3 Elk River TMDL Sediment Source Analysis

3.1 Introduction to the Elk River Sediment Source Analysis

The purpose of a TMDL sediment source analysis is to inventory and describe all sources of sediment discharge that are impacting the beneficial uses of water in the impaired water body. This chapter presents the natural and management-related processes that affect sediment delivery in the Elk River watershed. The analysis also provides a quantification of sediment source delivery for the forested portions of the watershed. The sediment source analysis for the Elk River Sediment TMDL utilizes the following approach:

- Reliance, to the extent practicable, on existing data from sediment source inventories conducted in the Elk River and adjacent Freshwater Creek watersheds. When possible new data sets were also developed to fill identified data gaps.
- Quantification of sediment sources for seventeen of the twenty individual TMDL sub-basins within the Elk River watershed.
- Where sub-basin specific data were unavailable, generalized rates were developed based upon study sub-basins within Elk River and Freshwater Creek. These rates were then extrapolated to the Elk River sub-basins.
- Use of the empirical sediment budget approach (i.e. grouping areas with similar geology and management histories into discrete land classes) to estimate sediment discharge rates and volumes for some of the sediment source categories identified in the Elk River watershed.
- Natural sediment source categories evaluated in this analysis include: soil creep, stream bank erosion, streamside landslides, shallow hillslope landslides, and deep seated landslides.
- Management-related sediment source categories evaluated in this analysis include: headward incision of low order stream channels, soil creep, stream bank erosion, road-related landslides, shallow hillslope landslides, streamside landslides, management related discharge sites (e.g. road related gullies and stream crossings), post-treatment sediment discharge sites (post-restoration adjustment discharges), skid trail related features, road surface erosion, and harvest (in-unit) surface erosion.
- Information regarding the potential implications for watershed implementation actions is also included for management-related source categories.

This sediment source analysis is organized to present:

1. A description of the geographic scope of sediment source analysis (Section 3.1.1).
2. A brief summary of the data sources used in the analysis (Section 3.1.2).
3. A description of the study sub-basin approach, including the use of a reference watershed, to provide estimates for some of the identified sediment source categories and their associated erosion rates and relative discharge volumes (Section 3.2.1).

4. A description of the empirical sediment budget approach, (i.e. grouping areas with similar geology and management histories into discrete land classes), and evaluating sediment delivery rates from the land classes, used to estimate the rate of natural shallow landsliding and the influence of management activities on shallow landsliding (Section 3.2.2).
5. A description of a study to quantify the management influence on headward incision of low order streams as well as an estimation of the natural and management-influenced drainage densities (Section 3.2.3). The resulting drainage densities are used to quantify, in part, several natural and management-related source categories.
6. A description of the natural sediment source categories, including the method used to determine if a discrete source feature was the result of natural or management related causes (Section 3.3).
7. A description of management-related sediment source categories, including the methods used to determine if a discrete source feature was the result of natural or management related causes (Section 3.4).
8. A summary of the sediment source categories, and their relative magnitude over time (Section 3.5).

3.1.1 Geographic Scope of the Sediment Source Analysis

The Elk River Basin is divided into six (6) main hydrogeographic areas (Chapter 1.4). These hydrogeographic areas are further divided into twenty TMDL sub-basins (Figure 3.1). The Elk River TMDL sub-basins and their relative drainage areas are presented in Table 3.1.

This sediment source analysis was developed for the seventeen sub-basins located in the upper portion (44.13 miPP$^{2)}$ of the Elk River watershed. Due to significant differences in land use, data availability and physical characteristics of the three most downstream sub-basins (Martin Slough, Lower Elk River West, and Lower Elk River), this sediment source analysis was not applied to these areas. The sediment source analysis for the lower three sub-basins will be developed at a later time.

The primary differences in the three most downstream sub-basins include:

1. Land uses. While the upper seventeen (17) sub-basins are forested and have historically been managed for timber harvest production and light density rural residential uses, the lower three sub-basins are dominated by agricultural uses and rural and urban residential uses. Residential and other land uses are projected to increase dramatically in the Martin Slough sub-basin in the near future. Changing land uses can significantly affect municipal and industrial stormwater discharge which in turn affects sediment discharge.
2. Sediment source data availability. The Regional Water Board has focused its regulatory and non-regulatory efforts in the upper forested sub-basins due to concern over timber harvest-related discharges and control of sediment sources.
3. Instream conditions. Similarly, the instream conditions have been monitored and the effects of sediment loading on beneficial uses and nuisance conditions have been characterized in the upper watershed. A comprehensive monitoring effort in the lower most sub-basins has not been undertaken. The nuisance flooding

conditions and impaired water supplies are best documented in the upper extent of the Lower Elk River watershed.

4. Topography. The lower most three sub-basins encompass the valleys along Mainstem Elk River and Martin Slough. They include the majority (76%) of lands with less than five percent hillslope gradient and a little less than half (42%) of the streams with less than one percent gradient.
5. Geologic formations. The geologic formations of the lower most sub-basins are not representative of the upper sub-basins. Over half (57%) of the Hookton Formation and related Quaternary terrace deposits (Qh-Qrt-Qmts) and more than three-quarters (79%) of the Quaternary alluvium, dune sand deposits (Q-Qds) present in the Elk River watershed are located in the lower three sub-basins. These formations may exhibit different patterns of erosion and as such warrant further investigations before use of the generalized rates developed in the upper watershed are applied to them.

Table 3.1 Elk River TMDL sub-basins and drainage areas (Stillwater, 2007).

	Sub-basin	**Area, mi^2**
1	Martin Slough	5.91
2	Lower Elk River West	2.36
3	Lower Elk River	5.83
4	Bridge Creek	2.20
5	Dunlap Gulch	0.66
6	Browns Gulch	0.89
7	Upper North Fork Elk River	4.36
8	McWhinney Creek	1.27
9	Lower North Fork Elk River	5.02
10	North Branch North Fork Elk River	4.02
11	Lower South Fork Elk River	2.90
12	Railroad Gulch	1.20
13	Clapp Gulch	1.00
14	Tom Gulch	2.51
15	Lake Creek	2.12
16	McCloud Creek	2.36
17	Upper South Fork Elk River	6.45
18	South Branch North Fork Elk River	1.93
19	Little South Fork Elk River	3.59
20	Corrigan Creek	1.66
Total		**58.22**

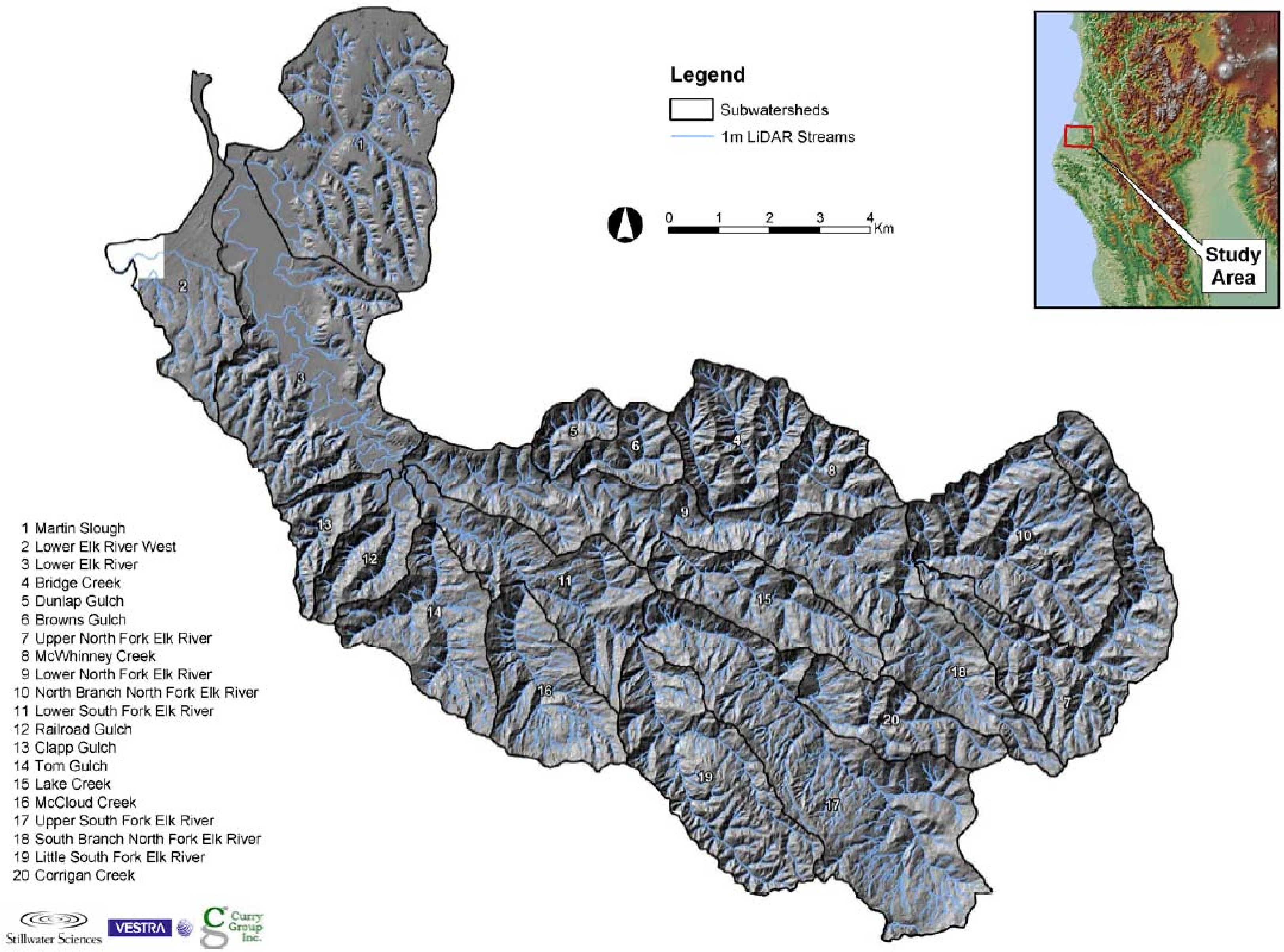

Figure 3.1 Elk River TMDL sub-basins (Stillwater (2007).

3.1.2 Analysis Time Periods

The time periods evaluated in this sediment source analysis reflect past sediment delivery. Some sediment sources persist and are not necessarily a reflection of sediment loading resulting from current management measures. The analysis time periods correspond to aerial photograph periods used in the identification of sediment sources, primarily landslide sources. The analysis time periods considered in this sediment source analysis include 1955-1966, 1976-1974, 1975-1987, 1988-1997, 1998-2000, and 2001-2003. Analyses of more recent time periods were precluded primarily due to lack of updates to landslide inventories. As updates are made to sediment source inventories, Regional Water Board staff anticipates that sediment loadings may be readily calculated for more recent time periods, allowing for evaluation of the effect on sediment loading resulting from contemporary management activities.

3.1.3 Channel Storage

In Chapter 2: Problem Statement, Regional Water Board staff identified significant stored sediment deposits as a primary driver of impaired beneficial uses and nuisance flooding conditions in the low gradient portions of lower North and South Forks, and upper Mainstem Elk River near the confluence. The stored channel sediment contributes to physical conditions that limit the streams ability to pass water and sediment. This source analysis identifies the origin, timing and magnitude of hillslope sediment sources.

With respect to the sediment deposits within the area of the confluence, the targets will identify instream conditions supportive of beneficial uses and channel conditions capable of passing expected streamflows and sediment loads. The linkage analysis will evaluate the timing and magnitude of discharges that likely contributed to the deposition as well as evaluate how the current channel conditions affect the transport capacity of the river system. The load allocations will be developed to achieve the targets while reflecting the stream's current assimilative capacity.

The implementation chapter will identify actions necessary to recover beneficial uses of water, abate nuisance flooding conditions, and achieve the load allocations. Implementation actions will include control measures for the hillslope sources identified in this source analysis as well as a strategy for channel restoration. Regional Water Board staff anticipates that restoration actions, beyond control of hillslope sediment sources, will be necessary to recover the streams transport capacity in the area of the confluence.

3.1.4 Overview of the Data Sets Used in the Sediment Source Analysis

Sediment source inventories have been prepared for portions of the upper Elk River watershed beginning in 1997, with updates occurring on an annual basis. The data collection efforts were developed in part in response to Regional Water Board Cleanup and Abatement Orders and Waste Discharge Requirements, and in part for ownership-specific management purposes. These sediment source inventories presented data relative to both discrete sources as well as providing estimated erosion rates for the various physical processes at work in the watershed. Sediment source data developed for the adjacent Freshwater Creek watershed, which has similar physical characteristics and land management history as the Elk River watershed, were also used to inform the sediment source analysis. The Elk River TMDL sediment source analysis largely relies upon the watershed inventory efforts. In addition, new data sets were developed, particularly for categories in which Regional Water Board staff identified a significant level of uncertainty associated with available data. Where site specific data were unavailable, generalized rates were developed and applied. A summary of the sources of uncertainty identified by Regional Water Board staff, including the use of generalized rates are included, as appropriate, in the following sections.

Regional Water Board staff relied upon the following data sets in the development of the Elk River sediment source analysis:

1) Sediment source inventory summary for Pacific Lumber Company lands in North Fork Elk River (PWA, 1998).
2) Sediment source inventory summary for Pacific Lumber Company lands in South Fork and Upper Mainstem Elk River (PWA, 2001).
3) Shallow landslide data and attribute information for discrete landslide features identified on aerial photos on and near Pacific Lumber Company lands in North Fork, South Fork and Upper Mainstem Elk River (Palco, 2004b) (as summarized in item 1 and 2).
4) Site specific data and attribute information of road-related sediment discharge sites on Pacific Lumber Company lands in North, South and Mainstem Elk River (Palco, 2004c) (as summarized in item 1 and 2).
5) The Pacific Lumber Company Elk River Salmon Creek Watershed Analysis sediment budget (Palco, 2004).
6) Cleanup and Abatement Orders (CAOs) sediment source database which incorporated and built upon earlier source inventory efforts (item 3 and 4) (HRC, 2010).
7) Pacific Lumber Company Report of Waste Discharge (ROWD) Landslide database integrating aerial photo data (item 3), the road data set (item 4) and 2003 landslides (Palco, 2005c)[1].
8) Inventory of skid trail related sediment sources in Freshwater Creek (Palco, 2007).
9) Inventory of road-related sediment discharge sites on Green Diamond Resource Company lands in South Fork Elk River (PWA, 2006).
10) Inventory of non-road sediment discharge sites on Green Diamond Resource Company lands (GDRC, 2007, 2008, 2009, & 2010).
11) Inventory of the road system and a portion of the skid trail-related sediment discharge sites within the Headwaters Forest Reserve (PWA, 2000, 2004, & 2005).
12) Aerial photograph interpretation of shallow landslides within the old-growth portion of the Headwaters Forest Reserve (PWA, 2008).

[1] Subject to a data use agreement (Palco, 2005) GIS information was provided to Regional Water Board contractors but not to Regional Water Board staff. Contractors provided the Regional Water Board with data analyses, summaries, and model outputs. Due to data use restrictions, some data analyses were limited associated with this sediment source analysis, as described in Section 3.4.4.

13) Bank erosion surveys of portions of Elk River and Freshwater Creek (PWA, 2006).
14) Aerial photograph interpretation and field surveys for small streamside landslides in portions of Elk River and Freshwater Creek (PWA, 2008).
15) Staff field surveys to establish the headward extent of low-order stream channels.
16) Evaluation of soil creep rates for application in Elk River and Freshwater Creek watersheds (Buffleben, 2009).
17) Evaluation of various studies estimating sediment discharge volumes generated as a result of sediment control treatments (Palco (2006& 2007), GDRC (2005&2006), PWA (2005a & b), Klein (2003), Madej (2001), Bloom (1998), and BLM (2010)).
18) Evaluation of timber harvest history data in Elk River (CDF (2010), Palco (2005b)).

3.2 Approaches Used in the Elk River Sediment Source Analysis

This section describes approaches used to characterize aspects of the sediment source analysis, including use of study sub-basins to compare reference and management conditions of specific erosional processes, the empirical sediment budget approach to assess sediment production of specific land classes, and a study characterizing the effects of management on low order channel initiation and its effects on drainage density.

3.2.1 Study Sub-basin Approach

When a data gap or significant uncertainty was identified with the suite of data developed under previous efforts, additional studies were conducted within study sub-basins. Results from these studies were then used to develop generalized rates for application in this Elk River sediment source analysis.

In order to characterize specific erosion related parameters, discharge rates, and sediment loads in the forested portion of the Elk River watershed, three of the seventeen (17) sub-basins were selected for detailed study. The results of the sub-basin studies were used to develop generalized sediment loading rates (delivery per unit area) which were extrapolated, as appropriate, to apply to the forested portion of the Elk River watershed. The three (3) study sub-basins have similar physical characteristics with differing land management histories. Two of the sub-basins, South Branch North Fork Elk River (SBNFE) and Corrigan Creek (CC) have been subject to logging activities while the third sub-basin, Little South Fork Elk River (LSFE), is a nearly pristine old-growth basin. The location of the three study sub-basins are shown in Figure 3.2.

Data from these three study sub-basins were used to compare the following erosional processes and their relative natural and management-related sediment loads:

- Drainage area needed to initiate headward incision of low-order stream channels.
- Rates of streamside landslides.
- Rates of stream bank erosion.
- Landslide feature size detection limits for aerial photograph analysis.

Additionally, these three study sub-basins are being monitored for streamflow, turbidity, and suspended sediment concentration (see Section 2.3.3.4.2.3).

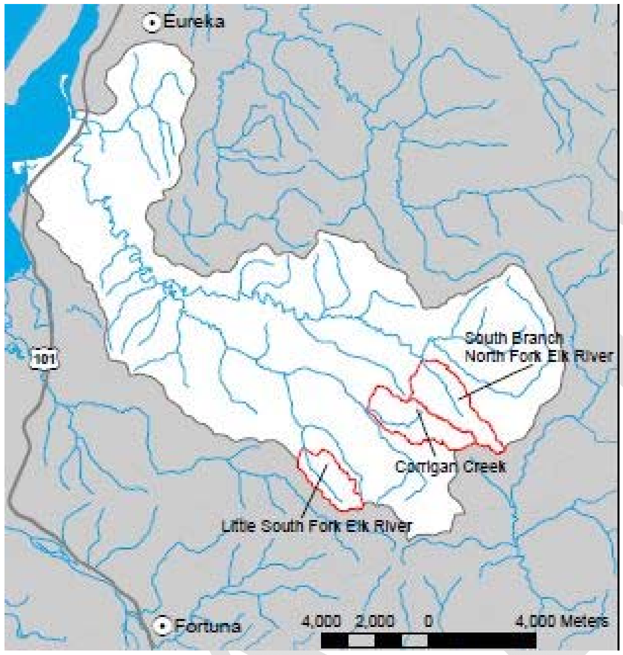

Figure 3.2 Location of study sub-basins within the Elk River watershed (Buffleben (2009).

3.2.1.1 Physical Characteristics of the Three Study Sub-basins

The three sub-basins selected for more detailed data evaluation have similar physiographic characteristics, including: drainage area (Table 3.2), orientation and distance from the ocean (Figure 3.2), geologic characteristics (Table 3.2), average annual rainfall (Figure 3.3), and hillslope gradients (Figure 3.4). See Chapters 1.4 and 2.3 of this Staff Report for additional information on watershed characteristics. Given the uniformity in physical attributes, it is expected that the three study sub-basins would be subject to similar natural processes, including the timing and magnitude of natural erosion trigging events. The relative uniform characteristics allow for the isolation of management effects on hydrologic and erosional processes.

The main stream channels in the three study sub-basins have down-cut through the overlying soft, erosion-prone Wildcat Formation to expose the harder, more erosion resistant Yager Formation, with its associated cobble and gravel component. Table 3.2 presents the lithologies as a proportion of the sub-basin area.

Figure 3.3 demonstrates the average rainfall rate of approximately 55 inches per year for the three study sub-basins.

Hillslope gradient (or percent slope) is an important parameter in developing sediment delivery rates. Figure 3.4 provides a graphic depiction of the relative similarities in hillslope gradients in the three sub-basins.

Table 3.2 Lithology of the study sub-basins (Buffleben, 2009).

	Little South Fork Elk River	Corrigan Creek	South Branch North Fork Elk River
	Percent area in Lithology		
QTw (Wildcat)	71%	75%	83%
Ty (Yager)	29%	25%	17%
Area (mi^2)	1.20	1.70	1.89

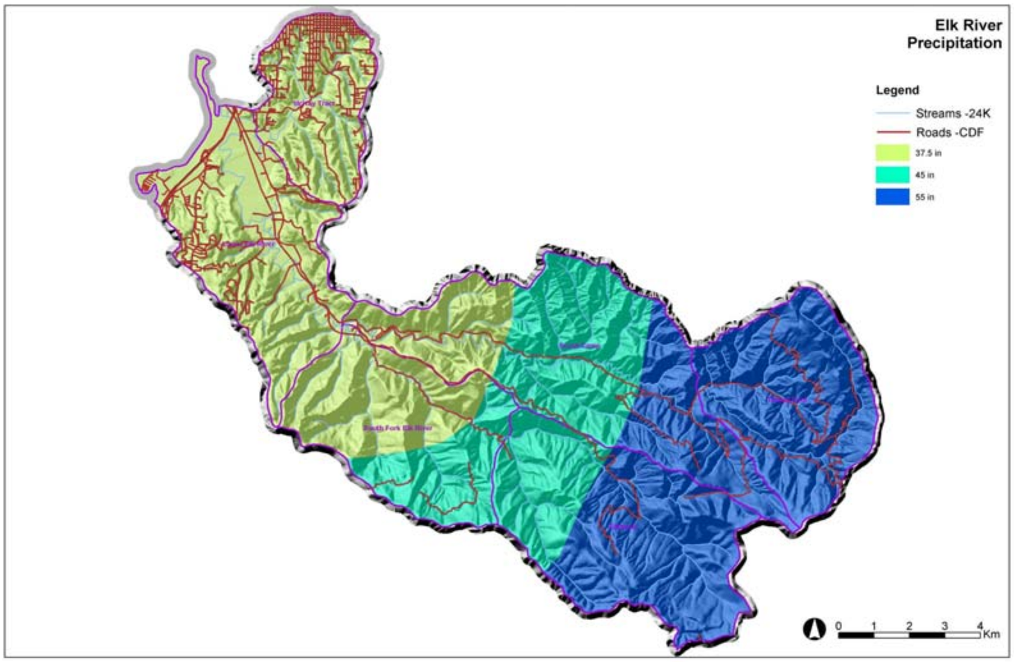

Figure 3.3 Annual average rainfall in Elk River (Stillwater, 2007).

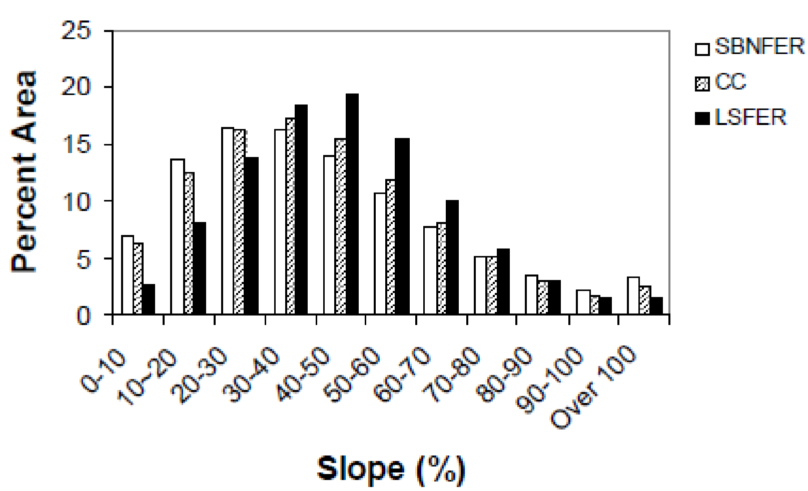

Figure 3.4 Distribution of hillslope gradients within the study sub-basins (Buffleben, 2009).

3.2.1.2 Management History of the Three Study Sub-basins

The following section presents a summary of the management history for the three sub-basins selected for more detailed study.

Reference Study Sub-basin - Little South Fork Elk River

The Little South Fork Elk River (LSFER) sub-basin has been subject to the least amount of documented land management activities in the Elk River basin. While the lower portion of the LSFER sub-basin was subject to past timber harvest activities, the upstream drainage area was never harvested and as such is comprised entirely of late successional, old-growth redwood and mixed conifer forest with a dense overstory canopy. As used in this analysis the LSFER sub-basin encompasses the old-growth portion of the watershed, and is coincident with the drainage area upstream of an established turbidity monitoring station (Chapter 1, Figure 1.15). This 1.20 mi^2 portion of LSFER serves as the reference watershed for the Elk River TMDL analyses.

The only active land management identified in the upstream portion of the study sub-basin is a 1.44 mile length of road associated with a 1986 timber harvesting plan (THP 1-86-388 HUM). This 200-foot wide road, referred to as the “Worm Road”, began at the upstream boundary of the LSFER sub-basin and ran adjacent to the LSFER channel. This road was subject to a Regional Water Board staff enforcement action (Regional Water Board staff, 1989) that required the treatment and control of actual and threatened sediment discharge sources associated with the Worm Road.

The entire LSFER sub-basin was acquired by the federal Bureau of Land Management (BLM) in 1999 as part of the Headwaters Deal. As part of Headwater’s Forest Reserve Resource Management Plan (BLM, 2003), sediment inventories and associated restoration and sediment control work was prioritized. Among the first restoration projects embarked upon by BLM was the obliteration of the Worm Road which included treatment of 1.4 miles of road, seven stream crossings, and fourteen landslides (BLM, 2010). Decommissioning of stream crossings and re-contouring of the hillslopes began in 2000 and was completed in 2003. As part of the restoration work, BLM also conducted monitoring of treatment-related discharges by measuring post-treatment voids (Section 3.5.9). Native vegetation has become re-established along the re-contoured hillslopes and at the pulled stream crossings. Road density in the LSFER is estimated at 0.74 mi/mi^2 due to remaining effects from the obliterated Worm Road.

Despite the presence of the obliterated road, the upstream portion of LSFER best characterizes reference or natural watershed conditions for Elk River, given the extensive land management history in the North Cost Region. Importantly for this sediment source analysis, the rainfall-runoff relationship has not been modified by canopy removal, soil compaction, and stream diversions. With a virtually undisturbed or natural hydrologic regime, the stream flow-turbidity-suspended sediment responses also represent reference conditions. Erosion rates developed for the LSFER are considered in the Elk River TMDL to representative of background conditions, including stream bank erosion, small streamside landslides, and open-slope shallow hillslope landslides.

South Branch North Fork Elk River Study Sub-basin

Timber harvesting and associated road building were first documented in the lowermost portion of the South Branch North Fork Elk River (SBNFER) in 1954 aerial photography. The remainder of the 1.89 mi^2 sub-basin appeared to be uncut until the 1974 air photo time period. During this time period, the lower portion of the sub-basin was reentered and the upper quarter (25%) of the sub-basin was harvested using primarily tractor clear-cut methods (PWA, 2006). From 1982 to 1987, another quarter (25%) of the watershed was harvested. Between 1987 and 1992, an additional third (33%) of the watershed was harvested. In summary, the SBNFER study sub-basin was entirely harvested over the 40 year photo period, with about two-thirds (61%) of the sub-basin re-entered using clear-cut methods in the 10-year period between 1982 and 1992.

Corrigan Creek Study Sub-basin

Timber harvesting and road building in the 1.70 mi^2 Corrigan Creek (CC) sub-basin was first documented in the 1954 aerial photography. Timber harvesting activities at this time where located in the lower portion of the sub-basin. During the 1966 air photo time period harvesting continued primarily using tractor clearcut silvicultural methods. Only minor tractor harvesting was documented on the 1974 aerial photography. By the time of the 1987 aerial photography, the remainder of the middle portion and upper portions of Corrigan Creek were harvested, again using primarily the tractor clearcut method. During the 1997 air photo time period, a few localized areas were tractor harvested, primarily in the upper portions of the sub-basin. The lower portion of Corrigan Creek has undergone recent (since 2000) harvesting with approximately a quarter (25%) of the sub-basin harvested using a thinning silvicultural prescription with a few small clearcut units interspersed. The harvesting primarily employed tractor yarding, although portions were yarded using a cable system (PWA, 2006). Corrigan Creek has been entirely harvested over the 40 year photo period, though between 1987 and 2002, little harvesting occurred. In 2002 the lower portion (15%) of the sub-basin, which was dominated by advanced second growth, was harvested using primarily ground-based yarding thinning methods.

Summary of Management History in Study Sub-basins

The management history within the study sub-basins is summarized in Table 3.3.

Table 3.3 Summary of management history in the study sub-basins.

Study sub-basin	Drainage Area (mi^2)	Harvest History	Road Density (mi/mi^2)	Skid Density (mi/mi^2)	Total Tractor Compacted Area (% sub-basin area[1])
LSFER	1.20	None	1.2[2]	[3]	0%[4]
CC	1.70	1954-2003: 100% 1987-2002, little harvesting 2002: 15% thinned	9.0	50.5	10.4%
SBNFER	1.89	1954-2003: 100% 1982-1997: 61% clear-cut	9.8	52.9	11%

[1]Assuming a road width of 16 feet and a skid trail width of 8 feet.
[2]Effects from obliterated Worm Road.
[3]A few short skid trails, associated with construction of the Worm Road, were built but impacts were not quantified.
[4]Assuming a 25-foot road width, 0.4% was compacted from Worm Road; restoration treatments addressed compaction.

For the purpose of this sediment source analysis, the management history is limited enough in the reference study sub-basin to serve as the basis for characterizing natural conditions. Additionally, the management histories in the two managed study sub-basins are considered similar enough that the combined data could serve as the basis for development of generalized erosion rates associated with management-related influences.

3.2.2 Use of Empirical Sediment Budget Approach (ESBA) to Quantify Sediment Loads in 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[2]. 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 this sediment source analysis, the empirical sediment budget approach is used to:

1) Provide one estimate of background shallow landslide loading (Section 3.3.4.2).
2) Estimate the influence of timber harvest activities on shallow hillslope landslide sediment loading within the dominant geologic groups in the Elk River watershed (Section 3.4.4.2).

While this sediment source analysis generally relies on sub-basin 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 and 2) areas not harvested within the past fifteen (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.

$$S = \sum c_i a_i \qquad (1)$$

where:
S is the rate of sediment production per unit area ($L^3/L^2/T$)
cRR_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.

$$R = \sum r_i a_i \qquad (2)$$

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

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

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

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.

3.2.2.1 Method Used to Group Elk River Watershed 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 (USFWS, 1999) geologic restrictions.

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 fifteen (15) years versus no harvest in the past fifteen years.

Grouping 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 3.4 presents the geologic groupings, grouping criteria, and drainage area for each of the seventeen TMDL sub-basins evaluated in this sediment source analysis.

Table 3.4. Geologic groups, sub-basins, grouping criteria, and associated drainage areas of seventeen forested TMDL 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

Grouping of Land Classes by Management History

The dominant past, present and probable future land use in the upper Elk River watershed is timber harvesting. The collection of landslide data attributes was based upon the premise that fifteen (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 fifteen (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[3]. 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 periods. 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 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

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

for the years 1980-1986. Information on THPs submitted before 1980 was not available through CalFire and thus other sources of information were consulted[4]. 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.

3.2.2.2 Results - Groupings of the Elk River Watershed into Land Classes

The land classes developed as a result of groupings the watershed into classes based on geology and harvested history are shown in Table 3.5. These land classes are employed in Section 3.2.4.2 to provide one estimate of background shallow landslide sediment production, and in Section 3.3.4.2 to evaluate influence of timber harvest activities on shallow hillslope landslide sediment production.

Table 3.5 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 last 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.

3.2.2.3 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>UUGeologic 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.
- The limited availability of early THP data yield uncertainty in the pre-1986 data.

[4] 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.

- 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 Elk River are summarized based upon a history of areas harvested greater than or less than fifteen (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[5].

3.2.3 Management-Related Effects on Channel Initiation

Quantification of sediment delivery to the stream channel network includes not only inventory of discrete erosion features and determination of erosion rates, but also a quantification of the extent of the stream channel network. The stream channel network can be characterized through identification of the headward extent of channels and associated drainage area necessary for the formation of those channels. The resulting drainage density can be calculated as length of stream channel per area of watershed (mi/mi^2). Sediment source inventories can be conducted along a known length of channel resulting in sediment delivery estimates per channel length and then applied to a greater areal extent based upon the drainage density therein.

Timber harvesting and the construction of skid trails used to transport timber to the road system leads to increases in peak flow, ground water interception, soil compaction and drainage diversion. All of these factors contribute to upslope (headward) incision of stream channels reducing the drainage area necessary to initiate stream channels, and increasing the density of the stream channel network (Buffleben, 2009).

PWA (1999) conducted surveys to determine the impacts of clearcut, cable-yarded harvest areas on the stream network and sediment delivery. Only cable yarded areas were included in the study to exclude the complicating affects of tractor disturbance (fills, compaction) on channels. In the old-growth areas, they found that valley catchments served as groundwater reservoirs with most runoff carried through groundwater flow and an interconnected subsurface pipe system that was intermittently visible from the valley floor. The incised channels or gullied swales within the old-growth areas were discontinuous, inactive and located much farther downstream (i.e., have larger upslope drainage areas) than those identified in the clearcut drainages of the harvested areas. In contrast, the swales in harvested areas experienced gully/incision, a response the PWA attributed to first cycle timber harvesting. These results were briefly discussed in the Freshwater Creek Watershed Analysis (Palco, 2003). However, the surveys were never shared in enough detail with Regional Water Board staff to be useful within the context of this sediment source analysis.

Reid (2010) describes results a Caspar Creek study in which gullies were monitored in a managed (clearcut and cable yarded) watershed and a forested control watershed.

[5] 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.

The observations indicate about a quarter (28%) increase in drainage density as a result of hydrologic change from logging and potential channel disturbance due to the cable operations.

As part of the Elk River TMDL efforts, Regional Water Board staff conducted surveys in the three study sub-basins designed to 1) develop appropriate drainage area thresholds for channel initiation; 2) determine how the drainage area associated with channel formation varied with management; and 3) determine the associated drainage density for use in the Elk River sediment source analysis.

3.2.3.1 Methods Used to Determine Management Effects on Channel Initiation

The three study sub-basins were divided into catchment areas using a flow accumulation model[6] based on LiDAR DEM[7] and a two-hectare drainage area. Once the catchment areas were defined, a random sample was selected and field surveys were conducted by Regional Water Board staff to determine if channel heads were present in the inventoried catchment areas. Channels heads were defined as the farthest upslope location of a channel with defined banks. If a channel head was identified in the catchment area, its location was recorded using global positioning system (GPS) coordinates to accurately and reliably record its position on the landscape.

These catchments were inspected from October 2005 to May 2006. This period represented a wetter than average winter period where 58 inches of rainfall occurred for an area that has a yearly average of 38 inches of rainfall (California Data Exchange Center, 2008).

The three study sub-basins were divided into distinct catchment areas. A total of 125, 117, and 83 separate catchment areas were identified in SBNFER, CC, and LSFER, respectively. Study catchment areas were randomly selected. Within the study sub-

[6] Geographic Information System developed by ESRI, ArcGIS, includes a hydrologic analysis tool, Flow Accumulation, which can be used to create a stream network by applying a threshold value of contributing area or cells.

[7] Light Detection and Ranging (LiDAR) is a remote sensing technique in which an airplane mounted sensor releases laser pulses towards the ground surface. As the pulses hit hard surfaces, the beam "bounces" back to the sensor in a return pulse. The elevation difference between the sensor and the hard-hit surface is recorded. GPS coordinates of the plane allow the determination of the x, y, and z coordinates of the hard-hit surface. Multiple returns can be registered from one laser pulse, thus characterizing the canopy and the ground surface at one location. Subsequent data processing can separate the different returns and generate a bare earth DEM that has the effects of trees and buildings removed from the projection.

The Elk River and Freshwater Creek LiDAR survey effort was designed to collect masspoints at approximately 4.5 points per m^2 over an 116 mi^2 project area. First and last returns were produced. Last return data was filtered to represent the bare earth surface (average 2.2 points per m^2) and was used to interpolate a regularly spaced grid of elevation values. An interpolation technique known as Kriging was used to connect the point data and develop a regular spaced 1-m grid of elevation data from the irregularly spaced bare earth point data grid using a spherical semivariogram, search radius of 20 m, and maximum of 16 points (Sanborn 2005).

basins, the surveyed catchments constituted 12.8%, 14.5%, and 16.9% of the total number of catchments and 14.6%, 12.1%, and 14.4% of the total area in SBNFER, CC, and LSFER, respectively.

3.2.3.2 Results - Management Effects on Channel Initiation Analysis

It should be noted that five (5) of the eighty-five (85) randomly-selected catchment areas in the Little South Fork Elk River sub-basin are potentially influenced by the presence of the decommissioned Worm Road described in Section 3.1.3.2.. As such, two results for LSFER are presented in this analysis, one reflecting the presence of the road and the other without affects from the road included.

Of the surveyed catchment areas in SBNFER, CC, and LSFER (road and no-road), respectively, 94%, 65%, 40%, 44% catchments contained channel heads. The results of the surveys indicate that in the unmanaged portion of LSFER, an average drainage area of 4.2 hectares is necessary for the formation of a channel. However, in the two managed sub-basins, SBNFER and CC, the average drainage area threshold for channel incision is 0.5 hectares. Table 3.6 presents the resulting drainage densities within each of the study-sub-basins for natural and managed conditions.

Table 3.6 Drainage density (mi/mi^2) using the median drainage areas for channel incision as determined from the catchment survey results.

	Natural Drainage Density (mi/mi^2) (Drainage Area = 4.22 ha)	Managed Drainage Density (mi/mi^2) (Drainage Area = 0.52 ha)	Management-Induced Increase in Drainage Density (mi/mi^2)
South Branch North Fork Elk River	6.3	18.8	3.0
Corrigan Creek	5.3	16.4	3.1
Little South Fork Elk River	5.3	14.2	2.7
Average	**5.6**	**16.5**	**2.9**

The natural drainage density and managed drainage densities likely vary with geology. The surveys were conducted in the study sub-basins which are dominated by Wildcat and Yager formations. As such, neither the Franciscan nor Hookton formations are represented in the study area. Due to the soft erosion-prone nature of the Wildcat Formation, it is likely that the drainage density estimates are higher than would be expected in the more erosion-resistant Franciscan geology.

The Caspar Creek research watershed is located in the Jackson State Demonstration Forest in western Mendocino County (approximately 120 miles south of Elk River). It is a coastal, redwood-mixed conifer dominated forest underlain by the Franciscan Formation and actively managed for timber production. Reid (2010) presents results indicating that twelve years after timber harvest operations, the drainage area at the head of forested channels was 1.9 hectares compared to 1.2 hectares at the head of logged channels. The drainage densities area associated with the control and treated areas were 7.4 mi/mi^2 and 9.6 mi/mi^2, respectively. The difference amounts to about a quarter (28%) increase in drainage density as a result of hydrologic change from cable logging operations. The Caspar Creek results represent an expected minimum change in drainage density because 1) the control watershed was previously impacted by first cycle logging (not a reference condition), and 2) the treatment watershed was cable yarded, avoiding the complicating efforts of ground based yarding (e.g. skid trail construction, soil compaction, etc.

Palco Watershed Analysis (WA) includes a summary[8] of channel lengths associated with different stream classes. Table 3.7 presents this summary data for the purpose of comparison with the TMDL drainage density results.

Table 3.7 Summary of stream network as presented in the Palco Elk River Watershed Analysis (Palco, 2004)[9].

Stream Class[10]	Stream Length (all ownerships) (mi)	Percent Total Stream Length in Stream Class	Drainage Density (mi/mi^2)
Class I	56.54	13%	1.07
Class II	106.88	25%	2.03
Class III	266.57	62%	5.06
Total Channel Length	429.99		8.17

Palco Report of Waste Discharge (ROWD) (2005) includes a summary of drainage density associated with different stream orders[11]. The summary indicates that nearly all stream lengths within THP units are low (1st to 3rd) order streams (or Class II and III and streams, using the Forest Practice Rules definition). Table 3.8 shows the stream densities as presented in the ROWD.

Table 3.8 Summary of low order stream network as presented in the Palco Elk River ROWD (2005).

Stream Order	Drainage Density (mi/mi^2)	Percent Total Stream Length in Stream Order
Order I	7.21	13%
Order II	2.67	25%
Order III	1.49	62%
Total	11.37	

Generally, Class I watercourses are 4th order or greater streams. Assuming that Table 3.8 does not include Class I watercourses, the inclusion of the Class I lengths from Table 3.7 results in a total drainage density of 12.44 mi/mi^2.

