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Comparison of slope instability screening tools following a large storm event and application to forest management and policy

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ABSTRACT

The objective of this study was to assess and compare the ability of two slope instability screening tools developed by the Washington State Department of Natural Resources (WDNR) to assess landslide risks associated with forestry activities. HAZONE is based on a semi-quantitative method that incorporates the landslide frequency rate and landslide area rate for delivery of mapped landforms. SLPSTAB is a GIS-based model of inherent landform characteristics that utilizes slope geometry derived from DEMs and climatic data. Utilization of slope instability screening tools by geologists, land managers, and regulatory agencies can reduce the frequency and magnitude of landslides. Aquatic habitats are negatively impacted by elevated rates and magnitudes of landslides associated with forest management practices due to high sediment loads and alteration of stream channels and morphology. In 2007 a large storm with heavy rainfall impacted southwestern Washington State trigging over 2500 landslides. This storm event and accompanying landslides provides an opportunity to assess the slope stability screening tools developed by WDNR. Landslide density (up to 6.5 landslides per km^2) from the storm was highest in the areas designated by the screening tools as high hazard areas, and both of the screening tools were equal in their ability to predict landslide locations. Landslides that initiated in low hazard areas may have resulted from a variety of site-specific factors that deviated from assumed model values, from the inadequate identification of potentially unstable landforms due to low resolution DEMs, or from the inadequate implementation of the state Forest Practices Rules. We suggest that slope instability screening tools can be better utilized by forest management planners and regulators to meet policy goals regarding minimizing landslide rates and impacts to sensitive aquatic species.

1. Introduction

In the Pacific Northwest, landslide frequencies in areas with forest clearing are up to thirty-four times higher than natural background rates (Rood, 1984). Timber harvest is the primary factor responsible for this difference (Sidle et al., 1985). Landslides alter aquatic habitats by elevating sediment delivery, creating log jams, and causing debris flows that scour streams and stream valleys down to bedrock (Rood, 1984; Cederholm and Reid, 1987; Hogan et al., 1998). The short-term and long-term impacts of higher rates of landslides on fish include habitat loss, reduced access to spawning and rearing sites, loss of food resources, and direct mortality (Cederholm and Lestelle, 1974; Cederholm and Salo, 1979; Reeves et al., 1995). The restoration of geomorphic processes to natural disturbance regimes is crucial to the recovery of endangered salmonids (*Oncorhynchus* spp.) and other aquatic species in the Pacific Northwest as these species evolved under conditions with much lower sediment delivery and landslide frequency (Reeves et al., 1995; Montgomery, 2004).

In December 2007, a series of large storms moved through northwestern Oregon and southwestern Washington State. The storms brought heavy precipitation (up to 48 cm) and hurricane-force winds over four days (Mote et al., 2007). Significant flooding took place on numerous rivers in southwest Washington with record floods observed on the Chehalis River. Other rivers in the region recorded return period floods ranging from 2 to 100 years (Reiter, 2008). At least 2503 landslides were triggered in southwestern Washington by this storm event (Turner et al., 2010; Fig. 1). Upon entering steep and/or confined stream channels many of these landslides turned into debris avalanches, flows, and torrents (Sarikhan et al., 2008) further adding to the sediment volume of the original slides. Debris flows from landslides in smaller stream drainages can lead to short term stream discharge rates orders of magnitude above 100-year return period flood levels (Jakob and Jordan, 2001). Extrapolating from the number and area of the landslides, tens of millions of cubic meters of sediment, logs and debris were delivered to the stream networks in southwest Washington and northeast Oregon (Forest Debris Recovery Team, 2008; Sarikhan et al., 2008; ENTRIX,

