Forest Ecology and Management 304 (2013) 20–32

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Estimating catchment-scale annual soil loss in managed native eucalypt forests, Australia

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ARTICLE INFO

Article history:
Received 19 October 2012
Received in revised form 8 April 2013
Accepted 15 April 2013
Available online 20 May 2013

Keywords:
Soil erosion estimation
RUSLE
Spatial variability
Raster data layers
Forest management
Australia

ABSTRACT

Conservation of soil and water resources is one of the key criteria underpinning sustainable forest management. While soil and water resources are important determinants of forest productivity, without appropriate assessment of soil erosion risk and the application of best management practices (BMPs), some forest management activities can adversely affect hillslope erosion rates with detrimental consequences for aquatic environments and downstream water users. In the multiple-use native eucalypt forests of New South Wales (NSW), Australia, hazard matrix tables are currently used to identify soil erosion risk based upon rainfall erosivity, soil regolith stability and slope classes at the compartment scale prior to undertaking forestry activities. Resultant "inherent hazard levels" (IHLs) direct the BMPs to be used, such as riparian buffer widths, during harvesting and roading operations. The IHL model, being an ordinal classification system, only provides a relative indication of erosion potential without any quantitative estimate of possible post-harvest erosion rates. To potentially better identify erosion risk and quantify likely soil erosion under a range of forest management and climatic scenarios at the hillslope and/or catchment scale, in this paper we utilised an alternative approach by modelling soil erosion using the empirically-derived Revised Universal Soil Loss Equation in combination with a GIS-based spatially distributed raster analysis. In four case study catchments in Kangaroo River State forest, two of which were subjected to single-tree selection harvesting operations, mean annual changes in soil loss were estimated at a grid cell level. Potential differences in soil loss estimates were assessed before, during and after selective logging. Vegetation cover and soil samples were recorded in a 500 × 1000 m rectangular network laid out across the catchments. Slope gradient was found to contribute substantially to the spatial variability of soil loss estimation across the catchments. However, between-year differences demonstrate that the highest estimated annual rates of soil loss occurred on steep hillslopes when high levels of rainfall were recorded, while the values on those same areas remained considerably lower during low rainfall periods. The major effect of the rainfall component in generating soil erosion overshadows the modest impacts of selective logging operations.

1. Introduction

The conservation and maintenance of soil and water resources is one of the seven essential criteria for the sustainable management of temperate and boreal forests (Montréal Process, 2009). While soil and water resources underpin forest ecosystem productivity it is well established that forest management activities, if not appropriately conducted, can significantly increase soil erosion and sediment delivery to drainage features (e.g. Beschta, 1978; Chappell et al., 2004; Gomi et al., 2005; Walsh et al., 2011) with potentially negative effects on downstream water supplies (e.g. Webb, 2012; Neary, 2012) and detrimental consequences for aquatic ecosystems (e.g. Kreutzweiser and Capell, 2001; Sutherland et al., 2002; Kreutzweiser et al., 2005; Zhang et al., 2009). Where erosion hazards are identified and appropriate best management practices (BMPs) employed, the effects of forestry activities on the aquatic environment can be greatly reduced (e.g. Wallbrink and Croke, 2002; Kreutzweiser et al., 2009; Webb et al., 2012; Young et al., 2013). Hence, the key indicators pertaining to the conservation and maintenance of soil and water resources are the assessment of soil erosion hazard (Montreal Process Implementation Group for Australia, 2008) and the implementation of BMPs (Montréal Process, 2009).

Within the state of New South Wales (NSW), Australia, "inherent soil erosion and water pollution hazard" (EPA, 1998) is assessed prior to any forestry activities occurring in public,

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0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.04.032

multiple-use native hardwood eucalypt forests, in compliance with State and Federal legislation (Webb, 2012). A range of BMPs is then applied to reduce the potential for soil erosion and water pollution, including soil conservation measures for the design of bridges, culverts and causeways; appropriate drainage spacings on roads and skid trails; seasonal harvesting restrictions; slope restrictions for harvesting and road construction activities; wet weather restrictions on the use of roads and log landings; mass movement hazard conditions; soil dispersibility conditions; and protection of all drainage features by the use of filter strips and/or buffer strips from where harvesting is excluded (Webb and Haywood, 2005). The soil erosion and water pollution hazard model currently used takes the form of a series of hazard matrix look-up tables that vary according to the intensity of forest harvesting to be undertaken as well as the method of log extraction being used (EPA, 1998). Inherent soil erosion hazard is calculated for each compartment, which may be several hundred hectares in area, based on the average rainfall erosivity of the compartment, slopes within defined classes and the assessed soil regolith stability (Murphy et al., 1998). The inherent hazard level (IHL) for the compartment is then determined and assigned as either low (IHL1), high (IHL2), very high (IHL3) or extreme (IHL4). The designated IHL directs the level of activity allowed – for example harvesting is prohibited in areas of IHL4 – and/or the extent of BMPs to be applied, such as the width of riparian buffer or filter strips (EPA, 1998).

