Appendix C: Sediment Source Assessment for the Lower Eel River Watershed

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Section C.1: Methodology

The sediment source assessment for the Lower Eel River and tributaries was conducted to identify the relative contribution of sediment delivered to stream channels. This involved identifying, quantifying, and classifying sediment sources and providing information pertaining to the management association of sediment production. The sediment source assessment covers the period 1955 – 2003, in order to capture the sediment delivered during large storms (especially 1964 and 1997). There were two general components to the sediment source assessment: an analysis on lands not owned by PALCO (the largest private landholder in the basin) and a separate analysis on PALCO-owned land in the Lower Eel River watershed. A channel migration zone study was also performed along the main channel. Methods associated with each study component are described below.

Non-PALCO Lands

I. Background Information/Reference Materials for the Sediment Source Assessment Conducted on Non PALCO lands in the Lower Eel River TMDL Study Area

Source and reference information for the Non PALCO Lower Eel River TMDL sediment source assessment study included:

- Historical aerial photography for the Lower Eel River TMDL study area (including the 1966, 1988 and 2003 air photo sets).
- USGS 7.5 minute quadrangle 10 meter digital elevation model (DEM)
- Geology of the Cape Mendocino, Eureka, Garberville, and Southwestern Part of the Hayfork 30 x 60 Minute Quadrangles and Adjacent Offshore Area, Northern California (McLaughlin et al., 2003)
- California Department of Forestry and Fire Protection, Fire and Resource Assessment Program 1:24000 GIS road layer
- Unpublished data from bank erosion inventory conducted as part of the PALCO Freshwater Creek Watershed Analysis used to develop bank erosion estimate for the Upper Salt River, Lower Eel River, and Larabee Creek terrain types.
- Unpublished data from bank erosion inventory conducted as part of the PALCO Upper Eel River Watershed Analysis used to develop bank erosion estimate for the Upper Salt River, Lower Eel River, and Larabee Creek terrain types.
- Unpublished data from past road sediment source inventory conducted as part of the PALCO Lower Eel/Eel Delta Watershed Analysis used to develop episodic road related sediment delivery estimate for the Upper Salt River and Lower Eel River terrain types.
- Unpublished data from past road sediment source inventory conducted as part of the PALCO Van Duzen River Watershed Analysis used to develop episodic road related sediment delivery estimate for the Larabee Creek terrain types.

II. Terrain Type Delineation

The non PALCO Lower Eel River TMDL study area was delineated into 12 terrain types based on location, vegetation type (forested vs. un-forested) and geology (young vs. old). Young geology includes Wildcat Group and younger lithologies (i.e. terrace and marine sediments and alluvium). Old geology includes the Yager Formation and older lithologies (i.e. Franciscan sandstone and mélange).

The 12 terrain types for non PALCO lands in the Lower Eel River TMDL study area include:
1. Eel River Floodplain/Terrace Un-forested Young Geology
2. Eel River Floodplain/Terrace Forested Young Geology
3. Salt River Floodplain/Terrace Un-forested Young Geology
4. Salt River Floodplain/Terrace Forested Young Geology
5. Upper Salt River Un-forested Young Geology
6. Upper Salt River Forested Young Geology
7. Lower Eel River Un-forested Young Geology
8. Lower Eel River Forested Young Geology
9. Lower Eel River Un-forested Old Geology
10. Lower Eel River Forested Old Geology
11. Larabee Creek Un-forested Old Geology
12. Larabee Creek Forested Old Geology

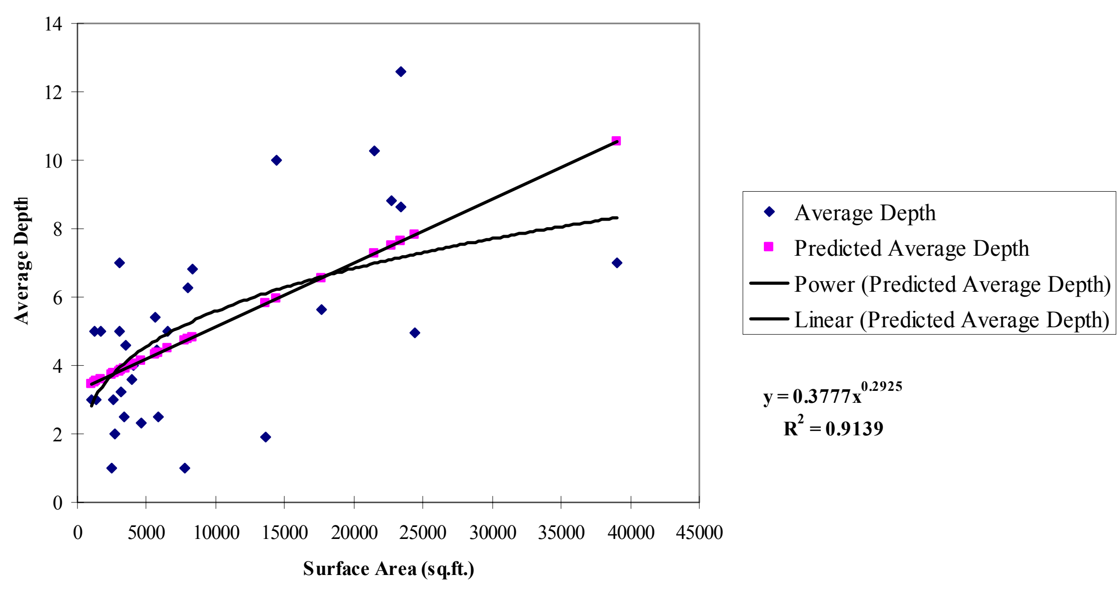
III. Analysis Assumptions

The following assumptions were used in developing sediment delivery rates and estimates for non PALCO lands in the Lower Eel River TMDL study area. The sediment delivery rates used in the Lower Eel River TMDL sediment source investigation were developed from existing studies either within watersheds contained in the Lower Eel River TMDL study area (i.e. Lower Eel River/Delta and Upper Eel River watershed analysis areas), or from studies in adjacent watersheds with similar geomorphic terrains and geologies (i.e. Van Duzen WA). Existing data from watersheds within and adjacent to the study area was determined to be the most relevant and representative for the study area.

1. Conversion factor for yds^3 to tons = 1.4 $tons/yd^3$. This conversion factor is based on previous studies conducted in nearby watersheds. The same conversion factor was used in the Upper Eel watershed analysis (PALCO, 2007).
2. Time period = 49 years (1955-2003). Consistent with previous sediment source analyses, 1955 was selected as the beginning of the study period. This year has been selected because it is assumed that features that have occurred in the previous one to two decades can be readily identified during air photo analysis. Specifically, many of the landslide features on the air photos showed little to no re-vegetation and are therefore considered more recent. As a result, the time frames are defined as 1955-1966 (12 years), 1967-1988 (22 years), and 1989-2003 (15 years).
3. Depth for landslides, debris flow sources (excluding earthflows) was calculated using a power equation developed from 36 field verified air photo identified landslides from the PALCO Upper Eel River Watershed Analysis Mass Wasting Module, where Depth = $0.3777 \times Area^{0.2925}$ (Figure 1). Past TMDL studies that have utilized area depth regression analysis to develop depth estimates for landsides include the North Fork Eel TMDL, Upper Eel River TMDL, Middle Main Eel TMDL, and Van Duzen TMDL. PALCO studies that have utilized an area depth regression analysis include Freshwater Creek Sediment Source Investigation and Watershed Analysis, Bear Creek Sediment Source

Investigation, Jordan Creek Sediment Source Investigation, Lower Eel River/Delta Watershed Analysis, and Upper Eel River Watershed Analysis.

Figure 1. Depth Regression: Line Fit Plot with Power Trendline



4. Torrent tracks and gullies were calculated using an equation developed from studies conducted by PWA in the Jordan Creek (1999b) and Bear Creek (1998) watersheds (flow into the lower Eel) Torrent track erosion = Length * 2.91 yds^3/ft. This rate may be low for gullies, and as a result may underestimate the sediment delivery from these features. The rate is based on torrent track erosion which assumes channel-like erosion with lateral bank collapse and channel down cutting. The process of gully erosion is different and may yield a larger erosion rate. Although the rate may be higher, applying a higher rate to the non road-related gullies identified in the TMDL analysis would only increase the total sediment delivery from air photo features by 0.7%, and the total sediment delivery from all sediment sources by 0.2%. Non road-related gullies are a minor input as compared to debris landslides, debris flows and torrent tracks.
5. Earthflow erosion was calculated using an average earthflow toe retreat rate applied to the width of the toe of the earthflow and an average toe depth. Earthflow erosion = Width of EF toe*16 ft average depth*1.82 ft retreat per year of earthflow activity. (See Section IV Methodology for Earthflow Sediment Delivery Estimate)
6. Bank erosion was calculated using annual rates developed from bank erosion inventories and past studies conducted as part of the PALCO Upper Eel River and Freshwater Creek Watershed Analyses. Annual bank erosion rates were developed according to Strahler stream order for the Larabee and Lower Eel River terrains (1^{st} order = 7.4 yds^3/mi/yr, 2^{nd} order =5.7 yds^3/mi/yr, 3^{rd} order = 11.7 yds^3/mi/yr, Class 1 streams or 4^{th} order or higher = 20 yds^3/mi/yr). Annual bank erosion rates for the Eel River Terraces/Floodplains and

Salt River Terraces/Floodplains were estimated from field bank erosion inventories conducted as part of this project (4 yds^3/mi/yr). (See Section V Methodology for Bank Erosion Estimate)

7. Estimates of road surface erosion were determined from SEDMODL analysis using the road construction history developed from historic aerial photography. (See Section VI Methodology for Road Surface Erosion (SEDMODL2) Analysis)
8. Episodic road-related erosion rates for the Lower Eel and Larabee terrains were derived from unpublished data from past road-related erosion studies conducted in the Lower Eel River and Van Duzen River watersheds as part of PALCO watershed analyses. The episodic road-related erosion rates were estimated at: 1) Upper Salt River Young geology and Lower Eel River Young geology = 75 yds^3/mi, 1.9 yds^3/mi/yr; 2) Lower Eel Old Geology = 315 yds^3/mi, 7.9 yds^3/mi/yr; 3) Larabee Old Geology = 240 yds^3/mi, 6 yds^3/mi/yr. Finally, Eel River Terrace/Floodplain and Salt River Terraces/Floodplains episodic road-related erosion rate were based on past road erosion inventory as part of this study and was estimated at 15 yds^3/mi or 0.4 yds^3/mi/yr. (See Section VII Methodology for Episodic Road Sediment Delivery Estimate)

IV. Methodology for Earthflow Sediment Delivery Estimate

Earthflow erosion and sediment delivery were estimated using an earthflow toe retreat or movement rate of approximately 1.82 ft/yr developed from previous studies in the Middle Fork Eel River (Department of Water Resources, 1982). A number of other past studies conducted in Redwood National Park (Nolan and Janda 1995; Swanston, Ziemer and Janda 1995; Harden, Colman and Nolan 1995) and the Van Duzen River (Kelsey, 1977) were reviewed for the development of the earthflow toe retreat rate. An average rate of 4.3 ft/yr was estimated for the Van Duzen River and Redwood Creek earthflows. These earthflows are much larger and more active than the earthflows identified in the Lower Eel River TMDL study area. The Middle Fork Eel River earthflow toe retreat rate was more applicable to the size of the earthflows in the study area.

