POST-WILDFIRE HYDROLOGY AND DEBRIS FLOW ANALYSIS USING HYDROLOGIC MODELING SYSTEM (HEC-HMS)

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Abstract

Post-wildfire hydrology and debris flow prediction is one of the most fundamental indices used to determine the operation and maintenance of debris basins. The accuracy of post-wildfire hydrology and debris flow prediction impacts downstream communities in terms of emergency response, flood control, debris flow control, and water quality and supply. Specifically, the upcoming wet season after fires consisting of high intensity-short duration rainfall events threatens to cause debris flows and increased flooding in areas affected by wildfires. The post-wildfire hydrology and debris flow modeling features in the Hydrologic Modeling System (HEC-HMS) are great tools to better understand the expected increase in peak flows and debris yields from burned watersheds.

The objective of this paper is to highlight the post-wildfire hydrology, debris flow, and debris basin management application tools within HEC-HMS that provide necessary outputs for the development of post-wildfire debris flow risk and emergency management strategies.

HEC-HMS provides flexible options to simulate post-wildfire hydrology including a simple Soil Conservation Service (SCS) curve number (CN) loss method and a sophisticated dynamic infiltration loss method based on the Pak & Lee fire factor equation (2008). For the subbasin elements, HEC-HMS has five different methods for debris yield estimation from burned watersheds ranging from a simple approach using rainfall intensity to a detailed approach using peak flow. In addition to clean out records, HEC-HMS can provide critical information in managing the remaining capacity of debris basins based on predicted debris inflow volume using the dynamic reservoir volume reduction feature in the reservoir element. The dynamic reservoir volume reduction feature uses trap-efficiency methods based on sediment/debris inflow from upstream watersheds. For reach elements, HEC-HMS provides several sediment/debris routing methods including the existing seven sediment potential methods and a new Muskingum & Sediment Delivery Ratio (SDR) method.

This paper demonstrates the usefulness of applying the post-wildfire hydrology, debris yield prediction, and dynamic reservoir volume reduction modeling features in HEC-HMS for post-wildfire debris flow risk management and emergency management.

Introduction

HEC-HMS is a computer program designed to model watershed hydrology. Historically, HEC-HMS has focused on modeling rainfall-runoff and sediment transport processes for unburned watersheds. Recently, new post-wildfire hydrology and debris flow modeling features were implemented in HEC-HMS to simulate the expected increase in peak flows and debris yields from burned watersheds. This paper describes the new post-wildfire hydrology, debris flow, and debris basin management application capabilities in HEC-HMS 4.11.

The HEC-HMS subbasin element represents a catchment where precipitation falls and causes surface runoff. Erosion within the catchment results from a combination of several different physical processes including post-fire hydrologic conditions. Raindrops cause erosion during impact with the ground surface and break apart the top layer of the soil, dislodging soil particles transported with overland flow. Overland flow also imparts an erosive energy to the ground surface that may further break apart the surface sediments. Watersheds following wildfires may experience rapidly increased overland flow that causes large runoff volumes. The large runoff volumes lead to increased channel erosive energy and high loads of sediment and debris. Total debris yield is closely linked to precipitation rate, land surface slope, and soil burn severity (Cannon et al., 2002). Five debris yield methods are currently coded within HEC-HMS for the subbasin element to help quantify post-wildfire debris yields: the LA Debris Method EQ1, LA Debris Method EQs 2-5, Multi-Sequence Debris Prediction Method (MSDPM), USGS Long-Term Debris Model, and USGS Emergency Assessment Debris Model.

The HEC-HMS reach element is used to convey stream-flow downstream in the basin model. Inflow into the reach element can come from one or many upstream hydrologic elements. Outflow from the reach is calculated by accounting for translation and attenuation of the inflow hydrograph. The existing suite of empirical equations were developed for estimating the transport of sediment within Newtonian fluids. Recently, HEC-HMS added a Sediment Delivery Ratio (SDR) sediment potential method and a Muskingum sediment routing method for modeling debris flow within the reach element. With these methods, HEC-HMS can manually control hyper-concentrated sediment/debris flow (non-Newtonian Fluid) routing through channel elements with user-specified input parameters (delivery ratios, attenuation coefficient, and travel time for each grain size).

