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Impacts of land use conversion on bankfull discharge and mass wasting

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Abstract

Mass wasting and channel incision are widespread in the Nemadji River watershed of eastern Minnesota and northwestern Wisconsin. While much of this is a natural response to glacial rebound, sediment coring and tree ring data suggest that land use has also influenced these erosional processes. We characterized land use, inventoried mass wasting, surveyed stream channels and collected discharge data along segments of five streams in the Nemadji River watershed. Due to natural relief in this region, wetlands and agricultural lands are concentrated in the flatter terrain of the uplands of the Nemadji watershed, while forestland (coniferous or deciduous) is concentrated in the deeply incised (50–200% slope) stream valleys. Bankfull discharge was higher where forests had been converted from coniferous to deciduous forests and where there were fewer wetlands. Mass wasting increased exponentially with bankfull flows. While mass wasting was not correlated with forest type conversion and agricultural land use, it was negatively dependent upon wetland extent in headwater areas. Interactions between the spatial distribution of land use and terrain obfuscate any clear cause-and-effect relationships between land use, hydrology and fluvial processes.
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1. Introduction

The Nemadji River watershed encompasses 1110 km^2 of eastern Minnesota and northwestern Wisconsin (Fig. 1). This region, dominated by lacustrine clay deposits, glacial till, and beach sands, is naturally unstable and extremely erosive. The Nemadji River transports an average of 120,000 tons of sediment to Lake Superior annually (NRCS, 1998a). This is the largest source of sediment to Lake Superior, second only to lake bluff erosion (Stortz and Sydor 1976). Much of the Nemadji's sediment load is the result of a natural erosional response to active geologic uplifting and climate. However, sediment core analyses from the neighboring St Louis River delta in Lake Superior indicate that the rate of alluvial sediment deposition has increased in the past 150 years (Kingston et al., 1987). The onset of this increase in the mid to late 1800s coincided with intensive forest harvesting across the St Louis and Nemadji watersheds. Kemp et al. (1978), using a combination of *Ambrosia* pollen analysis and lacustrine sediment dating, determined that the sedimentation rates of western Lake Superior, near the outlet of the Nemadji River, have increased from 0.89 mm/year during the pre-historic, post-glacial period to 2.00 mm/year from 1890 to 1955. During this period, the Nemadji River watershed experienced intensive forest harvesting, two major forest fires (Hinckley Fire 1894, Moose Lake Fire 1918) and conversions to agricultural land use in the early 1900s.

Results from dendrochronological analysis of trees on floodplains, terraces and relic channels in the Nemadji watershed revealed that episodes of channel incision co-occurred with forest harvesting in the 1850s, forest fires in 1894 and 1918, and agricultural expansion in the 1930s and 1950s (Riedel et al., 2001; Verry, 2000). Fitzpatrick (1999) reported a similar pattern of fluvial response following widespread forest harvesting and agricultural land use conversion in the Fish Creek watershed, located

