APPENDIX 11

OVERVIEW OF EXISTING SEDIMENT STUDIES RELEVANT TO THE JDSF EIR

Introduction

This document provides an overview of the sediment yield estimates that have been compiled for the Jackson Demonstration State Forest (JDSF) EIR assessment area, and discusses the implications of this information for JDSF management. The main sources of information for sediment yield in the JDSF EIR assessment area are: 1) watershed assessments completed by privately held timber companies, 2) Stillwater Sciences' watershed analysis for the draft JDSF HCP/SYP, 3) Total Maximum Daily Load (TMDL) documents produced by the U.S. EPA, 4) sediment source area investigations conducted to support TMDL development, 5) data collected by the USDA Forest Service—Pacific Southwest Research Station at Caspar Creek, and 6) recent cosmogenic radionuclide data for long-term average erosion rates.

Numerous sediment studies have been conducted within the JDSF EIR assessment area over the past several years. At the large watershed scale (i.e., the Noyo and Big River basins), this work has generally consisted of office-based watershed assessments using techniques such as aerial photograph reconnaissance with limited field data collection. Some sediment data has been collected in the South Fork Noyo River, which provides a context for watershed assessment conclusions reached in the Noyo River basin. In contrast, research-level sediment data has been collected for 40 years in the headwater basins of the North and South Forks of Caspar Creek, a small coastal watershed located on Jackson Demonstration State Forest (JDSF) that is situated between the much larger Noyo and Big River basins.

Sediment yield estimates are summarized and discussed by individual watershed first, and then for the assessment area used for the JDSF draft HCP/SYP. Discussion of the results of the various assessments follow, along with management implications. Tables 1 and 2 in the Comparison of Sediment Yields section provide a summary of sediment yield estimates completed in the JDSF EIR assessment area.

Noyo River Watershed

Graham Matthews and Associates (1999) developed a preliminary sediment budget from a reconnaissance-level sediment source area analysis for the Noyo River basin. The study was based on analysis of air photos and digital mapping data. For the 67-year period between 1933 and 1999, total sediment inputs were estimated to be 590 t mi^{-2} yr^{-1} (Figure 1). Total sediment input was estimated to be 658 t mi^{-2} yr^{-1} for the period from 1958 through 1999. Matthews states that sediment input sources are likely to be underestimated due to the information available and the limitations of the analytic techniques employed. Under current conditions, it was estimated that about 35% of the sediment inputs for which estimates were developed are management related.

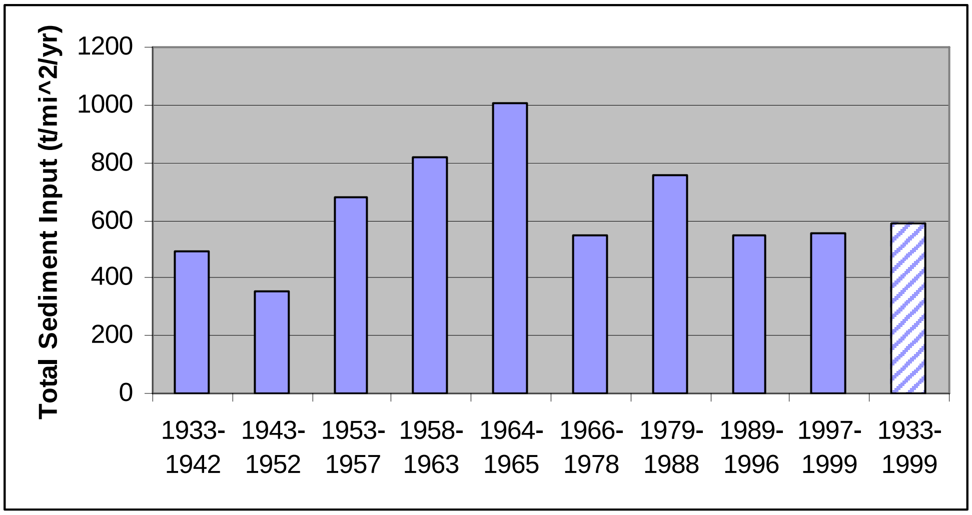

Figure 1. Estimated total sediment input values for the Noyo River watershed for varying time periods (Matthews and Associates 1999).

Graham Matthews and Associates' (1999) sediment source area analysis was the basis of the sediment data for the Noyo River TMDL (US EPA 1999). It is restated that the average annual sediment input over the 67 year period is 589 t mi^{-2} yr^{-1}. This document combines Matthews' periods of observation from the original nine (1933-1942; 1943-1952; 1953-1957; 1958-1963; 1964-1965; 1966-1978; 1979-1988; 1989-1996; and 1997-1999) to three (1933-1957; 1958-1978; and 1979 to 1999). With this grouping, the TMDL concludes that sediment delivery has generally increased over time, including an estimate of 667 t mi^{-2} yr^{-1} for the period from 1979 to 1999. Background sediment yield was stated as 374 t mi^{-2} yr^{-1} (56%), timber harvest[1] 36 t mi^{-2} yr^{-1} (5%), roads 251 t mi^{-2} yr^{-1} (38%), and railroad 6 t mi^{-2} yr^{-1} (1%) (see Table 14 in the Attachments to this appendix, reproduced from the Noyo River TMDL, for more detailed information).

The Noyo River TMDL states that the practices used during the Forest Practice Act period of 1979 to 1999 appear to have contributed to a deceleration in the rate of sediment delivery from management-related sources, but have not controlled them. For this period, 43% of the sediment yield is estimated to have come from timberland management, 1% from other management related sources, and 56% is attributed to natural/background sources.

[1] The timber harvest category includes hillslope mass wasting (landslides) and "in-unit" surface erosion (e.g., surface erosion from skid trails).

Because the US EPA estimates for the Noyo River TMDL were developed using office methods rather than field measurements, geomorphic mapping of the South Fork Noyo River valley floor was undertaken to quantify the volume of sediment stored in the watershed, and 10 streamflow and suspended sediment sampling stations were established for water year 2001 (Koehler and others 2001, 2002, 2004). These field measurements showed that large amounts of historic logging-related sediment trapped in long-term storage along the South Fork channel are transported downstream during high discharge events. This sediment increases the overall suspended sediment load and was not accounted for in the previous TMDL calculations, indicating that the TMDL overestimated sediment generated by upslope management practices (Koehler and others 2002, 2004). This study concluded that accurately quantifying channel sediment storage is a critical step for assessing sediment budgets, especially in TMDL documents attempting to relate upslope management to suspended sediment production.

Similarly, Benda and Associates (2004a) estimated bank erosion rates to be 2.75 in/yr in the Little North Fork Noyo River watershed as part of comprehensive field study. This high rate was thought to possibly reflect continuing channel incision and lateral migration of the channel related to historical logging (prior to 1970) that either filled the channel with sediment and wood, or otherwise changed their hydraulic geometry. The calculated sediment flux from bank erosion for third and higher order channels was reported as approximately 1060 t mi^{-2} yr^{-1}, which is inconsistent with the US EPA (1999) TMDL estimate of 200 t mi^{-2} yr^{-1}, developed primarily with office techniques. Benda and Associates (2004a) state that this suggests that the EPA TMDL for the Noyo River underestimated the bank erosion component of the sediment budget by approximately 500% and consequently the “background” sediment yield by 250%. They caution that while this analysis is preliminary and deserving of additional analysis, it suggests the EPA TMDL for the Noyo River is inaccurate and quantitative values obtained from it should be treated with caution. If Benda and Associates (2004a) estimate of bank erosion is used with the other US EPA TMDL estimates, it reveals that management-related sources are responsible for approximately 20% of the total sediment yield of 1527 t mi^{-2} yr^{-1}. [2] And the proportion of management-related sediment could be reduced even more by accounting for the downstream channel deposit erosion reported by Koehler (2001).

The watershed analysis conducted by Mendocino Redwood Company (2000) for the Noyo River watershed analysis unit (WAU)[3] estimated that the average sediment input for the past 40 years was 470 t mi^{-2} yr^{-1}. Watershed analysis was conducted based on a modified version of the Washington Forest Practice Board watershed analysis procedure (WFPB 2001). Inputs were attributed to hillslope mass wasting (42%), road mass wasting (24%), road surface and fluvial erosion (24%), and skid trail erosion (10%) (see Figure 2). Road associated erosion was found to be the dominant sediment contributing process in the Noyo watershed assessment area, with road associated mass wasting, surface and fluvial erosion combined accounting for 48% of the

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[2] Benda and Associates (2004b) report similar results for two subbasins in the Ten Mile River basin.
[3] The Mendocino Redwood Company watershed analysis work was only conducted on the portion of the watershed within their ownership.

estimated sediment inputs. Mass wasting from roads and hillslopes accounted for 66% of sediment inputs.