The earthflow toe retreat rate of 1.82 ft/yr (Department of Water Resources, 1982) was applied to high annual precipitation years between 1955 and 2003 with a maximum earthflow displacement time period of 2 years for each high precipitation year (high precipitation years were selected to maintain consistency with previous studies). In order to be classified as a high annual precipitation year, annual rainfall had to exceed mean annual precipitation at the Scotia, California gage by at least 10%. Annual precipitation estimates were delineated from historic records from the Scotia gage (i.e., mean annual precipitation for Scotia from 1955 – 2003 was multiplied by 1.1 to determine the threshold of high precipitation; annual precipitation values that fell above this threshold were considered high precipitation years). High precipitation years with more frequent and long duration storms tend to trigger earthflow activity that can last over a period of two years.

Previous studies have shown that the duration of earthflow displacement can occur over a period of days to years (Harden, Colman and Nolan 1995). Based on studies conducted on the Minor Creek earthflow in Redwood Creek (Iverson 1984) and the Davilla Hill earthflow complex (Keefer and Johnson 1983), a duration of 2 years for cumulative earthflow displacement was applied to each high annual precipitation year to estimate earthflow sediment delivery on non

PALCO lands in the Lower Eel River TMDL study area. Earthflow activity was determined for the following years: 1957, 1958, 1959, 1960, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1981, 1982, 1983, 1984, 1985, 1995, 1996, 1997, 1998, 1999, and 2000. For estimates of earthflow sediment delivery we applied 4 years of activity for the 1955-1966 air photo time period (1957-1960), 14 years of activity for the 1966-1988 air photo time period (1969-1977 and 1981-1985), and 6 years of activity for the 2003 air photo time period (1995-2000).

V. Methodology for Bank Erosion Estimate

Estimates of bank erosion were calculated from rates developed from current and past bank erosion inventories conducted in the study area and in nearby watersheds. Bank erosion rates for the Eel River and Salt River Floodplain and Terrace areas were developed from a past bank erosion inventory conducted as part of the sediment source assessment on non PALCO lands in the Lower Eel River TMDL study area.

Approximately 7.8 miles of channel were inventoried in the Eel River/Salt River Floodplain and Terrace terrain types for evidence of past bank erosion occurring between 1955 and 2006. Tidally influenced channels (sloughs) were not sampled for bank erosion as part of this study. Slough channels mapped and named on the USGS topographic map were classified as tidally influenced. Bank erosion rates were not applied to tidally influenced channels. Sample bank erosion inventory reaches were selected randomly and by accessibility. Attributes for past bank erosion included bank erosion volume, sediment delivery %, bank erosion location, age of bank erosion and bank erosion cause (natural vs. anthropogenic). Between 1955 and 2006, approximately 1,500 yds^3 of bank erosion was identified along inventoried stream reaches resulting in an estimated unit bank erosion of 200 yds^3/mi and a bank erosion rate of 4 yds^3/mi/yr (note: bank erosion age is very difficult to determine in the field unless it was caused by a specific recorded event and is generally classified by decade rather than specific year).

Bank erosion rates for the Upper Salt River, Lower Eel River and Larabee Creek terrain types were developed from bank erosion inventories conducted as part of the 2006 PALCO Upper Eel River Watershed Analysis and 2000 Freshwater Creek Watershed Analysis (PALCO, 2007 and PALCO, 2000). Annual bank erosion rates were developed according to Strahler (Strahler, 1952) stream order. Specifically, bank erosion rates for the Upper Salt River, Lower Eel River and Larabee Creek terrain types were estimated as 7.4 yds^3/mi/yr for 1st order, 5.7 yds^3/mi/yr for 2nd order, 11.7 yds^3/mi/yr for 3rd order, and 20 yds^3/mi/yr for Class 1 streams or 4th order or higher.

The bank erosion rates were extrapolated to approximately 736 miles of stream channel on non PALCO lands in the TMDL study area. Approximately 15 miles of streams were identified in the Eel River Floodplain and Terrace terrain type and 29 miles were identified in the Salt River Floodplain and Terrace terrain type. Tidally influenced channels (sloughs) were not included in the miles of stream channel used to develop the bank erosion estimates. Nearly 53 miles of stream channel were identified in the Upper Salt River terrain types, 287 miles were identified in the Lower Eel River terrain types and 352 miles of stream channel were identified in the Larabee Creek terrain types.

The management allocation for bank erosion was estimated by multiplying the total extrapolated sediment delivery from bank erosion by the percent management allocation for each terrain type. Based on the bank erosion studies conducted in the Upper Eel Watershed Analysis (PALCO, 2007), management allocation was estimated as 60% natural and 40% land use associated (anthropogenic). The 60%-40% split was based on a bank erosion survey conducted as part of the Upper Eel River Watershed Analysis on PALCO lands. PWA conducted an inventory of stream channels by Strahler order in several sub-watersheds to determine bank erosion and stream side landslides sediment delivery estimates for the entire watershed analysis area. Channels were systematically inventoried, and each bank erosion or slide feature identified was mapped on an air photo and assessed for particular attributes such as erosion dimensions, sediment delivery, activity, land use association, erosion cause, geomorphic association, etc. Bank erosion estimates were developed from the field data and tallied by anthropogenic versus natural causes. From this analysis, 60% of the erosion was attributed to natural causes and 40% was attributed to anthropogenic land use practices. The 60% natural/40% management allocation breakdown was applied to the Upper Salt River, Lower Eel River and Larabee Creek terrain types.

Ninety percent (90%) of the bank erosion identified in the field studies conducted in the Eel River and Salt River Floodplain and Terrace terrain types was classified as having no apparent cause (natural) and 10% was classified as anthropogenic or management associated. As a result, we applied the 90% natural/10% management allocation in order to determine the estimate of bank erosion by management association. The management allocations in the Floodplain/Terrace terrain types reflect local bank erosion processes and do not necessarily reflect upslope hydrologic change due to management practices, roads or rural land use.

VI. Methodology for Road Surface Erosion (SEDMODL2) Analysis

To develop an estimate of road surface erosion for the Lower Eel TMDL study area, SEDMODL2 was applied to roads identified as part of the air photo analysis on non PALCO lands in the Lower Eel River TMDL study area. SEDMODL2 is a GIS-based model developed by NCASI (2003) to determine the portions of roads that directly and indirectly drain to streams. By employing a series of assumptions, the model provides an average annual sediment input (tons/yr) from road reaches that deliver road runoff and fine sediment to streams. To run, the model required a comprehensive GIS road layer that included all the pertinent roads on non PALCO lands within the Lower Eel River TMDL study area.

The comprehensive road history layer was developed for non PALCO lands by using the CDF FRAP 1:24,000 roads layer supplemented by air photo analysis (California Department of Forestry and Fire Protection, 2001). The FRAP road layer was used as the base transportation layer that was then modified to correct road position and to add additional roads not present on the FRAP roads layer. All roads were age-dated according to first appearance on the historic aerial photography (1966, 1988, and 2003).

Approximately 563 miles of road were mapped on the FRAP 1:24,000 road layer. After air photo analysis, an additional 525 miles of road were combined with the FRAP road layer resulting in a total of 1,088 miles of road on non PALCO lands in the Lower Eel River TMDL study area. According to the historic aerial photography, the FRAP road layer only represented 52% of the existing road mileage on non PALCO lands in the study area.

In addition to roads, other GIS data requirements for the SEDMODL2 included topography generated from available DEM layers, hydrology, study area boundary, precipitation data, geology, and soils (soils depth and bulk density). For the purposes of generating road surface erosion estimates for non PALCO lands in the Lower Eel River TMDL study area, SEDMODL2 was run on a terrain type scale. Topography and hydrography GIS layers were developed from the USGS 10 meter DEM. Precipitation data used in the SEDMODL2 analysis was derived from PRISM data for California compiled by Oregon State University.

The geology GIS layer for the TMDL study area was developed from the Geology of the Cape Mendocino, Eureka, Garberville, and Southwestern Part of the Hayfork 30 x 60 Minute Quadrangles and Adjacent Offshore Area, Northern California (McLaughlin et al., 2003). Geologic units were attributed according to SEDMODL2 geologic erosion factors (NCASI, 2003). SEDMODL2 erosion factors range between 1 and 5 based on erodibility (5 being more erodible). Factor 1 represents lithified Quaternary, Tertiary, Mesozoic, Paleozoic and Precambrian rocks. Geologic factor 5 applies to unlithified sands and silts. Table A outlines the geologic factors applied to lithologic units found in the Lower Eel River TMDL study area.

