Effects of rain-on-snow events on suspended-sediment loading in the Truckee River Basin, California: Implications for water quality and aquatic habitat

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Introduction

Mountain drainages in the eastern Sierra Nevada are defined as snowmelt-dominated hydrologic systems in which the annual flood typically occurs in the spring with peak snowmelt runoff (Kattelmann 1996). In recent decades, however, mid-winter rain-on-snow events have resulted in the highest annual peak floods in the Truckee River Basin. McCabe et al. (2007) highlighted an increase in rain-on-snow events in high elevation areas of the western United States over the last 35 years and suggested very little is known about the relative importance of rain-on-snow events on fluvial processes including sediment transport or loads. In our research, we measured suspended-sediment loads in the Truckee River and several different tributaries and quantified loads for rain-on-snow driven events and compared them to loads for spring snowmelt runoff events.

Background

The Truckee River harbors several aquatic species of concern, including the federally-listed Lahontan cutthroat trout, that rely on clean gravels to support spawning habitat and macro-invertebrate food sources. The Truckee River is also a primary source of water for both municipal water supply, and irrigation for downstream communities in Nevada. Water quality is vital for continued uses. In Lake Tahoe, the delivery of fine-grained sediment from tributary basins is listed as a major cause of water-clarity deterioration in the lake (Simon 2008). The Middle Truckee River, between Lake Tahoe downstream to the Nevada-California state line was listed as impaired by fine-sediment concentration in 1994. A result, a Total Maximum Daily Load (TMDL) was established in 2008 under the Clean Water Act, Section 303(d). Kulchawik et al. (2014) evaluated bed sedimentation in the Middle Truckee River, downstream of Lake Tahoe, over a multi-year period and found fine sediment filling pool habitat and an overall fining of the bed with an increase in the sand fraction of fluvial sediment. Herbst et al. (2013) found that fine sediment in the Middle Truckee River reduced macroinvertebrate species diversity, altered food web function, and modified the abundance and types of aquatic life that inhabit the river. Given these resources, management actions to control fine sediment sources and reduce potential increases to fine sediment loading in the Truckee River Basin are imperative in preparation for conditions under current and future climate change conditions.

Sierra Nevada rivers are most often viewed as snowmelt-dominated systems, and habitat is most affected by fine sediment, so regional studies have primarily focused on the role snowmelt runoff has had on the annual suspended-sediment load (Dana et al. 2004, Langlois et al. 2005). However, a few studies (Costa and O'Connor 1995, Kattelmann 1996, Inman and Jenkins 1999) have shown that the majority of suspended sediment load carried by a river in eastern California is usually transported during one or few extreme events. Under current climate change models for the Sierra Nevada Mountains of California, average precipitation is not expected to change; however, minimum and maximum temperatures are expected to rise and result in more precipitation as rain instead of snow (Coats 2010, Jepsen et al. 2016). This is likely to increase the frequency of rain-on-snow events, often characterized as extreme events. Extreme or episodic events, while typical in mountain drainages of the eastern Sierra Nevada, have implications for channel geomorphology, aquatic habitat and water quality if they become more frequent. We examine suspended-sediment load dynamics between rain-on-snow event and snowmelt runoff events in order to better understand how changing climate and potentially more frequent extreme events may affect fine-sediment loading and habitat under present and future conditions.

Methods

This research originated from several separate monitoring projects funded to support implementation of the TMDL for fine sediment in the Middle Truckee River watershed. Funders included the Truckee River Watershed Council, California Department of Water Resources (DWR), National Fish and Wildlife Foundation (NFWF), California Department of Fish and Wildlife (CDFW), Town of Truckee, and Placer County.

Near-continuous streamflow and turbidity gaging stations were installed on 3 perennial tributaries to the Truckee River near Truckee, California (Cold Creek, Middle Martis Creek, and West Martis Creek). In addition, a near-continuous turbidity instrument was co-located with U.S. Geological Survey (USGS) streamflow gaging station on the mainstem Truckee River near Truckee, California (USGS 10338000). The mainstem Truckee River flows out of Lake Tahoe, and though the contributing watershed includes Lake Tahoe, runoff and sediment delivery to the gaging station is most influenced by the 119 km^2 watershed downstream of the lake, since the lake outflow is regulated by the Tahoe City Dam. Within this effective watershed, elevations range between 1792 m and 2745 m. Tributary stations are located downstream of the mainstem Truckee River station and include watersheds that range between 10.6 km^2 and 32.6 km^2 and between 1780 m and 2728 m in elevation (Figure 1).

