THE AUTOMATED GEOSPATIAL WATERSHED ASSSESMENT TOOL (AGWA): USING RAINGAGE, RADAR AND STREAMFLOW RECORDS FROM BURNED WATERSHEDS TO EVALUATE AND IMPROVE PARAMETER ESTIMATIONS

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Abstract: Precipitation and runoff records from several burned watersheds have been used to evaluate the performance of the AGWA/KINEROS2 modeling scheme that Department of Interior Burned Area Emergency Response (DOI BAER) teams use to assess risk immediately following a wildfire. Although DOI BAER teams use this parameterization/modeling framework to assess the relative change in watershed behavior following a wildfire by driving the model with National Oceanic and Atmospheric Administration (NOAA) design storms, calibrations performed on actual events using rainfall estimations provided by rain gages and radar provide insight into the model's performance, and potentially inform changes and developments to the AGWA parameter estimation scheme. Results indicate that current parameter modifications made by AGWA to represent fire provide reasonable results for DOI BAER risk assessments, though additional modifications to saturated hydraulic conductivity may be necessary to represent a broader range of storm sizes and intensities.

INTRODUCTION

Runoff response to rainfall changes following a wildfire (DeBano et al., 1998). This is a result of the removal of canopy cover and organic litter (duff), which decreases interception and surface roughness respectively. Hydrophobic soils can also form as a result of wildfire, which can reduce infiltration rates. The loss of interception, decrease in surface roughness and decrease in infiltration rates all contribute to an increase in surface runoff. This increase in surface runoff presents a risk of flooding and erosion. Hydrologic modeling is often used in order to anticipate this risk, and target areas for mitigating efforts.

AGWA Background: AGWA (see: www.tucson.ars.ag.gov/agwa or http://www.epa.gov/esd/land-sci/agwa/) is a GIS interface jointly developed by the USDA-Agricultural Research Service, the U.S. Environmental Protection Agency, the University of Arizona, and the University of Wyoming to automate the parameterization and execution of a suite of hydrologic and erosion models (SWAT and KINEROS2 – the latter with the Rangeland Hydrology and Erosion Model (RHEM) and the Water Erosion Prediction Project (WEPP) for hillslope erosion options). Through an intuitive interface the user selects an outlet from which AGWA delineates and discretizes the watershed using a digital elevation model (DEM). The watershed model elements are then intersected with nationally available data sets for soils and land cover to derive the requisite model input parameters. The soils layer provides a texture-based estimation of saturated hydraulic conductivity (Ks), and the land cover layer provides information associated with land cover types, such as percent cover, interception, and hydraulic

roughness (Manning's *n*). With the addition of a burn severity map, AGWA can be used to change the existing land cover to reflect burned conditions.

The key challenge to using AGWA in a post-fire context is developing rules to change important model parameters (canopy cover, interception, saturated hydraulic conductivity and hydraulic roughness) as a function of the original cover type and the degree of disturbance based on the burn severity map. To account for burn effects, AGWA reduces the percent canopy cover (CC) parameter using a land cover look up table. Currently for severe, moderate, and low burn severity the CC for a given land cover vegetation class is reduced by 50%, 32%, and 15%, respectively (Burns et al., 2013). AGWA increases the soil texture based Ks using equation (1) based on percent canopy cover (CC) for all land cover types; therefore reductions in CC due to fire will decrease Ks from pre-fire conditions which result in an increase in post-fire runoff.

$$Ks = Ks_{soil} * e^{0.0105*CC} \tag{1}$$

However, preliminary calibration efforts have shown that changes to land cover look-up tables for burn severity alone were insufficient to calibrate Ks for several of the events examined in this study. This could imply that the model input for soils is not sufficiently representative of reality, that the CC reduction percentages are not large enough, that hydrophobic conditions have developed, or that Ks is also a function of rainfall intensity or amount.