[8] CWE Section, Table 2
[9] The watershed analysis area comprised 52.66 mi^2.
[10] Forest Practice Rules definitions (Table 1): Class I watercourse: 1) Domestic supplies, including springs, on site and/or within 100 feet downstream of the operations area and/or 2) Fish always or seasonally present onsite, includes habitat to sustain fish migration and spawning. Class II watercourse: 1) Fish always or seasonally present offsite within 1000 feet downstream and/or 2) Aquatic habitat for non-fish aquatic species. 3) Excludes Class III waters that are tributary to Class I waters. Class III watercourse: No aquatic life present, watercourse showing evidence of being capable of sediment transport to Class I and II waters under normal high water flow conditions after completion of timber operations.
[11] Table 6.4

The overall drainage density presented in the WA (8.17 mi/mi^2) or the ROWD (12.44 mi/mi^2) is approximately half to three-quarters of the drainage density suggested by TMDL surveys (16.47 mi/mi^2). Possible explanations for this discrepancy include:

- Incomplete mapping of low order channels in the watershed assessment area. Considering that most watercourses are mapped on USGS topographic maps, the use of LiDAR for channel mapping would likely influence the channel mapping.
- Outdated mapping of channel network. Channels may have extended following first, second, and third cycle logging.
- Channel survey conducted in the Wildcat Formation may over estimate the drainage density in terrain dominated by less erodible formations.

Figure 3.5 presents the drainage densities associated with the TMDL surveys in the study sub-basins, the Caspar Creek results, the Palco WA, and the Palco ROWD (adjusted to include Class I streams) stream network data.

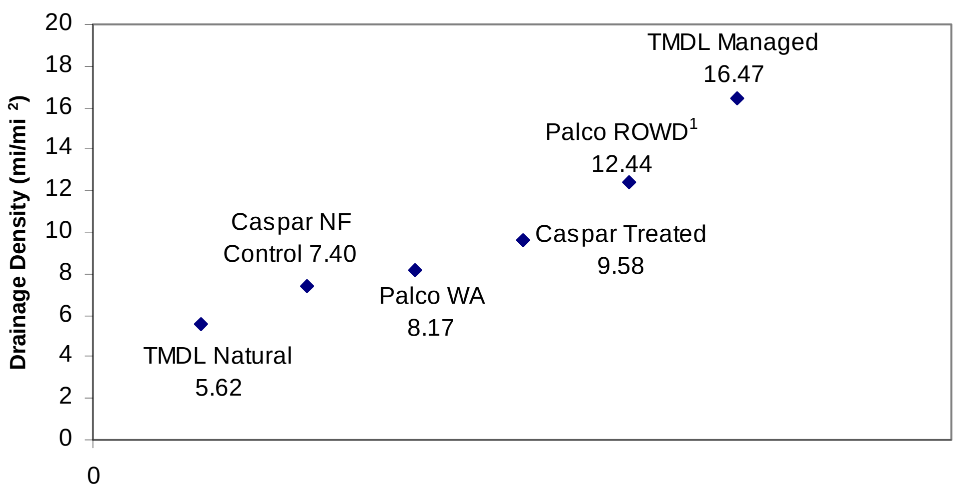

Figure 3.5 Drainage densities associated with the TMDL surveys in the study sub-basins, the Caspar Creek results, the Palco Watershed Analysis and Palco ROWD drainage network data.
[1]Staff modified the Palco ROWD stream network data to include Class I stream lengths described in the Palco WA results.

For the purposes of this sediment source analysis, the natural drainage density developed from the TMDL survey data (5.6 mi/mi^2) was applied over all the TMDL sub-basins for use in determining erosion rates associated with natural sources.

Regional Water Board staff acknowledges that management-related headward channel incision (like natural incision) varies with soils and geologic formation. The TMDL channel incision study data for managed sub-basins resulted in a drainage density of 16.5 mi/mi^2. For the purposes of this sediment source analysis, this value is used in determining channel lengths receiving management related sediment delivery within the Wildcat Formation.

Within the sub-basins underlain with the Franciscan Formation, staff deemed that the Caspar Creek results (Reid, 2010) were applicable, with modification. Specifically, the

Caspar Creek results represent changes in drainage density resulting from increased peak flows, but not from tractor impacts. According to the TMDL channel incision study, in the managed sub-basins approximately a third (35%) and over half (59%) of the channel heads surveyed in Corrigan Creek and South Branch, respectively, were influenced by skid trails (Buffleben, 2009). To account for the influence of skid trails in the portions of the Elk River watershed dominated by Franciscan geology, Regional Water Board staff evaluated the potential effects of tractors in Wildcat dominated geology. The following considerations were used in the estimation of the relative influence of tractor logging in the Franciscan Formation:

- The total percent change in drainage density due to management (hydrologic change, skid trail and road compaction and cut and fill) in the Wildcat-dominated TMDL study sub-basins was 193%.
- Assuming the natural drainage density, prior to first cycle logging, in Caspar Creek is equal to that of the reference TMDL study sub-basin, the total percent change in drainage density due to hydrologic change in the Caspar Creek study would be 70%.
- Assuming that 70% of the total change observed in the TMDL study sub-basins is due to hydrologic change, the remaining 122% is due to skid trail and road compaction and excavation.

To account for the influence that skid trail and road compaction and cut and fill would have on a Franciscan dominated area, the treated drainage density in Caspar Creek was multiplied by 122%, resulting in a drainage density of 11.75 mimi^2. This value was used as the drainage density for the managed portions of the Franciscan dominated areas.

Comparing the estimated managed drainage density in the Franciscan (11.75 mi/mi^2) to that reported in the Palco ROWD (11.37 mi/mi^2 and 12.44 mi/mi^2, without and with Class I watercourses included, respectively), the results are quite similar, giving confidence to Regional Water Board staff's estimate for managed density in the Franciscan based geology. The Palco ROWD density includes data from Wildcat dominated areas, thus the density for Franciscan dominated areas is likely lower than reported in the ROWD.

With respect to the Hookton Formation, little information is available regarding drainage density. The HRC Geology Department (HRCGD, 2009) summarized the influence of the Hookton Formation on stream channel excavation. Their summary indicates that within the Hookton, there are deep unconsolidated deposits that are permeable, subject to weathering, unstable and pose a greater risk of deep-seated landsliding than compared to other lithologies. Regional Water Board staff expects that the treated channels don't incise as far upslope as occurs in Wildcat dominated areas. However, the erosion associated with disturbance in Wildcat dominated areas is expected to be greater than for Hookton geology. Due to lack of soil cohesion, headcuts are expected to be larger features. Considering these conditions, and lacking formation-specific information, Regional Water Board staff extrapolated the values used to develop Wildcat specific delivery values as appropriate, to sediment delivery rates for use in the Hookton dominated portions of the watershed.

The headward extension of the channels was assigned time periods for consideration in sediment source categories which utilize drainage density. Due to a lack of comprehensive harvest history data, Regional Water Board staff assumed that three-quarters (75%) of the headward extension occurred as a result of first cycle logging and the discharge associated with this process was assigned to the 1950's time period. Staff assumed an additional five percent (5%) of the total headward extension per decade thereafter. Table 3.9 demonstrates the resulting drainage density associated with different time periods.

Table 3.9 Drainage density associated by decade for Elk River geologic formations.

Time period	1950 (Natural)	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009 (Current)
Percent of current drainage density present by decade		75%	80%	85%	90%	95%	100%
Wildcat and Yager Drainage Density (mi/mi^2)	5.6	12.4	13.2	14.0	14.8	15.6	16.5
Franciscan Drainage Density (mi/mi^2)	5.6	8.8	9.4	10.0	10.6	11.2	11.7
Hookton Drainage Density (mi/mi^2)	5.6	12.4	13.2	14.0	14.8	15.6	16.5

Source category evaluations that utilized these drainage densities include soil creep, bank erosion, and streamside landslides.

The drainage densities presented in Table 3.9 were then applied to the sub-basins based upon the Geologic Groupings presented in Section 3.1.4.1. Additionally, the associated drainage densities present during each of the photo periods evaluated in the sediment source analysis were calculated. For computation purposes, staff assumed the drainage density present at the end of the photo period was representative of the whole photo period. The resulting densities within the TMDL sub-basins for the different photo periods are shown in Table 3.10.

Table 3.10 Drainage densities associated with TMDL subbasins for source analysis time periods.

			Drainage Density (mi/mi^2)								
Geologic Formation	Geologic Group	Subbasin Name	Pre 1950 (Natural)	1950-1954	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	2004-2009 (Current)
Wildcat / Yager	A	Bridge Creek	5.6	9.0	12.8	13.7	14.5	15.5	15.9	16.1	16.5
	A	Dunlap Gulch									
	A	Browns Gulch									
	A	McWhinney Creek									
	B	Lower North Fork									
	B	Lower South Fork									
	B	Tom Gulch									
	A	Lake Creek									
	A	McCloud Creek									
	F	Upper South Fork									
	C	South Branch North Fork									
	C	Little South Fork									
	C	Corrigan Creek									
Hookton	D	Railroad Gulch	5.6	9.0	12.8	13.7	14.5	15.5	15.9	16.1	16.5
	D	Clapp Gulch									
Franciscan	E	Upper North Fork	5.6	7.2	9.2	9.8	10.3	11.0	11.4	11.5	11.7
	E	North Branch North Fork									

3.2.3.3 Uncertainties Associated with Channel Initiation Analysis

Assumptions and uncertainties identified by Regional Water Board staff are identified below.

- It is assumed that the natural drainage density is uniform throughout the watershed, though it likely varies with topography and geologic formation.
- Staff assumed that the Geologic Group E in Elk River behaves similar to the Caspar Creek area.
- Staff assumed that the proportion of impacts associated with hydrologic change versus skid trail and road excavations and fills is consistent between the TMDL study sub-basins and Caspar Creek.
- Staff assumed that natural drainage density of Caspar Creek is consistent with TMDL study sub-basin survey results.
- Staff assumed that Hookton drainage density is same as in Wildcat dominated areas.
- The time periods for the impacts are assumed to be uniform throughout the basin. The introduction of tractor equipment certainly affected the drainage network. As such the 1950's time period was selected as the timeframe for initial management-related channel incision. Staff observations indicate that headward extension can occur with contemporary logging operations, thus the allocation of continued extension is appropriate.

3.3 Natural Sediment Source Categories

Natural sediment sources identified, evaluated and quantified in this source analysis include:

- Soil creep.
- Stream bank erosion.
- Streamside landslides.
- Hillslope landslides.
- Deep seated landslides.

Each of these sources is described in more detail below, including a discussion on the analysis methods used, summary of the data results, and identification of the uncertainties associated with each source category.

3.3.1 Natural Soil Creep

As used in this analysis, soil creep is defined as a natural process in which soil and/or rock debris slowly moves downslope under the influence of gravity. Colluvium (rock and other related debris derived from the hillslope) is supplied to stream banks via soil creep at a rate equal to the stream bank erosion rate, if equilibrium conditions are assumed.

3.3.1.1 Methods Used to Determine Natural Soil Creep Rates

Buffleben (2009) reviewed a suite of measured soil creep rates developed in the temperate rainforests of northern California for use in the Elk River and Freshwater Creek watershed analysis. Two types of creep rates were evaluated, surface and volumetric. Surface creep rates ranged from 0.5 to 10 mm/yr (higher rates were measured in continental versus maritime temperate zones) and up to a depth of 25 cm.

Reid and Dunne (1996) suggest determination of sediment delivery rates based upon the volumetric creep rate, adjusted for creep depth when stream banks are shallower than the creep depth. According to Buffleben (2009), the only available volumetric creep rates measured fairly locally are from Lehre (1987), and were measured in the grasslands of Marin County (located approximately 250 miles south of Elk River).

Buffleben (2009)[12] evaluated available creep delivery estimates based upon two criteria: 1) a method that produces a conservative estimate for soil creep to ensure an implicit margin of safety and 2) a method that matches theoretical mechanisms and local field measurements. Buffleben found that using volumetric creep movement rates from Lehre (1987) fits these criteria the best, because it provides a conservative estimate, it uses rates where a depth profile is not assumed, and the measurement rates are from a location relatively close to Elk River.

Of the reported values from Lehre, Buffleben found the most applicable value to Elk River was the median value of 0.37 cm^3/cm/yr with an upper median bound of 1.63 cm^3/cm/yr. Since the colluvial bank heights in Little South Fork Elk River were greater

[12] Table 4-4.

than 0.4 m (greater than the depth of movement), no adjustments were made to the volumetric creep rates.

3.3.1.2 Results - Natural Soil Creep Analysis

The soil creep rate of 0.37 $cm^3/cm/yr$ corresponds to a rate of 0.078 $yd^3/mi/year$. With a natural drainage density of 5.6 mi/mi^2, the resulting sediment loading from soil creep is 0.44 $yd^3/mi^2/yr$. This rate was then used to estimate the sediment delivery from soil creep process for the upper portion of the Elk River watershed.

3.3.1.3 Uncertainties Associated with the Natural Soil Creep Analysis

Uncertainty is associated with the estimates established through the analysis due to the following considerations:

- Soil creep rates likely vary with topography and soil depth, thus are likely to vary throughout the watershed, whereas Regional Water Board staff applied a uniform rate in this sediment source analysis.
- Soil creep estimates cover a wide range and can influence the magnitude of natural sediment loading. The estimate used in this staff report is in the lower range of estimates.

3.3.2 Natural Stream Bank Erosion

For the purposes of this study, bank erosion is defined as stream bank erosion caused by lateral migration of stream flows (i.e. flow deflection or stream undercutting). Bank erosion does not include streamside hillslope failures (mass wasting), or stream channel incision (vertical down cutting) caused by fluvial processes.

3.3.2.1 Methods Used to Determine Natural Stream Bank Erosion Loads

This analysis assessed stream bank erosion rates within the Little South Fork Elk River reference study sub-basin using a stream bank erosion void assessment method (Reid and Dunne 1996; PWA 1999; PALCO 2007), PWA (2008). Bank erosion volumes for erosion features greater than five cubic yards (>5 yd^3) of delivery were inventoried under this approach. These volumes were estimated by measuring bank erosion height and root exposure depth along lengths of eroded stream bank. The volume of bank erosion was computed as:

Bank erosion height (ft) x root exposure depth (ft) x length of eroded channel (ft)

Bank erosion sites less than five cubic yards (<5 yd^3) were tallied by stream order and erosion from these sites was estimated by multiplying the number of smaller features by an average delivery of 2.61 yd^3 (2 m^3) per site (PWA, 2008).

Unit bank erosion (yd^3/mi) was determined for 1st, 2nd, 3rd and greater than 4th order channels[13] based on the total estimate of field inventoried bank erosion (>5 yd^3 and <5 yd^3 features combined) in each stream order. Unit sediment delivery was then

[13] A stream layer was developed for the reference study sub-basin assuming an 0.8 hectare drainage area defining the location of stream inception. This stream layer was used to designate the Strahler order of all tributary channels within the reference study sub-basin (PWA, 2008).

extrapolated to the total length of stream (by stream order) in each of the study sub-basins.

Specific bank erosion void attributes were collected on field data forms for erosion features with sediment delivery >5 yds^3 and mapped on 1:1200 LiDAR based DEM shaded relief field maps. The specific bank erosion attributes collected in the field are presented below. The locations of bank erosion sites <5 yds^3 were flagged in the field and mapped on the field maps. Data forms were not filled out for the smaller features.

Seventeen randomly selected stream reaches were inventoried in the Little South Fork Elk River reference study sub-basin. Inventoried stream reaches within this sub-basin averaged approximately 176 meters in length. The stream reach inventory included approximately 900 meters of 1st order streams; 590 meters of 2nd order streams, 750 meters of 3rd order streams, and 760 meters of 4th order and greater streams. The dominant substrate observed during the inventory was primarily sand sized particles with minor amounts of cobble and gravel. The channel morphology of the sampled 1st and 2nd order streams were formed primarily by subsurface flow. The channel morphology observed in the 3rd, 4th order and higher order stream reaches were predominantly low gradient riffles. The 4th order and higher stream reaches were all located in the mainstem portion of the Little South Fork Elk River watershed.

3.3.2.2 Results - Natural Stream Bank Erosion Analysis

The unit bank erosion sediment delivery rate calculated for Little South Fork Elk River was 0.045 m^3/m (94.72 yd^3/mi) for the fifty-seven (57) year period between 1950-2007. Assuming a natural stream drainage density of 5.6 mi/mi^2 (based upon analyses presented in Section 3.5.2), the annual natural stream bank erosion rate was calculated to be 9.36 $yd^3/mi^2/yr$. However, because soil creep is calculated as a separate category, the natural soil creep loading of 0.44 $yd^3/mi^2/yr$ (Section 3.5.1) was subtracted from the field-determined natural bank erosion rate. As such, the resulting natural stream bank erosion loading was found to be 8.92 $yd^3/mi^2/yr$.

3.3.2.3 Uncertainties Associated with the Natural Stream Bank Erosion Analysis

Uncertainty is associated with the estimates established through the analysis due to the following considerations:

- The bank erosion inventory estimates assumed a uniform erosion rate throughout the 1950-2007 time period. However, because delivery rates vary with streamflow, the application of a uniform rate over the study time period overestimates the inputs rates during dry periods and underestimates them during periods of higher flows.
- Natural bank erosion likely varies spatially with differences in geology, hillslope, and stream gradients affecting erosion rates. The bank erosion analysis assumes a uniform rate across the Elk River watershed.

3.3.3 Natural Small Streamside Landslides

Small streamside landsides are landslide features that originate from streamside slopes and too small to detect on aerial photographs. The rate of streamside landsliding in the reference sub-basin (Little South Fork Elk River) was used as the basis for the rate of natural streamside landsliding in this sediment source analysis.

Recent studies evaluating the effects of land management on landslide initiation rates have indicated that the presence of landslides may be masked during aerial photography analysis in forest lands dominated by a relatively closed forest canopy. This can result in a bias in estimating landslide rates in harvested areas versus areas of old-growth or relatively closed canopy. PWA (2006) describes the ranking factors affecting landslide visibility on aerial photographs, indicating that canopy conditions, as a surrogate for land use, is the most important factor influencing landslide visibility.

3.3.3.1 Methods Used to Determine Natural Small Streamside Landslide Loads

PWA (2006) conducted an aerial photo and field-based comparison of three distinct forest canopy types: 1) old-growth, 2) advanced second-growth and 3) recently (less than 15 years ago) clearcut areas in the Elk River and Freshwater Creek watersheds. This study provided estimates of the relative streamside landslide erosion and delivery associated with each of the three canopy types. This study was also designed to estimate relative levels of uncertainty associated with using aerial photo interpretation for landslide detection.

In 2006, PWA (2006) surveyed 3.6 miles of channel in the reference sub-basin (LSFER) for evidence of past or recent streamside landslides. Only landslides that delivered to the stream system were included in the inventory. Each feature was inventoried based on volume (greater than or less than ten (10) cubic yards). Average dimensions and sediment delivery estimates were also recorded for each feature.

Landslides were age-dated using geomorphic and vegetative site conditions (scarp morphology, slide scar re-vegetation, leaning trees, sapling growth whorls, soil bareness, type of cover (herbaceous versus trees), etc.) and placed in one of three age categories: 1) 1975–1987; 2) 1988–1997; and 3) 1998–2003). This age determination required professional judgment. Landslide that initiated during these time periods would be subject to potential identification on air photos from 1987, 1997 and 2003. Landslides judged to pre-date 1975 and post-date 2003 were mapped but not inventoried on data forms.

3.3.3.2 Results - Natural Streamside Landslide Analysis

Within the 3.6 miles of stream sampled for this streamside landslide analysis, twelve (12) small (<10yd^3) landslide features were identified for a total sediment delivery of sixty (60) yd^3, with an average sediment delivery of five (5) yd^3 per site. A total of eight (8) large (>10 yd^3) landslides were identified for a total sediment delivery of 352 yd^3 and an average delivery volume of forty-four (44) yd^3 per feature. All of the eight (8) large landslides were field identified as debris slides, two (2) were associated with Wildcat

Formation and six (6) were located within terrain dominated by the Yager Formation. Four (4) large slides were attributed to the 1975 through 1987 time period, two (2) were attributed to the 1988 through 1997 period, and two (2) were attributed to the 1998 to 2003 period. The conifer overstory-canopy ranged from forty (40%) to ninety-five (95%) percent and the shrub cover ranged from sixty (60%) to ninety-five (95%) percent. None of these features were detected on aerial photographs. The PWA inventory did not attribute time period to the smaller features. For the purposes of this analysis, Regional Water Board staff assumed the small landslides occurred during the same time frames proportional to those of the large landslides.

Figure 3.6 presents the unit channel delivery from small and large streamside landslide inputs. The PWA surveys indicate total combined inputs from natural small and large streamside landslides was 1.9 $yd^3/mi^2/yr$, 1.6 $yd^3/mi^2/yr$, and 5.3 $yd^3/mi^2/yr$, for the photo periods 1975-1987, 1988-1997, and 1998-2003, respectively. The 29-year average based upon the PWA surveys is 3.95 $yd^3/mi/yr$.

PWA surveys were based upon a drainage network with an assumed 0.8 hectare drainage area. TMDL stream channel incision surveys (Section 3.4) indicate that the natural drainage network is based upon a 4.22 hectare drainage area and managed areas are based upon a 0.52 hectare drainage area. Consequently, in the reference study sub-basin, PWA conducted surveys of swales upslope of areas defined within the natural TMDL drainage network. Evaluation of their results indicate that an additional approximately 1.05 miles of stream length was included in the survey and an associated five (5) small features and one (1) large feature were included, for a total estimated volume of 69 yd^3. Adjustment of the data to exclude these survey lengths and features results in an increase in the 29 year annual average sediment delivery from natural stream side landslides from 3.95 $yd^3/mi/yr$ to 4.63 $yd^3/mi/yr$. Because it is unknown to Regional Water Board staff which time period was assigned to the excluded features, the adjusted long-term average loading was applied to the sub-basins in this sediment source analysis. Table 3.11 presents the results of the adjusted PWA surveys. Figure 3.6 shows the PWA results as well as the long-term average based upon the adjusted results.

Table 3.11 Results of streamside landslide surveys based upon adjusted PWA surveys (all photo periods combined)[14]

Small streamside landslide feature	Number of features	Average volume (yd^3)	Total Volume (yd^3)	Volume per channel length (yd^3/mi)	Annual average volume per channel length ($yd^3/mi/yr$)
Small (<10 yd^3)	7	5	35	13.70	0.47
Large (>10 yd^3)	7	44	308	120.58	4.16
Small and Large Combined	14	--	343	134.29	4.63

[14] Adjusted to exclude stream lengths and features upslope of the drainage network used in this source analysis (based upon a 4.2 ha drainage threshold (Section 3.2.3.2)).

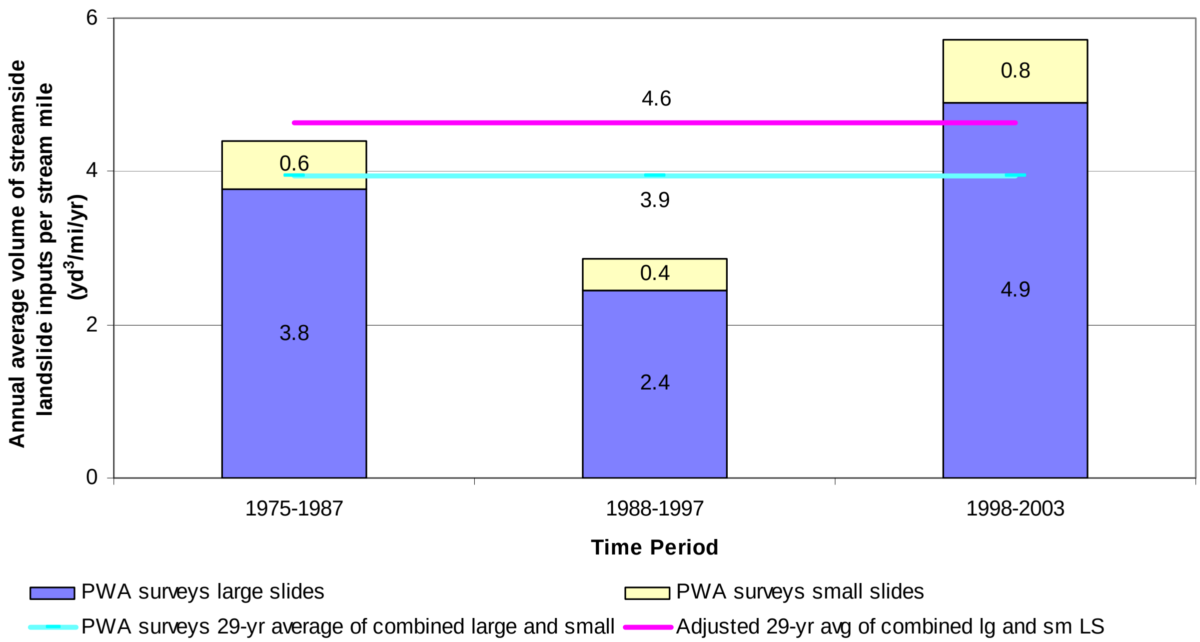

Figure 3.6 Annual average delivery per channel length from streamside landslide in reference study sub-basin. The original PWA surveys are represented by bars and the lines demonstrate the 29-year average based upon the original and the adjusted PWA surveys.

The annual average loading from natural streamside landslides, based upon a delivery of 4.63 yd^3/mi/yr and a natural drainage density of 5.63 mi/mi^2 is 26.08 yd^3/mi^2/yr.

3.3.3.1 Uncertainties Associated with the Natural Streamside Landslide Analysis

Uncertainty is associated with the estimates established through the analysis due to the following considerations:

- The adjustment to the PWA surveys to account for channel segments and features being surveyed and identified upslope of the TMDL drainage network may have introduced error by 1) the excluded channel lengths being either over or under estimated, 2) the excluded features may have had volumes significantly different than the average volumes for large or small features.
- The dating of streamside landslide features and the placement of the features into the appropriate photo period was subject to best professional interpretation by the field crews. Thus, the actual time period for sediment delivery from any specific feature may be different than that used in the calculations. Uncertainty associated with time period increases with older features. The long-term average was used in this sediment source analysis.
- The natural drainage density likely varies depending on topography and geology. However, a fixed value of 5.6 mi/mi^2 was used for all areas regardless of hillslope gradients. The areas where this assumption is expected to least accurately reflect actual drainage densities is in flood-prone areas, thus leading to an over estimate of natural sediment loadings from these areas.

3.3.4 Natural Hillslope Shallow Landslides

Hillslope shallow landslides are landslide features that are typically visible on aerial photographs with a size of greater than 400 ft^2.

3.3.4.1 Methods Used to Determine Natural Shallow Hillslope Landslide Loads

Two approaches were evaluated to determine reasonable estimates of natural hillslope landslide sediment delivery volumes for use in the Elk River TMDL analyses. One method is based upon data derived from the Little South Fork Elk River reference study sub-basin, referred to in this Staff Report as the reference watershed approach. The other approach is based upon developing estimates using data from those areas in the watershed that have not been subject to recent harvesting activity (i.e. no harvest in the last 15 years), referred to in this Staff Report as the empirical sediment budget approach. A brief description of each approach and their respective results are presented below.

Considerations important to the characterization of naturally occurring shallow hillslope landslides include:

- Minimal management influence on hillslope landslide rates.
- Acknowledgement of spatial and temporal variability of landsliding.
- Data quality comparable to that associated with management-related landslide data.
- Determination of level management influence is verifiable and objective.

This section describes the methods associated with each of the two approaches evaluated to estimate natural hillslope landslide loading, including the Reference Watershed Approach (RWA) and the Empirical Sediment Budget Approach (ESBA).

Use of the Reference Watershed Approach (RWA) to Quantify Loads from Natural Shallow Hillslope Landslides

As described in Section 3.2.1, Regional Water Board staff selected the Little South Fork Elk River as the watershed that best reflects the natural or unmodified sediment delivery rates and hydrologic process at work in the basin. Data from this sub-basin were used to characterize natural (background) conditions for the Elk River.

The reference watershed approach (RWA) assumes a natural hillslope landslide loading based upon the loading derived from aerial photo analyses conducted within the old-growth portions of Little South Fork Elk River sub-basin (PWA, 2008).

An air photo analysis of the Little South Fork Elk River (reference study sub-basin) using four sets of historic air photos (1987, 1997, 2003, and 2007) [15] was conducted to identify landslides with sediment delivery potential within the 1.20 mi^2 sub-basin (PWA 2006).

[15] All air photos used as part of this project were obtained with permission from the Pacific Lumber Company and analyzed using a stereoscope in their Scotia office.

For the landslide history conducted in the reference watershed each new landslide which appeared on the photographs was inventoried. Specifically, all visible recent or active landslides with a minimum area of 400 ft^2 that deliver sediment to streams were mapped and feature attributes were recorded.

Landslide depths were determined by using a linear regression equation developed for the Freshwater Creek Sediment Source Investigation (PWA, 1999). The following equation is based on the relationship between landslide surface area using field data collected during the field verification phase of this 1999 investigation, where:

$$Depth=0.00024*Area + 1.426\ (R^2 = 0.52)$$

Landslide volumes were calculated from the areas derived from the air photos and depths derived from the regression curve. A maximum of 15 ft depth was assumed for landslides greater than 57,000 ft^2. The features were not field verified. PWA estimated percent delivery for the features based upon aerial photo interpretation.

Use of the Empirical Sediment Budget Approach (ESBA) to Quantify Sediment Loads from Natural Shallow Hillslope Landslides

This sediment source analysis utilized the empirical sediment budget approach to develop a second estimate of sediment delivery volumes from natural shallow hillslope landslides. This approach is based upon evaluating areas that had not been harvested in the fifteen years prior to initiation of the landslide event. The geologic groupings (Section 3.2.2.1) were used, rather than evaluation of the individual sub-basins because the finer resolution results in areas too small to provide good measures of representative rates (i.e. too small of a sample size). The landslide database (Palco, 2005)[16] was evaluated to estimate the sediment delivery volume from shallow hillslope landslides within areas not harvested in the past fifteen years.

The land classes which describe the portion of geologic groups harvested in the fifteen year period prior to the end of the landslide photo period (Section 3.2.2.2), were consulted to determine the portion of the watershed not harvested in that fifteen year period.

The landslide database (Palco, 2005) was used to identify landslides within each of the sub-basins. Those data were then grouped by geologic group (Table 3.4), sorted by the aerial photo year that the landslide was first visible, and by the attribute representing if the slide was within areas harvested in the past fifteen years (recently harvested) or areas not harvested within the past fifteen years (not recently harvested). The landslide delivery volume associated with not recently harvested areas was summed by photo period, for each of the geologic groups. The total volume per reference land class was then determined (i.e. by geologic groups without non-recent harvest) for the photo

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[16] Final Report of Waste Discharge (Palco, 2005). The excel spreadsheet database contains entries, including past delivery volumes, for 1144 landslides.

periods for which there was corresponding harvest history data (1988-1997, 1998-2000, 2001-2003).

3.3.4.2 Results - Natural Shallow Hillslope Landslide Analysis

Within the reference study sub-basin, PWA (2008) identified two landslides during the 1988-1997 photo period for a estimated delivery of 107 yd^3, one landslide during the 1998-2003 photo period for a estimated delivery of 382 yd^3, and two landslides during the 2004-2007 photo period for a estimated delivery of 510 yd^3. Based upon the RWA, Figure 3.7 shows the average annual sediment loading associated with natural landslides based on the reference watershed approach. The average sediment loading for 1988-2007 (weighted by length of photo period), based on the reference watershed approach, is 41.6 $yd^3/mi^2/yr$.

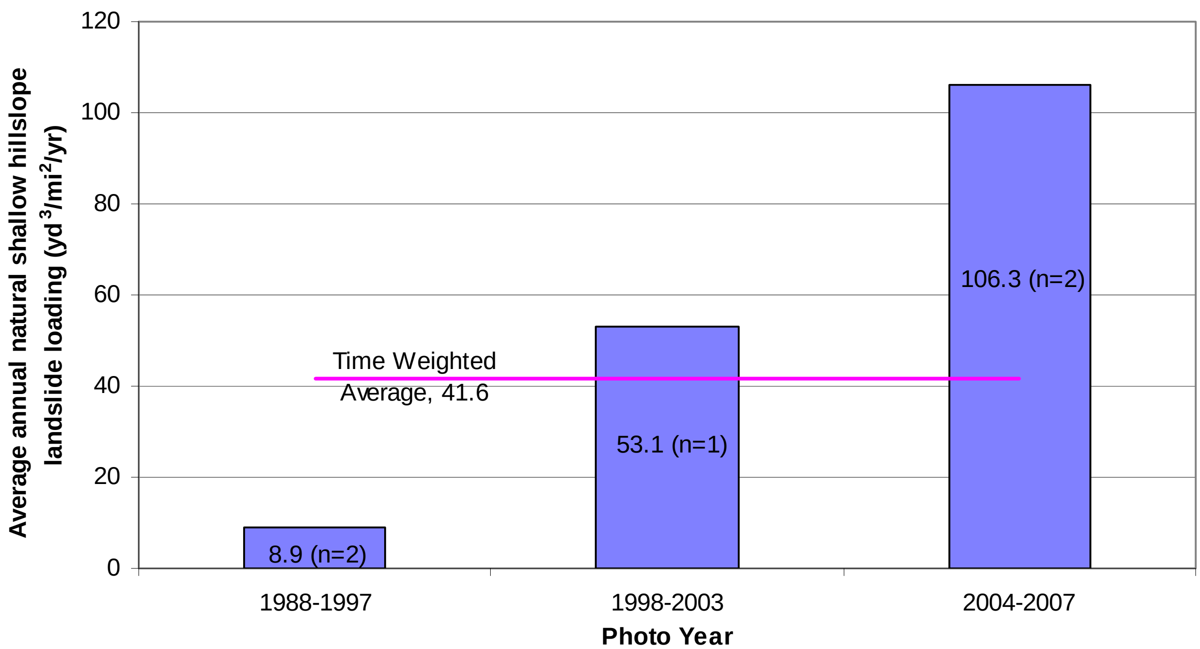

Figure 3.7 Natural shallow hillslope landslide sediment loading ($yd^3/mi^2/yr$) based upon the reference study sub-basin for available photo periods, as determined by reference watershed approach.

The limited pool of landslide features available for the RWA has the potential for each feature to significantly shift the loading within a given photo period. The relatively small size of the reference study sub-basin may be insufficient to characterize natural hillslope landslide loading throughout the watershed. Additionally, PWA (2008) assigned a measure of certainty to the identified features which ranged from medium to low; field verification would improve the certainty of the estimates.

The data presented in Table 3.12 was derived using the empirical sediment budget approach. Table 3.12 demonstrates the reference land class areas as a portion (percentage) of each of the areas not harvested in the past fifteen years by geologic group. Geologic Group F represents the smallest fraction unharvested in the past fifteen years for all photo periods.

Table 3.12 Land class areas (*ai*) (dimensionless)

Landslide period	1988-1997	1998-2000	2001-2003
Period of no harvesting	**1973-1997**	**1983-2000**	**1986-2003**
Geologic Group	***Percent of area not harvested in last 15 years, (a_i)***		
A	75%	73%	68%
B	85%	83%	82%
C	75%	75%	83%
D	70%	70%	70%
E	69%	66%	65%
F	42%	42%	41%

Table 3.13 demonstrates the sediment production from the land class areas which have not been harvested in the past fifteen years (reference production). The area weighted and time weighted averages are also presented.

Table 3.13 Reference Sediment Production Coefficient (r_i)

Landslide period	1988-1997	1998-2000	2001-2003	Time weighted average
Period of no harvesting	**1973-1997**	**1983-2000**	**1986-2003**	
Geologic Group	***Annual volume of sediment delivered per unit area from areas not harvested in last 15 years ($yd^3/mi^2/year$)***			
A	36	0	2	23
B	107	7	42	76
C	1	40	0	8
D	153	25	0	100
E	0	0	11	2
F	6	0	0	4
Area weighted average	42	9	12	**30**

Figure 3.8 demonstrates the different sediment loading estimates for shallow hillslope landslides as determined by the reference watershed approach and the empirical sediment budget approach.

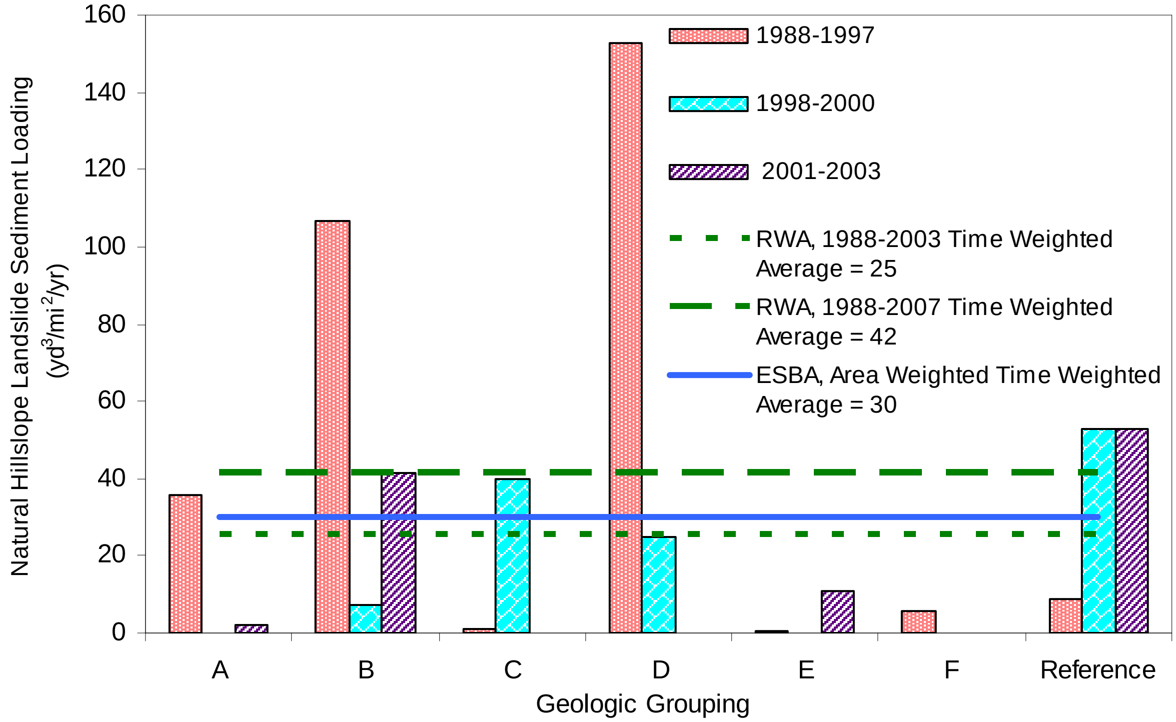

Figure 3.8 Natural shallow hillslope landslide sediment loading based upon estimates from the reference watershed approach and the empirical sediment budget approach.

Staff determined that the area weighted time weighted average derived from empirical sediment budget approach (1988-2003, 30.1 yd^3/mi^2/yr) is the most reasonable estimate of the natural shallow hillslope landslide loading for use in this sediment source analysis. Section 3.3.4 describes considerations important to the characterization of naturally occurring shallow hillslope landslides; following is a description of how this analysis of naturally occurring hillslope landslides satisfies those considerations.

- The empirical sediment budget approach (ESBA) does not reflect the “no management” influences on shallow hillslope landslide rates as well as the reference watershed approach does. Staff believes this is due to some level of recovery of hillslope stability in the preceding fifteen (15) year period of no harvesting.
- The ESBA represents the spatial variability of landsliding over various topographic or geologic areas.
- The landslide inventories which provide the basis for the ESBA natural landslide loading are the same as those used for evaluation of management- related landslide loading.
- The rates of landsliding both on areas without recent harvest and within the reference study sub-basin can be monitored over time to verify and improve estimates of natural hillslope landslide loading.
- The approach is objective and does not rely on professional judgment to determine if a slide is induced by natural or management related factors.

The ESBA yields a conservative estimate and Regional Water Board staff judged that it is the most reliable estimator because the pool of landslides available for the RWA is too small to provide meaningful or reasonable results.

3.3.4.3 Uncertainties Associated with the Natural Shallow Hillslope Landslide Analysis

Uncertainties and assumptions associated with using the empirical sediment budget approach to estimate inputs from natural shallow hillslope landslides include:

- Areas previously harvested (greater than fifteen (15) years ago) likely over-estimate natural landslide rates since:
  1) It is unlikely that root strength recovers to unharvested conditions in fifteen (15) years.
  2) Hydrologic changes associated with rainfall interception and evapotranspiration resulting from harvesting is unlikely to return to old-growth conditions in a fifteen (15) year period.
- The harvest history is not well documented prior to 1986. Thus, uncertainty in harvest history prior to landslides in the 1988-1997 photo period may result in either under or overestimation of rates.

Due to the use of land classes, the sediment and harvest data may result in either over or underestimation of rates for the individual sub-basins within the geologic groupings.

3.3.5 Deep-seated Landslides

As part of the report, *Landslide Hazard in the Elk River Basin,* Stillwater (2007) reports "Large storm events can activate debris slides and rotational landslides associated with pre-existing deep-seated landslide features (De La Fuente, et al. 2002). Despite the potential importance of deep-seated landslides to sediment delivery, the physical factors controlling deep-seated mass movement are poorly understood and few physical models have been developed to assess deep-seated landslide hazards (Miller 1995). Deep-seated landslide morphology is typically characterized by crescent-shaped major and minor scarps; flat-lying and backtilted blocks; benched topography; and lobate accumulation zones with hummocky topography, seepage lines and springs, ponded and deflected or irregular drainage patterns. Deep-seated landslides and their corresponding level of activity are typically identified based on interpretation of these topographic signatures on maps and aerial photographs. Confirmation of these features is supplemented by field observations. These approaches, however, require substantial effort, are limited by vegetation that obscures relevant features, and require professional judgment based on experience with the local geology and topography. This approach can result in the production of a hazard map that is based on subjectivity and would be difficult to replicate."