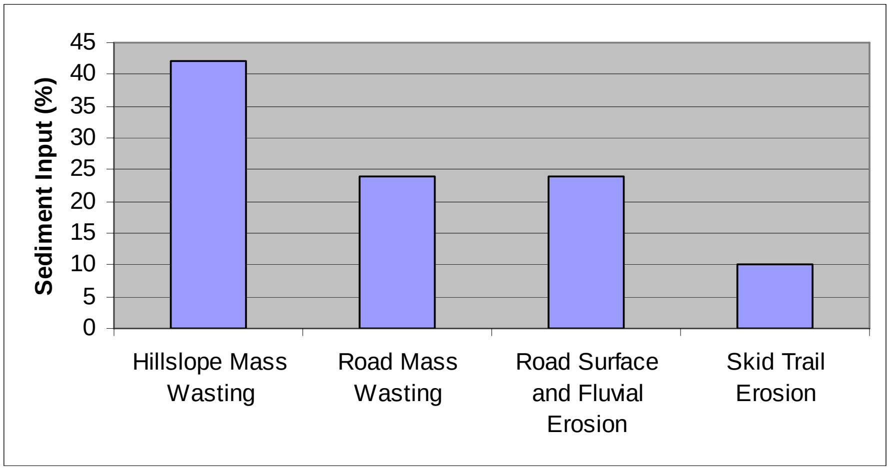

Figure 2. Sediment input percentages for the Mendocino Redwood Company's Noyo River watershed analysis unit (MRC 2000).

In contrast to the approaches that rely on air photo analysis as part of a watershed assessment process, Griggs and Hein (1980) estimated the suspended sediment yield of the Noyo River based on a combination of regional sediment yields, basin drainage

areas, LANDSAT imagery, and existing sediment data. They reported a higher sediment yield of 1510 t mi^{-2} yr^{-1} for the period from approximately 1955 to 1980. Suspended sediment rate was used to estimate denudation rates, but may be 15 to 30% too low since bedload and dissolved loads were not taken into account. The average erosion (or denudation) rate for the Noyo River watershed was reported as slightly greater than 0.25 mm/yr, or approximately 1930 t mi^{-2} yr^{-1} [assuming that the an erosion rate of 1 mm/yr is approximately 7710 t mi^{-2} yr^{-1} of sediment, using a density of rock of 2.7 g cm^{-3} (Ferrier and others 2003a)].

In summary, these sediment studies indicate that sediment input estimates for the Noyo River basin over the past 20 to 40 years range from approximately 500 to 1900 t mi^{-2} yr^{-1}, depending on the methods and time frames considered.

Big River Watershed

As with the Noyo River basin, Graham Matthews and Associates (2001) developed a preliminary sediment budget for the Big River basin using a rapid reconnaissance-level sediment source area analysis. Limited streamflow and sediment data were collected for water years 2000 and 2001. Matthews (2001) reported improvements in management practices since 1974 have resulted in decreases in road-related mass wasting and harvest-related surface erosion, but sediment delivery from these processes is still well above estimated background rates. Significant construction of new roads has led to increasing sediment yields from road surface erosion, despite improved practices (see Table 27 in the Attachments, reproduced from Matthews 2001).[4] Combined management-related sediment sources (management-related landslides, skid trail and road surface erosion) were estimated to be producing 51.7% of the current sediment loads, while non-management related sediment sources comprise the remaining 48.3%. Due to greater levels of disturbance in earlier periods, the overall average for the 80-year period was estimated to be 66.4% management-related and 33.6% non-management related.

The TMDL document for Big River (US EPA 2001) uses Graham Matthews and Associates' (2001) sediment estimates and states that estimated average sediment delivery in the watershed from 1921 to 2000 was 944 t mi^{-2} yr^{-1} (Figure 3). Sediment production was lower during the periods of 1966 to 1978 (594 t mi^{-2} yr^{-1}), 1979 to 1988 (618 t mi^{-2} yr^{-1}), and 1989 to 2000 (600 t mi^{-2} yr^{-1}) (Figure 3). The average rate from 1979 to 2000 was estimated to be 609 t mi^{-2} yr^{-1} (US EPA 2002). Background during this period was estimated at 261 t mi^{-2} yr^{-1} (43%), timber harvest 115.5 t mi^{-2} yr^{-1} (19%), roads 202 t mi^{-2} yr^{-1} (33%), and grassland landslides 30.5 t mi^{-2} yr^{-1} (5%). During this period, 52% of the sediment yield was estimated to be related to timberland management, 5% related to other management related sources (i.e., grassland related landslides), and 43% to natural/background sources (see Table 7, reproduced from the Big River TMDL, in the Attachments for more detailed information).

The Mendocino Redwood Company (2003) draft Big River watershed analysis states that the average estimated sediment input for the past 30 years for the Big River watershed analysis unit (WAU) is 880 t mi^{-2} yr^{-1}.[5] The inputs in the Big River WAU over the last 30 years have come from mass wasting (48%), and surface and point source erosion (52%). Road associated erosion is reported to be the dominant sediment contributing process in the Big River assessment area. Road associated mass wasting, surface and point source erosion combined accounts for 65% of the estimated sediment inputs in the Big River WAU. When skid trail erosion is included with the road sediment inputs, the combined amount totals 81% of the sediment inputs to the Big River assessment area. Specifically, road associated mass wasting was estimated to produce 255 t mi^{-2} yr^{-1} (29%), road surface erosion 190 t mi^{-2} yr^{-1} (22%), road point source erosion 130 t mi^{-2} yr^{-1} (15%), hillslope mass wasting 170 t mi^{-2} yr^{-1} (19%), and skid trail erosion 135 t mi^{-2} yr^{-1} (15%) (Figure 4).

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[4] Road building rates increased in the late 20th century partly due to the need to convert from ground-based logging systems (i.e., tractor logging) to aerial yarding systems (i.e., skyline cable yarding). Tractor logging used roads located in the bottoms of drainages, while cable yarding requires roads located near ridgelines.

[5] The Mendocino Redwood Company watershed analysis work was only conducted on the portion of the watershed within their ownership.

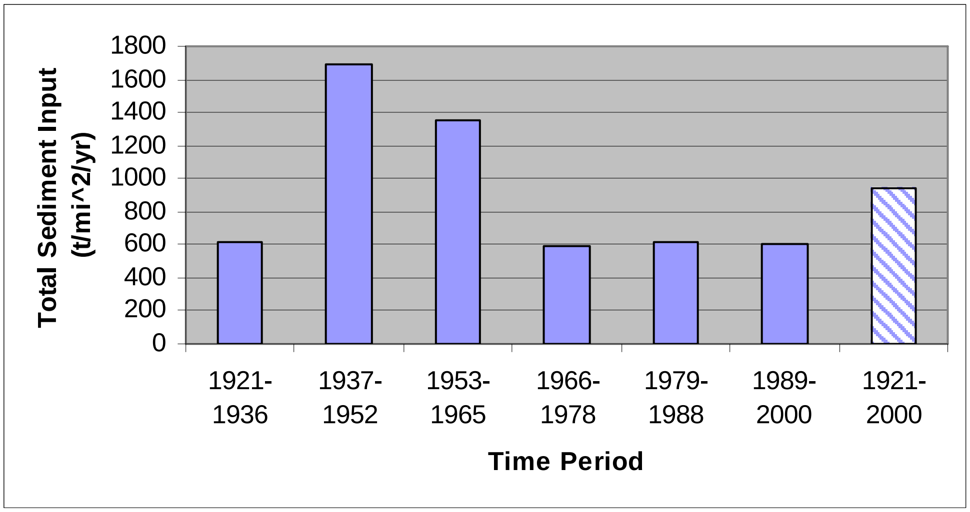

Figure 3. Estimated total sediment input values for the Big River watershed for varying time periods (U.S. EPA 2001 and Matthews and Associates 2001).

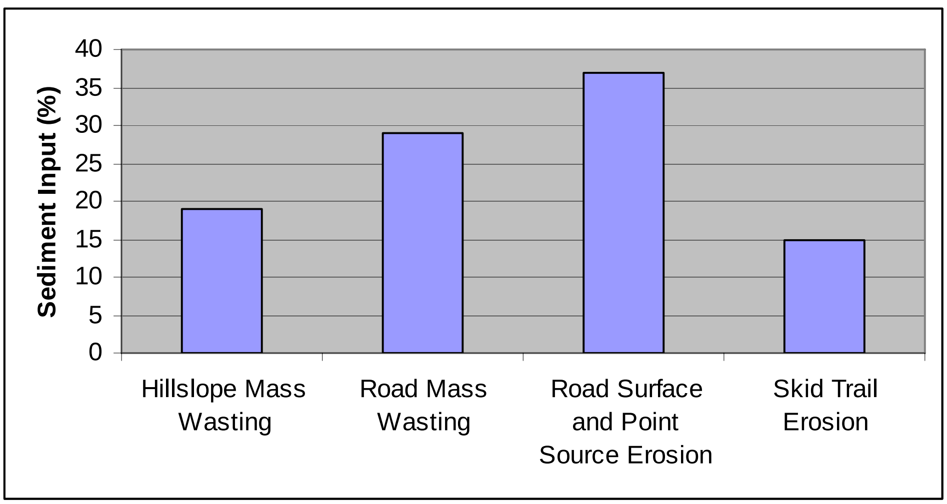

Figure 4. Sediment input percentages for the Mendocino Redwood Company's Big River watershed analysis unit (MRC 2003).

