Appendix 4-B

Use of the Empirical Sediment Budget Approach to Quantify Sediment Loads in Upper Elk River

The empirical sediment budget approach (ESBA) stratifies a watershed into distinct land classes as a basis for quantifying sediment production using empirical coefficient rates. Similar to the study sub-basin approach in which otherwise similar managed versus unmanaged areas are compared for relative rates of sediment delivery, the empirical sediment budget approach groups similar areas, differing by their management level and compares the sediment production per unit area. The two approaches differ, however, in that the empirical sediment budget approach defines the sediment production rates for the land classes rather than the use of generalized rates developed from a small, representative area for extrapolation to larger areas. By grouping similar areas in the basin into discrete land classes, data analyses may be conducted at a scale that provides meaningful results due to a greater sample size.

Modeling watershed sediment production in this manner allows for the subdivision of the landscape into logical land class categories based on physical processes governing erosion and other pertinent factors, such as management-related land disturbance. Consequently, the model can be tailored to differences that exist within watersheds. Likewise, the model may be used to describe a comprehensive sediment budget or can be tailored to evaluate individual source components of a sediment budget.

The empirical sediment budget approach has been applied to the Elk River watershed by Reid (1998) and reviewed by the Independent Science Review Panel (ISRP, 2002) on behalf of the Regional Water Board. Regional Water Board staff (2006) also applied the empirical sediment budget approach in establishing the effluent limitation included as a requirement in the Landslide Reduction Model in the Waste Discharge Requirements (WDRs) for Elk River and Freshwater Creek[1]. These previous applications in Elk River were used to determine timber harvest rates (acres/year) that would ensure management-related open-slope shallow landslides would not exceed a certain threshold of management-related landslide sediment, defined as twenty percent (20%) over naturally occurring background (Reid, 1998) and twenty-five percent (25%) over naturally occurring background landslide sediment (Regional Water Board, 2006).

In the Sediment Source Analysis for Upper Elk, the empirical sediment budget approach is used to Provide one estimate of background shallow landslide loading (Section 4.3).

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[1] Order Nos. R1-2006-0039 and R1-2006-0041, respectively, as amended by Order No. R1-2008-0100 to reflect new ownership.

While the sediment source analysis generally relies on subbasin scale data for the determination of sediment loading, the empirical sediment budget approach was evaluated to estimate landslide sediment loading from areas subject to 1) recent timber harvest activities (harvested within past 15 years) and 2) areas not harvested within the past 15 years.

The sediment production from a watershed can be represented as the sum of contributions from each distinct land class. Following is a mathematical description of the empirical sediment budget.

$$S = \sum c_i a_i$$ **Equation 1**

where:

S is the rate of sediment production per unit area ($L^3/L^2/T$)
c_i is the sediment production rate coefficient for land class i ($L^3/L^2/T$)
a_i is the dimensionless fraction of watershed area comprising land class i

Sediment production in a watershed is strongly dependent on spatial landscape variability, climate, and the stochastic occurrence of storm and seismic triggering events. To be able to discern changes in the sediment production rate due to land management and other anthropogenic influences, it is necessary to remove the variable effects of natural processes by defining sediment production relative to a background or reference rate. Equation 1 can be re-written to define this reference rate.

$$R = \sum r_i a_i$$ **Equation 2**

where:

R is the reference rate of sediment production per unit area ($L^3/L^2/T$)
r_i is the reference sediment production rate coefficient for land class i ($L^3/L^2/T$)

Dividing Equation 1 by Equation 2 gives

$$\frac{S}{R} = S_R = \sum (c_i / R) a_i = \sum w_i a_i$$ **Equation 3**

where:

S_R is the dimensionless rate of sediment production relative to reference conditions
w_i is the normalized, and therefore dimensionless, sediment production rate coefficient for land class i.

The empirical sediment budget approach allows for the distinction and comparison of sediment production associated with reference and managed land classes.

Methods Used to Group Upper Elk River into Land Classes

The empirical sediment budget approach is based on grouping the landscape into land classes (i.e. areas with similar conditions), taking into account intrinsic watershed characteristics and management histories, and determining the sediment production rates for these similar areas.

Previous applications of the empirical sediment budget approach included classification of areas based upon timber harvest in the past fifteen years versus no harvest in the past fifteen years (Reid, 1998; Regional Water Board Staff, 2006). Additionally, Regional Water Board Staff (2006) also included a consideration of the Palco HCP geologic restrictions (USFWS, 1999).

The land classes to be used are limited by what the data can support as there must be information about the land classes where the landslides occur. Ideally, land classes would include silvicultural treatments (even aged versus uneven aged or a clear-cut equivalency) and yarding techniques (ground-based versus full suspension), as well as landslide hazard classes determined by landslide process models. However, due to limited data attributes and limitations set forth in data use agreements (Palco, 2005), the land classes evaluated were also limited. In the future, data collection and analyses should be done to support the empirical sediment budget approach using a landslide hazard map, such as the one produced by Stillwater (2007), and harvesting techniques.

As part of this sediment source analysis, Regional Water Board staff selected the following as the defining variables in the establishment of land classes:

1. Underlying geology to define intrinsic watershed characteristics; and.
2. Timber harvest in the past 15 years versus no harvest in the past 15 years.

Groupings of Land Classes by Geology

Geologic composition was selected as the defining variable to segregate the watershed area into land classes based upon intrinsic watershed characteristics. Underlying geologic formation is commonly recognized as among one of the most important factors influencing sediment production rates in a watershed. Table 1 presents the geologic groupings, grouping criteria, and drainage area for each of the seventeen TMDL sub-basins evaluated in this sediment source analysis.

