Journal of Environmental Management 164 (2015) 67–73

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Review

On the apparent failure of silt fences to protect freshwater ecosystems from sedimentation: A call for improvements in science, technology, training and compliance monitoring

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ARTICLE INFO

Article history:
Received 15 May 2015
Received in revised form
11 August 2015
Accepted 24 August 2015
Available online xxx

Keywords:
Sediment control
Geotextile
Best practices
Mitigation
Aquatic habitat disturbance

ABSTRACT

Excessive sedimentation derived from anthropogenic activities is a main factor in habitat and biodiversity loss in freshwater ecosystems. To prevent offsite movement of soil particles, many environmental regulatory agencies mandate the use of perimeter silt fences. However, research regarding the efficiency of these devices in applied settings is lacking, and fences are often ineffective due to poor installation and maintenance. Here, we provide an overview of the current state of research regarding silt fences, address the current culture surrounding silt fence installation and maintenance, and provide several recommendations for improving the knowledge base related to silt fence effectiveness. It is clear that there is a need for integrated long-term (i.e., extending from prior to fence installation to well after fence removal) multi-disciplinary research with appropriate controls that evaluates the effectiveness of silt control fences. Through laboratory experiments, *in silico* modelling and field studies there are many factors that can be experimentally manipulated such as soil types (and sediment feed rate), precipitation regimes (and flow rate), season, slope, level of site disturbance, fence installation method, type of fence material, depth of toe, type and spacing of support structures, time since installation, level of inspection and maintenance, among others, that all require systematic evaluation. Doing so will inform the practice, as well as identify specific technical research needs, related to silt fence design and use. Moreover, what constitutes "proper" installation and maintenance is unclear, especially given regional- and site-level variation in precipitation, slope, and soil characteristics. Educating and empowering construction crews to be proactive in maintenance of silt fencing is needed given an apparent lack of compliance monitoring by regulatory agencies and the realities that the damage is almost instantaneous when silt fences fail. Our goal is not to dismiss silt fences as a potentially useful tool. Instead, we question the way they are currently being used and call for better science to determine what factors (in terms of fence design, installation and site-characteristics) influence effectiveness as well as better training for those that install, maintain and inspect such devices. We also encourage efforts to "look beyond the fence" to consider how silt fences can be combined with other sediment control strategies as part of an integrated sediment control program.

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http://dx.doi.org/10.1016/j.jenvman.2015.08.033
0301-4797/

1. Context

As a result of human activities freshwater biodiversity around the globe is in crisis (Dudgeon et al., 2006; Strayer and Dudgeon, 2010). Although there are many factors that contribute to the degradation of freshwater ecosystems, landscape alteration is regarded as one of the most insidious (Allan, 2004; Dudgeon et al., 2006). Human-driven landscape alterations (e.g., development, agriculture, mining) leads to dramatic changes in hydrology, water quality, and habitat configuration even when activities occur in the terrestrial realm away from water sources (Schlosser, 1991; DeFries and Eshleman, 2004; Allan, 2004). Changes to physicochemical characteristics of the environment (such as water temperature, flows, silt, and nutrients) alter biotic elements, including population abundance and community structure in aquatic systems (Paul and Meyer, 2001; Allan, 2004; Dudgeon et al., 2006). Of particular concern is the introduction of fine sediment from terrestrial sources that run off into lotic and lentic systems and have the potential to cause direct and indirect negative effects on aquatic biodiversity.