METHODS

Changes in soil infiltration and hydraulic roughness are often a result of fire (Canfield et al., 2005). They are also sensitive parameters in the KINEROS2 model (Yatheendradas et al., 2008) and were therefore altered during calibration to match observed runoff in an attempt to determine how they might be altered in AGWA post-fire lookup tables. Gridded searches of the saturated hydraulic conductivity (Ks) and hydraulic roughness (n) parameter space were conducted using the Nash-Sutcliffe (NSE) and the Kling-Gupta Efficiencies (KGE) in order to determine their optimal calibrating multipliers. Multipliers were used to alter parameter values in order to maintain the spatial variability of the parameters given by the spatial data layers, while keeping the number of calibrating parameters small. For this initial investigation the CC parameter was set to zero, and calibrating multipliers were applied to all hillslope model elements in the watershed.

Storms of various sizes at three different small watersheds, Marshall Gulch (8 km^2) in the Santa Catalina Mountains outside of Tucson Arizona, Starmer Gulch (3 km^2) on the Las Alamos National Lab, New Mexico, and Eagle Creek (21 km^2) near Ruidoso, New Mexico, were used in this effort. These storms ranged in total accumulated rainfall depth of 6 to 41 millimeters, observed total outflow volumes ranged from 0.25-4.6 millimeters yielding runoff to rainfall ratios of 0.02-0.25. Peak flows ranged from 0.2-5.9 millimeters/hour. All storms used for analysis were reasonably well modeled with the lowest NSE value being 0.64.

RESULTS

Initial calibrations indicated that there is a correlation between the calibrated Ks values (figure 1), calibrating Ks multipliers (figure 2) and the total depth of the rainfall in an event. This will be explored further with the intention of determining rainfall intensity based thresholds for calibrating Ks multipliers.

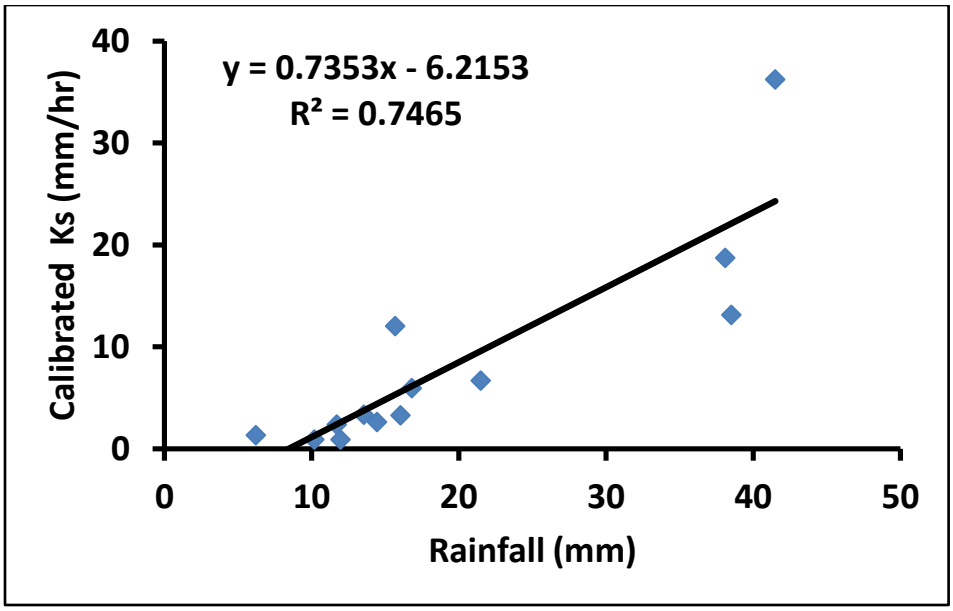

Figure 1 Correlation of rainfall amounts and calibrated Ks values (mm/hr).

