Journal of Hydrology 388 (2010) 414–425

Contents lists available at ScienceDirect

Journal of Hydrology

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

Dynamics of erosion and suspended sediment transport from drained peatland forestry

Hannu Marttila *, Bjørn Kløve

Water Resources and Environmental Engineering Laboratory, Department of Process and Environmental Engineering, 90014 University of Oulu, Finland

ARTICLE INFO

Article history:
Received 31 August 2009
Received in revised form 5 February 2010
Accepted 12 May 2010

This manuscript was handled by L. Charlet, Editor-in-Chief, with the assistance of Ewen Silvester, Associate Editor

Keywords:
Erosion
Suspended solids
Sediment transport
Organic sediment
Peatland drainage
Forestry

SUMMARY

Erosion and suspended sediment transport dynamics were studied in the open water season (April–November) of three consecutive years in a drained peatland forest. Discharge and suspended solids were monitored continuously and sediment properties surveyed with individual samples. Sediment transport dynamics were studied using statistical methods and plotted as hysteresis, duration and effective discharge plots. Sediment rating curves for averaged daily data for months and total season were established to seek empirical sediment yield predictive model(s). The discharge patterns in the study catchment were dominated by peak runoff events resulting from snowmelt and intensive rainfall. Fluctuations in suspended sediment concentrations (SSC) were associated with discharge fluctuations. Sediment transport varied markedly during the study months and years, with organic sediment playing an important role. The present study demonstrates sediment transport processes and reveals the underlying mechanics operating in forested peatland areas. These include inter-storm sediment storage, bank collapse and the role of peak runoff rate on erosion in peak flow events. Sediment availability in drainage network channels also played a major role in erosion and SSC. The results indicate that summer runoff peaks can be a dominant element controlling annual sediment yield, partly contradicting previous studies in drained peatland areas identifying spring snowmelt as the dominant element. Sediment yield prediction with the empirical sediment-transport rating curve gave good regressions for some data, but simple regression models were not adequate to provide accurate annual predictions.

1. Introduction

Peatland drainage and afforestation operations result in erosion of peat and underlying mineral soils. Understanding this erosion and suspended sediment transport processes is essential in developing better water protection and pollutant control strategies, as prescribed by e.g. the EU Water Framework Directive (WFD). A major concern in catchment and stream management is increased suspended sediment load due to intensive land use. Nutrient losses from drained peatland forestry areas are largely associated with the load of suspended solids (SS) and organic material in drainage water. Organic sediment in suspension can increase dissolved organic carbon (DOC) production as the organic material breaks downs (Koelmans and Prevo, 2003). In pristine Finnish peatlands, erosion is minor due to low precipitation intensity, a protective ground vegetation cover and the soil being frozen for part of the year (e.g. Mattsson et al., 2003). In Finland, peatlands have traditionally been used for forestry, peat harvesting and agriculture, with almost 5.7 million hectares having been drained for forestry purposes (Peltola, 2003). There is a growing need for forestry drainage network maintenance in large areas (Kansallinen metsäohjelma, 2008), leading to concerns about the negative impacts of such maintenance on stream water quality and aquatic habitats. Extensive peat drainage has also been carried out in other regions, e.g. the Netherlands, Ireland and, in recent years, tropical areas such as Indonesia and Malaysia, where palm oil is produced for bioenergy. These drainage networks will also have to be maintained in coming years.

The rate of erosion in a catchment depends on climate, land use and a number of landscape characteristics such as slope, topography, soil type, vegetation and drainage conditions. In peatland forestry, drainage enhances erosion conditions and large amounts of SS transport can occur (Heikurainen et al., 1978; Ahtiainen, 1990). Erosion usually decreases over time (Joensuu, 2002) but the erosion yield can increase significantly if drainage channels extend into the mineral soil below the peat profile (Heikurainen et al., 1978; Konstantinov and Suhorukova, 1980). Therefore, drainage operations in thin peat layers or mire or heath can create a greater risk of erosion. Spring snowmelt and storm events erode ditch banks (Ahti et al., 1995), with the majority of SS transport occurring during such events (Mattsson et al., 2003). Peat proper-

* Corresponding author. Tel.: +358 8 553 4389; fax: +358 8 553 4507.
E-mail address: hannu.marttila@oulu.fi (H. Marttila).

0022-1694/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhydrol.2010.05.026

ties and weathering affect erosion processes and yield (Evans and Warburton, 2007). Furthermore, suspended organic peat sediment is an important component in the carbon cycle (Evans and Warburton, 2005; Worrall et al., 2003; Evans et al., 2006), but still unknown for peatland forestry.

