LANDSLIDE SEDIMENT PRODUCTION RATES IN THE MIDDLE FORK AND UPPER EEL RIVER BASINS, NORTHERN CALIFORNIA

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Abstract: The Eel River basin of northwestern California has been identified as one of the highest sediment producing systems in the world. High quality water aquatic habitat, including that utilized by anadromous fish, and reservoirs are important natural resources in the basin. Human activities, such as logging, road construction, and grazing, can accelerate sediment production/delivery and adversely affect these resources. In 2003 and 2004 sediment source inventories were conducted in the Middle Fork Eel and Upper Eel sub-basins of the Eel River to support the development of sediment Total Maximum Daily Loads (TMDL) by the US Environmental Protection Agency (EPA). Both the Middle Fork Eel and Upper Eel watersheds are listed under section 303(d) of the Clean Water Act as impaired due to excessive sediment and temperature. The sediment source inventories examined sediment production/ delivery rates from landslides, smaller erosion sites and gullies, and channels and the magnitude of the effect of human activities on these rates. The studies were conducted by the US Forest Service (USFS), North State Resources, and Pacific Watershed Associates (PWA), funded and directed by the EPA, and in consultation with the California North Coast Water Quality Control Board. This paper focuses on the landslide element of the studies.

Air photo inventories along with field sampling were used to measure landslide-derived sediment in both the Middle Fork and Upper Eel sub-basins. A versatile GIS method (geodatabase) was used to capture and store multiple movement episodes of individual overlapping landslides. Methods for measuring small sources and channel-derived sediment were different in each basin, but both involved field sampling techniques. Determinations of natural vs. human-related sediment were made subjectively, according to a rule set developed prior to conducting the survey. For example: landslides which occurred in pre-existing clearcuts were classified as harvest-related, and landslides initiating at a road were classified as road-related. This classification does not imply cause, but rather that human activities were likely contributing factors. In the Middle Fork Eel and in the Upper Eel the majority of the landslide-related sediment production was found to be natural.

These studies provide invaluable information on local sediment production, including predominant sediment producing processes, impact of land management activities, changes in sediment production through time, and the impact of large storm events. This information is key to developing a sediment budget and to understanding how current watershed condition relates to past events. Further, it will eventually allow for extrapolation to adjacent basins and sediment modeling.

INTRODUCTION

The Middle Fork Eel and Upper Eel are 4th field watersheds located in northwestern California about 150 miles north of San Francisco (Figure 1). The Middle Fork Eel occupies about 750 square miles of which 51% is publicly owned. It includes five 5th field watersheds: Upper Middle Fork Eel, Black Butte River; Elk Creek, Williams/Thatcher, and Round Valley. The Upper Eel watershed is about 700 square miles of which 48% is publicly owned. In the Total Maximum Daily Load (TMDL) assessment prepared by the US Environmental Protection Agency (EPA), this watershed was referred to as the Upper Main Eel and Tributaries; however, we are using the naming convention of the United States Geological Survey (1981). The Upper Eel includes five 5th field watersheds: Upper Main Eel and Rice Fork (which together comprise the watershed of Lake Pillsbury), Soda Creek, Tomki Creek, and Outlet Creek (Figure 3).

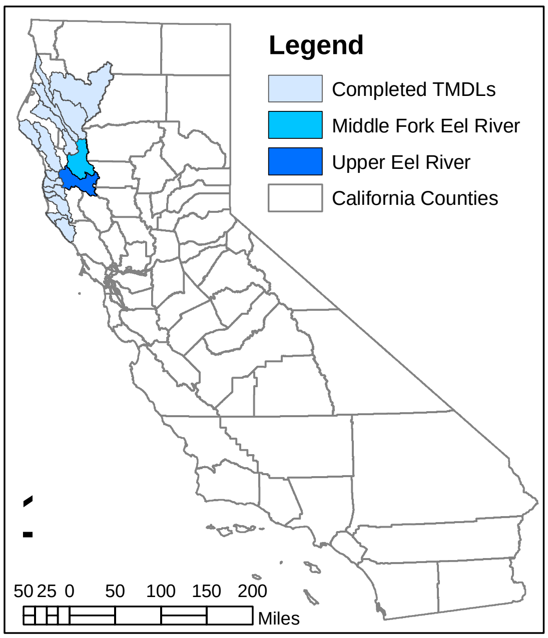

Figure 1 Location map for the Middle Fork and Upper Eel River sub-basins, along with other completed sediment TMDL's in northern California.