The HEC-HMS reservoir is an element with one or more inflow and one computed outflow that allows for temporary water and sediment storage. Inflow comes from other elements in the Basin Model. If there is more than one inflow, all inflow is added together before computing the outflow. It is assumed that the water surface in the reservoir pool is level. Several methods are available for defining the storage properties of the reservoir. The reservoir element can be used to model reservoirs, lakes, debris basins, and ponds. Sediment entering a reservoir and settling eliminates some of the storage space of the reservoir. Over time the cumulative storage lost to sediment settling may be significant. HEC-HMS has the capability to compute the sediment balance in the reservoir over time. The Reservoir Capacity Method is the HEC-HMS option for simulating the dynamic reservoir/debris basin volume reduction using trap efficient methods based on sediment/debris inflow from the upstream watersheds. When selecting “Yes” for the reservoir capacity method, two deposition shape options (V-Shape and Elongated Taper) are available.

Subbasin Sediment/Debris Yield

Within the subbasin, erosional processes can occur from a combination of several different physical processes. Raindrops can cause erosion when they strike the ground surface and break apart the top layer of the soil, dislodging soil particles that can move with overland flow. Overland flow also generates erosive energy to the ground surface that further breaks apart the topsoil layer. As the overland flow rate increases under post-wildfire conditions, flow concentrates in rills increasing the erosive energy on the surface. Total erosion is closely linked to precipitation rate, land surface slope, and post-wildfire conditions. All the subbasin sediment/debris yield equations must be coupled with the appropriate hydrologic parameters (e.g., rainfall hyetographs, loss rates, flow transforms, etc.) to perform sediment yield estimates. Some methods require a different set of parameters for estimating debris and not all methods are equally adept at representing a particular watershed. The proposed methods listed below for debris yield prediction following fire events can be useful tools to schedule cleanout operations for debris basins and to develop an emergency response strategy for semi-arid areas where plentiful sediment supplies exist and frequent fires occur. More details on these methods can be found here: https://www.hec.usace.army.mil/confluence/hmsdocs/hmsguides/applying-debris-yield-methods-in-hec-hms/introduction-to-the-debris-yield-methods.

- **LA Debris Method EQ 1**: Event simulation for use in watersheds of 0.1 to 3.0 mi^2 in areas where flow data is not available. Based on maximum 1-hr rainfall intensity, relief ratio, drainage area, and fire factor (Gatwood et al, 2000).
- **LA Debris Method EQ 2-5:** Event simulation for use in watersheds of 3.0 to 200 mi^2 in areas where flow data is available. Based on unit peak runoff ($ft^3/s/mi^2$), relief ratio, drainage area, and fire factor (Gatwood et al, 2000).
- **Multi-Sequence Debris Prediction Method (MSDPM):** Event and continuous simulation for use in watersheds of 0.1 to 3.0 mi^2 in areas where flow data is not available. Based on the maximum 1-hr rainfall intensity, relief ratio, drainage area, and fire factor (Pak and Lee, 2008).
- **USGS Emergency Assessment Debris Model:** Event simulation for use in watersheds of 0.004 to 12.7 mi^2 in areas where flow data is not available. Based on maximum 1-hr rainfall intensity, relief, drainage area, and burn area (Gartner et al., 2014).
- **USGS Long-Term Debris Model:** Continuous simulation for use in watersheds of 0.004 to 12.7 mi^2 in areas where flow data is not available. Based on maximum 15-min rainfall intensity, relief, drainage area, and burn area (Gartner et al., 2014).

Predicting debris yields under post-wildfire conditions is important for hazard mitigation and flood risk planning. Debris flows can block access to roads and bridges inhibiting emergency responders, as well as damaging a community's water supply and infrastructure. Current debris prediction efforts are aimed at estimating the volume. Predicting debris yield volume and estimating debris basin capabilities are essential information needed for mitigating flood and debris hazards.