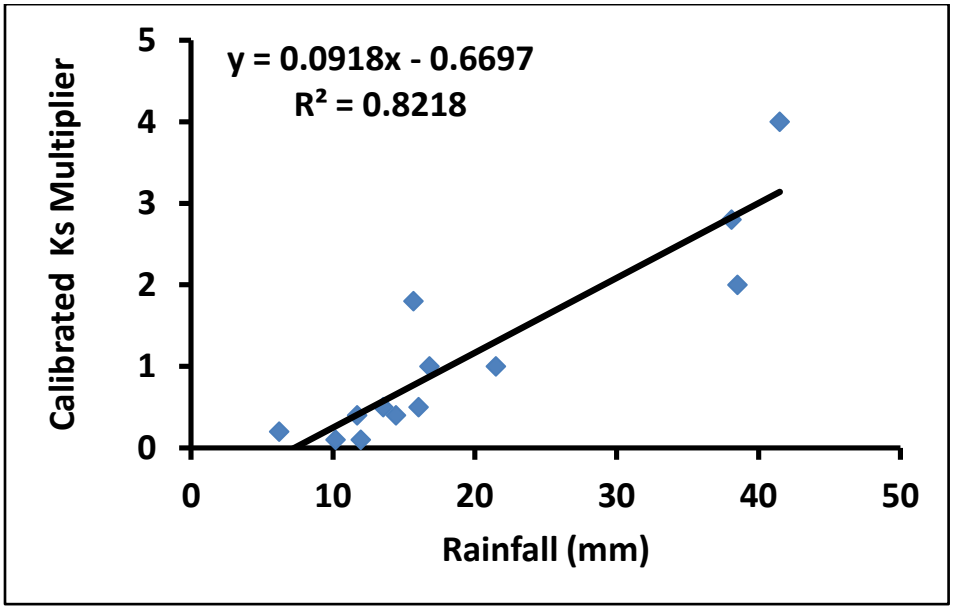

Figure 2 Correlation of rainfall amounts and calibrated Ks multiplier values.

Although many burned watersheds had stream flow and rain gages installed following a wildfire, pre-fire data is rarely available, and storm events appropriate for model calibration are infrequent. The record of data at Marshall Gulch following the 2003 Aspen Fire is the longest record of stream flow and rainfall data used in this study. Dating from 2003-2013, this record gives the opportunity to use data from ten years following a wildfire as a proxy for pre-fire conditions. The storms of 7/29/2003 and 7/15/2013 show that it takes much less rainfall on a burned landscape (figure 3, table 1) to generate similar peak flow on a forested landscape (figure 4, table 1). This is the difference between a storm that is likely to occur every year and a NOAA twenty-five year return period, one-hour design storm.

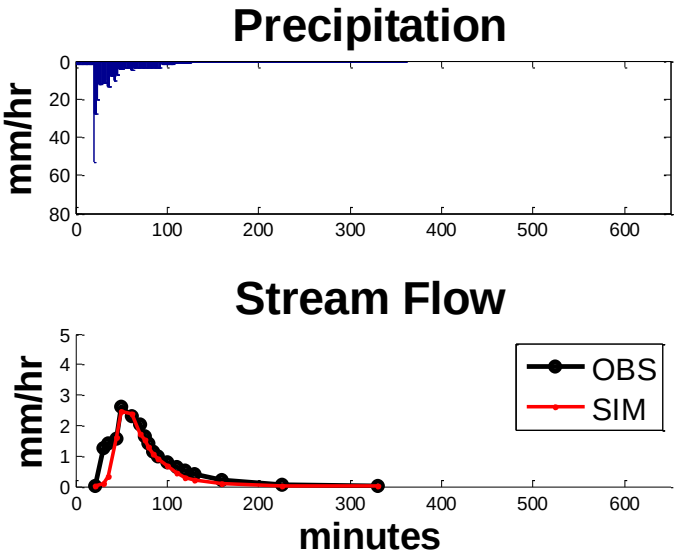

Figure 3 Hyetograph from storm of 7/29/2003 (upper) and simulated and observed streamflow (lower) at the Marshall Gulch Pima County Flood Control gage using Ks and roughness parameters listed in table 1.