A suite of tools for objective delineation of terrain prone to deep-seated landslides and earthflows using high-resolution digital topographic data is currently being developed (McKean and Roering 2004, Roering et al. 2005, Mackey et al. 2005, Mackey et al. 2006, Roering et al. 2006). These deep-seated landslide and earthflow detection (DSLED) algorithms identify terrain that has already experienced deep-seated slope instability, and thus has a higher potential for reactivation (Roering et al. 2006). The methods provide predictive power in identifying slide-prone terrain, and are best utilized as reconnaissance tools in combination with aerial photographic interpretation and field mapping. The models are being developed and tested at sites in the northern California Coast Range, Western Cascade Range of Oregon, and elsewhere (Roering et al. 2006). The models have been used to successfully identify deep-seated mass movement associated with the Franciscan melange in the nearby Eel River basin (Mackey et al. 2005, Mackey et al. 2006). Two of the three DSLED algorithms, DSLED Rough and DSLED Drain, were used to identify surface roughness and drainage patterns associated with potential deep-seated mass movement in the Elk River basin. As work is accomplished to characterize the type, boundaries, timing, and activity level of deep-seated landslides in the basin, efforts should be made to better validate the deep-seated model results and develop appropriate hazard classes.

3.3.5.1 Methods Used to Determine Deep Seated Landslide Loads

Two deep-seated landslide inventories were conducted in the Elk River watershed. Hart Crowser produced one as part of the “Elk River/Salmon Creek Watershed Analysis” (Palco, 2004) and the California Geologic Survey (CGS) produced the other as part of their mapping of “Geologic and Geomorphic Features Related To Landsliding in Elk River” (Marshall & Mendes, 2005). The Palco (2004) Watershed Analysis inventory included landslide activity level[17] that allowed an estimate of sediment delivery rates to be developed. The CGS map does not identify this activity level or any information from which to determine sediment delivery rates. As such this sediment source analysis relied on the Palco (2004) inventory for estimates of the deep seated landslide delivery as the best available information.

A deep seated landslide inventory as developed for and presented in the Elk River Watershed Analysis (Palco, 2004) includes 336 deep-seated features were identified within the Elk River watershed assessment area. The larger features average 30 acres in size, with the surface features averaging 22 acres in size. Of the inventoried features, 90.5% were classified as dormant, 6.8% were classified as relict. Palco (2004) considered the delivery of sediment from dormant historic, dormant, and relict deep-landslide features to be part the background soil creep estimates. Two features demonstrated activity within the available photo record. Palco (2004) assumed a rate of movement for these active features at 1 foot per year. This estimate was based upon the low end of reported rates for earthflow movement in the local area (Kelsey 1978) because there is no local data on the rate of movement of active deep-seated landslides other than for earthflows. The active features were identified in Upper South Fork Elk and Tom’s Gulch and had cross-sectional areas of the toes of 3,000 ft^2 and 400 ft^2, respectively. Palco (2004) attributed these deep seated features to natural sources.

3.3.5.2 Results - Deep Seated Landslide Analysis

Only the two identified “active” deep-seated features, as included in the Palco WA, were included explicitly in this Source Analysis as natural sources. The sediment delivery associated with these features, based on their size and a rate of one-foot per year, results in natural deep-seated delivery of 17.2 $yd^3/mi^2/yr$ in Upper South Fork Elk River

[17] Based after Keaton and DeGraff (1996)

and 5.9 $yd^3/mi^2/yr$ in Toms Gulch. It was assumed sediment delivery associated with the features classified other than "active" is included in the soil creep estimates.

3.3.5.3 Uncertainties with Deep Seated Landslide Analysis

Uncertainty is associated with the estimates established through the analysis due to the following considerations:

- Recent activity has been observed at the toes of features in the Lower South Fork TMDL sub-basin that are mapped as "dormant" features (pers comm. Sam Flannigan, 2011). Staff assumed that the landslides at the toes of deep-seated landslides are captured in the shallow hillslope landslide inventory and thus are accounted for in this sediment source analysis.
- Staff assumed that sediment delivery from the active deep-seated features is natural. Movement of deep-seated features may be aggravated by management activities including hydrologic changes and road cuts. These effects are not incorporated into this analysis.
- More work is needed to characterize the type, boundaries, timing, and activity level of deep-seated landslides in the basin in order to better validate the deep-seated model results and develop appropriate hazard classes.

3.3.6 Summary of Natural Sediment Sources

The natural sediment source analysis is based largely upon rates determined from within the watershed. Figures 3.9A and 3.9B present the annual average loading from the various source categories in $yd^{3/}/mi^2/yr$ and $tons/mi^2/yr$, respectively. Based upon this sediment source analyses, the annual average sediment loading, with the exception of deep seated landslides[18], is uniform throughout the basin.[19]

The sediment source analysis indicates that the largest inputs associated with natural sediment sources in the Elk River basin are shallow hillslope landslides and stream bank landslides.

[18] Active deep seated landslides have been identified in two sub-basins, Toms and Upper South Fork Elk River, with annual average loading of 5.9 and 17.2 $yd^3/mi^2/yr$, resulting in a total natural loading of 66.1 and 77.4 $yd^3/mi^2/yr$, respectively

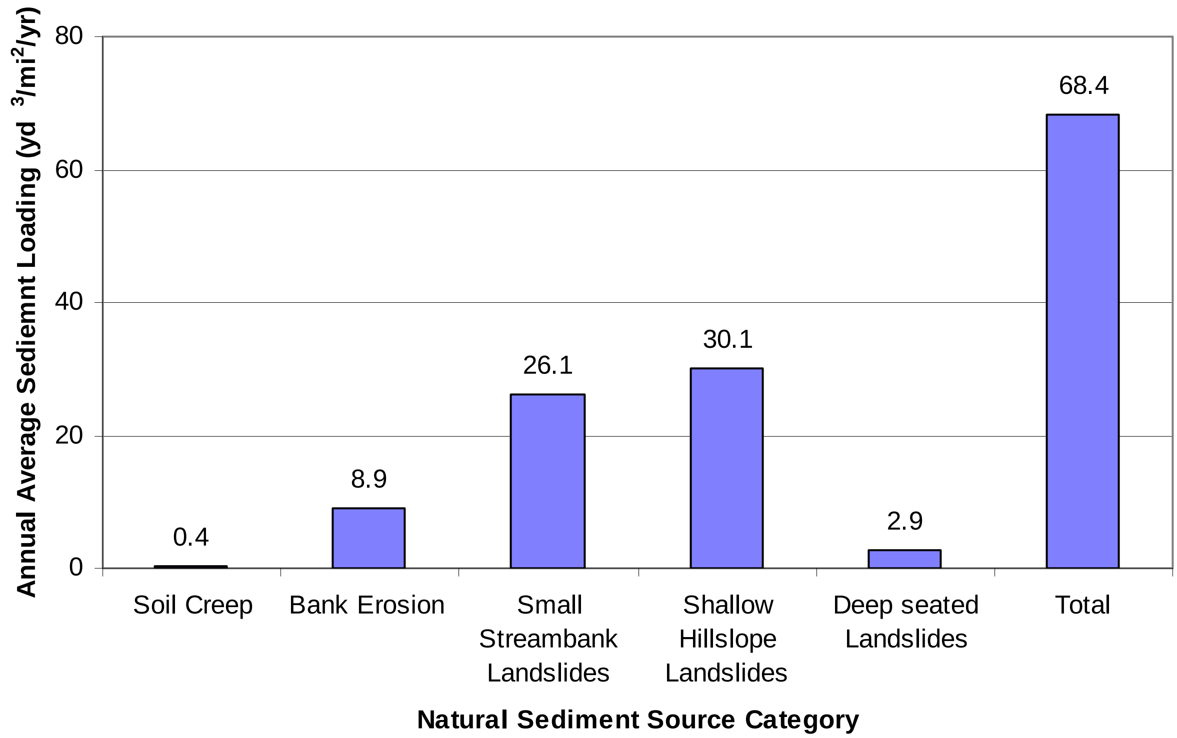

Figure 3.9A Summary of annual average loading from natural sediment sources in the Elk River watershed ($yd^3/mi^2/yr$).

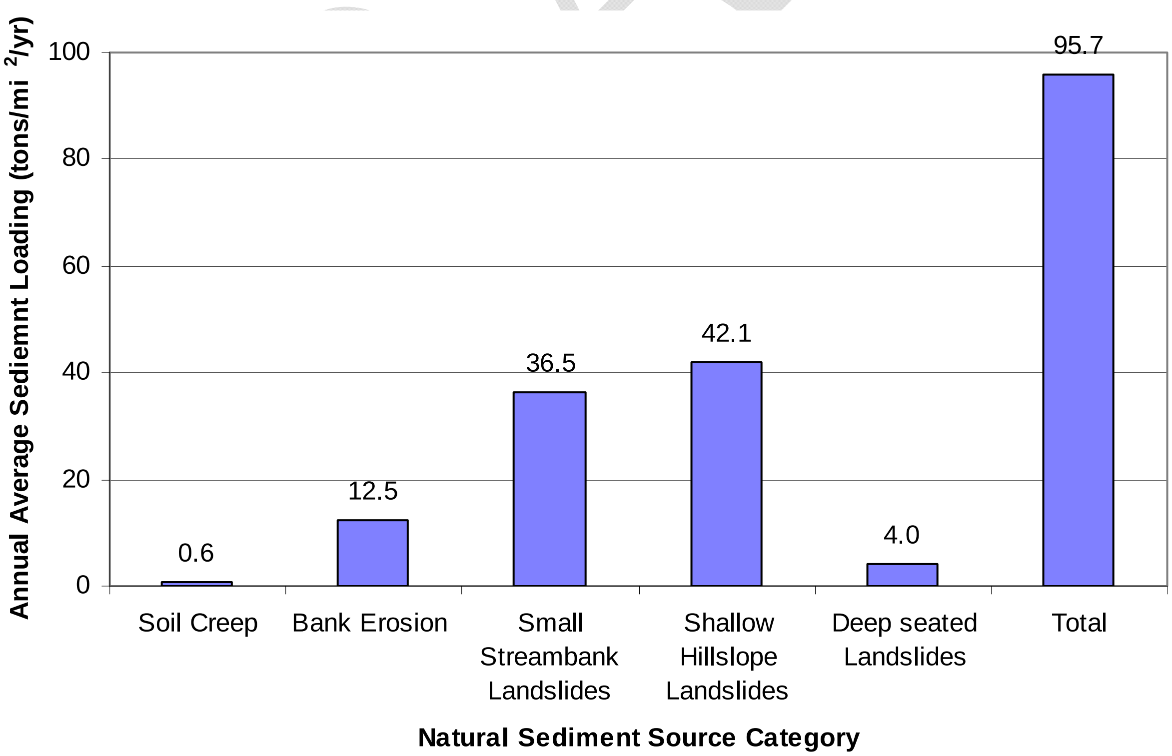

Figure 3.9B Summary of annual average loading from natural sediment sources in the Elk River watershed ($yd^3/mi^2/yr$).

3.4 Management Related Sediment Sources

Management activities, such as rates of timber harvesting, road construction and reconstruction and restoration (cleanup of controllable sediment sites) can all affect the creation of sediment sources and discharge rates associated with those sites. The sediment sources affected by management activities in Elk River include:

- Low order channel incision (headward scour).
- Soil creep within the management-related drainage network
- Stream bank erosion
- Road-related shallow hillslope landslides
- Open-slope shallow hillslope landslides
- Small streamside landslides.
- Management-related sediment discharge sites (e.g. gullies and stream crossing erosion features)
- Post-treatment discharge sites (e.g. erosion following correction of controllable sediment delivery sites).
- Skid trail features (e.g. diverted watercourses, compacted soil).
- Road surface erosion.
- Harvest (in unit) surface erosion.

Each of these sources is described in more detail below, including a discussion on the analysis methods used, summary of the data results, uncertainties associated with each source category and implications for watershed implementation actions.

3.4.7 Management-Related Channel Initiation in Low Order Streams

Scour of low-order channels (headward migration of the stream channel) can occur as a result of management-related activities. See Chapter 3.2.3 for more information regarding channel initiation and the increase in drainage density from the headward incision of watercourses as a result of timber harvest activities. The increase in channel density affects both the volume of sediment discharged per unit area as well as increasing the length of stream channel that is susceptible to direct sediment inputs. This source analysis accounts for this volume of sediment as management induced low-order channel scour.

3.4.7.1 Methods Used to Determine Management-Related Channel Initiation Loads

The natural drainage density (DD) and the managed drainage density data were evaluated to determine the difference in channel length for each of the sub-basins. This was determined as:

$$(DD_{Managed}*Area_{sub\text{-}basin})-(DD_{Natural}*Area_{sub\text{-}basin})=Length_{Channel\ Scour}$$

Regional Water Board staff assumed that the management-related headward migration of channels occurred in low-order (1^{st} and 2^{nd} order) channels. The average channel dimensions were determined based upon data collected by both staff from both the Regional Water Board and PWA in the study sub-basins. Specifically, average channel depth was estimated using data collected as part of the Regional Water Board surveys.

This evaluation indicated channel depth ranged from 0.5 to 2.0m (average=1.25 m, 4.1 ft) (Buffleben, 2009). Average channel width was based up the 1st and 2nd order channels surveyed in the three study sub-basins by PWA (2008) which ranged from 0.28 to 1.6 m (average=0.8m, 2.64 ft). These same dimensions were applied to the Franciscan and Hookton formations.

Thus the total volume of channel scour was calculated as:

$$Length_{Channel\ Scour} \times Depth_{Low\ order\ channel} \times Width_{Low\ order\ channel}$$

As described in Table 3.9, Regional Water Board staff assumed that the first seventy-five (75) percent of the current erosion was attributable to the first cycle logging which staff assumed occurred in the 1950's. Staff attributed the remaining erosion from channel initiation to the subsequent decades at a rate of five percent (5%) of the current total per decade, averaged evenly over each year. Staff assumed that one-hundred percent (100%) of the eroded sediment volume was delivered to the fluvial system.

3.4.7.2 Results - Management-Related Channel Initiation Analysis

Based upon the estimated changes in drainage densities over time for each of the geologic formations (Table 3.10), Regional Water Board staff calculated the annual average sediment loading by analysis period since 1950. The results are presented in Table 3.14.

Table 3.14 Sediment loading ($yd^3/mi^2/yr$) associated with management-related headward initiation of low order channels by time period.

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Wildcat, Yager, Hookton Low Order Channel Initiation Loading ($yd^3/mi^2/yr$)	74	25	14	23	34	13
Franciscan Low Order Channel Initiation Loading ($yd^3/mi^2/yr$)	37	18	10	16	24	9
Upper Elk River Low Order Channel Initiation Loading ($yd^3/mi^2/yr$)	67	23	14	21	32	12

3.4.7.3 Uncertainties Associated with Management-Related Channel Initiation

Uncertainty is associated with the estimates established through the analysis due to the following considerations:

- Staff assumed a uniform time period for channel initiation due to lack of a comprehensive harvest history to support a more refined estimate.
- These estimates do not account for channel storage or routing rates but are rather estimates of sediment loads discharged to the stream network.

- The estimates assume the total channel cross-section eroded as result of headward incision. There was likely a soil pipe void that expanded. Not considering that void results in an over estimate of the scoured volume.

3.4.7.4 Implications for Watershed Implementation Actions

Control of sediment loading from channel initiation in low order channels may be accomplished by

1) Avoiding new tractor crossings in swales (no defined channel present) and the upslope drainage area is greater than that required for channel initiation.
2) Avoiding peak flow increases in swales where the drainage area is greater than that required for channel initiation.

3.4.8 Soil Creep Loading Due to Management-Related Channel Initiation

This sediment source analysis provides an estimate of the sediment load derived from soil creep processes that are delivered to the stream from the channel initiation described previously.

3.4.8.1 Methods Used to Determine Soil Creep Loading Due to Management-Related Channel Initiation

As described in Section 3.1.2, this sediment source analysis relies on an annual soil creep rate of 0.078 yd^3 per stream mile. With a natural drainage density of 5.6 mi/mi^2, the natural sediment loading from soil creep is 0.44 yd^3/mi^2/year. Regional Water Board staff calculated the total soil creep loading over time considering the increases in drainage density due to management-related channel initiation. The management-related soil creep loading is calculated as the total soil creep loading minus the natural soil creep loading.

3.4.8.2 Results - Soil Creep Loading Analysis

Table 3.15 presents the management-related sediment loading associated with soil creep resulting from increase in drainage density as a result of management-related channel initiation. Unlike the sediment loading from the headward migration of these channels, in which the erosion occurs once for a given channel length, the soil creep loading is ongoing.

Table 3.15 Management-related sediment loading associated with soil creep by time period.

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Wildcat, Yager, Hookton Management-related Soil Creep Loading ($yd^3/mi^2/yr$)	0.56	0.63	0.69	0.77	0.80	0.81
Franciscan Management-related Soil Creep Loading ($yd^3/mi^2/yr$)	0.27	0.32	0.37	0.42	0.45	0.45
Upper Elk River Management-related Soil Creep Loading ($yd^3/mi^2/yr$)	0.5	0.6	0.6	0.7	0.7	0.7

3.4.8.3 Uncertainties Associated with Soil Creep Analysis

Uncertainty is associated with the estimates established through the analysis due to the following considerations:

- There is uncertainty associated with the drainage densities over time. Staff assumed a uniform time period for channel initiation due to lack of a comprehensive harvest history to support a more refined estimation.
- Soil creep rates likely vary with topography and soil depth, thus are likely to vary throughout the watershed, whereas Regional Water Board staff applied a uniform rate.

3.4.8.4 Implications for Watershed Implementation Actions

Same as management-related channel initiation scour of low order channels (Section 3.4.1.4).

3.4.9 Management-Related Stream Bank Erosion

For the purposes of this study, management-related bank erosion is defined as the accelerated stream bank erosion (lateral migration of stream flows) as a result of human activities. As with the natural bank erosion source category, this source does not include streamside hillslope failures (mass wasting), or stream channel incision (vertical down cutting) caused by fluvial processes.

As described in Section 3.3.2, Pacific Watershed Associates (PWA, 2008) conducted a comparison of stream bank erosion rates in managed versus unmanaged areas; these bank erosion rates were used to determine bank erosion-related inputs for the various sub-basins. Regional Water Board staff multiplied the PWA-determined rates by sub-basin stream length, both for natural and current drainage networks, to determine the bank erosion inputs. The difference between the current inputs and the natural inputs is attributed to management.

3.4.9.1 Methods Used to Determine Management-Related Stream Bank Erosion Loading

The field data collections methods are as described in Section 3.3.2.1. The surveys were conducted in the three study sub-basins, with those conducted in Corrigan Creek and South Branch North Fork Elk River used to determine the current bank erosion rates in managed sub-basins and those conducted in Little South Fork Elk River used to determine the natural bank erosion rates.

3.4.9.2 Results - Management-Related Stream Bank Erosion Analysis

The results from the Little South Fork Elk River surveys are provided and discussed in Section 3.3.2.2. Corrigan Creek and South Branch North Fork Elk River exhibited nearly the same unit stream bank erosion sediment delivery for the entire stream network within these managed sub-basins (0.143 m^3/m and 0.144 m^3/m, respectively). For these analyses, Regional Water Board staff relied on a value of 0.14 m^3/m, or 303 yd^3 per mile of stream channel over the fifty-seven (57) year time period to estimate the total bank erosion rate. The natural stream bank erosion rate in the reference sub-basin, as calculated from field survey data (Section 3.3.2.2) is 0.05m^3/m or 94.72 yd^3 per mile of stream for the fifty-seven year time period.

Using the estimated natural and management-related drainage densities, as described in Section 3.2.3.2, the stream lengths were determined based on the sub-basin areas. The sediment loading associated with the surveyed stream bank erosion rates was calculated for each geologic formation based upon the drainage network estimated for each of the analysis time periods since the 1950s. The management-related stream bank erosion loading was calculated as that for the managed streams adjusted to eliminate the natural inputs and the soil creep inputs. The resulting loadings from management-related bank erosion are presented in Table 3.16.

The management-related bank erosion loading was calculated as the managed stream bank erosion rate minus the natural stream bank erosion rate minus soil creep rate times the drainage density:

$$\textit{Management-related bank erosion loading} = (BE_m - BE_n - SC) x DD_m$$

Table 3.16 Management-related sediment loading associated with stream bank erosion.

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Wildcat, Yager, Hookton Management-related Bank Erosion Loading ($yd^3/mi^2/yr$)	45.7	48.7	51.6	55.1	56.7	57.2
Franciscan Management-related Bank Erosion Loading ($yd^3/mi^2/yr$)	32.6	34.8	36.8	39.3	40.4	40.8
Upper Elk River Management-related Bank Erosion Loading ($yd^3/mi^2/yr$)	43	46	49	52	54	54

3.4.9.3 Uncertainties Associated with Management–Related Stream Bank Erosion Analysis

Uncertainty is associated with the estimates established through the analysis due to the following considerations:

- There is uncertainty associated with the drainage densities over time. Staff assumed a uniform time period for channel initiation due to lack of a comprehensive harvest history to support a more refined estimation.
- These estimates do not account for channel storage or routing through the system.
- Uncertainty is associated with Regional Water Board staff's assumption that the rates of natural and management-related bank erosion, as determined for the study sub-basins are applicable to the rest of the Elk River watershed. Harvest history, including silvicultural and yarding techniques and the level of riparian protections influence bank erosion loading.

3.4.9.4 Implications for Watershed Implementation Actions

Management related stream bank erosion may be controlled to some level by:

- Avoid additional management related headward channel incision.
- Promote stable channels in equilibrium by reducing sediment loading and enhancing structural stability.

3.4.10 Management-Related Shallow Hillslope Landslides

As described earlier, shallow hillslope landslides are landslide features that are typically visible on aerial photographs with a size of greater than 400 ft^2. This source category includes those shallow hillslope landslides that were initiated by management-related actions Due to complex hillslope processes that influence landsliding and the inherent difficulty in assigning a causal mechanism to a landslide, especially for earlier time periods, determination of a slide feature as either natural or management related is difficult. Rather than assigning a cause (management-related or natural) to each individual slide, the management-related landslide delivery is defined as the total landslide delivery minus the 30.1 $yd^3/mi^2/yr$ natural rate of shallow hillslope landsliding (described in Section 3.3.4):

$$Landslide_{Management} = Landslide_{Subbasin} - Landslide_{Natural}$$

This sediment source analysis categorizes those slides that exceed the natural value as being management-related. This section presents information relative to all landslides categories, their attributes, and estimated sediment loading for management-related landslides presented. This section is organized to present landslide by ownership, with road and non-road related slides segregated. Much of the area has undergone ownership and management style changes over the analysis time periods; the management-related shallow landslide analysis does not reflect current management strategies.

3.4.10.1 Methods Used to Determine Management-Related Shallow Hillslope Landslide Loading

Two landslide data sets were evaluated by Regional Water Board staff for use in determining sediment loading from shallow hillslope landslides in the Elk River watershed. Information from these two data sets, with modifications described below, was used to develop an estimate of management-related shallow hillslope landslide loading.

1. Palco WA Landslide Database[20]. The aerial photo review for the Elk River Watershed Analysis (Palco, 2004b) was the basis for a landslide database that covers the dominant ownerships in the seventeen TMDL sub-basins covered by this source analysis. The data set contains attributes and past delivery estimates for 856 landslides. Spatial information for these landslide features could not be determined from the data that was submitted, however a map in pdf format was provided.
2. Palco ROWD Landslide Database[21]. The dataset contains 1144 landslide features, including 820 features identified in the PWA Aerial inventory (PWA, 2004b), 260 landslides from the PWA road dataset (PWA, 2004c), and 64 identified during a 2003 inventory conducted by Palco Geology Department.

[20] Palco (2004b). Shallow landslide data and attribute information for discrete landslide features identified on aerial photos on and near Pacific Lumber Company lands in North Fork, South Fork and Upper Mainstem Elk River.
[21] Pacific Lumber Company Report of Waste Discharge (ROWD) Landslide Database integrating aerial photo data (item 3), the road data set (item 4) and 2003 landslides (Palco, 2005).

Comprised of an excel spreadsheet. Under a 2005 data use agreement with Palco (Palco 2005), spatial data associated with the features was not directly provided to the Regional Water Board staff for evaluation[22]. Staff worked with a map in pdf format.

To determine sediment loading from shallow hillslope landslides on the individual dominant ownerships, Regional Water Board staff used the following approach:

- For BLM lands, staff relied upon the WA Landslide Database. Staff identified slides on BLM lands from the WA Landslide Database by visually consulting the associated map and property lines.
- For GDRC lands, staff relied upon the WA Landslide Database. Landslides were identified in the WA Landslide Database as part of the GDRC ROWD (GDRC, 2006).
- For HRC lands, staff relied upon the Palco ROWD Landslide Database (with landslides data for features on GDRC and BLM lands removed).

Staff evaluated data in the WA Landslide Database to determine if the landslides on BLM and GDRC were also included in the Palco ROWD Landslide Database. The comparison indicated:

- On BLM lands, 118 slides are identified in the WA Landslide Database with 99 (84%) identified in the Palco ROWD Landslide Database. The slides not included in the Palco dataset were all initiated in 1997 and had a total discharge volume of 3,969 yd^3. This accounts for fifteen percent (15%) of the total volume of sediment loading from shallow hillslope landslides on BLM lands in the WA Landslide database.
- On GDRC lands, 47 slides are identified in the WA Landslide Database with 36 (81%) identified in the Palco ROWD Landslide Database. The slides not included in the Palco dataset were all initiated in 1997 and had a total discharge volume of 40,048 yd^3. This accounts for seventy percent (70%) of the total volume of sediment loading from shallow hillslope landslides that are identified in the WA Landslide Database.

Neither the Palco ROWD Landslide Database nor the WA Landslide Database included data for GDRC nor BLM lands for the 2003 photo period. This likely results in an underestimation on sediment loading from the shallow hillslope landslide for the 2001-2003 time periods in the Upper South Fork Elk River, Lower South Fork Elk River, Little South Fork, McCloud Creek, Toms Gulch, and Railroad Gulch sub-basins.

[22] Subject to a data use agreement (Palco, 2005) in which the GIS information may be furnished to Regional Water Board contractors but not to Regional Water Board staff, rather contractors may provide the Regional Water Board with data analyses, summaries, and model outputs. Due to data use restrictions, some data analyses were limited associated with this sediment source analysis, as described in Section 3.4.4.

3.4.10.2 Results - Management-Related Shallow Hillslope Landslide Analysis

The total shallow hillslope landslide loading per sub-basin for available photo periods is presented in Figure 3.10. Over the forty-nine (49) year time period evaluated in this analysis, a total of 486,915 yd^3 of sediment delivered to the fluvial system from shallow hillslope landslides. The time periods with the greatest delivery were 1955-1966 (34% of the total) and 1988-1997 (48%). The sub-basins receiving the majority of the landslide derived sediment were Bridge Creek (18%), Lake Creek (15%), North Branch North Fork Elk River (14%), Lower North Fork Elk River (12%), Upper North Fork Elk River (11%), and Lower South Fork (9%).

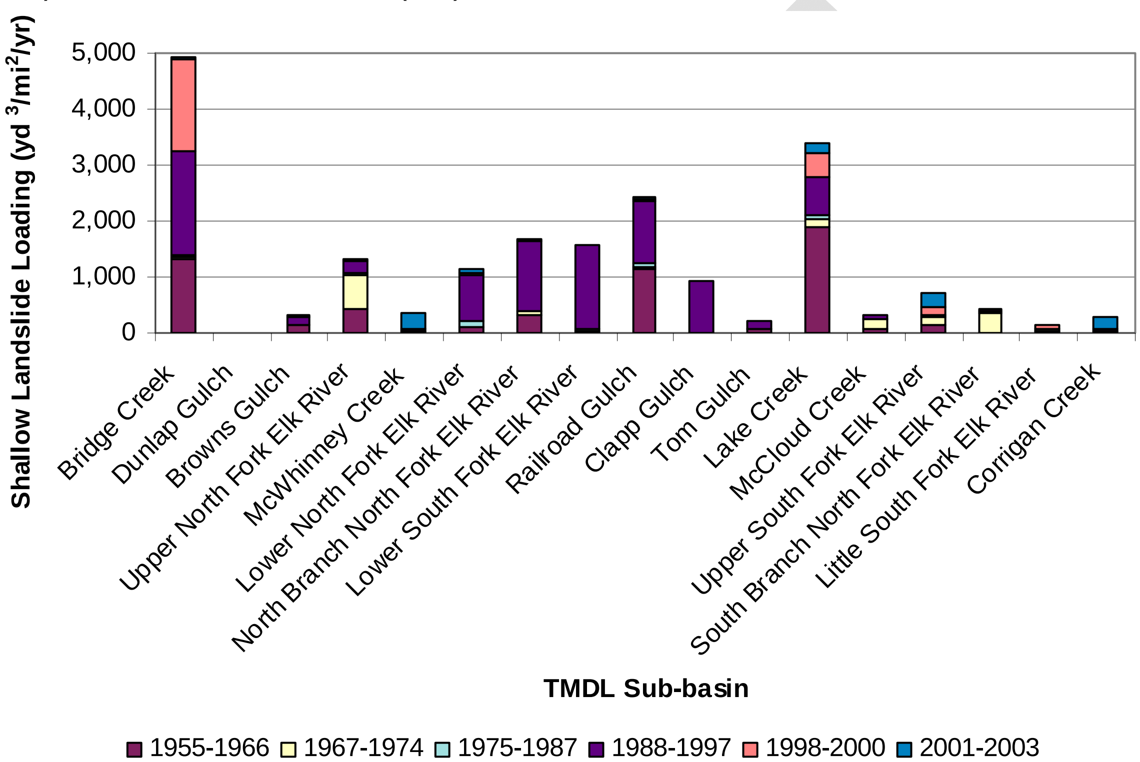

Figure 3.10 Annual average sediment loading from shallow hillslope landslides by photo period and sub-basin.

The Palco WA (Palco, 2004) evaluated the delivery distance of shallow landslides to different stream classes for the 1988-2000 photo period[23]. The data provide information pertinent to the design of riparian buffers that may protect streams from delivery of shallow landslide sediment. The data indicate that of the shallow landslide sediment originating from within 400 feet of a stream, it is distributed amongst stream classes with 36% delivered to Class I watercourses, 26% delivered to Class II watercourses, and 38% delivered to Class III watercourses. Figure 3.11 demonstrates the cumulative percentage of the sediment delivery as a function of delivery distance from the streams.

[23] Figure AA-1.

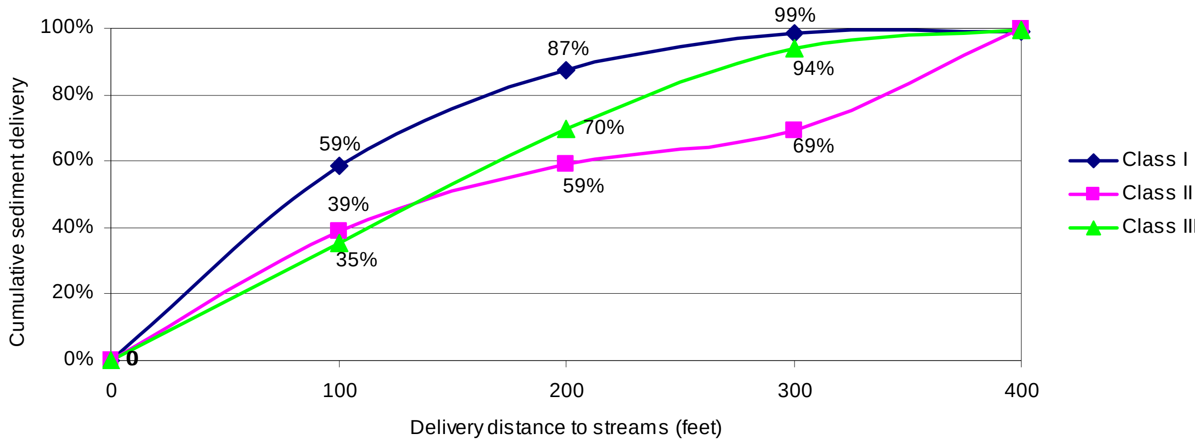

Figure 3.11 Cumulative sediment delivery from shallow landslides as a function of distance to watercourse for the 1988-2000 photo period (Palco, 2004).

To provide further refinement on the analysis of sediment delivery from hillslope landslides and to facilitate development of implementation actions designed to control management-related discharge, Regional Water Board staff segregated the available landslide data into road related and open-slope landslides (Sections 3.7.5.2.1. and 3.7.5.2.2, respectively). Open-slope landslides are those hillslope slides that can not be attributed to the presence of roads or landings; the management-related portion is determined by subtracting the natural shallow landslide loading from the total open slope landslide loading. This sediment source analysis presents the road-related and open-slope landslide data by ownership and as a cumulative total for the watershed.

3.4.10.3 Results - Road-Related Shallow Hillslope Landslide Analysis

The annual average sediment loading associated with road-related landslides on the dominant ownerships in the seventeen (17) upper TMDL sub-basins is shown in Figure 3.12. From 1955-2003, a total of 209,635 yd^3 of sediment associated with road-related landslides was delivered to the fluvial system. The greatest sediment delivery was associated with 1955-1966, twenty-five percent (25%) and 1988-1997 with sixty-five percent (65%) of the total delivery to the fluvial system. The sub-basins receiving the majority of the road-related landslide sediment delivery were North Branch North Fork Elk River (25%), Lake Creek (22%), Lower North Fork Elk River (21%), and Bridge Creek (10%).

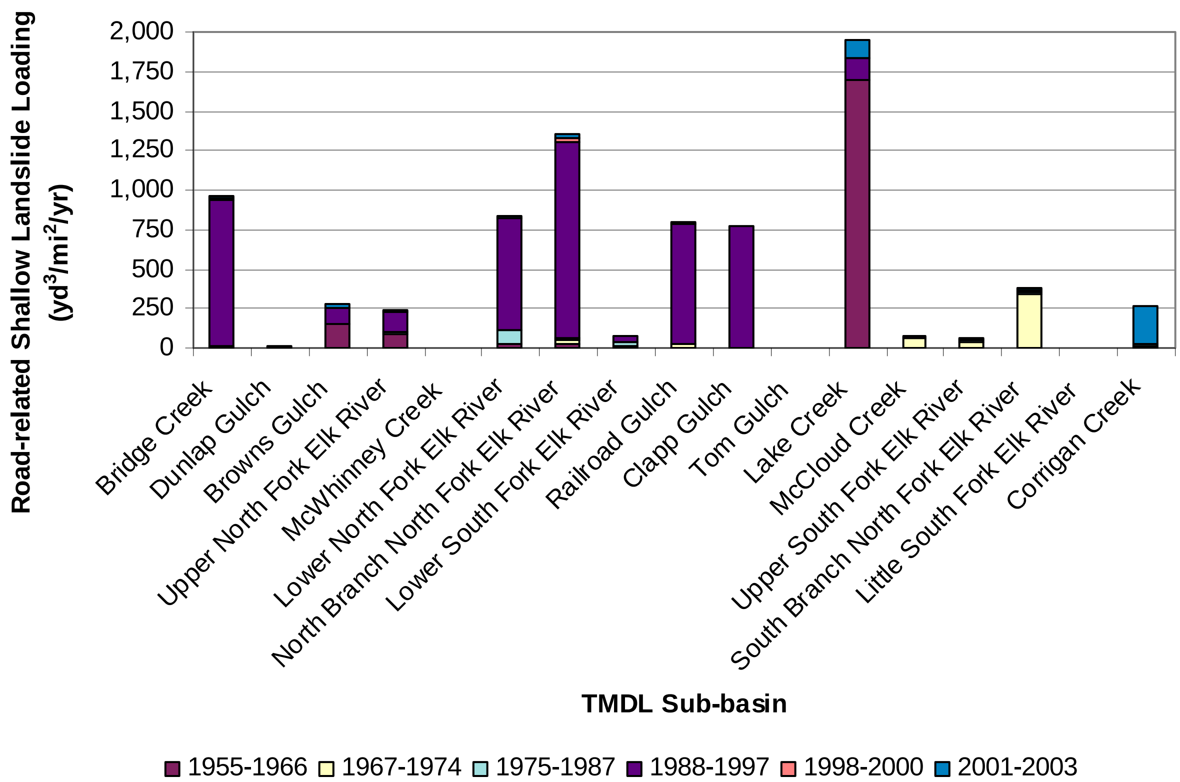

Figure 3.12 Annual average sediment loading from road-related landslides by photo periods for all dominant ownerships.

Table 3.17 presents the sediment loadings from management-related open-slope landslides to Upper Elk River as a whole.

Table 3.17 Annual sediment loading from road-related landslides in Upper Elk River ($yd^3/mi^2/yr$)

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Annual Road-related Landslide Loading in Upper Elk River ($yd^3/mi^2/yr$).	189	82	6	201	118	51

The incidence of road- related landslides can often be correlated to the design, engineering and construction techniques implemented by individual landowners. For this reason Regional Water Board staff evaluated the available road-related landslide data separately for each of the large ownerships (BLM, GDRC, and HRC). Landslide sediment delivery and annual average loading are presented for BLM lands (Figures 3.13 and 3.14, respectively), GDRC lands (Figures 3.15 and 3.16, respectively), and HRC lands (Figures 3.17 and 3.18, respectively). Reactivated slides comprised 22%, 0%, and 15% of the number of road-related slides on BLM, GDRC, and HRC lands, respectively.

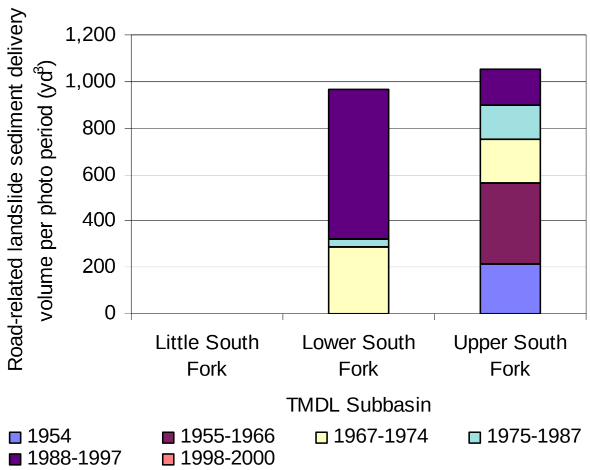

Figure 3.13 Road-related landslide delivery volume from BLM lands.

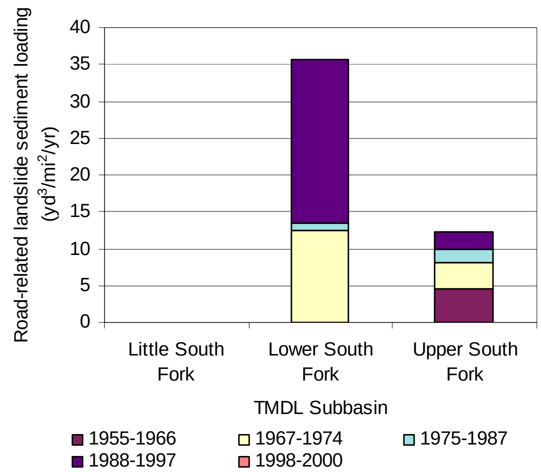

Figure 3.14 Road-related landslide loading for BLM lands.

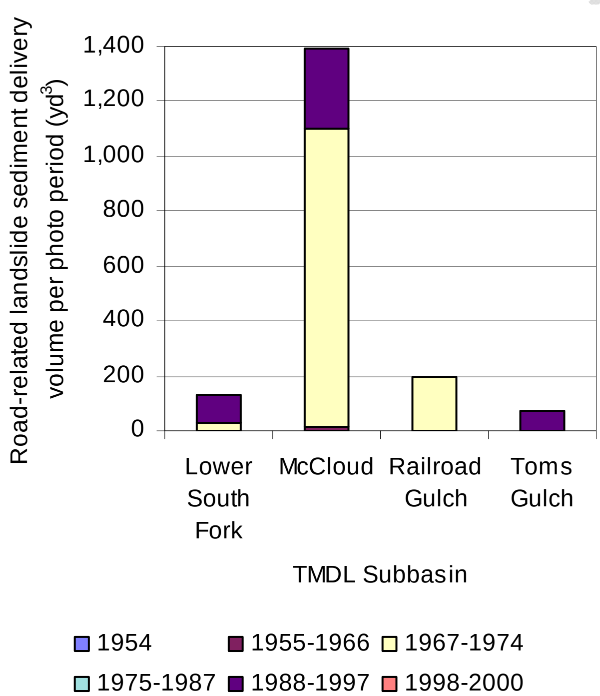

Figure 3.15 Road-related landslide delivery volume by photo period for GDRC lands.