The primary beneficial use, as defined by the EPA, of the Eel River is salmonid habitat. Historically, both the Middle Fork and Upper Eel watersheds provided habitat to significant chinook salmon and steelhead populations. These salmonid populations are sensitive to excessive sediment and changes in sediment size distribution. The purpose of the sediment source analyses was to determine how sediment production rates have changed through time.

Bedrock: The Middle Fork and Upper Eel River are underlain primarily by Cretaceous rocks of the Franciscan Complex, including coastal belt rock, mélange, and metavolcanic rock. A relatively small proportion of the Middle Fork Eel watershed is occupied by Cretaceous rocks of the Great Valley Sequence, and sediments of the dominantly Tertiary Wildcat Group. Quaternary alluvium is exposed in the Upper Eel watershed in the vicinity of Willits, California.

Geomorphology: The Middle Fork and Upper Eel sub-basins are dominated by deep seated landslides, with higher elevation lands (>6,000 feet) sculpted by glaciers. Slump and earthflow deposits abound, and local reactivation of these features delivers a large proportion of the sediment which currently enters the stream system. Some of the slump and earthflow deposits occupy several square miles. Prominent inner gorges are developed in the lower reaches of most of the perennial streams.

Figure 2: Oblique aerial photograph of the Taliaferro landslide in the Middle Fork Eel sub-basin.

Management History: The Eel River basin was intensively grazed in the late 1800's and early 1900's (DWR, 1982). Much of the road system was in place prior to the 1964 flood. Regeneration harvesting (clearcutting) on National Forest lands was very limited until the 1980's; however, regeneration prescriptions were applied to some of the lands under other ownerships prior to the 1970's.

METHODS

Both TMDL's on the Middle Fork and Upper Eel utilized a time sequence of air photos to identify landslides over the entire basin, and a sampling method with field plots to identify other small sediment sources (EPA 2003, 2004). This paper addresses the results of the air photo landslide inventories only. The USFS conducted the photo inventories for all of the Middle Fork and the eastern part of Upper Eel, while the western, privately-owned part of the Upper Eel was inventoried by Pacific Watershed Associates (Figure 4). This paper presents USFS data only, because of variations in mapping protocols further described below.

Middle Fork Eel: Air photos from 1952 through 2000 were used, and all landslides visible on the photos were mapped, down to a minimum dimension of 50 feet. Data recorded for each landslide included: landslide type, air photo year and number, length, width, depth, percent of the volume delivered to any channel, management association, certainty of identification, channel association, and comments. Approximately 5% of the inventoried landslides were examined in the field to calibrate estimates of depth and of the percent of material delivered to channels.

Upper Eel: Air photos from 1952, through 1998 were analyzed, using the same protocols as in the Middle Eel. In addition to landslides, gullies and altered channels were also mapped. The Pacific Watershed Associates (PWA) inventory excluded landslides smaller than 3,000 cubic yards (EPA, 2004). This variation in minimum landside dimension resulted in an order of magnitude difference in mapped landslide density in the two areas. In order to minimize variability introduced by different methodologies, we chose not to include the PWA data.

FINDINGS

Rates are given in tons per square mile per year for landslides and reservoir sedimentation and assume 1.5 and 1.25 tons per cubic yard respectively. Brown (1971) reported less than 1 ton per cubic yard for the fine sediment in the Lake Pillsbury.

Middle Fork Eel: The total landslide sediment delivery rate from 1940-2002 was estimated at 829 t/mi^2/yr, of which 4.3% is management-related (3.4% related to roads and 1.0% to harvest). The highest rate occurred during the 1940 to 1969 interval (Figure 3), which included the 1955 and 1964 flood events. A total of 4122 landslides were identified (de la Fuente et al. 2003).