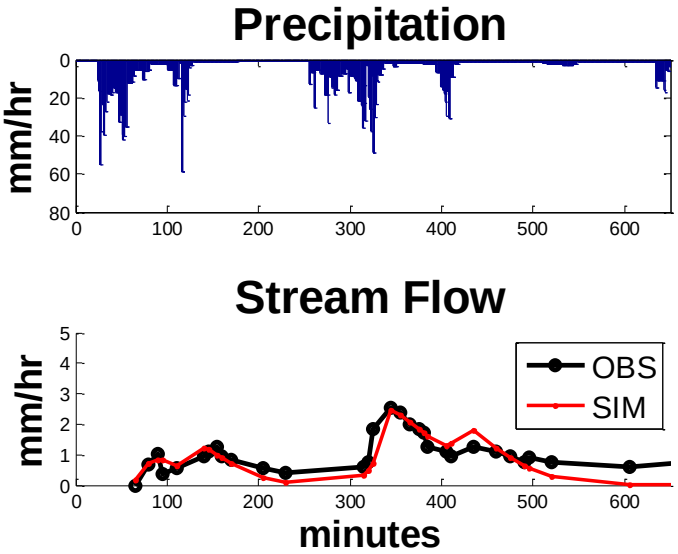

Figure 4 Hyetograph from storm of 7/15/2013 (upper) and simulated and observed streamflow (lower) at the Marshall Gulch Pima County Flood Control gage using Ks and roughness parameters listed in table 1.

Table 1 Rainfall, runoff to rainfall ratio (RO Ratio), observed (OBS) and simulated (SIM) stream flow, Nash-Sutcliffe Efficiency (NSE), and calibrated values of Ks and Manning's *n* (n) for storm events 7/29/2003 and 7/15/2013.

			Peak (mm/hr)		Volume (mm)				
Storm	Rain(mm)	RO Ratio	OBS	SIM	OBS	SIM	NSE	Ks	n
7/29/2003	10.19	0.25	2.62	2.46	2.57	1.96	0.75	1.35	0.03
7/15/2013	58.73	0.21	2.52	2.47	12.43	6.92	0.64	4.50	1.28

The Marshall Gulch responses to storms similar to a NOAA five year return period, one-hour design storm also show quite different behavior for burned (figure 5, table 2) and unburned conditions (figure 6, table 2). Peak flows for burned conditions were nearly five times greater than forested conditions.

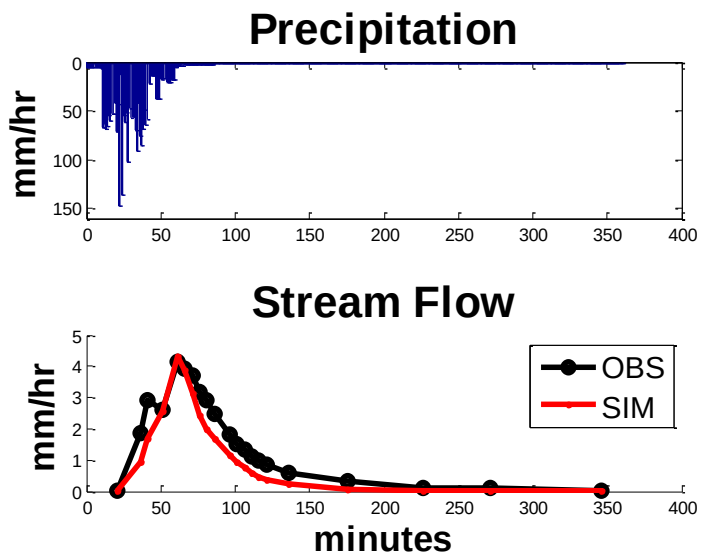

Figure 5 Hyetograph from storm of 7/24/2003 (upper) and simulated and observed streamflow (lower) at the Marshall Gulch Pima County Flood Control gage using Ks and roughness parameters listed in Table 2.