Table 1. Geologic groups, sub-basins, grouping criteria, and associated drainage areas of seventeen Upper Elk River sub-basins.

Group	Sub-basin	Geologic Grouping Criteria	Area (mi^2)
A	Bridge Creek Dunlap Gulch Browns Gulch McWhinney Creek Lake Creek McCloud Creek	100% Wildcat	9.50
B	Lower North Fork Elk River Lower South Fork Elk River Tom Gulch	>75% Wildcat, remainder Hookton	10.42
C	South Branch North Fork Elk River Little South Fork Elk River Corrigan Creek	>75% Wildcat, remainder Yager	7.18
D	Railroad Gulch Clapp Gulch	>50% Hookton	2.20
E	Upper North Fork Elk River North Branch North Fork Elk River	Presence of Franciscan	8.38
F	Upper South Fork Elk River	Yager dominated	6.45

Groupings of Land Classes by Management History

The dominant past, present and probable future land use in Upper Elk River is timber harvesting. The collection of landslide data attributes was based upon the premise that 15 years represents the time period associated with reduced hillslope stability as a result of timber harvesting. As such, Regional Water Board staff selected recently harvested areas (areas harvested in the past 15 years) as the defining variable to establish land classes based upon management history. Ideally, evaluation of harvest method (i.e. yarding technique) would also be evaluated. However, the data is not available to support such analyses.

The development of a metric for acres recently harvested is based on the timber harvest history which was determined for each of the seventeen sub-basins, and subsequently for each of the six geologic grouping areas. Timber harvest history was developed primarily using CalFire electronic data for 1986-2008[2]. The CalFire data represents year of the timber harvest plan (THP) submission. The analyses assumed that THPs were harvested one and a half years (1.5 years) following plan submission.

Pre-1986 THP data is not available from CalFire in electronic format resulting in much greater uncertainty with the data associated with this earlier time period. In 1980, CalFire began recording THP history by maintaining hand-drawn Mylar maps, indicating THP number and boundaries of the harvest units. These maps were used to generate a list of approved THPs in each of the TMDL sub-basins for the 1980 to 1986 time period. A query of the CalFire THP database for this six year time period produced data for only fifteen of the thirty-five mapped THPs. The lack of a

[2] Available for download at ftp://ftp.fire.ca.gov/forest

complete data set resulted in the uncertainty referred to above. The average size of the THPs included in the database was calculated to be 176 acres. This acreage was applied to the list of identified THPs for the years 1980-1986. Information on THPs submitted before 1980 was not available through CalFire and thus other sources of information were consulted[3]. For the purpose of this sediment source analysis, the area weighted rate of 67 acres per year was applied to North Fork, South Fork, Clapp Gulch and Railroad Gulch for 1973-1985.

Results – Grouping of Upper Elk River into Land Classes

The land classes developed, as a result of grouping the watershed into classes based on geology and harvested history, are shown in Table 2. These land classes are employed in Section 4.3 to provide one estimate of background shallow landslide sediment production.

Table 2. Empirical Sediment Budget Approach land class areas (a_i)

Sediment Production Time Period	1988-1997	1998-2000	2001-2003
Harvest Time Period	1973-1997	1983-2000	1986-2003
Geologic Group	Percent of area harvested in prior 15 years at time of landslide initiation[1]		
A	25%	27%	32%
B	15%	17%	18%
C	25%	25%	17%
D	30%	30%	30%
E	31%	34%	35%
F	58%	58%	59%

[1] Assuming landslide initiation corresponds to end of photo period.

Uncertainties Associated with the Land Class Groupings

Regional Water Board staff has identified the following issues as containing levels of uncertainty that could affect the accuracy of the approach in land classification:

<u>Geologic Groupings</u>:

- The watershed was classified into six (6) very general groupings based solely upon geology. There was no evaluation of other intrinsic parameters, such as topography, which also influence shallow landslide sediment production.
- Areas that contain more than one geologic formation (contact zones) may perform differently than those with a more homogenous geology.
- Small relative drainage area for Group D compared to other groups.

<u>Management History Groupings:</u>

- While the canopy removal coefficients are intended to characterize the different silvicultural approaches, there is considerable variability in the amount of canopy actually removed under any individual harvest.

[3] PWA (1998) 1974-1987 North Fork Elk River average harvest was 67 acres per year; staff assumed a similar level in South Fork. RWQB (2005) (PG. 23) Tom Gulch contained two harvest plans in 1982 and 1983 which covered 1,105 acres.

- The limited availability of early THP data yield uncertainty in the pre-1986 data.
- After some number of years, it is assumed that root strength, hydrologic function, and the protective vegetation has become re-established over disturbed areas, thus protecting it from significant triggering events to a degree that approximates pre-harvest conditions. The landslide data in Upper Elk River are summarized based upon a history of areas harvested greater than or less than 15 years prior to initiation of the landslide feature. Earlier applications of the empirical sediment budget approach also used this same time period for recovery criteria (Reid 1998a and 1998b; ISRP 2002; and Regional Water Board staff, 2006). Other data exists that indicates this may underestimate the time required to turn to pre-harvest conditions[4].

[4] While the actual number of years for root strength recovery varies, published studies in non-redwoods studies indicate the period of minimum root strength ranges from about 3-5 years to about 10-20 years following harvest, depending on climate and the associated root decay and vegetative regrowth.