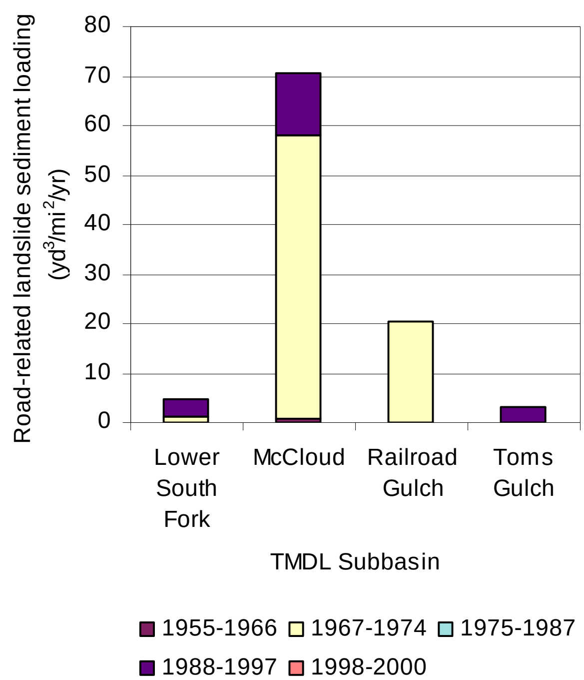

Figure 3.16 Road-related landslide loading by photo period for GDRC lands.

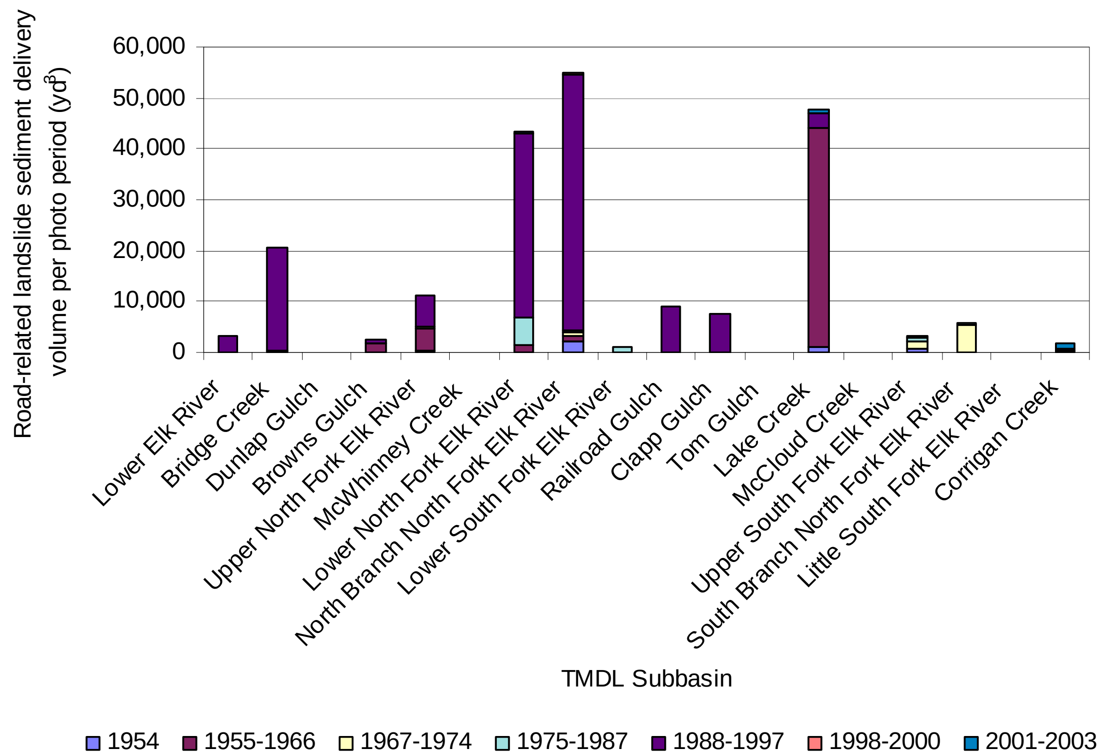

Figure 3.17 Road-related landslide delivery volume by photo period for HRC Lands

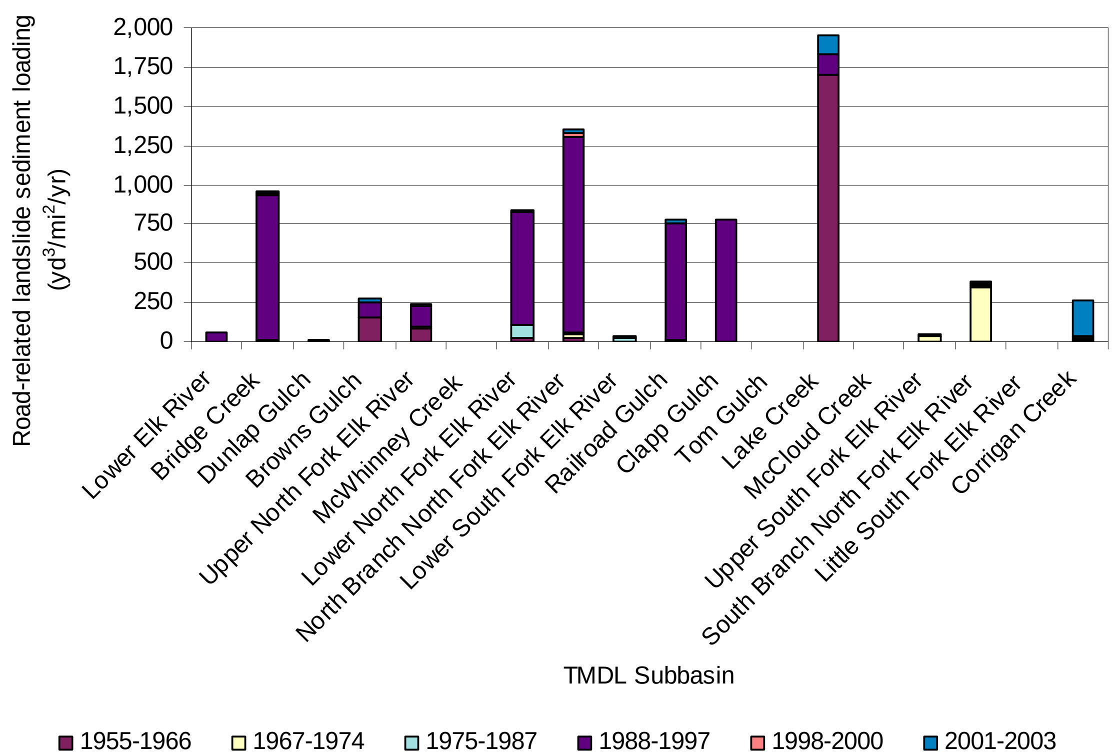

Figure 3.18 Road-related landslide sediment loading by photo period for HRC lands

3.4.10.4 Results – Open-Slope Shallow Hillslope Landslide Analysis

The annual average sediment loading associated with landslide identified as open-slope for the dominant ownerships in the seventeen of the TMDL sub-basins is shown in Figure 3.19. From 1955-2003, a total of 277,280 yd^3 of sediment was delivered from open-slope landslide features. The time periods associated with the greatest sediment delivery were 1955-1966 (40%) and 1988-1997 (35%). The TMDL sub-basins receiving the majority of the open-slope landslide sediment delivery were Bridge Creek (25%), Upper North Fork Elk River (16%), Lower South Fork Elk River (16%), Lake Creek (9%), and Upper South Fork Elk River (9%).

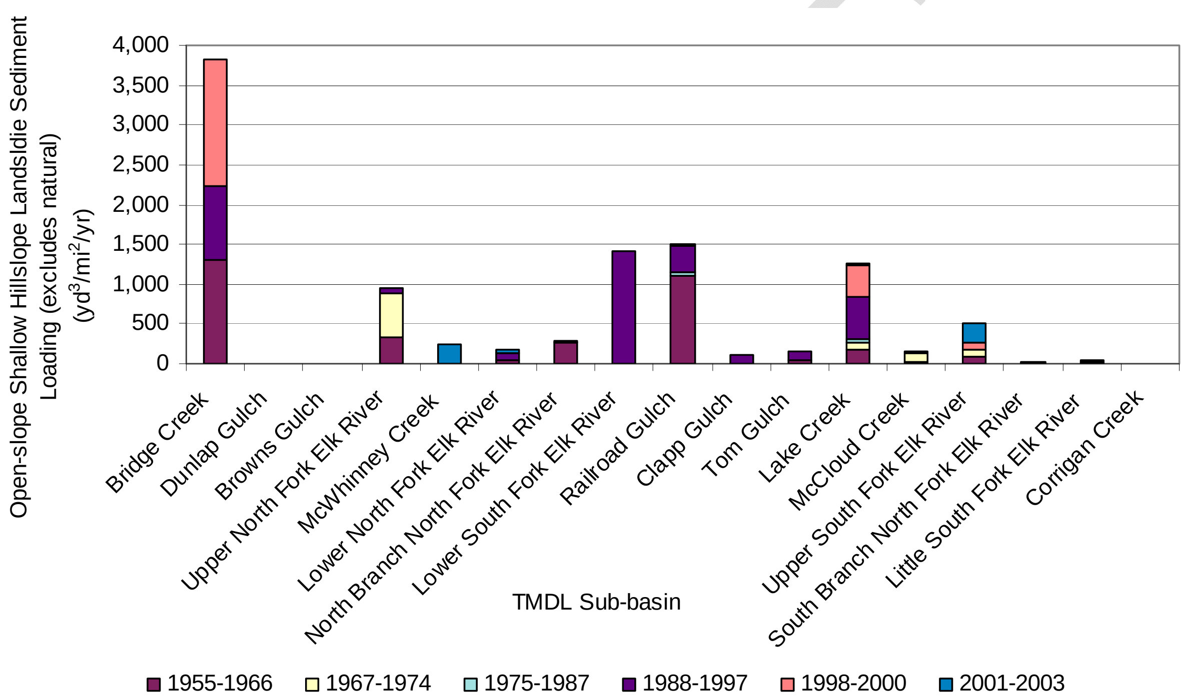

Figure 3.19 Sediment loading associated with open-slope landslides for all ownerships (excludes natural shallow hillslope landslide loading).

Table 3.18 presents the sediment loadings from management-related open-slope landslides to Upper Elk River as a whole.

Table 3.18 Annual sediment loading from open-slope landslides in Upper Elk River (yd^3/mi^2/yr)

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Annual management-related open-slope landslide loading in Upper Elk River (yd^3/mi^2/yr).	189	82	6	201	118	51

Open-slope landslide data was evaluated separately for BLM, GDRC, and HRC lands. Landslide sediment delivery and annual average loading are presented for BLM lands (Figures 3.20 and 3.21, respectively), GDRC lands (Figures 3.22 and 3.23, respectively), and HRC lands (Figures 3.24 and 3.25, respectively). Reactivated slides comprised 8%, 9%, and 8% of the total number of open-slope slides on BLM, GDRC, and HRC lands, respectively.

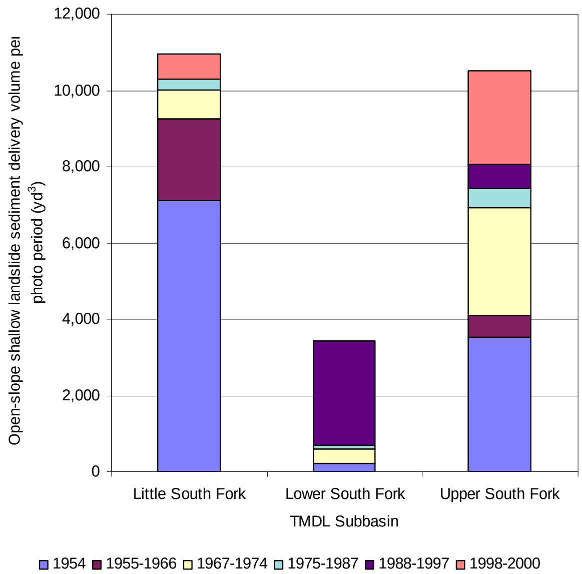

Figure 3.20 Open-slope landslide volume from BLM lands (based upon the Palco WA Landslide Database)

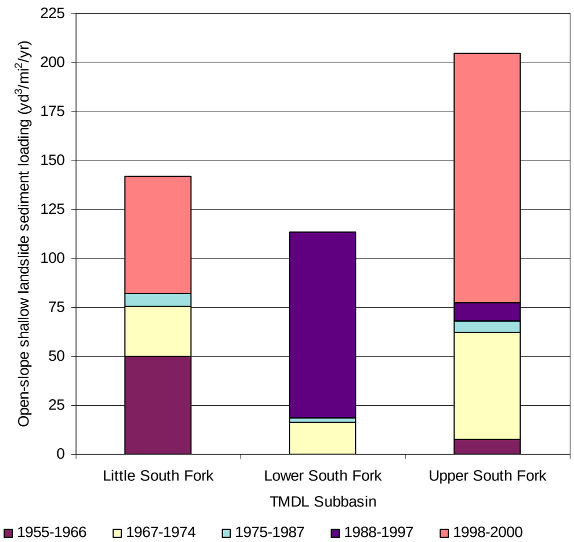

Figure 3.21 Open-slope landslide loading on BLM lands (includes natural loading).

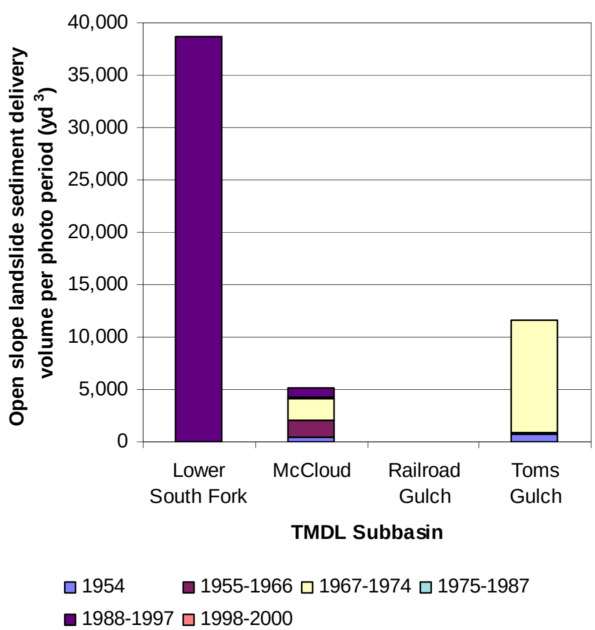

Figure 3.22 Open-slope landslide delivery volume per photo period for GDRC lands[24].

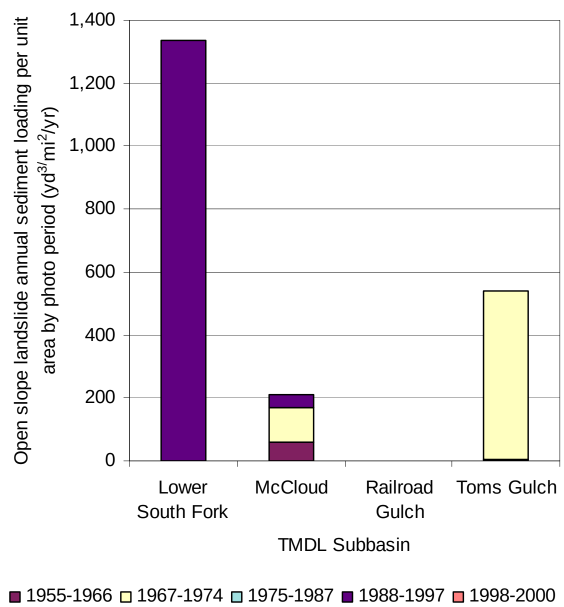

Figure 3.23 Open-slope landslide loading for GDRC lands (includes natural loading).

[24] Based upon the Palco WA Landslide Database

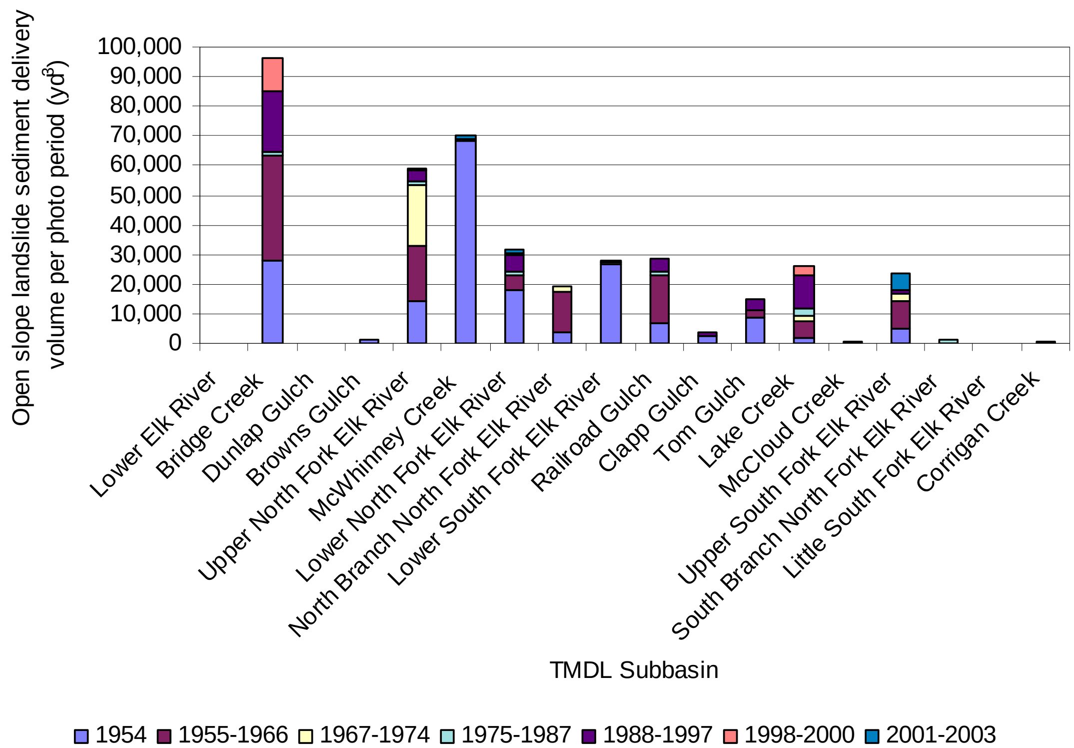

Figure 3.24 Open-slope landslide delivery volume on HRC lands .[25]

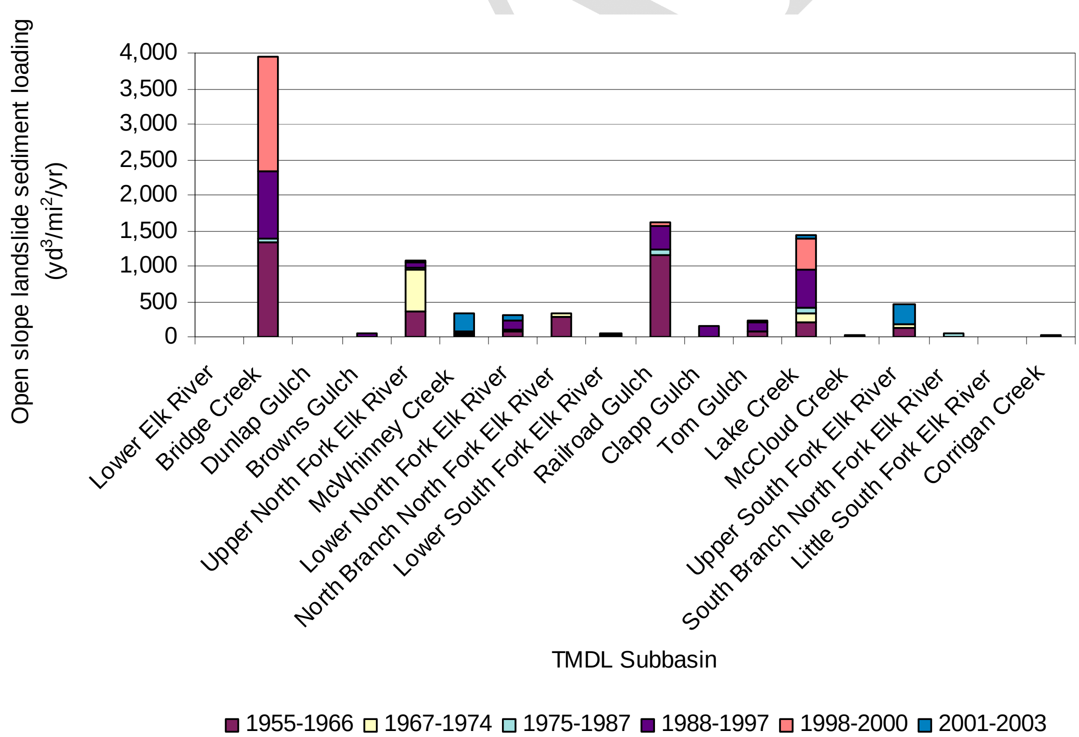

Figure 3.25 Annual average open-slope landslide loading on HRC lands (includes natural loading).

[25] Based upon the Palco ROWD Landslide Database

Empirical Sediment Budget Approach

For the purposes of investigating the affect of timber harvesting on open-slope landslide rates, the empirical sediment budget approach was employed. The open-slope landslide data were parsed by geologic group. Using the harvest history data presented in Section 3.2.2.1, the landslide delivery volume per acre was calculated for areas harvested in the past fifteen years (Table 3.17) and areas not harvested in the past fifteen years (Table 3.19) for each of the geologic groupings. Table 3.21 presents the Sediment Production Ratio, *S/R,* which represents the ratio of sediment produced from managed areas compared to that produced in the reference area.

Table 3.19 Sediment Production, S

Landslide Period	1988-1997	1998-2000	2001-2003
Harvest Period	1973-1997	1983-2000	1986-2003
Geologic Group	Sediment volume per unit area from areas harvested in last 15 years ($yd^3/mi^2/yr$)		
A	1325	1768	150
B	2996	94	123
C	0	0	0
D	567	45	0
E	112	0	0
F	7	220	0

Table 3.20 Reference Sediment Production, R

Landslide Period	1988-1997	1998-2000	2001-2003
Harvest Period	1973-1997	1983-2000	1986-2003
Geologic Group	Sediment volume per unit area from areas not harvested in last 15 years ($yd^3/mi^2/yr$)		
A	36	0	2
B	107	7	42
C	1	40	0
D	153	25	0
E	0	0	11
F	6	0	0

Table 3.21 Sediment Production Ratio, S/R

Landslide Period	1988-1997	1998-2000	2001-2003
Harvest Period	1973-1997	1983-2000	1986-2003
Geologic Group	Sediment ratio, *S/R*, harvested in past 15 years: not harvested in past 15 years		
A	37	1768[1]	83
B	28	13	3
C	0	0	0
D	4	2	0
E	379	0	0
F	1	220[1]	0

[1]Assumed an *R* value of 1 avoid division by zero

For all photo periods, Geologic Group A (100% Wildcat) demonstrates significantly greater landslide sediment delivery per unit area from areas harvested in the last fifteen (15) years, versus not harvested in the last fifteen (15) years. Similarly, though less dramatically, Group B (>75% Wildcat, remainder Hookton) demonstrates greater delivery from recently harvested areas for all photo periods. The results presented in Table 3.21 highlight the significant affect that harvesting has on landslide sediment production in Geologic Groups A and B.

3.4.10.5 Uncertainties Associated with Management-Related Shallow Landslide Analysis

The following issues have been identified by Regional Water Board staff as containing a level of uncertainty that could affect the analysis:

- The estimates of delivery associated with landslide features identified on aerial photographs[26] are imprecise.
- Stand age[27] is interpreted based upon the difference between the current stand age and the date of the aerial photo on which the landslide first appeared.
- Some portion of the open-slope landslides is influenced by skid trails that were not identified as part of the analysis.
- Interaction of earthworks (roads, skid trails, landings, etc) was based on aerial photo interpretation without benefit of field verification.
- The actual dates of landslide initiation are unknown. Initiation dates were estimated using a time sequence series of aerial photos. Inferences may be made about the timing of large storm events and the likely initiation data.
- No landslide inventory was available for GDRC and BLM lands for the 2001-2003 photo period. This could result in a significant underestimation of the total loading for that time period in the sub-basins which include BLM and GDRC ownership.
- Regional Water Board staff compared sources of landslide data including the Palco ROWD Landslide Database, the Palco WA Landslide Database, and the summary data from PWA (2001). In some cases, the ROWD database did not include landslide volumes found in the other sources, indicating a potential underestimation of landslide related sediment loading. Table 3.22 summarizes the potential underestimation in landslide sediment loading.
- Landslides were segregated by ownership based upon the available mapping. There is uncertainty in the location of the landslide origin along ownership boundaries. Additionally, conditions on adjacent ownerships may affect landslides. The area most likely to experience influences from an adjacent ownership is on BLM lands South Fork Elk River corridor in which BLM manages the a 300-foot wide corridor on either side of South Fork Elk River.

[26] Palco (2004)
[27] Palco,(2004)

Table 3.22 Potential underestimation of landslide loading based upon differences in the Palco ROWD Landslide Database, Palco Watershed Analysis Landslide Database, and PWA (2001).

	Shallow hillslope landslide sediment loading ($yd^3/mi^2/yr$)				
TMDL Sub-basin	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000
Browns Gulch					67
Clapp Gulch		16	15	936	627
Dunlap Gulch			1		7
McWhinney Creek					4
North Branch North Fork			6		69
Railroad Gulch	882		99	517	447
South Branch North Fork	0			34	32
Tom Gulch		187	81	280	167
Upper North Fork Elk River			30	26	140
South Fork (includes Upper South Fork, Lower South Fork and Corrigan Creek)			9		

3.4.10.6 Implications for Watershed Implementation Actions

- Stream buffers should be designed such that vegetation is maintained capable of capturing and minimizing landslide sediment and from which large wood may be delivered to the stream system.
- The identification, prevention, and control of landslides have been a major focus of landowners and the Regional Water Board throughout the Elk River TMDL development process. This was a result of the recognized contribution landslide delivery had on the overall sediment load in the Elk River watershed. Efforts have been made to reduce the potential of management-related activities to affect landslide initiation and/or reactivation. These ongoing efforts include:
    - Limitations on ground-based yarding activities and road construction on steep slopes and headwall swales.
    - Limitations on timber harvesting (felling and yarding of trees) on and adjacent to landslide features.
    - Limitation on rate and scale of land disturbing activities in the sub-basin.
    - Identification of existing landslide features by trained professionals.
    - Evaluation by Registered Geologists of proposed management activities (tree felling, road construction, etc) on and adjacent to landslide features.

  Limitations on the effectiveness of these efforts include:
    - Poor resolution of topographic maps making site characterization difficult.
    - Lack of comprehensive effectiveness monitoring program to quantify prevention efforts.
    - Existing and persistent effects from management activities (e.g. increases in flow from upslope hydrologic alterations).

To address identified data gaps and provide a foundation for watershed implementation actions, Regional Water Board staff commissioned the development of two new datasets for use in the Elk River watershed. These datasets include:

- High resolution topographic mapping of the entire Elk River watershed.
- Landslide hazard mapping based upon the application and testing of probabilistic landslide hazard models. These efforts and resulting tools are described briefly. For more detailed information on the effort the project reports (Sanborn, 2005 and Stillwater, 2005) are available for download[28].

First, topographic data (i.e. digital elevation model (DEM)) derived from LiDAR (Light Detection and Ranging) data were collected during March 2005. The resulting LiDAR DEM is useful for field and planning efforts for identifying landforms, management features (e.g. roads and skids), watercourses (as employed in the channel incision surveys), channel slopes, etc.

Second, two distributed, physically-based models were initially selected for predicting potential shallow landslide hazards based on their common usage and past performance in forested mountainous terrain: the deterministic model SHALSTAB (Montgomery and Dietrich 1994, Dietrich et al. 2001) and the probabilistic model PISA (Haneberg 2004, 2005). SHALSTAB is a physically-based, deterministic model that combines an infinite slope stability model and a steady-state hydrologic model to predict the potential for shallow landsliding controlled by topography and pore water pressure (Montgomery and Dietrich 1994, Dietrich et al. 2001). PISA is a physically based, probabilistic model that predicts spatially distributed static and seismic shallow slope stability for topography obtained from a digital elevation model and geotechnical information (Haneberg 2004, 2005). Two versions of each model were applied to Elk River to identify the relative landslide hazard.

Hypothesis tests were developed to objectively validate model results and to evaluate the relative performance of the modeling approaches. Tests in difference geologic terrains were conducted with the goal of evaluating the extent to which model performance and model threshold values vary in different geologic terrains. The testing results can be interpreted to identify model threshold values for which a defined percentage of landslides are expected to be included on a corresponding percentage of the landscape, thus informing beneficial use protection and economic tradeoffs. In areas over selected thresholds management avoidance or mitigations can be employed.

A resulting landslide hazard map will be based upon the integration of the model results into landslide hazard classes by normalizing results from the best-performing deterministic and probabilistic model approaches. The LiDAR DEM

[28] http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/elk_river/

and landslide hazard map, in combination with existing landslide mitigations, are expected improve identification of landslide prone areas and inform appropriate management strategies to ultimately control the sediment loading from management-induced shallow hillslope landslides.

3.4.11 Management-Related Streamside Landslides

As used in this analysis, streamside landsides are landslide features that originate from streamside slopes and are too small to detect on aerial photographs. This source category includes those streamside landslides that were initiated as a result of management-related actions. As part of this TMDL development effort, PWA (2006) conducted aerial photo and field-based comparisons in three randomly selected areas of different timber stand ages, including old-growth, advanced or mature second growth (stand age >30 years), and young forest (stand age <30 years). These inventories are relied upon in this source analysis as a basis for an estimate of sediment delivery associated with smaller streamside landslides that are not identifiable on aerial photographs. Comparison is made with Palco Watershed Analysis estimates (Palco, 2004) as well as the timing of delivery relative to open-slope landslides (Section 3.4.4.2).

3.4.11.1 Methods to Determine Management-Related Streamside Landslide Loading

Section 3.3.3.1 of this source analysis describes the field data collection methods used for both the old-growth portion of the sub-basin as well as a description of the field efforts to develop data for the other forest types. The management-related streamside landslide analysis relies on the old-growth data as well as data from the advanced second growth and young stands. Figure 3.26 displays the streamside landslide survey areas. The old-growth sample area is located in Little South Fork Elk River reference study sub-basin, the advanced second growth area is located in Upper Freshwater Creek and the young forest area is located in Little Freshwater Creek.

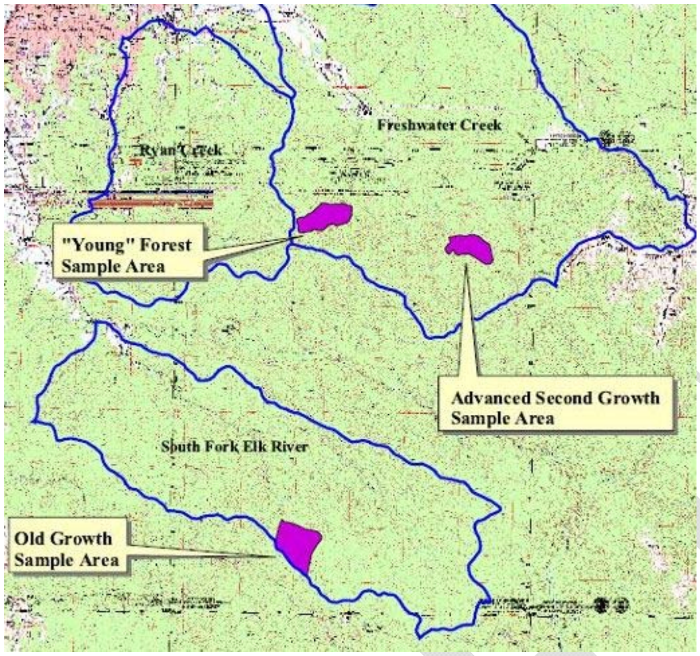

Figure 3.26 Locations of the streamside landslide study areas. (PWA, 2006).

PWA (2006) reported the number of slides in the small and large categories (less than and greater than 5yd^3, respectively) and provided an estimate of the total volume of large slides for each of the corresponding photo periods (1975-1987, 1988-1997, 1998-2003). Regional Water Board staff calculated the average slide volume for each of the different forest types and applied that average volume to the number of slides per photo period. This approach was used to estimate the volume of sediment delivery associated with the different photo periods in the different forest types. Regional Water Board staff also assumed that the proportion of the small slides per photo period to the total small slides, for each area, was consistent with that of the large slides.

3.4.11.2 Results - Management-Related Streamside Landslide Analysis

Table 3.23 shows the results of the field surveys described above. The results indicate that as forest age decreases, the number of small and large landslides increases, as does the average large slide volume.

Table 3.23 Survey results from streamside landslide survey (PWA, 2006).

Forest Type	Unmanaged Old growth[1]	Advanced Second Growth	Recently Harvested Areas
Watershed	Little South Fork Elk River	Upper Freshwater Creek	Little Freshwater Creek
Length of inventoried stream channel (miles)	2.5	3.2	3.3
No. large (>10yd^3) / small (<10yd^3) landslides[2,3]	7 / 7	15 / 14	21 / 27
1975-1987 (13 years)		3 / 2.8	2 / 2.6
1988-1997 (10 years)		9 / 8.4	11 / 14.1
1998-2003 (5 years)		3 / 2.8	8 / 10.2
Volume Sediment delivered from large landslides (yd^3)	308	1056	4791

Average volume per larger slides (yd^3/slide)	44	70	228
Volume sediment delivered from small landslides (yd^3)[4]	35	70	135

[1]Numbers reflect adjusted survey described in Section 3.6.3.
[2]Totals for all photo periods.
[3]Assuming the proportion of the small slides per photo period to the total small slides, for each area, was consistent with that of the large slides.
[4]Assuming an average small slide volume of 5 yd^3.

Because the spatial age distribution of riparian stands is unknown, Regional Water Board staff assumed that management-related streamside landslides in Elk River followed a pattern indicated by pooling the data from the advanced second growth and recently harvested areas (Table 3.24). This assumption likely over estimates the age of riparian stands throughout portions of the Elk River watershed, resulting in an underestimate of the streamside landslide loading in those younger stands. Similarly, using the average of the two managed forest types will result in an overestimate of delivery in older areas.

Table 3.24 Combined results for delivery per channel length for recently harvested (<30 year stands) and advanced second growth (> 30 years stands).

	Number of large / small[1] slides in managed areas[2]	Average volume per large / small slide (yd^3/LS)	Annual unit delivery from large / small slides in managed areas (yd^3/mi/year)	Total annual unit delivery from small and large slides in managed areas (yd^3/mi/year)
1975-1987 (13 years)	5 / 5.69		9.6 / 0.3	9.9
1988-1997 (10 years)	20 / 22.78	162 / 5	50.0 / 1.8	51.7
1998-2003 (5 years)	11 / 12.53		55.0 / 1.9	56.9

[1]Assuming the proportion of the total small slides per photo period is the same as that of the large slides.
[2]Combined survey length of 6.5 miles

Staff evaluated the Palco Elk River Watershed Analysis (Palco, 2004) which presented results from streamside landslide surveys conducted in North Fork Elk River[29]. The WA estimated streamside landslide loading for the 1988-2000 photoperiod from all streamside landslides not documented on the PWA aerial photograph landslide inventory (WA Landslide Database), attributing all non-road streamside landslide loading to natural sources. The WA surveys were conducted in three areas of North Fork Elk River: 1) In the Lower Elk River TMDL sub-basin, along the North Fork Elk River just downstream of the mouth of McWhinney Creek; 2) In the Bridge Creek TMDL sub-basin, along a portion of West Fork Bridge Creek; and 3) In the Upper North Fork TMDL sub-basin, along North Fork Elk River. Table 3.25 presents the results from the WA surveys. The WA streamside landslide surveys and analyses which include Class I and Class II watercourses and do not include Class III streams, which the WA indicates comprises about two-thirds (62%) of the total channel length in the 58.22 mi^2 watershed assessment area (see Section 3.2.3.2, Table 3.7).

[29] Section A.7.2 Small Streamside Landslides.

Table 3.25 Palco Watershed Analysis streamside landslide survey results for photo period 1988-2000 (Palco, 2004).

Stream Class	Survey Length	Number Landslides per 3300' of channel	Volume per Landslide (yd^3/LS)	Volume per channel length (yd^3/mi)	Volume per channel length (yd^3/mi/yr)	Drainage Density (mi/mi^2)	WA Annual Loading (yd^3/mi^2/yr)
Class I	6400	7.7	128	1577	121.30	1.07	130
Class II	2800	10.8	68	1175	90.39	2.02	183
Total CI and CII:			Average = 98		Average = 100.86[1]	3.10	313

[1]Weighted average based upon percentage of total stream length comprised by stream class, as presented in Table 3.7 (Section 3.2.3.2).

The WA streamside landslide surveys indicate a greater annual unit delivery than the PWA survey results, likely because the PWA surveys were not limited to Class I and II watercourses. It is expected that within the expanded network, as stream power decreases with decreasing drainage area, the volume per slide and the slide frequences also is expected to go down.

Application of the PWA survey results to the current drainage network estimates results in an unreasonably high loading estimate for streamside landslides by Regional Water Board staff judgment. This is likely due to the extent of the current drainage network, much of which is comprised of watercourses with low stream power where loading associated streamside landsliding is expected to be much less than larger watercourses.

For this sediment source analysis, Regional Water Board staff calculated the streamside landslide loading within the natural drainage network based upon the PWA survey results. Within the expanded network, the slides are expected to be smaller and less frequent and Regional Water Board staff assumed that the small streamside landslides are accounted for in the stream bank erosion estimates (Section 3.4.3).

For the purposes of developing streamside landslide loading estimates for analysis time periods before 1975, Regional Water Board staff conducted a comparison of the streamside landslides and open-slope landslides. For the period of 1975-2003, corresponding to the streamside landslide surveys, the total delivery associated with small streamside landslides in managed areas was 988 yd^3/mi. For the same period, the total delivery from open-slope landslides was 18,891 yd^3. Regional Water Board staff assumed the ratio of small streamside landslides to open-slope landslide delivery for the 1975-2003 period was constant for all photo periods. Those results indicate a much lower estimate of streamside landslide loading for the 1975-1987 period, a similar loading for the 1988-1997 period, a higher estimate for the 1998-2000 period and a loading in 2001-2003 similar to that of 1988-1997. This method allows for estimation of streamside landslide loading for the earlier time periods (1955-1974) for which open-slope landslide estimates are available but not streamside landslide estimates.

For the purposes of this sediment source analysis, within the natural drainage network, Regional Water Board staff relied on the streamside sediment delivery estimated by PWA for the 1975-2003 time periods, and the estimates based upon the ratio of streamside to open-slope landslides for the 1955-1974 time periods. The management-related streamside landslide loading was calculated as the total loading for the managed areas minus the natural loading of 26.08 $yd^3/mi/yr$. Figure 3.27 presents the resulting management-related streamside landslide loading.

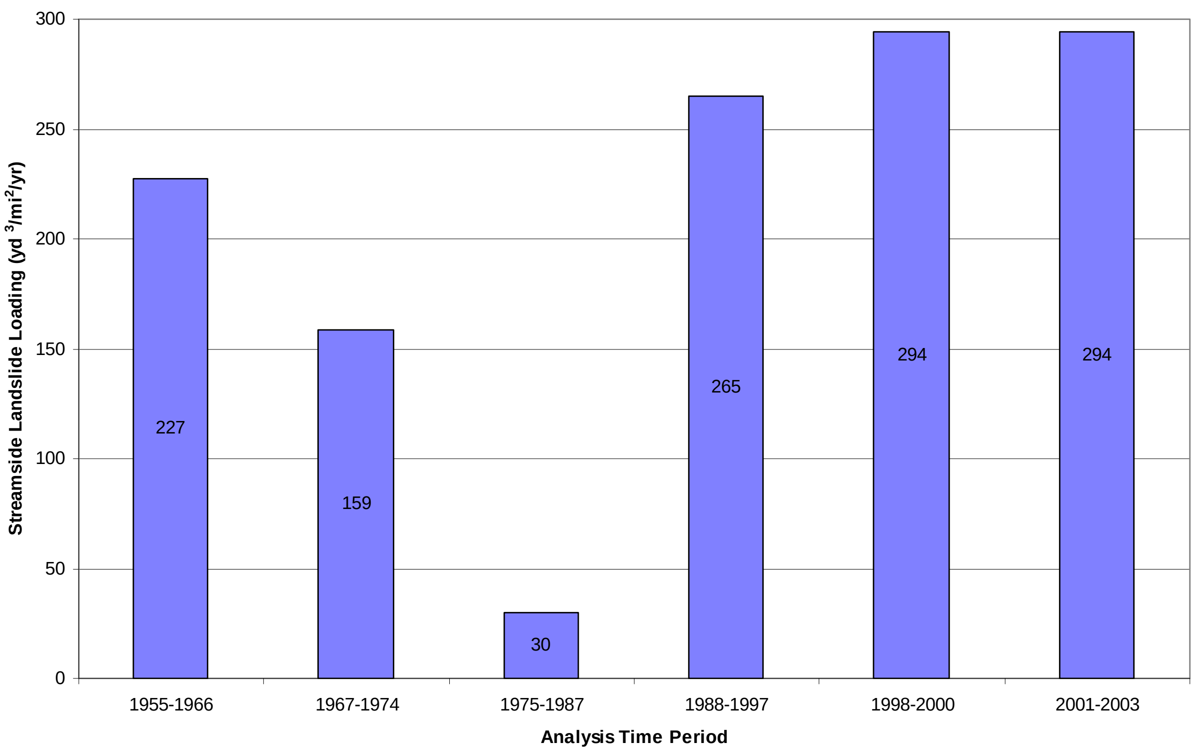

Figure 3.27 Annual average sediment loading associated with management-related streamside landslides.