In aquatic systems, excessive sedimentation – herein inclusive of suspended sediment, siltation, and turbidity - has been named the most detrimental form of aquatic habitat degradation and its effects on aquatic wildlife is the subject of numerous comprehensive reviews (e.g. Newcombe and Macdonald, 1991; Waters, 1995; Henley et al., 2000; Robertson et al., 2006; Kemp et al., 2011). Land-use alterations change natural sedimentation processes, increasing fine sediment suspension and deposition (Waters, 1995), and the effects on aquatic ecosystems are extensively documented and generally undisputed. Increased inorganic sediment loading changes the physical habitat of aquatic ecosystems by altering water pH (Lemly, 1982), water clarity, and decreasing oxygen flow through substrate by in-filling of interstitial space between larger substrate materials (Beschta and Jackson, 1979). Such changes to the abiotic aspects of aquatic ecosystems have great implication for the biotic: suspended sediment decreases photosynthetic activity by blocking light (Newcombe and Macdonald, 1991; Madsen et al., 2001), limiting primary production, and can limit feeding at higher trophic levels (Zamor and Grossman, 2007), increase foraging demands (Gregory and Northcote, 1993; Utne-Palm, 2004), physically harm sensitive oxygen exchange tissue (Redding et al., 1987; Lake and Hinch, 1999) and alter filter feeding behaviour (Rundle and Hellenthal, 2000) in aquatic organisms, potentially increasing metabolic demands (du Preez et al., 1996). Once settled, deposited sediments can cause substrate to be unsuitable for spawning (Chapman, 1988), directly smother eggs (Greig et al., 2007), prevent emergence of fry (Jennings et al., 2010), and bury food sources for invertebrate species (Suren, 2005; Kent and Stelzer, 2008).

The amount of sediment transport increases dramatically during construction compared to pre- and post-construction levels (Cleveland and Fashokun, 2006). To minimize the movement of sediment off site, regulatory agencies require the use of sediment mitigation techniques during construction activities (Kerr, 1995; Harbor, 1999). Although there are a variety of sediment control measures and tools, silt fences are among the most commonly used. These geotextile systems consist of semi-permeable fabrics and/or composites that filter sediment. Silt fences are widely used because of their low cost, versatile application, and ease of installation and removal (Robichaud et al., 2001). Fences can also be easily customized in design and installation to best suit the conditions of the site, such as changes in type and placement of support stakes and type of geotextile used (Kouwen, 1990; USEPA, 2012). For any sediment control devices deployed, proper design, installation, and maintenance is key to their efficiency (Kouwen, 1990; Barrett et al., 1998; Gogo-Abide and Chopra, 2013).

Here we argue that silt control fences, despite being widely adopted, have failed to prevent silt from entering aquatic ecosystems. We submit that the science behind silt control fences is limited and that there are few rigorous assessments to identify the extent to which such controls actually reduce aquatic sediment mobilization. We also discuss the role of improper use and maintenance of silt control fences and limited compliance monitoring on silt mobilization. Given the manifold negative effects of silt on aquatic systems and our ability to pinpoint the source (i.e., largely point source – or at least identifiable), it would seem that we should be better able to address this pressing issue contributing to the degradation of aquatic ecosystems around the globe. To that end, we identify a number of improvements needed to advance the science, technology and practice of silt control.

2. The science of silt control

As new materials and designs emerge, studies on the performance efficiencies of silt fence installation design and fabrics are crucial. Generally, laboratory testing consists of a flume in which a portion of geotextile is drawn across tightly and secured (e.g. Barrett et al., 1998; Keener et al., 2007) and samples are collected pre- and post-material to assess efficiency of sediment concentration removal and changes in turbidity. Flow through-rate – the amount of time for sediment-laden water to pass through the material – is also measured: prolonged retention leaves silt fences vulnerable to failure due to overtopping, undermining or sediment diversion (Harbor, 1999; Keener et al., 2007). Under laboratory conditions, studies often report high removal efficacies compared to field studies (Crebbin, 1988; Kouwen, 1990; Chapman et al., 2014). For example, Barrett et al. (1998) found that flow through was two orders of magnitude less than values reported by manufacturers due to clogging of pores in the materials. The way geotextiles are installed in test flumes prevents any overtopping or undermining of the material, meaning that any efficiency results are only applicable when fences are perfectly installed and maintained. Indeed discrepancies between laboratory and field tests have been indicated by paired study designs (Barrett et al., 1998).

More testing of silt fence sedimentation rates in field settings is vital to assess realized efficiencies of this widely applied mitigation