Control of flow sequence and spatial distribution of debris flow input on river network modeling

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Extended Abstract

Debris flows can have long-term effects on a watershed as deposited sediment at the upstream end of a river network can act as a sediment supply source for decades to centuries. Therefore, long-term simulation is critical to predict the combined effects of flow magnitude, duration, sequence, and intermittency for debris flow sediment routing (Czuba, 2018; Murphy et al., 2019; Pfeiffer et al., 2020; Ahammad et al., 2020; Ahammad et al., 2021). While such modeling scope in large spatial and temporal scale is often restricted by computational capacity, simplifying the flow hydrograph can help make the modeling tractable. Along with a 30-year daily flow simulation, this study explores the control of flow sequence and constant flow on debris flow transport through the Provo River network at different time horizons (Figure 1).

To investigate the effect of hydrograph structure and sequencing on debris flow sediment transport, we assembled several different hydrographs (Figure 1). The first was a 30-year daily hydrograph (H1). The second one (H2) was a constant 2-year flow hydrograph and in another (H3) we only kept all the flows greater than half of the 2-year flow. Thus, the 30-year daily hydrograph was reduced to 688 days by excluding all the low flows (lower than half of the 2-year flow). Different sequencing of one-year sections of the H3 reduced hydrograph (low year to high year: H4; high year to low year: H5; and randomizing years: H6) was tested for debris flow simulation, along with completely randomizing the 688 days of flow (H7; complete loss of any hydrograph sequencing). For the constant 2-year flow, we simulated for 344 days, i.e., half of that of the reduced hydrographs H3-H7.