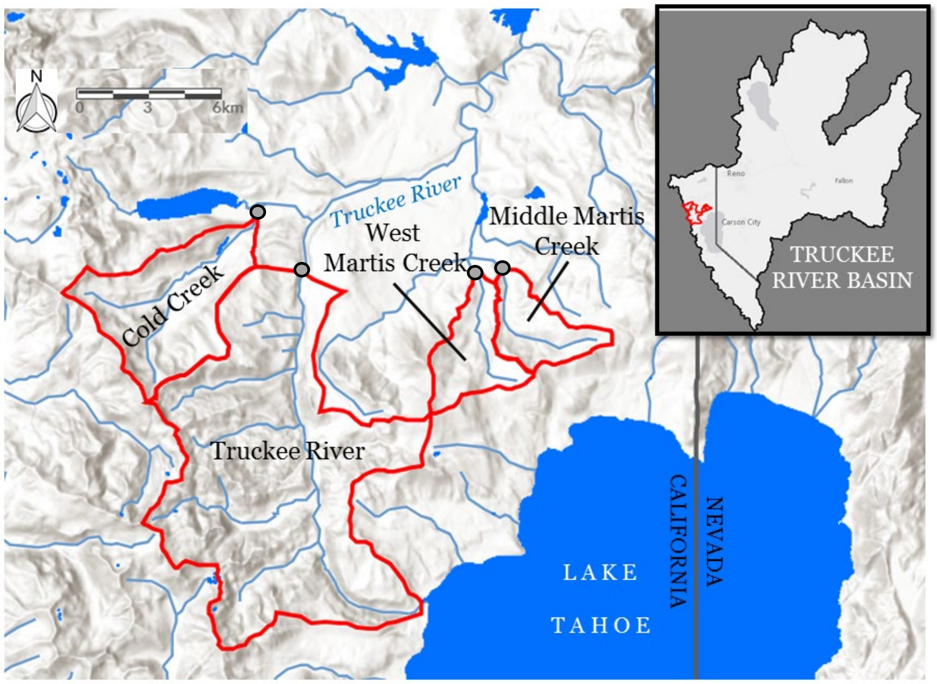

Figure 1. Study Location, Truckee River Basin, California

Data were collected between water year 2011 (WY2011) and WY2017, but not all stations were operated during the same period. Total precipitation and snowpack in WY2012, WY2013, WY2014, WY2015 was below average, so these are considered as dry years; WY2016 was an average precipitation year, and WY2011 and WY2017 were above-average (wet) years. Near-continuous turbidity was measured at all stations. Suspended-sediment samples were collected over a range of hydrologic conditions, during different times of the year, and over multiple years to develop correlations between instantaneous turbidity and suspended-sediment concentration to calculate estimated suspended-sediment loads. Sampling emphasis was placed on peak flows occurring during rain-on-snow events and snowmelt runoff. In some instances, discharge-based suspended-sediment rating curves were also used to compute loads.

Results and Discussion

Data evaluated under this study were collected during water years that ranged from extremely dry (WY2014 and WY2015, 23% of long-term, average annual runoff) to extremely wet (WY2017; 180% of long-term, average annual runoff) as measured at a long-term USGS streamflow gaging station (Sagehen Creek near Truckee, California; USGS 10343500). We measured between 2 and 5 rain-on-snow events in each water year with durations lasting from several hours to a several days. Duration of snowmelt runoff periods ranged between 37 days (WY2012) and 102 days (WY2017) (Figure 2).