Although previous research has led to several practical means of preventing erosion and SS transport from forestry peatlands (e.g. ditch breaks, sedimentation bonds), little or no information is available on the factors and mechanics influencing the ditch erosion and SS transport processes. Better understanding of these processes would help in the development of numerical or process models to predict the SS concentration during storm events and annual yields from the drained area. This would also help in the assessment of land use impacts such as drainage and in the design of water protection methods. Our main interest in the present study was the impact of the magnitude and duration of on discharge on ditch erosion and transport of suspended sediments. Specific objectives of the study were: (1) to examine suspended sediment dynamics in peatland drainage channels during different events, (2) to quantify the variation in SS concentration with discharge, (3) to study the variables affecting transport and erosion, (4) to identify and quantify sediment supply and storage elements, (5) to identify links between suspended sediment transport processes and (6) to evaluate the applicability of empirical suspended sediment transport models. To achieve these objectives, detailed data on continuous SS transport were collected in the drained boreal peatland forestry catchment chosen for the study. To our knowledge, the study is the first attempt to measure suspended sediment transport processes from peatland forestry.

2. Methods

2.1. Study areas

The study was conducted in a drained peatland forest, Virkosuo catchment (36 ha), located in Central Finland (63°15′53″N, 25°97′11″E) and surrounded by mineral soil catchment areas with gentle slopes as shown in Fig. 1. The site was monitored for three open water seasons in the period 2006–2008. The first forest ditches were installed here during the 1970s and in June 2006 these ditches were renovated and some new ditches were added to improve drainage of Scots pine (*Pinus sylvestris*) stands. The area is continuously forested. The catchment areas represent good or medium productive peatland sites with closed canopy thinning stands dominated by Scots pine (*P. sylvestris*, L.). Occasional admixture of pubescent birch (*Betula pubescens* Erhr.) and Norway spruce (*Picea abies*, L.(Karst.)) exists."

The ditch system within the study area consisted of a linear channel network with an average drainage depth of 1 m, width 1–1.5 m and a ditch spacing of 35–40 m, which is typical for peatland forestry. Part of the channel network was ephemeral, with water depth fluctuating from a few centimetres to 1 m in the main drainage channel. The drainage channels extended into the mineral soil at several locations in the drainage network. The average gradient in the main drainage channels was 0.1–1%. The runoff water from the study areas was diverted to one main drainage channel at the outlet, which was sampled continuously.

The geology in the region is predominantly glacial till, peatlands and eskers. The study areas peat land is valley fen, which is surrounded by glacial eskers. The soil under peat layer is dominantly clay and fine lodgement till, which contains only slight of rocks. The bedrock is located approximately 0–10 m below the soil surface. The topography is characterised by gentle slopes with an altitude of 130–160 m in the study area. Mean annual precipitation is 613 mm, mean annual evaporation 400 mm and mean summer temperature 12 °C, the mean winter temperature −6 °C and the mean year temperature is 4 °C. The length of the thermal winter (mean temperature <0 °C) is 5 months and consequently 30–40% of precipitation falls as snow. The mean degree of decomposition of peat in the Virkosuo catchment is 3–6 according to the von Post scale (Hobbs, 1986), the porosity 0.75 and peat type varied from Sphagnum to Carex. The saturated hydraulic conductivity in the upper peat layers (10–100 cm) as determined with a direct push infiltrometer ranged from 4.2×10^{-4} to 2.42×10^{-7} m s^{-1} and peat depth ranged from 0.5 to 1 m.

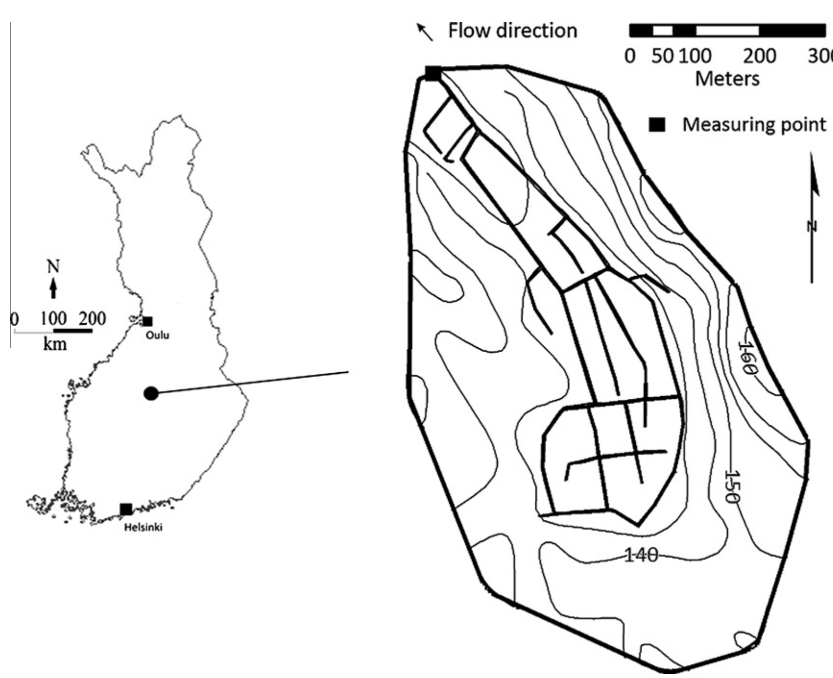

Fig. 1. Sketch of the Virkosuo study catchment.