As in the Noyo River basin, Griggs and Hein (1980) estimated the suspended sediment yield of Big River based on a combination of regional sediment yields, basin drainage areas, LANDSAT imagery, and existing sediment data. They reported a yield of 940 t mi^{-2} yr^{-1} for the period from approximately 1955 to 1980, which is nearly identical to the Matthews (2001) total sediment yield estimate from 1921 to 2000. Suspended sediment rate was used to estimate denudation rates, but may be 15 to 30% too low since bedload and dissolved loads were not taken into account. The average erosion (or denudation) rate for the Big River basin was reported as about 0.20 mm/yr, or approximately 1540 t mi^{-2} yr^{-1}. As stated above, an average erosion rate of 1 mm/yr is approximately 7710 t mi^{-2} yr^{-1} of sediment, assuming a rock density of 2.7 g cm^{-3}.

In summary, the GMA (2001) and U.S. EPA (2001) documents conclude that sediment yields in Big River have averaged about 950 t mi^{-2} yr^{-1}over an 80 year period. Sediment production was estimated to be lower for the periods beginning in 1966. Griggs and Hein (1980) reported a similar suspended sediment yield for approximately a 25 year period ending about 1980, with a total sediment yield up to 1540 t mi^{-2} yr^{-1}. The TMDL document (US EPA 2001) found an average of about 610 t mi^{-2} yr^{-1}over the past 30 years, while MRC's (2003) sediment yield estimate is 880 t mi^{-2} yr^{-1}over the past 30 years. Therefore, there is general agreement that sediment input ranges from about 600 to 1540 t mi^{-2} $yr^{-1}$for the Big River basin.

Caspar Creek Watershed Study

Annual sediment loads for suspended sediment and bedload have been measured at the North and South Forks of Caspar Creek, a small coastal watershed situated between the Noyo and Big River drainages, for the past 40 years.[6] Mean annual sediment yields in the North and South Forks from 1963 to 2002 are 440 t mi^{-2} yr^{-1} and 495 t mi^{-2} yr^{-1}, respectively (using data from USFS-PSW 2004).[7] Lewis (1998) reported that approximately 70% of the total sediment load is transported as suspended sediment and 30% is bedload. Extremely high annual variability in sediment yield has been documented, based on number and size of storm events for a given winter, as well as watershed treatments applied (Figure 5). The Caspar Creek data set is unique in California, since it is the only forested experimental watershed currently in operation with a continuous long-term flow and sediment record (Ziemer and Ryan 2000). The long-term average sediment yields for Caspar Creek are of great value and provide a benchmark for comparison with office-based sediment budget values developed for JDSF and the larger river basins to the north and south.

Recent work using cosmogenic radionuclides in Caspar Creek has determined the average erosion rate over approximately 5500 to 8900 years for this basin (Ferrier and others 2004). They report an average denudation rate of 0.09 $\pm$0.02 mm/yr, or approximately 695 t mi^{-2} yr^{-1} (physical erosion plus chemical weathering fluxes). This figure is somewhat greater than the mean erosion rate measured over the past 40 years (0.057 $\pm$0.015 mm yr^{-1} and 0.064 $\pm$0.012 mm yr^{-1}) for the North and South Forks, respectively (~440 and 495 t mi^{-2} yr^{-1}) (Ferrier and others 2004) (see Figure 6).[8]
If it is assumed that the 1963-1975 suspended sediment sampling at Caspar Creek over-estimated sediment yields by a factor of 2-3 times (Lewis 1998) due to over sampling the rising limb of the storm hydrograph, short-term suspended sediment yields

[6] Sediment data are available for water years 1963 through 2002, with the exception of water year 1977.
[7] Solute erosion is assumed to be approximately 40 t mi^{-2} yr^{-1} for the South Fork of Caspar Creek based on an estimate of 8 percent of total sediment yield provided in Griggs and Hein (1980). Solute erosion is not included in these total erosion estimates.
[8] Note that this does not include chemical weathering fluxes.

can be reduced 40% to account for sampling bias (Ferrier and others 2004). With this revision, erosion rates at the North and South Fork weirs are 0.044±0.009 mm yr^{-1} and 0.046±0.007 mm yr^{-1}, respectively (~340 and 355 t mi^{-2} yr^{-1}).

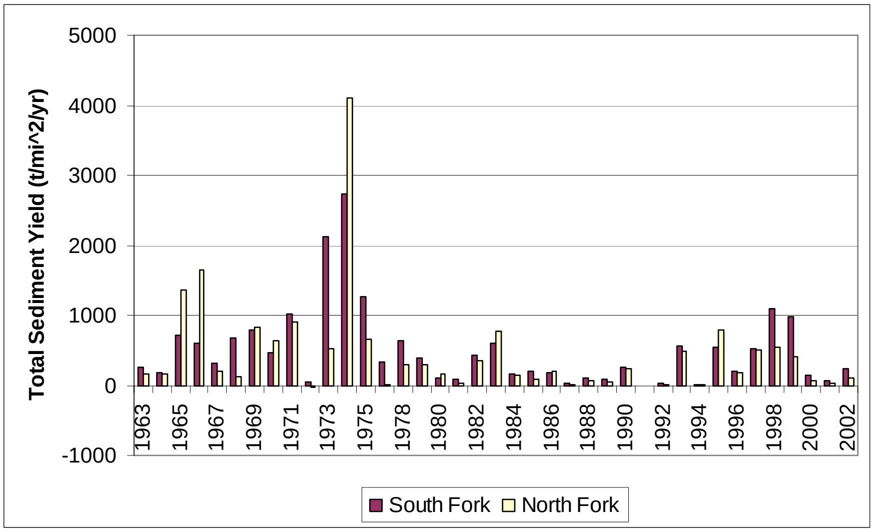

Figure 5. Total annual sediment yield measured for both the South and North Forks of Caspar Creek (USFS-PSW 2004).

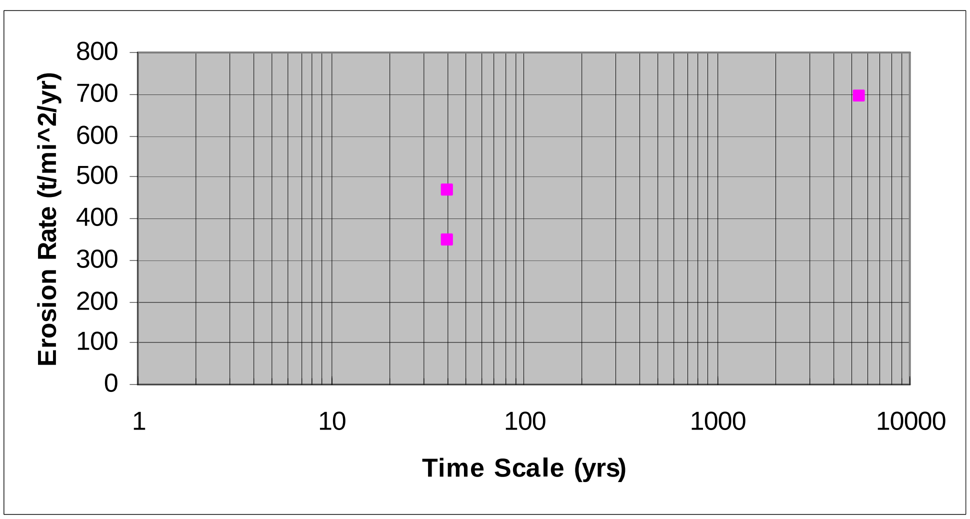

Figure 6. Erosion rates over different time scales at the North and South Forks of Caspar Creek (Ferrier and others 2004). Average erosion rates over the past 40 years are displayed as measured (average of the North and South Fork values), and with a 40% reduction for the years from 1963-1975 due to oversampling the rising limb of the hydrograph. Long-term physical erosion and chemical weathering fluxes are shown at the 5500 year time scale.

With this data modification, Ferrier and others (2004) state that the long-term measurements imply that Caspar Creek has experienced erosion rates that are approximately 2 times higher than decadal erosion rates (i.e., measured from 1963 through 2003). As a potential explanation, they state that sediment delivery to streams is highly episodic and that over 40 years of monitoring, relatively few large storm events that dominate long-term average erosion rates will have occurred. Evidence that indicates that the long-term erosion rates are dominated by large mass movement events with long recurrence intervals at Caspar Creek includes the presence of a large landslide (1,000,000 to 5,000,000 cubic yard) that dammed the North Fork of Caspar Creek and initiated sediment deposition in the upper part of the watershed (Cafferata and Spittler 1998). The landslide dam initiated sedimentation about 7000 years BP as determined by radio carbon (^{14}C) dating by Reneau (1989). Other landslides in the watershed are also substantially larger than any that have failed during the past 40 years (Spittler and McKittrick 1995).

