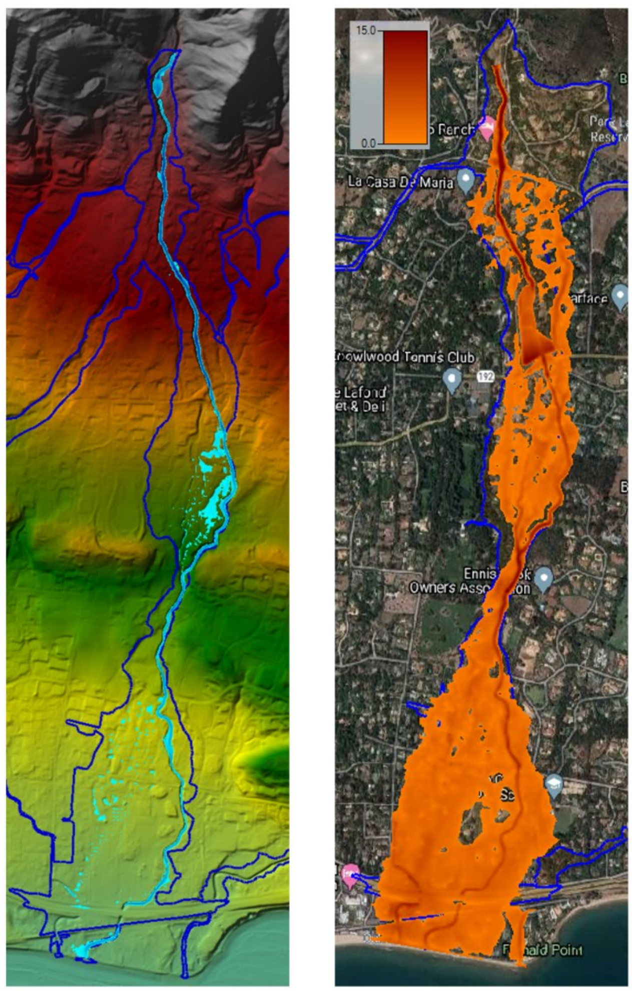
NON-NEWTONIAN MODEL DEVELOPMENT FOR POST-WILDFIRE FLOOD RISK MANAGEMENT – EXTENDED ABSTRACT

Wildfire effected watersheds frequently produce significant flooding, sedimentation, and destructive non-Newtonian debris flows in response to even moderate precipitation events. This research demonstrates a post-wildfire hydrology and hydraulic numerical modeling approach, utilizing a recently developed non-Newtonian library (DebrisLib), that can be used to predict hydrology runoff sediment yields and downstream velocity and inundation conditions for representative post-wildfire flows (e.g., debris flow, ash flows, mudflows, hyperconcentrated flows). This was accomplished with U.S. Army Corp of Engineer's (USACE) modeling software, Hydrologic Engineering Center, Hydrologic Modeling System (HEC-HMS), the two-dimensional the two-dimensional HEC, River Analysis System (HEC-RAS), and two-dimensional Adaptive Hydraulics (AdH) numerical model. The work presented here presents a demonstration of the effectiveness of the library-based methodology, using these widely-used USACE engineering models with a comparison to Kean et al.'s datasets following the January 9, 2018 post-wildfire flooding and debris flows in Santa Barbara, California. The debris flow generating rainfall event produced extreme runoff and debris flows displacing approximately 680,000 m^3 of material and sediment with observed (e.g., Kean et al., 2019) and predicted velocities of around 4.0 m/s. The hydrology modeling approach presented is a simplistic computational method that represents the current state-of-practice approach for predicting hydrology rainfall-runoff and routing following wildfires. Evaluation of the numerical models versus field data collected by Kean et al. (2019) indicate that classic Newtonian physics are inadequate for predicting post-wildfire flood runout and inundation. When the GSSHA, HEC-RAS and AdH models were linked with DebrisLib, the models sufficiently predicted velocity, depths, and floodplain inundation. This paper demonstrates the utility of a library-based framework applying conservative (fixed-bed conditions and constant sediment concentration) non-Newtonian rheology-based closures using engineering-based models for post-wildfire flood risk management and emergency response.

The hydraulic two-dimensional HEC-RAS models were used to simulate the 09 January 2018 Thomas Fire flood and debris flow events by varying the Manning's Roughness and non-Newtonian rheology parameters until agreement between simulated inundation area and the observed inundation area using the Kean et al. (2019) inundation data. The roughness coefficients were determined from the 2016 National Land Cover Database and building locations and footprints ranging from 0.014 for channels to 0.035 for vegetated reaches. The model simulation of inundation was conducted using both Newtonian and non-Newtonian closure to determine the effects of non-Newtonian behavior on downstream inundation. The Newtonian and non-Newtonian simulated inundation areas are provided in Figure 1, with the observed inundation boundaries in dark blue. The Newtonian simulations using the post-wildfire hydrology model input interestingly approximates the 100-year floodplain delineated prior to the 2019 debris flow events (FEMA, 2014, 2018), as presented in Kean et al. (2019). The model inundation areas for San Ysidro creek is provided in Figure 1, with simulated model results shown in orange-brown and the observed inundation boundaries shown in blue. As anticipated the HEC-RAS model with DebrisLib with the current assumptions would introduce considerable uncertainty. The predicted depths for Montecito Creek where more similar with an $R^2 = 0.43$ than the San Ysidro results with an $R^2 = 0.2$.

The complexity of flow and sedimentation patterns present several challenges when modeling observed data of post-wildfire runoff and inundation. In this work we show how post-wildfire hydraulic simulations that include non-Newtonian processes outperformed the Newtonian-based simulations at predicting depth and inundation with model results diverging from observed depths from Kean et al. (2019). This deviation is most likely a result of the assumptions used here. This limits simulations to a single yield strength and dynamic viscosity across the model domain, which can lead to over or under prediction of depth. Watersheds within mountainous wildfire prone areas are at significant risk of damaging post-wildfire floods, debris flows, and sedimentation hazards such as those documented following the 2017 Thomas Fire. Watershed erosion, runoff, and debris flow processes in recently burned areas are complex and often behave non-linearly with complex feedback mechanisms.



Newtonian Non-Newtonian

Figure 1. Comparison of Inundation using Newtonian (on left) and Non-Newtonian (on right) modelling approached for San Ysidro Creek. Observed inundation boundaries are shown in dark blue (Kean et al., 2019) Copied from Floyd et al., 2021. Units in feet.

References

Kean, Jason W., et al., 2019. Inundation, flow dynamics, and damage in the 9 January 2018 Montecito debris-flow event, California, USA: Opportunities and challenges for post-wildfire risk assessment. Geosphere 15.4, p. 1140-1163.

Floyd, I., 2021. Non-Newtonian Model Development for Post-Wildfire Flood Risk Management. Louisiana State University and Agricultural & Mechanical College.