While the inherent soil erosion hazard model employed to date provides a broad-scale relative indication of soil erosion potential, a comprehensive survey and assessment of soil erosion in 94 logged compartments demonstrated high unexplained variation in actual erosion within each of the four IHL classes (Walsh and Lacey, 2003). Furthermore, being an ordinal classification system, the IHL model only provides a relative indication of erosion potential without any quantitative estimate of possible post-harvest erosion rates.

An alternative approach is to utilise an empirically-derived model such as the Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997) in combination with a GIS-based spatially distributed raster analysis (e.g. Lin et al. 2002; Kouli et al., 2009) to better identify erosion risk and quantify likely soil erosion under a range of forest management and climatic scenarios at the hillslope and/or catchment scale. Developments in estimating soil erosion prior to logging using empirical models facilitate monitoring of potential quality changes in aquatic environments and provide a basis for sound management practices. However, since different environmental and anthropogenic factors cause spatial and temporal variability in soil loss and sediment yield, there is a high degree of uncertainty in attributing the effects of a specific parameter like vegetation removal on soil and water quality degradation.

The identification and then quantification of the contribution of a particular parameter to sediment yield can lead to the introduction of appropriate forest logging procedures. The current study examines the influence of rainfall, soil and slopes in triggering soil erosion in logged and unlogged catchments. The main objective of this paper is to assess the efficacy of predicting catchment-scale soil erosion potential in forest environments using a raster-based modelling system in which the RUSLE model is applied using locally distributed values of environmental variables. Specifically, the study aims to estimate annual soil loss in four catchments forming part of a replicated paired catchment experiment in which, after a period of calibration, two catchments were selectively logged and the other two remained undisturbed. Potential differences in soil loss estimates were assessed before, during and after selective logging.

2. Methods and materials

2.1. Study area

The study was carried out in four neighbouring catchments of native eucalypt forest in Kangaroo River State forest in northern NSW, Australia (Fig. 1). The paired catchments consisted of two non-harvested (control) catchments and two selectively harvested (impact) catchments in which rainfall, streamflow and suspended sediment loads were measured between 2001 and 2009 (Webb et al., 2012). The topography involves a range of gradients with steep mountainous slopes and mainly V-shaped valleys to

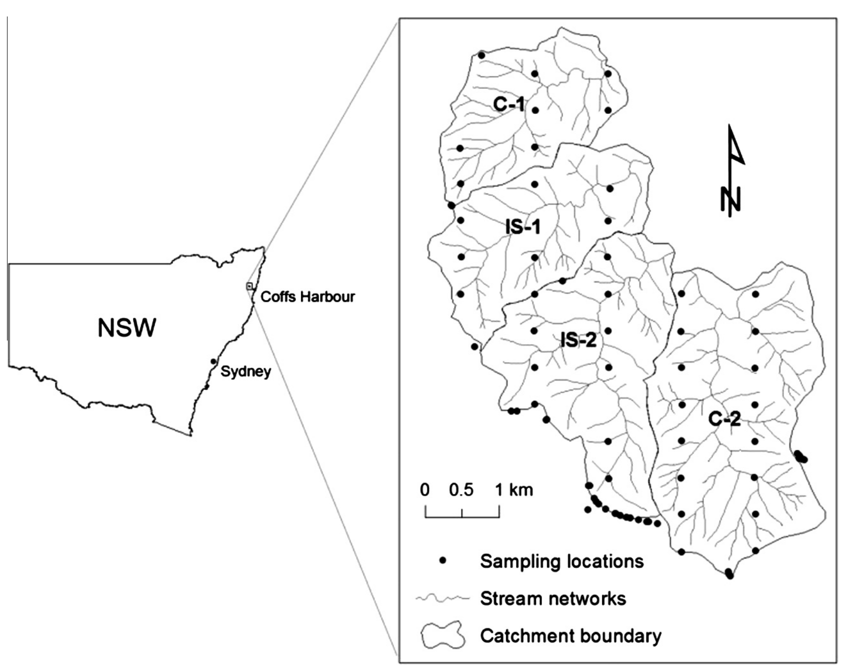

Fig. 1. The geographical position of the study catchments including Control 1 (C-1), Impact Site 1 (IS-1), Impact Site 2 (IS-2), and Control 2 (C-2) together with the location of systematically collected soil and vegetation cover samples and additional data acquisition from satellite imagery for bare soil on the catchment boundaries.