Kirchner and others (2003) have used cosmogenic radionuclide geochemistry at dozens of sites in the western hemisphere and found that in the northern California Coast Range, long-term erosion rates are within a factor of two to three of modern day sediment yield measurements, suggesting that sediment delivery over decadal timescales is broadly consistent with the long-term average rate of sediment production in these watersheds (Ferrier and others 2003a, 2004).[9]

Ferrier and others (2004) state that the 5500- to 8900-year average erosion rate at Caspar Creek (0.09 mm/yr) is less than the local uplift rate, which is 0.3 to 0.4 mm/yr averaged over the past 300,000 years. Merritts and Bull 1989 reported that the average tectonic uplift has been relatively uniform throughout the Holocene (10,000 years ago to the present) and is approximately 0.3 mm/yr off the Mendocino County coast (inferred from marine terrace ages). These data imply that the mean elevation of the North Fork of Caspar Creek is still increasing (Ferrier and others 2004).

While the Caspar Creek watershed is considerably smaller than the Noyo and Big River basins (9 mi^2 vs. 113 mi^2 and 181 mi^2, respectively), it has a comparable land use history.[10] Additionally, the geology, soils, climate, and vegetation are grossly similar to those found in the larger basins. Old-growth redwood and Douglas-fir were logged from Caspar Creek from 1864 to 1904 (Napolitano 1996). Young-growth harvesting began in the late 1950s utilizing crawler tractors on steep slopes and roads located near channels, with improved forest practices occurring after the mid-1970s. In the experimental watersheds, the South Fork was logged from 1971 to 1973 with practices used prior to the implementation of the modern California Forest Practice Rules, while portions of the North Fork were logged from 1985 to 1992 using modern forest practices

[9] In contrast, comparison of long-term erosion determined with cosmogenic radionuclides to present day erosion in a largely deforested tropical highland in Sri Lanka shows that there has been a 10 to 100 fold recent increase in average erosion rates. Soil is being lost 10 to 100 times faster from agriculturally utilized areas than it is being produced in this location (Hewawasam and others 2003).

[10] The entire Caspar Creek basin where it enters the ocean is 9 mi^2, but the North and South Fork watersheds above the weirs, where sediment has been measured, are only 1.9 mi^2 and 1.7 mi^2, respectively.

(Henry 1998). Numerous landslides occurred after road construction and logging in the South Fork due to inadequate road, skid trail, and landing design, placement, and construction (Cafferata and Spittler 1998). Similar problems were not observed in the North Fork following harvesting that primarily utilized skyline cable yarding and roads located near ridges.

A complete sediment budget has yet to be prepared for the entire Caspar Creek watershed. Napolitano (1996), however, completed a sediment budget for the mainstem of the North Fork of Caspar Creek (from the weir to the old splash dam site). This work revealed that the main channel is still adjusting to severe channel impacts caused by splash dam operations and log drives that occurred in the nineteenth century.[11] In addition, large wood loading was greatly diminished by these historical logging activities (Napolitano 1998). Old-growth logging appears to have produced lasting channel impacts, including channel incision, simplification of channel form, and reduction in sediment storage capacity. During the 1980 to 1988 water years covered by Napolitano's (1996) sediment budget, average annual sediment yield was only approximately 200 t mi^{-2} yr^{-1}, reflecting the relatively low discharge events experienced during this period. Changes in sediment storage were measured, but sediment inputs from various types of hillslope erosion features (e.g., shallow rapid landslides, deep slow landslides, and road surface erosion) were not estimated. Lewis' (1998) subsequent work, however, concluded that roads were relatively unimportant sediment sources in the North Fork due to their location on ridges away from channels. Sediment increases from channel erosion associated with unbuffered intermittent small streams in burned and, to a lesser degree, in unburned areas, were found to be a significant sediment source in recently harvested areas. Increased erosion was attributed to increased gullying of headwater channels (Keppeler and others 2003).

Recent work in the Caspar Creek watershed also has found bank erosion to be an important sediment source (similar to that reported by Benda and Associates 2004a for the Little North Fork Noyo River watershed). Tributary and headwater valleys show signs of incision along much of their lengths, and Dewey and others (2003) report that ongoing levels of suspended sediment delivery correlate well with total amount of exposed channel bank. On an annual to decadal time-scale, they found that rates of suspended sediment delivery per unit area of watershed area correlate better with the amount of exposed bank area in reaches upstream of stream gages, than with the volume of sediment delivered by landslide events, with total basin area, or with peak storm flow per unit area.

[11] It may be that some of the channel adjustment is due to the establishment of an effective channel through the old landslide dam, as well as active downcutting that is in response to the regional tectonic uplift (T. Spittler, CGS, Santa Rosa, electronic communication).

JDSF Draft HCP/SYP Sediment Budget

In 1999, Stillwater Sciences developed a rapid sediment budget for the JDSF Habitat Conservation Plan (HCP)/Sustained Yield Plan (SYP) watershed assessment area (approximately 156 mi^2).[12] This sediment budget included estimates of hillslope erosion, sediment yield to channels, and changes in sediment storage within channels (CDF 1999). Results from the surface erosion and mass wasting modules completed for the watershed assessment were used for this work. A sediment yield estimate was provided for the period from 1958 to 1997, because 1978 and 1996 air photos provided a record of landsliding covering the period from 1958 to 1996. Separate sediment budgets could not be constructed for the periods from 1958 to 1978 and 1978 to 1997 because rates of road and natural surface erosion, deep-seated landslides, and soil creep sediment production could not be differentiated, but discrete rates of landsliding for the two periods were produced. Therefore, the overall sediment yield estimate encompasses a very wide range of forestry practices.

The rapid sediment budget indicated that road-related surface erosion accounted for 45% of hillslope erosion, road-related shallow landslides produced 27%, deep seated landslides 2%, soil creep 2.5%, hillslope shallow landslides 21%, and background surface erosion 2.5% (Figure 7). Combined road-related erosion (surface and mass wasting) accounted for 72% of the total hillslope erosion. The remaining 28% of the hillslope erosion was associated with natural and management related sources (e.g., in-unit landslides) on hillslopes and inner gorges. Average sediment yield was estimated at 856 t mi^{-2} yr^{-1} for the period from 1958 to 1997, which is a 2.5 fold increase over estimated background rates (342 t mi^{-2} yr^{-1}).

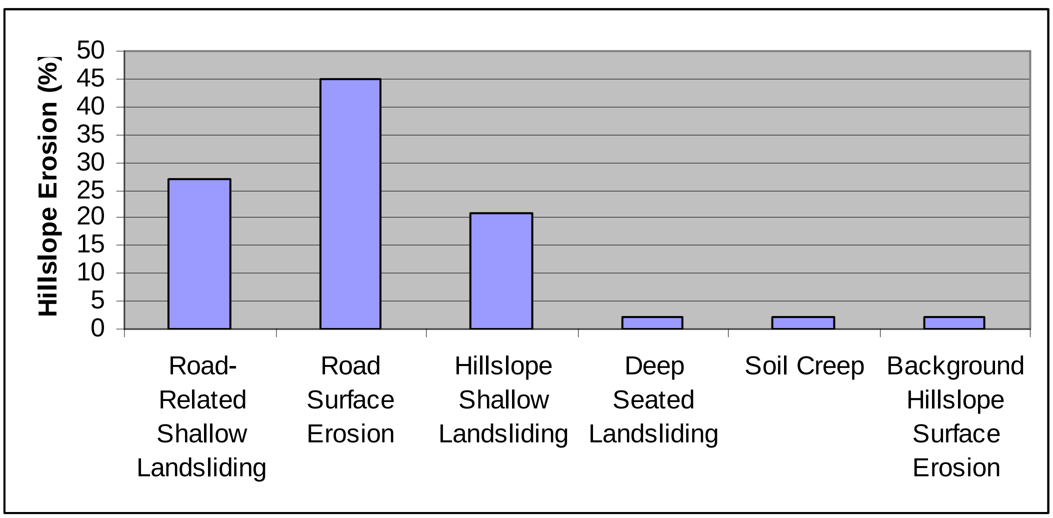

Figure 7. Rapid sediment budget produced for the draft JDSF HCP/SYP assessment area, 1958-1997 (CDF 1999).

[12] The assessment area for the draft JDSF HCP/SYP included the South Fork of the Noyo River, four small coastal watersheds (Hare, Mitchell, Caspar Creeks, and Russian Gulch), Lower Big River, and the North Fork of Big River.

Stillwater Sciences reported two results that show improved forestry practices required by the modern Forest Practice Rules have significantly reduced sediment yields in the past two decades (CDF 1999). First, the amount of sediment from road-related shallow landslides from 1979 to 1996 was approximately half that found during 1958 to 1978. Second, logging in the South Fork of Caspar Creek that was conducted prior to the implementation the modern rules produced from 2.4 to 3.7 times more suspended sediment than was produced in the later North Fork logging (Lewis 1998, Lewis and others 2001). Most of the increase in suspended sediment measured at the North Fork weir resulted from one large landslide that occurred in January 1995 (Lewis and others 2001).