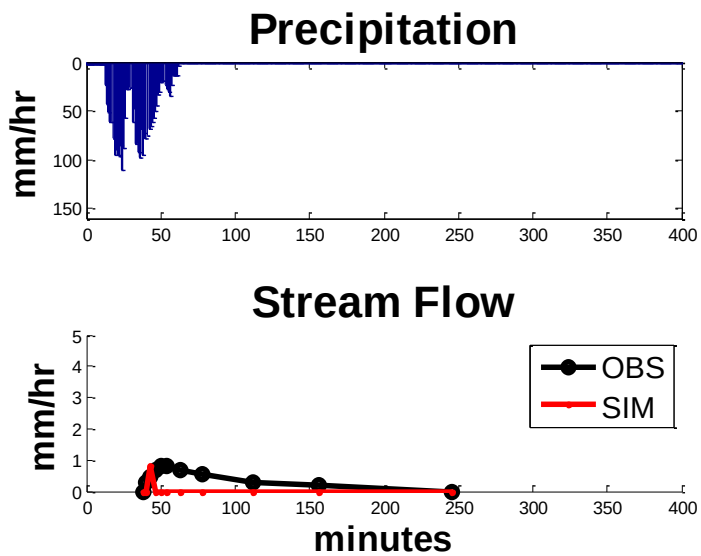

Figure 6 Hyetograph from storm of 7/27/2013 (upper) and simulated and observed streamflow (lower) at the Marshall Gulch Pima County Flood Control gage using Ks and roughness parameter listed in Table 2.

Table 2 Rainfall, runoff to rainfall ratio (RO Ratio), observed (OBS) and simulated (SIM) stream flow, Nash-Sutcliffe Efficiency (NSE), and calibrated values of Ks and Manning's *n* (n) for storm events 7/24/2003 and 7/27/2013. Rainfall amount is equivalent to NOAA five year return period, one-hour design storm.

			Peak (mm/hr)		Volume (mm)				
Storm	Rain(mm)	RO Ratio	OBS	SIM	OBS	SIM	NSE	Ks	n
7/24/2003	41.49	0.11	4.14	4.34	4.58	3.23	0.85	36.00	0.06
7/27/2013	44.60	0.02	0.83	1.17	0.72	0.06	-0.54	15.00	1.44

DISCUSSION

Figures 3 through 6 and tables 1 and 2 demonstrate that the calibrated model better reproduces the 2003 event (burned conditions) hydrographs than the 2013 event (proxy for unburned conditions) hydrographs. This is likely because the KINEROS2 model only represents overland flow generation as infiltration excess, the expected dominant runoff process in burned conditions/areas, and in unburned, forested conditions shallow subsurface flow is an important runoff process which KINEROS2 does not represent. In addition events with low runoff ratios are difficult to model as the uncertainties associated with observed rainfall can be a very large part of the overall runoff signal (high noise to signal ratio – Goodrich et al., 2012).

The difference in the observed responses to the storms of 7/24/2003 and 7/27/2013 provided an opportunity to see how well the AGWA relative difference approach used by DOI BAER teams anticipates change in response to a NOAA five year, one-hour design storm. Hydrographs of the uncalibrated simulated flows at the outlet of Marshall Gulch are shown below (figure 7). The percent change in peak flow for the modeled flows was 456% (table 3), i.e. peak flows in burned conditions are expected to be roughly 5.6 times greater than unburned conditions. For observed

flows a 399% (table 3) increase was calculated, i.e. peak flows in burned conditions are expected to be roughly 5 times greater than unburned conditions. This comparison of storms shows that the method used by DOI BAER would have been a very reasonable estimate of peak flow for use in risk assessment.

