Earth-Science Reviews 147 (2015) 30–53

Contents lists available at ScienceDirect

Earth-Science Reviews

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

Legacy effects on sediments in river corridors

Ellen Wohl

Department of Geosciences, Colorado State University, Fort Collins, CO 80523-1482, United States

A R T I C L E I N F O

Article history:
Received 20 February 2015
Accepted 4 May 2015
Available online 9 May 2015

Keywords:
Legacy sediment
Dams
Agriculture
Instream wood
Beavers
Contaminants

A B S T R A C T

Legacy effects on river sediments are those which alter the location and volume of sediments and/or presence of contaminants within the sediments as a result of human activities. This review broadens the typical definition of legacy sediments and discusses human activities that create legacy effects on sediments in terms of three categories: activities that reduce sedimentation within river corridors — defined as channels, floodplains and riparian zones, and hyporheic zones; activities that enhance sedimentation in river corridors; and activities that contaminate river sediments with diverse pollutants. People reduce sedimentation within river corridors via three basic mechanisms: reducing sediment supply to the river corridor through changes in land cover or by trapping and storing sediment within the river corridor; increasing the ability of a river to transport sediments downstream by either increasing water supply to the channel or reducing physical channel complexities that promote flow separation, hydraulic resistance, and sedimentation; and disconnecting channels from floodplains, which are typically sediment storage zones and sediment sources for the channel. Conversely, enhanced sedimentation within river corridors results from increased sediment supply from uplands or upstream river segments and from decreased ability of a river to transport sediments downstream. Contamination of river sediments can result from nearly every conceivable human activity within a drainage basin (e.g., deforestation, agriculture, urbanization, industrial facilities, wastewater treatment). Contaminants can also enter a drainage basin from sources outside the basin boundaries because of contaminant transport within the tissues of migratory animals and via atmospheric deposition. Because many contaminants travel adsorbed to sediments, these pollutants can be concentrated within river corridors by activities that enhance sediment deposition. Legacy effects on sediments are now ubiquitous and abundant within river corridors around the world and can continue to alter river form and function long after cessation of the human activity that created the legacy. River management must be informed by accurate knowledge of the distribution and characteristic of legacy effects on sediments and geoscientists can contribute specialized knowledge to understanding and managing these sediments.

Contents

http://dx.doi.org/10.1016/j.earscirev.2015.05.001

1. Introduction

A river is sometimes thought of as simply the active channel in which water and sediment are conveyed downstream. This is an unrealistically restrictive definition because most natural rivers interact continuously with the underlying hyporheic zone, the channel banks, and, during higher discharges, with the adjacent floodplain and riparian zone. Consequently, the focus here is on the river corridor, which includes the active or low flow channel(s), the floodplain and riparian zone, and the hyporheic zone.

As the topographic low points within any landscape, river corridors receive water, solutes, mineral sediment, and particulate organic matter from the entire landscape, as well as atmospheric deposition of precipitation, solutes, and particulates. Water provides the fundamental driving force that transports solutes and particulate materials downstream within river corridors, but surface and subsurface water fluxes are strongly influenced by diverse characteristics of the river corridor, including valley and channel geometry, vegetation and other biota, and human activities. This paper focuses on the effects of human activities on sediment dynamics within river corridors. Sediment dynamics includes sediment supply, the processes of entrainment, transport, erosion, and deposition, and the storage of sediment.

One of the particularly well-documented effects of human activities within drainage basins is to create *legacy sediment*. Although studies documenting this effect began more than a century ago (Marsh, 1864), the phrase *legacy sediment* has been used since 2004 (Novotny, 2004; James, 2013), but with differing meanings. The most common use refers to sediments deposited as a result of past human activities such as changes in land cover (Trimble, 1974) or construction of mill dams (Walter and Merritts, 2008), although the resulting sediment persists and continues to strongly influence river process and form. Here, a broader definition is used: legacy sediments are those for which the location, volume, and/or presence of contaminants result from past and contemporary human activities. This definition incorporates the idea of legacy contaminants and legacy pollution and incorporates the broader definition called for in James (2013), which extends beyond river corridors and excess sediment. Legacy effects on sediment also include how human activities have reduced sedimentation along river corridors. Contemporary human alterations are included because (i) defining the minimum time elapsed before a past human alteration becomes a legacy is arbitrary, (ii) many past activities that have substantially altered sediment dynamics within a particular river network continue at present, and (iii) contemporary alterations of river sediment constitute a legacy for the future. This broader examination of legacy effects on river sediments reflects the fact that human manipulation of river corridors and of the greater watershed can reduce or eliminate sedimentation within specific portions of a river corridor, enhance sedimentation, or contaminate sediments with diverse pollutants.