Table A. SEDMODL Geologic Factor by Lithologic Unit, Non PALCO lands, Lower Eel River TMDL Study Area

Lithologic Unit (McLaughlin, et al 2003)	SEDMODL Geologic Factor
Qal (alluvium)	3
Qt (terrace deposits)	3
Qm (marine)	3
QTw (Wildcat Group)	1
TKy (Yager Formation)	1
Franciscan sandstone, limestone, basalt, chert	1
Franciscan mélange and serpentine	2

Quaternary alluvium, alluvial terrace and marine terrace deposits were classified with a geologic factor of 3. According to the SEDMODL2 Technical Documentation Manual v.2 (NCASI, 2003), coarse-grained soft sediments (gravelly) are classified with a geologic factor of 1 and fine-grained sediments (sand and silt) are classified with a geologic factor of 5. Because the alluvium and terrace deposits contain a range of sediment sizes from silts to cobbles, we determined an average geologic factor of 3 for these Quaternary deposits. Rocks of the Wildcat Group, Yager Formation, and Franciscan sandstone are classified with a geologic factor of 1 due to lithification and lack weathering. Franciscan mélange and serpentine lithologies were classified with a geologic factor of 2 due to lithification and the minor degree of metamorphism.

The required SEDMODL factors for soils include soil depth and soil bulk density. A soil depth of 5 feet was estimated for the TMDL study area based on average soil depth data employed in nearby watersheds (2003 PALCO LEED and 2007 Upper Eel River watershed analyses). In addition, an average soil bulk density of 1.4 tons/yd^3 was selected to maintain consistency with previous studies (2003 PALCO LEED and 2007 Upper Eel River watershed analyses).

Road surface and traffic factors are required for SEDMODL calculation of road surface erosion. Due to the limited project budget, roads in the Lower Eel River TMDL study area were not field verified for culvert drainage locations or for the specific road erosion factors necessary to optimize model output. As a result, average road erosion factors were developed for roads in the TMDL study area according to the SEDMODL2 guidelines. Table B outlines the road erosion factors used in the SEDMODL2 model runs on non PALCO roads in the Lower Eel River TMDL study area. All of these factors are outlined in detail in the SEDMODL2 program manual (NCASI, 2003).

Table B. SEDMODL Road Erosion and Traffic Factors, Non PALCO lands, Lower Eel River TMDL Study Area

Traffic Use	Traffic Factor	Tread Surfacing Factor	Road Surface Type	Road Width (ft)	Cutslope Cover (%)	Cutslope Height (ft)	Maximum Sediment Delivery Road Distance (ft)	Average Road Slope Gradient (%)	Road Age Factor
County Road	50	0.03	Paved	35	70	2.5	1,000	7	1
Primary Road	10	0.2	Gravel	25	70	10	1,000	7	1
Secondary Road	2	1	Native	18	70	10	1,000	7	1

VII. Methodology for Episodic Road Sediment Delivery Estimate

Episodic road-related sediment delivery was estimated from past road-related sediment delivery rates developed from current and past road-related erosion inventories conducted in the Lower Eel River TMDL study area and in nearby watersheds. Episodic road-related sediment delivery rates developed for the Eel River Floodplain/Terrace and Salt River Floodplain/Terrace terrain types were derived from data collected as part of a field past road erosion inventory conducted as an element of this TMDL study. Specifically, 10.96 miles of road were inventoried on non PALCO lands for past road-related sediment sources. Sample roads were chosen at random and based on accessibility. Private roads were not inventoried due to the lack of landowner access. All past erosion features with sediment delivery to streams were inventoried and mapped on 1:12,000 base maps. Past road-related erosion attributes collected in the field included site type, past erosion volume, past sediment delivery percent, and age of erosion. Between 1955 and 2006, approximately 155 yds^3 of past road-related sediment delivery was identified along inventoried road reaches, resulting in a past road-related sediment delivery estimate of 15 yds^3/mi and a past road-related sediment delivery rate of 0.4 yds^3/mi/yr.

Episodic road erosion rates for the Upper Salt River and the Lower Eel River terrain types were derived from a past road-erosion inventory conducted for the PALCO Lower Eel River Watershed Analysis (2003). In 1999, PWA conducted a comprehensive past road erosion inventory on roads in the Lower Eel River Watershed Analysis study area (including Monument Creek, Kiler Creek, Dinner Creek, Twin Creek, Greenlaw Creek, Pepperwood, Bridge Creek, Shively Creek, Darnell Creek, Sammy & Kari Creeks, North Central, and Scotia sub-watersheds in LEED WA study area, but excluding Stitz Creek). In addition, road erosion data were used from the past and future sediment source investigations conducted in Jordan Creek and Bear Creek. The Jordan Creek and Bear Creek inventories are more extensive than the past sediment source inventory conducted in the LEED sub-watersheds listed above. The Jordan Creek and Bear Creek sediment source assessments provided detailed future sediment delivery estimates and site specific erosion control and erosion prevention treatments. For the Lower Eel River TMDL study, the unpublished past road-related sediment delivery data was analyzed by geology in order to develop unit past sediment delivery and past sediment delivery rates for roads located on young geology slopes and for roads located on older geology slopes (75 yds^3/mi and 1.9 yds^3/mi/yr and 315 yds^3/mi and 7.9 yds^3/mi/yr, respectively).

Episodic road-related sediment delivery rates for the Larabee Creek terrain types were derived from unpublished data collected as part of a past erosion inventory conducted for the PALCO Van Duzen River Watershed Analysis (2002). The unit sediment delivery and sediment delivery rate derived for the Larabee Creek terrain types was estimated at 240 yds^3/mi and 6 yds^3/mi/yr, respectively.

Past road-related sediment delivery rates were applied to the air photo identified non PALCO roads by road age in the Lower Eel River TMDL study area. Specifically, past road-related sediment delivery rates were extrapolated to the total cumulative road mileage by each air photo time period (1955-1966, 1967-1988, 1989-2003) in order to provide an estimate of total episodic road-related sediment delivery from non PALCO roads in the Lower Eel River TMDL study area for the study time period (1955-2003).

PALCO Lands

Initially, Pacific Watershed Associates was contracted by Tetra Tech to conduct a sediment source assessment for only non PALCO lands, as part of the Lower Eel River sediment TMDL sediment source investigation. At that time, EPA intended to analyze the existing PALCO data in order to determine the sediment TMDL for PALCO lands. In July 2006, Pacific Watershed Associates was able to secure permission to use specific PALCO data for the non-PALCO analysis of sediment sources for the Lower Eel River TMDL sediment source assessment. These data included the 2003 forensic landslide data for Bear, Jordan, and Stitz Creeks and data from the reports on Jordan, Freshwater, and Bear Creeks in order to develop sediment delivery rates.

In November 2006, the project scope was adjusted and a new contract was developed for PWA to conduct the sediment source assessment on PALCO lands. PWA, EPA, and Tetra Tech requested a data sharing agreement from PALCO for additional data necessary for the development of sediment delivery estimates for PALCO lands. PALCO did not agree to the data sharing agreement and PWA was forced to use existing information from public reports of studies conducted within the Lower Eel River TMDL study area and in adjacent and geologically similar watersheds. Although a complete data set for the PALCO lands in the Lower Eel TMDL study would have been preferable, PWA was able to develop rates from watersheds within the study area or in watersheds adjacent to the Lower Eel River (e.g., Van Duzen River). Therefore the data are comparable, because the existing data is from watersheds within and in the TMDL study area and geologically similar terrains immediately adjacent to the study area.

I. Background Information/Reference Materials for the Sediment Source Assessment Conducted on PALCO lands in the Lower Eel River TMDL Study Area

Source and reference information used to develop bank erosion and episodic road-related erosion is outlined in the non PALCO methodology described above. Source and reference information for the PALCO Lower Eel River TMDL sediment source assessment study included:

- Historical aerial photography for the Lower Eel River TMDL study area (including the 1966, 1988 and 2003 air photo sets).
- Geology of the Cape Mendocino, Eureka, Garberville, and Southwestern Part of the Hayfork 30 x 60 Minute Quadrangles and Adjacent Offshore Area, Northern California (McLaughlin et al., 2003)
- California Department of Forestry and Fire Protection, Fire and Resource Assessment Program 1:24000 GIS road and vegetation layers
- Tabular data from the unpublished Lower Eel River/Eel Delta Watershed Analysis: Surface Erosion Module report prepared by Hart Crowser was used to develop road surface erosion estimates on PALCO lands.
- Tabular data from the unpublished Van Duzen River TMDL sediment source study (PWA, 1999c), PALCO Upper Eel River Watershed Analysis, Bear Creek (PWA, 1998) and Jordan Creek (PWA, 1999b) sediment source investigations, Lower Eel River/Eel Delta Watershed Analysis (PALCO, 2003) and Upper Eel River Watershed Analysis (PALCO, 2007) were used to develop mass wasting past sediment delivery rates by time frame for the PALCO lands within the Lower Eel River TMDL study area.

II. Terrain Type Delineation

The PALCO Lower Eel River TMDL study area was delineated into 10 terrain types based on location, vegetation type (forested vs. un-forested) and geology (young vs. old). Young geology includes Wildcat Group and younger lithologies (i.e. terrace and marine sediments and alluvium). Old geology includes the Yager Formation and older lithologies (i.e. Franciscan sandstone and mélange).

The 10 terrain types for PALCO lands in the Lower Eel River TMDL study area include:

1. Upper Salt River Un-forested Young Geology
2. Upper Salt River Forested Young Geology
3. Lower Eel River Un-forested Young Geology
4. Lower Eel River Forested Young Geology
5. Lower Eel River Un-forested Old Geology
6. Lower Eel River Forested Old Geology
7. Larabee Creek Un-forested Old Geology
8. Larabee Creek Forested Old Geology

9. Larabee Creek Un-forested Young Geology
10. Larabee Creek Forested Young Geology

III. Analysis Assumptions
Assumptions and methodologies used to develop past sediment delivery estimates for bank erosion and episodic road related sediment delivery are the same as employed in the non PALCO Lower Eel River TMDL sediment source assessment. Refer to the final results document sent to Tetra Tech and EPA on 13 October 2006 for the descriptions of the assumptions and methodologies used to develop bank erosion and episodic road related sediment delivery estimates.