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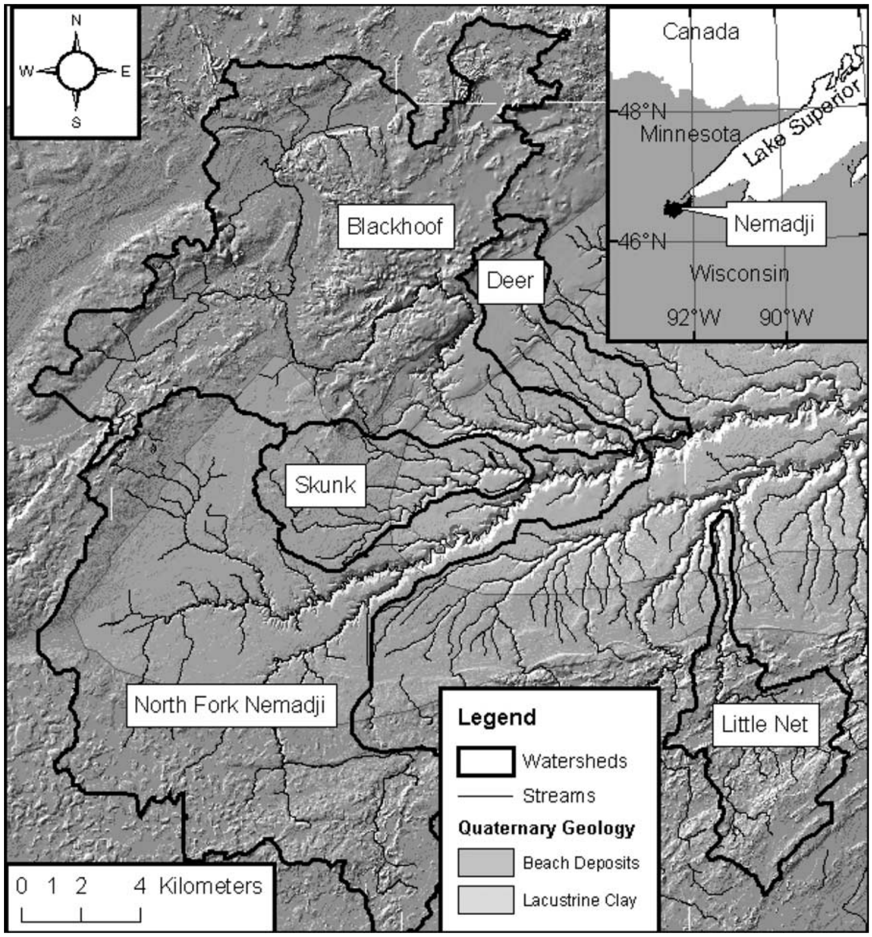

Fig. 1. Location of Nemadji River watershed, study sites and watershed boundaries. Lacustrine clay and beach deposits are from glacial lakes Duluth and Nemadji.

approximately 160 km east of the Nemadji watershed. This co-occurrence of land use change and increased sedimentation rates suggest that erosional processes in this region respond to land use change. Our objectives were to determine: first how differences in land use, through alteration of hydrologic regime, explain differences in bankfull discharge; second, to determine how differences in bankfull discharge affect mass wasting and third, determine if there is empirical evidence of a causal link between land cover and mass wasting in the Nemadji River watershed.

The conversion of a forested landscape from one forest type to another or, from forest to non-forest, changes the hydrologic regime of a watershed. Perhaps the most significant change results from differences in evapotranspiration (interception and transpiration) losses between various vegetation types, as summarized by Calder (2002), Whitehead and Robinson (1993) and Bosch and Hewlett (1982). Land management practices, such as forest harvesting and conversion to agriculture, which reduce interception capacity and vegetative transpiration typically increase water yield (Sun et al., 2004). The magnitude of water yield increase is dependent upon the scale of the forest harvesting or conversion. Clear-cutting hardwood and coniferous forests in boreal forests of the Great Lakes region increased annual stream-flow by 30–80% during wet and dry years, respectively, (Verry, 1986). The conversion of mature pine forests (*Pinus* spp.) to aspen (*Populus* spp.) increased net annual precipitation by 15% by simply reducing the canopy interception of rainfall and snowfall (adapted from Verry, 1976). Murray and Buttle (2003) reported similar results following the clear-cut of a northern hardwood forest in Ont., Canada. Snow accumulation and snow water equivalents were higher on the clear-cut sites. The larger snow packs melted faster, increasing the volume and rate of spring runoff.

Trimble and Weirich (1987) investigated water budgets in the southern United States ranging in size from 2820 to 19,450 km^2 and concluded that 10–28% increases in forest cover reduced annual water yield by 4–21% (3–10 cm). On average, this translated to a 0.3 m^3 reduction per square meter of reforestation. Land use conversions from coniferous to deciduous forests or from forested to non-forested cover types reduce interception and transpiration losses, causing soil moisture to increase and raising water table elevations (Sun et al., 2004; Whitehead and Robinson, 1993; Bosch and Hewlett, 1982). Over the past 150 years,