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Long-term impacts of land cover changes on stream channel loss

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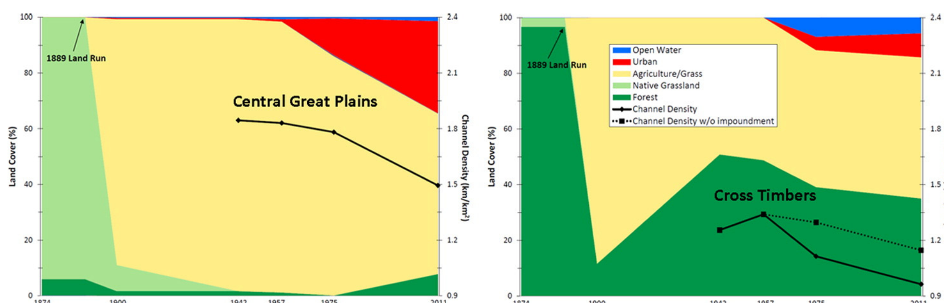
HIGHLIGHTS

- Land use changes lead to stream channel losses characteristic of type of land use
- Over 70 years, 244.8 km of channel (25%) was lost in the 666-km^2 watershed
- Two dams caused the most rapid loss, eliminating 71 km of channel over just 5 years
- Most channel loss was linked to agriculture, but urban losses are increasing

GRAPHICAL ABSTRACT



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ABSTRACT

Land cover change and stream channel loss are two related global environmental changes that are expanding and intensifying. Here, we examine how different types and transitions of land cover change impact stream channel loss across a large urbanizing watershed. We present historical land cover in the 666-km^2 Lake Thunderbird watershed in central Oklahoma (USA) over a 137 year period and coinciding stream channel length changes for the most recent 70 years of this period. Combining these two datasets allowed us to assess the interaction of land cover changes with stream channel loss. Over this period, the upper third of the watershed shifted from predominantly native grassland to an agricultural landscape, followed by widespread urbanization. The lower two-thirds of the watershed changed from a forested landscape to a mosaic of agriculture, urban, forest, and open water. Most channel length lost in the watershed over time was replaced by agriculture. Urban development gradually increased channel loss and disconnection from 1942 to 2011, particularly in the headwaters. Intensities of channel loss for both agriculture and urban increased over time. The two longest connected segments of channel loss came from the creation of two large impoundments, resulting in 46 km and 25 km of lost stream channel, respectively. Overall, the results from this study demonstrate that multiple and various land-use changes over long time periods can lead to rapid losses of large channel lengths as well as gradual (but increasing) losses of small channel lengths across all stream sizes. When these stream channel losses are taken into account, the environmental impacts of anthropogenic land-use change are compounded.

1. Introduction

Stream channels provide many goods and services, including flood control, navigation, recreation, water supplies, aquatic/riparian habitat, and the transformation and transportation of nutrients, organic matter

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and sediments (Allan and Castillo, 2007; Freeman et al., 2007; Meyer et al., 2003). Losses of stream channels thus alter water and nutrient cycles, water quality, ecosystem function, and sustainability. The broadest contemporary impact on stream channel loss has been land use change (Paul and Meyer, 2001; Allan, 2004). Diversion, piping, and burial of stream channels are all common causes of stream loss during land development (Meyer and Wallace, 2001; Walsh et al., 2005; Elmore and Kaushal, 2008; Wild et al., 2011). Other needs to support urban and agricultural development (water supply, flood control, recreation) have led to the impoundment of stream channels for reservoirs and the excavation of ponds, which have also resulted in extensive channel loss (Graf, 1999; Pringle et al., 2000).

Several recent studies have quantified stream channel loss, but they have focused on one land use type. For example, Elmore and Kaushal (2008) detailed how urbanization in the Baltimore (Maryland, USA) metropolitan area resulted in 66% channel loss. Similarly, Roy et al. (2009) found that 93% of ephemeral and 43% of intermittent streams, respectively, were lost during the development of the Cincinnati (Ohio, USA) metro region. And Napieralski et al. (2015) recently found that some watersheds around Detroit (Michigan, USA) have lost all their streams from urbanization. Stammler et al. (2013) found a 13% loss of streams in row-crop dominated Ontario, CA. All of these researchers focused on one specific land use and did not examine how channel loss was influenced by the other historical land uses in the watershed. Our study examines stream loss due to the entire land use history in an effort to identify patterns of stream loss characteristic of particular land use changes.

Land use change is not usually a one-step process. Rather, it involves a series of transitions (DeFries et al., 2004; Foley et al., 2005). The typical pattern in grassland landscapes is that initial clearing and replanting leads to small-scale farms and then intensive agricultural production, followed often by urbanization (Foley et al., 2005). The temporal pattern in forested landscapes is similar, although greater soil losses and flow modification usually occur from forest harvests (Bruijnzeel, 2004). While comprising a small percentage of total area, land conversions to open water are also a land use change contributing to channel loss. The creation of reservoirs through impoundment has converted tens to hundreds of kilometers of lotic ecosystems in some watersheds into lentic ecosystems (Ward and Stanford, 1983; Benke, 1990; Pringle et al., 2000). Understanding the patterns of impact to streams as a result of various land use changes gives insight into how to plan cities to avoid loss of ecosystem services and guide restoration efforts that ameliorate historic damage to stream ecosystems (Groffman et al., 2014; Steele and Heffernan, 2014; Steele et al., 2014).

