Water supply vulnerability to post-wildfire reservoir sedimentation: a new modeling framework for the western US with applications to Salt Lake City, Utah

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Extended Abstract

Following the widespread damming of rivers and the establishment of the US Forest Service, the American West was largely settled under a perception that water was plentiful and that wildfire was not a serious risk (Murphy et al., 2018). However, a century of fire suppression combined with the increasing effects of anthropogenic climate change has resulted in rapidly increasing wildfire activity (Brown et al., 2004; Westerling et al, 2006; Abatzoglou et al., 2016) and decreasing water supplies relative to the boom of the mid-20th century (Bladon et al., 2014; Martin, 2016; Murphy et al., 2018). Today, more than 70 million people live in the West (with over a third residing in the Wildland-Urban Interface) (Murphy et al., 2018), and they all depend on a reliable and sustainable water supply. Snowpack is decreasing in many regions of the western United States (US EPA, 2016), delivering less water to reservoirs, the reservoirs are aging and filling with sediment, and more extreme wildfire activity is increasing the risk of catastrophic losses in water supply (Hallema et al., 2018; Murphy et al., 2018). This has already occurred in western cities like Flagstaff, Arizona and Fort Collins, CO (Martin, 2016); yet few reservoir management plans contain detailed models or evaluations of potential post-fire sedimentation (e.g., UDWR, 2010). This is rapidly changing though, and recognizing the risks, many municipalities are seeking to assess their post-fire vulnerabilities and establish plans to address them. However, one limitation has been a lack of tools to comprehensively model and predict post-wildfire erosion, watershed sediment dynamics, and sediment routing through large watersheds that drain to reservoirs (e.g., Murphy et al., 2019; Gannon et al., 2019).

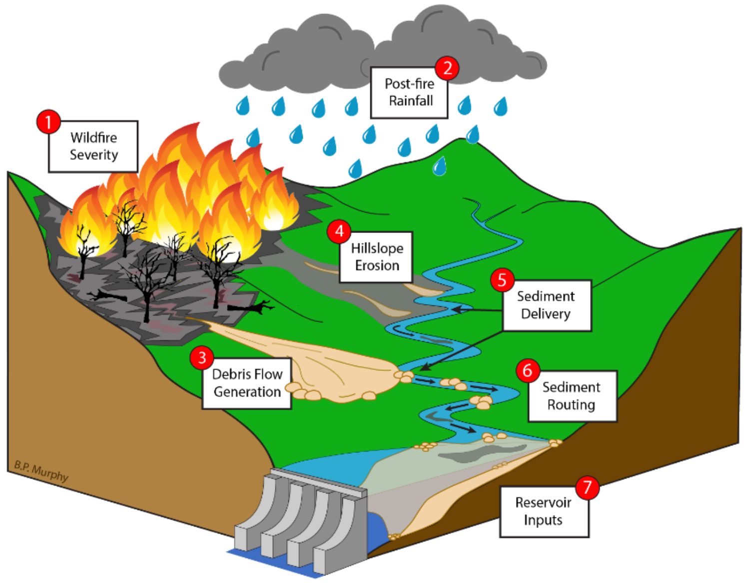

Figure 1. Conceptual cartoon of the major components in the Fire-WATER modeling framework. This includes: 1) real or simulated wildfire severity, 2) design storms of post-fire rainfall intensity, 3) debris flow probability and volume, 4) hillslope erosion (sheetwash & rilling), 5) river sediment delivery, 6) network sediment routing, and 7) estimates of sediment loads entering downstream reservoirs. Cartoon modified from Murphy et al. (2019).

Our group has created a new modeling framework (Figure 1), known as the Fire-Watershed Assessment Toolkit for Erosion and Routing (or Fire-WATER), that was developed as an easy-to-use, ArcGIS toolbox (*see presentation by David et al. for more details*). The Fire-WATER framework links three modeling tools developed within our group: 1) the new Utah State University AppLied (USUAL) Watershed Tools for rapid and comprehensive hydro-geomorphic delineation (David et al., 2022), 2) the Wildfire Erosion and Sedimentation Toolkit (WEST) (David et al., *in prep*), and 3) the Network Sediment Transporter (NST) (Czuba, 2018; Pfeiffer et al., 2020; Ahammad et al., 2021).

