely Creek), and Bridgeville (MS Rainbow Bridge), and most land use is relegated to low density housing developments, especially in the outlying areas of Hydesville and Carlotta, where relatively new development is taking place. Much of this terrain is in the Wolverton and Barber Creek Planning Watersheds, and falls outside of the catchment areas (area in white of the lower-most stretches of the main stem, Figure 4-2). However, developments in and around Carlotta are within the Hely Creek catchment (1.8%) and Bridgeville is within the MS Rainbow Bridge catchment area (2.1%).

Table 4-4. Categories of Landcover/Landuse, presented as a proportion of each catchment area within the Lower Van Duzen River Basin (Imagery as Grid data from EPA 2001).

	Summary Statistics (Catchment Areas) - Proportion Land Use			
Catchment Area	**Developed, Open Space**	**Developed, Low Intensity**	**Barren**	**Deciduous**
Wolverton Gulch	0.001	0.000	0.000	0.058
Yager Creek	0.012	0.000	0.000	0.098
Wilson Creek	0.007	0.000	0.000	0.093
Lower Cummings	0.020	0.000	0.000	0.026
Upper Cummings	0.013	0.000	0.000	0.022
Fox Creek	0.000	0.000	0.000	0.009
MS Weares	0.017	0.001	0.006	0.051
Flanigan Creek	0.002	0.000	0.000	0.005
Hely Creek	0.018	0.000	0.000	0.006
Grizzly Creek	0.009	0.000	0.000	0.058
MS Rainbow Bridge	0.021	0.001	0.004	0.081
Average >>>	0.011	0.000	0.001	0.046
	Proportion of Watershed			
Catchment Area	**Conifer**	**Mixed Forest**	**Shrub/Scrub**	**Grassland**
Wolverton Gulch	0.763	0.073	0.062	0.026
Yager Creek	0.529	0.058	0.160	0.132
Wilson Creek	0.518	0.190	0.099	0.012
Lower Cummings	0.867	0.023	0.060	0.006
Upper Cummings	0.881	0.013	0.065	0.005
Fox Creek	0.929	0.027	0.035	0.000
MS Weares	0.667	0.039	0.090	0.122
Flanigan Creek	0.950	0.017	0.023	0.002
Hely Creek	0.942	0.011	0.019	0.004
Grizzly Creek	0.576	0.053	0.125	0.178
MS Rainbow Bridge	0.543	0.044	0.125	0.174
Average >>>	0.742	0.050	0.078	0.060

Catchment Area	Proportion of Watershed			
	Pasture	Cultivated	Woody Wetland	Herbaceous
Wolverton Gulch	0.015	0.000	0.000	0.000
Yager Creek	0.006	0.000	0.002	0.000
Wilson Creek	0.080	0.000	0.000	0.000
Lower Cummings	0.000	0.000	0.000	0.000
Upper Cummings	0.000	0.000	0.000	0.000
Fox Creek	0.000	0.000	0.000	0.000
MS Weares	0.000	0.000	0.000	0.000
Flanigan Creek	0.000	0.000	0.000	0.000
Hely Creek	0.000	0.000	0.000	0.000
Grizzly Creek	0.000	0.000	0.000	0.000
MS Rainbow Bridge	0.000	0.000	0.000	0.000
Average >>>	0.009	0.000	0.000	0.000

Similar to conditions noted in the discussion of planning watersheds, the majority of these catchment areas are dominated by coniferous forest throughout. However Yager Creek, Grizzly Creek, and MS Rainbow Bridge show a substantial amount of shrub land and grassland in their more elevated northern areas (Chapter 3, Figure 3-16). Variations in elevation were represented using grid elevation data provided through the USGS as digital elevation models (DEMs) (Chapter 3, Figure 3-17).

Canopy Cover

Other grid-based EPA data include the canopy cover data described in Chapter 3. Canopy cover data, modified for clear cuts was subdivided into units of 10, and then processed as proportion of each catchment area containing a given percentage of canopy cover (from 0 to 100% in 10% increments) (Table 4-5). From the table, it is easily observed that Flanigan Creek registers the highest proportion of 0% canopy cover of any of the catchment areas (44.8%), which is followed by Grizzly Creek (36.6%), and Yager Creek (28.9%). Grizzly Creek, and Yager Creek especially, have considerable areas of grass and grazing land in the upper northeastern parts, but Flanigan Creek is in the middle of the Redwood forest ecozone, with no natural grasslands within its boundary.

Flanigan registered the lowest total amount of canopy cover greater than 50% (51.3%), which was dramatically lower than most of the other catchment areas. Grizzly Creek and Yager Creek also registered low canopy cover at 50% or greater (51.8% and 52.0% respectively). All other catchment areas had roughly 60% or more of their areas in 50% or greater canopy cover. These initial results suggest that Flanigan Creek, which is relatively small in area and was originally nearly all redwood forest, is a watershed that is severely impaired. This impairment can be attributed primarily if not completely, to over-harvesting (Table 4-6). Grizzly Creek and Yager Creek have substantial grasslands that comprise their upland areas.

Table 4-5. Percentage Canopy Cover, presented as a proportion of each catchment area within the Lower Van Duzen River Basin (Imagery as Grid data obtained from EPA 2001).

	Proportion with Designated Percentage Canopy (Plus Clear Cuts 2001-2007)							
Catchment Area	**0%**	**1-50%**	**51 - 60%**	**61 - 70%**	**71 - 80%**	**81 - 90%**	**91 - 100%**	**Total > 50%**
Wolverton Gulch	0.159	0.111	0.067	0.093	0.181	0.309	0.080	0.730
Yager Creek	0.289	0.191	0.101	0.126	0.150	0.123	0.021	0.520
Wilson Creek	0.273	0.122	0.088	0.120	0.172	0.196	0.030	0.605
Lower Cummings	0.103	0.081	0.042	0.071	0.167	0.317	0.218	0.816
Upper Cummings	0.094	0.081	0.041	0.067	0.160	0.314	0.242	0.825
Fox Creek	0.185	0.059	0.040	0.093	0.244	0.329	0.050	0.756
MS Weares	0.240	0.099	0.056	0.105	0.190	0.252	0.058	0.661
Flanigan Creek	0.448	0.038	0.030	0.056	0.140	0.256	0.032	0.513
Hely Creek	0.100	0.012	0.022	0.087	0.211	0.412	0.156	0.888
Grizzly Creek	0.366	0.116	0.060	0.090	0.131	0.180	0.057	0.518
MS Rainbow	0.256	0.145	0.076	0.138	0.224	0.154	0.007	0.599
Average >>>	**0.229**	**0.096**	**0.057**	**0.095**	**0.179**	**0.258**	**0.086**	**0.676**

Timber Harvest

Summary statistics on timber harvest (silvicultural methods) from 1991 through 2007 (Table 4-6) show that Flanigan Creek experienced over 50% of its area harvested by clear cutting alone (56.0%), which was dramatically higher than the next three highest areas, Wolverton Gulch (34.5%), Wilson Creek (32.3%), and Fox Creek (28.9%).

Flanigan Creek is an anomaly with respect to most other areas, and is a watershed that is out of balance and out of proportion. This catchment area has the highest proportion of large trees and highest ratio of large to small trees than any other area, yet the smallest proportion of adequate canopy cover overall. These data suggest that Flanigan Creek is poorly forested and has an inadequate density of trees overall (barely 50%), but of those trees present, they are mostly very large, suggesting there are insufficient densities of smaller replacement trees. Where these should be, there is only bare ground resulting from over harvesting of forest stock. Flanigan is typical of these small watersheds along the main stem of the Van Duzen River and those within the Redwood Forest ecozone along the Lawrence Creek sub basin, as discussed in Chapter 3. Some of these other watersheds in severe jeopardy include Hely Creek, Fox Creek, Cummings Creek, Wolverton Gulch, Cooper Mill Creek, Blanton Creek, Corner Creek, and Shaw Creek. These watersheds that drain into these streams need time to recover, and their associated forests need time to mature for the benefit of the streams and the associated hillsides.

In terms of total area harvested, the most severely impaired catchment area is again Flanigan Creek with 126% of its area harvested in the 17 year period from 1991 through 2007 (Table 4-6). Other severely impacted areas include Upper Cummings Creek (110%), Hely Creek (85%), and

Fox Creek (72%). Several of the other impaired watersheds listed above (Cooper Mill Creek, Blanton Creek, Corner Creek, and Shaw Creek) are contained within the Yager Creek catchment area, which because of the influence of the grazing lands to the east appears as only moderately impacted by timber harvest (27%).

Table 4-6. Categories of the nine most used silvicultural methods, presented as a proportion of each catchment area within the Lower Van Duzen River Basin from 1991-2007 (California Department of Forestry).

	Proportion of Catchment Areas with Designated Harvest Method				
Catchment Area	Alternative Prescription	Clear Cuts	Commercial Thin	Group Selection	Shelterwood Prep Cut
Wolverton Gulch	0.119	0.345	0.049	0.000	0.000
Yager Creek	0.017	0.063	0.035	0.012	0.000
Wilson Creek	0.036	0.323	0.007	0.000	0.000
Lower Cummings	0.072	0.134	0.245	0.006	0.000
Upper Cummings	0.076	0.106	0.256	0.000	0.000
Fox Creek	0.131	0.289	0.085	0.007	0.123
MS Weares	0.011	0.099	0.122	0.027	0.002
Flanigan Creek	0.000	0.560	0.421	0.000	0.005
Hely Creek	0.000	0.104	0.458	0.059	0.001
Grizzly Creek	0.017	0.177	0.064	0.008	0.000
MS Rainbow	0.004	0.035	0.054	0.055	0.000
Average >>>	**0.044**	**0.203**	**0.163**	**0.016**	**0.012**
	Proportion of Catchment Area				
Catchment Area	**Shelterwood Removal**	**Selection**	**Seed Tree Removal**	**Variable Retention**	**TOTAL [1]**
Wolverton Gulch	0.000	0.298	0.000	0.000	0.822
Yager Creek	0.023	0.047	0.067	0.000	0.268
Wilson Creek	0.000	0.062	0.000	0.000	0.428
Lower Cummings	0.020	0.313	0.068	0.168	1.095
Upper Cummings	0.023	0.309	0.077	0.180	1.101
Fox Creek	0.000	0.049	0.000	0.000	0.718
MS Weares	0.052	0.131	0.010	0.010	0.485
Flanigan Creek	0.000	0.246	0.000	0.000	1.259
Hely Creek	0.000	0.134	0.002	0.016	0.847
Grizzly Creek	0.018	0.108	0.032	0.004	0.434
MS Rainbow	0.103	0.173	0.002	0.000	0.427
Average >>>	**0.022**	**0.170**	**0.023**	**0.034**	**0.717**

Some of these catchment areas have experienced excessively high frequencies of clear cutting relative to other more ecologically sustainable methods, such as selection (Figure 4-7) or multi-aged harvest (Berrill & O'Hara 2003). This figure shows the degree to which Flanigan Creek, as well as Fox Creek, Wilson Creek, and Wolverton Gulch, and to a lesser extent Grizzly Creek have been subjected to clear cutting practices over the 17 year period. Clear cutting, especially when accompanied by tractor yarding methods, has been associated with greater rates of sedimentation of the streams (Moring 1982, Swanson et al. 1987, Bons 1990, Anon. 1993, Ziemer 1992, 2000, Ziemer et al. 1998, Lewis & Keppelar 2007, Lewis et al. 2001) and also disrupts the opportunity for natural succession, which normally contributes to the stability of the watershed and the lower basin as a whole. Natural succession leads to balanced size classes within the forest ecological zone, reduced erosion and sedimentation rates (thereby elevated water quality), and healthier streams and salmonid populations.