The following assumptions were used in developing mass wasting sediment delivery and road surface erosion estimates for PALCO lands in the Lower Eel River TMDL study area:

1. Conversion factor for yds^3 to tons = 1.4 $tons/yds^3$. This conversion factor is based on previous studies conducted in nearby watersheds. The same conversion factor was used in the Upper Eel watershed analysis (PALCO, 2007).
2. Time period = 49 years (1955-2003). Consistent with previous sediment source analyses, 1955 was selected as the beginning of the study period. This year has been selected because it is assumed that features that have occurred in the previous one to two decades can be readily identified during air photo analysis. Specifically, many of the landslide features on the air photos showed little to no re-vegetation and are therefore considered more recent. As a result, the time frames are defined as 1955-1966 (12 years), 1967-1988 (22 years), and 1989-2003 (15 years).
3. Estimates of road surface erosion were determined from average rates developed from SEDMODL analysis conducted in 2002 as part of the Lower Eel River and Eel River Delta Watershed Analysis. Average rates were developed by terrain type and applied to the roads identified in the road construction history developed from historic aerial photography. (See Section IV Methodology for Road Surface Erosion)
4. Mass wasting past sediment delivery for PALCO lands was estimated by extrapolating average sediment delivery rates by air photo time frame to the area of each terrain type. The average mass wasting sediment delivery rates employed in the sediment source assessment of PALCO lands were estimated at 1) 1966 – 3055 $yds^3/mi^2/yr$, 2) 1988 – 1134 $yds^3/mi^2/yr$, and 3) 2003 - 688 $yds^3/mi^2/yr$. (See Section V Methodology for Mass Wasting Sediment Delivery)
5. Non PALCO earthflow erosion rates by terrain type were used to develop PALCO earthflow erosion estimates.

IV. Methodology for Road Surface Erosion Estimates
To develop estimates of road surface erosion for PALCO lands in the Lower Eel TMDL study area, existing SEDMODL results developed for the Lower Eel River/Eel Delta (LEED) and Upper Eel River watershed analysis surface erosion modules were used to develop average road surface erosion rates by terrain type (PALCO, 2003, 2007). Because the LEED and Upper Eel River watershed analysis surface erosion module methods and results were reviewed by the watershed analysis scientific review teams (SRT) consisting of regulatory agencies (including NCRWQCB, CDFG, CDF, NMFS, etc.), it was assumed that the associated SEDMODL

assumptions, methodologies, and results were accurate and relevant for the use in the Lower Eel River TMDL study.

The LEED watershed analysis provided SEDMODL derived road surface erosion rates by sub-watershed. For the purposes of the Lower Eel River TMDL study on PALCO lands, the LEED watersheds were categorized into terrain types as delineated in the Lower Eel TMDL study area. Forested and un-forested Lower Eel River TMDL terrain types were combined to develop surface erosion rates by geology and location (Table C). Road surface erosion rates were then developed by deriving an average road surface erosion rate based on the LEED sub-watershed road surface erosion rates within each terrain type category. The rates for the LEED analysis were comparable to non-PALCO rates. Seasonal inputs from winter hauling on logging roads were not considered in this analysis. Road construction histories developed for this TMDL study were not classified by road surface or road use type. Classifying roads by use would require the acquisition of the PALCO road surface and use GIS layer. Due to the lack of a data sharing agreement with PALCO, spatial road data were not available for the analysis.

Road surface erosion rates were then extrapolated to existing roads located on PALCO lands in the Lower Eel River TMDL study area. PALCO roads used in the extrapolation were developed from a comprehensive road history layer using the CDF FRAP 1:24,000 roads layer supplemented by air photo analysis (California Department of Forestry and Fire Protection, 2001). Using the same methodology employed on non PALCO lands, the FRAP road layer was used as the base transportation layer that was then modified to correct road position and to add additional roads not present on the FRAP roads layer. All roads were age-dated according to first appearance on the historic aerial photography (1966, 1988, and 2003).

Table C. Average road surface erosion rate by terrain type, PALCO lands, Lower Eel River TMDL

Terrain Type	Average Road Surface Erosion Rate (ton/mi/yr)	Road Length (mi)
Upper Salt Young Geology (Forested and Un-forested)[1]	66.8	1.06
Lower Eel Young Geology (Forested and Un-forested)	66.8	191.23
Lower Eel Old Geology (Forested and Un-forested)	39.6	286.27
Larabee Young Geology (Forested and Un-forested)	3.4	126.99
Larabee Old Geology (Forested and Un-forested)	10.1	39.64

[1]No data available for the Upper Salt Young Geology terrain, therefore we employed the same rate as Lower Eel Young Geology terrain.

Approximately 136 miles of road were mapped on the FRAP 1:24,000 road layer. After air photo analysis, an additional 509 miles of road were combined with the FRAP road layer resulting in a total of 645 miles of road on PALCO lands in the Lower Eel River TMDL study area. According to the historic aerial photography, the FRAP road layer only represented 21% of the existing road mileage on PALCO lands in the study area.

V. Methodology for Mass Wasting Sediment Delivery Estimates

Due to the lack of mass wasting sediment source data for PALCO lands in the Lower Eel River TMDL study area, five technical reports from previous studies conducted in watersheds and sub-watersheds within and adjacent to the Lower Eel River TMDL study area were reviewed for relevant tabular data that could be used to derive average mass wasting past sediment delivery rates by time frames (1966, 1988 and 2003). The derived mass wasting sediment delivery rates were then extrapolated to the entire PALCO ownership within the Lower Eel River TMDL study area by terrain type.

Average mass wasting past sediment delivery rates by time frame were developed from tabular information provided in 4 PALCO studies including 1) Upper Eel River Watershed Analysis (2007), 2) Lower Eel River Watershed Analysis (2003), 3) Bear Creek Sediment Source Investigation (1998) and 4) Jordan Creek Sediment Source Investigation (1999) (Table D). In addition to the four PALCO studies, data from the Van Duzen TMDL study conducted in 1999 were also used to develop the average PALCO mass wasting sediment delivery rates.

The Van Duzen TMDL study provided past sediment source information by dominant land use domains (Lower Domain: timber management, Middle Domain: ranching and Upper Domain: public land management) and terrain types (based on geology). The PALCO lands in the Van Duzen TMDL study area are well represented in the Lower Domain (including Yager Creek, Lawrence Creek). According to the Van Duzen TMDL sediment source analysis, the Lower Domain was delineated into 5 terrain types based on geology. For the purposes of the Lower Eel River TMDL study, we chose Terrain #2 which includes both Wildcat Group and Yager Formation terrains. These terrain types are both common in the Lower Eel River TMDL study area.

Due to the lack of detailed data, mass wasting past sediment delivery rates could not be developed specifically for each terrain type. As a result, we assumed one weighted average rate for each of the 1966, 1988 and 2003 time frames for all PALCO lands in the Lower Eel River TMDL study area (3,830 $yds^3/mi^2/yr$, 1,296 $yds^3/mi^2/yr$ and 920 $yds^3/mi^2/yr$, respectively) (Table D). These weighted averages were calculated based on five different study areas: Van Duzen River, Jordan Creek, Bear Creek, Lower Eel River/Eel Delta, and PALCO's Upper Eel River area (PWA, 1998, 1999b, 1999c; Pacific Lumber Company, 2003, 2007). Weighted average rates were calculated based on the volume of sediment delivery in each study area and the size of the study area (mi^2). Mass wasting past sediment delivery estimates were calculated by time period for each terrain type by applying the average sediment delivery rate by the area of each terrain type and the number of years within the time frame period.

In order to develop estimates of management-related and non management-related sediment delivery, we developed an average percentage of management-related sediment delivery based on existing studies and apportioned the mass wasting sediment delivery in each terrain type according to the derived management-related percentages. Specifically, we reviewed tabular results from the Van Duzen River TMDL, and the Jordan Creek and Bear Creek Sediment Source Investigation reports and determined what percent of the mass wasting sediment delivery was observed as anthropogenic (Table D). An average of 70% of the sediment delivery for the 3 studies analyzed was associated with management activities and 30% of the sediment delivery was considered natural or background.

Table D. Mass wasting sediment delivery rates used to develop average rates for the Lower Eel TMDL sediment delivery from PALCO lands

Study area	Study area (mi^2)	Management Influence? (%)[1]		Sediment delivery rate by time frame ($yds^3/mi^2/yr$)[2]		
		Mgt	No Mgt	1966	1987	2003
Van Duzen River TMDL	11.5	70	30	8,453	1,769	2,532
Jordan Creek Sediment Source Investigation	8	65	35	2,550	744	682
Bear Creek Sediment Source Investigation	5.98	75	25	14,317	1,936	4,703
Lower Eel River/Eel Delta Watershed Analysis	56.3	NA	NA	1,440	1,337	541
Upper Eel River Watershed Analysis	43.6	NA	NA	4,493	1,132	510
Weighted Average (based on study area)	**--**	**70**	**30**	**3,830**	**1,296**	**920**

[1]The NA pertains to “Not Available”. The LEED WA did not provide any data, tables or figures pertaining to management versus non management influence. The Upper Eel WA only provided data for management versus non management for the most recent time period 1988-2003. Although these studies did provide data necessary to derive sediment delivery rates by air photo time periods, they did not provide data necessary to derive management/non management allocation.
[2]The Bear Creek and Jordan Creek sediment source investigation air photo time period ranged from 1954 to 1997. In order to develop a mass wasting rate for the 2003 time frame, we combined the 1997 air photo data from the existing reports with the PALCO 2003 forensic landslide data from these 2 watersheds.