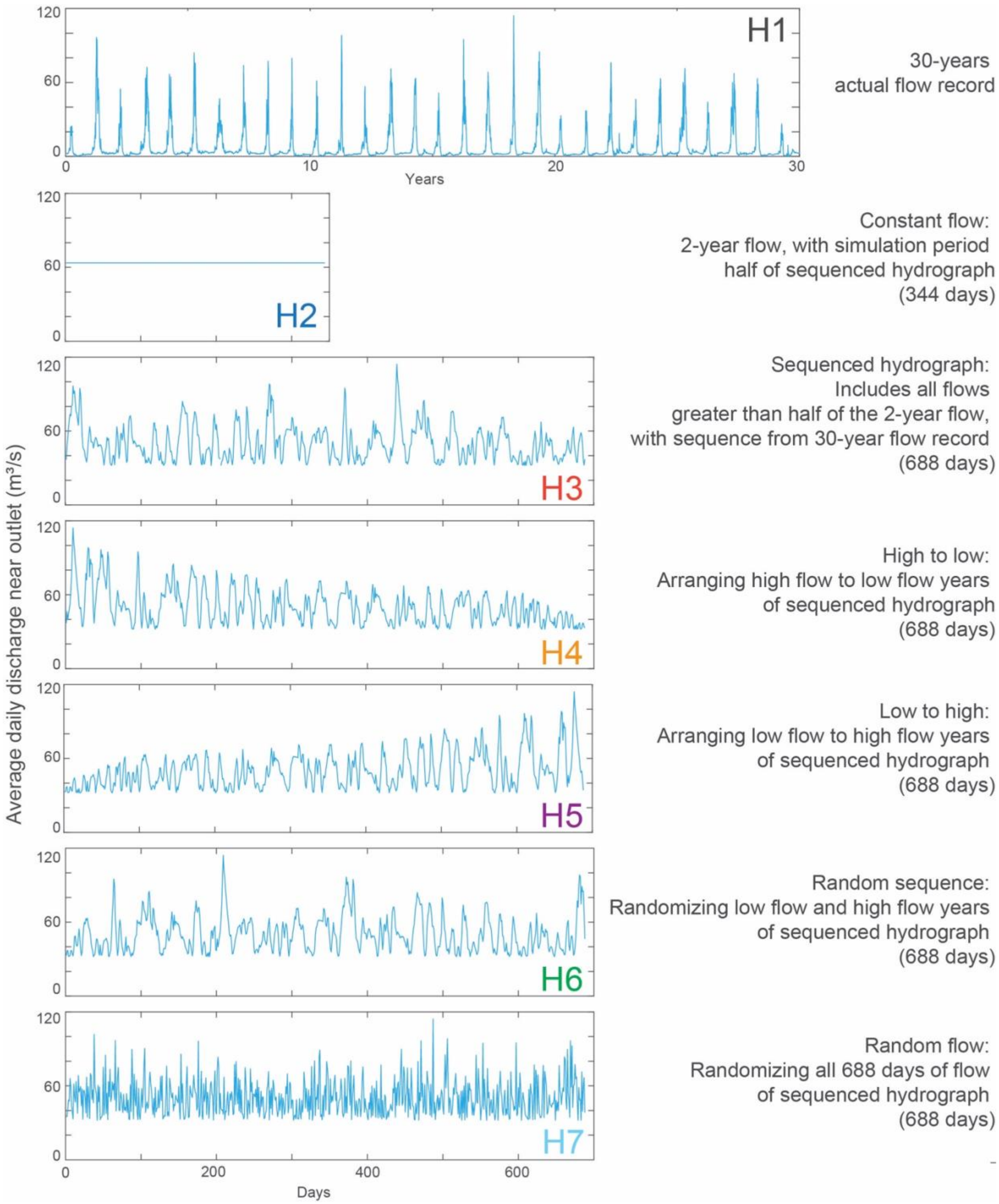

Figure 1. Construction of different hydrographs: H1 to H7. The discharge values are shown for USGS gage 10155000 (near basin outlet). The arranging of H4-H6 take average one-year segments of H3 when reordering/rearranging.

We focused on the Provo River Watershed upstream of the Jordanelle Reservoir in Utah. Additionally, this work also investigated the effect of differences in spatial distribution of debris flow sediment input to the network (inputs from six different tributaries, Sc1 to Sc6, one at a time) by analyzing corresponding tributary and mainstem characteristics (Scott et al., 2022). We used a network-based 1D Lagrangian sediment routing model (Czuba, 2018) for this gravel bedded river network, along with the framework developed by Murphy et al. (2019) to predict post-wildfire sediment generation and sediment impacts downstream from burned areas. Simulation results (Figure 2a, 2b) from the reduced hydrographs (of constant flow and different sequences) show that these can produce long-term transport comparable to the original flow record. Although the initial (1-5 years) discrepancy is high, these differences decrease over time (after 10 years). The effect of flow sequences was less important for sand than gravel, as both high and low flow would move sand initially. This eventually results in high total transport when the low flow years are followed by high flow years, because later high flows can move the coarse gravel after the early sand removal by low flows.

Because the simple compressed hydrograph approximated long-term transport, we employed a constant flow hydrograph to investigate the network characteristic controls on debris flow sediment transport. In order to do so, we introduced 30,000 m^3 of debris flow sediment volume each in 6 major tributaries, one at a time. This 30,000 m^3 debris flow sediment volume was equally distributed among 3 upstream links within each major tributary. Each input was added in total, instantaneously to the model at the beginning of the model run (time t = 0). Model results (Figure 2c, 2d) showed the importance of drainage area ratio between the tributary and mainstem (A_R) on storage (in mainstem and reservoir), similar to previous studies. When mainstem slope was similar to the tributary slope, the resulting overall transport volume was larger. This study also suggests that the extent of mainstem aggradation (explained in Figure 3) depends mainly on mainstem slope properties (i.e., mainstem slope, ratio between mainstem slope and tributary slope). Such a network-scale modeling study quantitatively identifies geomorphic significant tributaries, which are important for river biodiversity. Besides, this study focused on how the results from a reduced hydrograph vary from long-term records at different timescales. With the expected future increase of magnitude and frequency of high floods, and the potential of increased severity and frequency of extreme events due to climate change, the long-term simulation of flow sequences can inform river managers about how to better prepare to reduce loss from debris flows, and to improve overall river and watershed management.

