Automated Geospatial Watershed Assessment Tool (AGWA)

D. Phillip Guertin[1]; David C. Goodrich[2]; I. Shea Burns[3]; Yoganand Korgaonkar[4]; Jane Barlow[5]; Brain Scott Sheppard[6]; Carl Unkrich[7]; and William Kepner[8]

[1]Professor, School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona 85721. E-mail: dpg@email.arizona.edu
[2]Research Hydraulic Engineer, USDA Agricultural Research Service, Tucson, Arizona 85719. E-mail: dave.goodrich@ars.usda.gov
[3]Senior Research Specialist, School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona 85721. E-mail: shea.burns@ars.usda.gov
[4]Graduate Student, School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona 85721. E-mail: yoganandk@email.arizona.edu
[5]Graduate Student, School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona 85721. E-mail: jane.e.barlow@gmail.com
[6]Graduate Student, Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona 85721. E-mail: bss1@email.arizona.edu
[7]Hydrologist, USDA Agricultural Research Service, Tucson, Arizona 85719.
E-mail: carl.unkrich@ars.usda.gov
[8]Research Ecologist, U.S. EPA – Landscape Ecology Branch, Las Vegas, Nevada 93193. E-mail: kepner.william@epa.gov

Abstract

The Automated Geospatial Watershed Assessment tool (AGWA, see: www.tucson.ars.ag.gov/agwaor 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 (RHEM, KINEROS2 and SWAT). Through an intuitive interface the user selects an outlet from which AGWA delineates anddiscretizes the watershed using a Digital Elevation Model (DEM). The watershed modelelements are then intersected with terrain, soils, and land cover data layers to derive the requisitemodel input parameters. The chosen model is then run, and the results are imported backinto AGWA for graphical display. AGWA can difference results from multiple simulations to examine relative change over a variety of input scenarios (e.g. climate/storm change, land cover change, implementation of BMPs, present conditions and alternative futures).This allows managers to identify potential problem areas where additional monitoring can be undertaken or mitigation activities can be focused. Application examples of AGWA will be presented including post-fire assessment, implementation of rangeland BMPs, green infrastructure, and future change analysis. Versions of AGWA are available for ESRI ArcView 3.x and ArcGIS 9.x and 10.x.

INTRODUCTION

The ability to evaluate the effect on runoff, erosion and water quality of historical or future change in watershed conditions is essential for environmental management. Tools that can assess the impact of land use/land cover change, evaluate the effects of management actions, supports identifying areas that are at risk for impairment, and support identify monitoring locations are needed for watershed-based planning and decision-making. In order to be practical watershed assessment tools must not only be able to predict the impacts of changing watershed conditions, but should be fully functional with readily available/easily accessible data, provide output metrics important for decision-making, and be relatively easy to use.

The Automated Geospatial Watershed Assessment tool (AGWA, see: www.tucson.ars.ag.gov/agwa or http://www.epa.gov/esd/land-sci/agwa/) was designed to support watershed assessment and analysis across a range of spatial and temporal scales, to automate the model parameterizing process, and to graphically visualize modeling results. The development of AGWA has been a joint effort with the USDA Agricultural Research Service's Southwest Watershed Research Center, U.S. EPA Landscape Ecology Branch, University of Arizona, and University of Wyoming. This paper will provide an overview of AGWA and its application.

OVERVIEW

AGWA (Miller et al. 2007, Goodrich et al. 2012) is a Geographic Information System (GIS) based watershed modeling tool. The guiding principles for the development of AGWA were: 1) that it provide simple, direct, transparent, and repeatable parameterization routines through an automated, intuitive interface; 2) that it be applicable to ungauged watersheds at multiple scales; 3) that it evaluate the impacts of management and be useful for scenario development; and 4) that it use free and commonly available GIS data layers.

The models currently incorporated in AGWA are KINEROS2 (K2 – KINematic runoff and EROSion model, Smith et al. 1995), RHEM (Rangeland Hydrology and Erosion Model, Nearing et al. 2011), and SWAT (Soil & Water Assessment Tool version 2000 and version 2005, Arnold and Fohrer 2005). AGWA supports modeling along a continuum of spatial and temporal scales, ranging from hillslopes (~hectares) to large watersheds (>1000 km^2) and from individual storm events (minute time steps) to continuous simulation (daily time steps over multiple years). AGWA facilitates the parameterization and execution of the said hydrologic models for watershed modeling efforts by performing the following tasks: watershed delineation; watershed discretization into discrete model elements; watershed parameterization; precipitation definition; model simulation creation; model execution; and model results visualization (Figure 1). Various data are required to support this functionality, including: a raster-based DEM (digital elevation model); a polygon soil map (NRCS SSURGO, NRCS STATSGO, or FAO soil maps are supported); and a

classified, raster-based land cover (NLCD, NALC, and SWGAP datasets are supported via provided look-up tables, however other datasets may also be used if accompanied with a respective look-up table). AGWA does not require observed precipitation or runoff to drive the models when used for relative assessment/differencing between scenarios, and can use user-defined depths and durations, user-defined hyetographs, or design storms to drive K2, and included weather station-based generated, daily precipitation to drive SWAT. However, high-quality rainfall-runoff observations are required for calibration and confidence in quantitative model predictions (Goodrich et al., 2012).

