Appendix 4C

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 effects 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 the results of a Caspar Creek study in which gullies were monitored in a managed (clearcut and cable yarded) watershed and a forested control watershed. 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 Upper Elk River TMDL efforts, within the three study sub-basins described in Appendix 4A, Regional Water Board staff conducted surveys 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 Upper Elk River sediment source analysis.

Methods Used to Determine Management-Related Effects on Channel Initiation

The three study sub-basins were divided into catchment areas using a flow accumulation model[1] based on LiDAR DEM[2] 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 in Eureka where there is 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- 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.

Results - Management-Related 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 Appendix 4-A. 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

---

[1] 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.

[2] 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 mass-points at approximately 4.5 points per m^2 over a 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 semi-variogram, search radius of 20 m, and maximum of 16 points (Sanborn 2005).

hectares. Table 1 presents the resulting drainage densities within each of the study-sub-basins for natural and managed conditions.

Table 1. 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[3] of channel lengths associated with different stream classes. Table 2 presents this summary data for the purpose of comparison with the TMDL drainage density results.

[3] CWE Section, Table 2

Table 2. Summary of stream network as presented in the Palco Elk River Watershed Analysis (Palco, 2004)[4].

Stream Class[5]	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	100%	8.17

The Palco Report of Waste Discharge (ROWD) (2005) includes a summary of drainage density associated with different stream orders[6]. The summary indicates that nearly all stream lengths within THP units are low (1^{st} to 3^{rd}) order streams (or Class II and III and streams, using the Forest Practice Rules definition). Table 3 shows the stream densities as presented in the ROWD.

Table 3 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	100%

Generally, Class I watercourses are 4^{th} order or greater streams. Assuming that Table 3 does not include Class I watercourses, the inclusion of the Class I lengths from Table 2 results in a total drainage density of 12.44 mi/mi^2.

Figure 1 demonstrates drainage densities estimated be HRC in their Watershed Analysis (2012) for different stream classes; the area weighted average for all stream classes combined is provided by staff.

[4] The watershed analysis area comprised 52.66 mi^2.

[5] 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.

[6] Table 6.4

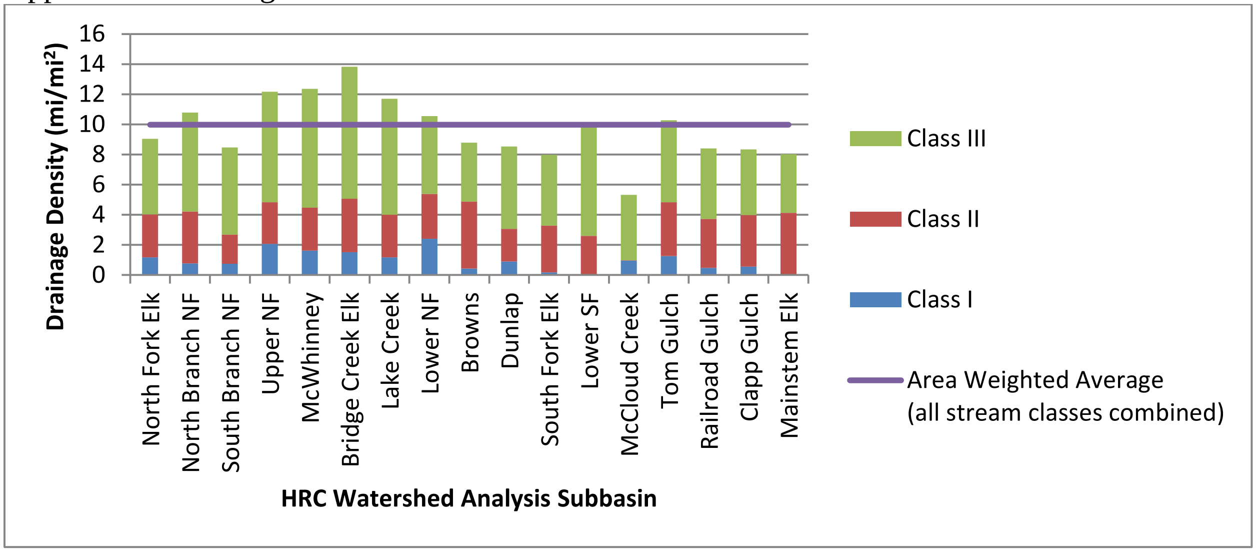

Figure 1. Drainage density for Upper Elk River Sub-basins as provided by HRC (HRC, 2012).

The overall drainage density estimates as presented in the 2004 Palco WA (8.17 mi/mi^2), the 2005 Palco ROWD (12.44 mi/mi^2), and the 2012 HRC WA (9.96 mi/mi^2) are 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 were initially 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 Franciscan and Yager formations.

Figure 2 presents the drainage densities associated with the TMDL surveys in the study sub-basins, the Caspar Creek results, the Palco WA, the HRC WA, and the Palco ROWD (adjusted to include Class I streams) stream network data.

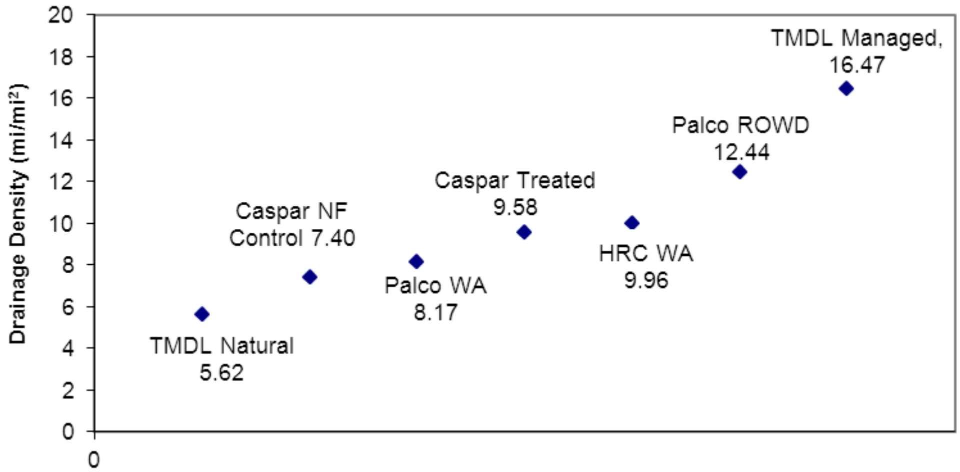

Figure 2. Drainage densities associated with the TMDL surveys in the study sub-basins, the Caspar Creek results, the Palco Watershed Analysis and Palco ROWD drainage network data. Staff modified the Palco ROWD stream network data to include Class I stream lengths described in the Palco WA results.

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 (unless otherwise specified).

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 mi/mi^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 (HRC, 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 4 demonstrates the resulting drainage density associated with different time periods.

Table 4. Drainage density associated by decade for Upper 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 4 were then applied to the sub-basins based upon the Geologic Groupings presented in Appendix 4-B. 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 5.

Table 5. 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									

Uncertainties Associated with Management-Related Effects on 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 Upper Elk River 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.