In-Stream Debris Routing

Sediment processes within a reach are directly linked to the capacity of the stream flow to carry eroded soil. The transport capacity of the flow can be calculated from the flow parameters and sediment properties. If the stream can transport more sediment than is contained in the inflow, additional sediment will be eroded from the stream bed and entrained in the flow. However traditional hydraulic sediment processes have limited application in hyper-concentration sediment/debris flow situations. Therefore, HEC developed two new features, the Sediment Delivery Ratio (SDR) transport potential method and the Muskingum sediment routing method

in the reach element, especially for hyper-concentration sediment/debris flow situations. The SDR transport potential method requires a user-specified ratio of each grain. Ratios greater than 1 are typical for erosional situations, ratios less than 1 are typical for depositional situations, and ratios equal to 1 suggest the sediment flow is at equilibrium. Transport potential is calculated as the SDR time of the inflow sediment to a subreach for each grain class.
The Muskingum sediment routing method uses a simple conservation of mass approach to route sediment/debris through the stream reach. For each time interval, available sediment is calculated from the upstream sediment and local erosion or deposition is calculated based on a comparison to the sediment transport capacity of the reach. The available sediment in each grain size class is routed using the Muskingum routing parameters (attenuation coefficient and travel time**)**. This allows sediment of different grain sizes to move at different speeds and approximates attenuation through the reach. Calibration with observed data is recommended to assign parameter values.

Reservoir Debris Routing

Dams and reservoirs disrupt the natural transport of sediment in streams by creating large backwater areas with low velocities, allowing the sediment to settle to the bottom of the reservoir. Over time, the volume and surface area of a reservoir are reduced as sediment accumulates, which can have a detrimental effect on authorized purposes, such as flood control and recreation. Predicting sediment/debris deposition can be accomplished by estimating the incoming sediment/debris load and the trapping efficiency of the reservoir, along with other parameters (i.e., precipitation, hydrology, etc.). The sediment size gradation is often also estimated from the suspended sediment sample. The trapping efficiency of a reservoir can be estimated using methods such as the Chen (1975) or Brune (1953) Trap Efficiency Methods. Using the dynamic reservoir volume reduction methods with two different trap efficiency method options, predicting debris yield volume, estimating debris basin capabilities, and developing yield mitigation alternatives by selecting debris basins size and locations can provide essential information for mitigating flood and debris hazards. A debris basin application workshop is available at the HEC-HMS tutorials and guides website (https://www.hec.usace.army.mil/confluence/hmsdocs/hmsguides/applying-debris-yield-methods-in-hec-hms/task-3-debris-yield-modeling-with-debris-basin-with-new-debris-volume-conversion-to-mass-with-unit-weight-density). An example HEC-HMS project within this workshop is shown in Figure 1.

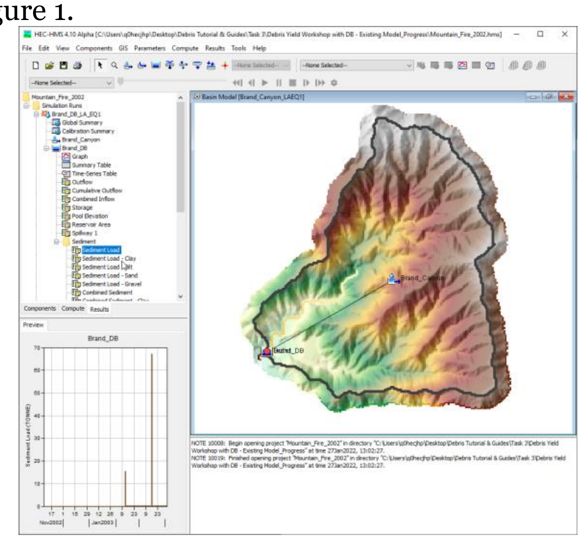

Figure 1. Debris Yield Modeling with Debris Basin

Summary and Conclusions

This paper presents a brief description of the new sediment modeling methods that will be available in HEC-HMS version 4.11. The new features will make it possible to use HEC-HMS to estimate the debris flow/hyper-concentrated sediment load that can be used as input boundary conditions for a debris flow analysis using HEC's River Analysis System (HEC-RAS). These new debris flow capabilities of HEC-HMS focus on post-wildfire hydrology and debris flow to streams, rivers, and lakes. HEC-HMS will be able to model the amount of runoff and debris from burned watersheds and route it through the streams and reservoirs/debris basins. Future versions of the program beyond HEC-HMS 4.11 will include a convenient user interface to specify the necessary data for debris flow analysis and a wide range of available outputs for analyzing both hydrologic and sediment results.

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