Earthflow erosion was not a significant factor in the Jordan Creek and Bear Creek sediment source investigations or the LEED and Upper Eel River watershed analyses. Although earthflow erosion is much more significant in the Lower Domain of the Van Duzen TMDL study area, by itself it does not represent the observed trend of earthflow activity in the Lower Eel River TMDL study area. Since earthflow erosion is considered to be primarily natural or background erosion, we defaulted to the non PALCO Lower Eel River TMDL rates of earthflow erosion according to terrain type. These rates were extrapolated to each terrain type by area and by time frame.

Non-PALCO and PALCO Analysis

Where applicable, the PALCO and non-PALCO results were combined to represent the entire Lower Eel River TMDL study area. Table E identifies all of the data sources used to complete the analyses. These results are presented in Section C.2.

Table E. Data Sources for the Non-PALCO and PALCO Sediment Source Investigation

Data Type	Data Source: Non-PALCO	Data Source: PALCO
Mass Wasting	Original air photo analyses (1966, 1988, 2003) Earthflow toe retreat of 1.82 ft/year (DWR, 1982) Other assumptions: PALCO, 2003; PWA, 1998, 1999b	Sediment delivery rates from previous studies (PALCO, 2003, 2007; PWA, 1998, 1999b, 1999c)
Road Surface Erosion	Original SEDMODL2 modeling (NCASI, 2003) Roads layer modified from FRAP (California Department of Forestry and Fire Protection, 2001) Other assumptions: PALCO, 2003, 2007	Previous SEDMODL results (PALCO, 2003, 2007)
Stream Bank Erosion	Field inventory for Eel River floodplain and terrace and Salt River floodplain and terrace Existing studies for all other terrain types (PALCO, 2000, 2007)	
Episodic Road Erosion	Field inventory for Eel River floodplain and terrace and Salt River floodplain and terrace Existing studies for all other terrain types (PALCO, 2002, 2003)	

Channel Migration Zone Analysis

Project Description

As a component of the Lower Eel River TMDL sediment source study, a channel migration zone analysis was conducted in order to provide a historical perspective of the changes in the channel morphology of the Eel River within the Lower Eel River TMDL study area. The channel migration zone (CMZ) analysis was focused on a 33 mile section of the Lower Eel River extending from approximately 1 mile downstream of the confluence of the Eel River and the South Fork Eel River, to Fortuna, California. Downstream of Fortuna, the lower Eel River is bounded by extensive man-made levees, making the CMZ analysis in this area unnecessary. The levee system was not evaluated. Temperature and erosion may be affected by the lack of vegetation on the levees. The levees are designed for flood control and not habitat enhancement. They are required to be stripped of vegetation to ensure reduced channel roughness, in order to move the water downstream as efficiently as possible.

For the purposes of this study, a channel migration zone is a section of stream or river generally bounded by floodplains and terraces on both banks of the active channel, and exhibiting a large valley floor width to depth ratio. It is on these valley floor locations where severe and dramatic changes can occur in the sinuosity and location of the active channel over time. To estimate changes in channel stored sediment occurring in the CMZ of the Lower Eel River TMDL study area, the 33 mile long study reach was analyzed using historical aerial photography and field reconnaissance of terrace and floodplain heights at selected locations along the CMZ study reach.

Methodology

The 1954, 1966, and 2003 aerial photographs were chosen for analysis to accurately capture the effect of the 1964 and 1997 flood events on the Lower Eel River CMZ. Specifically, the earliest aerial photography available was in 1954 and this was used to provide baseline information of the channel position. The 1966 photography documents the channel position after the 1964 flood while the 2003 photography illustrates channel position after the 1997 storm. Mylar overlays were affixed to the stereo-paired photographs with the channel closest to the center of the photo to minimize distortion and complications from oblique aspect. Channel, gravel bars/point bars, floodplains, and terraces within the analysis area were delineated as polygons on the mylar overlays. The polygons were transferred to large scale base maps based on the USGS 7.5 minute topographic quadrangle maps. Base maps were scanned using a large flat-bed scanner and the resulting imagery was "rubber-sheeted" or geo-referenced using ArcMap software. The landform polygons were then heads-up digitized from the geo-referenced imagery.

Changes in the CMZ were delineated by overlying the 1954 landform polygon map and the 1966 landform polygon map. A new layer of polygons was developed from this comparison, defining areas of sediment storage or sediment input (mobilization) to the stream system between 1954 and 1966. For example, if a particular area was delineated as terrace on the 1954 map and delineated as active channel on the 1966 map, the polygon of the changed area would be considered a sediment input area (i.e. the channel had migrated laterally eroding former terrace deposits). Similarly, a second storage and input polygon map was created by comparison of the 1966 and 2003 landform polygon maps. The area of each storage or input polygon was determined using ArcMap software.

Field measurements of selected terrace and floodplain heights were taken at as many locations of identified sediment input or storage (i.e. channel changes) as landowner access would allow. In all cases, measurements were taken to determine the estimated average height of the feature above the currently active channel.

A volumetric estimate for each input or storage polygon was derived from the measured height and determined area. In instances where the relevant terrace, floodplain, or gravel bar was measured in the field, the measured height was applied to the polygon area to determine a sediment volume for the polygon. In instances where the relevant terrace or floodplain height was not measured in the field, the average terrace, floodplain, or gravel bar height measurement was used. These results are presented in the following section.

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Section C.2: Sediment Source Assessment Results

Combined Non-PALCO and PALCO Assessment Results

Table 1. Basin area by stratum, location, terrain type (geology) and vegetation, Non PALCO + PALCO ownership, Lower Eel River TMDL study area

Watershed	Stratum	Location	Terrain/ Geology Type[1]	Vegetation Type[2]	Area (mi^2)		
					Non-PALCO	PALCO	Total
Lower Eel watershed TMDL study area	1	Eel River Terraces and Floodplains	Young Geology	Un-forested	26.3	0.0	26.3
	2	Eel River Terraces and Floodplains	Young Geology	Forested	2.3	0.0	2.3
	3	Salt River Terraces and Floodplains	Young Geology	Un-forested	21.0	0.0	21.0
	4	Salt River Terraces and Floodplains	Young Geology	Forested	0.7	0.0	0.7
	5	Upper Salt River	Young Geology	Un-forested	1.4	0.01	1.4
	6	Upper Salt River	Young Geology	Forested	11.2	0.2	11.4
	7	Lower Eel River	Young Geology	Un-forested	28.2	2.3	30.5
	8	Lower Eel River	Young Geology	Forested	29.6	28.7	58.3
	9	Lower Eel River	Old Geology	Un-forested	3.9	2.0	5.9
	10	Lower Eel River	Old Geology	Forested	12.2	41.1	53.3
	11	Larabee Creek	Old Geology	Un-forested	12.9	1.3	14.2
	12	Larabee Creek	Old Geology	Forested	51.7	16.9	68.6
	13	Larabee Creek	Young Geology	Un-forested	0.0	0.5	0.5
	14	Larabee Creek	Young Geology	Forested	0.0	4.7	4.7
	Total				**201.4**	**97.7**	**299.1**

[1] Young geology pertains to Wildcat Group and younger lithologies (primarily Quaternary). Old Geology pertains to terrain older than the Wildcat Group (i.e. Yager terrain and Franciscan mélange)
[2] Forested terrain refers to areas dominated by conifers and hardwoods. Un-forested terrain is dominated by grasslands, scrub/brush, and areas not dominated by conifers and hardwoods.

Map 1 illustrates the geographic distribution of the fourteen terrain types in the Lower Eel River TMDL area.

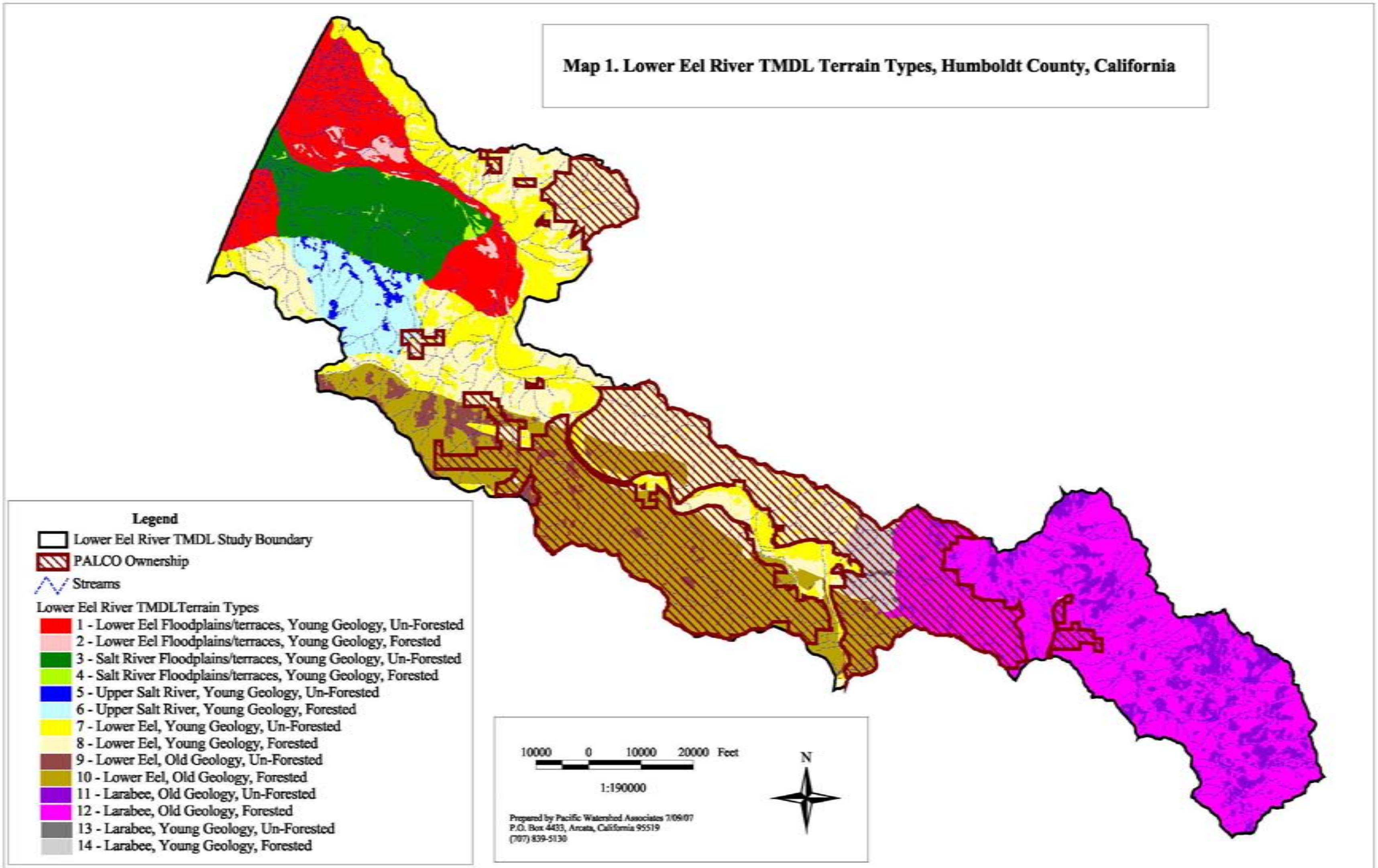

Table 2. Non-PALCO* Total estimated erosion and sediment delivery from air photo identified erosion features greater than 400 ft^2 in area by stratum type and feature type[1] (1955-2003).

