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Conversion to drip irrigated agriculture may offset historic anthropogenic and wildfire contributions to sediment production

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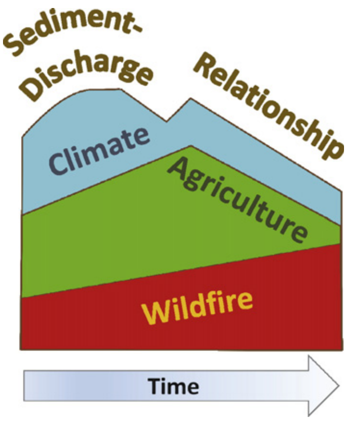
HIGHLIGHTS

- Suspended sediment concentrations decreased despite increasing burn area.
- Rapid conversion from sprinkler/furrow to drip irrigation occurred over this time.
- Irrigation changes seem to have obscured wildfire influenced sediment production.

GRAPHICAL ABSTRACT



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ABSTRACT

This study is an investigation into the roles of wildfire and changing agricultural practices in controlling the interdecadal scale trends of suspended sediment production from semi-arid mountainous rivers. In the test case, a decreasing trend in suspended sediment concentrations was found in the lower Salinas River, California between 1967 and 2011. Event to decadal scale patterns in sediment production in the Salinas River have been found to be largely controlled by antecedent hydrologic conditions. Decreasing suspended sediment concentrations over the last 15 years of the record departed from those expected from climatic/hydrologic forcing. Sediment production from the mountainous headwaters of the central California Coast Ranges is known to be dominated by the interaction of wildfire and large rainfall/runoff events, including the Arroyo Seco, an ~700 km^2 subbasin of the Salinas River. However, the decreasing trend in Salinas River suspended sediment concentrations run contrary to increases in the watershed's effective burn area over time. The sediment source area of the Salinas River is an order of magnitude larger than that of the Arroyo Seco, and includes a more complicated mosaic of land cover and land use. The departure from hydrologic forcings on suspended sediment concentration patterns was found to coincide with a rapid conversion of irrigation practices from sprinkler and furrow to subsurface drip

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irrigation. Changes in agricultural operations appear to have decreased sediment supply to the Salinas River over the late 20th to early 21st centuries, obscuring the influence of wildfire on suspended sediment production.

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1. Introduction

1.1. Watershed sediment flux

Fluvial suspended sediment fluxes from developed watersheds in semi-arid environments are influenced by natural and human induced changes to the land surface that interact with extremely variable climatic regimes. Environmental monitoring and sedimentary records indicate that fluvial sediment flux dynamics often exhibit temporal dependence over event to inter-decadal time scales, particularly in arid to semi-arid climates (Morehead et al., 2003; Walling and Fang, 2003; Syvitski et al., 2005; Gao et al., 2013; Gray et al., 2015b). However, attributing changes in sediment regimes to a discrete cause is often complicated by the overprinting of many external drivers and internal dynamics that affect watershed scale sediment production and transport, which tend to obscure the effects of individual forcing factors (Walling, 1977; Syvitski et al., 2000). Furthermore, factors affecting watershed scale sediment production operate over a wide range of time scales, with even seemingly discrete events generating legacy effects that may last for years or decades (Warrick et al., 2012; Warrick et al., 2013; Gray et al., 2014). Semi-arid basins in particular have been found to display persistent dependence on climatically driven antecedent basin conditions, such as storm/flood and wildfire histories (Abraham, 1969; Tanji et al., 1980; Lenzi and Marchi, 2000; Lana-Renault et al., 2007; Warrick and Rubin, 2007; López-Tarazón and Vericat, 2011; Gray et al., 2015a). The addition of human influences further complicates sediment flux controls in the highly developed portions of the world that are the most intensively studied (Walling, 2006; Syvitski and Milliman, 2007).

Thus, elucidation of temporal dependence in the suspended sediment dynamics of a highly developed, semi-arid basin is a forensic exercise of implicating and eliminating a host of potential controls. For this reason, when discrete controls on sediment dynamics are discovered in a given watershed it is often the result of scenarios where proportionally large areal disturbances have dominated the sediment response of relatively small (area < 1000 km^2) watersheds. In this way, wildfire (Florsheim et al., 1991; Cerdà, 1998; Lavé and Burbank, 2004; Warrick et al., 2012), urbanization (Wolman and Schick, 1967; Trimble, 1997; Warrick and Rubin, 2007), and agriculture (Gao and Pasternack, 2007; Abaci and Papanicolaou, 2009; Estrany et al., 2009; Florsheim et al., 2011) have been found to exert significant control on fluvial sediment flux. However, understanding the fluvial sediment dynamics of most systems over inter-decadal time scales requires the disentanglement of multiple controls, particularly at larger spatial scales.