3.4.11.3 Uncertainties Associated with the Management-Related Streamside Landslide Analysis

The following issues have been identified by Regional Water Board staff as containing a degree of uncertainty that could affect the analysis:

- Characterizing the age of features can be difficult, contributing to uncertainty associated with assigning a time period to the streamside landslides. Specifically, smaller features get masked over time, thus smaller older features may be missed in the inventories. Additionally, if features reactivate, they may be attributed to the time period associated with reactivation and the original feature may not be included in the earlier time periods.
- The estimation of the streamside landslide loading associated with the 1955-1966 and 1967-1974 time periods are subject to greater uncertainty due to reliance on the ratio with open-slope landslide loading. It is likely that the earlier

time periods have a higher loading from small streamside landslides due to the lack of stream buffers and the use of streams as yarding corridors.

- These estimates do not account for channel storage or routing through the system.
- Uncertainty is associated with staff's assumption that the rates of natural and management-related streamside landslides, as determined within the sample reaches are applicable to the Elk River watershed as a whole.
- PWA (2008) data did not include an estimate for the time period associated with delivery from small streamside landslides. For this analysis Regional Water Board staff assumed that the relative proportion of delivery from small landslides within each photoperiod was the same as for large landslide features.
- Staff calculated an average volume per large slide for each of the sample areas and applied that volume across each of the photo periods. There is uncertainty associated with this assumption as land management changes or storm magnitude could have big effect on slide volume.
- The management-related streamside landslide rates are based upon combined data for the recently harvest and advanced second growth. The decision to represent managed areas by one rate was made due to the lack of a comprehensive, spatial representation of harvest history and the resulting stand age. Harvest history, including silvicultural and yarding techniques and the level of riparian protections influence streamside landslide loading.

3.4.11.4 Implications for Watershed Implementation Actions

Discharge associated with management-related streamside landslides may be controlled by:

1) Preventing additional headward channel incision. This can be controlled by minimizing upslope hydrologic impacts including removal of significant portions of the canopy and creation of stream diversions.
2) Avoiding or minimizing hillslope disturbing activities such as substantial road cuts and fills upslope of watercourses.
3) Maintaining adequate stand volumes to decrease slide frequency and volume as slide frequency and volume increases in younger stands (Table 3.17). Providing protective stream buffers of adequate width and vegetative condition to minimize sediment delivery from streamside landslides that do occur.

3.4.12 Management-Related Discharge Sites

As used in this sediment source analysis, discharge sites are erosion features that discharge (or have the potential to discharge) sediment in violation of applicable water quality requirements, are caused or affected by human activity, and will respond to management measures. This definition is synonymous with "controllable sediment discharge site" as used in the timber-related waste discharge requirements adopted by the Regional Water Board for the Elk River watershed (NCRWQCB, 2004). By definition, some treatment is possible at these management-related sites. Discharge sites include sites associated with watercourse crossings, roads, skid trails, gullies, road-related and non-road-related landslides. Typically these sites are treated by removing some volume of fill material and then treating the channel and excavated slopes to minimize post-treatment sediment delivery (see section 3.4.7). Double counting of discharge sites are avoided by removing road and non-road landslide features from the databases, as they are included in the management-related shallow landslide categories (see Section 3.4.4)

Significant effort has been put forth to develop and implement programs to identify, prioritize, treat and monitor these sites in Elk River. On Humboldt Redwood Company (HRC) ownership in the Elk River, the program is implemented through a series of Cleanup and Abatement Orders[30] and on a timber harvest plan (THP) by THP basis pursuant to enrollment under their watershed-wide Waste Discharge Requirements[31]. The program on Green Diamond Resource Company (GRDC) lands is implemented on a THP by THP basis pursuant to their watershed-wide Waste Discharge Requirements[32]. On land controlled by the Bureau of Land Management (BLM), the program is implemented through the Headwaters Forest Management Plan[33]. On non-industrial timber lands the program is implemented within THP[34] and NTMP[35] harvest areas and roads appurtenant to the harvest operations. The data available for this sediment source analysis reflects the status of the program to date: where property-wide programs are in place, relatively complete data sets are available, where no property-wide program is in place, robust data sets are unavailable. The following sections present information by ownership to reflect the differences in the available datasets. Data are presented to quantify, over time, the past sediment loading associated with discharge sites, the treatment progress to date, and potential future delivery from the sites.

3.4.12.1 Discharge Sites on Humboldt Redwood Company (HRC) Lands

The Elk River property-wide programs for inventory, prioritization, and treatment of discharge sites began on Humboldt Redwood Company (HRC) property in Elk River in 1997[36]. As a result, available data are much more extensive on HRC lands than other ownerships in the watershed.

Data Sources Used to Determine Loads from Discharge Sites on HRC Lands

1. The PALCO Elk River Watershed Analysis sediment budget and the aerial photo analysis landslide data (Palco, 2004b) (WA Landslide Database). This data set includes landslide feature data and attributes for 856 discharge sites on Palco (now HRC), BLM, and GDRC properties identified on 1954-2000 aerial photos. It includes estimates of past delivery for these landslide features.
2. The PALCO Elk River Watershed Analysis sediment budget road database (Palco, 2004c) (WA Road Database). This data set identified discharge sites related to stream crossings, stream banks, road gullies, cut bank, fillslope, road and ditch, torrent track, and hillslope debris features. The Watershed Analysis only reported

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[30] Order No. R1-2004-0028 (South Fork Elk River and Mainstem Elk River) and No. R1-2006-0055 (North Fork Elk River) (as amended by Order No. R1-2008-0100 to reflect new ownership).
[31] Order No. R1-2006-0039 (as amended by Order No. R1-2008-0100 to reflect new ownership)
[32] Order No. R1-2006.-
[33] The United States Department of the Interior, Bureau of Land Management and California Department of Fish and Game Management Plan for the Headwaters Forest Reserve (2003).
[34] Order No. R1-2004-0030, and Order No. R1-2009-0038.
[35] Order No. R1-2009-0038.
[36] Order No. R1-1997-0115

the inputs for the 1990's. This source analysis evaluated discharge sites by delivery volume per decade (beginning in 1955). The data was based upon field and aerial photo descriptions and by sub-basin. A total of 1,346 sites are included in the database, including 476 sites not included in the WA Landslide Database.

3. Field inventories of discharge sites in South Fork and Mainstem Elk River (PWA, 2001)[37]. An inventory of the entire (100%) road system was conducted to identify road-related sites of past erosion and sediment delivery. An air photo inventory was also preformed to identified non-road and road-related shallow landslides (and estimated sediment delivery volumes) using historic aerial photos from 1954, 1966, 1974, 1987, and 1997. Summary tables of preliminary estimates of past erosion and delivery from non-road debris landslides and debris torrent sources and road-related sources for the analyzed areas by photo period (for landslides) and by decade (for field inventories) were made available to Regional Water Board staff. Skid trail-related landslides were classified as non-road-related landslides while railroad-related landslides were classified as road-related landslides. A total of 829 sites were identified and summary information provided.
4. Cleanup and Abatement Orders (CAOs) Database[38]. CAOs required the inventory, prioritization, treatment, and reporting of sediment discharge sites. Data relative to past delivery was not required under the CAO requirements and as such this information is not reflected in the database. Additionally, no discharge sites in the Clapp Gulch sub-basin are included in the database. A total of 1,425 sites are in the CAO Database[39].
5. The Palco ROWD Landslide Database (Palco, 2005) was developed and submitted to the Regional Water Board staff as part of the Final Palco Report of Waste Discharge (ROWD). The database is a compilation of all available earlier databases, with the addition of landslides identified on the 2003 aerial photos. The database contains attributes for 1,144 landslides.

For the purposes of this sediment source analysis, both past and future sediment delivery are of interest; past such that a source analysis could be constructed and future to guide future watershed implementation actions. The WA Road Database was used to quantify past sediment delivery and CAO Database was used to determine future sediment delivery. Because none of the data sources appear wholly comprehensive, nor do their attributes fully coincide, Regional Water Board staff evaluated the maximum differences in sediment loading based upon all the available data sources and expressed the differences in terms useful in the development of a margin of safety.

Methods Used to Determine Loading from Discharge Sites

The WA Road Database was analyzed for past sediment delivery (1950-2000) associated with discharge sites. The PALCO ROWD Landslide Database was used to characterize shallow hillslope landsliding (Section 3.4.4). To avoid double counting any

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[37] Memo dated December 10, 2001, To: Matt O'Connor, OEI, From: Eileen Weppner, PWA, subject: Road-related and non-road related erosion and sediment delivery to Clapp Gulch, Railroad Gulch, South Fork Elk River, and lower Mainstem Elk River (interfluves).

[38] a) CAO No. R1-1997-115, CAO No. R1-1998-100, CAO No. R1-2002-0114, CAO No. R1-2004-0028, CAO No. R1-2006-0055.

[39] 2010 Elk River Inventory Update.

sites in this sediment source analysis, sites in the WA Road Database were compared with the ROWD Landslide Database and the landslide sites were removed from the WA Road data.

The sub-basins used in the WA differed slightly from the sub-basins used in this source analysis. As such, some of the sub-basin names referred to in the WA were modified to match those of the TMDL analyses. Additionally, areas were combined where appropriate to be consistent with the TMDL analyses. Specifically, the WA did not include Corrigan Creek as a sub-basin as it was included in the South Fork basin. For consistency with this analysis, South Fork basin (as used in the WA) was renamed Upper South Fork, Mainstem was renamed Lower Elk River, and North Fork was renamed Upper North Fork. The Lower North Fork and Upper North Fork were combined and renamed Lower North Fork.

The data were then sorted by sub-basin and sediment delivery by decade was determined as a sum of the sites. A number of the sites did not have dates associated with the past yield estimates. In this case, the sediment delivery was distributed evenly over the decades following the date of construction.

The average sediment delivery per year was determined by dividing the decade associated with the erosion by ten (10) years. In the case of the 1950’s, the first erosion and road construction was associated with the 1954 photos, thus the value was divided by five (5) to represent 1955-1959.

In addition to the Palco WA Road Database, the PWA 2001 data were evaluated for the available areas. The non-landslide data were selected, including: stream crossing washout, gullies (fillslope/hillslope/road), and stream bank erosion. The sediment delivery per year was similarly determined from the decadal data.

Future sediment delivery from discharge sites was estimated based upon data in the CAO Database.

Results – Discharge Sites Analysis on HRC Lands

Figure 3.28 presents sediment loading associated with non-landslide management-related discharge sites.

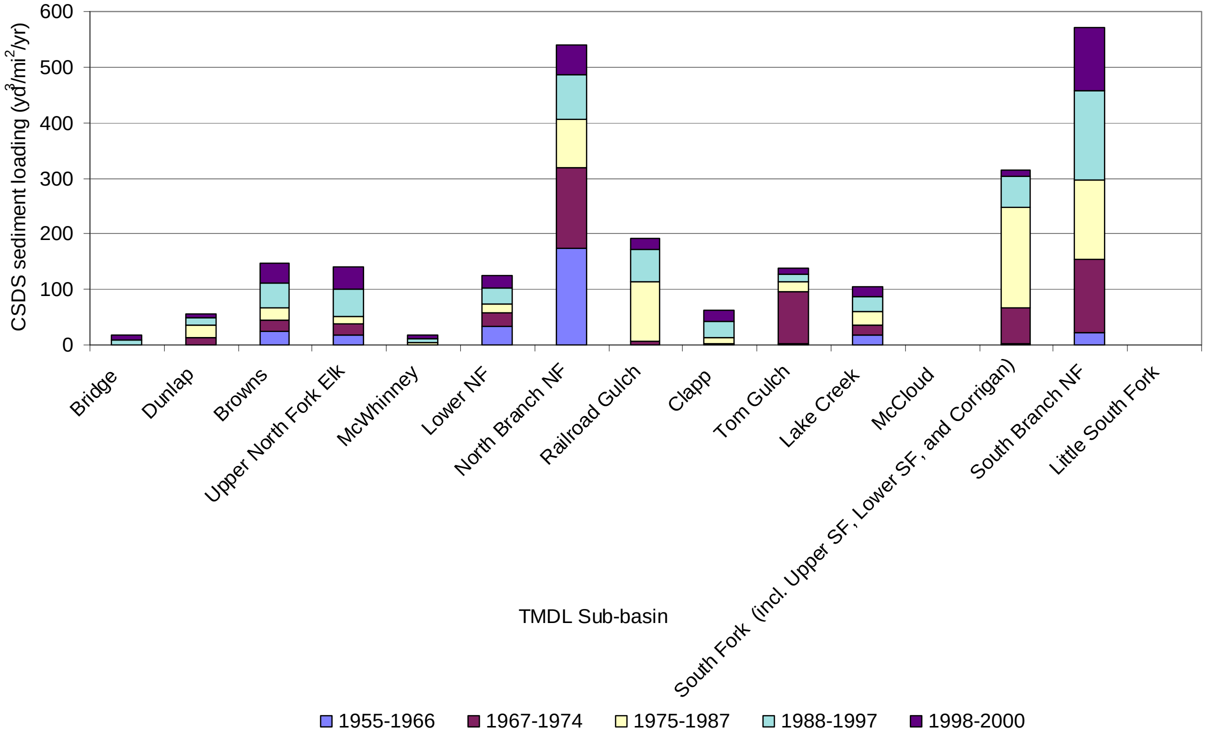


Figure 3.28 Past sediment delivery by sub-basins from non-landslide discharge sites for analysis photo periods[40].

Future sediment delivery from discharge sites was estimated based upon data in the CAO Database. Figures 3.29 and 3.30 depict the number and the volumes associated with discharge sites identified in the sub-basins, respectively, as well as their treatment status. Lower North Fork had the largest total volumes of delivery associated with discharge sites and Lake Creek has the largest volume pending (Figure 3.30).

The future delivery from the known discharge sites that remain to be treated is depicted in Figure 3.31. Figure 3.32 show the potential annual sediment loading from remaining untreated sites in the TMDL sub-basins on HRC lands. These annual delivery rates were determined by amortizing the future yield across the number of years indicated by the treatment immediacy attribute. High = 5 years, High/Medium = 10 years, Medium/Not Stated = 20 years, Medium/Low = 30 years, and Low = 50 years. These data can provide information to inform treatment scheduling strategies.

Regional Water Board staff note a discrepancy in the data presented in the summary Table and the inventory data representing sites pending treatment[41]. The 2010 Summary Table (Figure 3.30) includes 158,060 yd^3 more volume associated with sites pending treatment than shown in the inventory data (Figure 3.31).

[40] WA Road Database and non-landslide sources in South Fork and Mainstem Elk River, PWA (2001).
[41] Based on the 2010 CAO update

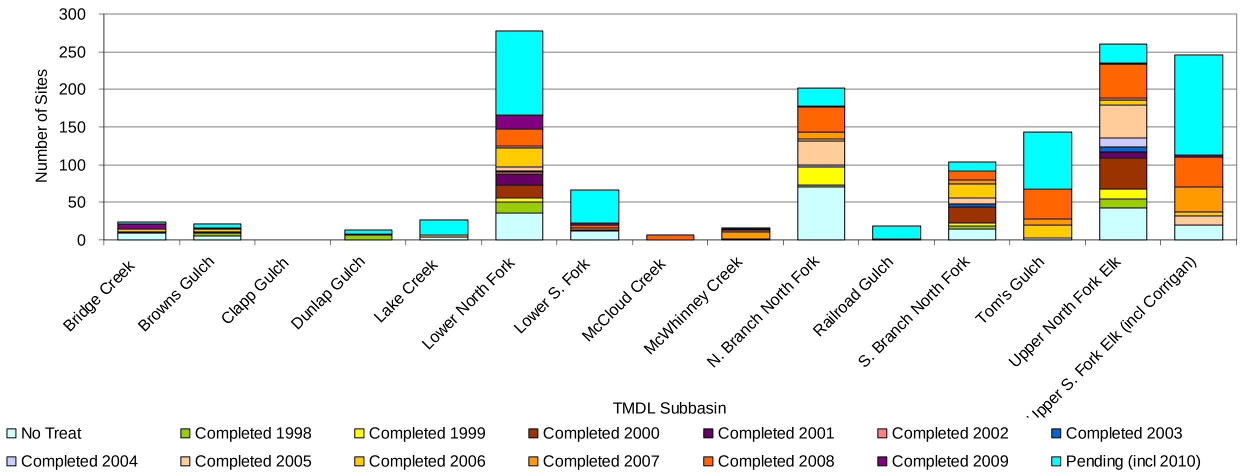
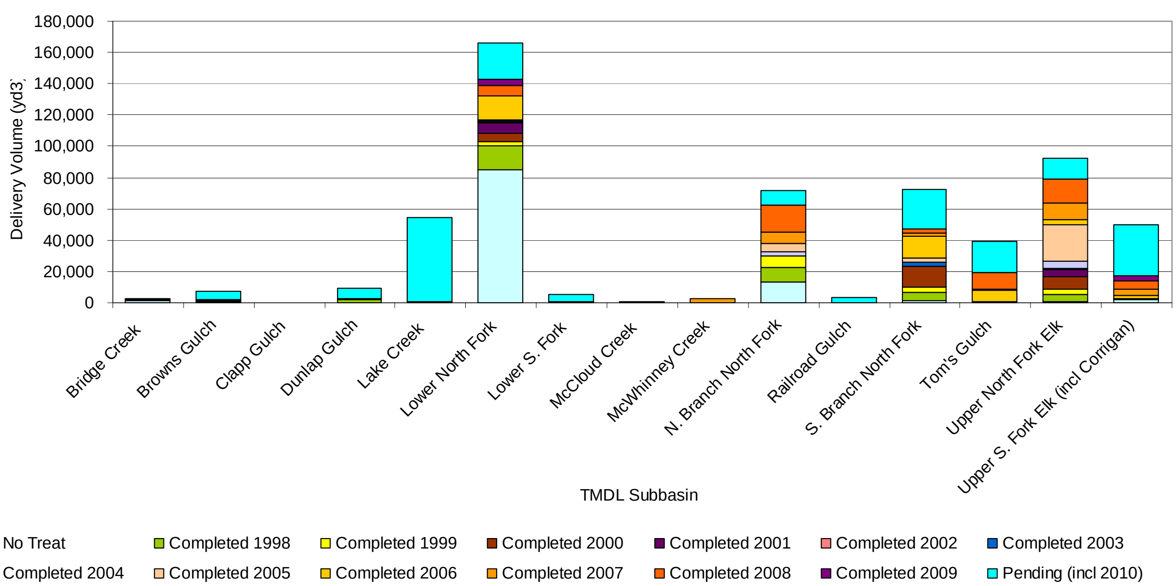


Figure 3.29 Number of discharge sites identified in the CAO Database[42] and their treatment status by sub-basin.



TTFigure 3.30 Volume associated with discharge sites identified in the CAO Database[40] and their treatment status by sub-basin.

[42] HRC 2010 CAO update summary table.

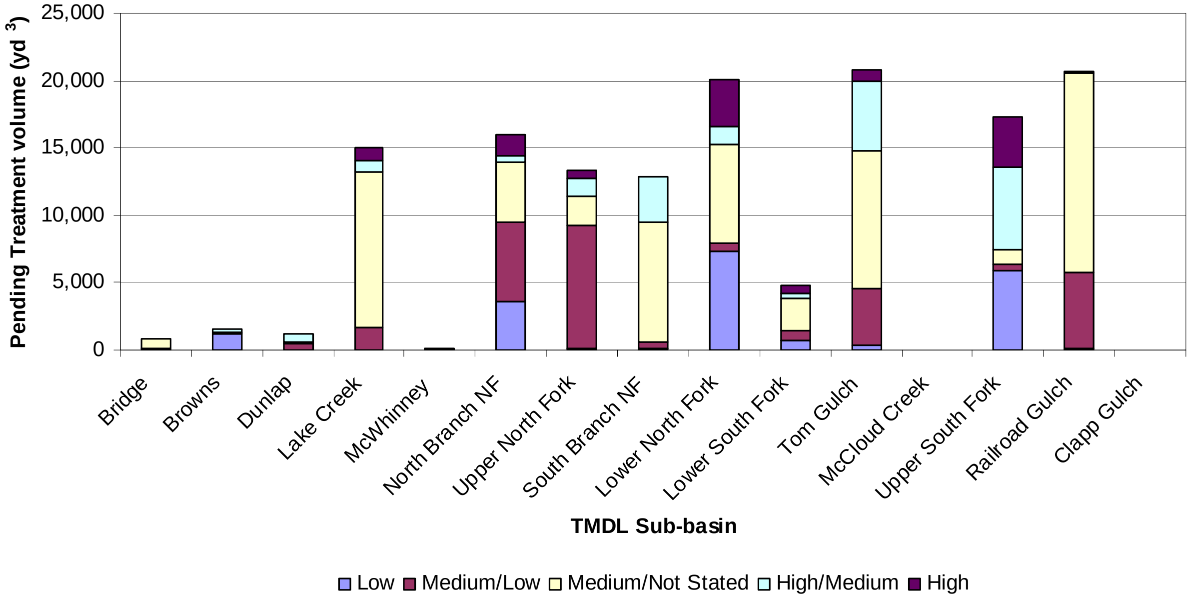


Figure 3.31 Future sediment delivery from untreated discharge sites, by treatment priority, for HRC lands[43].

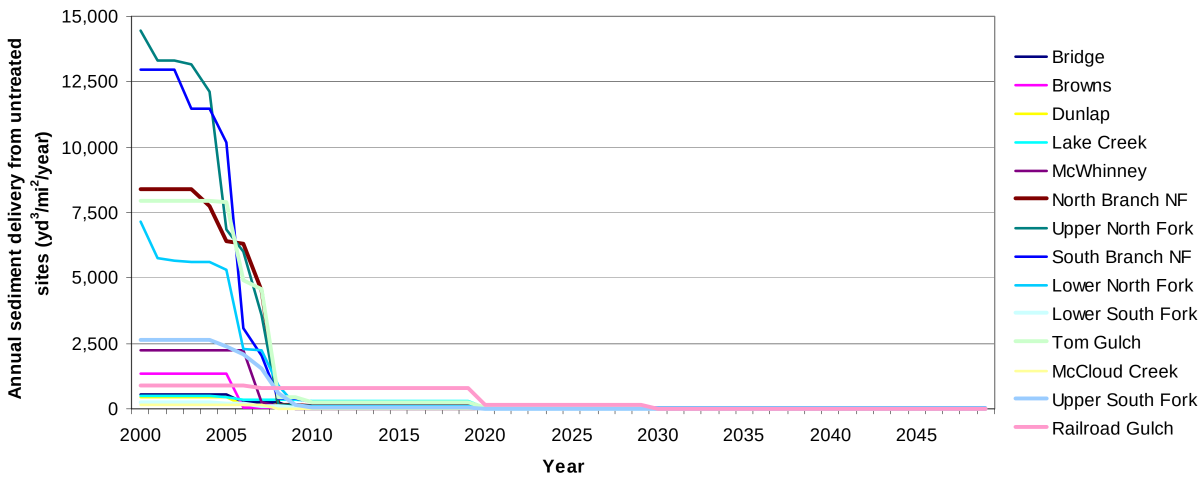


Figure 3.32 Future annual sediment loading from remaining untreated discharge sites, assuming a uniform rate of annual discharge.

Due to a significant difference in the magnitude of delivery of past delivery estimates from the WA Road Database and the future delivery estimates within the CAO Database based upon treatment immediacy, Regional Water Board judge that the treatment immediacy is not reliable for loading estimates. Regional Water Board staff assumed that the discharges from sediment discharge sites from 2001-2003 were the same as from 1998-2000.

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[43] Based on 2010 CAO update inventory database. Includes sites identified as infeasible to treat in the CAO database.

Uncertainties Associated with Discharge Sites Analysis on HRC Lands

- Not all areas of the watershed have been fully inventoried, thus the available data are unlikely complete. Data updates occur as additional inventories are conducted and should be included in the CAO Database. Until a complete inventory is available, the past delivery estimates will be underestimated.
- Of the available data sources described in 3.1.2, there are inconsistencies in the included areas, number of sites, time periods, and past and future delivery attributes. HRC has attempted to rectify these differences under the ROWD Landslide and CAO databases. Despite these efforts, some uncertainty remains with the past and future delivery estimates from these sites.

3.4.12.2 Discharge Sites on Green Diamond Redwood Company (GDRC) Lands

As part of their Elk River WWDR[44], Green Diamond Resource Company (GDRC) is scheduled to have all discharge sites inventoried and treated on their ownership by 2015. To that end, GDRC inventoried their ownership for road-related sites with potential for future sediment delivery. The findings were documented in PWA (2006). In addition to the road inventory, and scheduling and treatment of sites identified therein, the WWDR requires that all areas in the watershed be inventoried and treatment of discharge sites implemented. To ensure all discharge sites are identified and treated, the WWDR required GDRC to address also non-road related discharge sites, both within and beyond THP boundaries.

Data Sources Used to Determine Loads from Discharge Sites on GDRC Lands

1. 2006 GDRC Road inventory[45]. Pursuant to the WWDR requirements, a complete road survey was conducted on GDRC lands. It includes a written report and excel database of sites. A total of 151 sites are included in the GDRC Road Inventory Database. Attributes include past and future delivery volumes, as well as treatment priority.
2. GDRC Master Treatment Schedule[46]. Also pursuant to the WWDR requirements, GDRC developed a schedule for all inventoried sites.
3. GDRC Annual Reports[47]. Pursuant to the WWDR requirements, annual reports describing status of site treatments and inventories of non-road areas are submitted annually to the Board.
4. Palco WA Landslide Database. Includes a total of 47 slides are on GDRC property for the period 1954-2000. Analyses of these shallow landslides are covered in detail in Section 3.4.4.

Methods Used to Determine Loads from Discharge Sites on GDRC Lands

Regional Water Board staff reviewed the GDRC Road Inventory Database for data relative to past and future sediment delivery. Additionally Regional Water Board staff reviewed the GDRC Annual Reports to assess information regarding non road-related

[44] Order No. R1-2006-0043.
[45] Road Inventory for GDRC Lands in South Fork Elk River (PWA, 2006)
[46] Master Treatment Schedule for South Fork Elk River (GDRC, 2007)
[47] Completed Annual Summary Report for South Fork Elk River (GDRC 2007, 2008 and 2009)

sources. Based on the review of the GDRC Annual Reports, no additional sites were encountered from 2007-2009. Regional Water Board staff did not include additional volumes to account for areas not yet inventoried.

Regional Water Board staff compared the GDRC Road Inventory Database numbers to the GDRC Master Treatment Schedule map to determine the location of sites by TMDL sub-basins. The time period associated with past erosion was not provided for all sites. In such cases, staff assumed a time period based upon 1) the time period of construction, and 2) time periods associated with other sites along the same road segments. Generally the time periods assigned for past erosion are decadal. These were then converted to the TMDL analysis photo periods for consistency with other source categories.

The GDRC Master Treatment Schedule includes sites that are not found in the GDRC Road Inventory Database. In this case, staff added the mapped sites into the database. For these sites, staff assigned “erosion priority”, “past delivery volume”, and “future delivery volume”, based upon evaluation of the other sites in the database. Table 3.26 presents the characteristics of the discharge sites recorded in the database.

Table 3.26 Discharge site characteristics on GDRC lands[48].

Erosion Priority	Future Delivery (years)	Number of Sites	Percent of Total Sites Assigned Priority	Average Past Sediment Delivery (yd^3)	Average Future Sediment Delivery (yd^3)	Ratio of past: future delivery
H	5	24	17%	159	363	0.44
HM	10	30	22%	55	324	0.17
M	20	31	22%	63	319	0.20
LM	30	41	29%	37	185	0.20
L	50	13	9%	48	60	0.79
	Erosion Priority Weighted Average = 21	Total=139	Total=100%	Erosion Priority Weighted Average = 69	Erosion Priority Weighted Average = 264	0.26

Determination of past and future volumes was made by calculating the average past and future erosions, weighted by the percent of total sites within assigned priority groups. The resulting volumes were estimated as 69 yd^3 average from past erosion and 264 yd^3 from future delivery. These volumes were assigned to sites where no volume data was included in the database. An erosion priority of “moderate” was assigned to sites where no priority had been assigned.

According to the GDRC Roads Inventory written report (PWA, 2006)TT, twenty-four road related landslides are included in the dataset. However, the GDRC Roads Inventory Database does not describe site type. The Palco WA Landslide Database includes fifty-eight landslides on GDRC property, including eight road-related landslides. In an attempt to avoid double counting, Regional Water Board staff assumed the road-related

[48] Based upon the Road Inventory Database for GDRC Lands (PWA, 2006)

landslides in the HRC ROWD Landslide Database were included in GDRC Road inventory. Staff only included open-slope landslides from the landslide Database for GDRC lands in the landslide analyses (Section 3.4.4.2).

Results - Discharge Site Analysis on GDRC Lands

The resulting past and future sediment loadings are based upon the sub-basin area rather than GDRC ownership within the sub-basin, thus the loadings from their ownership is higher, especially in Toms Gulch and Lower South Fork where GDRC owns little of the sub-basin.

Past annual sediment loading from discharge sites on GDRC lands is presented in Figure 3.33.

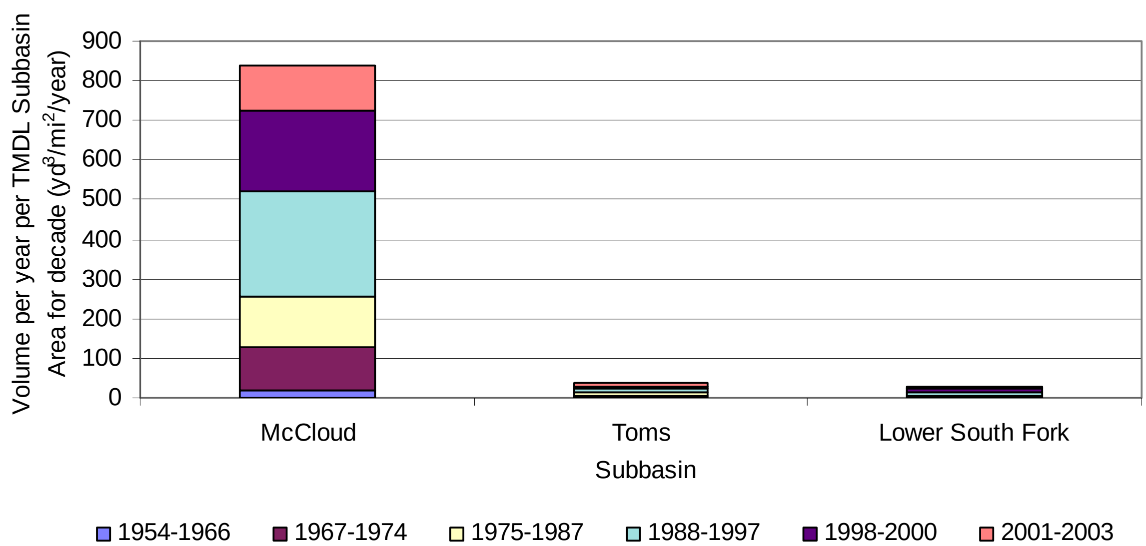

Figure 3.33 Annual past sediment loading into TMDL sub-basins for analysis time periods resulting from identified discharge sites on GDRC lands.

The estimated future sediment delivery was evaluated for sites based upon information in the GDRC Roads Inventory Database or, where no data was provided, was estimated as described. Figures 3.34 and 3.35 depict the number and the volumes associated with sites identified in the sub-basins, respectively, as well as their treatment status. The future sediment delivery from the known discharge sites that remain to be treated is depicted in Figure 3.36. Figures 3.37 shows the potential annual sediment loading from remaining untreated sites in the TMDL sub-basins on GDRC lands. These annual delivery rates were determined by amortizing the future yield across the number of years indicated by the treatment immediacy attribute. High = 5 years, High/Medium = 10 years, Medium/Not Stated = 20 years, Medium/Low = 30 years, and Low = 50 years. These data can provide information to inform treatment scheduling strategies.

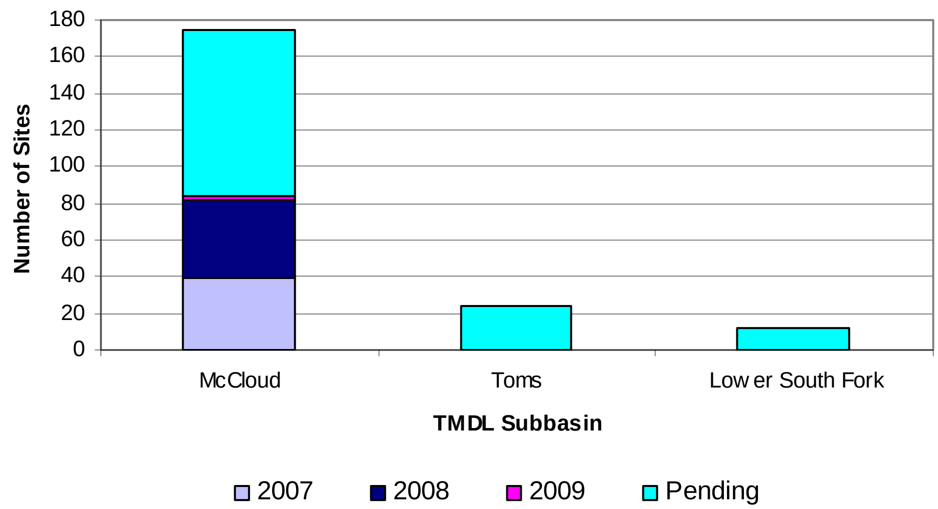

Figure 3.34 Number of inventoried discharge sites and treatment date for GDRC lands.

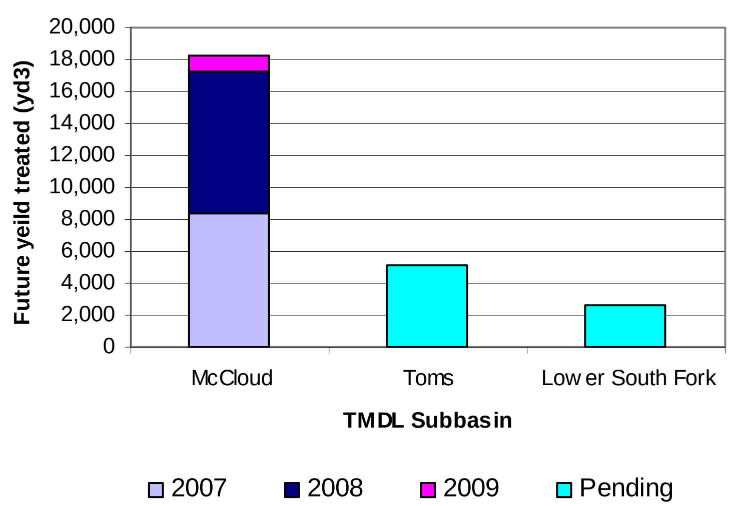

Figure 3.35 Volume of known discharge sites and treatment date for GDRC lands.

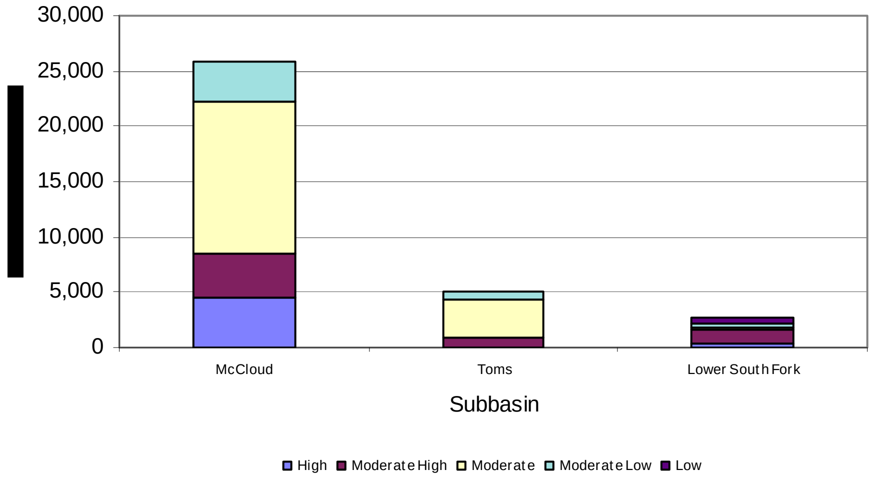

Figure 3.36 Future delivery from untreated discharge sites by treatment priority on GDRC lands.

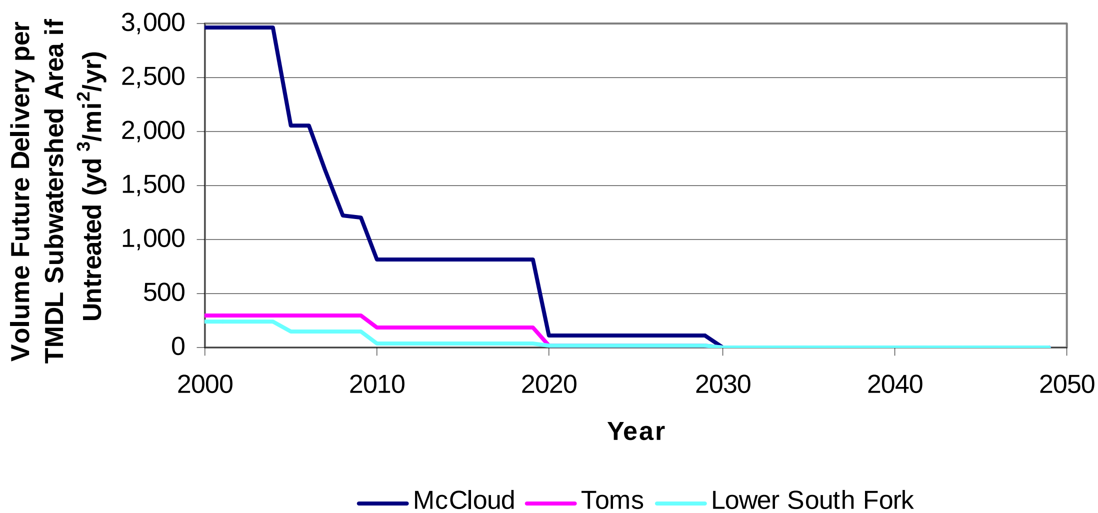

Figure 3.37 Future annual loading from remaining untreated sites on GDRC, assuming uniform rates of annual discharge associated with treatment priorities.

Evaluation of the results indicates a significant difference in the estimated discharge based upon the past delivery estimates (Figure 3.33) and future delivery estimates (Figure 3.37) for the same time period (2001-2003). This discrepancy highlights the uncertainty associated with the inventory delivery estimates and that treatment priority appears to be an unreasonable estimator of sediment loading.

Uncertainties Associated with Discharge Site Analysis on GDRC Lands

- The GDRC Road Inventory, and GDRC Master Treatment Schedule (and Annual Reports) only include sites with the potential for future delivery. Thus sites that have already discharged their entire volume and no longer have erosion potential are not quantified; this results in an underestimate of past sediment loading associated with discharge sites.

- The loadings are based upon the TMDL sub-basin areas rather than GDRC ownership within the sub-basin, thus the loadings from their ownership is higher, especially in Toms Gulch and Lower South Fork.
- Assumptions about past and future delivery volumes may affect the estimates.
- There is uncertainty about the accuracy of the past and future delivery estimates.

3.4.12.3 Discharge Sites on Bureau of Land Management (BLM) Lands

The Bureau of Land Management (BLM) acquired the Headwaters Forest area in 1999. The discharge sites on those lands were created before the land transfer occurred and are not reflective of BLM management. As part of the Headwater Forest Management Plan, BLM has a program to identify and treat discharge sites.

Data Sources Used to Determine Loads from Discharge Sites on BLM Lands

1. 2000 Headwaters Watershed Assessment[49]. Written report summarizing PWA erosion inventory and a plan for decommissioning the Worm Road in upper Little South Fork Elk River. Includes a reconnaissance assessment of 3.6 miles of roads and a sample of skid trails in recently harvested areas of Elk Head Springs in the Upper South Fork Elk River. The assessment was designed to identify treatable non-road erosion problems that would otherwise be missed in an inventory of road related erosion and to determine the relative importance of both sources of sediment production and delivery (PWA, 2000).
2. TT2002-2004 Road Assessment[50]. Written report summarizes 1) a complete inventory of all future road-related sediment sources on roads within the lands now under BLM management, and 2) a decommissioning plan, including methods and estimated costs for erosion prevention projects and for re-contouring (outsloping) most roads in the project area. The assessment identified all recognizable current and future sediment sources from roads in Little South Fork and along the riparian corridor in upper South Fork Elk watershed. The erosion potential and future delivery volume was estimated for each site (PWA, 2004).
3. 2004-2005 Road Treatment Summaries[51]. Describes status, as of 2005, to treat the inventoried erosion sites indentified in the 2002-2004 Road Assessment (PWA, 2005a).
4. BLM Site Treatment Database[52]. Electronic data from BLM including treatment summaries: site number, treatment status, and potential future delivery volume from treated sites. No past sediment delivery was estimated.
5. Palco WA Landslide Database. Includes a total of 118 slides on BLM property for the period 1954-2000. These shallow landslides are covered in detail in Section 3.4.4.