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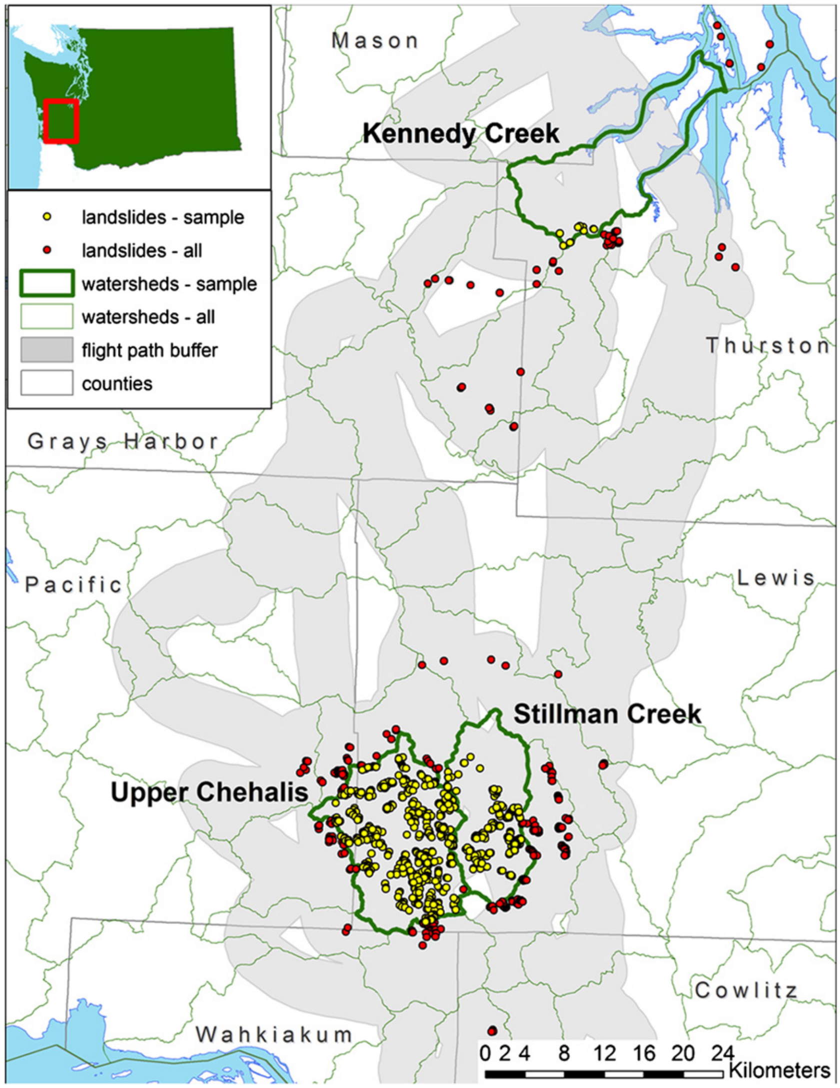

Fig. 1. Landslides from the December 2007 storm (WDNR, 2009) and watersheds sampled for this study (see Section 2.1).

2009). These streams were likely already aggraded from elevated sediment input rates associated with past forest practices (Stover and Montgomery, 2001).

Forest practices in Washington State are governed by state Forest Practices Rules which include site-specific prescriptions intended to prevent the increase in landsliding caused by forest practices beyond natural background rates in order to protect aquatic species and public resources (Washington Administrative Code (WAC) 222-10-030). For example, timber harvest, road-building, and related activities are limited on potentially unstable landforms (such as bedrock hollows, convergent headwalls, and inner gorges) on slopes steeper than 70% (35°; WAC 222-16-050(1)(d)). In response to the December 2007 storm, the effectiveness of the Forest Practices Rules at reducing landslide density and sediment delivery to the stream network was evaluated (Stewart et al., unpublished results). Where the Rules were fully implemented they appeared to be effective, but a large proportion (45%, $N=514$) of the identified landslides that entered streams initiated at locations that had not been defined as potentially unstable by the Rules (the Rules did not apply to these sites; Stewart et al., unpublished results). Because the Rules were only partially effective in limiting landslide rates to background levels, improvements in the Forest Practices Rules for identifying potentially unstable landforms or improvements in their implementation may be needed.

Models have been developed as screening tools to identify locations of potentially unstable landforms. Use of these screening tools as hazard maps help forest managers determine where forest practices should or should not be located in order to minimize and avoid damage to aquatic habitats and other public resources as well as private property (Shaw and Vaugeois, 1999). The success with which slope instability screening tools can be applied in forest land management depends on evaluation of the accuracy of model predictions and the long-term response by land-use agencies (Wilcock et al., 2003). The objective of this study was to assess and compare the ability of two slope instability screening tools to predict actual landslide locations from the December 2007 storm. We show that these tools are useful in the identification of potentially unstable slopes, and we describe ways they can be better utilized in forest management to minimize landslide rates and harm to sensitive aquatic species.

2. Methods

2.1. Study area and sample criteria

Landslide initiation point data was gathered by the Washington Department of Natural Resources (WDNR) during reconnaissance flights across southwest Washington immediately following the