	Frequency of Air Photo Identified Features by Stratum Type (#)													
Erosion Feature Type	**1. Eel R. -FP/Terr. Young Geology Un-forested**	**2. Eel R. - FP/Terr. Young Geology Forested**	**3. Salt R. -FP/Terr. Young Geology – Un-forested**	**4. Salt R. - FP/Terr. Young Geology Forested**	**5. Upper Salt River – Young Geology Un-Forested**	**6. Upper Salt River – Young Geology Forested**	**7. Lower Eel – Young Geology Un-Forested**	**8. Lower Eel – Young Geology Forested**	**9. Lower Eel – Old Geology Un-Forested**	**10. Lower Eel – Old Geology Forested**	**11. Larabee – Old Geology Un-forested**	**12. Larabee – Old Geology Forested**	**Total estimated erosion (yds^3)**	**Total estimated sediment delivery (yds^3)**
Debris Slide	0	1	1	0	6	98	88	246	13	148	21	198	5,166,724	3,210,709
Debris Flow (including torrent track)	0	0	0	0	0	2	9	8	2	1	7	12	416,608	340,605
Complex Debris Slide	0 0		0	0	0	3	2	0 1		0	0	0	1,699,114	611,109
Translational Debris Slide	0 0		0	0	0	3	1	1 3		0	0	0	561,820	159,477
Earthflow	0 0		0	0	0	3	9	4 5		2	2	2	235,686	235,686
Non Road-Related Gully	0 0		0	0	0	2	9	4 1		1	4	9	54,822	51,856
Totals	**0**	**1**	**1**	**0**	**6**	**111**	**118**	**264**	**24**	**152**	**34**	**221**	**8,134,774**	**4,609,442**

[1] Episodic road-related erosion (including fluvial erosion and mass wasting features <275 yds^3) and bank erosion were calculated using rates derived from past and current erosion studies. Road-related erosion features and bank erosion were not included in the air photo analysis to ensure no data duplication. The air photo data includes road-related mass wasting features >275 yds^3

Landslide depths calculated using a power regression equation ($0.3777 x Area^{0.2925}$)

Debris Flow Track sediment delivery= Length of torrent track x 2.91 yds^3/ft

Earthflow sediment delivery = (Earthflow toe width (ft) x average earthflow toe height (16 ft) x 1.82 ft/year retreat) x the number of years of earthflow activity.

Note: PALCO air photo data were not available; therefore, this table only addresses lands not owned by PALCO in the Lower Eel River TMDL study area.

Table 3. Total Estimated Non PALCO + PALCO road mileage by terrain type, Lower Eel River TMDL study area.

Air Photo Time Period	Estimated PALCO + Non-PALCO Road Mileage (mi)														Total estimated road mileage (mi)
	1. Eel R. - FP/Terr. Young Geology - Un-forested	2. Eel R. -FP/Terr. Young Geology - Forested	3. Salt R. - FP/Terr. Young Geology - Un-forested	4. Salt R. - FP/Terr. Young Geology - Forested	5. Upper Salt River – Young Geology-Un-Forested	6. Upper Salt River – Young Geology-Forested	7. Lower Eel – Young Geology-Un-Forested	8. Lower Eel – Young Geology-Forested	9. Lower Eel – Old Geology-Un-Forested	10. Lower Eel – Old Geology - Forested	11. Larabee – Old Geology – Un-forested	12. Larabee – Old Geology – Forested	13. Larabee – Young Geology – Un-forested	14. Larabee – Young Geology – Forested	
1955 - 1966	63.5	3.4	67.3	2.1	10.5	34.8	180.2	150.1	36.4	181.7	49.9	253.5	1.7	6.8	1041.9
1967 - 1988	4.5	0.0	2.9	0.1	1.3	7.7	21.7	117.9	3.7	40.5	13.0	81.1	0.3	7.8	302.4
1989 - 2003	3.4	0.2	0.9	0.0	3.7	13.6	32.3	88.4	14.6	124.2	18.8	79.6	2.4	20.5	402.6
Totals	**71.4**	**3.6**	**71.1**	**2.2**	**15.5**	**56.1**	**234.1**	**356.4**	**36.8**	**346.4**	**81.7**	**414.1**	**4.4**	**35.2**	**1,746.9**

[1] Non PALCO roads were mapped using the FRAP roads layer and additional roads mapped through air photo analysis. The FRAP roads layer was modified by adding existing roads not present on the FRAP layer. PALCO Roads were compiled from PALCO road layers and attributed through air photo analysis.

Table 4. Total Estimated Non-PALCO and PALCO episodic road road-related sediment delivery by terrain type, Lower Eel River TMDL study area.

Air Photo Time Period	Estimated Non-PALCO and PALCO Episodic Road-Related Sediment Delivery (yds^3) by terrain type														Total estimated sediment delivery (yds^3)
	1. Eel R. - FP/Terr. Young Geology - Un-forested	2. Eel R. -FP/Terr. Young Geology - Forested	3. Salt R. - FP/Terr. Young Geology - Un-forested	4. Salt R. -FP/Terr. Young Geology - Forested	5. Upper Salt River – Young Geology-Un-Forested	6. Upper Salt River – Young Geology-Forested	7. Lower Eel – Young Geology-Un-Forested	8. Lower Eel – Young Geology-Forested	9. Lower Eel – Old Geology - Un-Forested	10. Lower Eel – Old Geology - Forested	11. Larabee – Old Geology – Un-forested	12. Larabee – Old Geology – Forested	13. Larabee – Young Geology – Un-forested	14. Larabee – Young Geology – Forested	
1955 - 1966	285.75	15.30	302.85	9.45	235.13	782.55	4054.28	3377.93	3439.80	17172.54	3594.96	18249.84	121.68	491.04	52,133
1967 - 1988	561.00	28.38	579.15	17.82	484.69	1752.30	8326.73	11056.24	6945.59	38496.15	8304.12	44156.64	265.32	1935.12	122,909
1989 - 2003	401.63	20.48	399.94	12.21	434.53	1577.25	6584.91	10023.75	6455.53	40920.86	7354.80	37266.30	399.60	3168.00	115,020
Totals	**1,248**	**64**	**1,282**	**39**	**1,154**	**4,112**	**18,966**	**24,458**	**16,841**	**96,590**	**19,254**	**99,673**	**787**	**5,594**	**290,062**

[1]Episodic road-related erosion rates, assuming average road age = 40 years:

Salt River/ Eel River Floodplains and Terraces = 15 yds^3/mi, 0.4 yds^3/mi/yr

Upper Salt Young Geology and Lower Eel Young Geology = 75 yds^3/mi, 1.9 yds^3/mi/yr

Lower Eel Old Geology = 315 yds^3/mi, 7.9 yds^3/mi/yr

Larabee Old Geology = 240 yds^3/mi, 6 yds^3/mi/yr

Table 5. Total past erosion and sediment delivery by erosion type and terrain type on Non PALCO + PALCO lands in the Lower Eel River watershed study area.

Terrain Type	Mass Wasting Erosion		Episodic Road-Related Sediment Delivery (yds^3)	SEDMODL Road Surface Erosion Sediment Delivery (yds^3)	Bank Erosion Sediment Delivery (yds^3)	Total Sediment Delivery (yds^3)
	Non Earthflow Sediment Delivery (yds^3)	Earthflow Erosion (yds^3)				
1. Eel R. -FP/Terr. Young Geology - Unforested	0	0	1,249	6,658	2,798	10,705
2. Eel R. -FP/Terr. Young Geology - Forested	2,017	0	64	513	228	2,822
Subtotal	**2,017**	**0**	**1,313**	**7,171**	**3,026**	**13,527**
3. Salt R. -FP/Terr. Young Geology - Unforested	3,219	0	1,282	6,837	5,488	16,826
4. Salt R. -FP/Terr. Young Geology - Forested	0	0	39	316	292	647
5. Upper Salt River – Young Geology- Un-Forested	8,553	0	1,155	14,950	5,521	30,179
6. Upper Salt River – Young Geology- Forested	1,337,956	10,874	4,112	34,356	15,774	1,403,072
Subtotal	**1,349,728**	**10,874**	**6,588**	**56,459**	**27,075**	**1,450,724**
7. Lower Eel – Young Geology- Un-Forested	514,142	102,886	18,965	113,325	28,953	778,271
8. Lower Eel – Young Geology- Forested	3,421,391	78,076	24,457	346,112	111,953	3,981,989
9. Lower Eel – Old Geology- Un-Forested	426,212	60,536	16,841	20,685	3,962	528,236
10. Lower Eel – Old Geology - Forested	4,520,889	56,637	96,590	288,265	89,117	5,051,498
Subtotal	**8,882,634**	**298,135**	**156,853**	**768,387**	**233,985**	**10,339,994**
11. Larabee – Old Geology – Un-forested	387,317	1,433	19,254	49,902	18,807	476,713
12. Larabee – Old Geology –Forested	1,918,103	263,025	99,673	313,287	156,229	2,750,317
13. Larabee – Young Geology – Un-forested	44,136	1,684	787	946	38,764	86,317
14. Larabee – Young Geology – Forested	414,878	6,256	5,594	6,726	79,793	513,247
Subtotal	**2,764,434**	**272,398**	**125,308**	**370,861**	**293,593**	**3,826,594**
Totals	**12,998,813**	**581,407**	**290,062**	**1,202,878**	**557,679**	**15,630,839**

Table 6. Sediment delivery from all sources (in cubic yards) by primary land use association and terrain type for Non PALCO + PALCO lands in the Lower Eel River TMDL study area.