All of the data reviewed to this point (especially canopy cover and timber harvest methods (i.e., silviculture) strongly indicate that several of these watersheds are in a state of extensive impairment. Digital timber harvest data provided by CDF includes all of these attributes within the same dataset. As clear cutting can be considered the most severe harvest method within a watershed, it could also be stated that tractor yarding methods have much greater impact on the land and give rise to higher sedimentation rates than other less severe methods such as helicopter or cable yarding methods. With that consideration, yarding methods were summarized for each catchment area in a similar manner to silvicultural harvest methods.

Results on yarding methods serve to substantiate earlier conclusions based on harvest methods, vegetation, and canopy cover, which indicate that Flanigan Creek has experienced the greatest degree of impairment of any other area within the lower basin, in that besides having the greatest frequency of clear cutting, it also registers the greatest frequency of area harvested by tractor (Table 4-7, Figure 4-8). Flanigan Creek had, by far and away, the highest proportion of its area harvested by tractor of any catchment area (101%) within the 17 year period of digitally recorded harvest plans. The high level of tractor yarding in Flanigan Creek was followed by Cummings Creek (83%) and Hely Creek (53%) a distant third. These data indicate that irrespective of silvicultural method, the most dominant yarding method from 1991 through 2007 in the lower basin (and probably universally) has been tractor based (Figure 4-8). Catchment areas in which tractor yarding dominates timber harvest methods include Flanigan Creek, Cummings Creek, Hely Creek, Fox Creek, Wolverton Gulch, and the main stem Van Duzen River (which includes Root Creek). These watersheds, along with several in the Lawrence Creek sub basin (Yager catchment area) have also experienced the most intensive logging activity in the lower basin.

Timber harvest records show that clear cutting is directly associated with tractor yarding methods, therefore indicating these two methods are co-related. It is, however, unfortunate that these two most ecologically damaging methods should also be the most frequent throughout the lower basin (Figures 4-7 & 4-8). If timber harvesting is to approach any degree of sustainability, methods such as clear cutting and tractor yarding must be eliminated from future activities. These methods intensely debilitate the capacity of watersheds to withstand the impact of timber harvest on the landscape and its effects on the integrity of streams. Moreover, the rates of timber harvest, as presented in the data, are far too great (e.g., more than 100% in 17 years in some watersheds) to facilitate a sustainable timber equilibrium into the future.

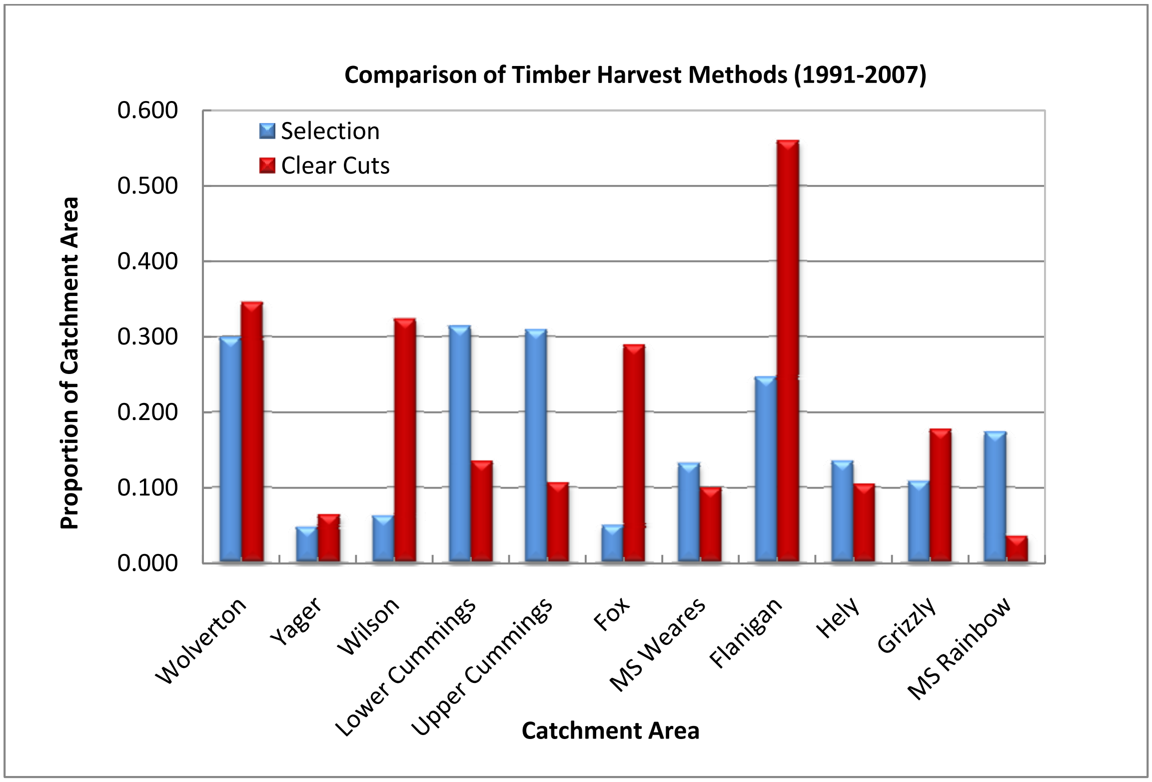

Figure 4-7. Comparison of Clear Cuts versus Selection silvicultural methods of timber harvest, presented as a proportion of each catchment area within the Lower Van Duzen River Basin from 1991 – 2007 (CDF).

Table 4-7. Categories of yarding methods, presented as a proportion of each catchment area within the Lower Van Duzen River Basin from 1991-2007 (California Department of Forestry).

	Proportion of Catchment Areas with Designated Yarding Method				
Catchment Area	**Balloon/ Helicopter**	**Cable/ Helicopter**	**Cable System**	**Cable/ Tractor**	**Tractor/ Cable**
Wolverton Gulch	0.038	0.108	0.248	0.000	0.080
Yager Creek	0.002	0.006	0.027	0.004	0.053
Wilson Creek	0.000	0.001	0.264	0.000	0.089
Lower Cummings	0.013	0.004	0.255	0.071	0.069
Upper Cummings	0.010	0.001	0.267	0.074	0.064
Fox Creek	0.050	0.003	0.092	0.006	0.051
MS Weares	0.039	0.016	0.087	0.015	0.069
Flanigan Creek	0.050	0.138	0.075	0.022	0.259
Hely Creek	0.086	0.086	0.152	0.056	0.120
Grizzly Creek	0.040	0.004	0.137	0.003	0.072
MS Rainbow	0.003	0.000	0.025	0.016	0.057
Average >>>	**0.030**	**0.033**	**0.148**	**0.024**	**0.089**

Table 4-7 (continued). Categories of yarding methods, presented as a proportion of each catchment area within the Lower Van Duzen River Basin from 1991-2007 (California Department of Forestry).

Catchment Area	Proportion of Catchment Area				
	Tractor/ Helicopter	Tractor/ Skidder	Total [1]	Cable or Helicopter	Tractor Related
Wolverton Gulch	0.049	0.299	0.822	0.393	0.428
Yager Creek	0.007	0.175	0.275	0.035	0.240
Wilson Creek	0.001	0.073	0.428	0.265	0.163
Lower Cummings	0.034	0.656	1.102	0.273	0.829
Upper Cummings	0.024	0.670	1.110	0.279	0.831
Fox Creek	0.084	0.356	0.642	0.145	0.497
MS Weares	0.006	0.260	0.492	0.142	0.351
Flanigan Creek	0.173	0.557	1.275	0.264	1.011
Hely Creek	0.003	0.354	0.858	0.325	0.533
Grizzly Creek	0.000	0.178	0.435	0.181	0.254
MS Rainbow	0.000	0.346	0.447	0.027	0.420
Average >>>	**0.035**	**0.357**	**0.717**	**0.212**	**0.505**

[1] Unidentified areas (polygons) are assumed to be outside harvest zone, and are not shown in the table (see Table 4-16 & Appendix 8-1).

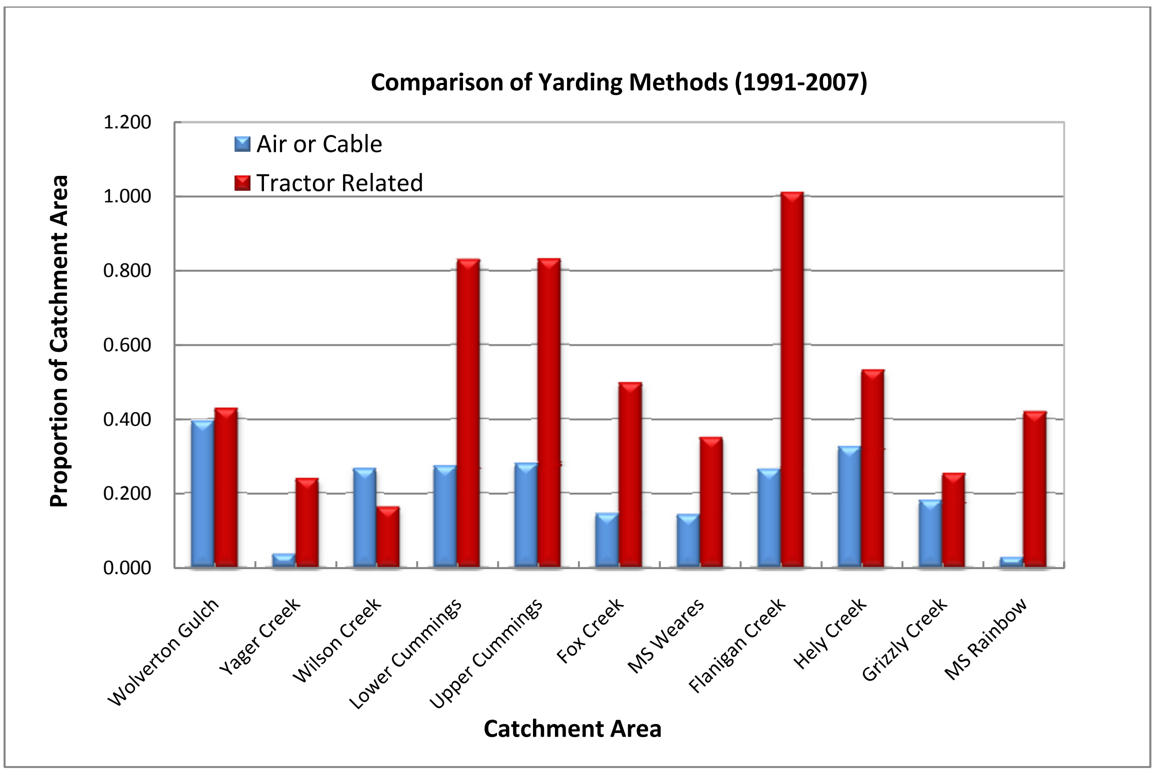

Figure 4-8. Comparison of Air/Cable versus Tractor Yarding methods, presented as a proportion of each catchment area within the Lower Van Duzen River Basin from 1991-2007 (CDF).