1.2. Internal and external controls

The most important external driver controlling inter-decadal scale sediment flux is regional climate, which interacts with internal factors such as geological substrate and topography to influence internal processes such as geomorphic evolution, soil development, vegetation assemblages, and fire frequency (Syvitski et al., 2000). The interaction of vegetation, topography and interannual to decadal scale climatic expression also largely determines wildfire regimes (Pyne et al., 1996). Sediment flux generally rises after wildfire due to increases in the erodibility of hillslope surfaces through the removal of vegetation and litter layers, destabilization of soil aggregates by organic matter combustion, and increases in soil mantle slides or overland flow due to the development of subsurface and surface soil hydrophobicity, respectively (Debano and Krammes, 1966; Keller et al., 1997; DeBano, 2000; Gabet, 2003). In systems experiencing dry seasons, such as much of the Western U.S., this results in down-slope dry-ravel transport through gravity alone (Swanson, 1981; Jackson and Roering, 2009; Lamb et al., 2011; Hubbert et al., 2012). Soil heating can also cause hydrophobicity increases in the soil surface that, along with decreases in interception and evapotranspiration, cause increases in surface runoff during the wet season (Shakesby and Doerr, 2006). Increased surface runoff further exacerbates erosion from the destabilized hillslope. Indeed, the timing of high-intensity precipitation plays a large role in post-fire sediment flux augmentation (Inbar et al., 1998; Warrick et al., 2012; Staley et al., 2014). Large storms produce precipitation intensities and volumes sufficient to traverse runoff regimes, from sheet flow, to rill and gully erosion, and mass wasting, which can very effectively erode wildfire destabilized hillslopes (Cannon, 2001; Moody et al., 2008). With increasing elapsed time between wildfire and high intensity precipitation events, hillslopes generally re-vegetate, re-stabilize, and yield less sediment for a given precipitation magnitude (Inbar et al., 1998; Cerdà and Lasanta, 2005; Malmon et al., 2007; Warrick et al., 2012), although decadal scale legacies of individual fires have been reported (Sass et al., 2012).

Humans have caused pre-historic to historic increases in global sediment flux due largely to agriculture and deforestation (Wolman and Schick, 1967; Beschta, 1978; Milliman and Meade, 1983; Pasternack et al., 2001; Piegay et al., 2004; Syvitski et al., 2005; Walling, 2006; Weston, 2014). This phenomenon has generally been followed by a rapid decrease in sediment flux during the 20th century, primarily from river impoundment, and to a lesser degree changes in agricultural practices and afforestation (Vorosmarty et al., 2003; Walling, 2006). Changes in agricultural practices over the last century have in many cases led to decreases in off-field sediment transport with the implementation of soil conservation practices, including changes to less erosive irrigation techniques (Carter et al., 1993; Koluvek et al., 1993; Tomer et al., 2010; Wilson et al., 2014). Flow regulation (i.e. damming) causes declines in basin scale sediment yield by trapping sediment in reservoirs and altering the natural flow regime, particularly through reduction of peak flood discharge magnitudes (Pasternack et al., 2001; Vorosmarty et al., 2003; Willis and Griggs, 2003; Walling and Fang, 2003; Walling, 2006; Warrick and Rubin, 2007; Estrany et al., 2009). After an initial spike during construction, urbanization can also lead to sediment load decreases with the increase in the cover of impervious surfaces (Wolman, 1967; Wolman and Schick, 1967; Warrick and Rubin, 2007; Minear, 2010). Conversely, extensive urbanization can act to increase sediment yield by altering basin scale precipitation – discharge characteristics (i.e. hydrologic response); for example shortening the time to peak flow, decreasing total flow duration, increasing peak magnitude, and increasing total runoff volume (Espey, 1969; Hollis, 1975; Trimble, 1997; Warrick and Rubin, 2007).

1.3. Assessment of sediment controls

Due to the difficulty and expense of collecting samples, fluvial suspended sediment flux is usually estimated on the basis of infrequent sediment monitoring coupled with more frequent or even continuous discharge monitoring (Horowitz, 2003). The most common technique is to compute sediment concentration (C_{SS})-discharge (Q) rating curves using log-linear regression or non-parametric localized regression methods such as LOESS (Walling, 1977; Walling and Webb, 1988; Tananaev, 2013). Anthropogenic disturbances and wildfire will alter C_{SS}-Q relationships if they result in disproportionate changes in the magnitude and/or timing of the supply of sediment or water relative to one another (Warrick, 2014).

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