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# Frequency and characteristics of sediment delivery pathways from forest harvest units to streams

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ABSTRACT

Timber harvest is typically the largest area of anthropogenic disturbance in forested watersheds, and harvested areas may generate from one to five times more erosion than undisturbed areas (Motha et al., 2003). When sediment from harvested areas reaches stream channels it can degrade water quality and aquatic habitat. Streamside management zones (SMZs) are often prescribed to minimize sediment delivery, but there is little information about sediment delivery through these zones. Hence the objectives of this study were to: (1) determine the frequency of sediment delivery pathways ("features") from timber harvest units; (2) measure the physical characteristics and connectivity of these features; and (3) develop models to predict the length and connectivity of features from harvest units to streams.

Nearly 200 harvest units with streamside management zones were assessed on four National Forests in the Sierra Nevada and Cascade Mountains of California. Only nineteen features were found below harvest units ranging in age from 2 to 18 years. Feature lengths ranged from 10 m to 220 m, and the length was significantly related to mean annual precipitation, cosine of the aspect, elevation, and hillslope gradient ($R^2 = 64\%$, $p = 0.004$). Six of the nineteen features were connected to streams and five of the six connected features originated from skid trails. The results indicate that timber harvest alone rarely initiated large amounts of runoff and surface erosion, particularly when newer harvest practices were utilized. Sediment delivery from timber harvest may be further reduced by locating skid trails away from streams, maintaining high surface roughness downslope of water bars, and promptly decommissioning skid trails following harvest.



## 1. Introduction

Anthropogenic sediment sources on forested hillslopes include roads, skid trails, and timber harvest units (e.g., Megahan, 1972; Beschta, 1978; Croke et al., 1999; Barrett and Conroy, 2001; Motha et al., 2003). Most recent research has focused on roads (e.g., Luce and Black, 1999; Jones et al., 2000; Lane and Sheridan, 2002; Coe, 2006), but timber harvest units represent the largest areas of anthropogenic disturbance and can increase erosion rates by one to five times relative to undisturbed areas (Motha et al., 2003).

The delivery of overland flow and sediment from disturbed hillslopes contributes to cumulative effects such as an increase in the size of peak flows (e.g., Jones, 2000; MacDonald and Stednick, 2003), the alteration of channel morphology (Troendle and Olsen, 1994; Madej and Ozaki, 1998), degradation of aquatic habitat (Shaw and Richardson, 2001), reductions in reservoir storage, and increases in pollutant transport (EPA, 2003). The delivery of sediment from hillslope sources to the stream network and the watershed outlet has been defined as sediment connectivity (Bracken and Croke, 2007). Connectivity of hillslope sediment pathways can be in the form of sediment plumes when there is an excess of sediment relative to overland flow, or in the form of rills and gullies when the transport capacity is greater than the sediment load.

For this paper a rill was defined by having incised banks with no minimum depth. Gullies were defined as incised features greater than 30 cm deep or with a cross-sectional area larger than about 1000 $cm^2$. Rills, gullies, and sediment plumes are collectively described as features in this paper, and we use the term rills for both rills and gullies unless otherwise specified.

In recent years forest management techniques have been modified to minimize surface runoff, erosion, and connectivity. Skid trails are often designed to follow hillslope contours (Kreutzweiser and Capell, 2001). Streamside management zones (SMZs) are intended to provide vegetative roughness and maintain infiltration rates that can slow or absorb overland flow and filter sediment out of the overland flow before it reaches a stream or water body (Kreutzweiser and Capell, 2001; Hairsine et al., 2002).

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Features can penetrate SMZs and thereby connect forest harvest units to streams (Lacey, 2000; Rivenbark and Jackson, 2004). In the Georgia Piedmont, USA, there was an average of one feature for every 20 acres of clearcut and site prepared land, and these were associated with convergent topography, steeper slopes, larger contributing areas, and less ground cover (Rivenbark and Jackson, 2004). In Australia 10-m wide buffer zones reduced the delivery of sediment from skid trails to streams by 95% (Lacey, 2000).

Measuring and modeling connectivity and sediment delivery are critical for quantifying and predicting the cumulative effects of timber harvest activities in forested watersheds (Bracken and Croke, 2007). The fieldwork described in this paper evaluated whether the areas disturbed by timber harvest and skid trails are connected to stream channels by rills and sediment plumes. The specific objectives were to: (1) determine the proportion of timber harvest units that generated rills or sediment plumes that penetrated at least 10 m into an adjacent SMZ; (2) measure the site characteristics, size, and connectivity of rills and plumes to stream channels; and (3) develop models to predict the length and connectivity of rills and sediment plumes originating from timber harvest units.