Comparison of Sediment Yield Estimates

Due to the differences in methodologies, time periods, and watershed scales, sediment input estimates for the JDSF EIR assessment area range from approximately 400 t mi^{-2} yr^{-1} to about 1900 t mi^{-2} yr^{-1} (Table 1). It is likely that actual sediment yield for the EIR assessment area during varying time periods is within this range, since the erosion rate measured over 40 years at Caspar Creek is almost 500 t mi^{-2} yr^{-1} and the long-term average erosion rate estimated over about 5500 to 8900 years at Caspar Creek is approximately 695 t mi^{-2} yr^{-1} (Ferrier and others 2004).

Table 2 puts the results of the above described sediment production studies into groups of planning watersheds, time periods, and sediment source areas for comparison of methodologies and sediment yields. Listed sediment yields vary in some cases from previous values because the results cover different time periods, the addition of estimated bedload transport, or subtraction of soluble load to give more comparable expressions of total sediment load.

This comparison shows the great amount of variation in the types and combinations of sediment sources used to arrive at overall estimates. None of the sediment budget methods (MRC 2000, MRC 2003, U.S. EPA 1999, U.S. EPA 2001, and CDF 1999) use the same combinations of erosion processes and sediment sources. For example, streambank erosion is only considered by U.S. EPA (1999 and 2001), and only U.S. EPA (2001) and CDF (1999) include soil creep in their sediment budget. However, considering the differences in methods, watershed sizes, management history, and time periods, results from these sediment budget approaches all fall within the mid-range of estimated sediment production (398 to 974 t mi^{-2} yr^{-1}). Other approaches that rely on physical estimates of sediment inputs, including streambank erosion (Benda 2004a) or measurement of instream sediment transport (Koehler 2001, Lewis 1998, and above in this EIR) report sediment yields that are both well above and well below the range of sediment budget results.

Table 1. Summary of Sediment Input Values, Sediment Yield Estimates, and Long-Term Erosion Rates Completed in the JDSF EIR Assessment Area.

Source	Time Period Considered	Primary Method	Noyo River Watershed (t mi^{-2} yr^{-1})	Big River Watershed (t mi^{-2} yr^{-1})	NF/SF Caspar Cr. Watershed[13] (t mi^{-2} yr^{-1})	JDSF Draft HCP/SYP Assessment Area (t mi^{-2} yr^{-1})
Matthews (1999)	**1958-1999**	**Office Assessment**	**658**			
U.S. EPA (1999)	**1979-1999**	**Office Assessment**	**667**			
MRC (2000)	**1960-2000**	**Office Assessment**	**470**			
Griggs and Hein (1980)	**~1955-1980**	**Office-based Estimate[14]**	**1930**			
Matthews (2001)	**1989-1999**	**Office Assessment**		**561**		
U.S. EPA (2001)	**1979-2000**	**Office Assessment**		**609**		
MRC (2003)	**1971-2001**	**Office Assessment**		**880**		
Griggs and Hein (1980)	**~1955-1980**	**Office-based Estimate[12]**		**1540**		
USFS-PSW (2003)	**1963-2002**	**Sediment Data Measurement**			**~440/495 [~340/355]**	
Ferrier and others (2004)	**~5500 to 8900 yrs**	**Cosmogenic Radionuclides**			**~695**	
CDF/Stillwater Sciences (1999)	**1958-1997**	**Office Assessment**				**856**

Measurements made in water year 2001 by Koehler (2001) in the South Fork Noyo River indicate suspended sediment transport of 25 t mi^{-2} yr^{-1} in 2001. Assuming that 30 percent of the total sediment load is transported as bedload, this gives a sediment yield of only 36 t mi^{-2} yr^{-1}. Koehler (2001) also found that 50 percent of the total suspended sediment load originated in a downstream stretch of river channel between major tributaries that includes only 10 percent of the watershed area, which indicates the potential importance of stream channel sediment sources.

In contrast to the relatively small sediment yields reported by Koehler (2001), Benda (2004a) determined that streambank and creep erosion in an upstream tributary to the South Fork Noyo River was producing 1,376 t mi^{-2} yr^{-1} of stream sediment. This difference between up and down stream measurements can be partly explained by the recognizing that Koehler's measurements were limited to a single, relatively dry year, while Benda's results represent an average over several decades that include some of the largest storms on record. In effect, the large, upstream sediment yields reported by

[13] Estimates do not include the solute erosion component.
[14] Griggs and Hein (1980) used a combination of regional sediment yields, basin drainage areas, LANDSAT imagery, and existing sediment data to estimate sediment loads.

Table 2. Sediment Yield Summary.

Watershed Name	Source of Estimate	Period (years)	Area (mi^2)	Mass Wasting Erosion Sources ($t\ mi^{-2}\ yr^{-1}$)									
				Hillslope	Road	Skid Trail	Railroad	Harvest	Grass.	Shallow	Deep	Bkgrd.	Total
Little NF Noyo	Benda (2004a) (1)	<37	13.18	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
South Fork Noyo	Koehler (2001) (2)	2001	27.32	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Upper Noyo	MRC (2000)	1958-1998	55.64	**189**	**53**	NA	NA	NA	NA	NA	NA	NA	**242**
Upper Noyo	U.S. EPA (1999)	1953-1978	52.24	NA	**81**	NA	**4**	**30**	NA	NA	NA	**104**	**219**
Upper Noyo	U.S. EPA (1999)	1979-1999	52.24	NA	**106**	NA	**5**	**7**	NA	NA	NA	**148**	**266**
Noyo River	U.S. EPA (1999) (3)	1953-1978	113.00	NA	**53**	NA	**33**	**14**	NA	NA	NA	**83**	**183**
Noyo River	U.S. EPA (1999) (3)	1979-1999	113.00	NA	**76**	NA	**6**	**20**	NA	NA	NA	**99**	**201**
Noyo River	Griggs (1980) (2)	1955-1980	113.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
S+U Big River	MRC (2003) (4)	1970-2000	69.70	**159**	**196**	NA	NA	NA	NA	NA	NA	NA	**355**
Big River	U.S. EPA (2001)	1953-1978	181.00	NA	**225**	**64**	NA	**195**	**49**	NA	NA	**199**	**732**
Big River	U.S. EPA (2001)	1979-2000	181.00	NA	**116**	**18**	NA	**87**	**30**	NA	NA	**146**	**397**
Big River	Griggs (1980) (2)	1955-1980	181.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
JDSF WWAAs	CDF (1999)	1978-1997	156.00	NA	NA	NA	NA	NA	NA	**195**	**26**	NA	**221**
SF Caspar Creek	This EIR	1963-2002	1.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SF Caspar Creek	Lewis (1998) (5)	1972-1978	1.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NF Caspar Creek	This EIR	1963-2002	1.83	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NF Caspar Creek	Lewis (1998) (5)	1990-1996	1.83	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Caspar Creek	Ferrier (2004) (6)	>5000	8.38	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Watershed Name	Source of Estimate	Period (years)	Creep ($t\ mi^{-2}\ yr^{-1}$)	Surface Erosion Sources ($t\ mi^{-2}\ yr^{-1}$)					Stream ($t\ mi^{-2}\ yr^{-1}$)		Load ($t\ mi^{-2}\ yr^{-1}$)		Sed. Yield ($t\ mi^{-2}\ yr^{-1}$)
				Road	Skid Tr.	Harvest	Bkgrd.	Total	Bank	Channel	Pre-Log	Increase	
Little NF Noyo	Benda (2004a) (1)	<37	**316**	NA	NA	NA	NA	NA	**1060**	NA	NA	NA	**1,376**
South Fork Noyo	Koehler (2001) (2)	2001	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**36**
Upper Noyo	MRC (2000)	1958-1998	NA	**102**	**54**	NA	NA	**156**	NA	NA	NA	NA	**398**
Upper Noyo	U.S. EPA (1999)	1953-1978	NA	**149**	**50**	NA	**75**	**274**	ND	ND	NA	NA	**493**
Upper Noyo	U.S. EPA (1999)	1979-1999	NA	**172**	**19**	NA	**75**	**266**	ND	ND	NA	NA	**532**
Noyo River	U.S. EPA (1999) (3)	1953-1978	NA	**136**	**26**	NA	**75**	**237**	**200**	ND	NA	NA	**620**
Noyo River	U.S. EPA (1999) (3)	1979-1999	NA	**175**	**16**	NA	**75**	**266**	**200**	ND	NA	NA	**667**
Noyo River	Griggs (1980) (2)	1955-1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**2,157**
S+U Big River	MRC (2003) (4)	1970-2000	NA	**271**	**90**	NA	NA	**361**	NA	NA	NA	NA	**716**
Big River	U.S. EPA (2001)	1953-1978	**85**	**55**	**28**	NA	NA	**83**	**74**	NA	NA	NA	**974**
Big River	U.S. EPA (2001)	1979-2000	**63**	**84**	**10**	NA	NA	**94**	**54**	NA	NA	NA	**608**
Big River	Griggs (1980) (2)	1955-1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1,343**
JDSF WWAAs	CDF (1999)	1978-1997	**29**	**428**	NA	NA	**29**	**457**	NA	**57**	NA	NA	**764**
SF Caspar Creek	This EIR	1963-2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**440**
SF Caspar Creek	Lewis (1998) (5) (6)	1972-1978	NA	NA	NA	NA	NA	NA	NA	NA	**171**	**787**	**486**
NF Caspar Creek	This EIR	1963-2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**495**
NF Caspar Creek	Lewis (1998) (5)	1990-1996	NA	NA	NA	NA	NA	NA	NA	NA	**76**	**59**	**135**
Caspar Creek	Ferrier (2004) (6)	>5000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**639**

(1) Creep and bank erosion only. (2) 30% bedload added. (3) Includes streambank sediment. (4) Excludes Leonardo Lake and Martin Creek. (5) Calculated from reported loads and post-harvest % increases. (6) Corrected for sampling bias. (7) Corrected for 8% soluble load. S+U = South + Upper. NA = Not applicable. ND = No data.