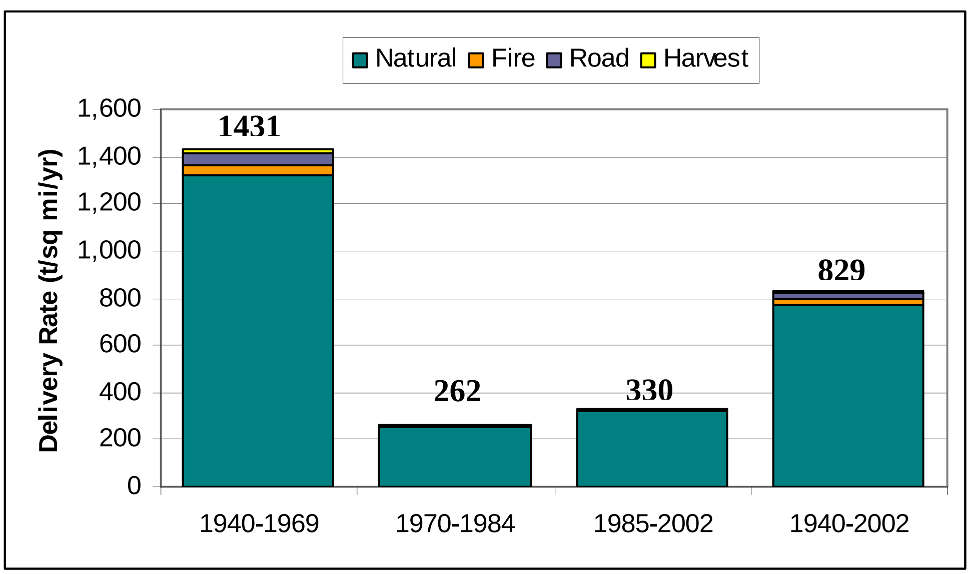

Figure 3 Middle Fork Eel landslide delivery rates by photo interval and disturbance class.

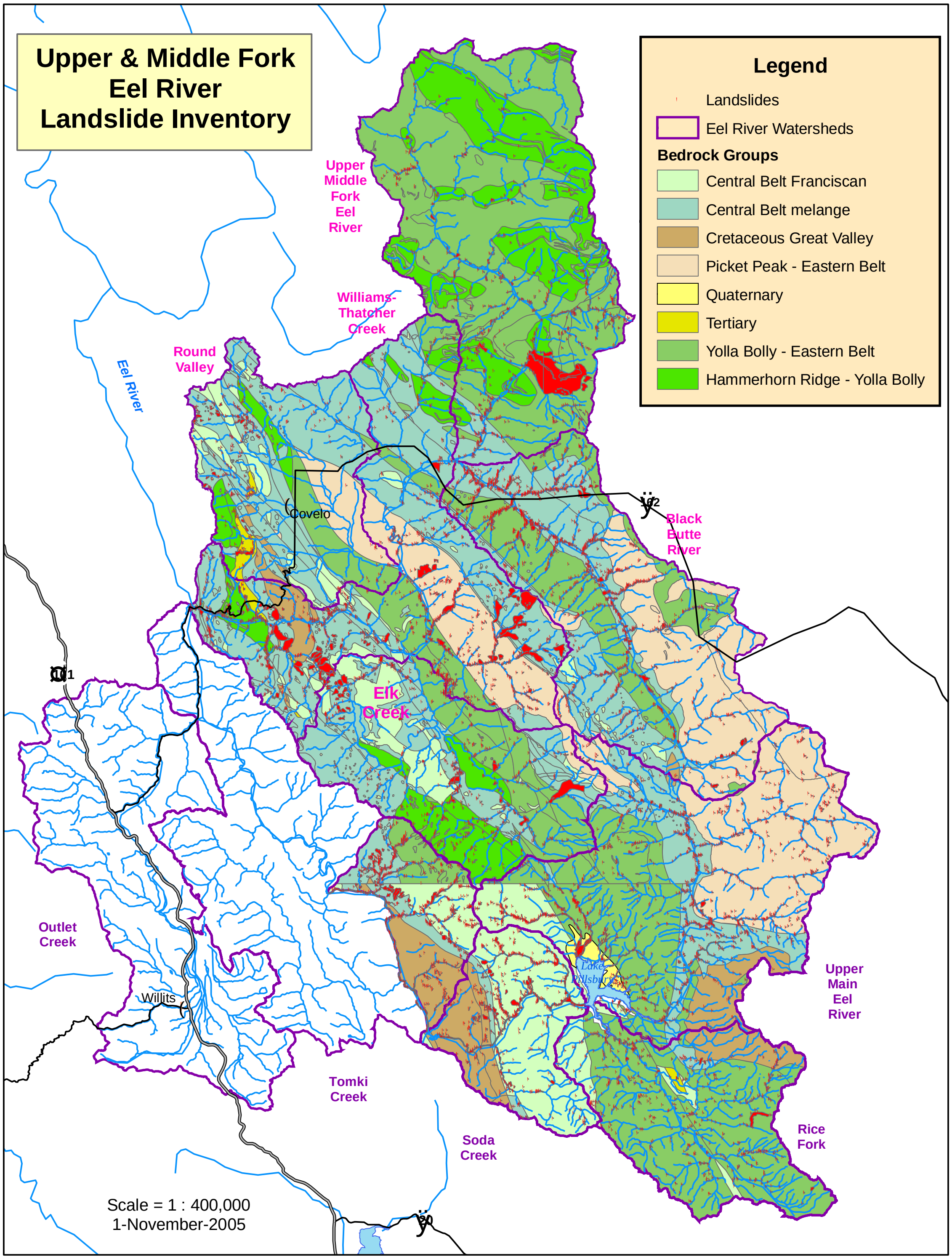

Figure 4 Map of landslides and altered channels mapped by the USFS for the Middle Fork and Upper Eel River watersheds. The southeast part of the sub-basin without mapping (Outlet and part of Tomki Creek) was inventoried by Pacific Watershed Associates.