Geology

While considerable information has been published regarding the negative impacts timber harvest practices have on watershed integrity and water quality in streams (Moring 1982, Swanson et al. 1987, Bons 1990, Anon. 1993, Ziemer 1992, 2000, Ziemer et al. 1998, Lewis & Keppelar 2007, Lewis et al. 2001), when these activities interact with naturally problematic conditions, such as unstable geology and slope instability, these problems become magnified. Major geologic formations within the Lower Van Duzen River Basin as described by Irwin (1997) were delineated in Chapter 3 (Figure 3-18), and it has been well documented that certain geologic types are by their very nature, more unstable than other types.

The Bear River Beds contain volcanic ash of late Miocene or early Pliocene and may correlate to ash layers found in the bottom beds of the Wildcat Group exposed along the Van Duzen River. The sediments near the Bear River have mollusks that show the environment was a shelf or an inner slope and may indicate an early Pliocene regression (McLaughlin et al., 2000). The Pullen, Eel River, Rio Dell, Scotia Bluff Sandstones and Carlotta Formations are collectively known as the Wildcat Formation and are found along the Van Duzen River as well as the Wild Cat Ridge south of the town of Ferndale, Centerville Beach, Rio Dell and at the Scotia Bluffs as well as near Bridgeville (McLaughlin et al., 2000).

The Wildcat Group is characterized by sandstone and conglomerate and is believed to be relatively unstable compared to the contrasting Yager Formation (D. Heaton, personal communication). Landslides are a prevalent geologic hazard in the Wildcat Hills due in part to the steep, rugged topography, relatively high rainfall, unstable geological structure, and high rates of tectonic activity. Rocks in the Wildcat Group are prone to erosion and contribute to the high potential for landslides (HCRCD Salt River Restoration Project Draft EIR 2010). The Rio Dell Formation, in particular, is soft and erodible and landslides failures are common along the interface between beds of mudstone and sandstone. The areas comprised by these formations have been quantified and are presented as proportions within each catchment area of the lower basin (Table 4-8).

Wildcat and Yager formations are especially interesting in that they represent aspects of the stability spectrum, and as such, can be displayed graphically to represent the relative stability of each catchment area based on geologic type (Figure 4.9). A figure such as this makes is easy to distinguish between inherently stable versus unstable areas. Flanigan Creek, Fox Creek, and Wolverton Gulch are solely composed of Wildcat, and Hely Creek shows a preponderance of Wildcat over Yager formation geology. These four catchment areas are in contrast to the remaining areas that are dominated by Yager Formation. Ironically, the four areas dominated by the unstable Wildcat formation are also those areas that have been subjected to the most intense and ecologically debilitating logging methods.

However, given climatic requirements, coastal redwoods may very likely grow best and most vigorously in the Wildcat-Alluvial geologic-based soils along the main stem Van Duzen River, and up through much of the Lawrence Creek sub basin, thus creating a prescription for the impairment of these watersheds (i.e.,, the most desirable trees grow readily in the most geologically unstable terrain within the entire basin). Acknowledgement of this relationship makes it all the more imperative that timber harvest management in the redwood forest ecosystem must be especially cognizant of these unstable conditions, and that only the most environmentally compatible and thus the most ecologically sustainable practices be employed.

Table 4-8. Categories of geologic formations, presented as proportions of each catchment area within the Lower Van Duzen River Basin (Irwin 1997).

	Summary Statistics (Catchment Zones) - Proportion Geologic Types			
Catchment Zone	Catchment Number	AREA (sq. meters)	AREA (sq. miles)	Alluvial Deposits
Wolverton Gulch	1	4733491	1.828	0.000
Yager Creek	2	347492400	134.167	0.004
Wilson Creek	3	4570694	1.765	0.000
Lower Cummings	4	11824930	4.566	0.000
Upper Cummings	5	10419280	4.023	0.000
Fox Creek	6	2487554	0.960	0.000
MS Weares	7	167433900	64.646	0.000
Flanigan Creek	8	1687232	0.651	0.000
Hely Creek	9	9329660	3.602	0.000
Grizzly Creek	10	49107260	18.960	0.000
MS Rainbow Bridge	11	62645300	24.187	0.000
Average >>>		61066518	23.578	0.000

	Proportion of Watershed			
Catchment Zone	Carlotta Formation	Coastal Melange	Hookton Formation	Scotia Bluffs
Wolverton Gulch	0.189	0.000	0.105	0.281
Yager Creek	0.005	0.618	0.000	0.007
Wilson Creek	0.424	0.000	0.000	0.408
Lower Cummings	0.174	0.000	0.000	0.069
Upper Cummings	0.078	0.000	0.000	0.078
Fox Creek	0.163	0.000	0.000	0.000
MS Weares	0.006	0.359	0.000	0.000
Flanigan Creek	0.000	0.000	0.000	0.000
Hely Creek	0.000	0.000	0.000	0.000
Grizzly Creek	0.000	0.489	0.000	0.000
MS Rainbow Bridge	0.000	0.576	0.000	0.000
Average >>>	0.094	0.186	0.010	0.077

Catchment Zone	Proportion of Watershed			
	Upland Remnants	Wildcat Formation	Yager Formation	Younger Alluvium
Wolverton Gulch	0.000	0.425	0.000	0.000
Yager Creek	0.019	0.037	0.302	0.008
Wilson Creek	0.000	0.000	0.082	0.086
Lower Cummings	0.000	0.171	0.572	0.014
Upper Cummings	0.000	0.194	0.650	0.000
Fox Creek	0.000	0.837	0.000	0.000
MS Weares	0.001	0.281	0.349	0.004
Flanigan Creek	0.000	0.988	0.000	0.012
Hely Creek	0.000	0.650	0.350	0.000
Grizzly Creek	0.004	0.119	0.388	0.000
MS Rainbow Bridge	0.000	0.000	0.424	0.000
Average >>>	0.002	0.337	0.283	0.011

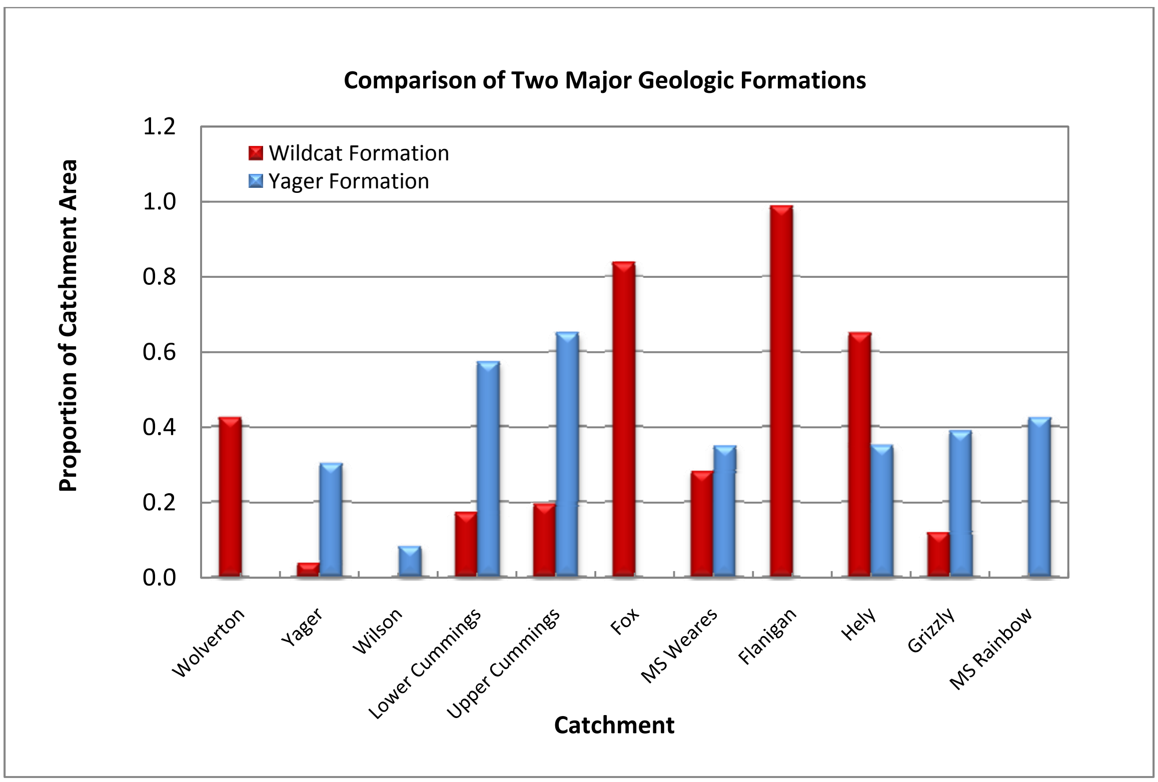

Figure 4-9. Comparison of two geologic formations, presented as proportions of each catchment area within the Lower Van Duzen River Basin (Irwin 1997).

Factors Affected by Watershed Impairment

Whenever the relative health of watersheds is considered in relation to upslope conditions, questions of causality inevitably arise. In order to adequately address causality or even co-relationships, it is first necessary to satisfactorily establish the most useful dependent and independent variables within the watershed. Dependent variables are those that best represent perceived levels of impairment, and independent variables are those that most readily or most likely influence the dependent variables. Statistical analyses used in this study were accomplished using Microsoft Excel spreadsheet plots and databases, and JMP^{R}, a SAS statistical software package (SAS Institute 1985).

As most of the water quality data collected throughout the study area were based on grab samples, it was understood from the beginning that a satisfactory dependent variable would have to be derived using grab sample data. A variety of dependent variables were thus considered from grab sample data, including maximum annual turbidity, an average of the five highest annual turbidities, average turbidity throughout the hydrologic year, the slope of the turbidity-discharge function, the slope of the logn turbidity-discharge function, and estimated annual sediment loading.

Average Turbidity

Plotting various independent variables versus maximum turbidity or average of the five maximum turbidities for a given stream produced no useful correlations. However, calculating average turbidity over the sampling season (Figure 4-10) for each monitoring site provided a useful dependent variable upon which several correlations were developed. The sampling season for HY07 ran from 15 November through the end of April, and in HY08 ran from 15 October through the end of April. However, in HY07, several volunteers terminated sampling on or near 12 April and in HY08 on or near 15 March, and thus in order to justify comparison of all average turbidity records, data from all of the monitoring sites could only be used through these dates for each season.