	Non Earthflow							Earthflow	
Terrain	**No land use association [1,2]**	**Road Related Mass Wasting and Fluvial Erosion[2]**	**SEDMODL Road-Related Surface Erosion**	**Timber Harvest[3]**	**Skid[3]**	**Land Use Associated Bank Erosion[4]**	**Total non EF sediment yield**	**No land use association**	**Total non-Earthflow and Earthflow (yd^3)**
1	2,518	1,249	6,658	0	0	280	10,705	0	10,705
2	2,222	64	513	0	0	23	2,822	0	2,822
Subtotal	**4,740**	**1,313**	**7,171**	**0**	**0**	**303**	**13,527**	**0**	**13,527**
3	8,158	1,282	6,837	0	0	549	16,826	0	16,826
4	263	39	316	0	0	29	647	0	647
5	3,959	2,656	14,950	6,406	0	2,208	30,179	0	30,179
6	1,310,196	5,000	34,356	22,862	13,474	6,310	1,392,198	10,874	1,403,072
Subtotal	**1,322,576**	**8,977**	**56,459**	**29,268**	**13,474**	**9,096**	**1,439,850**	**10,874**	**1,450,724**
7	361,929	34,797	113,325	152,412	1,341	11,581	675,385	102,886	778,271
8	1,625,897	58,537	346,112	1,809,835	18,750	44,782	3,903,913	78,076	3,981,989
9	299,578	16,841	20,685	129,011	0	1,585	467,700	60,536	528,236
10	1,859,510	199,687	288,265	2,579,799	31,952	35,647	4,994,860	56,637	5,051,497
Subtotal	**4,146,914**	**309,862**	**768,387**	**4,671,058**	**52,043**	**93,595**	**10,041,858**	**298,135**	**10,339,993**
11	317,219	19,254	49,902	81,383	0	7,522	475,280	1,433	476,713
12	934,476	104,392	313,287	1,068,988	3,658	62,491	2,487,292	263,025	2,750,317
13	36,499	787	946	30,895	0	15,506	84,633	1,684	86,317
14	172,339	5,594	6,726	290,415	0	31,917	506,991	6,256	513,247
Subtotal	**1,460,534**	**130,027**	**370,861**	**1,471,681**	**3,658**	**117,436**	**3,554,196**	**272,398**	**3,826,594**
Total	**6,934,763**	**450,179**	**1,202,878**	**6,172,006**	**69,175**	**220,430**	**15,049,431**	**581,407**	**15,630,838**

[1] No land use pertains to all sediment sources with no apparent land use association.
[2] Sediment delivery derived from air photo analysis, existing studies and extrapolated field studies.
[3] Sediment delivery derived from air photo analysis and existing studies.
[4] Sediment delivery derived from extrapolated field studies. Bank erosion management association for the Lower Eel and Larabee Creek terrains was determined as 60% no apparent land use and 40% land use associated based on field studies conducted as part of the PALCO Upper Eel River watershed analysis. Bank erosion management association for the Salt River/Eel River Floodplains and Terraces terrain was estimated as 90% no apparent land use and 10% land use associated according to field studies conducted as part of the Lower Eel River TMDL study.

Table 7. Sediment delivery rates from all sources (in tons/mi^2/year)1 by primary land use association and terrain type for Non PALCO and PALCO lands in the Lower Eel River TMDL study area (1955-2003).

Terrain Type	Non-Earthflow							Earthflow	Total non-Earthflow and Earthflow (tons/mi^2/year)
	No land use association [2,3]	Road Related Mass Wasting and Fluvial Erosion[3]	SEDMODL Road-Related Surface Erosion	Timber Harvest[4]	Skid[4]	Land Use Associated Bank Erosion[5]	Total non EF sediment yield	No land use association [4]	
1	3	1	7	0	0	0	12	0	12
2	28	1	6	0	0	0	35	0	35
Subtotal	**5**	**1**	**7**	**0**	**0**	**0**	**14**	**0**	**14**
3	11	2	9	0	0	1	23	0	23
4	11	2	13	0	0	1	26	0	26
5	80	54	303	130	0	45	612	0	612
6	3,272	12	86	57	34	16	3,477	27	3,504
Subtotal	**1,094**	**7**	**47**	**24**	**11**	**8**	**1,191**	**9**	**1,200**
7	339	33	106	143	1	11	632	96	729
8	1,616	58	344	1,799	19	45	3,880	78	3,957
9	4,367	245	302	1,881	0	23	6,818	882	7,700
10	752	81	117	1,043	13	14	2,020	23	2,043
Subtotal	**898**	**67**	**166**	**1,012**	**11**	**20**	**2,176**	**65**	**2,240**
11	1,736	105	273	445	0	41	2,601	8	2,609
12	917	102	307	1,048	4	61	2,440	258	2,698
13	78	2	2	66	0	33	181	4	185
14	87	3	3	147	0	16	257	3	260
Subtotal	**401**	**36**	**102**	**404**	**1**	**32**	**976**	**75**	**1,050**
total	**662**	**43**	**115**	**590**	**7**	**21**	**1,438**	**56**	**1,493**

[1] Assumes 1.4 tons/yds^3 conversion factor and a time period of 49 years (based on 1955-2003 air photo time period).
[2] No land use pertains to all sediment sources with no apparent land use association.
[3] Sediment delivery derived from air photo analysis, existing studies and extrapolated field studies.
[4] Sediment delivery derived from air photo analysis and existing studies.
[5] Sediment delivery derived from extrapolated field studies. Bank erosion management association for the Lower Eel and Larabee Creek terrains was determined as 60% no apparent land use and 40% land use associated based on field studies conducted as part of the PALCO Upper Eel River watershed analysis. Bank erosion management association for the Salt River/Eel River Floodplains and Terraces terrain was estimated as 90% no apparent land use and 10% land use associated according to field studies conducted as part of the Lower Eel River TMDL study.

Table 8. Sediment Delivery Rates (in $yds^3/mi^2/year$, $tons/mi^2/year$) from all sediment sources by terrain types and time frames for Non PALCO and PALCO lands in the Lower Eel River TMDL study area.

Terrain Type	Sediment Delivery Rate	Sediment Delivery Rates by Air Photo Time Frames						Total Sediment Delivery
		1955-1966		1967-1988		1989-2003		
		Non EF	EF	Non EF	EF	Non EF	EF	
1	$yds^3/mi^2/yr$	8	0	8	0	9	0	8
	$tons/mi^2/yr$	11	0	12	0	12	0	12
2	$yds^3/mi^2/yr$	7	0	47	0	7	0	25
	$tons/mi^2/yr$	10	0	66	0	10	0	35
Entire Eel River Floodplains and Terraces area	**$yds^3/mi^2/yr$**	**8**	**0**	**11**	**0**	**9**	**0**	**10**
	$tons/mi^2/yr$	**11**	**0**	**16**	**0**	**12**	**0**	**14**
3	$yds^3/mi^2/yr$	26	0	13	0	13	0	16
	$tons/mi^2/yr$	36	0	19	0	19	0	23
4	$yds^3/mi^2/yr$	19	0	19	0	19	0	19
	$tons/mi^2/yr$	26	0	26	0	27	0	26
5	$yds^3/mi^2/yr$	754	0	307	0	373	0	437
	$tons/mi^2/yr$	1,055	0	430	0	523	0	612
6	$yds^3/mi^2/yr$	6,574	2	413	30	2,249	19	2,503
	$tons/mi^2/yr$	9,203	3	578	41	3,148	26	3,504
Entire Salt River area	**$yds^3/mi^2/yr$**	**2,223**	**1**	**158**	**10**	**768**	**6**	**857**
	$tons/mi^2/yr$	**3,113**	**1**	**221**	**14**	**1,076**	**9**	**1,200**
7	$yds^3/mi^2/yr$	801	40	242	76	480	81	521
	$tons/mi^2/yr$	1,121	56	338	107	673	113	729
8	$yds^3/mi^2/yr$	2,811	18	868	35	939	23	1,393
	$tons/mi^2/yr$	3,935	26	1,215	49	1,314	32	1,950
9	$yds^3/mi^2/yr$	2,139	67	2,075	259	566	256	1,840
	$tons/mi^2/yr$	2,995	93	2,905	362	793	358	2,576
10	$yds^3/mi^2/yr$	4,087	8	1,246	31	1,156	19	1,936
	$tons/mi^2/yr$	5,721	11	1,744	43	1,618	27	2,710
Entire Lower Eel Area	**$yds^3/mi^2/yr$**	**2,829**	**21**	**923**	**51**	**908**	**43**	**1,426**
	$tons/mi^2/yr$	**3,960**	**29**	**1,292**	**71**	**1,271**	**60**	**1,996**
11	$yds^3/mi^2/yr$	465	0	272	0	1,458	7	684
	$tons/mi^2/yr$	651	0	381	0	2,041	9	958
12	$yds^3/mi^2/yr$	1,105	0	577	143	687	46	818
	$tons/mi^2/yr$	1,547	0	807	200	961	64	1,145
13	$yds^3/mi^2/yr$	11,172	44	1,600	84	1,254	90	3,915
	$tons/mi^2/yr$	15,640	62	2,240	118	1,755	126	5,480
14	$yds^3/mi^2/yr$	5,186	18	1,375	35	1,056	23	2,238
	$tons/mi^2/yr$	7,261	25	1,926	49	1,478	32	3,133
Entire Larabee Creek area	**$yds^3/mi^2/yr$**	**1,270**	**1**	**575**	**114**	**834**	**38**	**888**
	$tons/mi^2/yr$	**1,778**	**2**	**805**	**159**	**1,167**	**54**	**1,243**
Entire Lower Eel River TMDL study area	**$yds^3/mi^2/yr$**	**2,031**	**11**	**645**	**60**	**784**	**33**	**1,066**
	$tons/mi^2/yr$	**2,843**	**15**	**903**	**84**	**1,097**	**46**	**1,493**

