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Review

Forest operations, extreme flooding events, and considerations for hydrologic modeling in the Appalachians—A review

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Abstract

The connection between forests and water resources is well established, but the relationships among controlling factors are only partly understood. Concern over the effects of forestry operations, particularly harvesting, on extreme flooding events is a recurrent issue in forest and watershed management. Due to the complexity of the system, and the cost of installing large-scale hydrologic studies, data are usually limited. Therefore, hydrologic models are employed to evaluate specific land use issues during extreme conditions. Our objectives were to review literature regarding: (1) relevant forest hydrology concepts, (2) the effects of silviculture and forest operations on peak discharges and flood yields, and (3) the suitability of existing modeling approaches for assessing these effects on extreme peak discharges. Numerous studies have shown that the effects of forest operations on streamflow vary, and that the influence of vegetation, soils, and land use on streamflow generation diminishes as larger volumes of water are introduced to the system. The most significant impact forest operations might have on extreme flows is by routing via poorly located and designed road networks. Extreme events appear to have different hydrologic controls than lower-flow events, and that sharp thresholds may exist between these paradigms. There are a large number of hydrologic models currently available that have been developed for a wide variety of applications. Issues such as uncertainty, overparameterization, extrapolation of flood data, and logistic issues limit the use of hydrologic models for evaluating the specific controls and outcome of land-use change on extreme peak discharges.

Keywords: Best management practices; Forest operations; Flooding; Watershed management; Hydrologic modeling

Contents

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1. Introduction

The impact of forestry practices, particularly harvesting, on flooding and site hydrology is a recurrent scientific, social, and political theme in watershed management (Lull and Reinhart, 1972; McCulloch and Robinson, 1993; Andreassian, 2004; Calder, 2006). Floods caused an estimated 90 billion dollars in damage in the United States during the 1990s (Pielke et al., 2002). The premise that forests and related land-use affect watershed hydrology is ancient (Lull and Reinhart, 1972; Keller, 1988; Andreassian, 2004). It seems that throughout history, people have perceived that floods were occurring with increasing frequency and devastation. That perception remains today, and may be true from a purely economic standpoint (Harr et al., 1975; Pielke et al., 2002; Yeo, 2002; DeWalle, 2003; FAO and CIFOR, 2005).

The impact of floods could be as much the result of exposure due to population pressures as changes in climate or the environmental impact of human activity. There is some evidence that the frequency of severe flooding may be increasing due to climate change and permanent large-scale changes in land use (Macklin and Lewin, 2003). In addition, there has been a slight upward trend in 1-day rainfalls greater than 50 mm in the US since the 1930s (Kunkel et al., 1999). Some attribute perceived increases in flood damage to the increased development within flood-prone areas, and conclude that there is little evidence of a connection between forest conversion and large-scale, extreme flooding (FAO and CIFOR, 2005; Calder, 2006). Therefore, the magnitude of the influence of land use on flooding, and its specific mechanisms, remains the focus of much research and debate throughout the world.

Regardless, there is little doubt that forests influence the storage and movement of water in watersheds. The removal of trees through harvesting, or conversion to other land uses, generally reduces water demand and will affect water yield particularly during the growing season. Soil disturbance, skid trails, and road systems may alter hillslope hydrology and flow routing to rivers and streams (Megahan, 1972; Wemple et al., 1996; Sidle and Onda, 2004; Ziegler et al., 2004; Sidle et al., 2006b). Changing the timing and magnitudes of hillslope runoff in response to storms may in turn increase the frequency and magnitude of local and regional floods. Despite centuries of scientific observations and research inspired by significant flooding events, many aspects about the relationship between land-use and flooding, in particular extreme flooding, remain unresolved.

Hydrologists commonly define floods as any flow event that exceeds the normal banks of a river or stream (Jarvis, 1936; Leopold and Maddock, 1954). Floods are also defined by their return period or relative frequency as the maximum event for a given year in the long term (Barrows, 1948). Hydrologic research has traditionally been directed at studying frequent, minor to moderate flood events. In contrast, the public perception of floods is often restricted to more extreme events that result in loss of life or property. Significant public and political pressure to prevent future events often follows large, damaging floods and forest protection is regularly a centerpiece of any action plan (Miller, 1997; FATT, 2002; Brzozowski, 2004; FAO and CIFOR, 2005; Calder, 2006). The perceived importance of forests as a primary mechanism for comprehensive flood protection is at the core of new litigation against forest landowners claiming that harvesting activities increase risks for major floods (Mortimer and Visser, 2004).

A general misunderstanding regarding the nature of forest hydrologic function has been propagated by over-simplifications of the water cycle (Keller, 1988; Miller, 1997; FAO and CIFOR, 2005; Calder, 2006). This is coupled with an innate political need to take action in response to natural disasters. Unfortunately, most of what is known about the functional connection between forests and flooding is restricted to information based on non-extreme events. It is possible, if not probable, that information garnered from lesser events may apply to extreme events, which may be subject to entirely different hydrologic controls (Hawkins, 1993; Gaume et al., 2003, 2004; Lavigne et al., 2004). The infrequency of extreme floods, and the effort required to properly instrument watershed studies, has severely limited reliable scientific information about extreme events. As a result, hydrologic modeling has been used to estimate flood characteristics, but results have not always been satisfactory.

The objectives of this review paper are to explore (1) relevant forest hydrology concepts, (2) the effects of silviculture and forest land uses on flooding, and (3) to evaluate the suitability of existing models and modeling approaches for assessing the effects of forest practices on flooding, and in particular extreme peak discharges (return periods of 50–500 years). Although general concepts and a variety of results will