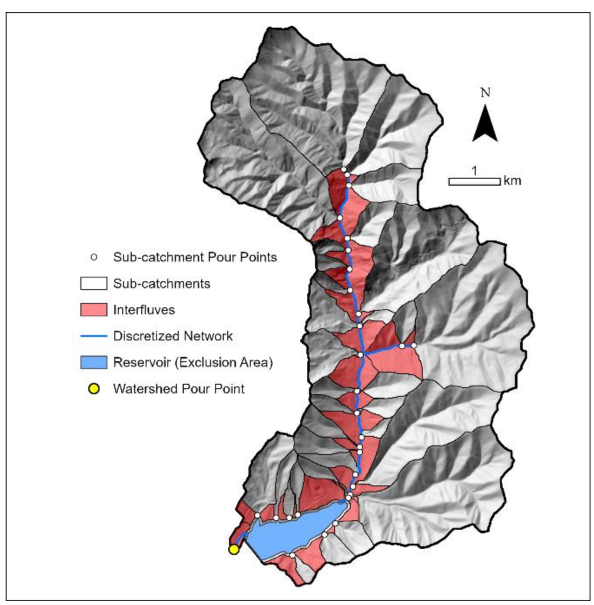

Figure 2. Example outputs of USUAL Watershed Tools – the GIS delineation pre-processor in Fire-WATER, here applied to the watershed draining to Little Dell Reservoir in Salt Lake City, UT. From a DEM and watershed pour point (yellow dot), USUAL delineates the river network (blue line), then identifies all contributing tributaries and their respective pour points (white dots), delineates the tributary sub-catchments (black outlines) and all of the interfluves between the sub-catchments (red polygons). Given a reservoir shapefile (blue polygon), USUAL will also automatedly adjust the delineations for all sub-catchments and interfluves draining directly to the reservoir.

Accomplishing post-wildfire modeling of this nature requires first delineating watersheds based on hydro-geomorphic process domains (e.g., potential debris flow catchments, interfluve hillslopes, river network) in order to characterize conditions within each feature, apply the appropriate process domain-specific models of post-fire erosion, attribute probabilities and magnitudes of erosion to respective features, and assign estimates of sediment loads as spatially explicit inputs along the river network. The new, fully automated, and open-access USUAL Watershed Tools (David et al., 2022) provides a suite of GIS toolboxes that can accomplish the necessary delineations in just minutes provided nothing more than a Digital Elevation Model (DEM) and a downstream pour point (Figure 2). Moreover, USUAL provides additional tools that will then discretize the river network into reaches with all the attributes needed to inform and run 1-D network routing models (e.g., NST).

Further, focusing our efforts on the Intermountain West and the state of Utah, we have collected new field datasets and developed new predictive models that have made it possible to use Fire-WATER as a pre-fire assessment tool. Namely, this includes a machine-leaning model designed to predict wildfire severity (Figure 3). This model has been trained and tested using extensive datasets from decades of Utah wildfires and can output a range of severity predictions for varying fuel and weather conditions (Klimas et al., *in prep*). Additionally, our group has collected original field data from post-fire debris flows across the state of Utah, as well as compiled all available from the Intermountain West, to develop a suite of novel empirical models to predict the sediment volumes and grain sizes of runoff-generated debris flows after wildfire (Wall et al., 2022).