The goal of this study was to assess the impacts of multiple land cover transitions on stream channel loss. We characterized land cover change over a century timescale and identified temporal and spatial patterns of stream channel loss associated with various land use changes. We selected a large, heterogeneous, mixed-land use watershed in order to capture a broad array of land cover changes and consequently a wide variety of channel changes. Our study area encompassed two distinct ecoregions, one forest and one prairie, which we analyzed separately. Based on our findings, as well as findings from other studies on land cover changes and channel changes, we present a conceptual model of stream channel network changes associated with historical land use changes. We believe this model has broad applicability to forest and grassland watersheds, but we expect this model to be revised with future studies from different regions that document different land use and channel changes.

2. Study area

We studied the 666-km^2 Lake Thunderbird watershed in central Oklahoma (Fig. 1) because it (1) had large areas of native forest and native grassland; (2) has experienced many different types of land use changes; (3) is large enough to have a wide range of channel sizes; and yet (4) is small enough to make stream mapping feasible at an intermediate resolution. The mainstem river in the watershed, the Little River, drains into the lower Canadian River and then to the Arkansas River before emptying into the Mississippi River.

The land cover of the watershed in 2011 was 36% agriculture, 41% forest, 17% urban, 5% water, and 1% barren and wetlands. The watershed drains portions of four large cities in central Oklahoma: Moore (to the west), Norman (to the southwest), and Oklahoma City and Midwest City (to the north). According to 2013 census estimates, the Oklahoma City metropolitan statistical area (MSA) had a population of 1.3 million, and is one of the fastest growing MSAs in the United States. The watershed has two large reservoirs, Lake Stanley Draper and Lake Thunderbird, completed in 1963 and 1965, respectively. Both reservoirs supply drinking water to the region, including the cities of Oklahoma City, Norman, Midwest City, and Del City. The reservoirs also offer recreation in the form of boating, fishing, and swimming, and Lake Thunderbird further provides flood control. Despite being a valuable regional water resource, Lake Thunderbird has several water quality issues including high turbidity, low dissolved oxygen, and high chlorophyll-a (ODEQ, 2013).

The watershed is bisected by two level III Ecoregions (Fig. 1; Woods et al., 2005). The Central Great Plains, covering the western/upper portion of the watershed (33% of its area), consists of mixed-grass prairie over scattered hills and riparian woodlands. The ecoregion has deep clay-rich soils underlain by Permian sedimentary rocks, and land use is a mix of rangeland and cropland, with urban centers located along major highways. The Cross Timbers ecoregion, covering the eastern/lower portion of the watershed (67% of its area), is dominated by dense, scrubby oak forests with some open woodlands. Eastern red cedar (*Juniperus virginiana*) is becoming more common in this ecoregion due to increased livestock grazing, fire suppression, and tree planting (Engle and Kulbeth, 1992; Woods et al., 2005; Ganguli et al., 2008). Soils are typically sandy, underlain by Pennsylvanian and

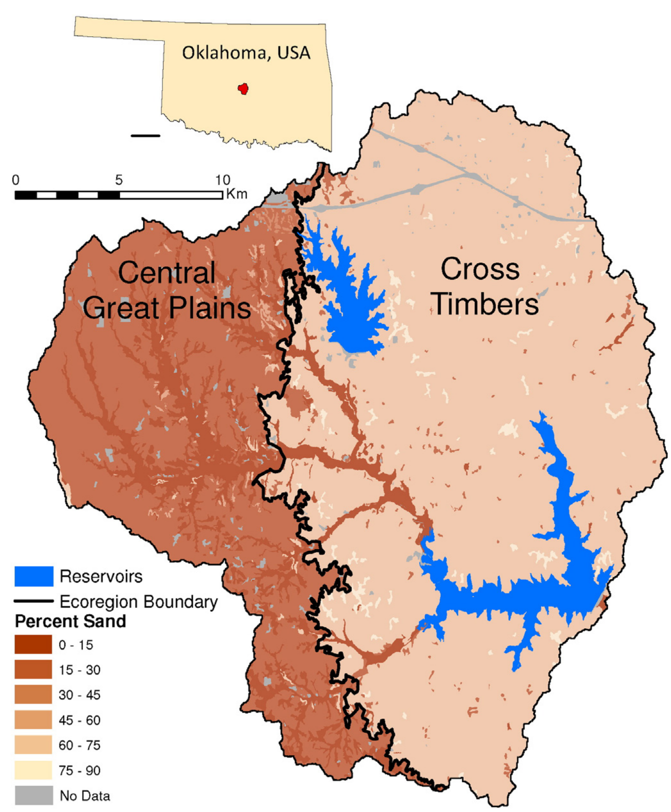

Fig. 1. Study area and ecoregions of the 666-km^2 Lake Thunderbird watershed in Central Oklahoma (USA). The Central Great Plains (left; 220 km^2) has clayey soils and is largely covered by mixed-grass prairie, whereas the Cross Timbers (right; 446 km^2) has sandy soils and is largely covered by scrubby oak forests.