Upper Eel: The total landslide sediment delivery rate from 1940-2004 was estimated at 531 t/mi^2/yr, of which 17% is management-related (12% related to roads and 4.7% to harvest). A total of 3129 landslides and altered channels were identified by Forest Service inventories.

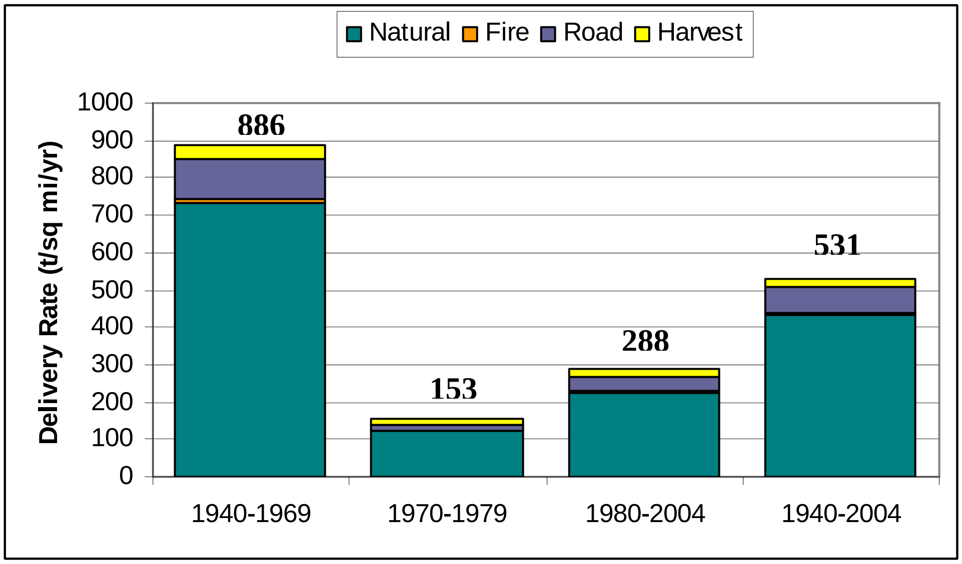

Figure 5 Upper Eel landslide delivery rates by photo interval and disturbance class.

Lake Pillsbury Bathymetry: In 2005, Pacific Gas and Electric conducted a bathymetric survey on Lake Pillsbury, and compared findings with previous surveys by USFS and California Department of Water Resources. The reservoir sedimentation rates increase through time and are significantly higher than our estimated landslide delivery rates (Figure 6).

Lake Pillsbury Drainage			
Bathymetric Survey		USFS Landslide Delivery	
Survey Interval	(t/mi^2/yr)	Photo Interval	(t/mi^2/yr)
1921-1959[1]	1400	1940-1969	535
1960-1984[1]	1737	1970-1979	86
1985-2005[1]	1898	1980-2004	307
1921-2005[2]	1625	1940-2004	369
[1]Buer et al., 1991			
[2]Eugene Geary, personal communication, Nov. 1, 2005			

Figure 6 Comparison of preliminary PG&E bathymetric survey data to USFS landslide sediment delivery rates for Lake Pillsbury basin.

Summary: The Middle Fork and Upper Eel sediment delivery rates follow a similar pattern through time. The 1940-1969 photo interval had by far they highest delivery rates, explainable by considering the large storm events in 1955 and 1964. Delivery rates decreased dramatically during the middle photo interval, and then increased in the most recent photo interval. The recent increase could be explained by the 1997 flood event and the increase in management activities on USFS land starting in the 1980's. There is a large difference between the sedimentation rates in Lake Pillsbury and the estimated landslide delivery rates from hillslopes for the same watershed (Figure 6). This could be explained by contributions from mobilized channel material and chronic, non-landslide sediment sources such as surface erosion and gullies. The time period of 1985-2005 shows rapid deposition in Lake Pillsbury, but low landslide sediment delivery rates. This could be due to gradual transport of stored channel sediment to the reservoir from large storm events, such those in 1955 and 1964.