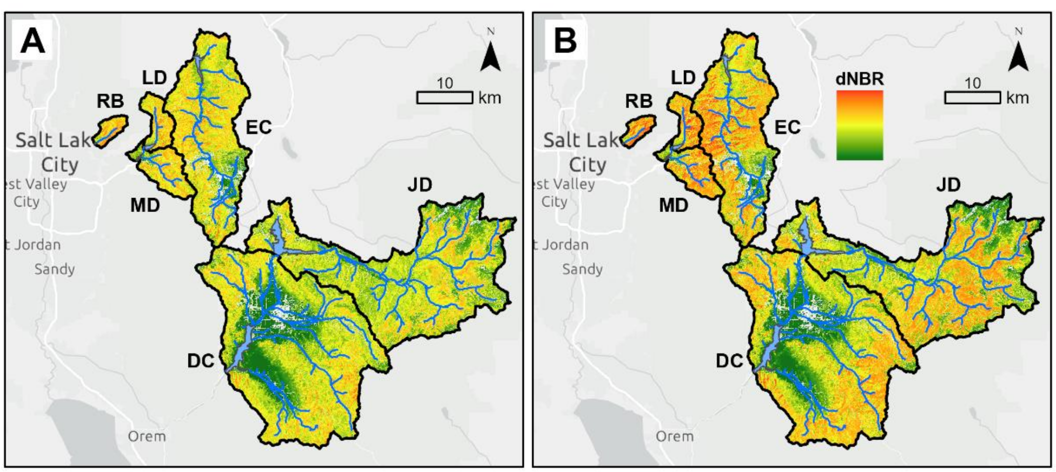

Figure 3. Predicted fire severity maps for watersheds draining to critical water supply reservoirs along the Wasatch Front, UT (RB: Red Butte, LD: Little Dell, MD: Mountain Dell, EC: East Canyon, DC: Deer Creek, JD: Jordanelle). Colors indicate modeled values of differenced Normalized Burn Ratio (dNBR) at 30-m resolution, with greater values (red) indicating higher burn severity. Panel A shows fire severity predictions for weather conditions representative of the 5th percentile in this region and panel B shows predicted severity at the 50th percentile (Kipling et al., *in prep*)

In our first application of the Fire-WATER framework, we have conducted pre-fire assessments for a half dozen water supply reservoirs that service the municipalities of the Wasatch Front in Utah, USA (Salt Lake City, Park City) with a primary objective of evaluating the potential vulnerability to post-wildfire sedimentation (measured as the modeled sedimentation losses relative to storage capacity) under a range of possible wildfire and post-fire environmental conditions (Figure 3). Specifically, wildfire severity was modeled at varying percentiles of analyzed regional weather and fuel conditions, debris flow and hillslope erosion were modeled at multiple recurrence intervals of rainfall intensity for this region, and finally, network sediment routing was modeled under various discharge conditions (*see Ahammad et al. presentation for more details on streamflow*).

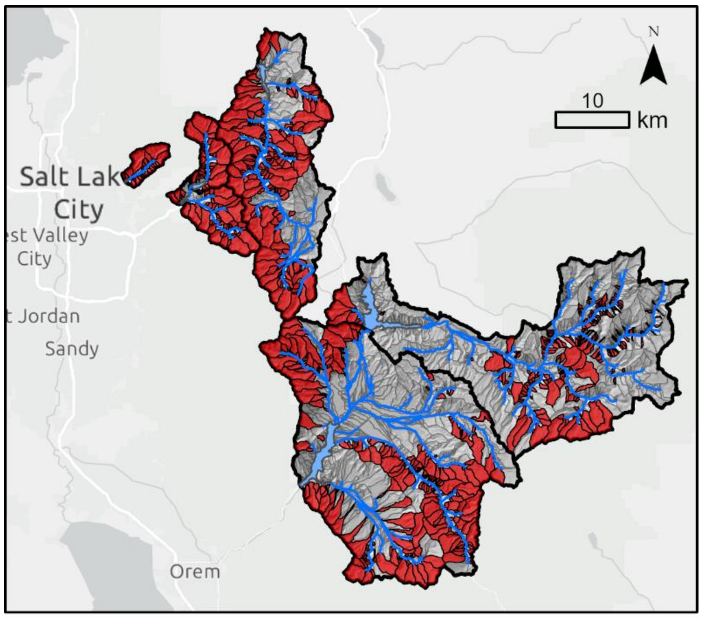

Figure 4. Example of predicted locations of post-fire debris flows across the study watersheds with the 2-year storm and the modeled 50th percentile fire severity map. Debris flow probabilities are modeled using the current USGS post-fire hazards model (Staley et al., 2017). For the purposes of modeling potential sedimentation risks, it is assumed that entire watersheds burn. While this certainly represents an end-member scenario, the watershed extents are all within the range of wildfire areas regularly burning in Utah and the western US.

Our novel and streamlined Fire-WATER framework enables efficient modeling of multiple scenarios to provide a range of estimated vulnerabilities in post-fire reservoir sedimentation. This is critical given the inherent uncertainties in modeling and stochasticity of both wildfire and post-wildfire landscape response. The comprehensive, spatially explicit, watershed-scale design allows for evaluating the entire cascade of potential post-fire sediment impacts (e.g., Murphy et al., 2019), including geohazard risks (Figure 4), eroded and delivered sediment loads (fractionated by grain size), locations of predicted erosion and aggradation throughout the river network, and finally, the downstream sedimentation impacts to critical infrastructure. All the data needed to inform and run the models included within the Fire-WATER framework are free and publicly available. Further, all the post-fire erosion models were trained and developed specifically for the western US, making this framework more widely applicable. We anticipate our new Fire-WATER framework will help facilitate natural resource agencies, public utilities, water districts, and local municipalities in assessing the vulnerability of their managed water supplies in the face of increasing risks to wildfire and post-fire sedimentation.

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