While the timing and frequency of samples varied depending on each volunteer, the beginning and end dates for average turbidity readings were controllable. Using average turbidity has the added advantage to absorb some degree of experimental error introduced by the occasional missing of peak turbidity during a storm event, especially for grab samples where it is easy to miss the peak discharge (and thus turbidity) of a storm. Average turbidity also seems to provide a more complete representation of stream behavior over the course of a hydrologic season than does using a maximum turbidity reading, thus these metrics were calculated for all monitoring sites during HY07 and HY08 (Figure 4-11).

Statistics were generated for each monitoring site during each hydrologic year and the two hydrologic years combined. Average turbidity data were used as the dependent variable in numerous regression analyses and indicated several significant as well as some non-significant relationships. Independent variables included road density, road-stream crossing density, density of roads on steep slopes (> 30%), area of timber harvest in general, area of timber harvest as clear cuts, area of timber harvest based on yarding method, and geology.

One of the most profound lessons learned from this study is how difficult it is to demonstrate relationships between dependent and independent variables when analyzing environmental data, which can exhibit extreme variability, noise (conflicting and interfering factors), and susceptibility to experimental and sampling error. An example of the inherent difficulty of using environmental data is road density. Road densities are extremely high in all of the catchment areas throughout the Lower Van Duzen River Basin (Figure 4-4), making it very difficult to show a statistically significant effect of roads on water quality. The effects of high road densities also tend to interfere with the effects of other independent variables, which in isolation could be shown to have significant or more significant effects on water quality than they do.

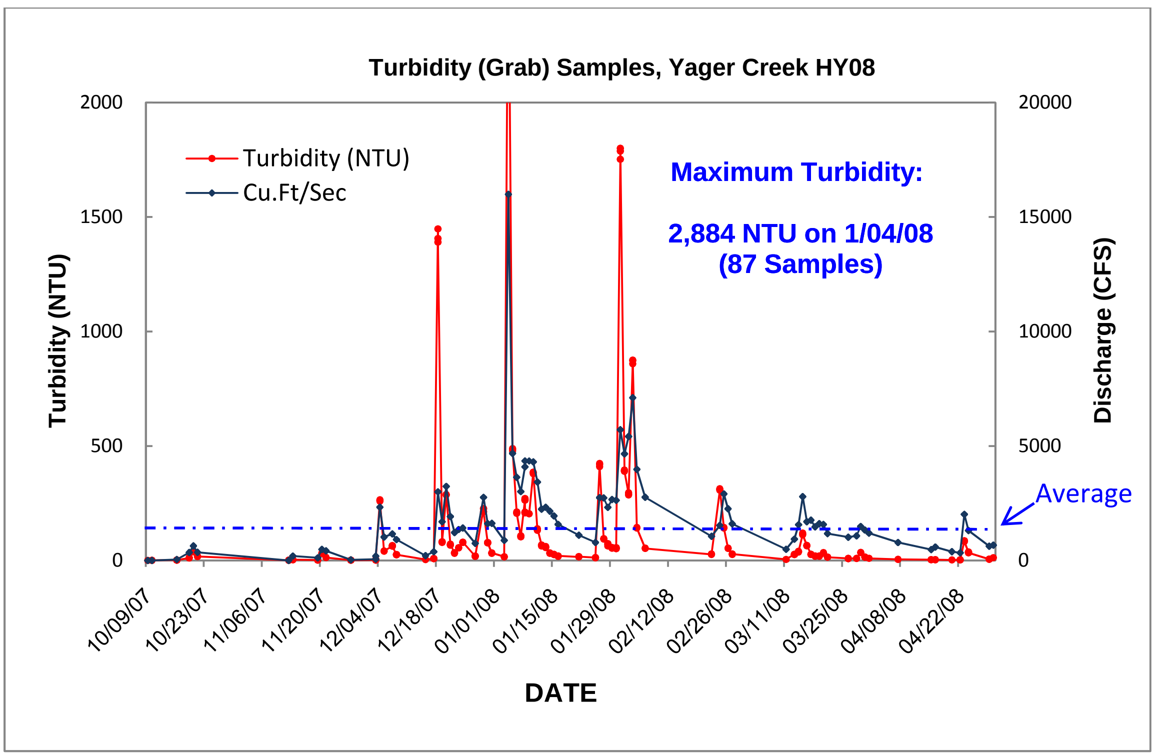

Figure 4-10. Grab samples for Yager Creek during HY08, showing average turbidity.

Considerable variation occurred in average turbidity between the different monitoring sites and between the two sampling seasons (Figure 4-11). With the exception of Wolverton Gulch, average turbidities were higher in HY08 than in HY07. While most likely a true reflection of annual variation, this trend in part, may have been accentuated due to 1) increased sampling efficacy in the second year, 2) a greater focus on sampling storm events in HY08.

The most dramatic increases from HY07 to HY08 occurred at Cummings Creek, MS Weares, Flanigan Creek, and Hely Creek, and to a lesser extent, Grizzly Creek and MS Rainbow. Wolverton Gulch and Yager Creek showed no net change between the two years. Whether the above results reflect actual conditions or sampling error cannot be determined. However, in general, some of the streams consistently showed higher turbidities than others (Table 4-9). The stream with the highest average turbidity (NTU) over the two-year sampling period was Flanigan Creek (224), followed by Fox Creek (196), Wolverton Gulch (183), and Hely Creek (167). The stream with the lowest average turbidity over the two-year period was Wilson Creek (106).

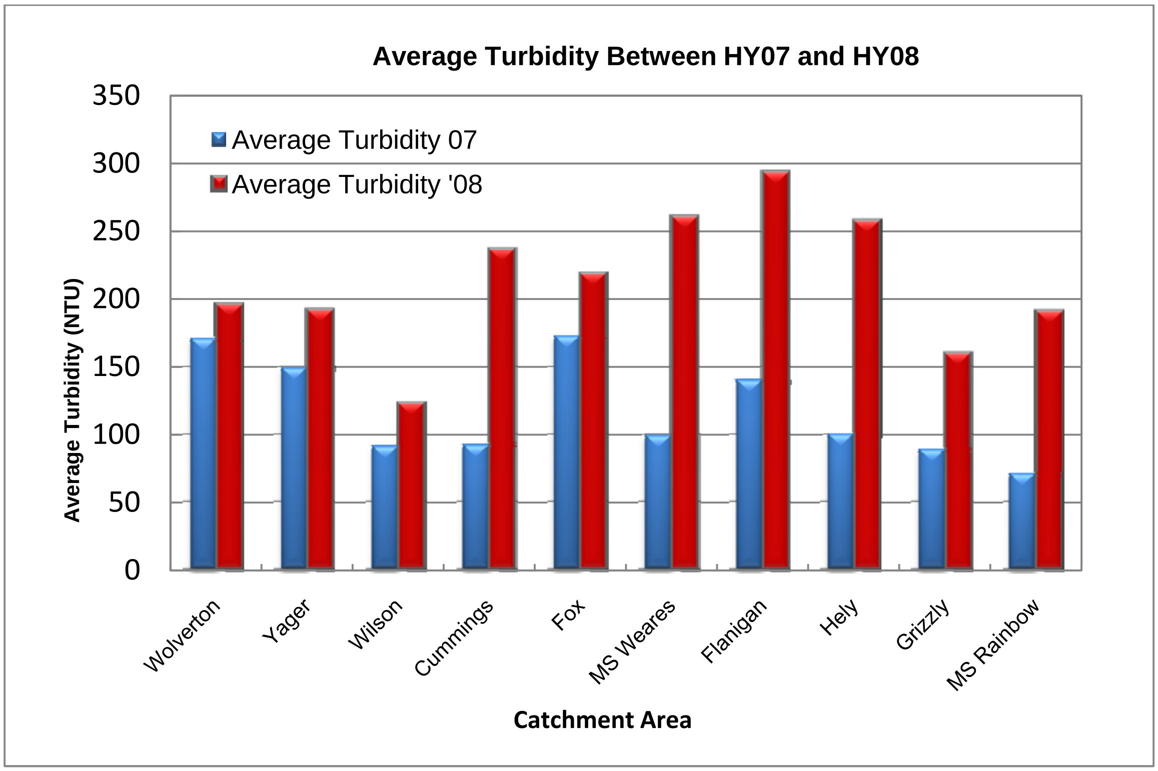

Figure 4-11. Comparison of average turbidity between HY07 and HY08 among 10 monitoring sites within the Lower Van Duzen River Basin. Lower Cummings was not sampled in HY07.

Calculations of average turbidity elucidated several problems and inconsistencies with the grab sample data. Primarily, data from HY08 especially, showed Wilson Creek and Lower Cummings Creek to have been inadequately sampled to provide usable data. Both of these sites were sampled infrequently and inconsistently, causing most of the peaks in turbidity to be missed. While missing a turbidity peak could be absorbed to some extent, the turbidity peaks at these sites were missed in a dramatic fashion, causing the averages to be substantially off. The same volunteer sampled each of these creeks at nearly the same time of day (on the way to work in the morning) throughout the season, and was not able to sample very often.

Table 4-9. Summary statistics on water quality indices for 11 monitoring sites within the Lower Van Duzen River Basin.

	Summary Statistics (Catchment Zones)				
NAME	Maximum Discharge (CFS) HY07	Average Discharge (CFS) HY07	Maximum Discharge (CFS) HY08	Average Discharge (CFS) HY08	Maximum Discharge HY07 - HY08
Wolverton	201	18	101	17	201
Yager	7,426	2,023	15,990	2,147	15,990
Wilson	95	18	175	34	174
Lower Cummings			144	47	
Upper Cummings	239	30	1115	132	1115
Fox	105	13	113	19	113
MS Weares	8,420	1,394	24,662	2,495	24,662
Flanigan	14	5	80	12	80
Hely	194	49	231	42	231
Grizzly	1051	196	1937	236	1937
MS Rainbow	6,930	1,396	20,600	1,861	20,600
NAME	Aver Discharge (CFS) HY07-08	Max Turbidity (NTU) HY07	Average Turbidity (NTU) HY07	Max Turbidity (NTU) HY08	Average Turbidity (NTU) HY08
Wolverton	17	2,385	171	2,496	196
Yager	2,085	1,392	149	2,884	192
Wilson	26	709	91	734	123
Lower Cummings				1,360	148
Upper Cummings	62	852	92	2,380	237
Fox	19	1,596	173	2,972	219
MS Weares	1,844	1,576	99	3,888	261
Flanigan	9	1,218	140	3,036	294
Hely	46	1,000	100	3,628	258
Grizzly	221	1,000	87	3,220	160
MS Rainbow	1,650	820	71	2,826	191
NAME	Max Turbidity HY07 - HY08	Average Turbidity HY07-HY08	Sediment (tons/mile^2/yr) HY07	Sediment (tons/mile^2/yr) HY08	Sediment (tons/ mile$^{2/}$yr) HY07-08
Wolverton	2,496	183	978	1354	1168
Yager	2,884	171	622	966	794
Wilson	734	106	537	875	706
Lower Cummings			NA	NA	NA
Upper Cummings	2,380	139	636	1975	1306
Fox	2,972	196	1066	1631	1350
MS Weares	3,888	167	374	1187	780
Flanigan	3,036	224	1240	3149	2197
Hely	3,628	167	666	2077	1373
Grizzly	3,220	133	579	1261	922
MS Rainbow	2,826	136	330	1079	706

Missing enough peak turbidities and by wide enough margins, could cause the calculation of average turbidity to be artificially low, and thus not representative of the true conditions in the stream. Review of the data allowed this situation to be easily recognized for Lower Cummings Creek (HY08). In all cases, both discharge and turbidity recorded values were lower at Lower Cummings than at Upper Cummings (Table 4-9), which is very unlikely, given that streams increase in discharge and turbidity, and collect more water and sediment from the hillsides, as they move from higher elevations to lower elevations. Therefore, values of discharge and turbidity should be higher at the lower monitoring site than at the higher monitoring site. Discharge and turbidity (as well as estimated suspended sediment) data from Cummings Creek shows the opposite effect, indicating that it was probably insufficiently sampled. Moreover, as Lower Cummings Creek was only sampled in HY08, it was decided to exclude these data, as well as the poorly sampled Wilson Creek data from the regression analysis. All regression analyses were run on turbidity averaged over two sampling seasons combined (HY07 - HY08).