Benda may be providing the stored sediments that are the source of Koehler's downstream findings. These findings also serve as an example, and warning, about the extreme variability of annual sediment production and the difficulty of representing sediment yield with a single number

Results of the Caspar Creek Studies reported by Lewis (1998) also give contrasting pictures of sediment yields from similar, small watersheds. Sediment production in the South Fork of Caspar Creek following 1970s tractor logging, with roads located near streams, was increased by nearly 212 percent to a total of over 486 t mi^{-2} yr^{-1}. In the nearby North Fork of Caspar Creek, a combination of skyline and tractor logging in the late 1980s, using modern Forest Practice Rules and upslope roads, increased the rate of sediment production by 89 percent to a total of only 135 t mi^{-2} yr^{-1}. Unfortunately, the loads measured in these two time periods cannot be compared directly because of generally higher flows during the earlier South Fork Study, but the percentage increase in sediment production from the South Fork logging was 2.4 times greater than in the North Fork Study. It is also interesting to note that the difference between longer-term estimates of sediment yield from the North and South Forks of Caspar Creek reported in this EIR is much smaller.

Discussion

Based on the work completed by Koehler and others (2001) and Benda and Associates (2004a), the percentages of sediment yield attributed to recent timber management in the Noyo and Big River basins as part of the TMDL documents appear to be too high. In a comprehensive review of the U.S. EPA's TMDL sediment yield estimates for seven North Coast watersheds (including Noyo and Big Rivers), Bedrossian and Custis (2002) reported that the natural/background rates of sedimentation in some cases were underestimated by at least an order of magnitude. The reasons for this included: 1) underestimates of erosion and sedimentation from deep-seated landslides, 2) tectonic uplift and erosion rates not considered, 3) lack of reference to past regional sediment source studies, 4) under-representation of legacy effects from past land use, 5) areas of significant natural/background sediment generation not included in analysis, and 6) inadequate consideration of impacts from land uses other than timber management.

For the Noyo River TMDL studies, Bedrossian and Custis (2002) state that even though deep-seated landslides were mapped in conjunction with TMDL development, deep-seated landslides were assumed to contribute little sediment except that derived from sheetwash or gullying processes (Matthews 1999). Virtually all large, dormant landslides were eliminated during the sediment source analysis. Bedrossian and Custis (2002) found that similar methods were used for the Big River sediment source analysis.

Kramer and others (2001) analyzed timber harvest and sediment loads in nine TMDL studies on the North Coast (including the Noyo River) and concluded that the TMDL sediment source analyses cannot distinguish whether post-Forest Practice Rule road-related sediment delivery originated from older roads or roads constructed under the current rules. Kramer and others (2001) state: "Although the degree of uncertainty depends upon the methodology used, the range of uncertainty in sediment source analyses is generally on the order of 40-50% (Raines and Kelsey 1991, Stillwater Sciences 1999). Methodological constraints (e.g., estimates of landslide frequency, areal extent, depth, age, bulk density, estimates of landslide delivery ratio, and natural temporal variability in erosion-triggering storms events) suggest that "this uncertainty may be too high to reliably detect differences between land uses or recent changes in land use practices such as those introduced in 1973 under the Z'berg-Nejedly Forest Practices Act (FPA) of 1973 (CCR 14 Chapters 4 and 4.5)." Similarly, Knopp (1993) found that post-modern Forest Practice Rule impacts cannot be easily or accurately extricated from legacy conditions after conducting a study of factors affecting coldwater fish habitat on the North Coast.

In addition to the work of Ferrier and others (2004) and Kirchner and others (2003), Constantine and others (2003) have studied very long-term sediment rates in a western Mendocino County river basin. They recently cored floodplains in the Navarro River basin to report on long-term sedimentation rates and found that land use change (i.e., old-growth and young-growth logging) has not had a significant impact in altering long-term average sediment deposition rates in this watershed.[15] Rather, climate and tectonics are suggested as the dominant controls on the evolution of Navarro River floodplains over hundreds to thousands of years. Constantine and others (2003) caution, however, that roads and large wood in low order drainages are storing large quantities of logging related sediment, preventing this material from escaping the lowest order tributaries and being deposited on established floodplains.

The work of Koehler and others (2001), Benda and Associates (2004a), Bedrossian and Custis (2002), Constantine and others (2003), each of which used different approaches to estimate sediment loading rates, combined with actual measurements made in Caspar Creek (USFS-PSW 2003, Dewey and others (2003), Ferrier and others 2003a,b), document that current timber operations under the modern Forest Practice Rules are unlikely to be responsible for producing 43 to 52% of the current sediment load, as reported by the TMDL work for Noyo and Big Rivers, respectively. The natural/background sediment generation in these North Coast watersheds is shown to be a considerably higher proportion of the total sediment load than that stated in the TMDL documents, since: 1) sediment from historic logging practices stored in low gradient channel networks that is being attributed to modern timber operations in the TMDLs is not supported by qualitative observational evidence or quantitative measurements; 2) channel bank erosion measured by researchers is substantially higher than that assumed in the TMDLs; and 3) long-term erosion rates associated with large mass movement events with relatively long recurrence intervals are documented to be a significant contributor to the background rate of sediment generation.
It is apparent from sediment source area studies completed for these watersheds and other hillslope monitoring work conducted in California that a majority of sediment

[15] The Navarro River mouth is about 8 miles to the south of the mouth of Big River.

related to current forest management activities is coming from road surfaces, road-related landslides, and road stream crossings (CDF 1999, Cafferata and Munn 2002, Bawcom 2003, Maahs and Barber 2001, MacDonald and others, in press).[16] Mass wasting (i.e., in-unit landslides) and surface erosion associated with timber harvesting appears to be a much smaller source of sediment (Figure 8). For example, Bawcom (2003) evaluated fifty clearcut units harvested from 1982 to 1994 in four watersheds to determine landslide occurrence in even-aged management units on JDSF following storms with the ability to trigger shallow rapid landslides. Of the 32 landslides identified in this study, all but four were associated with older roads, landings, and skid trails, and there was little evidence that vegetation removal associated with even-aged management in these coast redwood dominated watersheds was a significant contributor to slope instability or reactivations of dormant landslides for operations conducted under the modern Forest Practice Rules. In general, data collected to date in northwestern California areas with sprouting coast redwood does not show a clear relationship between clearcutting under the current FPR regime (sometimes in combination with requirements included in landscape level documents) and landslide rates. Most of the recent mass wasting features are related to roads and landings (Cafferata and Spittler 2004). Similarly in the central Sierra Nevada, MacDonald and others (in press) found surface erosion from roads was nearly an order of magnitude higher than that generated from harvested areas. On a national scale, Toy (1982) documents that the erosion rate associated with roads is an order of magnitude greater than that for harvesting and ground-based yarding.

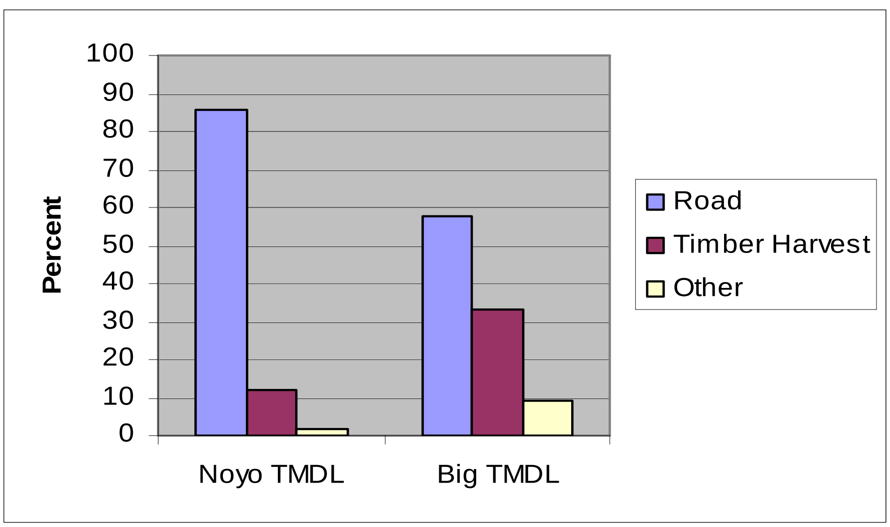

Figure 8. TMDL estimates of the percentage of management-related sediment resulting from roads, timber harvesting, and other sources for the Noyo and Big River basins (U.S. EPA 1999, 2001).