COMPARISON TO OTHER STUDIES IN NORTHERN CALIFORNIA

Study Comparison: Miller and de la Fuente (2004) compared the methodologies used in eighteen northern California sediment analyses, including those used to establish fifteen sediment TMDLs (Figure 1). They discovered a broad variability of sediment delivery rates, 600 to 12,500 t/mi^2/yr, and management-related contributions, 6 to 70%. The variability in these studies is due in part to physical differences between watersheds. However, an unknown proportion of the variability is introduced by differences in study methods. These numbers cannot be directly compared without consideration of time period of analysis, units of measurement, study methodology, and the physical variability of the watersheds.

Time Period: The relationship between the time period of a study and the timing of large storm events or changes in land management practices is important to consider. For example, refer to the impact of the 1955 and 1964 flood events on the sediment delivery rate of the Middle Fork Eel River (Figure 3). The 1940-2002 sediment delivery rate is 60% of the 1940-1969 interval, but about double the rates during the 1970-1984 and 1985-2002 intervals.

Units of Measurement: Additional consideration should be given to the units used in a study. All studies must be converted to the same units before a comparison can be made. If this requires converting between volume and mass an assumption of the sediment density must be made. Density can vary widely by bedrock, particle size, degree of weathering, and biotic activity.

Study Methodology: Sediment studies can generally be divided into three basic categories: reservoir bathymetric studies, suspended sediment/bedload measurements, and sediment source analyses. Sediment source studies typically use varying combinations of aerial photograph analysis, extrapolation based on field sampling, and published rates taken from the literature. Sediment source analyses are used in TMDLs because they enable categorization of sediment sources into management-related and natural. There are no set standards for field plot selection or density. There are also differences in what is considered to be management-related. This lack of consistency in methodology hinders our ability to review and compare analyses.

Physical Variability of the Watersheds: An accurate comparison of different sediment source studies needs to isolate the differences that are artifacts of the study methods or data used from those that result from real differences in physical characteristics of the landscape and geomorphic processes. Once this is done, bedrock and geomorphic mapping, river gage information, and a detailed management and fire history for each basin can be used to refine comparisons of sediment production rates and management effects. In tectonically active areas, rates of uplift, subsidence, or movement along faults may also prove useful.

RECOMMENDATIONS:

There needs to be standardization of study methodologies so that individual studies can be analyzed and compared. Guidelines should be developed that specify: 1) sediment source categories; 2) what information is collected for each type of sediment source (i.e. time period, dimensions, mobilized vs. delivered volume, management association, etc.); 3) protocols for field sampling including plot size, plot density, and plot selection criteria; 4) criteria for distinguishing natural from management-related sources; and 5) standard reporting units and even standardized graphs, such as those in Figures 4 and 5.

CONCLUSIONS

Large storm events play a dominant role in landslide sediment production in the Middle Fork and Upper Eel, emphasizing the importance of knowing the storm history of a basin.

Sediment source studies help us understand watershed processes, and how they are affected by human activity, but caution must be exercised in comparing results with adjacent studies because of variability in study methodology.

Sedimentation rates in Lake Pillsbury were several fold higher than landslide sediment production rates measured on hillslopes. While expected, this finding points out the importance of understanding the entire erosion/deposition process, from hillslope generation, to channel transport, to reservoir deposition.

REFERENCES

Brown, W.M., III, and Ritter, J.R. (1971). Sediment transport and turbidity in the Eel River basin, California, U.S. Geological Survey Water-Supply Paper 1986.

Buer, K., Scott, R., and Gentry, W. (1991). Lake Pillsbury Watershed Erosion Study, California Department of Water Resources, Northern District.

de la Fuente, J.A., Miller, A.R., Snavely, W.P. (2003). Landslide Assessment Middle Fork Eel River Final Report, US Forest Service, Region 5, Internal Document.

Department of Water Resources, State of California (DWR) (1982). Middle Fork Eel River Watershed Erosion Investigation, DWR, Northern District, Red Bluff, CA.

Miller, A.R. and de la Fuente, J.A. (2004). A comparison of northern California sediment TMDLs [abs.], Advancing the Fundamental Sciences, A Forest Service Physical Scientists, Poster Guide, p. 8.

US EPA Region 9, (2003). Final Middle Fork Eel River Total Maximum Daily Loads For Temperature and Sediment.

US EPA Region 9, (2004). Upper Main Eel River and Tributaries (including Tomki Creek, Outlet Creek and Lake Pillsbury) Total Maximum Daily Loads For Temperature and Sediment.

US Geological Survey, (1981). US Geological Survey Data Standard Codes for the Identification of Hydrological Units in the United States and the Caribbean Outlying Area, Geological Survey Circular, pp. 878-A.