Effects of Road and Road-Stream Crossing Densities

As referenced earlier, road densities were classified as extremely high in all catchment areas (Table 4-1), and there was no significant effect of roads on turbidity in the 11 catchment areas of the lower basin. Lack of significant effects are most likely because road densities, especially relating timber harvest, are high in all samples. Any effect of roads becomes swamped in a correlation type of analysis, thus making it highly unlikely that any differences or significant effects will emerge. Without sufficient variation within the population of the independent variable, obviously no significant effects will be detected, as can be seen in the road density function described by the linear equation (Table 4-10), which was not statistically significant. In other words, you need low densities as well as high densities within the study area in order to show an effect. In our study there were no low road densities. Likewise, there was no significant effect of roads on steep slopes (> 30%) on average turbidity.

Analysis of road-stream crossings showed a significant effect on turbidity. While the function described by the linear equation ($R^2 = 0.63$) is statistically significant ($P < 0.01$), the distribution of the data points is not uniform and suggests that it may be a poor fit of the dat. With the exception of the two highest turbidity values (Flanigan Creek and Fox Creek), the other data points are highly clumped, suggesting no significant differences in the effect of road-stream crossing density on turbidity at these seven stream sites given the level of variation available within the lower basin.

The relationship described above reflects the difficulty in demonstrating the effect of independent environmental variables that do not exhibit sufficient variability within the study area. Conditions in small streams may more easily or at least, more quickly reflect the impact of external factors on their relative condition, than do larger streams that drain larger catchment areas, which may also be more susceptible to external factors and noise. This phenomenon or relationship between the different monitoring sites reoccurs consistently throughout the analysis of factors that affect average turbidity.

Because of a dramatic lack of variability in a number of independent variables (e.g., road density), and because all of the catchment areas are undoubtedly severely impaired, it is difficult to observe any distinct effects of external factors on water quality in the Lower Van Duzen River Basin. In order to demonstrate statistically significant effects, it would be necessary to have at least one or several pristine watersheds, which do not exist in the lower basin. Environmental noise inherent in the system, as well as the limited variation in the dependent and independent variables make it difficult to tease apart any real effects that these factors play in affecting water quality. It is clear, however, that salmonid populations have experienced precipitous declines over the last 40-50 years, and that degradation of habitat in the freshwater system is undoubtedly the primary reason for this decline. Yet it is often difficult to show cause and effect.

Table 4-10. Results of simple linear regression of seven separate independent variables on Average Turbidity (NTU) at nine monitoring sites within the Lower Van Duzen River Basin for the combined years of HY07 & HY08.

	Linear Regression: Average Turbidity HY07 & HY08				
Independent Variable	**Slope**	**Intercept**	**F**	**P**	**R^2**
Road Density (mi per square mi)	7.80	110.69	0.81	0.3988	0.10
Stream Crossings (per stream mile)	21.95	123.97	11.88	0.0107	0.63
Proportion Timber Harvest (ALL)	43.70	137.56	2.14	0.1870	0.23
Proportion of Only Clear Cuts (CC)	143.33	140.13	13.68	0.0077	0.66
Tractor Yarding in Clear Cuts (TC)	173.81	145.31	13.76	0.0076	0.66
Proportion Wildcat Formation (WC)	71.07	140.56	17.62	0.0040	0.72
Proportion Yager Terrane (YG)	19.17	199.41	19.17	0.0032	0.73

Effects of Timber Harvest – Silviculture and Yarding Methods

Plotting average turbidity as a function of all timber harvest methods combined was not a significant ($P < 0.05$) effect, and produced a relatively loose relationship (Table 4-10, Figure 4-12). These data include the proportion of each catchment area in which all methods of timber harvest (from selection to clear cutting) occurred from 1991 through 2007. A loose distribution of points ($R^2 = 0.23$) led to reselecting the areas and calculating the proportional area of individual silvicultural methods, in order to tease out specific effects that could have more specific impacts on turbidity. A more significant effect was observed for the clear cutting method (Table 4-10, Figure 4-13) which produced a significant effect ($P < 0.0077$) and a relatively clear association of data points ($R^2 = 0.66$). This function however, is subject to the same problems described earlier, including lack of variability, sampling error, and environmental noise. Sampling error is especially applicable to these data, as several problems at Grizzly Creek during HY08 may have had an undue influence on the results.

Grizzly Creek runs very muddy during storm events, but peaks and falls very quickly. Grab sampling of this stream in HY08 was done by a new volunteer who sampled primarily on the way home from work. Although this volunteer actually collected more samples than his predecessor, the format for sampling at the same time each day probably caused several peaks to be missed (in particular, January 4 and January 31), during which extremely high turbidities were registered in other streams. Missing the peaks at Grizzly Creek undoubtedly resulted in a lower overall estimate of average turbidity than that which, in all probability, actually occurred.

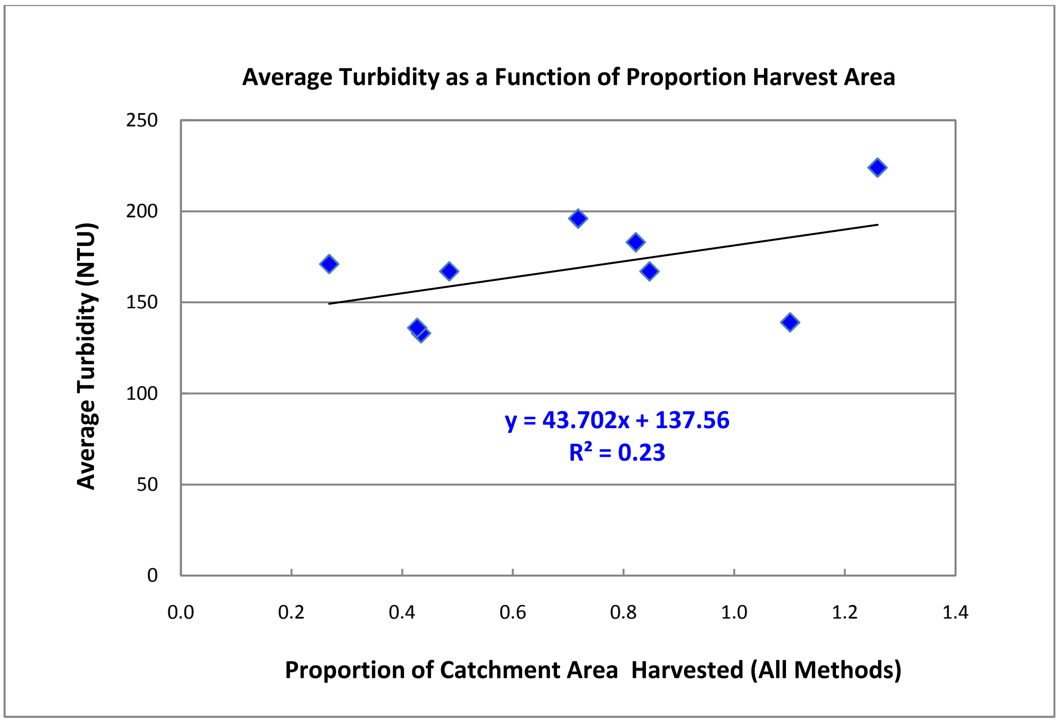

Figure 4-12. Potential effect of proportion timber harvest (all methods) on average turbidity in the Lower Van Duzen River Basin for the combined years of HY07 & HY08.

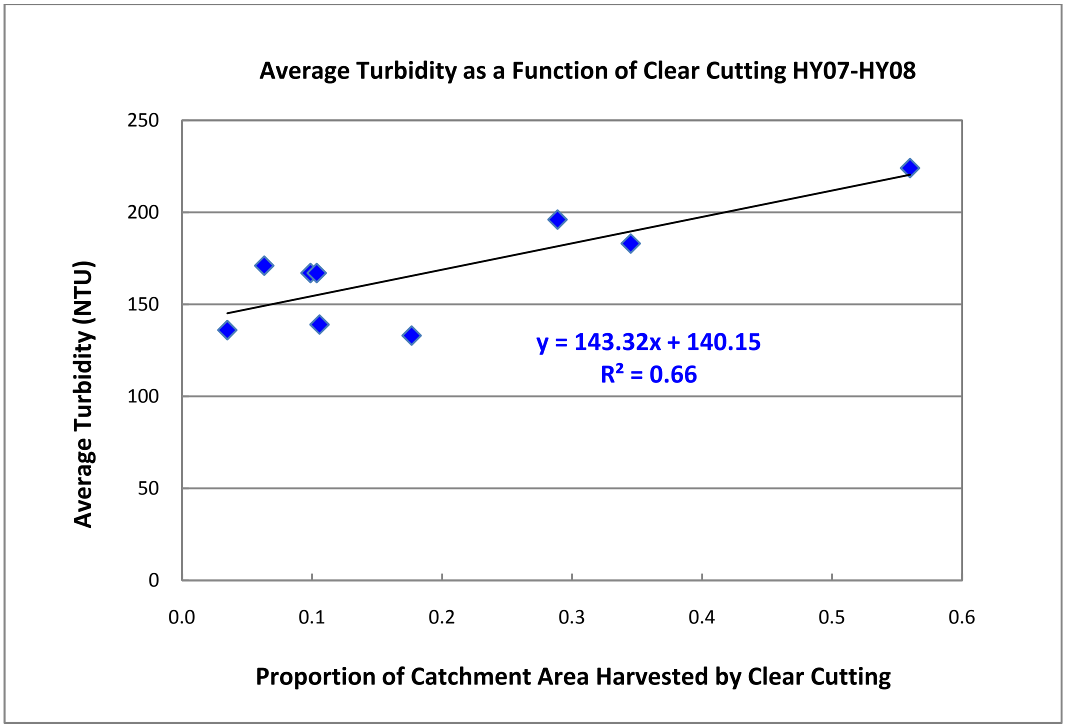

Figure 4-13. Potential effect of proportion clear cutting on average turbidity in the Lower Van Duzen River Basin for the combined years of HY07 & HY08.