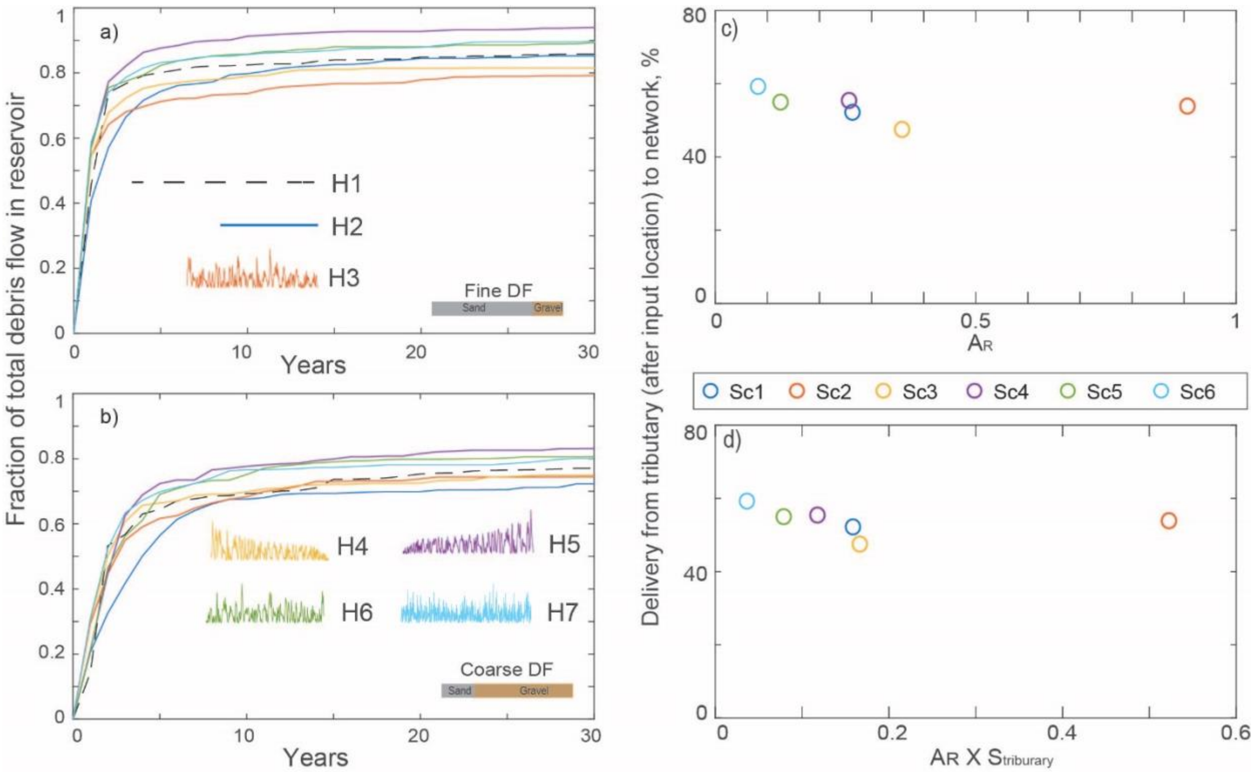

Figure 2. Debris flow sediment transported by all hydrographs for (a) fine and (b) coarse debris flow input. Percentage of input sediment (excluding the input location, gray area in Figure 3) delivered to mainstem after the 30-year simulation against (c) symmetry ratio ($A_R = DA_{tributary} / DA_{mainstem}$), and (d) product of symmetry ratio and tributary slope.