Table 9. Total estimated sediment delivery (cubic yards) for all sediment sources by terrain type, time frames and potential management association for Non PALCO and PALCO lands in the Lower Eel River TMDL study area

Terrain	Time period	Management	Non-Management		Total
		Non Earthflow	Non Earthflow	Earthflow	
1. Eel R. - FP/Terr. - Young Geology - Unforested	1955-1966 (12 years)	1,878	617	0	2,495
	1967-1988 (22 years)	3,679	1,130	0	4,809
	1989-2003 (15 years)	2,630	771	0	3,401
	Subtotal	**8,187**	**2,518**	**0**	**10,705**
2. Eel R. -FP/Terr. - Young Geology - Forested	1955-1966 (12 years)	143	50	0	193
	1967-1988 (22 years)	265	2,109	0	2,374
	1989-2003 (15 years)	192	63	0	255
	Subtotal	**600**	**2,222**	**0**	2,822
Entire Eel River Floodplains and Terraces area	1955-1966 (12 years)	2,021	667	0	2,688
	1967-1988 (22 years)	3,944	3,239	0	7,183
	1989-2003 (15 years)	2,822	834	0	3,656
	Subtotal	**8,787**	**4,740**	**0**	**13,527**
3. Salt R. - FP/Terr. Young Geology - Unforested	1955-1966 (12 years)	2,053	4,429	0	6,482
	1967-1988 (22 years)	3,914	2,217	0	6,131
	1989-2003 (15 years)	2,701	1,512	0	4,213
	Subtotal	**8,668**	**8,158**	**0**	**16,826**
4. Salt R. - FP/Terr. Young Geology – Forested	1955-1966 (12 years)	92	65	0	157
	1967-1988 (22 years)	173	118	0	291
	1989-2003 (15 years)	119	80	0	199
	Subtotal	**384**	**263**	**0**	**647**
5. Upper Salt River – Young Geology- Un-Forested	1955-1966 (12 years)	11,439	1,313	0	12,752
	1967-1988 (22 years)	7,959	1,572	0	9,531
	1989-2003 (15 years)	6,823	1,073	0	7,896
	Subtotal	**26,221**	**3,958**	**0**	**30,179**
6. Upper Salt River – Young Geology- Forested	1955-1966 (12 years)	19,793	882,643	265	902,701
	1967-1988 (22 years)	36,722	67,151	7,426	111,299
	1989-2003 (15 years)	25,487	360,402	3,183	389,072
	Subtotal	**82,002**	**1,310,196**	**10,874**	**1,403,072**
Entire Salt River area	1955-1966 (12 years)	33,377	888,450	265	922,092
	1967-1988 (22 years)	48,768	71,058	7,426	127,252
	1989-2003 (15 years)	35,130	363,067	3,183	401,380
	Subtotal	**117,275**	**1,322,575**	**10,874**	**1,450,724**
7. Lower Eel – Young Geology- Un-Forested	1955-1966 (12 years)	113,230	180,007	14,652	307,889
	1967-1988 (22 years)	116,644	45,626	51,264	213,534
	1989-2003 (15 years)	83,583	136,295	36,970	256,848
	Subtotal	**313,457**	**361,928**	**102,886**	**778,271**
8. Lower Eel – Young Geology- Forested	1955-1966 (12 years)	1,029,784	938,275	12,759	1,980,818
	1967-1988 (22 years)	761,800	352,613	45,059	1,159,472
	1989-2003 (15 years)	486,432	335,009	20,258	841,699
	Subtotal	**2,278,016**	**1,625,897**	**78,076**	**3,981,989**

Table 9. ***continued***

Terrain	Time period	Management	Non-Management		Total
		Non Earthflow	Non Earthflow	Earthflow	
9. Lower Eel–Old Geology- Un-Forested	1955-1966 (12 years)	75,047	75,369	4,692	155,108
	1967-1988 (22 years)	56,981	210,515	33,344	300,840
	1989-2003 (15 years)	36,094	13,694	22,500	72,288
	Subtotal	**168,122**	**299,578**	**60,536**	**528,236**
10. Lower Eel – Old Geology - Forested	1955-1966 (12 years)	1,555,843	1,055,942	5,153	2,616,938
	1967-1988 (22 years)	1,001,959	457,738	36,248	1,495,945
	1989-2003 (15 years)	577,547	345,831	15,236	938,614
	Subtotal	**3,135,349**	**1,859,511**	**56,637**	**5,051,497**
Entire Lower Eel River area	1955-1966 (12 years)	2,773,904	2,249,593	37,256	5,060,753
	1967-1988 (22 years)	1,937,384	1,066,492	165,915	3,169,791
	1989-2003 (15 years)	1,183,656	830,829	94,964	2,109,449
	Subtotal	**5,894,944**	**4,146,914**	**298,135**	**10,339,993**
11. Larabee – Old Geology – Un-forested	1955-1966 (12 years)	58,076	21,216	0	79,292
	1967-1988 (22 years)	59,710	25,328	0	85,038
	1989-2003 (15 years)	40,274	270,676	1,433	312,383
	Subtotal	**158,060**	**317,220**	**1,433**	**476,713**
12. Larabee – Old Geology – Forested	1955-1966 (12 years)	652,234	257,626	86	909,946
	1967-1988 (22 years)	561,270	309,408	215,946	1,086,624
	1989-2003 (15 years)	339,313	367,442	46,993	753,748
	Subtotal	**1,552,817**	**934,476**	**263,025**	**2,750,318**
13. Larabee – Young Geology – Un Forested	1955-1966 (12 years)	31,186	29,141	240	60,567
	1967-1988 (22 years)	10,964	4,878	836	16,678
	1989-2003 (15 years)	5,983	2,480	608	9,071
	Subtotal	**48,133**	**36,499**	**1,684**	**86,316**
14. Larabee – Young Geology – Forested	1955-1966 (12 years)	181,952	109,298	1,015	292,265
	1967-1988 (22 years)	99,406	42,213	3,619	145,238
	1989-2003 (15 years)	53,293	20,829	1,622	75,744
	Subtotal	**334,651**	**172,340**	**6,256**	**513,247**
Entire Larabee Creek area	1955-1966 (12 years)	923,448	417,281	1,341	1,342,070
	1967-1988 (22 years)	731,350	381,827	220,401	1,333,578
	1989-2003 (15 years)	438,863	661,427	50,656	1,150,946
	Subtotal	**2,093,661**	**1,460,535**	**272,398**	**3,826,594**
Entire Lower Eel River TMDL study area	1955-1966 (12 years)	3,732,750	3,555,991	38,862	7,327,603
	1967-1988 (22 years)	2,721,446	1,522,616	393,742	4,637,804
	1989-2003 (15 years)	1,660,471	1,856,157	148,803	3,665,431
	Total	**8,114,667**	**6,934,764**	**581,407**	**15,630,838**

Channel Migration Zone Analysis Results

Table 10 summarizes the estimated sediment delivery and changes in channel stored sediment in the Lower Eel River CMZ between 1954 and 2003 (1954 provided a baseline channel position, while the subsequent photographs illustrated channel changes due to significant events, namely the 1964 and 1997 storms. Between 1954 and 1966, a net input or increase of nearly 29,000,000 yds^3 of channel stored sediment occurred in the CMZ analysis area. During this time frame, 21% of the sediment input was from terrace sources, 49% was from floodplain sources, and 30% was from semi-active gravel bar sources.

Between 1966 and 2003, the estimated sediment production (input) from the Lower Eel River CMZ was nearly equal to the documented amount of channel stored sediment, with a net decrease in stored sediment of approximately 637,000 yds^3. Approximately 21% of the sediment input estimated from this time period was from terrace sources, 10% was from floodplain sources, and 69% was from semi-active gravel bar sources. Total estimated sediment input volume from this time period was nearly 50% less than that of the 1954 to 1966 time period, while the total estimated storage volume was approximately 30% greater.

The net increases in channel stored sediments reflect sediment production and sediment transport into the Lower Eel River CMZ from upstream areas. The severely aggraded conditions in the Lower Eel River CMZ suggest restoration efforts in the Lower Eel River and Salt River are unlikely to be successful.

Table 10. Estimated sediment input and storage from channel migration zone (CMZ) by air photo time frame, Lower Eel River TMDL Study Area.

Sediment Changes		**Period**		
		1954-1966	**1966-2003**	**Total**
Sediment Input	Terrace Delivery (yds^3)	9,592,000	5,387,000	14,979,000
	Floodplain Delivery (yds^3)	22,721,000	2,561,000	25,282,000
	Semi-Active Gravel Bar (yds^3)	14,315,000	17,297,000	31,612,000
	Total Inputs (yds^3)	**46,628,000**	**25,245,000**	**71,873,000**
Sediment Storage	Floodplain Aggradation (yds^3)	1,223,000	9,984,000	11,207,000
	Semi-Active Gravel Bar Aggradation (yds^3)	16,448,000	15,898,000	32,346,000
	Total Storage (yds^3)	**17,671,000**	**25,882,000**	**43,553,000**
Net Increase/ Decrease in Stored Sediment (yds^3)		**28,957,000**	**-637,000**	**28,320,000**