Moreover, the volunteer noticed that there was considerable runoff from Highway 36 into Grizzly Creek at the time the sample was taken, which could have resulted in a dilution of the sample, as the runoff was probably pure rainwater. Unfortunately, the volunteer failed to consider sampling upstream of the runoff entry point, thus contributing even more error into these suspect data. The average turbidities recorded for Grizzly Creek were substantially lower than would have been predicted, given the timber harvest activity in the upper watershed, and the muddiness regularly observed in the stream.

The type of yarding practices used in timber harvest, tractor yarding in particular, was also analyzed for a potential impact on average turbidity (Table 4-10). A significant positive effect ($P < 0.008$) and a reasonably good fit ($R^2 = 0.66$) was observed between the proportion of tractor yarding during clear cuts and the average level of turbidity in the streams. It should be noted that this variable is generated from only tractor yarding used during clear cuts. Tractor yarding used for all THP methods was not significant ($\alpha < 0.05$). This is not to say that it has no effect, but just that only a small effect was detected in this analysis ($R^2 = 0.21$).

Effects of Geology

Digital spatial data on geology of the Lower Van Duzen River Basin was obtained from several sources. One source in particular (Irwin 1997) provided a useful representation of the major geologic formations within the lower basin, and these data are included in the GIS (ArcMap) data base accompanying this project. Geologic formations of special interest include the Wildcat Group, which is generally composed of friable mudstone, siltstone, and sandstone (Ogle 1953), and is therefore considered to be relatively unstable, especially when compared to the formation known as Yager terrane (D. Heaton, personal communication). Therefore, the proportions of Wildcat and Yager types were calculated for each catchment area, and their potential relationship with average turbidity was determined (Table 4-10). There was a positive correlation ($R^2 = 0.72$) between the proportion of wildcat geology and average turbidity (Figure 4-14), which was highly significant ($P < 0.004$), and a negative correlation ($R^2 = 0.73$) between the proportion of Yager Terrane and average turbidity (Table 4-10), which was also statistically significant ($P < 0.003$). The positive correlation between turbidity and proportion Wildcat geology and the negative correlation between turbidity and Yager terrane supports the likelihood that turbidity (translation sediment) increases in association with Wildcat and decreases in association with Yager terrane.

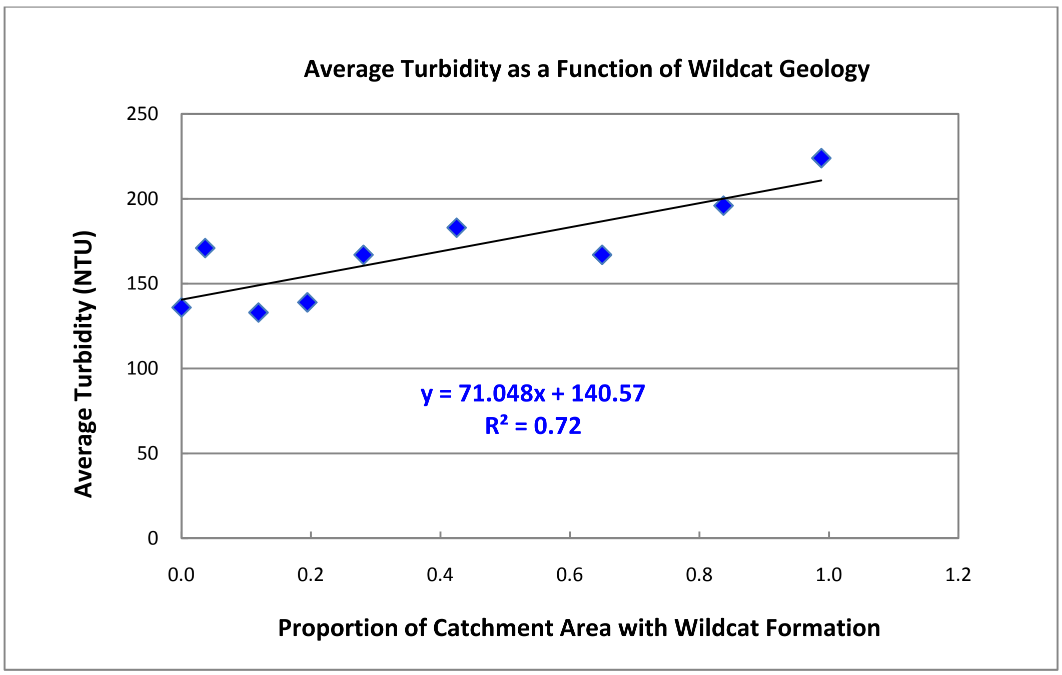

Figure 4-14. Potential effect of proportion of Wildcat Group formation on average turbidity in the Lower Van Duzen River Basin for the combined years of HY07 & HY08.

Multiple Effects

Two-way interactions were tested using multiple regression analysis of various functions for average turbidity. Significant interactions involving positive correlations with average turbidity were observed between proportion clear cuts, tractor yarding, and Wildcat geology, as seen in the following functions. Correlation between clear cutting and tractor yarding, which is operated primarily in clear cuts, is unavoidable. In this analysis, only the proportion of tractor yarding in clear cuts was used, further compounding the problem of correlation effects. However, framing the analysis in this way was the only means available to address the impact of tractor yarding in its most severe state. Simple linear regression of tractor yarding in clear cuts showed it to be the strongest human influence on water quality of streams in the lower basin (also see Table 4-11, sediment loading) and especially as it is most frequently associated with clear cutting. In all cases, the sample size represents the nine previously discussed catchment areas (n = 9).

Average turbidity (AT) as a function of Clear Cutting (CC) and Wildcat Geology (WC):

$$AT = 2.78\ WC - 31.02\ CC + 90.30\ CC \bullet WC + 144.98$$

$$F = 6.55,\ \ P < 0.0348,\ \ R^2 = 0.80$$

Average turbidity (AT) as a function of Clear Cutting (CC) and Tractor Yarding (TC) (CC and TC are correlated, and thus may be invalid due to tractor yarding in clear cuts):

$$AT = 79.49\ CC + 128.01\ TC - 69.13\ CC \bullet TC + 138.84$$

$$F = 3.91,\ \ P < 0.0879,\ \ R^2 = 0.70$$

Average turbidity (AT) as a function of Wildcat Geology (WC) and Tractor Yarding (TC):

$$AT = 39.74\ WC - 175.59\ TC + 244.43\ WC \bullet TC + 154.26$$

$$F = 5.83,\ \ P < 0.0435,\ \ R^2 = 0.78$$

Average turbidity (AT) as a function of Clear Cutting (CC), Wildcat Geology (WC), and Tractor Yarding (TC): Function # 1 (No Interaction)

$$AT = 59.61\ CC + 42.87\ WC + 17.95\ TC + 124.05$$

$$F = 5.75,\ \ P < 0.0447,\ \ R^2 = 0.78$$

Correlation between clear cutting and tractor yarding in clear cut areas led to an additional analysis that attempts to avoid the interaction between these two variables.

Average turbidity (AT) as a function of Clear Cutting (CC), Wildcat Geology (WC), and Tractor Yarding (TC): Function # 2 (No CC•TC Interaction)

$$AT = 21.05\ WC - 812.70\ CC + 1{,}210.96\ TC + 2{,}036.2\ WC{\bullet}CC - 2{,}545.20\ WC{\bullet}TC + 143.70$$

$$F = 4.06,\ \ P < 0.1393,\ \ R^2 = 0.87$$

The last function is not statistically significant, but is presented to show the higher level of fit ($R^2 = 0.87$) in the function describing the impact of the three independent variables and some of their interactions on average turbidity. This function also shows the problem with analyzing extensive interactions with a small sample size (9). As more interactions are added to the function, the degrees of freedom in the model are lost. This was also the case to an even greater extent for the full model (all two way and three-way interactions).

The above statistics show a significant positive effect of all three upslope variables on average turbidity, suggesting that these effects contribute to stream turbidity and support the individual effects observed earlier (Table 4-10). While correlations do not conclusively confer cause and effect, the relatively good fit of the function implicates these upslope factors in contributing to the increase in turbidity in the streams of the Lower Van Duzen River Basin. These results also give credibility to the two-year water quality monitoring program, that while experiencing problems, nonetheless provided useful information about the condition of these watersheds, as well as the factors that potentially affect these conditions.

Preliminary Recommendations

These analyses give strong support to the negative impacts of timber harvest, especially the effects of clear cutting and tractor yarding on stream habitat and watershed health. These results have added impact when natural geologic conditions are considered.

Long-term sediment production rates in the Pacific Northwest may, at the heart be geologic in nature and controlled by rates of tectonic uplift and shifting, which influence topography and mechanical properties of the bedrock. This geologic instability is therefore highly sensitive to land use (Ahnert 1970, Summerfield & Hulton 1994, Leeder 1991, Kramer et al. 2001), especially in the Lower Van Duzen River Basin. Timber harvest activities take on greater consequences in geologically unstable terrain, such as Wildcat formations. Therefore, it is extremely important that standard reviews of harvest plans (i.e., by the California Department of

Forestry) must (absolutely) be done with the knowledge, understanding, and consideration of natural conditions as they exist on the land. Harvest activities in unstable landscapes such as Wildcat geology should no longer be considered, especially on steep slopes, and clear cutting and tractor yarding must be eliminated in all areas of the Pacific Northwest, not just the Lower Van Duzen River Basin.

All of these conditions that signal severe impairment of the watersheds can be directly attributed to increased turbidity, which is caused by increased siltation and sedimentation that to a significant level can be linked to over harvesting of timber stands within the lower basin. Years of over harvest have led to dramatic increases in stream temperatures, degradation of stream habitat, and precipitous declines in salmon populations. More than any remediation measures, these watersheds need to be left alone for an extended period of time and allowed to rest. Healthy forests and stream habitats will regenerate, but only if allowed sufficient time, and only if left alone long enough for these natural processes to take place.

Turbidity-Discharge Function

Potentially useful indices of stream impairment and relative turbidity might be to calculate the slope of a straight line fitted through the data created by plotting turbidity (NTU) versus discharge (CFS). When these data are plotted for all catchment areas, the slopes can potentially be used as a dependent variable in regression analyses of upslope conditions. However plotting raw data for this function gives much greater weight to small streams over large streams, as small streams can reach high levels of turbidity at relatively low rates of discharge. Plotting very low discharge rates produces much steeper slopes in small streams relative to large streams with similar turbidity levels. Therefore the slope of turbidity-discharge function was abandoned as an index of water quality.

Another potential index of water quality is the linear slope of logn turbidity plotted versus logn discharge. In some cases this plot produces a cloud of data points and relatively good fit of the function, but in others, produces very loose and dispersed scattering of points. Poor distribution of the transformed data may relate to stream conditions, or sampler efficacy and sampling error. Whatever the causes, the slope of this function proved to be of little use as a dependent variable for describing the impact of the upslope conditions on water quality, and no significant effects could be demonstrated.