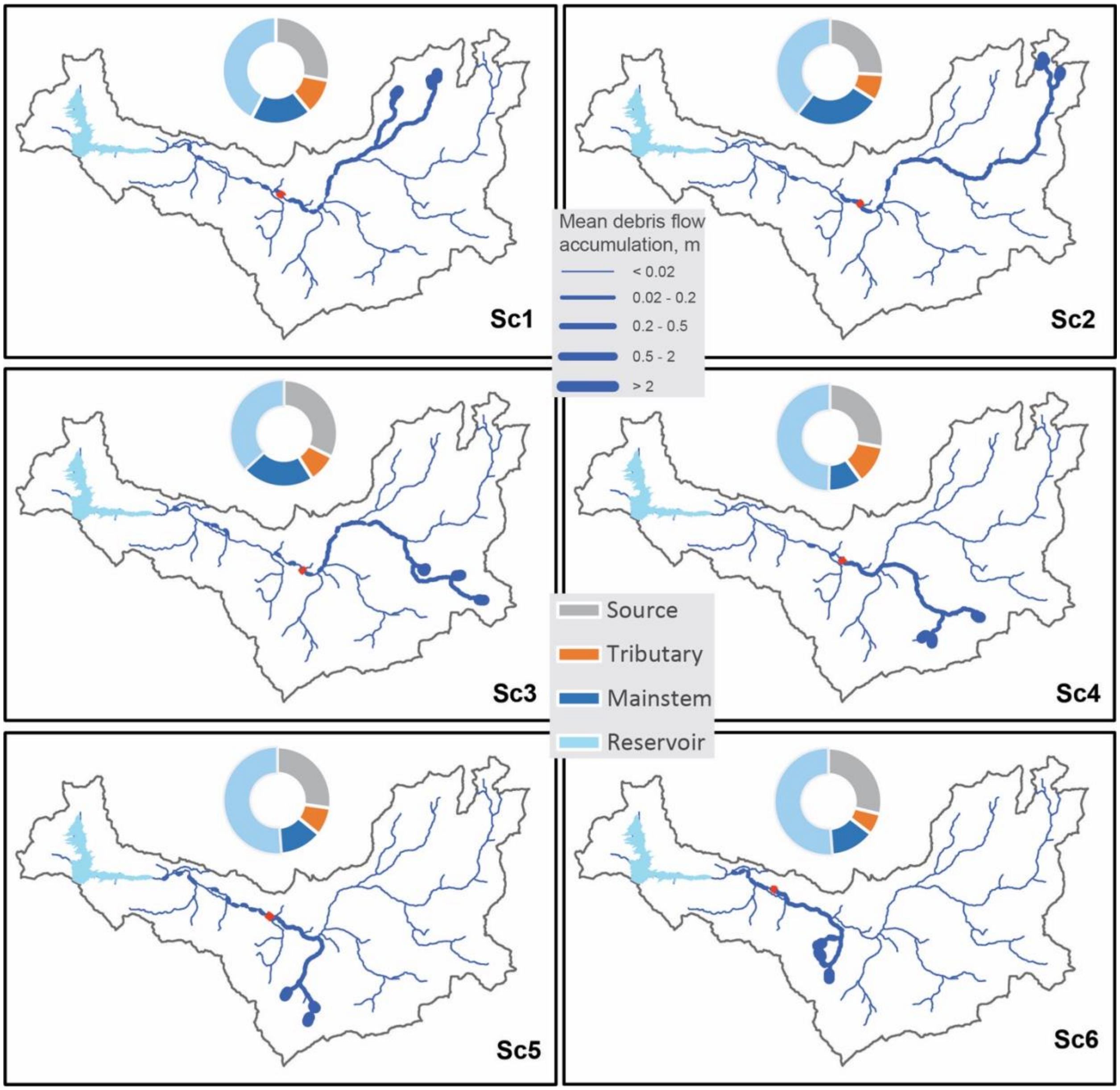

Figure 3. Debris flow accumulation in the Provo River network after the equivalent 30-yr flow simulation under different spatial input distributions (Sc1 to Sc6; initial placement at upstream tributary reaches). The proportions (of total 30,000 m^3) of storage in the source location, tributary, mainstem and reservoir are shown by different colors in the circle. The downstream extent of 50% mainstem accumulation is showed by a red mark in the mainstem for each case.

References

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