[16] This was not found to be the case for the North Fork of Caspar Creek, due to the fact that the roads were located high on the ridges, and only small spur roads off of ridges were built for the recent timber harvesting. It has also not been found for highly erodible watersheds such as Bear and Jordan Creeks in southern Humboldt County with very high rates of inner gorge landsliding (PWA 1998, 1999).

The main lesson to be learned from the sediment studies completed to date in the JDSF EIR assessment area is that roads and watercourse crossings need to be designed, constructed, surfaced, and maintained in a manner that will reduce long-term sediment yield. This can best be accomplished by application of a road management plan, which has been included as part of the JDSF Management Plan. Much of management-related sediment originates from points at or near where streams are crossed by roads, from roads with inside ditches, and from large road fill failures (Furniss and others 1991, Weaver and Hagans 1994). Inventorying and improving JDSF's roads to reduce sediment yield is needed due to the legacy of a road network partially relying on out-dated drainage systems and old segments located along watercourse channels. The road management plan will provide a systematic program to ensure that the design, construction, use, maintenance, and surfacing of the Forest's roads, road landings, and road crossings will be conducted to avoid, minimize, or mitigate adverse impacts to the aquatic habitats supporting anadromous fish, amphibians, and other aquatic organisms. Watercourse crossing inventories are an important component of this road management plan and can reduce sediment yield to streams by locating and prioritizing repair for high risk structures (Flanagan and others 1998, Flanagan and Furniss 1997).

The sediment data also support avoiding or intensively mitigating timber management activities (i.e., road building, tractor skidding, and other ground disturbing activities) on high risk portions of the landscape, such as unstable features, inner gorge areas along stream channels, and headwall swales located near ridges. Mass wasting avoidance strategies that include on-the-ground site review and recommendations by qualified professionals are included in the JDSF Draft Forest Management Plan (DFMP) and have been shown to be effective in reducing shallow, rapid landslide features in terrain that is more unstable than the JDSF EIR assessment area in Humboldt County (Marshall 2002, Marshall 2003, Smelser 2001).[17] The DFMP also calls for making use of the California Geological Survey's Relative Landslide Potential maps for identifying potentially unstable areas that should be avoided or carefully evaluated in the field prior to conducting potentially destabilizing activities such as road construction.

Similar efforts are underway on the industrial timberlands owned by Mendocino Redwood Company (MRC) and Hawthorne Timber Company (managed by Campbell Timberland Management) in the JDSF EIR assessment area. MRC has nearly completed a Habitat Conservation Plan (HCP) and Natural Communities Conservation Plan (NCCP) for its ownership in western Mendocino County. Both companies are actively improving their road network to reduce sediment yields to watercourses. Improved road-related practices and riparian zone protection throughout the vast majority of the JDSF EIR assessment area have been mandatory since the passage of the BOF's Threatened and Impaired Watersheds Rule Package, which became effective on July 1, 2000. The extensive efforts that JDSF, MRC, HTC, and other landowners have taken to reduce road sedimentation are documented in section VIII.2.1 in the EIR.

[17] Marshall (2002, 2003) and Smelser (2001) report on the presence of landslide features in watersheds located in southern Humboldt County on Pacific Lumber Company timberlands.

Conclusions

Key conclusions that can be drawn from this review of sediment studies conducted within the JDSF EIR assessment area include:

- Sediment production estimates have ranged from approximately 400 to 1900 t mi^{-2} yr^{-1}, depending on the watershed being considered, time frame analyzed, and analysis method used.
- Average annual sediment yield measured over 40 years at Caspar Creek is within this range (approximately 500 t mi^{-2} yr^{-1}). Recent work using cosmogenic radionuclides in Caspar Creek has determined the average erosion rate over 5500 to 8900 years for this basin is approximately 695 t mi^{-2} yr^{-1}, which is about twice the mean of sediment measurements made over the past 40 years when corrections for oversampling from 1963 to 1975 are incorporated (Ferrier and others 2004). Sediment delivery to Caspar Creek over the past four decades is somewhat lower than the long-term average rate of sediment production in this watershed, likely to due to the fact that sediment delivery to streams is highly episodic and few exceptionally large storm events that dominate long-term average erosion rates have occurred over the past 40 years (Ferrier and others 2004).
- Multiple sources of information (Noyo and Big River TMDL, Caspar Creek watershed study, JDSF draft HCP/SPY watershed assessment) indicate that improvements in management practices since implementation of the modern Forest Practice Act (i.e., after 1974) have resulted in decreases in road-related mass wasting and harvest-related surface erosion.
- While TMDL studies have estimated that 43 to 52% of the total sediment yield is produced by timber operations in the Noyo and Big River basins, respectively, more recent analysis and data show that: (1) natural/ background sediment production rates are probably much higher than reported in the TMDL documents, and 2) in-channel storage of sediment from historic logging operations is a likely source of some of the sediment that TMDLs have attributed to current timber management practices.
- Sediment budgets prepared for Noyo and Big River watershed assessments shows that road-related sediment (both from road surface erosion and road-related landslides) is a dominant source of sediment from current management activities, while in-unit hillslope erosion is a much smaller contributor.
- The Road Management Plan and the mass wasting avoidance strategy included in the JDSF Management Plan are expected to significantly reduce sediment yield associated with JDSF timber management activities.

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Attachments

Table 7—Big River Watershed Sediment Source Analysis, Preliminary Sediment Budget, Sediment Input Summary, Average Annual Unit Area Rates, reproduced from the Big River TMDL for sediment (U.S. EPA 2001)

Table 27—Big River Sediment Source Analysis, Road Construction History by Planning Watershed and Sub-Watershed, reproduced from Matthews (2001).

Table 14—Summary of Sediment Inputs to the Noyo River Watershed as Derived from Data Presented by Matthews (1999), reproduced from the Noyo River TMDL for sediment (U.S. EPA 1999).

Table 1—Preliminary sediment inputs and road density by planning watershed for Mendocino Redwood Company timberlands in the Big and Noyo River basins (C. Surfleet, MRC, electronic communication).

TABLE 7
BIG RIVER WATERSHED SEDIMENT SOURCE ANALYSIS
Preliminary Sediment Budget -- Sediment Input Summary -- Average Annual Unit Area Rates

STUDY PERIOD	NO. OF YEARS	INPUTS: BKGRND LANDSLIDES (t/mi2/yr)	TOTAL MGMT LANDSLIDES (t/mi2/yr)	HARVEST RELATED LANDSLIDES (t/mi2/yr)	ROAD RELATED LANDSLIDES (t/mi2/yr)	SKID TRAIL LANDSLIDES (t/mi2/yr)	GRASSLAND LANDSLIDES (t/mi2/yr)	TOTAL LANDSLIDES (t/mi2/yr)	SURFACE EROSION: BKGRND (t/mi2/yr)	SURFACE EROSION: SKID TRAIL (t/mi2/yr)	SURFACE EROSION: ROAD (t/mi2/yr)	FLUV/BANK EROSION (t/mi2/yr)	TOTAL NON-MGMT INPUTS (t/mi2/yr)	TOTAL MGMT INPUTS (t/mi2/yr)	TOTAL INPUTS (t/mi2/yr)
1921-1936	16	175	284	284	0	0	0	459	75	16	6	65	315	306	621
		28%	46%	46%	0%	0%	0%	74%	12%	3%	1%	10%	51%	49%	100%
1937-1952	16	179	1,336	847	364	3	122	1,515	75	8	23	65	319	1,367	1,686
		11%	79%	50%	22%	0%	7%	90%	4%	0%	1%	4%	19%	81%	100%
1953-1965	13	203	915	341	397	94	83	1,118	87	22	46	75	365	983	1,348
		15%	68%	25%	29%	7%	6%	83%	6%	2%	3%	6%	27%	73%	100%
1966-1978	13	194	148	48	52	34	14	342	83	33	64	72	349	245	594
		33%	25%	8%	9%	6%	2%	58%	14%	6%	11%	12%	59%	41%	100%
1979-1988	10	131	295	81	149	31	34	426	56	13	74	49	236	382	618
		21%	48%	13%	24%	5%	6%	69%	9%	2%	12%	8%	38%	62%	100%
1989-2000	12	159	214	92	88	7	27	373	68	7	93	59	286	314	600
		27%	36%	15%	15%	1%	5%	62%	11%	1%	16%	10%	48%	52%	100%
	80	19%	60%	33%	19%	3%	5%	79%	8%	2%	5%	7%	33%	67%	100%
1921-2000	80	175	566	313	178	26	48	741	75	16	47	65	315	629	944