Moreover, using the slope of the logn relationship is that it tends to error in the opposite direction of the raw turbidity-discharge slope. Log data tend to quench discharge effects and the levels of turbidity in small streams, thereby making it difficult to distinguish one stream from another, as well as appearing to give greater weight to larger streams over smaller streams. It is often the smaller streams that show a greater and faster response to the effects of sedimentation (i.e., turbidity), and may in fact be better indicators of how upslope conditions affect water quality. Therefore use of the logn turbidity-logn discharge function was also abandoned.

Annual Sediment Load

Another dependent variable used to test the effects of various upslope conditions on water quality was the estimation of annual sediment load, with units in tons per square mile catchment area (Table 4-9). Calculation of annual sediment loading per unit area was based on a comparison with sediment loads calculated for Cummings Creek at the TTS station, and modified based on sediment-turbidity ratios and relative size of the watersheds. The same independent variables used in the previous analyses were tested for single and multiple effects on annual sediment loads averaged over hydrologic years 2007 and 2008. Single linear effects were tested for road density, road-stream crossing density, proportion timber harvest in general and clear cutting and tractor yarding in particular, and proportion Wildcat and Yager types as representing variation in the effects of geologic stability.

Estimating annual loads per unit area over the sampling season for each monitoring site provided a useful dependent variable upon which correlations were developed similar to those tested on average turbidity. Using annual proportion sediment loads has the advantage of quantifying a tangible metric that is often used to characterize the health of watersheds and the streams that run through them. Annual proportional sediment loading also provides a representation of the effects of upslope processes on stream water quality that can be quantified over the hydrologic season, and can be useful for comparative purposes with other systems in other watersheds. Thus, these metrics were calculated for all monitoring sites during HY07 and HY08 (Table 4-11). Plotting suspended sediment as annual load produced better results in the regression over using average turbidity, which was a good estimate of impairment. Annual sediment loading on a per unit area basis appears to be an excellent index of water quality.

As with average turbidity, statistics were generated for each monitoring site for each hydrologic year and the two hydrologic years combined. Annual sediment load was used as the dependent variable in numerous regression analyses and indicated several significant as well as some non-significant relationships. Independent variables included road density, road-stream crossing density, density of roads on steep slopes (> 30%), area of timber harvest in general, area of timber harvest as clear cuts, area of timber harvest based on yarding method, and geology.

Table 4-11. Results of simple linear regression of seven separate independent variables on Average Annual Sediment Loading (tons/sq.mi./year) at nine monitoring sites within the Lower Van Duzen River Basin for the combined years of HY07 & HY08.

Independent Variable	Linear Regression: Annual Sediment Loading HY07 & HY08				
	Slope	Intercept	F	P	R^2
Road Density (mi per square mi)	231.39	-536.05	4.36	0.0751	0.38
Stream Crossings (per stream mile)	344.75	470.93	13.29	0.0082	0.66
Proportion Timber Harvest (ALL)	1,238.92	301.69	26.96	0.0013	0.79
Proportion of Only Clear Cuts (CC)	2,257.08	731.43	15.75	0.0054	0.69
Tractor Yarding in Clear Cuts (TC)	2,931.31	787.40	27.23	0.0012	0.80
Proportion Wildcat Formation (WC)	1,114.23	740.18	20.18	0.0028	0.74
Proportion Yager Terrane (YG)	-968.50	1442.38	2.05	0.1955	0.23

While results of simple linear regression analyses of annual sediment loading were similar to those obtained using average turbidity, with the exception of the effects of geology, P values and R^2 values were slightly better using sediment as a dependent variable. For example, the significant correlation between timber harvest and sediment loading (Figure 4-15) was not apparent when average turbidity was used as the dependent variable. Significant effects ($\alpha <= 0.05$) on sediment loading were observed for road-stream crossing density ($F = 13.29$, $P < 0.0082$, $R^2 = 0.66$), proportion timber harvest ($F = 26.96$, $P = 0.0013$, $R^2 = 0.79$), proportion clear cutting ($F = 15.75$, $P < 0.0054$, $R^2 = 0.69$), proportion tractor yarding in clear cuts ($F = 27.23$, $P < 0.0012$, $R^2 = 0.80$), and proportion Wildcat geology ($F = 20.18$, $P < 0.0028$, $R^2 = 0.74$).

These single regression analyses clearly indicate a significant effect of several factors, mostly human caused, on degradation of water quality in the streams of the Lower Van Duzen River Basin. The strongest effects were observed with timber harvest and the most common harvest method associated with clear cutting – that being tractor yarding. Moreover, while clear cutting is a severe silviculture practice and should be removed from consideration in Pacific Northwest harvest plans, when accompanied by tractor yarding, which is by far the most common practice, this mandate becomes increasingly more crucial, with extraordinary implications for environmental damage and impairment of water quality.

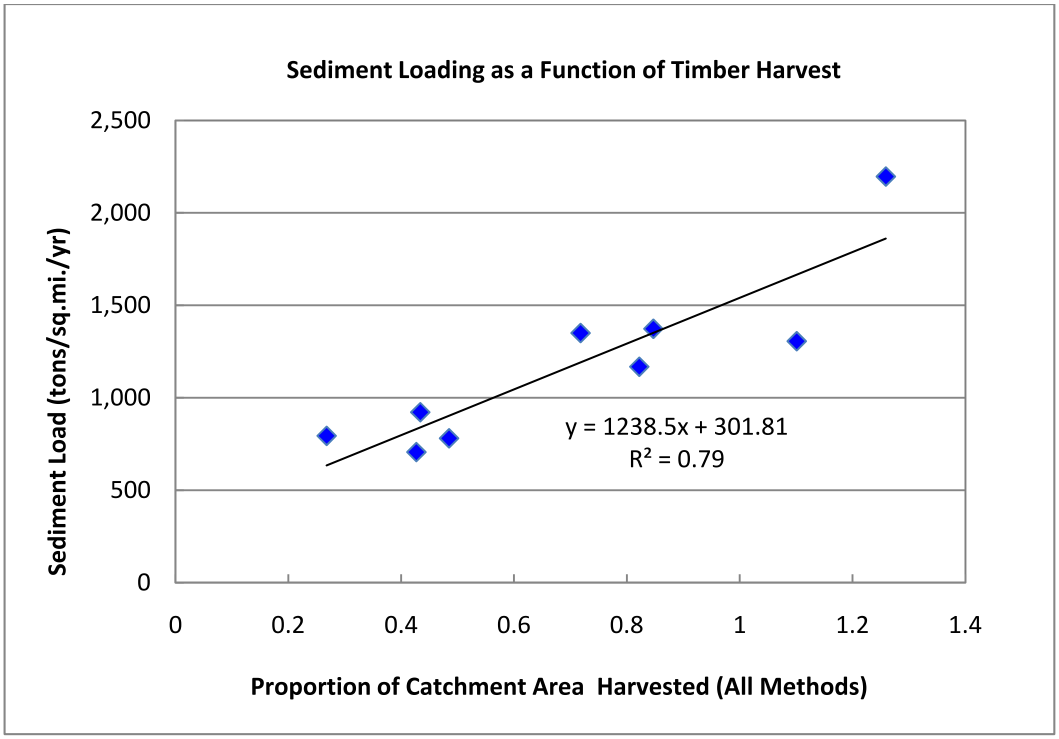

Figure 4-15. Potential effect of proportion of Timber Harvest on sediment loading in the Lower Van Duzen River Basin for the combined years of HY07 & HY08.

Regressing average sediment loads on tractor yarding in clear cuts produced the most significant signal linear effect ($P < 0.0012$) and the highest correlation coefficient ($R^2 = 0.80$) of any of the analyses tested. However, because these two practices (clear cutting and tractor yarding) are used together so frequently, and are thus correlated, it is difficult to separate their individual effects.

Based on the increase in the correlation coefficient over the analysis for just clear cutting, it is reasonable to conclude that tractor yarding as a harvest method, is by far the most ecologically severe method of timber harvest historically and in use today, and it is the strong recommendation of this report that state and federal officials remove tractor yarding practices from any further consideration in association with timber harvest plans. We have witnessed first-hand, anecdotally and scientifically, that clear cutting methods, especially when associated with tractor yarding, are extremely harmful to forest and aquatic ecosystems, and should be banned from all further timber harvest practices.

Multiple Effects

Two-way and three-way interactions were also tested using multiple regression analysis of the function for average annual sediment loading. Significant interactions involving positive correlations with sediment loading were observed between proportion clear cuts, tractor yarding, and Wildcat geology, as seen in the following functions. The levels of significance of these analyses were variable compared to those observed for average turbidity. In all cases, the sample size (n) represents the nine catchment areas.

Sediment Loading (SL) as a function of Clear Cuts (CC) and Wildcat Geology (WC):

$$SL = 439.67\ WC - 109.91\ CC + 1{,}648.84\ CC \bullet WC + 828.47$$

$$F = 8.66,\ \ P < 0.0201,\ \ R^2 = 0.84$$

Sediment Loading (SL) as a function of Clear Cutting (CC) and Tractor Yarding in clear cuts (TC) (CC and TC are correlated, and thus mat be invalid due to pre-association of these two factors):

$$SL = 450.73\ CC + 2{,}177.63\ TC + 458.43\ CC \bullet TC + 777.61$$

$$F = 6.76,\ \ P < 0.0328,\ \ R^2 = 0.80$$

Sediment Loading (SL) as a function of Wildcat Geology (WC) and Tractor Yarding (TC):

$$SL = 494.62\ WC + 1{,}851.10\ TC + 23.62\ WC \bullet TC + 734.75$$

$$F = 8.68,\ \ P < 0.0199\ \ R^2 = 0.84$$

Sediment Loading (SL) as a function of Clear Cutting (CC), Wildcat Geology (WC), and Tractor Yarding (TC): Function # 1 (No Interaction)

$$SL = 306.53\ CC + 477.93\ WC + 1{,}580.79\ TC + 718.85$$

$$F = 8.85,\ \ P < 0.0192,\ \ R^2 = 0.84$$

Sediment Loading (SL) as a function of Clear Cutting (CC), Wildcat Geology (WC), and Tractor Yarding (TC) (CC and TC may be correlated): Function #2 (Three-way Interaction only)

$$SL = 294.42\ CC + 613.46\ WC + 36.23\ TC + 4{,}000.94\ CC \bullet WC \bullet TC + 886.55$$

$$F = 12.08,\ \ P) < 0.0166,\ \ R^2 = 0.92$$

As seen earlier, possible correlation between clear cutting and tractor yarding in clear cut areas led to the following analysis that omitted the interaction between these two variables.

