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Channel processes following land use changes in a degrading steep headwater stream in North Island, New Zealand

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Abstract

In headwater streams in steep land settings, narrow and steep valley floors provide closely coupled relationships between geomorphic components including hillslopes, tributary fans, and channel reaches. These relationships together with small catchment sizes result in episodic changes to the amount of stored sediment in channels. Major sediment inputs follow high magnitude events. Subsequent exponential losses via removal of material can be represented by a relaxation curve. The influence of hillslope and tributary processes on relaxation curves, and that of altered coupling relations between components, were investigated along a 1.3 km reach of a degrading channel in the 4.8 km^2 Weraamaia Catchment, New Zealand. Extensive deforestation in the late 19th and early 20th centuries, followed by invasion of scrubs and reforestation, induced changes to major erosion types from gully complexes to shallow landslides. Changes in the size and pattern of sediment slugs from 1938 to 2002 were analysed from air photographs tied to detailed field measurement. The rate and calibre of sediment flux changed progressively following substantive hillslope input in a storm in 1938. Subsequently, the channel narrowed and incised, decoupling tributary fans from the main stem, thereby scaling down the size of sediment slugs. As a consequence, the dominant influence on the behaviour of sediment slugs and associated relaxation processes, changed from tributary fans to the type and distribution of bedrock outcrops along the reach.

Keywords: Channel morphology; Sediment slug; Relaxation process; Coupling processes; Land use change; Steep headwater catchments

1. Introduction

As headwater catchments are major sediment sources, interpretation of sediment delivery processes in these settings is a critical consideration in our understanding of basin-scale sediment dynamics. In steep land settings, particular attention must be given to various components of coupling relations (e.g., hillslope and channel, tributary fan and main stem, and reach to reach: Harvey, 2002), because their narrow and steep valley floors are likely to provide close linkages between geomorphic components (i.e., hillslope, tributary fan, and channel reach). Rates and texture of sediment yielded from hillslopes, tributaries and tributary fans can exert a major influence on channel processes by affecting the morphology, bed surface materials, and sediment availability along the channel course (Fukata et al., 1960; Rice, 1994, 1998; Buffington and Montgomery, 1999; Harvey, 2001).

Analysis of these geomorphic features in steep headwater catchments can also be used to characterize the episodic manner of sediment delivery processes. Narrow valley floors allow sediment to be directly transferred from outside the channels to inside. The small catchment areas

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often cannot generate flows large enough to transport the supplied sediment immediately, inducing major channel aggradation. Over time, as the amount of sediment input to the reach decreases, the amount of deposits gradually decreases due to the high sediment availability and steep and narrow valley floors that can produce sufficient transport capacity to rework deposits in subsequent floods. Decrease in the amount of available sediment is accompanied by the establishment of bedforms, coarsening of bed materials, and the development of armouring. Hence, decrease in flow and sediment input alters the sensitivity of the channel bed to change in its morphology (Whittaker and Davies, 1982; Bathurst, 1985; Abrahams et al., 1995; Madej, 2001; Lisle and Church, 2002), leading to an exponential regression trend in the amount of stored sediment (i.e. a relaxation curve: Chorley and Kennedy, 1971; Lisle and Church, 2002).

Although the package and coupling of geomorphic components in steep land settings is considered to work together to create an insensitive condition, as reflected in relaxation curves, most of the curves derived to date have been reported under conditions of negligible sediment supply from outside of the channel after the initial sediment input (Lisle and Church, 2002). This study examines the influence of coupling relations on relaxation curves, focussing on changes to the pattern of sediment slugs, or downsystem reach-to-reach coupling processes (Harvey, 2002). Sediment slugs are a mass of sediment released from channel beds. Their patterns differ depending on their size, which are largely associated with the degrees of coupling between geomorphic components (Hoey, 1992; Nicholas et al., 1995). For example, super-slugs occur when components are very well coupled in a catchment (Nicholas et al., 1995), which is often caused by mining (Gilbert, 1917; Pickup et al., 1983; Knighton, 1989; Marron, 1992) and clear-cutting (e.g., Trimble, 1983; Roberts and Church, 1986). They are large enough to alter the valley floor configuration (Nicholas et al., 1995), and the patterns are largely controlled by the amount of available sediment. Smaller-sized mega slugs are likely formed by sediment input from outside of the channel (e.g., hillslopes and tributaries; Nicholas et al., 1995). They alter bedforms at mega-scale (e.g., bar assemblages: Jackson, 1975; Church and Jones, 1982; Hoey, 1992) and the patterns are largely determined by the spatial arrangement of valley configuration (e.g., Church and Jones, 1982; Beschta, 1983; Macklin and Lewin, 1989; Madej and Ozaki, 1996). Macro slugs are even smaller-sized features, generally produced by reworking of mass deposits in a channel (Nicholas et al., 1995; Wathen and Hoey, 1998); that is, they can occur even when hillslope and channel processes are decoupled. They alter bedforms at macro-scale (Jackson, 1975; Church and Jones, 1982; Hoey, 1992), such as step-pools (Wohl and Cenderelli, 2000), riffle-pools (Kasai et al., 2004a,b), and bars (Wathen and Hoey, 1998), which, in turn, influence the subsequent pattern of sediment delivery and morphological change.

The distribution pattern of sediment slugs of each size can also be affected by forcing elements (Madej, 2001), such as bridges and gorges at mega-scale (Beschta, 1983), and bedrock outcrops, log jams, and boulders at macro-scale (Montgomery et al., 1996; Madej, 2001; Zimmermann and Church, 2001; Kasai et al., 2004a,b). Changes to the type and distribution of these controlling factors and forcing elements through morphological changes of each component alter coupling relations over time, impacting upon the subsequent pattern of sediment slugs as well as the efficiency of sediment conveyance, as reflected in the relaxation curve.

This study was carried out along a 1.26 km channel reach in the Weraamaia Catchment (Fig. 1), on the North Island of New Zealand (catchment area: 4.8 km^2), where recent changes in land use exerted a major influence upon hillslope processes. Kasai et al. (2005) generated a catchment sediment budget for this system, highlighting how changes to the dominant type of hillslope erosion affected channel morphology and coupling relations in tributaries and the main stem. That work provides a background to this study, which focuses on channel adjustments along the main stem.

2. Study site

The Weraamaia Catchment is one of the tributaries of the Mangaoporo River, which in turn drains into the Waiapu River (catchment area: 1734 km^2) (Fig. 1). It is located within the East Coast region of the North Island of New Zealand, close to the edge of the Australian Plate under which the Pacific Plate is subducting. Numerous phases of folding and faulting make the lithology of the region complex and weak (Mazengarb and Speden, 2000). Ninety percent of the Weraamaia Catchment consists of Late Cretaceous to Paleocene crushed and weathered sandstone and mudstone (Whangai Formation), on which extensive gully complex activity has been reported (DeRose et al., 1998; Mazengarb and Speden, 2000). The remaining 10% of the catchment on the northern edge is underlain by indurated sandstone and mudstone (Tapuaweroa Formation), which are also prone to gully complex activity (Mazengarb and Speden, 2000; Betts et al., 2003).

Average annual rainfall at Ruatoria, located about 10 km away from the study catchment (Fig. 1), is 1800 mm year^{-1} (Gisborne District Council). A storm in 1938 (762 mm rainfall in 30 h in Ruatoria) and Cyclone