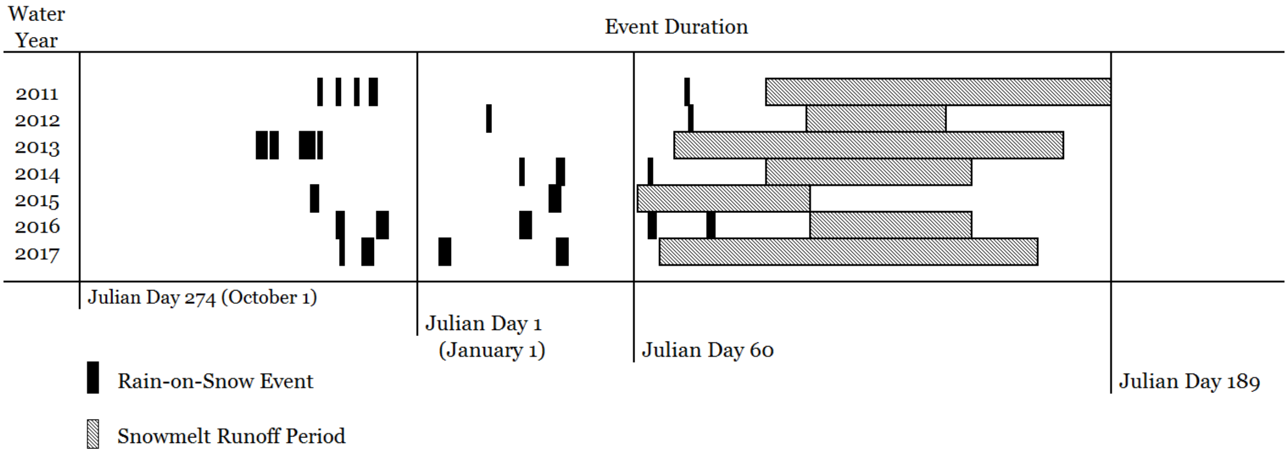

Figure 2. Duration and frequency of rain-on-snow events and snowmelt runoff periods, Truckee River Basin, water years 2011-2017

Suspended-sediment loads during rain-on-snow events exceeded suspended-sediment loads measured during snowmelt runoff periods in 4 of the 7 years at one or more stations in this study (Figure 3). For instance, the Truckee River exhibited higher suspended-sediment loads from rain-on-snow events relative to loads measured from snowmelt runoff in 3 of the 4 years measured. In those years, loads measured from rain-on-snow events exhibited a 2- to 25-fold increase over loads measured from snowmelt runoff.

