Fire-WATER: a new GIS framework to assess post-wildfire erosion, watershed-scale sediment dynamics, and downstream impacts in the western US

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Extended Abstract

Wildfires create a cascading series of watershed effects that extend beyond the direct risks from burning ecosystems and infrastructure. Runoff and erosion after fire can deliver substantial sediment loads to river networks, influencing river morphodynamics, aquatic habitat and populations, water quality and quantity, and downstream infrastructure. While models exist to predict the risks and impacts from individual hydro-geomorphic processes (e.g., debris flows, hillslope erosion), there is a need for efficient tools that incorporate the various models and are capable of predicting post-wildfire erosion, sediment delivery, and transport through large watersheds and river networks. Our group has developed a new modeling framework to better predict the integrated and interacting impacts of post-fire processes, constructed as an easy-to-use Python-based ESRI ArcGIS toolkit, that we are calling the Fire-Watershed Assessment Toolkit for Erosion and Routing (Fire-WATER).

The Fire-WATER framework links three toolkits that can all be operated individually for other applications: 1) the Utah State University AppLied (USUAL) Watershed Tools, 2) the Wildfire Erosion and Sedimentation Toolkit (WEST), and 3) the Network Sediment Transporter (NST). First, the USUAL Watershed Tools provide users with a streamlined, efficient, and easy-to-use set of ArcGIS tools to delineate watersheds, sub-catchments, river-adjacent interfluves, and river networks (David et al., 2023). Additionally, USUAL contains all the functions necessary to discretize the river network into reaches and extract a suite of hydro-geomorphic metrics required for 1-D network routing (e.g., upstream drainage area, average slope, river width) for each reach. The second toolkit, WEST, simulates post-wildfire erosion from both debris flow and hillslope processes (Figure 1) and estimates sediment delivery to river channels. WEST combines the current USGS post-fire debris flow model (Staley et al., 2017), which predicts the probability of debris flow generation for all burned sub-catchments, with regional debris flow volume models (Gartner et al., 2014, 2008; Wall et al., 2022), and an updated debris flow sediment delivery model (based on Murphy et al., 2019). Additionally, WEST simulates post-fire hillslope erosion from sheetwash and rilling by applying a post-fire version of the revised

universal soil loss equation (RUSLE) and calculates sediment delivery to river channels (Gannon et al., 2019). Collectively, the WEST components can all be run using publicly available datasets (at least for the western US), including but not limited to topography, rainfall intensity, soil erodibility, land cover, and wildfire soil burn severity.

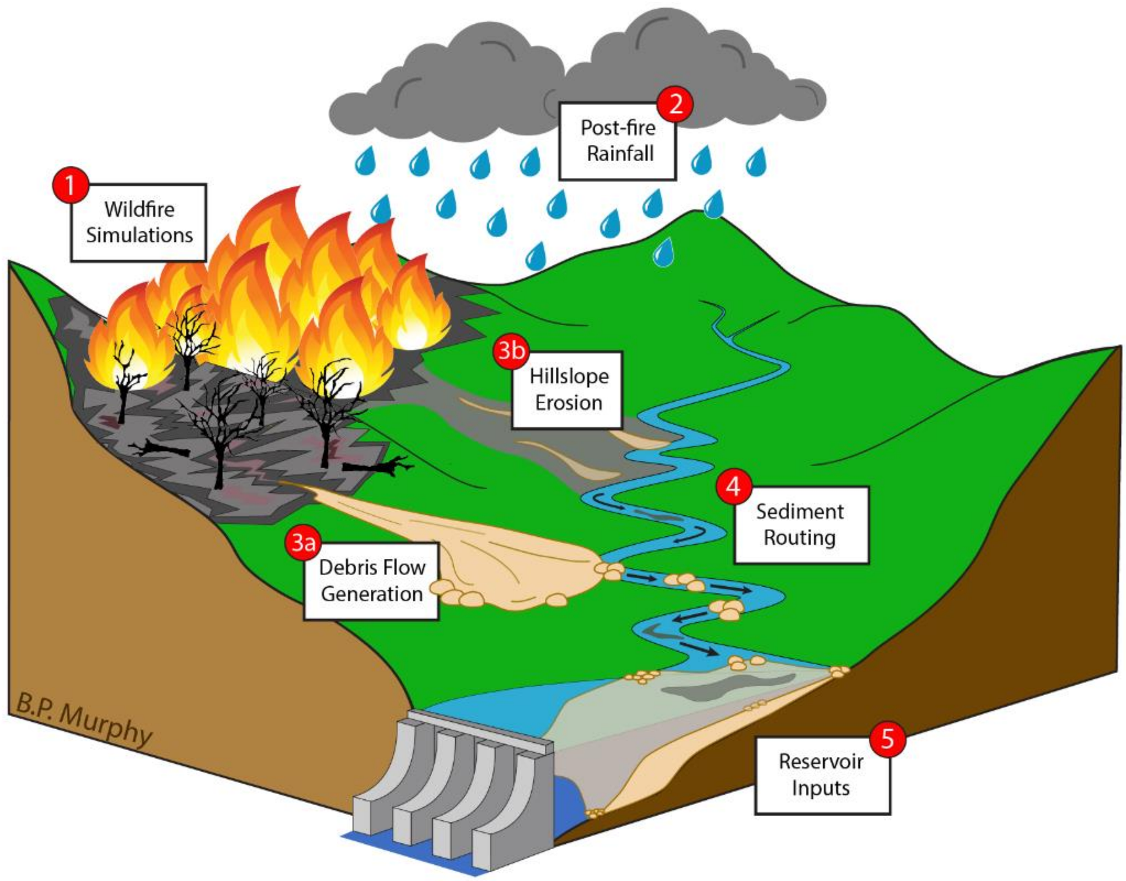

Figure 1. Conceptual illustration of the Fire-WATER model. 1) Wildfire simulations are a user input of measured burned severity or modeled burn severity. 2) Input rainfall scenarios are estimated rainfall intensity post-wildfire, which can be derived from the NOAA Precipitation Frequency Data Server. 3) Erosion estimates and sediment delivery to rivers illustrating two separate processes, debris flows (3a) and hillslope erosion (3b). 4) Sediment routing through the river network using NST. 5) Example of a downstream sink (e.g. reservoirs) to where sediment is routed.

Structured around the delineations from USUAL, WEST will output a set of spatially explicit locations of sediment inputs to the river network from debris flow catchments and interfluves that include estimates of both the volume and grain sizes (Figure 1). Finally, the NST 1-D sediment routing model (Czuba, 2018; Pfeiffer et al., 2020) uses the attributed and discretized river network from USUAL, sediment inputs from WEST, and additional streamflow inputs to route sediment through the river network based on mixed grain size transport equations. Collectively, the new Fire-WATER framework provides a streamlined and user-friendly approach to predicting source-to-sink sedimentation impacts in large watersheds (> 10 km^2) after wildfire.

Notably, Fire-WATER can be run for either pre-fire or rapid post-fire assessments. For pre-fire assessment, users can input simulated fire perimeters and fire severity layers. For post-fire assessment, standard BAER or MTBS layers can be used. While the individual components of Fire-WATER have potential applications far beyond wildfire analysis, this new framework will allow users to more easily and comprehensively assess potential post-wildfire erosion and sedimentation risks, including downstream impacts to aquatic habitat, water resources, and infrastructure.

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