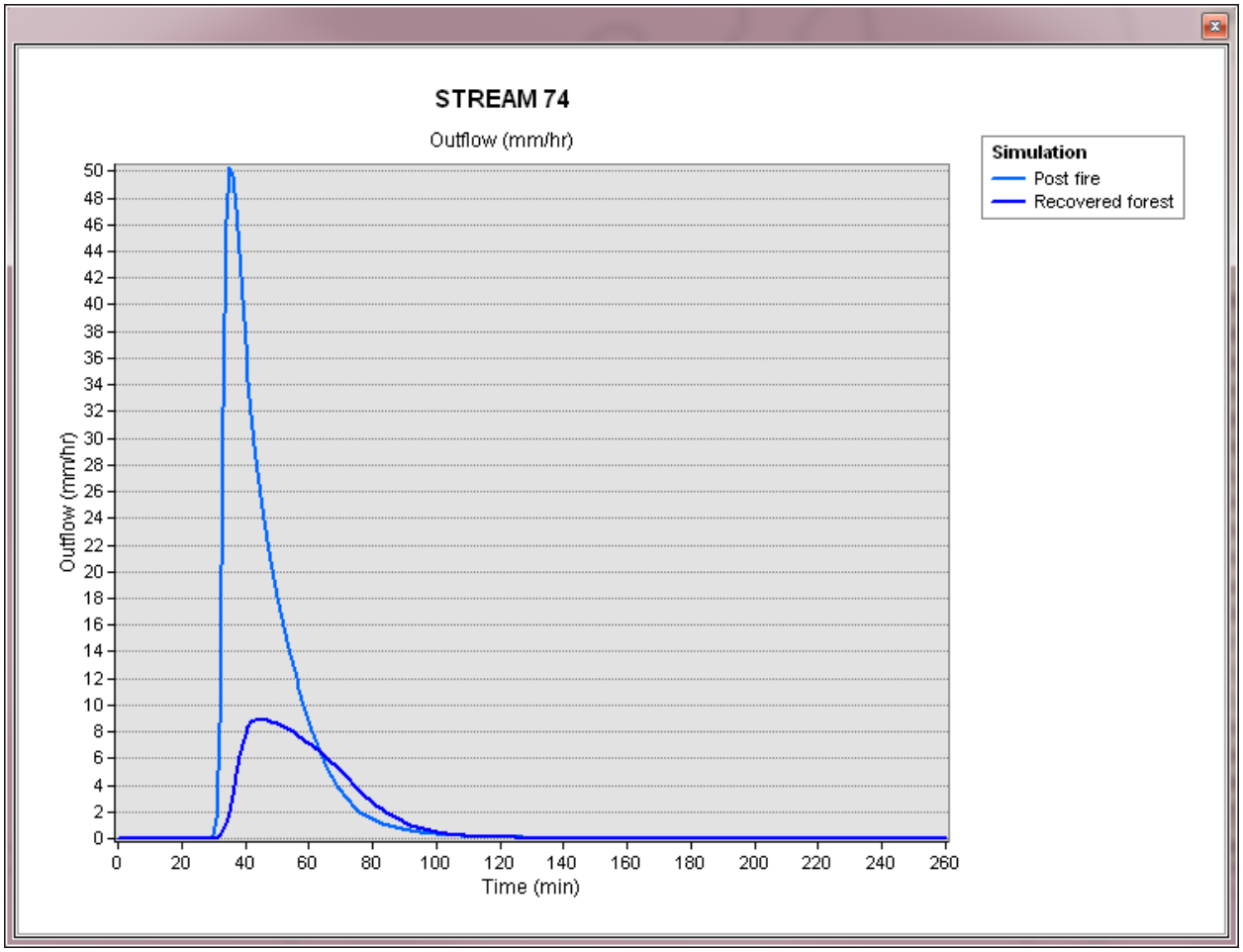

Figure 7 AGWA hydrograph output for uncalibrated KINEROS2 simulations of unburned and burned conditions responding to a NOAA five year, one-hour design storm.

Table 3 Percent change determined by modeling results and by observed data for NOAA five year, one-hour return storm.

	AGWA/K2	OBS
Unburned Conditions Peak Flow (mm/hr)	9	0.83
Burned Conditions Peak Flow (mm/hr)	50	4.14
Percent Difference	456	399

FUTURE WORK

Further investigations will be made using both rain gage records and bias corrected radar precipitation estimates to determine if thresholds can be established for calibrating Ks multipliers

for differing intensities of rainfall. Additional storms from Marshall Gulch, Starmer Gulch, Eagle Creek, and other watersheds will be calibrated to determine how similar or different the calibrating multipliers for Ks and surface roughness are at different locations. Once the correlation between rainfall intensity and Ks is better understood, refinement of this parameter for post-fire modeling use will be performed by including canopy cover values and applying calibrating multipliers only to burned hillslope elements in order to improve post-fire modeling use. Watershed recovery as a function of time since fire will also be investigated using post-fire events over long periods of time where they are available. In addition, remotely sensed estimates of cover condition over time will be assessed to see if they provide a reasonable surrogate measure for recovery.

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