[49] Pacific Watershed Associates. 2000. Headwaters Watershed Assessment. Prepared for BLM.
[50] Pacific Watershed Associates. 2004. 2002-2004 Road Assessment and Restoration Plan, Headwaters Forest Reserve. Agreement No. 1422-BA-0026, Task Order No. 4. Prepared for PCFWWRA and the US Bureau of Land Management.
[51] Pacific Watershed Associates. 2005a. Final Report 2004-2005 South Humboldt Bay Coastal Resources Protection Project, Salmon Creek and South Fork Elk River Watersheds. SWRCB Agreement #03-211-551. Prepared for SWRCB and BLM.
[52] BLM. 2010. Spreadsheet database of site Implementation for Headwaters Forest Reserve.

Methods Used to Determine Loads from Discharge Sites on BLM Lands

The BLM Site Treatment Database containing the treatment status of sediment discharge sites and the 2002-2004 Elk River Road Assessment were used as the basis for quantifying sediment discharge sites on BLM lands. Estimates for sediment volume saved (prevented from delivery to the stream system) and treatment year were gleaned from the Site Treatment Database for all sites treated between the years 2000 to 2010. The treatment priority for treated sites was obtained from the 2002-2004 Road Assessment[53]. Time periods of potential future sediment delivery were assigned to each site based upon the identified erosion potential.

Regional Water Board staff estimated the past sediment delivery for each site based upon the 2000 Headwaters Watershed Assessment, in which the documented average past delivery was 13% of the future delivery volume. Regional Water Board staff also assumed the time period associated with past sediment delivery was associated with disturbance in different areas of the Headwaters Forest Reserve, informed by the Headwaters Forest Management Plan (BLM, 2003), 2000 Headwaters Watershed Assessment, 2002-2004 Road Assessment and discussions with BLM staff (pers comm. Sam Flanagan, 2011). The time period used to estimate disturbance and associated sediment delivery with sites in the following sub-basins include:

- Lower Little South Fork; 1960, 1970, and 1990..
- Worm Road; 1990.
- Lower Elk River and Upper South Fork; uniformly distributed over the 1950's-2000's.

To ensure that past sediment delivery from shallow landslides were not double counted in the discharge sites and shallow hillslope landslide sediment source categories, landslides were not included in past sediment delivery in this landslide source category.

The resulting past and future sediment loadings are based upon the sub-basin area rather than BLM ownership within the sub-basin, thus the loadings per their ownership is greater than is presented herein.

Results - Discharge Site Analysis on BLM Lands

Figure 3.38 presents the sediment loading associated with past erosion from discharge sites on BLM lands within the TMDL sub-basins, based on the discharge site inventory data.

[53] Table 2.

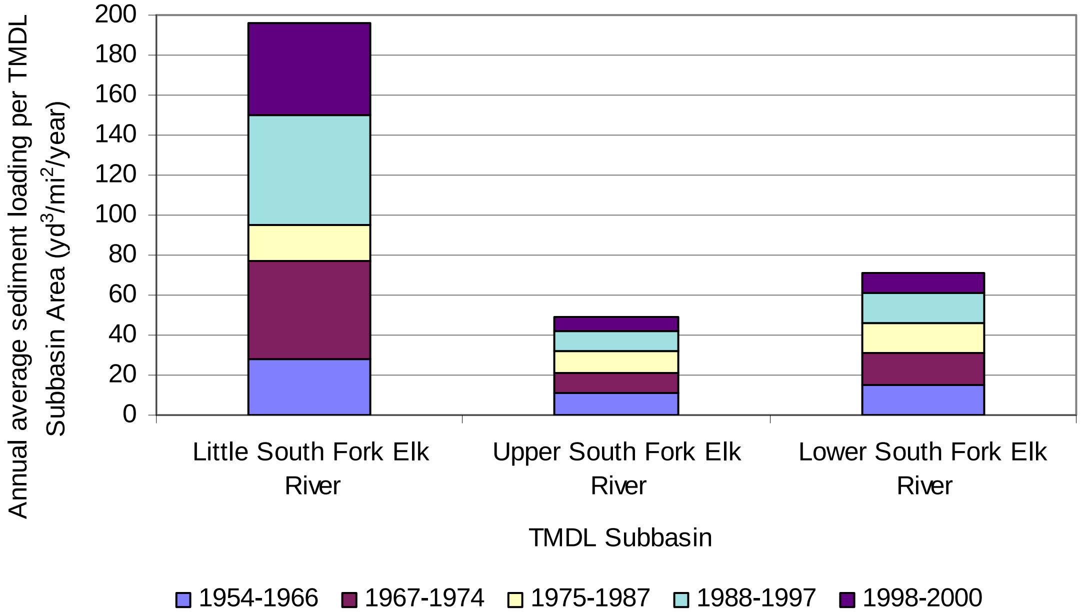

Figure 3.38 Sediment loading from discharge sites on BLM lands by photo periods.

Figures 3.39 and 3.40, respectively, present the number and potential delivery volume of identified discharge sites and their treatment status on BLM by TMDL sub-basin. Figures 3.41 presents the treatment priority associated with associated with identified discharge sites pending treatment.

The data in Figure 3.42 represents, for each year, the estimated loading associated with discharge from remaining sites, including estimated discharge from sites treated between the years 2000-2010. These annual delivery rates were determined by amortizing the future yield across the number of years indicated by the treatment immediacy attribute. High = 5 years, High/Medium = 10 years, Medium/Not Stated = 20 years, Medium/Low = 30 years, and Low = 50 years. These data can provide information to inform treatment scheduling strategies.

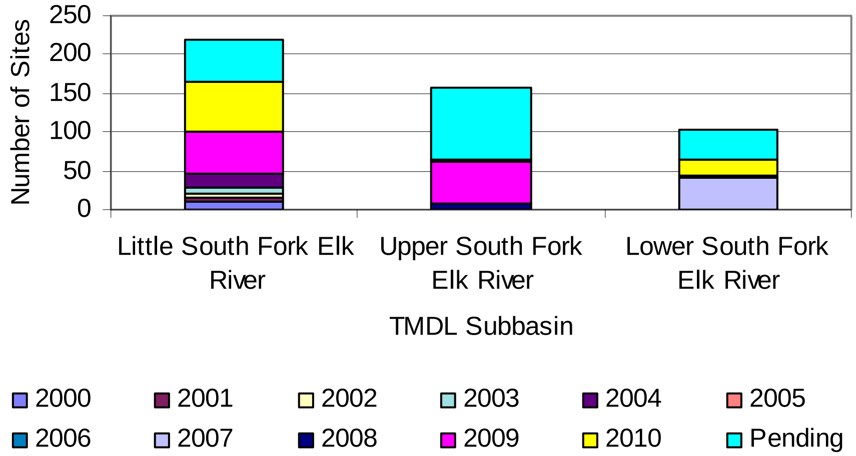

Figure 3.39 Number of discharge sites by treatment year for BLM lands.

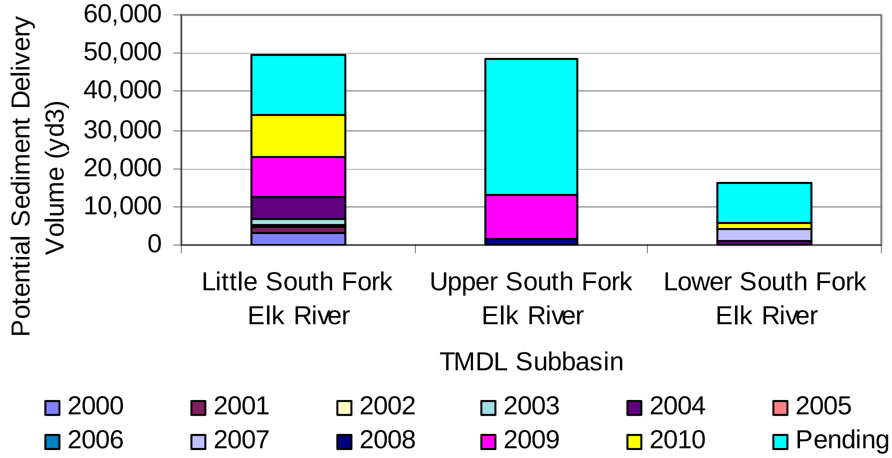

Figure 3.40 Future sediment volume from discharge sites by treatment year for BLM lands.

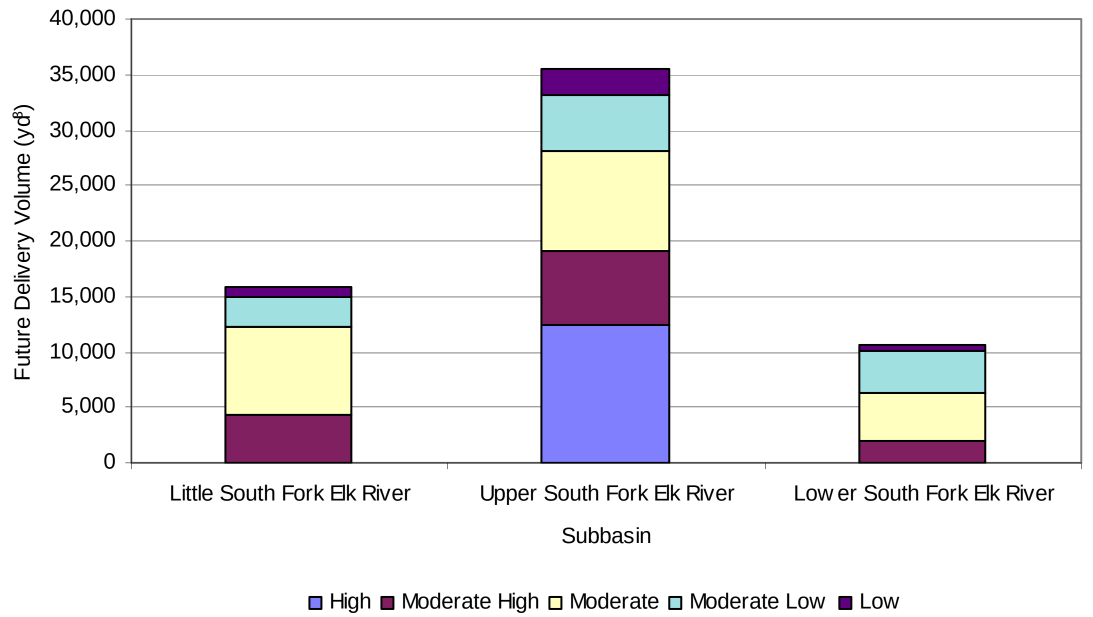

Figure 3.41 Future delivery associated with untreated discharge sites, by treatment priority for BLM lands.

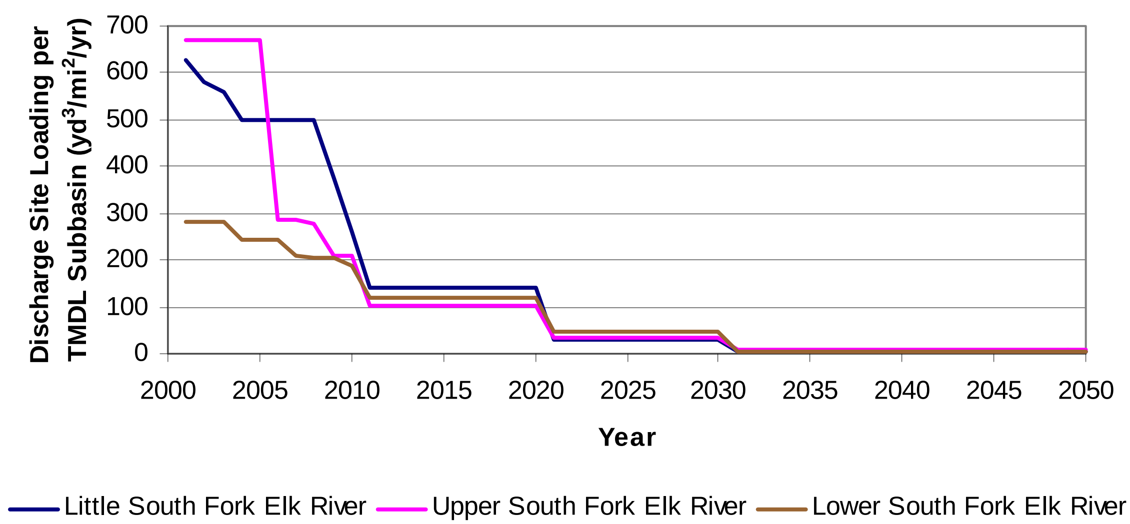

Figure 3.42 Estimated annual sediment loading from treated and remaining discharge sites on BLM lands, assuming a uniform rate of annual discharge associated with treatment priorities.

The site treatment priority, representing the potential time period for erosion, results in much greater loading rates (Figure 3.42) than the past erosion estimates based on the inventories (Figure 3.38). This discrepancy highlights uncertainty associated with timing of sediment delivery both based on the inventory and the site treatment priority. Additionally, this discrepancy precludes the use of the treatment priority of estimating loading rates associated with the 2001-2003 time period. Rather, Regional Water Board staff assumed the same loading rate as during the 1998-2000 analysis period. This rate does not however reflect the treatments accomplished within that period.

Additionally, the treatment priority parameter appears to be an unreasonable estimator of sediment loading.

Uncertainties Associated with the Discharge Site Analysis on BLM Lands

- A landslide inventory specific to the BLM lands has not been developed. Landslides identified on BLM lands included in the WA inventory[54] are assumed to be representative.
- The discharge site data for BLM lands lack site-specific field estimates of past delivery. The average ratio of past to future erosion volume is assumed to be representative,
- The discharge site data for BLM lands lack time period estimates of past sediment delivery. The time period for past erosion was assumed based upon staff's estimates of disturbance throughout the BLM lands.
- Lack of acreage totals owned by BLM in individual TMDL sub-basins result in sediment loadings per TMDL sub-basin lower than those specific to the BLM ownership.

3.4.12.4 Summary of Cumulative Past Loading from Discharge Sites for Dominant Ownerships

The ownership-specific past sediment loading associated with management-related discharge sites were summed for each of the seventeen sub-basins. The results are presented in Figure 3.43.

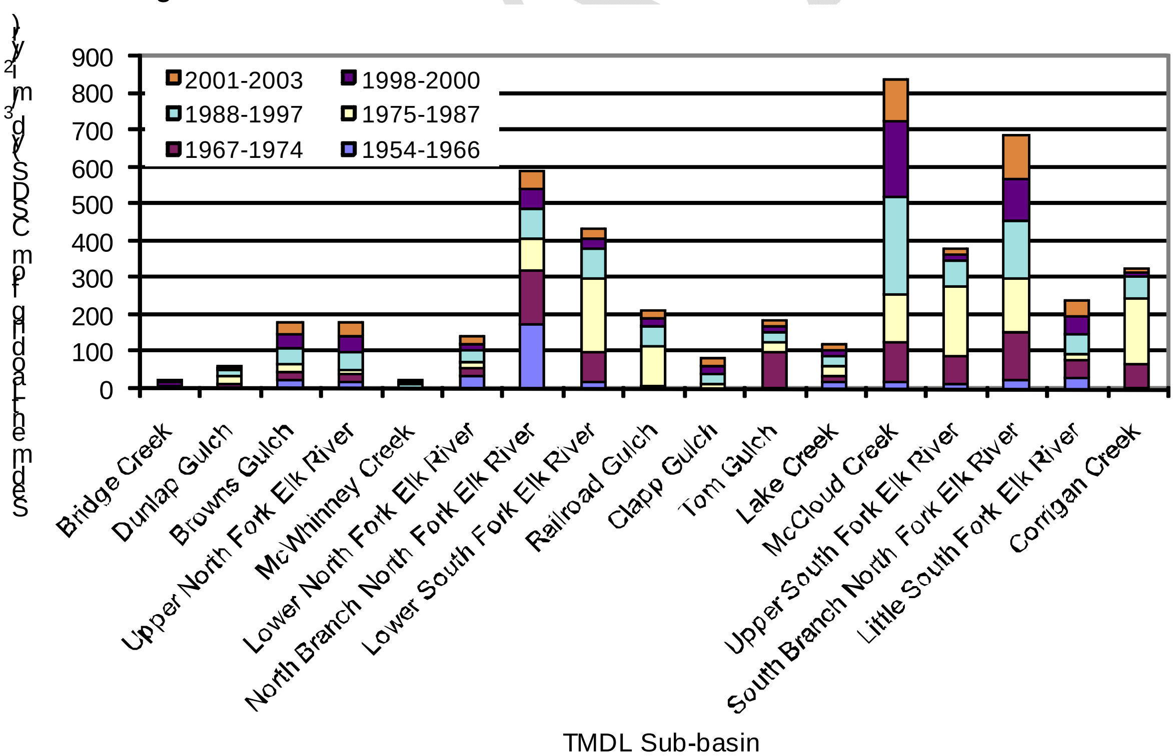

Figure 3.43 Annual average past sediment loading from discharge sites for dominant ownerships by sub-basins.

[54] Palco (2004b)

Table 3.27 presents the sediment loadings from management-related discharge sites to Upper Elk River as a whole.

Table 3.27 Annual sediment loading from management-related discharge sites in Upper Elk River ($yd^3/mi^2/yr$)

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Annual loading from management-related discharge sites in Upper Elk River ($yd^3/mi^2/yr$).	30	60	80	65	39	39

3.4.12.5 Implications for Watershed Implementation Actions

Factors that can reduce sediment discharge from discharge sites include:

- Avoid creation of new sites through avoidance of substantial earthworks (cut and fill) near watercourses, including stream crossings, and the concentration of overland flow (e.g. road and skid trial runoff).
- The cumulative future delivery estimates from discharge sites should be considered in prioritizing and scheduling site treatment.

3.4.13 Post-Treatment Discharge Sites

Decommissioning and upgrading of roads and stream crossings is recognized as important in preventing and minimizing large scale episodic sediment delivery. However, depending on site conditions, storm magnitude and timing, extent of site characterization and implementation techniques, there may be short-term adjustments and sediment delivery associated with road and stream crossing decommissioning and upgrading activities. The post-treatment discharge site source category captures these sediment inputs into the stream system.

Sediment discharges from treated sites can come in many forms, including but not limited to, channel scour, bank slumps, headward extension of nick points, culvert outlet and inlet scour, and surface erosion.

Stabilization of discharge sites, whether corrected with heavy equipment or hand-crews, often require additional surface and channel treatment in the form of mulching of exposed soils and armoring of channel and fillslopes to minimize sediment delivery due to post-treatment adjustment. Individual site conditions and operator experience heavily influence the magnitude of post-treatment erosion volumes. Several studies have been conducted on the North Coast to inform the magnitude of sediment discharged from this post-treatment related source (Table 3.28). From these studies, the combined average sediment delivery per treated site was 36 yd^3.

Table 3.28 Treatment-related sediment discharge volumes from north coast studies.

Study	Location	Average Delivery per Treated Site (yd^3)
Bloom (1998)[55]	Bridge Creek	113
Klein (2003)	Upper Mattole River	16
Klein (1984)[56]	Redwood National Park - small stream crossings	11
Madej (2001)	Bridge Creek (same as Bloom,	66

	Crossings + road segments)	
PWA (2001)	Rowdy Creek	13
PWA (2001)	Little River	12
PWA 2005d (DFG- all sites)	Road Decommissioning CDFG Fisheries Restoration Grant Program	24
PWA 2005d (DFG – Geologies present in Elk River)	Road Decommissioning CDFG Fisheries Restoration Grant Program	18
Average of all studies		**36**

Since 2000, Regional Water Board staff has sought to characterize the magnitude of restoration-related (post treatment) sediment discharges. This evaluation was necessary so that impacts from the treatment work could be documented and the overall discharge minimized over time by use of adaptive management techniques. The results of this monitoring effort in Elk River are presented in Table 3.29.

Table 3.29 Treatment-related sediment discharge volumes from Elk River studies.

Source	**Average Post-Treatment Delivery Volume per Site (yd^3)**	**Number of sites monitored**	**Average Assessed site delivery volume (yd^3)**	**Percent of assessed volume delivered**
BLM Headwaters Decommissioning (BLM, 2010)	15.4	26	2786.1	0.5%
GDRC WWDR 2006 Treatments (GDRC, 2007)	15.5	3	159.0	9.5%
GDRC WWDR 2007 Treatments (GDRC, 2008)	4.4	7	231.1	1.9%
PL CAO 2006 Treatments (Palco, 2007)	4.5	25	984.9	0.5%
PL CAO 2007 Treatments (Palco, 2008)	0.9	19	695.5	0.1%
Palco Elk Decommissioning, (PWA 2005c)	16.9	52	172.5	9.8%
Palco THP 1-97-520. (PWA 2005b)	6.5	43	NA	
Averages for Elk River studies	**9.1**	**53**	**838.2**	

The average sediment delivery per discharge site monitored in Elk River was determined to be 9.1 yd^3. The average percent sediment delivery per site, weighted by assessed site volume was 1.1% of the assessed site volume.

PWA (2005a&b) focused on post-treatment erosion of Elk River decommissioned sites. The study found that the most common and most volumetrically significant types of erosion at decommissioned stream crossings included channel incision within the excavated channel, and slumps of the excavated stream channel side slopes. Additionally, the most common problems at stream crossings included over steepened fill, unexcavated fill, undercutting of slopes by excavation, natural bank adjustments, and unstable geology.

The studies cited in both Tables 3.25 and 3.26 vary in terms of the length of time period monitored following treatment, stream power at the site, the storm history following treatment, the experience of the operators in the specific terrain, the level of site characterization, the level of operator oversight, and the budget per site. However, they offer insight into the range of potential discharges resulting from the sediment treatment work intended to restore the beneficial uses of water in Elk River.

3.4.13.1 Methods Used to Determine Loads from Post-Treatment Discharge Sites

For the purposes of the sediment source analysis, the average per site value from the Elk River studies, 9.1 yd^3 or 1.1% of the assessed volume, was used to determine the sediment delivery to Elk River from past treatment efforts as well as anticipated future efforts. Both 9.1 yd^3 per site and 1.1% of the assessed volumes were applied to the management discharge sites treated thus far in Elk River (described in Section 3.4.6). The average site treatment volume for site treated to date ranged from 168 to 845 yd^3.

3.4.13.2 Results - Post-Treatment Discharge Site Analysis

Staff calculated the sediment delivery associated with treatment of discharge sites on HRC, GDRC, and BLM lands. Figures 3.44 and 3.45 present the resulting sediment delivery based upon a per site discharge of 9.1 yd^3 or 1.1% of the assessed volume, respectively. The per site discharge volume results in a nearly a two-fold greater overall discharge than estimates based upon a percentage of the assessed site volume. For the purposes of this sediment source analysis, staff relied upon the discharge volume per site of 9.1 yd^3 to ensure that a margin of safety was included in the estimate.

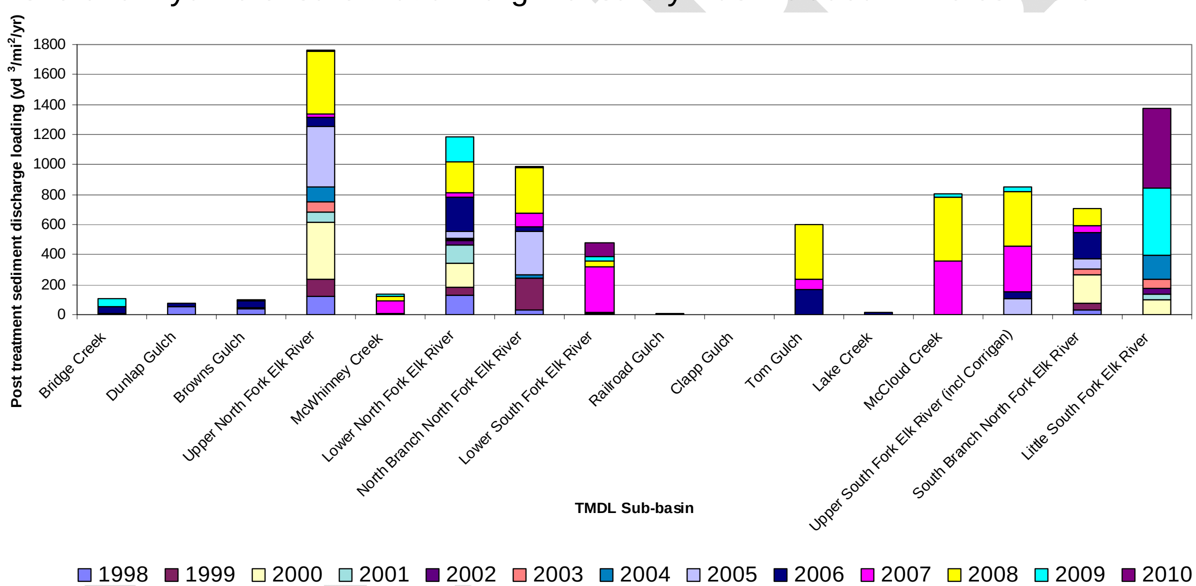

Figure 3.44 Sediment discharge associated with treatment of discharge sites based upon an estimated discharge of 9.1 yd^3 per site.

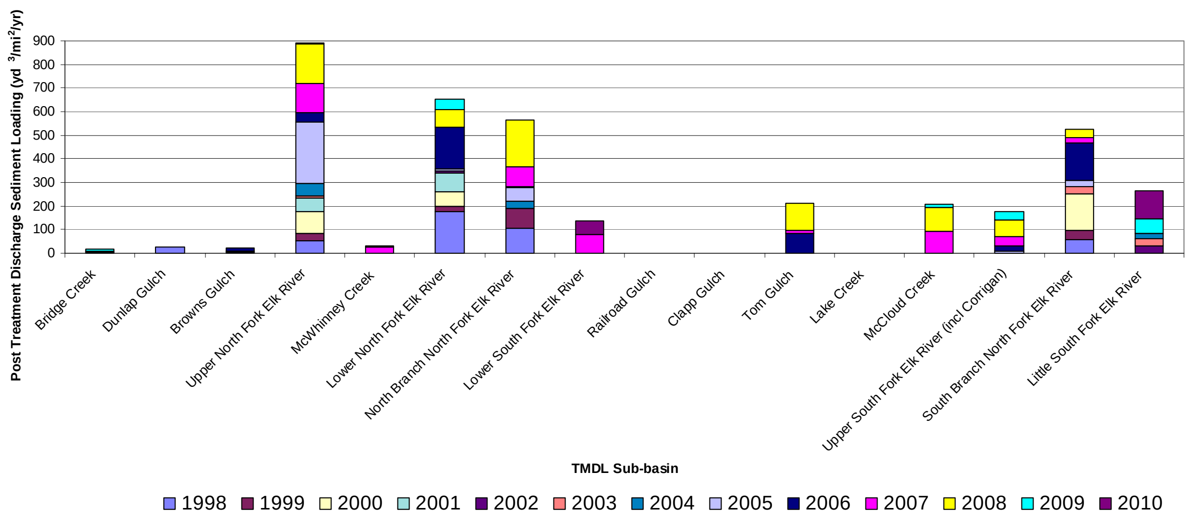

Figure 3.45 Sediment discharge associated with treatment of discharge sites based upon an estimated discharge of 1.1% of the assessed volume.

Table 3.30 presents the sediment loadings from management-related open-slope landslides to Upper Elk River as a whole.

Table 3.30 Annual sediment loading from management-related discharge sites in Upper Elk River ($yd^3/mi^2/yr$)

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Annual loading from management-related discharge sites in Upper Elk River ($yd^3/mi^2/yr$).	0	0	0	0	13	4

3.4.13.3 Uncertainties Associated with Post-Treatment Discharge Site Analysis

- Sediment discharge from disturbed sites varies with runoff. If a site experiences a significant rainfall and runoff event in the first year, it is most likely that discharges will occur. However, if a site has time to stabilize prior to such an event, then discharges will be minimized. This analysis relied on a uniform discharge rate. Effectiveness of site treatments varies with project budget, available time and materials, operator expertise, and site characterization. The discharges estimated in this section represent all Elk River sites synthesized.
- Refinements may be made to the loading estimates by segregating upgrade and decommission treatments.

3.4.13.4 Implications for Watershed Implementation Actions

- Improve site characterization to include identification of features that effect treatment design and implementation. Important features include but are not limited to areas of emergent water (springs), channel gradient, stored material, geologic contacts, and location of unstable features.
- Ensure the appropriate equipment is used for the job.
- Stabilize the slopes, channels and headwalls with adequately sized materials.

- Stabilize surfaces with treatments appropriate to slope angle and expected flow volume.
- Ensure adequate monitoring to allow for early detection and treatment of problems.
- Develop contingency plans and ensure materials are stockpiled on site to allow for emergency treatments.
- Consider cumulative discharge associated with concentration of treatment sites.

3.4.14 Ground-Based Yarding-Related Sites (Skid Trails)

Sediment delivery from sites associated with ground-based yarding activities (skid trails and associated crossings) was not consistently included in the sediment source inventories conducted in Elk River. Implementation of the ongoing programs (Section 3.4.6) will result, over time, in a more complete inventory and treatment effort for discharge sites associated with skid trails. For the purposes of this sediment source analysis, Regional Water Board staff evaluated the available data on skid trails and developed past delivery estimates were for use in the source inventory.

3.4.14.1 Data Sources Used to Determine Loads from Skid Trails

The following data sources were evaluated for estimation of sediment loading associated with skid trails; each is described in greater detail in the following sub-sections.

- Headwaters Watershed Assessment and Restoration Planning (PWA, 2000).
- HRC CAO database (HRC, 2008 update).
- Palco Freshwater Creek Skid Trail Study (Palco, 2007).
- HRC Skid Trail Surveys (HRC, 2010 update).

Headwaters Watershed Assessment and Restoration Planning

This planning project sampled and analyzed recently tractor logged areas, roads and skid trails in the Elk Head Springs area of the Upper South Fork Elk River for erosion potential and future sediment delivery. The area was selected for a reconnaissance level skid trail inventory and assessment primarily because of the recently heavily tractor logged hillslopes. The assessment was designed to identify treatable non-road erosion problems that might otherwise be missed in an inventory of road-related erosion, and to determine the relative importance of both road and non-road sources of sediment production and delivery.

The Elk Head Springs assessment area included 1.36 miles of road and a skid trail density of approximately 94 mi/mi^2. Skid trails were exposed and clearly visible on the 1994 and 1997 air photos, and were easily identified in the field. The surveyed area consisted of three haul roads, which traversed the cutover slopes. Many skid trails were constructed to access the main haul roads. The hillslopes in the assessment area were gently to moderately sloped, ranging from 0% to 50% percent in gradient, with the average slope gradient of 30%. Emergent springs are common throughout the assessment area.

The logging haul roads in the Elk Head Springs assessment area were built in the 1970's, and the upper hillslope areas were harvested around this same time. The eastern part of the assessment area was clearcut and tractor yarded in the 1980's but the majority of the assessment area was partially harvested at this time. Between 1987 and 1994, the areas which had been partially harvested previously were clearcut. The assessment area is adjacent and north of the un-entered old-growth portion of the Headwaters Forest Grove. To the north of the assessment area is the Elk Head Springs Grove, an old growth forest which was selectively harvested along its perimeter.

The assessment found that significant impacts were caused by first cycle tractor logging and the use of skid trails down broad headwall swale areas. This practice resulted in altering the natural hydrology by destroying the subsurface pipe system which resulted in reshaping surface drainage – the same effects described in Section 3.1.2.4. The assessment documented swales, with no evidence of prior surface flow, collapsing inward exposing subsurface soil pipes, with flow observable at the base of the pipes from 4 to 7 feet below the grade of the swale. A series of bank failures apparently resulted in the sink holes becoming connected and creating an open channel.

The majority of the erosion and sediment delivery problems that occurred on the skid trail network, and which would not have been discovered by an inventory of the adjacent logging roads, are gullies and skid crossings. In the assessment area, a total of 27.5 miles of skid trails were identified within the 0.3 mi^2 assessment area. The skid trails included ten stream crossings, three landslides, and eight "other sites", for a total of 0.76 sites per mile of skid trail. Table 3.31 describes the volume associated with skid-trail induced gullies and Table 3.32 presents the number and volume of road-related and skid trail-related sites in the Elk Head Springs assessment area.

Table 3.31 Gully size and distribution on skid roads in the Elk Head Springs assessment area.[57]

Gully type	Gully size and distribution on skid roads in the Elk Head Springs assessment area.	Assumed average gully cross-sectional area (ft^2)	Total length of gullies (mi)	% of skid network	Approximate gully volume (yd^3)
Gullies with no sediment delivery	<1' wide and 1' deep	0.5	2.3	8.4	225
	1' wide x 1' deep to 2' wide x 2' deep	2	0.14	0.5	55
Gullies with sediment delivery	<5 yd^3 (15 sites)	2.5	0.21	0.8	103
	>5 yd^3 (6 sites)	2	0.95	3.5	372
Total			3.6	13.2	754

Table 3.32 Past and future sediment yield rates in the Elk Head Springs assessment area.[58]

Inventory Area	Total number of sites	Past Yield (yd^3)	Future Yield (yd^3)	Number of Miles	Past sediment yield rate (yd^3/mi)	Future sediment yield rates (yd^3/mi)	Density (mi/mi^2)	Past Yield (yd^3/mi^2)	Future Yield (yd^3/mi^2)

Road related sites	22	907	7427	1.66	546	4474	6	3104	25,419
Skid-related sites	21	297	1593	27.5	11	58	94	1016	5452

The total number of sites was comparable between roads and skid-trails, though the volume per unit area of erosion associated with skid trails was approximately one-fifth of the volume of erosion associated with roads. Possible explanations for these differences could include 1) many of the skids were water-barred, thus minimizing sediment delivery, 2) the skid trails are generally narrower than roads, 3) the fill-slopes associated with skids are generally small than those associated with the wider haul roads and 4) skid trails can be constructed at steeper gradients then roads designed to accommodate a loaded log truck.

The assessment discusses the difficulty in stabilizing the sink-holes, suggesting the channels are in transition and except for removal of obvious fill, the erosion associated with the collapsing sink holes is uncontrollable (i.e. will not reasonably respond to human intervention).

Past delivery for skid-related sites was found to be 18% of the assessed future potential delivery volume.

Limitations include:

- The topography and hydrology of Elk Head Springs is not characteristic of the rest of the Elk River watershed. The gentle slopes and poorly incised stream channel network reduce the potential for erosion, even though there is abundant water in the area.
- The skid trail density is likely higher in the assessment area than in other parts of Elk River lay-outs were constructed for harvesting the old-growth trees within the Elk Head Springs area more extensively than was typical of Elk River.
- The volumes associated with the skid trail inventory do not include the downstream channel incision. PWA (2000) describes that the stream channel draining Elk Head Springs as "completely open and has experienced 6 feet of vertical incision… The incision in this channel has undercut the old growth trees on its banks, causing them to collapse inwards. The incision and collapse of these channels is causing substantial erosion with direct delivery. This process is irreversible, and untreatable."

HRC Cleanup and Abatement Order Database

The CAO Database contains information about a number of discharge sites, including some skid trials, though they were not consistently included in the inventory efforts.

Query of the 2008 HRC CAO Database using a simple word search of the site attributes (problem and comment fields) found that a portion of the sites were influenced by skid trails. Table 3.33 presents the frequency and volume of sites influenced by skid trails included in with the HRC CAO Database. Table 3.34 presents the findings based upon TMDL sub-basin.

Table 3.33 Summary of frequency and magnitude of skid trail-related discharge sites included in the HRC CAO Database.

	South Fork	North Fork	Sum
Number of sites in original CAO database	460	816	1,276
Number of sites influenced by skid trails	59	166	225
Percentage sites influenced by skid trails	13%	20%	
Volume of future delivery from sites in original database	98,531	265,166	363,697
Volume of future delivery from sites influenced by skid trails	11,071	76,156	87,227
Percentage volume influenced by skid trails	11%	29%	

Within the HRC CAO Database, an average of 17% of the sites were influenced by skid trails and 23% of the future sediment delivery volume was associated with sites influenced by skid trails.

Table 3.34 Summary of delivery volumes associated with sites influenced by skid trails in the CAO Database by sub-basin.

Sites by sub-basin	Number sites	Total volume of sites (yd^3)	Average volume per site (yd^3)	Volume per unit area (yd^3/mi^2)
Lower South Fork Elk River	6	558	93	193
Bridge Creek	2	653	327	297
Lower North Fork Elk River	5	1,669	334	333
Upper South Fork Elk River (Including Corrigan Creek)	23	3,692	161	455
Browns Gulch	4	489	122	551
Lake Creek	5	1,710	342	805
McWhinney Creek	3	1,152	384	904
Tom Gulch	30	6,821	227	2,718
Dunlap Gulch	3	2,019	673	3,076
Upper North Fork Elk River	63	23,784	378	5,451
North Branch North Fork Elk River	57	27,186	477	6,770
South Branch North Fork Elk River	24	17,494	729	9,062
sum/average	**225**	**87,227**	**354**	**2,551**

The CAO inventories were not focused on identifying skid trail-related sites and thus the results do not represent a complete inventory of skid trail sites.

Palco Freshwater Creek Skid Trail Study

Because the CAO inventories did not originally target skid trail-related sources, PALCO conducted a skid trail specific study (PALCO 2007[59]) to determine the relative magnitude of skid trail related sources. This study also evaluated the extended to which the sites may have been identified in the previous inventories. The Freshwater Creek study was conducted in two units in areas predominated by the Wildcat and Yager formations.

The two units were selected based on the extend of tractor yarding conducted on the units. Units exhibiting a high intensity of ground-based yarding were selected to help define the extent to which lack of skid trail specific data influences a sediment budget. The units were selected to be representative of the watershed. Field inventories were conducted using LIDAR-based topographic maps to focus on watercourse areas, where a higher potential for sediment delivery exists.

Table 3.35 presents the frequency and volume of sites influenced by skid trails as identified in the Palco Freshwater Creek Skid Trail Study.

Table 3.35 Sediment delivery associated with skid trails

Characteristic	Parameter	School Forest Unit 1	Cloney Gulch Unit 2
Area of survey unit	mi^2	0.25	0.24
Total number of skid trail sources	Count in unit	36	36
	Percent identified in previous Inventory	36%	25%
Frequency	Number / mi^2	147	147
Volume delivered	Total volume from unit (yd^3)	2,810	2,365
	Average volume per site (yd^3)	78	66
	Annual delivery volume from unit (yd^3/yr)	120	118
	Annual volume per unit area (yd^3/mi^2/yr)	480	492
	Average annual volume per source (yd^3/yr)	3.3	3.3

Within the units inventoried under this effort, 64-75% of the skid trail sites were missed by the previous inventories. The average site volume tended to be smaller than those identified in Table 3.33, perhaps indicative of the more thorough investigation.

The study also investigated the feasibility of treating identified sites. The authors found that 33-50% of the sites were feasible to treat, for an annual sediment discharge reduction of 35-55 yd^3/yr.

No such study was conducted in the Elk River watershed. The timing and techniques of the tractor logging in the surveyed areas may not be representative of conditions in Elk River.

HRC Skid Trail Surveys

Pursuant to CAO requirements, Palco, and subsequently HRC, conducted surveys of skid trails in both Freshwater Creek and Elk River. According to a 2010 CAO update (HRC, 2010), 1,337 sites were found with an average future delivery of 159 yd^3. According to those data, the estimated past delivery is 53% of future delivery, resulting in an average past delivery of 84 yd^3.

3.4.14.2 Methods Used to Determine Loads from Skid Trails

For the purposes of the sediment source analysis, the following elements are relied upon from the sources of data described above:

- The HRC CAO Database indicates an average of 6.1 sites/mi^2.
- Based upon the Palco Freshwater Creek Skid Trail study, Regional Water Board staff assumed the HRC CAO inventory missed 70% of the skid trail sites, indicating an additional 10.4 sites/mi^2 (6.1 sites/mi^2 * 1.7).
- The average future sediment delivery volume of sites not included in the HRC CAO Database are based upon the average of the Palco Freshwater Creek Skid Trail study units (64 yd^3 and 78 yd^3) and the Elk Head Springs inventory (76 yd^3), resulting in an average assessed future delivery volume of 73 yd^3.
- Past delivery is based upon the Elk Head Spring inventory in which the past volume was estimated to be 18% of the assessed future delivery volume.
- For lack of a comprehensive skid trail construction history, Regional Water Board staff assumed the past sediment delivery occurred at similar rates of discharge as the past delivery from all other discharge sites (see Section 3.7.5.2): 9% of total 1954-1967; 21% of total 1967-1974; 29% of total 1975-1987; 26% of total 1988-1997; and 16% of total 1998-2000.
- Assume future delivery will occur uniformly over the next 50 years (time period associated with a low treatment priority schedule).

3.4.14.3 Results - Skid Trail Analysis

Figure 3.46 presents sediment loading from skid-trail related past sediment delivery for the TMDL sub-basins.