Sediment Loading (SL) as a function of Clear Cutting (CC), Wildcat Geology (WC), and Tractor Yarding (TC): Function #4 (No CC•TC Interaction)

$$SL = 316.76\ WC - 11{,}050.09\ CC + 25{,}900.35\ WC \bullet CC + 20{,}929.99\ TC - 36{,}200.06\ WC \bullet TC + 592.10$$

$$F = 4.32,\ \ P < 0.1291,\ \ R^2 = 0.88$$

As with average turbidity, this last function is not statistically significant, but is also presented to show the higher fit of the function ($R^2 = 0.88$). As previously, this function also shows the problem with analyzing extensive interactions with a small sample size (9), and as more interactions are added to the function, degrees of freedom are lost from the calculation of the F value. This was also the case to an even greater extent for the full model (all two way and three-way interactions).

In contrast to analysis using average turbidity, removing the clear cut – tractor interaction from the previous function did not significantly improve fitness. However, in each case, geology and harvest methods predicted sediment loading equally as well as average turbidity.

Analysis Overview

Approaches using some aspect of the turbidity-discharge function seem to have problems in that they modify and possibly bias the results in some way. Using logn transformed data tends to quench the results by diminishing the differences between smaller and larger turbidity values. As such, the slope of the natural log of the turbidity-discharge function proved to be unusable as a dependent variable for describing the impact of various factors on water quality. Difficulty in using the slope of the logn relationship appears to be that the quenching of data, especially for small streams, appears to give greater weight to larger streams. In the present study, it was the smaller streams that showed a greater and faster response to silting and sedimentation.

In overview, there are several relationships that emerged as a result of this study. With the exception of road density discussed earlier, most of the regression interaction models using the average turbidity and average annual suspended sediment were significant or highly significant ($\alpha < 0.01$), especially in cases of multiple factor interactions. These results give additional credibility to the importance of understanding the complexity of the factors that contribute to sedimentation in the streams and the impairment of watersheds. Obviously, these analysis represent only a small picture of the complexity of problems facing these watersheds, but they strongly support the need for a greater understanding of how a multitude of factors influence water quality within the Lower Van Duzen River Basin. This understanding becomes even more critical when making decisions regarding human activities on the land that ultimately affect these streams, their watersheds, and the survival of the extremely important salmon, steelhead, and other cold water species that inhabit these waters.

Only analyses of raw data showed significant effects of upslope conditions on water quality, such as average turbidity and average annual sediment load. Data based on the slope of the turbidity-discharge function may not meet criteria for normality and are somewhat correlated, indicating that a transformation (e.g., logn) might be required. However, these transformations nullified any significant effects that were observed using raw data, and are therefore not presented. Lack of significant effects using transformed data suggests potential problems with the data, and reduces confidence in their potential validity.

CDFG stated that watershed assessment needs to consider interactions among natural processes, human activities, and resource conditions in order to assess watershed health. Interactions within the watershed are numerous, complex, non-linear, and may occur over extended periods of time and space. Moreover, the forces that drive or affect these factors may lie outside the watershed or occur at a much larger scale, and single cause-and-effect relationships are, therefore, difficult to identify (CDFG 2010).

Another problem with attempting to observed relationships between dependent and independent factors within the watershed is that the time by which these effects are expressed is unknown. As described by CDFG (2010),

> ... sediment from a road failure may take 30 years to work its way down many miles of stream, affecting fluvial processes, impacting water quality conditions, and altering stream substrate as it moves. As the sediment transports downstream, it can cause spatial and temporal changes channel conditions through initial aggradation, possible lateral migration that undercuts channel banks, and eventually degradation as the channel attempts to reach its initial base level. Thus, this additional sediment may alter channel and channel bank structures, flow hydraulics and impede riparian vegetation re-establishment.

Therefore, the task of clearly demonstrating cause and effect between any of the many factors that potentially cause and influence the amount of sediment in the streams, is very difficult. For example, roads have been documented repeatedly to increase erosion and sediment runoff from the hillsides, yet our analyses could show no effect of road density on sediment or turbidity. Coupled with the difficulty of interactions in space and time, our project area had virtually no reference (control or pristine) creeks or reference planning watersheds.

There were a number of problems in the experimental design of this project that only became evident during data analysis of the second year, after most of the project had been completed. The relationship of the data suggests that there were numerous inconsistencies in the way samples were collected, including the use of volunteers to collect turbidity and suspended samples from the various streams. The volunteers not only naturally collect samples in their individually different ways, but also throughout both seasons, continually collected samples at different frequencies (number of times per season), on different days, and at different times (from each other) during the day. Thus, extreme variations in these four processes alone probably introduced a tremendous amount of experimental error and variability into the data. Beyond the problems with taking samples at the streams, it was extremely difficult to collect the samples from the volunteers in the field and to transport these samples to a place where the turbidity measurements could be made. Moreover, there were at any given time, at least three different individuals using instruments to record turbidity of the samples, which also undoubtedly introduced additional experimental error into the data.

A single person collecting and reading the turbidity samples would have eliminated much of the experimental error and conferred a greater confidence in the validity of the results. This means of collecting the data could have been accomplished by hiring one person (and possibly and alternate) to sample all of the streams and make all of the turbidity measurements on a consistent basis throughout each season. However, one of the goals of the project was to involve the community in a monitoring program, and to provide a means through which members of the community and landowners could participate and become more connected with their watersheds. A volunteer monitoring program using a Citizens Monitoring Group, as was done in this project, seemed to be an appropriate way to accomplish this goal. However, it would appear that the quality of the data suffered as a result.

Another series of problems was encountered when trying to process and measure suspended sediment grab samples from different streams. Our original intent was to transport all samples to the Salmon Forever Sediment Laboratory in Sunny Brae (near Arcata, CA). However, at the beginning of HY08, Salmon Forever experienced an administrative and procedural upheaval, causing a shutdown of the Sunny Brae lab just at the most critical time of the season when our suspended sediment samples were being collected. A decision was made by the director of Salmon Forever to move the lab to Elk River, one of the primary sample sites used by the organization. However, this move resulted in a delay of several months, before the new lab was operational. In the interim, our samples were handled by several different individuals, typically student help at the water quality lab in the Fish and Wildlife Department at Humboldt State University. Upon reviewing the results of the suspended sediment analyses, it became clear that numerous samples had been mishandled or misread, and many of these results had to be discarded, leading to a lack of confidence in the use of these data as well.

However, given the problems encountered during this project, there is nonetheless a substantial amount of interesting and usable information that has been produced. Considering the opportunity for problems in the design of the field experiments, especially the use of volunteers for collecting water samples, definite trends and significant relationships were observed between upslope conditions and water quality in the streams. Given that the project duration was limited to two years makes it very difficult to reach a satisfactory conclusion regarding the behavior of the streams in the lower basin relative to the major factors of influence. Certainly, many years of data collecting and analysis would be necessary to conclusively establish the relative health of these watersheds and to confidently ascribe causes and effects regarding water quality. Nonetheless, the project has succeeded in establishing the first step towards completing that goal, and has demonstrated valid and useful methods, as well as recommendations (see Chapter 6) for continuing this process into the future.

Recommendations and Objectives for Cummings Creek - Turbidity and Sediment Sampling

1) As Cummings Creek was the first stream in the Lower Van Duzen River Basin to receive a turbidity threshold sampling (TTS) station, it would be highly valuable to maintain this station in perpetuity.
    - Standardized, repeatable data collection is an important contribution to understanding the fluctuations in turbidity and suspended sediment that occur in these streams month to month, and year to year.
    - Now that dependable data collecting has begun for Cummings Creek, these data will take on greater importance as more data are collected from the same stream on an annual basis.
    - With numerous years of TTS data collected on the same stream, we may be able to more fully understand how and why these streams fluctuate to such an extent, and more fully quantify how and why streams such as Cummings Creek behave in response to storm events and upslope conditions.

Recommendations and Objectives for the Lower Van Duzen River Basin - Turbidity and Sediment

1) Phase out the use of grab sampling to where it will only be necessary where placement of a TTS station is extremely difficult or unfeasible.

2) Establish eight turbidity threshold sampling (TTS) stations over a ten-year period on appropriate streams throughout the lower basin, including HRC lands, to record suspended sediment annually and track the degree to which project short and long term goals (e.g., sediment reduction, habitat rehabilitation) are being achieved. These stations will be located on streams that are deemed to have the highest priority with respect to the level of

impairment (anticipated amount of sediment yield in the watershed), but also the greatest potential for restoration and successful reintroduction of salmonid stocks (Table 10-6).

3) Likely candidates for placement of TTS stations in the Lawrence - Yager Creek sub basins (see Chapter 3 for map of planning watersheds, Figure 3-1) include:
   - Lawrence Creek and Yager Creek, above (upstream of) their confluence.

4) Likely candidates for placement of TTS stations in the Central Lower Van Duzen River Basin (see Chapter 3 for map of planning watersheds, Figure 3-1) include:
   - Cummings Creek, Flanigan Creek, Hely Creek, Root Creek, Stevens Creek, and Grizzly Creek, all of which represent direct tributaries to the Van Duzen River and historically important streams for salmonid habitat.
   - Root Creek is problematic as it is located on the south side of the Van Duzen River and access may be difficult to reach in the winter season during severe storm events. However, this watershed is a critical tributary to the main stem Van Duzen River, and if provided access by Humboldt Redwood Company, information on this stream would be extremely valuable. This is the only north running stream of significance on the south side of the river within the lower basin.

Recommendations and Objectives for Water Quality Improvement in the Lower Van Duzen River Basin

1) Water temperatures, especially in July, suggest that maximum temperatures in the main stem Van Duzen River and Yager Creek, as well as some of its tributaries are above the acceptable range for juvenile salmonids. Therefore maintain and expand instream continuous monitoring of stream temperatures throughout the summer months using HOBO temp data loggers.

   - Expand the number of continuous HOBO temp monitoring sites within the lower basin during the summer months on a continual annual basis.
   - Stream sites will include the original seven monitored during our project, which include Wolverton Gulch, Lower Yager Creek (downstream from the Lawrence Creek convergence), Cummings Creek, Hely Creek, Grizzly Creek, and two sites on the main stem Van Duzen River, plus 22 additional sites.

   → All streams will be monitored a minimum of three consecutive years during summer months

2) Streams will also be monitored year-round for Dissolved Oxygen, pH, and Conductivity for each of three consecutive years. The number of streams that are sampled will be more than doubled over those that were sampled in the current project, which will include Lawrence Creek, Booths Run, Shaw Creek, Corner Creek, Cooper Mill Creek, Blanton Creek, Upper Yager Creek, Cuddeback Creek, Fiedler Creek, Fox Creek, and Stevens Creek.

3) As the amount of water in the streams is limiting factor for cold water species.

- More effort will be made to monitor and record flow rates, or discharge, on an annual basis, in order to show the relationships between flow rates in the wet season versus the dry season.
- Intact, healthy watersheds with forests of increasing age structure and complexity will have a greater water holding capacity than impaired watersheds, where forests are of a single dimension and lack complexity. Greater water holding capacity will reflect intact forests that facilitate sustainability in timber harvest management.
- In those streams where TTS stations are installed (at least 8 sites), stream discharge is monitored continuously, and is therefore part of the cumulative data base. However, flow rates should also be monitored in at least 15 other streams throughout the year.