This paper reviews the evidence that human alteration of sediment dynamics is so ubiquitous and intensive that past and present human activities now dominate erosional, depositional, and geochemical processes in river corridors. Considering only the alteration of sediment transport and storage associated with dams, for example, as of 2006, the United States had nearly 8100 major dams (>15 m tall) and only an estimated 2% of river kilometers were not affected by flow regulation from dams (Graf, 2001, 2006). Globally, more than half of the major river basins are moderately to severely altered by flow regulation from dams and >48,000 major dams exist (Nilsson et al., 2005b; Syvitski and Kettner, 2011). Although human-induced soil erosion has increased the sediment transport of rivers by 2.3 billion metric tons per year (relative to estimated pre-human rates of 14 billion metric tons per year), sediment flux to the world's coasts has been reduced by 1.4 billion metric tons per year because of retention within reservoirs (Syvitski et al., 2005a,b). The cumulative effect of increased sediment supply to river networks and reduced sediment transport within river networks has been to create legacy-affected sediments along the vast majority of the world's river corridors.

This review covers three categories of legacy effects on river sediments – reduced sedimentation, enhanced sedimentation, and contaminated sedimentation – drawing on case studies from headwater channels to the world's major rivers and from widespread geographic locations. Although Earth scientists sometimes regard river corridors primarily from the perspective of physical process and form, river corridors are fundamentally ecosystems that sustain diverse aquatic and riparian biota and provide numerous ecosystem services (SCEP, 1970) to human communities. The implications of legacy effects on river sediments are particularly important in the context of ecosystem services. An integrated understanding of the human activities that result in legacy effects, as well as the characteristics of the resulting sediments, is critical to maintaining and restoring river ecosystem services.

Legacy effects on sediments can result from activities that occur across a broad range of temporal and spatial scales, and the resulting sediments also have widely varying spatial extents, rates of accumulation, and persistence within river corridors. Removal of a beaver colony and its dams may primarily reduce sedimentation within a portion of a river corridor that occupies only a few hectares (Westbrook et al., 2006), whereas construction of tens to hundreds of kilometers of levees can reduce overbank sedimentation along extensive portions of a large river corridor (Meade and Moody, 2010). Analogously, construction of a single milldam can enhance sedimentation over several hectares (Walter and Merritts, 2008), but widespread removal of native vegetation within the upland portion of a drainage basin can result in aggradation of valley bottoms along most of a river network (Trimble, 2013). Treatment of wastewater effluent that has contaminated river sediments with pathogens and excess nutrients can allow microbial processes to remove contaminants from sediments within less than a year (McClain et al., 2003a,b), but heavy metals or synthetic chemicals such as DDT and PCBs can persist at toxic levels within river sediments for decades to centuries (Eisler, 1986; Nowell et al., 2000).

Diverse types of legacy effects on river sediments can also result from a single human activity. This diversity can be primarily spatial: Construction of a dam, for example, can enhance upstream sedimentation in the backwater zone, concentrate contaminants adsorbed to silt and clay accumulating in the backwater, and result in reduced sedimentation downstream from the dam. Diversity in legacy effects from a single activity can also be primarily temporal: Removal of native vegetation can initiate asynchronous sedimentation and erosion between tributaries and mainstem or upstream and downstream portions of a river network (Trimble, 2013).

Mitigating the adverse effects of legacy-affected sediments on river corridors is not necessarily simple or rapidly accomplished, but better understanding of the conditions under which legacy effects alter river sediments is a starting point for effective management. Before discussing the ways in which human activities can alter sediment dynamics, I briefly review the concept of a balanced sediment regime.