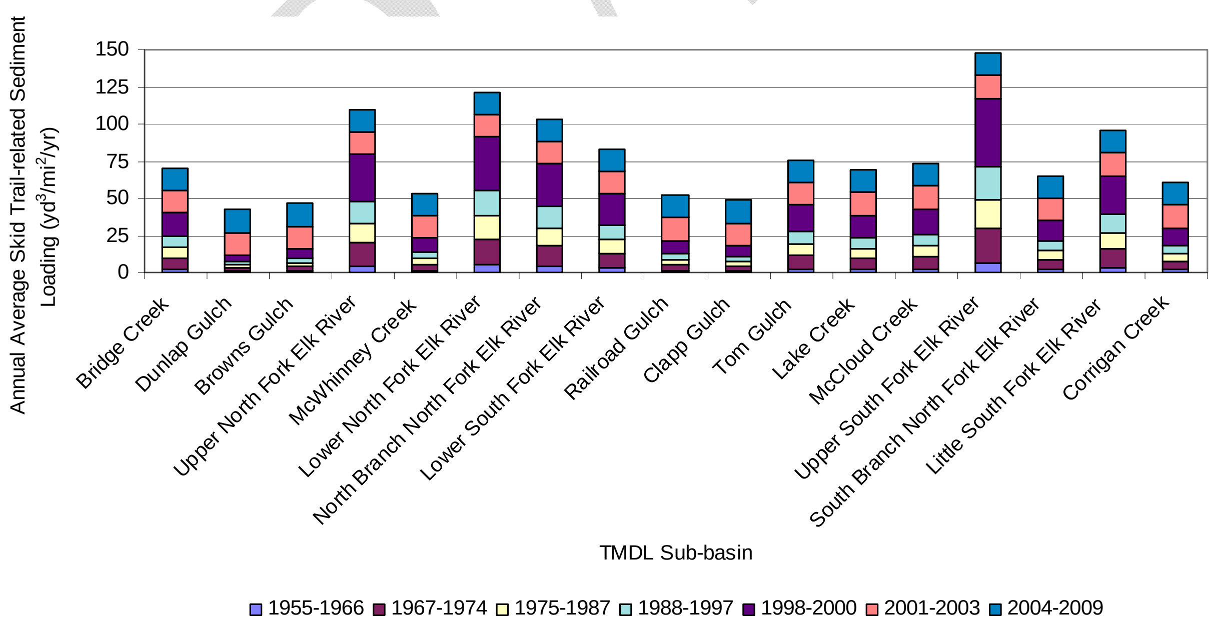

Figure 3.46 Annual average past sediment loading from skid trail-related sources by TMDL sub-basins.

Table 3.36 presents the sediment loadings from skid trail sites to Upper Elk River as a whole.

Table 3.36 Annual sediment loading from skid trail sites in Upper Elk River (yd^3/mi^2/yr)

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Annual loading from skid trail sites in Upper Elk River (yd^3/mi^2/yr).	4	12	11	12	26	15

3.4.14.4 Uncertainties Associated with the Skid Trail Analysis

- No skid trail study was conducted for Elk River. The timing and techniques of the tractor logging in the Freshwater Creek surveyed areas may not be representative of conditions in Elk River.
- The CAO inventories were not focused on identifying skid trail-related sites and thus the results do not represent a complete inventory of skid trail sites.
- For lack of a skid trail construction history, Regional Water Board staff assumed the past sediment delivery occurred at similar rates of discharge as the past delivery from all other discharge sites on HRC lands (see Section 3.4.6.1).
- Regional Water Board staff assumed future delivery will occur uniformly over the next fifty years, consistent with a low treatment priority. Some skid trail sites may erode more rapidly.
- The topography and hydrology of Elk Head Springs is not characteristic of the rest of the Elk River watershed. The gentle slopes and poorly incised stream channel network reduce the potential for erosion, even though there is abundant water in the area. Other steeper areas of the watershed may result in greater erosion potential.
- The skid trail density is likely higher in the assessment area than in other parts of Elk River since tractors were used to construct lay-outs for harvesting the old-growth trees with the Elk Head Springs area.
- The volumes associated with the skid trail inventory do not include the downstream channel incision.

3.4.14.5 Implications for Watershed Implementation Actions

- Skid trail features should be included in future inventories.
- Avoid creation of new discharge sites from skid-related features by use of alterative yarding systems, as appropriate.
- Treat skid trail-related sink hole erosion as part of sediment control programs.
- Develop and implement a strategy to treat skid trail-related sink hole erosion in areas inaccessible to heavy equipment.

3.4.15 Road Surface Erosion

Road surface erosion represents the sediment transport and delivery from the road surfaces within the watershed. The material eroded from road surfaces is relatively fine grained in size and discharge can occur during each rain event (a press event), rather than discharging in an episodic nature (pulse event) such as occurs in discharge associated with landslide features. For this reason road surface erosion has a chronic effect on water quality.

Factors affecting sediment discharge from road surfaces include:

- Rainfall intensity, frequency and timing;
- Soil and geologic properties;
- Road location on the landscape (e.g. near stream, mid-slope, ridge top);
- Hillslope and road gradients;
- Road construction techniques (e.g. insloped or outsloped road prism; characteristics and number of stream crossings);
- Surfacing (e.g. native surface, rock);
- Seasons of use (year-around versus summer);
- Usage (e.g. quads, pickup truck, loaded log trucks).

3.4.15.1 Methods Used to Determine Road Surface Erosion Loads

While road density is not a direct measure of road surface erosion delivery, the higher the density, the higher the potential for surface erosion delivery. Staff reviewed the Elk River Watershed Analysis (WA) (Palco, 2004) and Palco ROWD (2005) for road construction history and resulting road densities in Elk River. Four sources of information are presented in the WA:
1) Road construction history for North Fork Elk River 1954-2000 (CWE Table 9).
2) Road densities by sub-basin for Elk River area as of 2002 (Table B-10).
3) Road segment data used in the Palco WA SEDMODL2 runs to evaluate road-related surface erosion (ERSC Road Surface Erosion.xls).
4) Road miles and associated sediment loading by different surface categories in North Fork and South Fork Elk River as of 2004 (Palco ROWD).

Figure 3.47 presents road density, based on the North Fork construction history (item 1 above, over time.

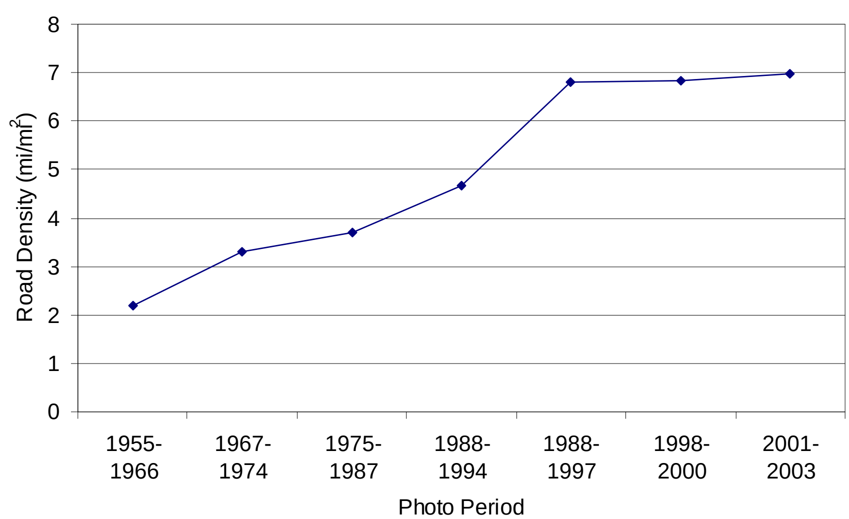

Figure 3.47 Road construction history in North Fork Elk River (based on Palco WA CWE Table 9).

Regional Water Board staff estimated the TMDL sub-basins densities in 2002 based upon the sub-basin road densities (item 2) and road segment data (item 3). Staff estimated the change in road densities in the TMDL sub-basins based on the rate of change demonstrated in North Fork in Figure 3.47. The resulting road densities over the TMDL analysis time periods in the TMDL sub-basins are presented in Figure 3.48.

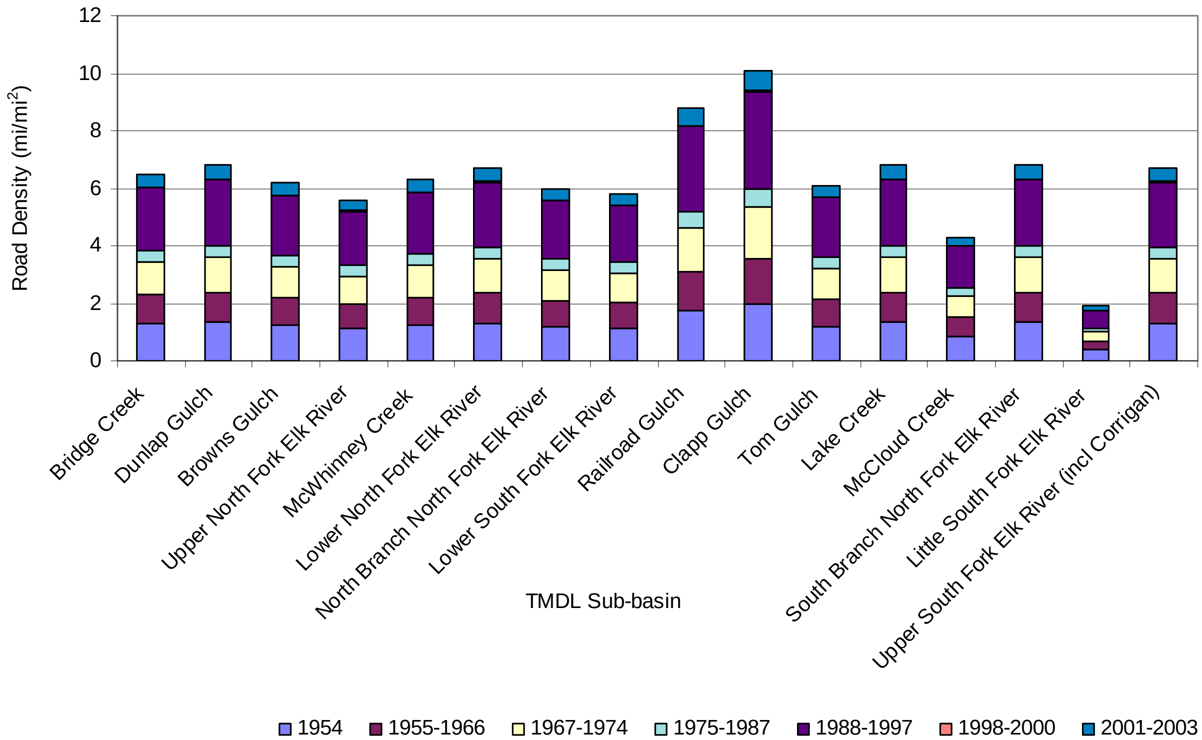

Figure 3.48 Estimated road densities in TMDL sub-basins.

The Palco ROWD[60] presents road categories, associated lengths and sediment delivery estimates for North Fork and South Fork Elk River (HRC lands only) based upon conditions as of 2004 (Table 3.37).

Table 3.37 Road category, associated length, and estimated sediment loading based upon Palco ROWD (2005).

		North Fork (HRC Lands only)		South Fork (HRC Lands only)	
Road category	Unit sediment delivery (yd^3/mi/yr)	Density (mi/mi^2)	Loading ($yd^3/mi^2/yr$)	Density (mi/mi^2)	Loading ($yd^3/mi^2/yr$)
General use – Rocked Stormproofed	7.3	1.55	11.3	0.55	4.0
RS – THP	16.6	0.69	11.4	0.64	10.6
RS- Idle	4.2	0.30	1.3	0.26	1.1
Paved	3.6	0.15	0.5	0.07	0.2
Dirt Stormproofed	19.1	0.58	11.1	0.52	9.9
Rocked	7.0	0.30	2.1	0.25	1.8
Dirt	24.4	1.18	28.8	1.06	25.8
Abandoned	3.2	1.87	6.0	8.44	27.0
Total		**6.63**	**72.5**	**11.78**	**80.4**

Regional Water Board staff estimated the proportion of the roads in the different road categories presented in Table 3.37 and applied those proportions to the sub-basins in North Fork and South Fork, respectively as representing 2001-2003 conditions. Staff assumed that the road densities in the Clapp and Railroad sub-basins were proportional to the South Fork densities. Staff applied the unit sediment delivery from Table 3.32 to the 2001-2003 conditions. To estimate1998-2000 conditions, staff assumed 1) the proportion of rocked roads present in 2001-2003 was the best estimate available and 2) roads were not "stormproofed." For the periods 1955-1997, Regional Water Board staff assumed roads were unrocked and of native material (dirt).

3.4.15.2 Results- Road Surface Erosion Analysis

Figure 3.50 presents the resulting sediment loading estimates from road surface erosion over time for the TMDL sub-basins.

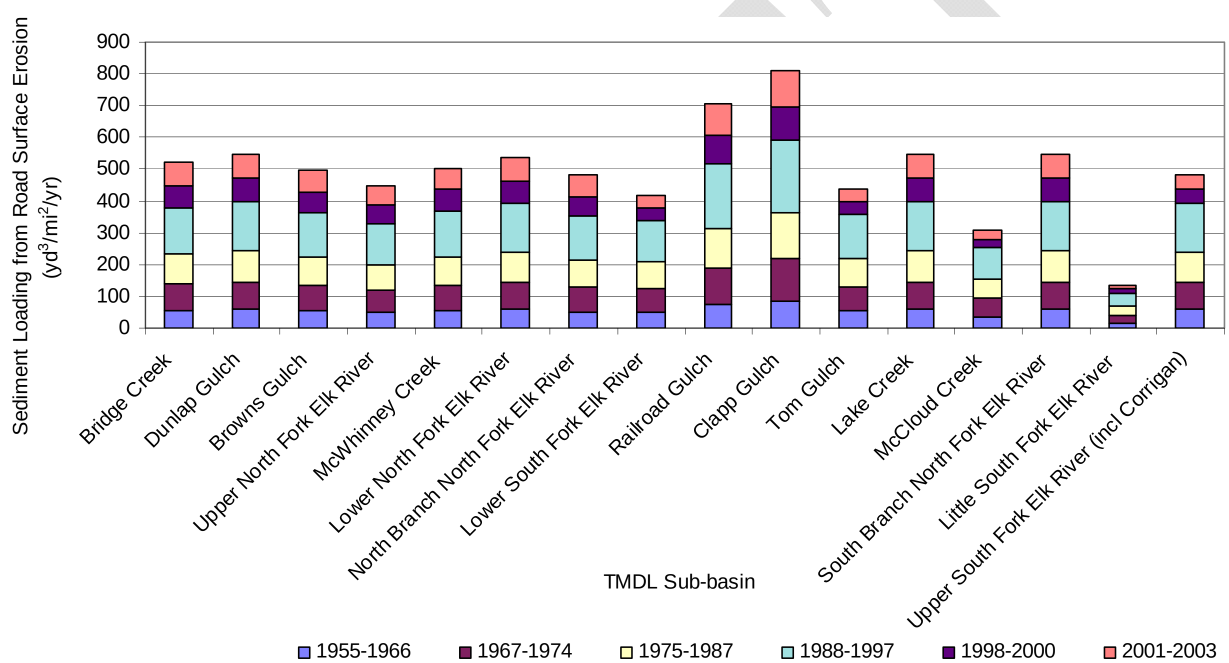

Figure 3.49 Sediment loading associated with road surface erosion for TMDL sub-basins.

Table 3.38 presents the sediment loadings from road surface erosion to Upper Elk River as a whole.

Table 3.38 Annual sediment loading from road surface erosion in Upper Elk River ($yd^3/mi^2/yr$)

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Annual loading from road surface erosion in Upper Elk River ($yd^3/mi^2/yr$).	52	78	87	137	55	56

3.4.15.3 Uncertainties Associated with the Road Surface Erosion Analysis

- WA presents information regarding the sensitivity of parameters associated with SEDMODL (Figure 3.50); these sensitivity results indicate that the frequency of use has a significant effect on the production of sediment from roads. If the traffic factor is not representative of actual conditions, the resulting loadings estimates will be very affected.

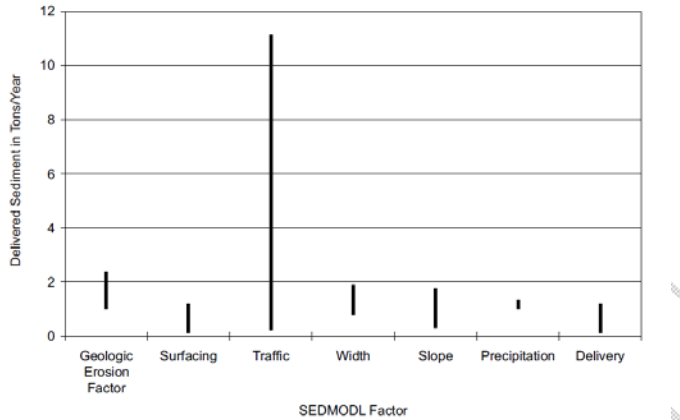

Figure 3.50 SEDMODL parameter sensitivity (reproduced from Palco, 2004).

- Regional Water Board staff did not conduct the SEDMODL runs but rather evaluated the data files and results of the SEDMODL runs associated with the Palco WA and the estimate provided in the Palco ROWD.
- Lack of comprehensive road construction history for TMDL sub-basins limit the confidence in the results.

3.4.15.4 Implications for Watershed Implementation Actions

Control measures applicable to road surface erosion include:

1) Road surface material greatly influences the sediment discharge associated with roads. Rock surfacing can minimize rills and chronic discharges, especially if the road has any gradient. Road sections draining to watercourses should be treated up to the hydrologic divide.
2) . Ensure road surface can support intended use. Avoid use of roads with vehicles that can cause erosion. This includes quads and light trucks on dirt roads and may include loaded trucks on rocked roads.
3) Reduce existing road densities. Avoid new road construction, unless offset by replacing poorly located roads. Decommission unneeded roads.
4) Stabilize surface of abandoned roads by applicable of mulch, tree planting, etc
5) Ensure road drainage is prevented from direct delivery to watercourses (hydrologically disconnected).

3.4.16 Management-Related Harvest Surface Erosion

Section 3.3.1 describes soil creep, the natural process of movement of soil particles downslope and its consequent delivery to streams accounted for as soil creep. This natural process is affected by the topography, soils and geology, climate, and vegetation in the watershed. Management-induced vegetation and ground disturbance can influence the magnitude of surface erosion. Specifically, timber harvest activities 1) Removes overstory canopy cover resulting in elevation in the effective rainfall reaching the ground to dislodge and transport soil particles. 2) Causes soil compaction through the use of heavy equipment, skidding trails of logs, and site preparation thus altering surface and subsurface flow paths, concentrating and diverting water, 3) Disturbs the understory vegetation, top soil, and mycology network, all which have the ability to affect the natural binding properties protecting from erosion. 4) Harvesting trees and mechanical site preparation disturbs and removes future recruitment of duff which naturally protects the forest soils from disturbance and erosion. 5) Burning reduces cation exchange capacity and long-term productivity of soil and exposes soil to erosion. 6) Herbicides bind with soil particles increasing erosion.

The style and location of timber harvest operations affect surface erosion. Generally speaking the magnitude of management-related surface erosion is a function of slope, ground disturbance and canopy removal.

3.4.16.1 Methods Used to Determine Loads from Management-Related Harvest Surface Erosion

Staff relied upon the sediment loading estimates for in-unit harvest surface erosion as developed by Palco (2004) in the Watershed Analysis. They applied Water and Erosion Prediction Program (WEPP)[61] and estimated sediment delivery of 0.8 tons/acre using clearcut methods (tractor or cable) and 0.5 tons/acre for partial cut methods (tractor or cable). While it is acknowledged that sediment delivery from surface erosion continues for several years following harvest, staff assumed that delivery occurred the year of harvest.

Staff relied on harvest history data from CDF described in Section 3.2.2.1 for the 1988-2010 time period and data presented in the Palco WA[62] for the earlier time periods. Staff assumed the same proportion of harvesting in North Fork occurred in the rest of the watershed.

Harvest history included acres harvested and silvicultural method employed, for the watershed. This parameter is calculated simply as the “clearcut equivalent acres” harvested during a particular time period. The harvest acres were converted to clearcut equivalents by applying a weighting coefficient that reflects the proportion of canopy removed for the listed silvicultural method (Table 3.39). The coefficients were based upon the best professional judgment of staff at Redwood Science Lab, CalFire (formerly CDF), and Regional Water Board.

Table 3.39 Canopy removal coefficients used to calculate clearcut-equivalent acreages from harvest history.

Silvicultural Method	Canopy Removal Coefficient
Clearcut Road Conversion Rehabilitation	1
Shelterwood Removal Cut Seedtree Removal Cut Seedtree Step Cut Shelterwood Prep Step Variable Retention	0.75
Selection Commercial Thin Transition Alternative Prescription	0.5

Staff assumed that harvest prior to 1988 was represented by a canopy removal coefficient of 0.75.

3.4.16.2 Results - Management-Related Harvest Surface Erosion Analysis

Figure 3.51 demonstrates the resulting clearcut equivalent acres data for the TMDL sub-basins. Figure 3.52 demonstrates the estimated sediment loading resulting from harvest-related surface erosion.

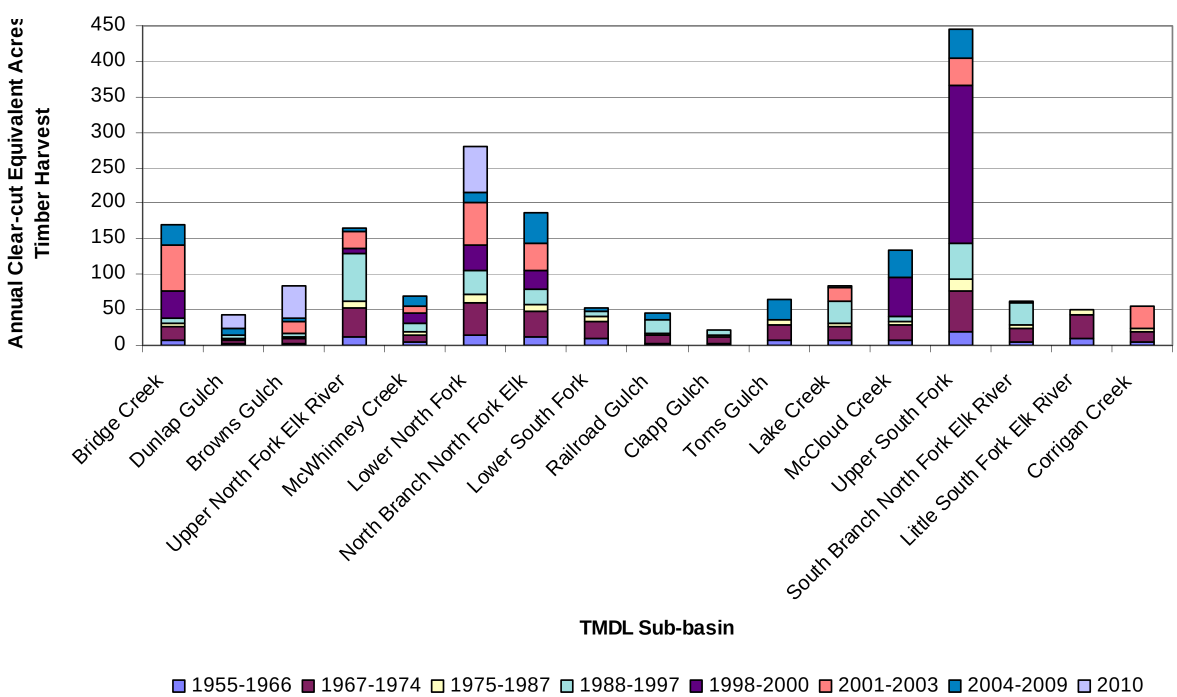

Figure 3.51 The annual clear-cut equivalent harvest acres for TMDL sub-basins over analysis time periods.

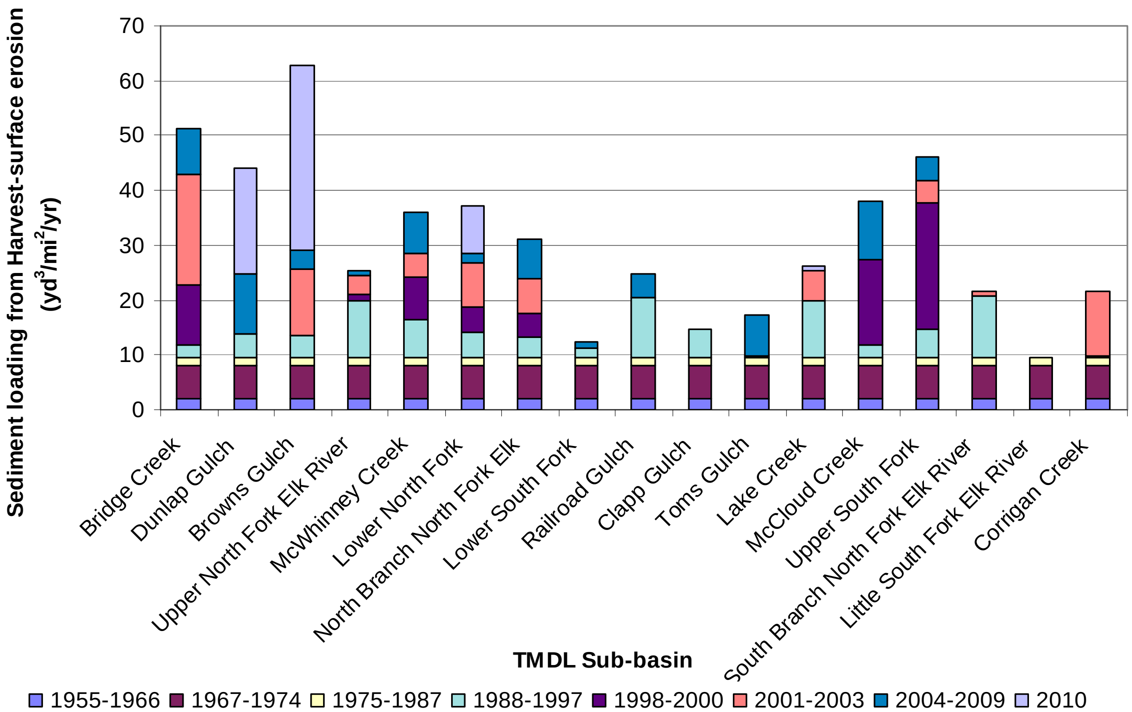

Figure 3.52 Sediment loading to TMDL sub-basins from harvest-related surface erosion over analysis time periods.

Table 3.40 presents the sediment loadings from harvest surface erosion to Upper Elk River as a whole.

Table 3.40 Annual sediment loading from harvest surface erosion in Upper Elk River (yd^3/mi^2/yr)

Time Period	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Annual loading from harvest surface erosion in Upper Elk River (yd^3/mi^2/yr).	2	6	2	5	6	5

3.4.16.3 Uncertainties in Management-Related Harvest Surface Erosion Analysis

- The surface erosion sediment delivery estimates are based upon values reported in the Palco Elk River Watershed Analysis, as estimated from applications of WEPP. Staff did not apply WEPP.
- Discharge of sediment following harvest likely follows an exponential decay for a period of years until ground cover is regained through growth of understory vegetation and re-accumulation of duff material. For simplicity sake, staff assumed the discharge occurred in the first year of harvest.
- The harvest history prior to 1988 is uncertain do to lack of a comprehensive harvest history for the Elk River watershed.
- WEPP is unproven in our area and is untested to demonstrate its effectiveness. The parameters
- According to Palco (2004), no direct measurements of surface erosion rates were made in the Elk River Watershed during the watershed analysis, but incidental

observations of the evidence of surface erosion were made during field survey investigations for the Freshwater Creek Watershed Analysis.
- The WEPP model documentation states that the accuracy of predicted erosion rates is, at best, ±50 percent (Palco, 2004 citing Elliot et al. 2000).
- The Palco WA (2004) discusses other estimates of harvest surface erosion sediment delivery, including:
  - A study in Redwood Creek, 2-7 tons/acre/yr for cable and 2-30 tons/acre/yr for tractor yarded slopes.
  - Observations in Freshwater Creek indicating at least 5 tons/ac/yr for the first year following a cable yarded and burned unit and 4-6 tons/ac/yr from skid trails for the first three years following harvest.

Based upon these other estimates, the WEPP estimates may underestimate harvest surface erosion by 2.5 to 37 times.

3.4.16.4 Implications for Watershed Implementation Actions

Controllable factors applicable to harvest surface erosion include:

1) Minimize the extent of disturbed land through the rate and scale of land disturbance
2) Minimize ground disturbance through selection of management measures including Harvest and yarding techniques.
3) Minimize hydrologic modification due to canopy removal, compaction, and site treatment
4) Minimize disturbance of slopes over 20%
5) Maintain duff producing trees capable of post harvest leaf drop to ensure
6) Implement surface erosion control measures on areas of disturbed and unvegetated soil, including and especially skid trails. Consider the use of portable chippers.
7) Recover healthy soil and reduce soil mobility through use of mulch, compost tea, and mycelium.

3.4.17 Summary of Management-Related Sediment Loading

The magnitude of management-related sediment sources are estimated for nine sediment source categories including:

- Low order channel scour (headward incision).
- Bank erosion.
- Streamside landslides.
- Creation of gullies and road-related landslides.
- Skid trail features (e.g. diverted watercourses, compacted soil).
- Shallow hillslope landslides.
- Restoration-related adjustments (e.g. correction of controllable sediment delivery sites).
- Road surface erosion.
- Harvest (in unit) surface erosion.

The source categories are evaluated on a sub-basin scale for the seventeen (17) sub-basins in upper Elk River. The magnitude of the annual average sediment loading is estimated for six analysis periods, including: 1955-1965, 1966-1974, 1975-1987, 1988-1997, 1998-2000, and 2001-2003.

Figures 3.54 - 3.58 and Table 3.41 present the source category data by sub-basin for each of the analysis time periods.

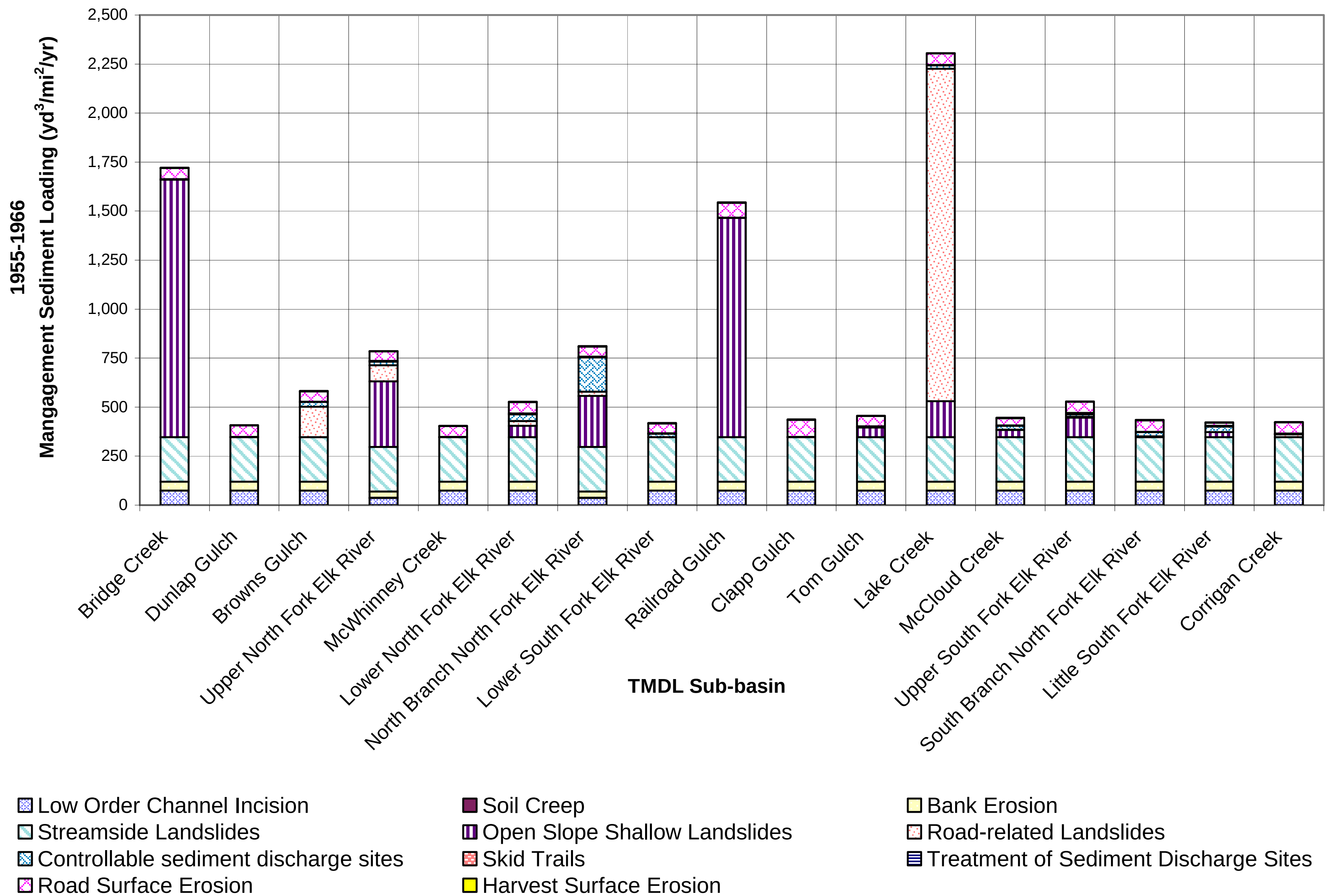

Figure 3.53 Annual sediment loading by management source category for TMDL sub-basins for the 1955-1966 analysis time period.

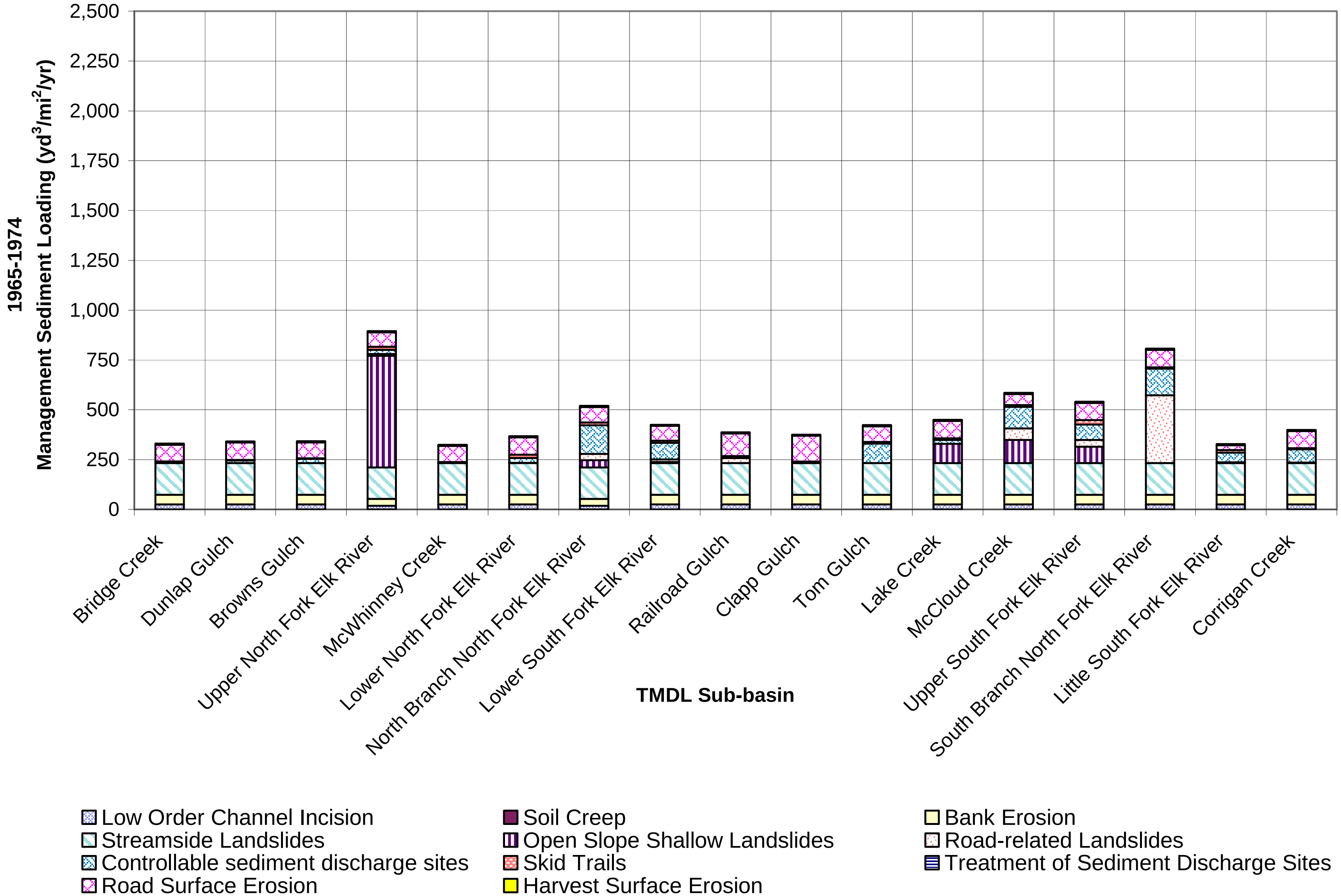

Figure 3.54 Annual sediment loading by management source category for TMDL sub-basins for the 1965-1974 analysis time period.

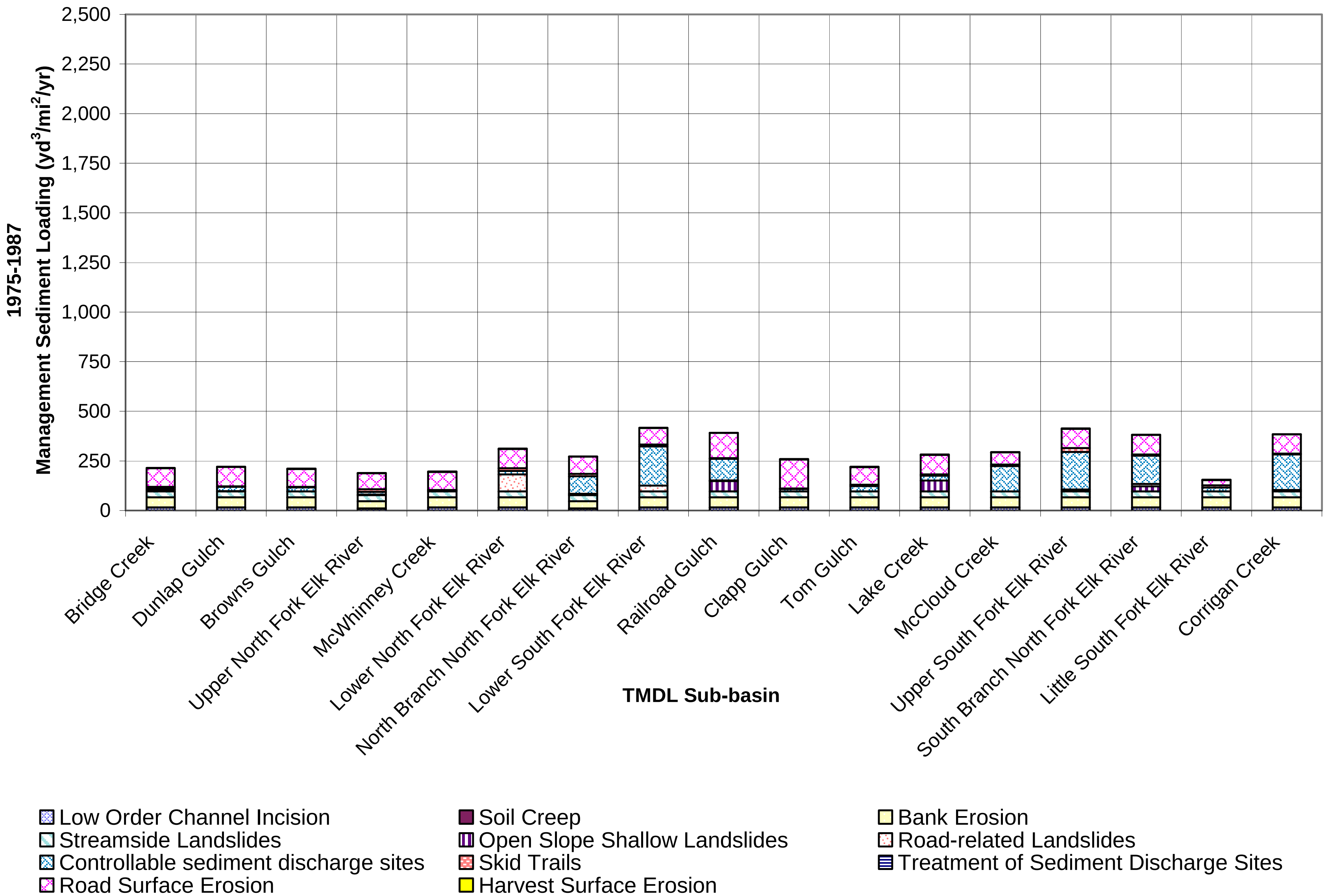

Figure 3.55 Annual sediment loading by management source category for TMDL sub-basins for the 1975-1987 analysis time period.