## 2. Study area

The study area included timber harvest units on the Eldorado, Lassen, Plumas, and Tahoe National Forests (NF) in the Sierra Nevada and Cascade mountains of California (Fig. 1). The area has a Mediterranean climate with moist air flows from the Pacific Ocean. The amount and type of precipitation is heavily influenced by the high elevations and rain shadow effect of the mountains so that mean annual precipitation ranges from as much as 2000 mm on the west side to as little as 370 mm on the east side (Teale GIS Solutions Group, 1997). Ninety-five percent of the precipitation occurs during the winter wet season, and above 1500 m the precipitation falls mostly as snow (USDA Forest Service, 1986). Summer convective thunderstorms are more frequent on the east side of the mountains than on the west side (USDA Forest Service, 1983).

Forests on the west side are composed primarily of ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), Douglas fir (*Pseudotsuga menziesii*), red fir (*Abies magnifica*), white fir (*Abies concolor*), and incense cedar (*Libocedrus decurrens*) (USDA Forest Service, 1983, 1986, 2002). The dominant understory shrubs are green leaf manzanita (*Arctostaphylos patula*), huckleberry oak (*Quercus vaccinifolia*), and mountain whitethorn (*Ceanothus cordulatus*). Forests on the drier east side consist primarily of ponderosa pine, Jeffrey pine (*Pinus jeffreyi*), and white fir, with some lodgepole pine (*Pinus contorta*), western juniper (*Juniperus occidentalis*), and black oak (*Quercus kelloggii*). Most forest harvest takes place on soils weathered from andesitic, granitic, and meta-sedimentary material (USDA Forest Service, 1983, 1986, 2002).

## 3. Methods

### 3.1. Data collection

The study was conducted on the four NFs shown in Fig. 1 because they have higher levels of timber harvest than the other eighteen NFs in Region 5 of the USDA Forest Service (USFS). Most of the recent timber management projects in these NFs tend to be larger-scale projects of about five hundred to several thousand hectares. Individual harvest units within these project areas average 15 ha with a general range of 1–80 ha (Tangenberg, USFS, pers. comm., 2008).

Harvest projects with erosion and sedimentation problems were identified by direct discussions with USFS personnel and querying the USFS Best Management Practices Evaluation Program (BMPEP) database (USDA Forest Service, 2004). The BMPEP

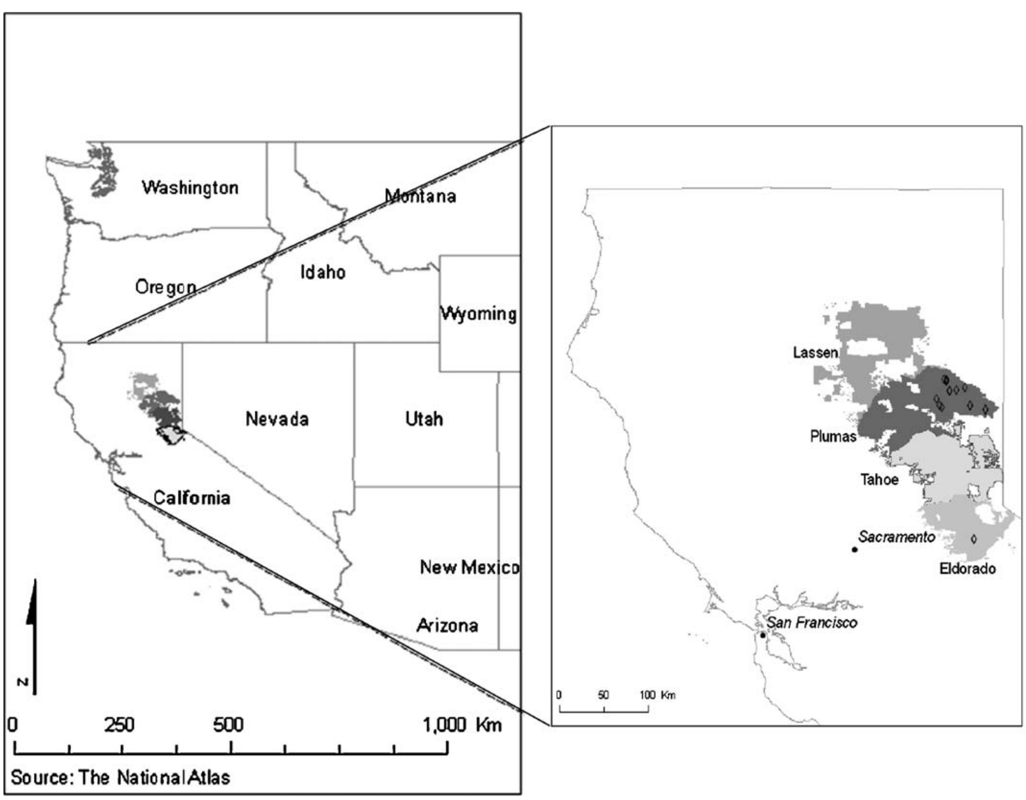


**Fig. 1.** Location of the four National Forests used to assess harvest unit connectivity. The open diamonds indicate the location of the rills and sediment plumes identified in this study. Given the coarse scale of this map, some diamonds represent multiple features that occurred in close proximity.