Source: GMA 2001

TABLE 27
BIG RIVER SEDIMENT SOURCE ANALYSIS
ROAD CONSTRUCTION HISTORY BY PLANNING WATERSHED AND AND SUB-WATERSHED

PLANNING WATERSHED Sub-Watershed	Drainage Area	MILES OF ROAD CONSTRUCTED IN PERIOD 1921-1936	1937-1952	1953-1965	1966-1978	1979-1988	1989-2000	TOTAL BY PW OR SW (mi)	% TOTAL WATERSHED ROAD MILES (mi)
BIG RIVER HEADWATERS	**32.78**	**0.00**	**41.53**	**53.99**	**27.37**	**41.53**	**69.36**	**233.8**	**18.8%**
	% of PW Total	**0.0%**	**17.8%**	**23.1%**	**11.7%**	**17.8%**	**29.7%**		
Upper Mainstem Big River	12.55	-na-	16.05	26.70	5.33	12.56	24.13	84.8	6.82%
Martin Creek	9.28	-na-	16.28	15.05	8.33	4.66	22.47	66.8	5.38%
Lower Mainstem Big River	10.95	-na-	9.20	12.24	13.71	24.31	22.76	82.2	6.62%
NORTH FORK BIG RIVER	**43.49**	**3.60**	**82.15**	**71.11**	**68.16**	**19.70**	**44.27**	**289.0**	**23.3%**
	% of PW Total	**1.2%**	**28.4%**	**24.6%**	**23.6%**	**6.8%**	**15.3%**		
Upper North Fork Big River	8.46	-na-	13.31	18.59	7.79	3.41	16.76	59.9	4.82%
James Creek	6.96	-na-	12.29	17.70	4.20	7.01	10.30	51.5	4.15%
Chamberlain Creek	12.28	0.52	27.54	17.26	14.27	2.04	2.29	63.9	5.15%
East Branch North Fork Big	8.06	-na-	10.14	4.45	26.62	2.75	9.42	53.4	4.30%
Lower North Fork Big River	7.73	3.08	18.87	13.11	15.28	4.49	5.50	60.3	4.86%
MIDDLE BIG RIVER	**17.85**	**13.51**	**19.68**	**40.90**	**7.39**	**19.52**	**53.20**	**154.2**	**12.4%**
	% of PW Total	**8.8%**	**12.8%**	**26.5%**	**4.8%**	**12.7%**	**34.5%**		
Middle Big River	13.07	8.45	12.34	30.87	6.84	16.37	40.78	115.7	9.31%
Two Log Creek	4.78	5.06	7.34	10.03	0.55	3.15	12.42	38.6	3.10%
SOUTH FORK BIG RIVER	**54.46**	**1.83**	**82.57**	**72.32**	**69.08**	**22.86**	**67.94**	**316.6**	**25.5%**
	% of PW Total	**0.6%**	**26.1%**	**22.8%**	**21.8%**	**7.2%**	**21.5%**		
Upper South Fork Big River	8.32		17.59	8.77	1.60	1.56	4.76	34.3	2.76%
Middle South Fork Big River	11.17		20.85	17.90	5.94	1.22	11.81	57.7	4.65%
Daugherty Creek	16.65		33.83	26.38	18.53	5.06	25.17	109.0	8.77%
Lower South Fork Big River	18.32	1.83	10.30	19.27	43.01	15.02	26.20	115.6	9.31%
LOWER BIG RIVER	**32.47**	**48.83**	**30.35**	**22.55**	**36.19**	**38.81**	**71.77**	**248.5**	**20.0%**
	% of PW Total	**19.6%**	**12.2%**	**9.1%**	**14.6%**	**15.6%**	**28.9%**		
Lower Big River	7.69	20.88	3.65	2.21	18.85	4.43	13.28	63.3	5.10%
Little North Fork	12.49	12.03	18.62	11.21	4.31	13.89	24.79	84.8	6.83%
Laguna Creek	5.07	4.14	5.13	2.14	3.90	7.46	18.25	41.0	3.30%
Big River Estuary	7.22	11.78	3	6.99	9.13	13	15.45	59.3	4.78%
TOTAL BIG WATERSHED	**181.05**	**67.77**	**256.28**	**260.87**	**208.19**	**142.41**	**306.54**	**1242.06**	**100.0%**
% of Total Roads		**5.46%**	**20.63%**	**21.00%**	**16.76%**	**11.47%**	**24.68%**	**100.00%**	

Notes: Base road data from CDF, substantially added to and corrected by GMA.
Eastern portion of watershed not covered by 1936 aerial photographs.
Road segments not codified by year by CDF or mapped into specific period by John Coyle are all included in 2000 period.

Table 14: Summary of Sediment Inputs to the Noyo River Watershed as Derived from Data Presented by Matthews (1999)

Time period	Background Sediment Delivery (tons/mi²/yr)			Management-related Sediment Delivery (tons/mi²/yr)						Total (tons/mi²/yr)
	Mass wasting	Surface erosion	Stream bank erosion*	Mass wasting--Railroad	Mass wasting--Harvest	Mass wasting--Roads	Surface erosion--Roads	Surface erosion--Skid trails	Fluvial erosion--Roads	
HAA (27.17 mi²)										
1933-1957	24	75		0	2	0	41	18	unknown	160+
1958-1978	67	75		8	25	83	156	46	unknown	460+
1979-1999	140	75		9	8	106	162	17	unknown	517+
NFAA (25.07 mi²)										
1933-1957	6	75		0	0	6	11	1	unknown	99+
1958-1978	145	75		0	35	78	142	55	unknown	530+
1979-1999	157	75		0	5	106	182	21	unknown	546+
SFAA (27.46 mi²)										
1933-1957	305	75		13	9	14	74	3	unknown	493+
1958-1978	94	75		7	2	19	132	5	unknown	334+
1979-1999	98	75		0	5	18	148	13	unknown	357+
MAA (33.3 mi²)										
1933-1957	46	75		157	0	2	17	2	unknown	299+
1958-1978	40	75		100	0	37	118	4	unknown	374+
1979-1999	22	75		12	53	76	201	13	unknown	452+
NOYO RIVER WATERSHED										
1933-1957	95	75	200	49	3	5	35	6	unknown	468+
1958-1978	83	75	200	33	14	53	136	26	unknown	620+
1979-1999	99	75	200	6	20	76	175	16	unknown	667+
1933-1999	91	75	200	31	12	42	111	15	unknown	577+

*Stream bank erosion was estimated by applying a regional figure to all but about 30% of Noyo River watershed stream miles. The 30% excluded from the calculation represent the Noyo River itself that from limited observation appears to have relatively stable banks. The calculation was not broken down by assessment area. As such, the total sediment delivery for each assessment area does not include streambank erosion and is therefore underestimated. The total estimates of sediment delivery per assessment area and for the whole watershed are also lacking figures for fluvial erosion from roads. For this reason, too, the calculation results are underestimates.

** Any discrepancies between Table 13 and Table 14 are the result of rounding numbers up and down.

Table 1. Preliminary sediment inputs and road density by planning watershed for Mendocino Redwood Company timberlands in the Big and Noyo River basins (data provided by Mr. Chris Surfleet, MRC, Fort Bragg, CA).

Calwater Planning Watershed	Watershed Analysis Unit	Total Sediment Inputs ($tons/mi^2/yr^2$)	Total Sediment Inputs ($yd^3/mi^2/yr$)	Non-Road Mass Wasting Sediment Input (%)	Road Mass Wasting Sediment Input (%)	Road Surface and Point Source Sediment Input (%)	Skid Trail Sediment Inputs (%)	Road Density (mi/mi^2)
Dark Gulch	Big River	230	180	48%	9%	ND	43%	ND
East Branch NF Big River	Big River	940	720	15%	11%	43%	32%	ND
Laguna Creek	Big River	ND	ND	ND	ND	ND	ND	ND
Lower North Fork Big River	Big River	870	670	28%	24%	31%	17%	ND
Martin Creek	Big River	ND	ND	ND	ND	ND	ND	ND
Mettick Creek	Big River	1050	810	18%	30%	19%	32%	ND
Rice Creek	Big River	740	570	37%	11%	49%	3%	ND
Russell Brook	Big River	910	700	10%	22%	48%	20%	ND
South Daugherty Cr	Big River	990	760	15%	27%	39%	18%	ND
Two Log Creek	Big River	1400	1080	20%	23%	21%	36%	ND
Hayworth Creek	Noyo River	690	530	50%	3%	14%	33%	6.2
McMullen Creek	Noyo River	490	380	53%	20%	11%	16%	6.8
Middle Fork Noyo River	Noyo River	440	340	37%	2%	32%	29%	7.5
North Fork Noyo River	Noyo River	370	280	28%	8%	31%	33%	8.1
Olds Creek	Noyo River	380	290	32%	27%	36%	5%	7.4
Redwood Creek	Noyo River	210	160	21%	14%	43%	22%	7.7
Upper Noyo River	Noyo River	730	560	26%	59%	15%	ND	14.7