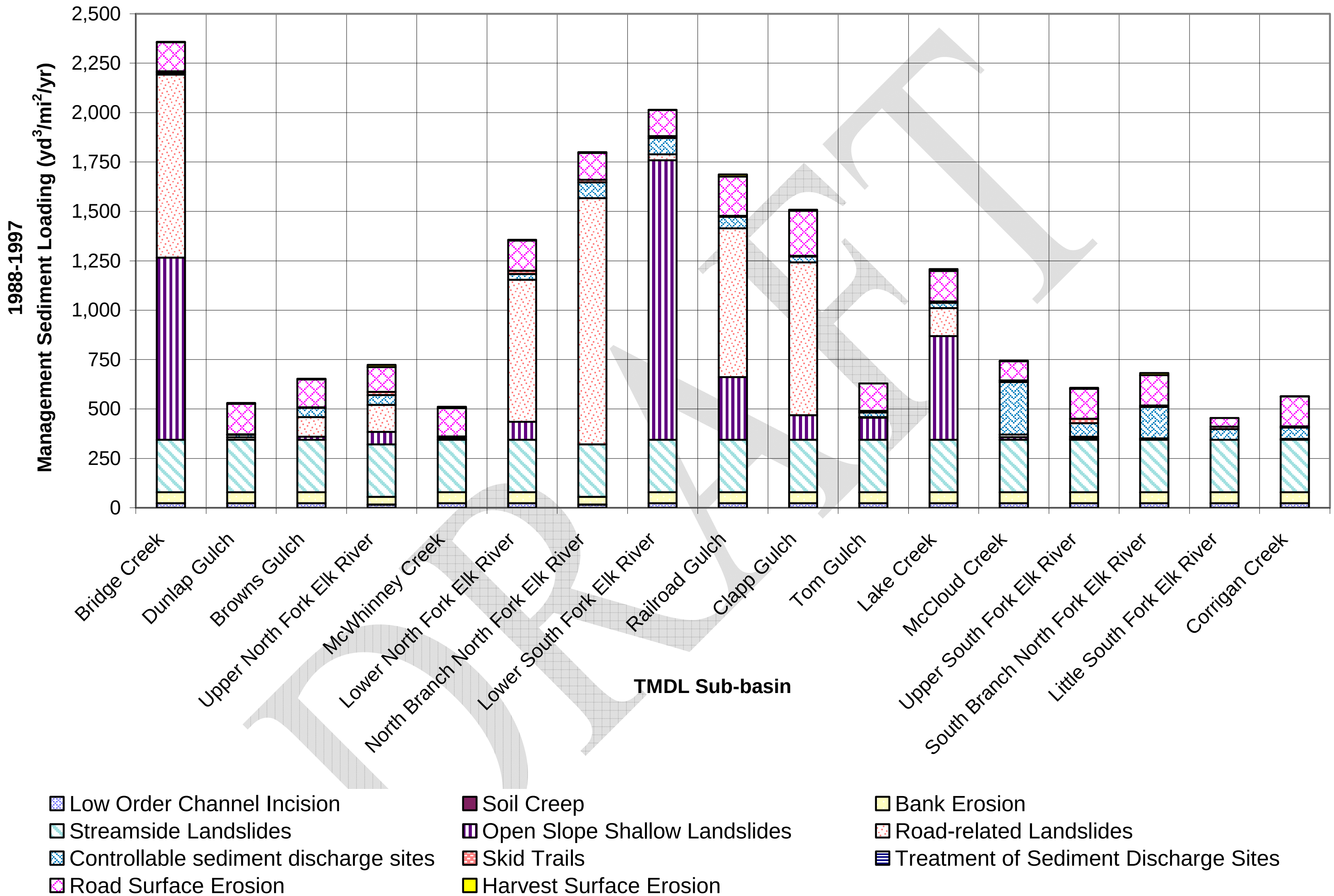

Figure 3.56 Annual sediment loading by management source category for TMDL sub-basins for the 1988-1997 analysis time period.

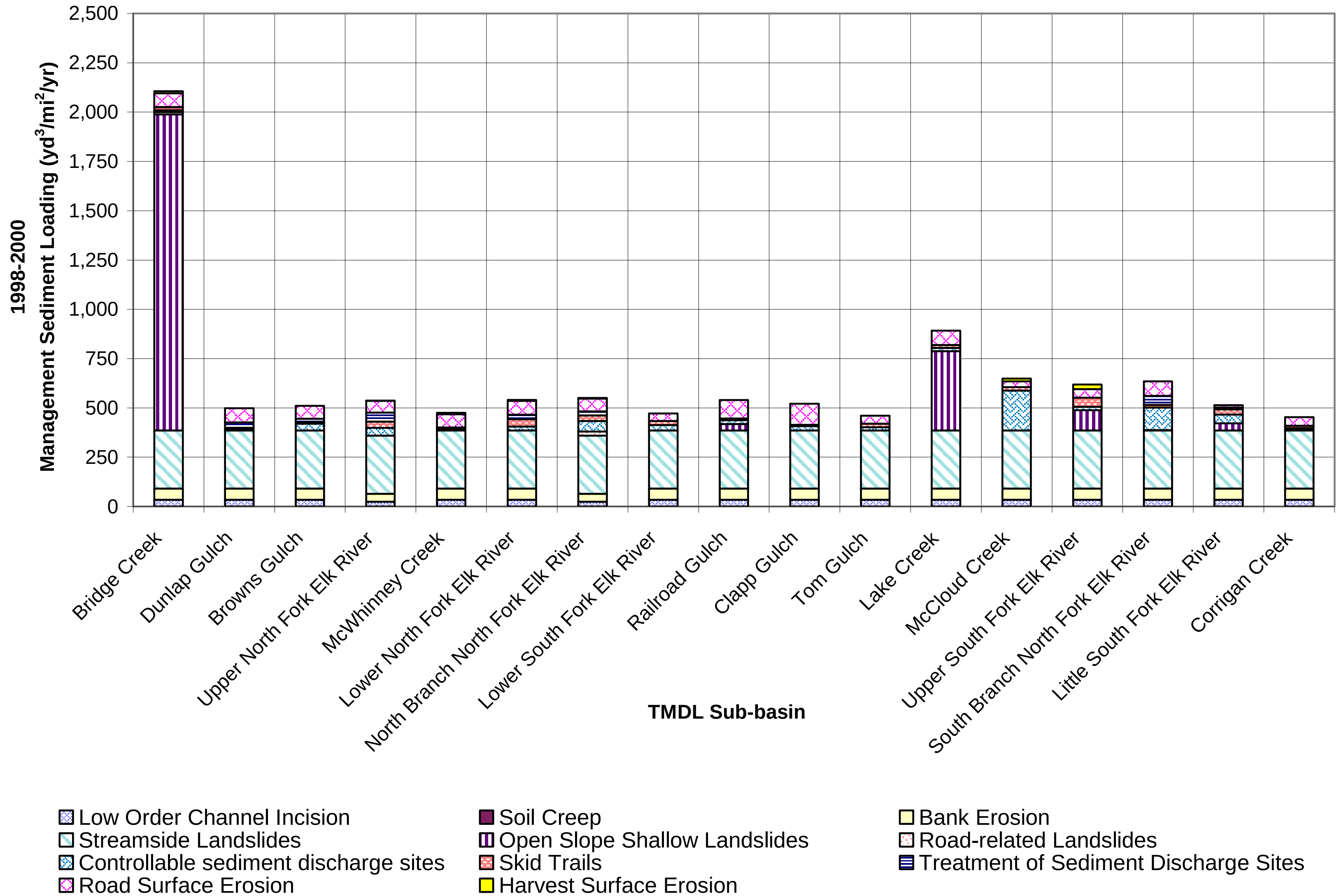

Figure 3.57 Annual sediment loading by management source category for TMDL sub-basins for the1998-2000 analysis time period.

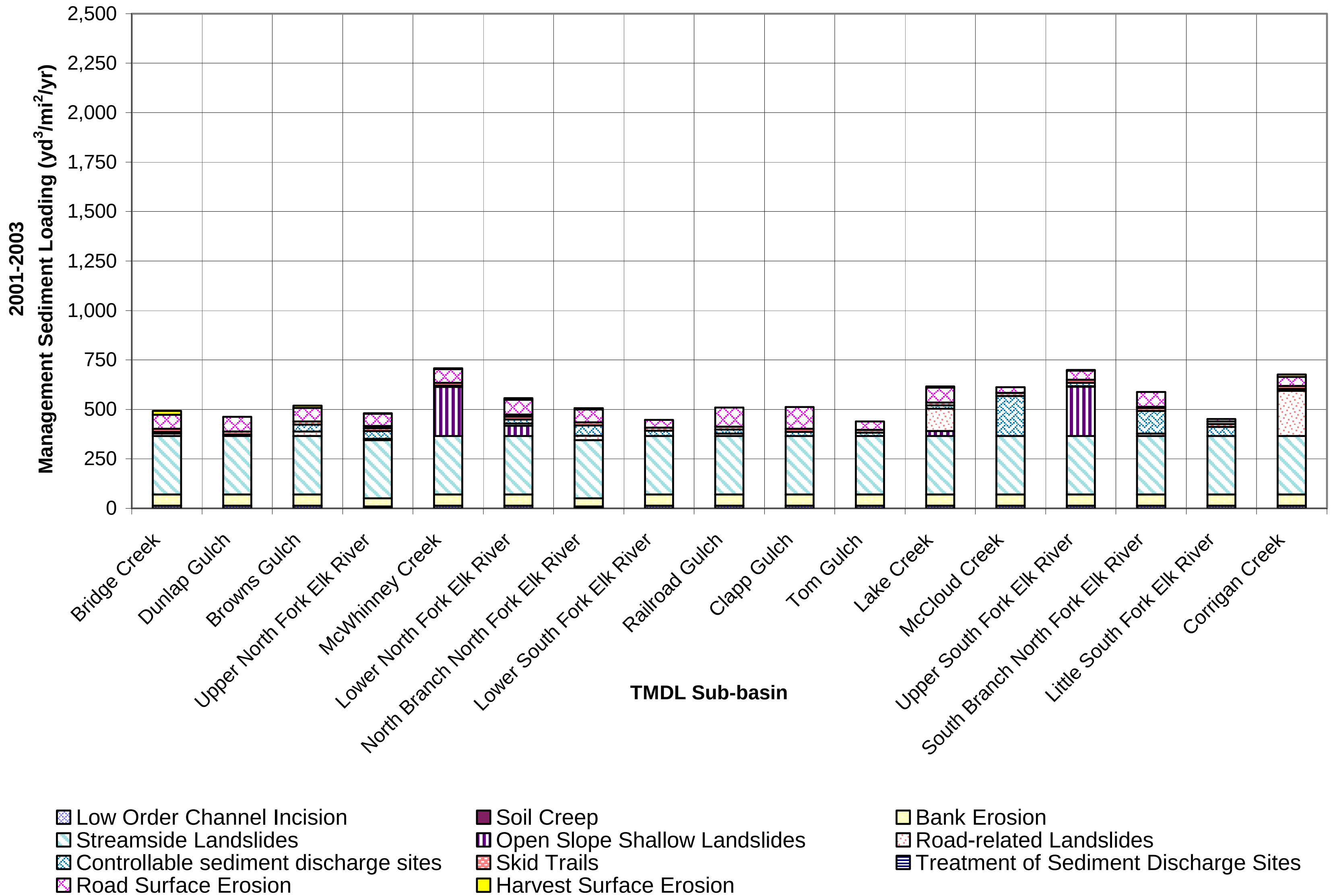

Figure 3.58 Annual sediment loading by management source category for TMDL sub-basins for the 2001-2003 analysis time period.

Table 3.41 Summary of sediment loading ($yd^3/mi^2/yr$) from management-related sediment source categories for TMDL sub-basins by analysis time period.

			Low Order Channel Incision						Soil Creep						Bank Erosion						Streamside Landslides					
	Sub-basin	Area (mi^2)	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
4	Bridge Creek	2.20	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
5	Dunlap Gulch	0.66	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
6	Browns Gulch	0.89	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
7	Upper North Fork Elk River	4.36	37	18	10	16	24	9	0	0	0	0	0	0	33	35	37	39	40	41	227	159	30	265	294	294
8	McWhinney Creek	1.27	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
9	Lower North Fork Elk River	5.02	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
10	North Branch North Fork Elk River	4.02	37	18	10	16	24	9	0	0	0	0	0	0	33	35	37	39	40	41	227	159	30	265	294	294
11	Lower South Fork Elk River	2.90	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
12	Railroad Gulch	1.20	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
13	Clapp Gulch	1.00	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
14	Tom Gulch	2.51	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
15	Lake Creek	2.12	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
16	McCloud Creek	2.36	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
17	Upper South Fork Elk River	6.45	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
18	South Branch North Fork Elk River	1.93	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
19	Little South Fork Elk River	3.59	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294
20	Corrigan Creek	1.66	74	25	14	23	34	13	1	1	1	1	1	1	46	49	52	55	57	57	227	159	30	265	294	294

			Open Slope Shallow Landslides						Road-related Landslides						Controllable sediment discharge sites						Skid Trails					
	Sub-basin	Area (mi^2)	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1954-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1954-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
4	Bridge Creek	2.20	1314	0	10	922	1603	0	0	0	7	926	12	13	0	0	0	10	8	0	2	8	7	8	16	15
5	Dunlap Gulch	0.66	0	0	0	0	0	0	0	0	1	12	0	0	0	13	22	14	8	0	1	2	2	2	5	15
6	Browns Gulch	0.89	0	0	0	16	0	0	154	0	0	100	0	23	25	20	20	46	35	0	1	3	3	3	6	15
7	Upper North Fork Elk River	4.36	334	559	0	63	0	0	83	9	3	138	0	7	18	21	13	49	39	30	4	15	13	15	31	15
8	McWhinney Creek	1.27	0	0	0	2	0	248	0	0	0	3	0	0	0	0	3	8	6	0	1	4	4	4	9	15
9	Lower North Fork Elk River	5.02	57	0	0	92	0	53	24	1	85	719	0	10	34	24	16	29	21	240	5	18	15	17	36	15
10	North Branch North Fork Elk River	4.02	261	36	0	0	0	0	21	32	7	1245	21	22	175	143	88	80	53	5	4	14	12	14	29	15
11	Lower South Fork Elk River	2.90	0	4	0	1414	0	0	0	14	29	31	0	0	17	83	198	82	27	41	3	10	9	10	21	15
12	Railroad Gulch	1.20	1118	0	52	318	32	0	0	25	3	753	0	13	0	6	108	58	20	21	1	4	4	4	9	15
13	Clapp Gulch	1.00	0	0	0	126	0	0	0	1	0	773	0	0	0	2	12	29	21	0	1	4	3	3	7	15
14	Tom Gulch	2.51	48	0	0	112	0	0	0	0	0	3	0	0	4	97	26	24	17	64	3	9	8	9	18	15
15	Lake Creek	2.12	183	97	54	525	401	26	1696	0	0	141	0	112	17	19	25	27	17	86	2	7	6	7	15	15
16	McCloud Creek	2.36	37	116	0	14	0	0	1	58	0	12	0	0	19	109	127	266	203	0	2	8	7	8	17	15
17	Upper South Fork Elk River	6.45	99	82	0	7	103	249	5	34	10	10	0	4	12	77	189	68	17	91	7	23	19	22	47	15
18	South Branch North Fork Elk River	1.93	0	0	25	0	0	0	4	340	13	7	2	12	22	133	142	160	115	0	2	7	6	7	14	15
19	Little South Fork Elk River	3.59	25	3	0	0	35	0	0	0	0	0	0	0	28	49	19	55	46		4	13	11	12	26	15
20	Corrigan Creek	1.66	0	0	0	0	0	0	14	2	6	6	2	229	2	66	179	57	10	91	2	6	5	6	12	15

			Treatment of Sediment Discharge Sites						Road Surface Erosion						Harvest Surface Erosion						Totals					
	Sub-basin	Area (mi^2)	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
4	Bridge Creek	2.20					1	0	56	84	94	147	69	71	2	6	2	2	11	20	1,721	330	215	2,358	2,107	484
5	Dunlap Gulch	0.66					28	0	58	88	98	154	72	74	2	6	2	4	0	0	408	342	221	531	499	455
6	Browns Gulch	0.89					17	0	53	80	89	140	66	68	2	6	2	4	0	12	583	342	211	653	510	483
7	Upper North Fork Elk River	4.36					47	10	48	72	81	127	60	61	2	6	2	10	1	3	786	894	189	723	538	471
8	McWhinney Creek	1.27					0	0	54	81	91	143	67	69	2	6	2	7	8	4	405	324	196	511	475	702
9	Lower North Fork Elk River	5.02					22	11	57	86	97	152	71	73	2	6	2	4	5	8	527	367	312	1,356	541	776
10	North Branch North Fork Elk River	4.02					20	0	51	77	86	136	64	66	2	6	2	4	5	6	811	520	273	1,800	551	458
11	Lower South Fork Elk River	2.90					0	0	50	75	84	131	38	40	2	6	2	2	0	0	419	425	418	2,014	472	461
12	Railroad Gulch	1.20					0	0	75	113	127	199	94	96	2	6	2	11	0	0	1,544	387	392	1,687	540	510
13	Clapp Gulch	1.00					0	0	87	130	146	229	107	110	2	6	2	5	0	0	437	376	259	1,508	521	491
14	Tom Gulch	2.51					0	0	52	79	88	138	40	42	2	6	2	0	0	0	456	423	220	629	461	486
15	Lake Creek	2.12					0	0	58	88	98	154	72	74	2	6	2	10	0	6	2,306	450	282	1,209	892	684
16	McCloud Creek	2.36					0	0	37	55	62	97	28	29	2	6	2	2	15	0	445	585	295	744	649	410
17	Upper South Fork Elk River	6.45					0	0	57	86	97	152	44	46	2	6	2	5	23	4	529	541	413	607	619	773
18	South Branch North Fork Elk River	1.93					46	6	58	88	98	154	72	74	2	6	2	11	0	1	435	806	382	683	634	474
19	Little South Fork Elk River	3.59					9	13	16	24	27	43	13	13	2	6	2	0	0	0	423	328	155	454	515	406
20	Corrigan Creek	1.66							57	86	97	152	44	46	2	6	2	0	0	12	424	399	385	564	454	757

Figure 3.59 presents the total management related loading per sub-basin per analysis time period.

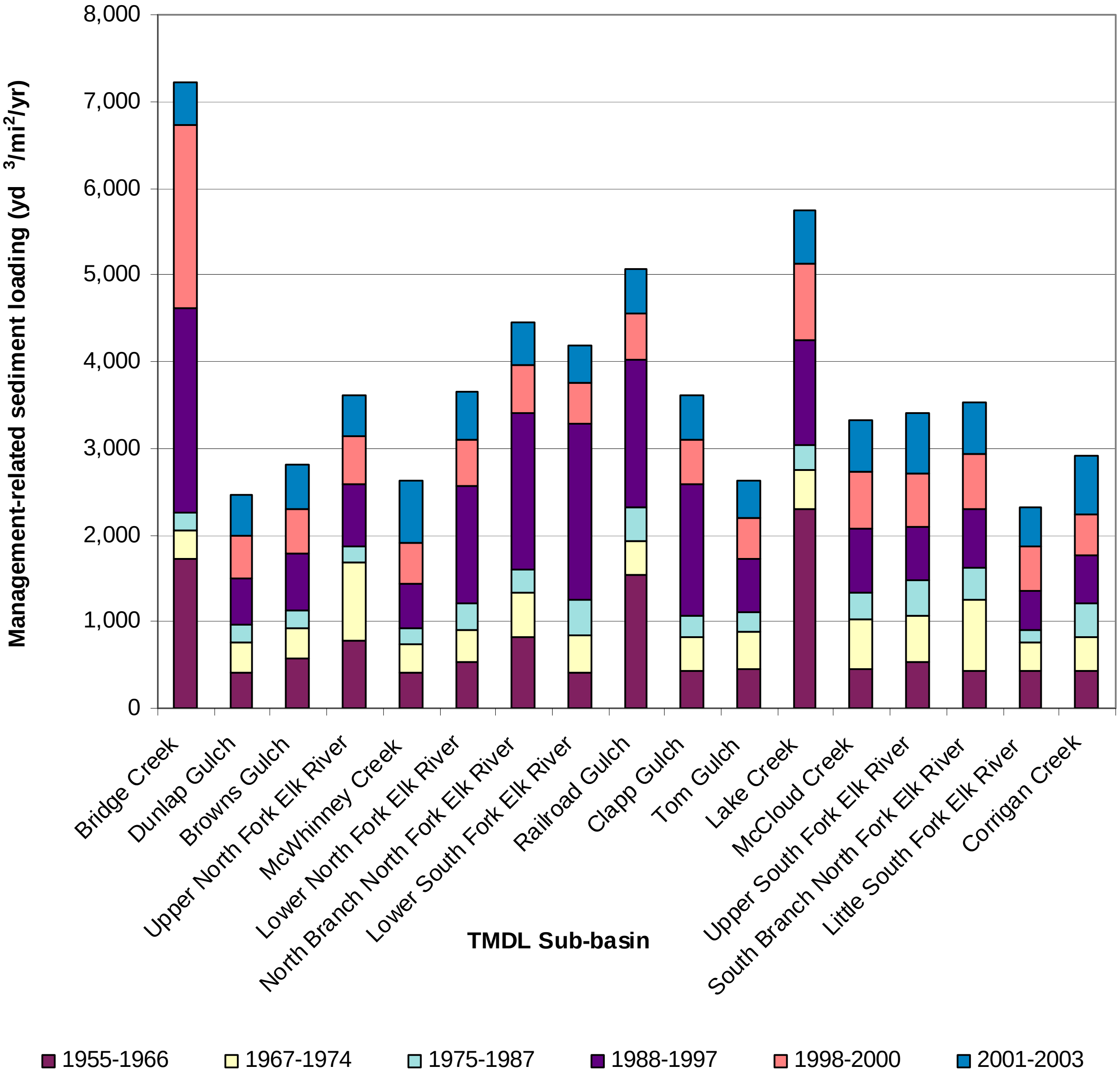

Figure 3.59 Total management loading by sub-basin by analysis photo period

Cumulatively, Bridge Creek has had the largest loading followed by Lake Creek and Railroad Gulch. The greatest inputs are associated with the 1988-1997 time period.

Table 3.42 and Figure 3.60 present the total loading by source category per analysis time period, as well as the natural loading and management -related sediment loading over naturally occurring background. The Elk River loading values were calculated as the area-weighted averages from the sub-basins. The 1988-1997 time period represents the greatest loading over the analysis periods, 1,134 $yd^3/mi^2/yr$ or 1659%

over naturally occurring background. Table 3.43 presents the total loading in terms of tons/mi^2/yr.

Table 3.42 Total Elk River loading (yd^3/mi^2/yr) by source category for analysis time periods.

	Source Category	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Manage-ment	Low Order Channel Scour	67	23	14	21	32	12
	Management-Related Soil Creep	1	1	1	1	1	1
	Management-Related Bank Erosion	43	46	49	52	54	54
	Management-related Streamside Landslides	227	159	30	265	294	294
	Management-related Open Slope shallow landslides	189	82	6	201	118	51
	Road-related Landslides	99	29	15	307	3	20
	Controllable sediment discharge sites	30	60	80	65	39	39
	Skid Trails	4	12	11	12	26	15
	Treatment of Controllable Sediment Discharge Sites	0	0	0	0	13	4
	Road surface erosion	52	78	87	137	55	56
	Harvest surface erosion	2	6	2	5	6	5
	Total management-related Loading	714	495	293	1,066	640	551
Natural	Soil Creep	0.44	0.44	0.44	0.44	0.44	0.44
	Bank Erosion	9	9	9	9	9	9
	Small Streambank Landslides	26	26	26	26	26	26
	Shallow Hillslope Landslides	30	30	30	30	30	30
	Deep seated Landslides	3	3	3	3	3	3
	Total Natural Loading	68	68	68	68	68	68
Total	Total Loading	782	564	361	1,134	708	620
	Percent over Natural Loading	1144%	824%	528%	1659%	1036%	906%

Table 3.43 Total Elk River loading (tons/mi^2/yr) by source category for analysis time periods[1].

		Sediment Loading (tons/mi2/yr)					
	Source Category	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
	Low Order Channel Scour	94	33	19	30	45	17
	Management-Related Soil Creep	1	1	1	1	1	1
	Management-Related Bank Erosion	60	65	68	73	75	76
	Management-related Streamside Landslides	318	222	42	371	412	412
	Management-related Open Slope shallow landslides	265	115	8	281	165	71
	Road-related Landslides	139	40	21	429	4	28
	Controllable sediment discharge sites	42	84	112	91	55	55
	Skid Trails	5	17	15	17	36	21
	Treatment of Controllable Sediment Discharge Sites	0	0	0	0	18	5
	Road surface erosion	72	109	122	191	76	79
	Harvest surface erosion	3	8	2	7	8	6
Management	Total management-related Loading	999	693	410	1492	895	772
	Soil Creep	1	1	1	1	1	1
	Bank Erosion	12	12	12	12	12	12
	Small Streambank Landslides	37	37	37	37	37	37
	Shallow Hillslope Landslides	42	42	42	42	42	42
	Deep seated Landslides	4	4	4	4	4	4
Natural	Total Natural Loading	96	96	96	96	96	96
	Total Loading	1095	789	506	1588	991	868
	Percent over Natural Loading	1144%	824%	528%	1659%	1036%	906%

[1T]Calculated based upon a bulk density of 1.4 tons/yd^3

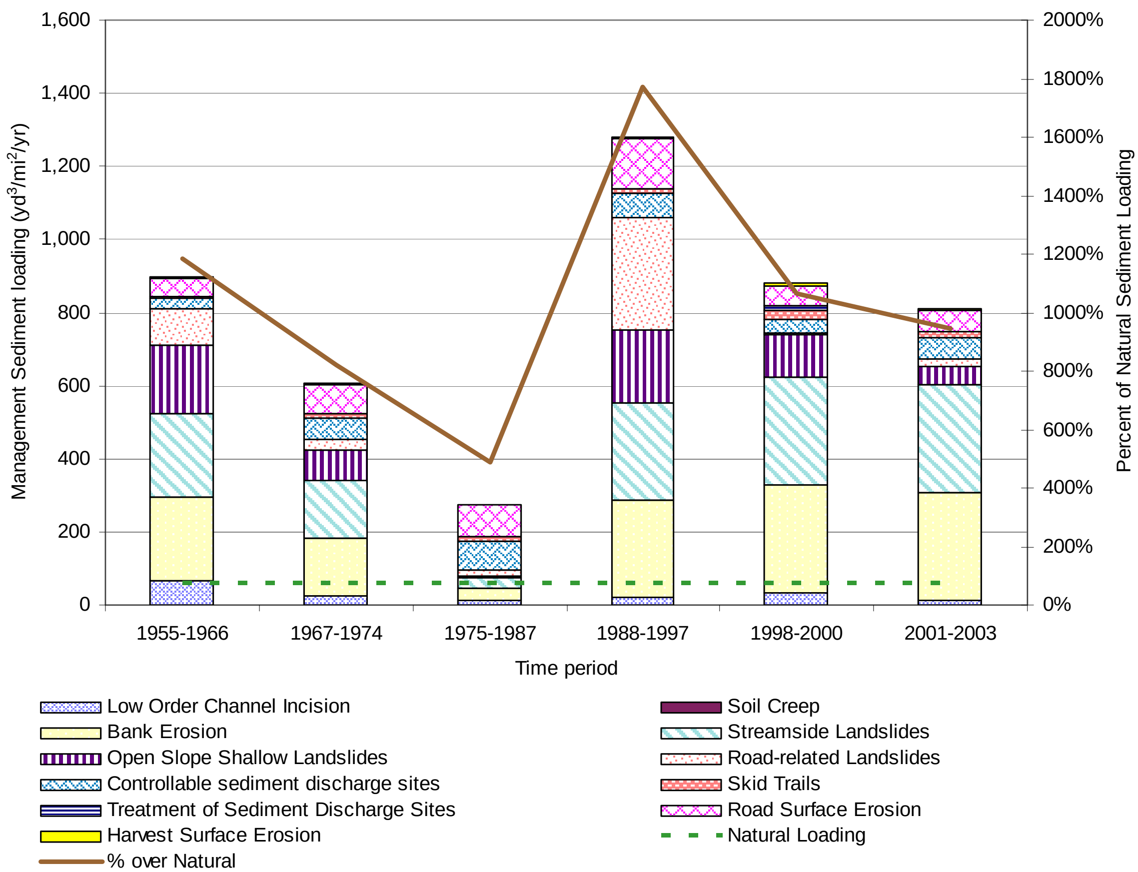

Figure 3.60 Elk River loading by source category for analysis time periods.

3.4.17.1 Road-Related Loading

Road-related sources evaluated as part of this source analysis include road-related landslides, controllable sediment discharge sites, treatment of controllable sediment discharge sites, and road surface erosion. Road-related sources are an important component of the management-related sediment loading, contributing large volumes associated with episodic events via road-related landslides and erosion of gullies and stream crossings, as well as chronic inputs via road-surface erosion. Table 3.44 and Figure 3.66 present the road-related sediment loading. Cumulatively, road-related sources comprise one-third to one-half of the management-related sources from 1955-1997. While the relative significance of road-related sources has decreased since 1998, the overall loading has not decreased significantly; rather other management-related sources have increased.

During the 1988-1997 period, there was particularly high road-related loading in Bridge Creek, Lower North Fork, North Branch North Fork, and Railroad and Clapp Gulches. During this time, these basins received more than 50% of the road-related loading from the entire 55-year analysis period, largely due to road-related landsliding.

Table 3.44 Summary of road-related sediment loading ($yd^3/mi^2/yr$) to TMDL sub-basins over analysis time periods.

	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Bridge Creek	56	84	100	1,083	91	92
Dunlap Gulch	58	100	121	180	108	82
Browns Gulch	233	100	110	287	118	126
Upper North Fork Elk River	148	102	97	314	146	118
McWhinney Creek	54	81	94	154	73	75
Lower North Fork Elk River	116	111	198	899	114	115
North Branch North Fork Elk River	247	253	182	1,461	158	140
Lower South Fork Elk River	67	172	311	245	65	67
Railroad Gulch	75	144	238	1,010	114	129
Clapp Gulch	87	133	157	1,030	128	131
Tom Gulch	56	176	114	165	57	59
Lake Creek	1,771	107	123	322	89	203
McCloud Creek	57	222	189	375	231	232
Upper South Fork Elk River	74	197	296	229	61	66
South Branch North Fork Elk River	83	561	253	321	234	207
Little South Fork Elk River	45	73	46	98	68	71
Corrigan Creek	73	155	282	215	56	284
Elk River area-weighted average road-related loading	**181**	**166**	**182**	**509**	**109**	**120**
Percent of total management-related loading	**25%**	**34%**	**62%**	**48%**	**17%**	**22%**

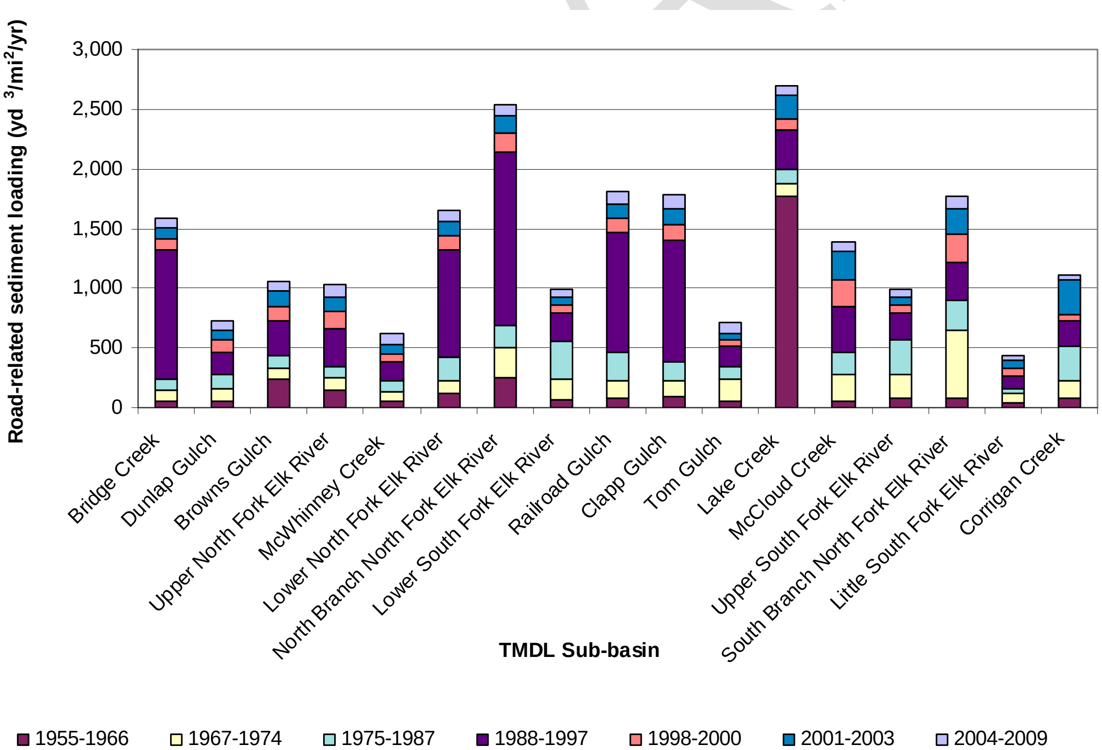

Figure 3.61 Summary of road-related sediment loading ($yd^3/mi^2/yr$) by sub-basin for analysis time periods.

3.4.17.2 Harvest-Related Loading

Harvest-related sediment loading is represented by the combined inputs of low-order channel incision, management-related soil creep, bank erosion, stream-side and open-slope landslides, skid trails and harvest surface erosion. Harvest-related sources dominated the sources in the forest sub-basins of Elk River. Episodic events trigger open-slope and streamside landslides, bank erosion, and skid trail failures. Chronic sediment loading is associated with the extended low order channels and harvest surface erosion. Table 3.45 and Figure 3.62 present the harvest-related loading results. Over the analysis time periods, harvest-related sources have dominated the management-related sediment loading, with a low of 38% of the total in 1975-1987 during a period of relatively low delivery from management-related open-slope landslides and small streamside landslides. Over the analysis time periods, small streamside landslides was the largest source category accounting for 34% of the management-related sources, followed by management-related open-slope shall hillslope landslides accounting for 15% of the management-related loading.

Table 3.45 Summary of harvest-related sediment loading ($yd^3/mi^2/yr$) by sub-basin for analysis time periods.

	1955-1966	1967-1974	1975-1987	1988-1997	1998-2000	2001-2003
Bridge Creek	1,665	247	115	1,276	2,016	400
Dunlap Gulch	350	241	100	350	390	380
Browns Gulch	350	242	101	366	392	392
Upper North Fork Elk River	638	792	92	409	392	363
McWhinney Creek	351	243	102	357	403	633
Lower North Fork Elk River	412	257	113	458	426	441
North Branch North Fork Elk River	564	267	91	339	393	366
Lower South Fork Elk River	352	253	107	1,769	407	380
Railroad Gulch	1,469	243	154	677	426	380
Clapp Gulch	350	242	101	478	393	380
Tom Gulch	400	248	106	465	404	380
Lake Creek	535	343	159	886	802	412
McCloud Creek	389	363	105	368	418	380
Upper South Fork Elk River	455	343	118	378	558	633
South Branch North Fork Elk River	351	246	129	362	400	381
Little South Fork Elk River	378	255	109	356	447	380
Corrigan Creek	351	245	103	350	398	392
Elk River area-weighted average harvest-related loading	**533**	**329**	**111**	**557**	**530**	**432**
Percent of total management-related loading	75%	66%	38%	52%	83%	78%

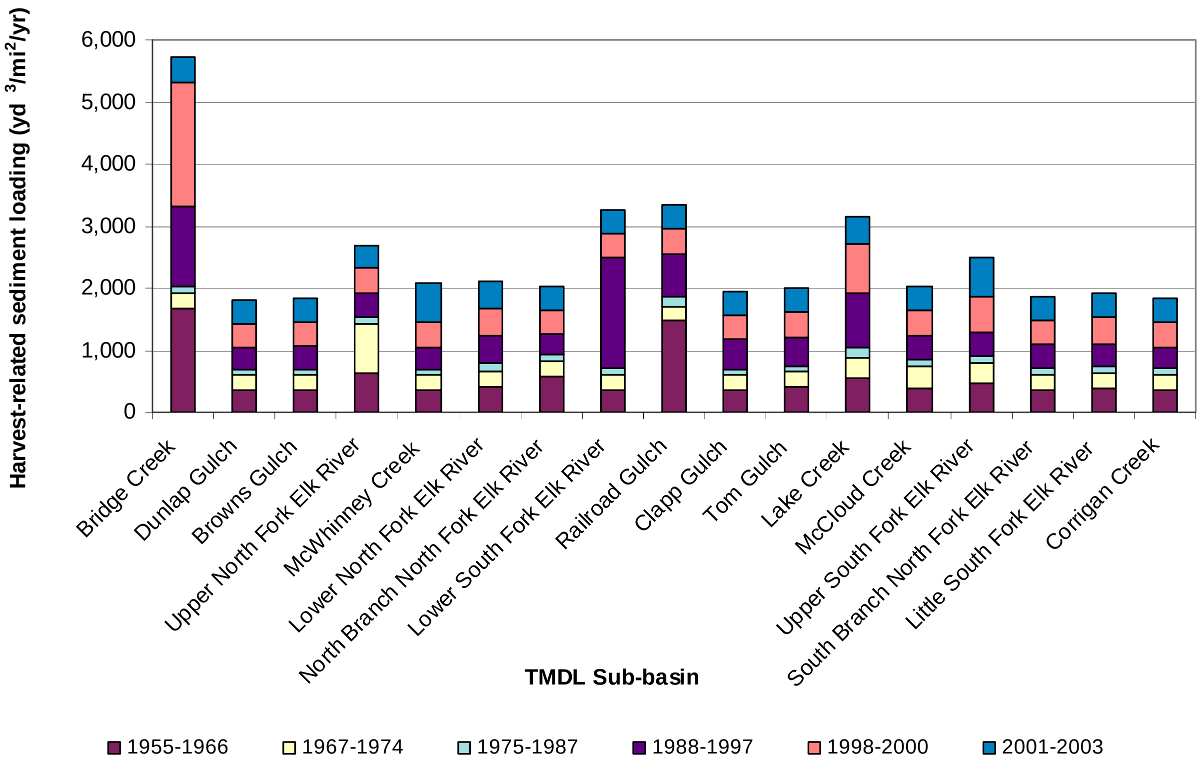

Figure 3.62 Summary of harvest-related sediment loading ($yd^3/mi^2/yr$) by sub-basin for analysis time periods.

3.4.17.3 Comparison with Palco Watershed Analysis

The Palco Elk River Watershed Analysis (Palco, 2004) constructed a sediment budget quantifying both natural and management-related sediment loading estimates for the 1988-2000 time period. The WA included most of the same source categories as evaluated in this source analysis, with the exception of management-related low order channel scour, management-related soil creep, skid trails, and post-treatment discharge sites. The distinction between natural and management-related sources differed in that:

- all non road-related streamside landslides were attributed to natural sources;
- bank erosion was split evenly between natural (50%) and management (50%) sources;
- shallow hillslope landslide loading was split between natural (40%) and management sources (60%).

Table 3.46 provides a comparison of the source categories and the associated loading for Elk River based upon the TMDL source analysis estimates and the WA sediment budget estimates for the common time period 1988-2000. The WA estimates are for Palco lands only because many of the source categories were not available for other ownerships.

Table 3.46 Comparison of TMDL sediment sources and Palco Elk River Watershed Analysis sediment sources (Palco, 2004)

	TMDL Source Category	1988-2000 ($yd^3/mi^2/yr$)	Palco WA Source Category	1988-2000 ($yd^3/mi^2/yr$)
Natural	Soil Creep	0.44	Soil Creep	52
	Bank Erosion	9	Bank Erosion	38
	Shallow Landslides	26	Shallow Landslides	68
	Streamside Landslides	30	Streamside Landslides	276
	Deep Seated Landslides	3	Deep Seated Landslides	3
	Natural Total	69	**Natural Total**	**437**
Management-related	Low Order Channel Headward Incision	24		
	Soil Creep	1		
	Bank Erosion	52	Bank Erosion	38
	Streamside Landslides	272	Road-related Streamside Landslides	162
	Open-slope Shallow Landslides	182	Open-slope Shallow Landslides	144
	Road-related Shallow Landslides	237	Road-related Shallow Landslides	168
	Discharge sites	59	Gullies	28
	Skid Trails	15		
	Post-Treatment Discharge Sites	3		
	Road surface erosion	118	Road surface erosion	32
	Harvest Surface Erosion	5	Surface Erosion	6
	Management Total	967	**Management Total**	**579**
Total	**Total Loading**	1036	**Total Loading**	**1,016**
	Percent over Natural Loading	1512%	**Percent over Natural Loading**	**232%**

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