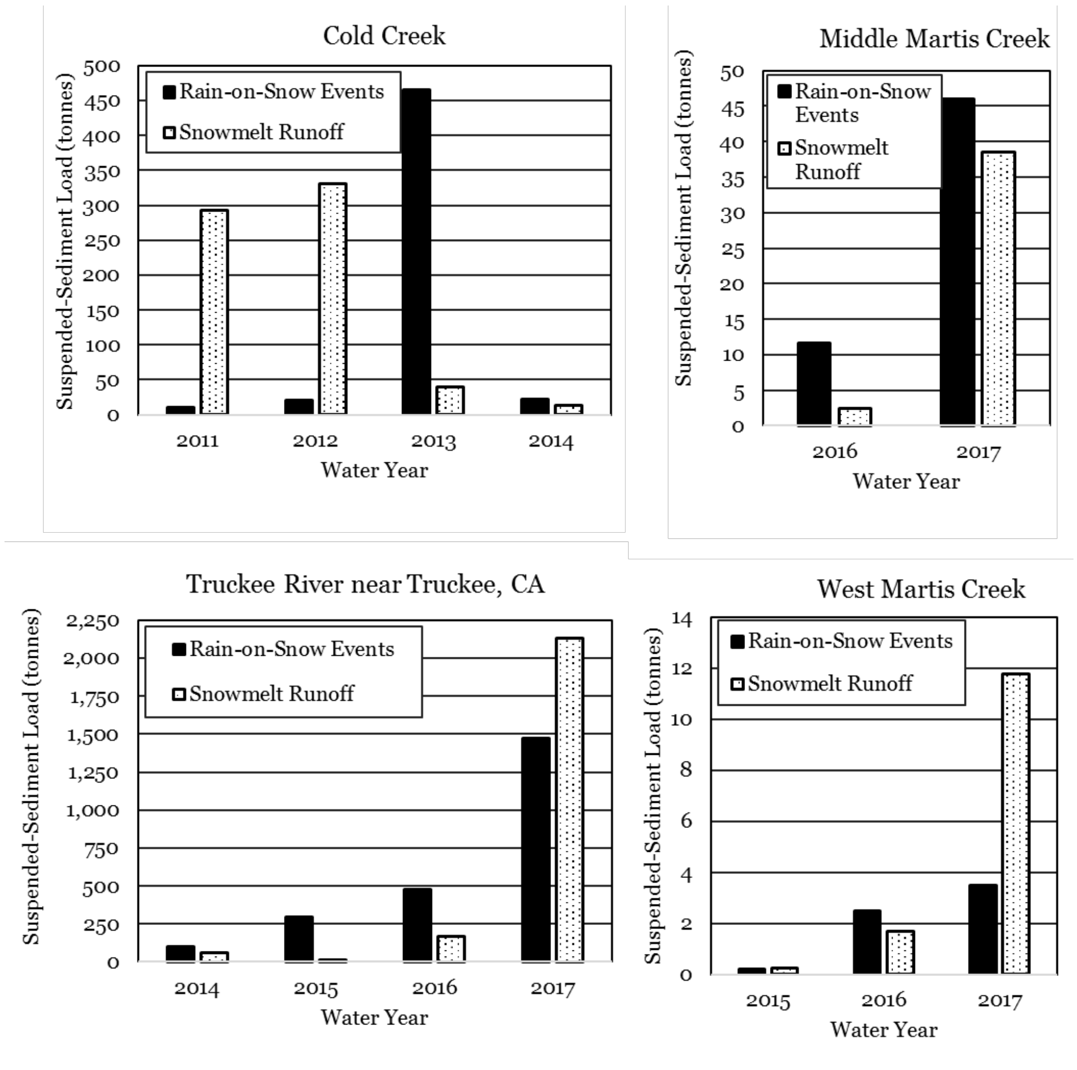

Figure 3. Suspended-sediment loads measured from the Truckee River and 3 tributaries for rain-on-snow events and snowmelt runoff periods, water years 2011-2017

Suspended sediment loads were generally higher during snowmelt runoff events in years with above average snowpack and annual runoff (WY2011 and WY2017). Water year type does not, however, correlate with loads in Cold Creek. Across all 4 years when suspended-sediment was measured in Cold Creek, the highest load was measured in WY2013, one of the drier years. In this case, a single rain-on-snow event on December 2, 2012 (WY2013) generated 348 tonnes of suspended-sediment, an order of magnitude greater than the load measured for the entire snowmelt runoff period in WY2013 (39 tonnes). This single event load also exceeded loads measured from snowmelt runoff in a wet year (293 tonnes, WY2011). This event was an atmospheric river with warm temperatures and abundant rainfall recorded over a period of days with the bulk of the precipitation recorded on December 2. Soil saturation and rapid snowmelt resulted in a mid-winter flash flood in high elevation drainages and likely increased channel and bank erosion.

Across all stations, suspended-sediment yields ranged between 0.02 tonnes/km^2 and 14.3 tonnes/km^2 for all rain-on-snow events, and between 0.02 tonnes/km^2 and 17.9 tonnes/km^2 for all snowmelt runoff periods. Because not all streams were monitored over the same years, comparisons across watersheds is difficult. The Truckee River exhibited the highest yields when compared to tributaries measured in the same years, even though the Truckee River is a regulated system.

While this study included measurements over multiple years, it is important to consider sediment loading on a decadal scale, especially under climate change scenarios. If rain-on-snow events become more frequent, the sum of loads measured from these events are likely to exceed loads measured from snowmelt runoff. Management strategies, therefore, targeted at extreme events are likely to be most effective in protecting and restoring aquatic habitat in snowmelt-dominated systems. Possible management actions in tributary watersheds may include: a) identification and mitigation of sediment sources, b) enforcement of construction and post-construction best management practices, c) regulation of new developments such that they avoid disturbance of sensitive soils, d) riparian enhancements to reduce bank erosion, and e) floodplain restoration and enhancements to sequester fine sediment.

In addition to controlling sources of fine sediment in tributaries, changes in dam operations may be useful in managing fine sediment transport and deposition on the Truckee River bed. The Truckee River Operations Agreement (TROA), implemented in 2015, provides operations flexibility and efficiency to provide environmental benefits. It may be possible under TROA to mimic flushing events after rain-on-snow events if snowmelt runoff peak flows are insufficient to scour pools and bed habitat of fine sediment deposition.

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