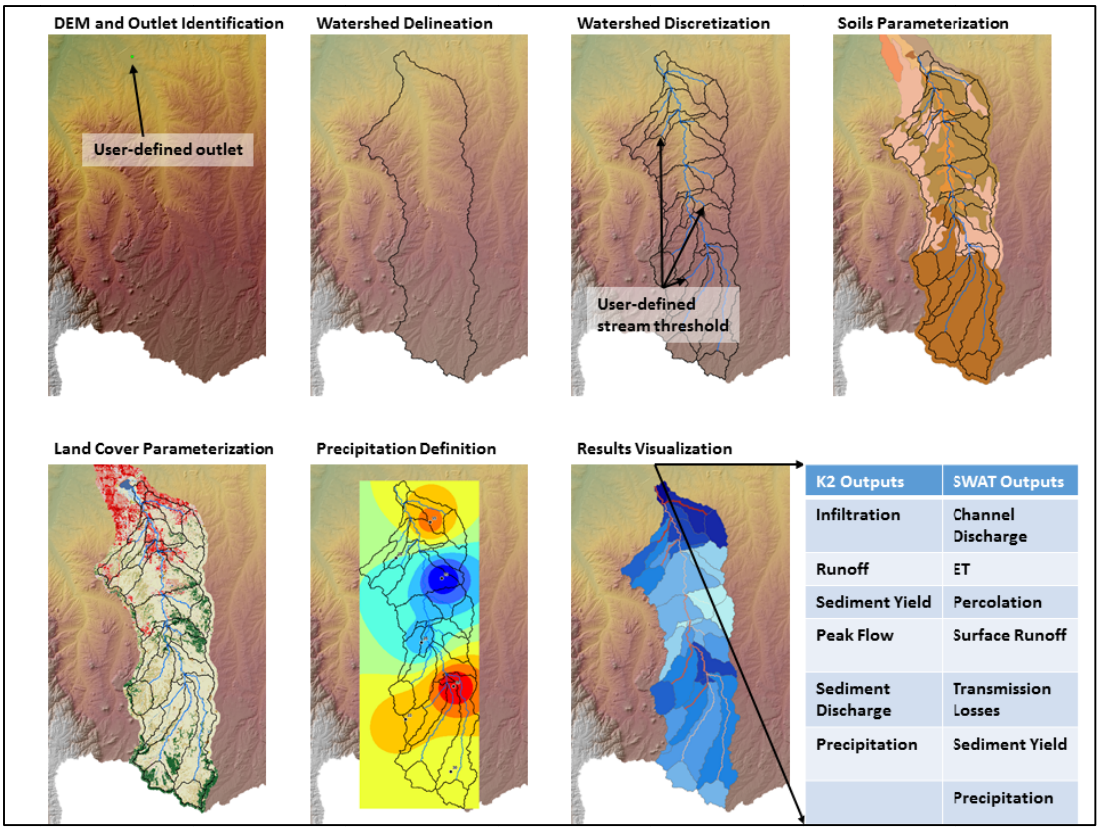

Figure 1: The required steps in AGWA to perform a watershed assessment. A DEM is used to delineate the watershed, subdivide it into model elements, and parameterize the elements in conjunction with the soils and land cover layers. Precipitation drives the model and model results are imported and visualized in the GIS.

Watershed Delineation: Watershed delineation is performed by, at a minimum, selecting a workspace location, delineation name, DEM, and watershed outlet. If the DEM has not been filled to ensure proper drainage, AGWA will fill it. Likewise, if a flow direction raster and a flow accumulation raster have not been selected, AGWA will create them in the delineation process. Selecting a watershed outlet entails selecting a pre-existing outlet point or by defining an outlet and snapping it to the highest flow accumulation value within a user-defined search radius. Alternatively,

the user can delineate a group of watersheds using multiple pre-existing outlet points or by selecting an area of interest and defining a maximum extent for the group of watersheds. Watershed delineations are stored as feature classes within a geodatabase created during this step.

Watershed Discretization: Watershed discretization is performed, fundamentally, by defining a stream network for the watershed delineation and subdividing the watershed based on the stream network. Various methods exist for creating the stream network, including: a minimum accumulated area required for stream definition (contributing source area, or CSA, approach); a minimum accumulated flow length required for stream definition (flow length approach); or a pre-existing stream network approach where streams are defined by snapping the from nodes of the first-order streams in the selected stream network to the highest flow accumulation or flow length within a set distance. Model selection is also defined during the watershed discretization step because the models have non-compatible watershed representations. Watershed discretizations are stored as feature datasets containing single polygon, polyline, and nodes feature classes within the geodatabase created in the watershed delineation.

Watershed Parameterization: Watershed parameterization is performed by intersecting the model elements from the watershed discretization with a DEM-derived slope raster, a soils polygon, and a land cover raster. The model elements are then characterized using the topographic, soil, and land cover properties from the layers they intersect and these parameters are stored in related tables (with an associated parameterization name to identify it) within the geodatabase created in the watershed delineation.

Precipitation Definition: Precipitation definition is performed differently for each model because of the difference between event-based precipitation versus continuous daily precipitation. For K2, precipitation is created using user-defined hyetographs, user-defined depths and durations, pre-defined design storms, or raster-based precipitation surfaces representing return period-duration depths. For non-user-defined hyetographs, K2 precipitation events can be represented with a uniform intensity or with an intensity derived from the SCS Type II distribution. For SWAT, precipitation is created by selecting one or more rain gages and providing a continuous, daily rainfall record for each gage. If more than one rain gage is selected, AGWA will create Thiessen polygons to intersect with the watershed discretization to area-weight the depth assigned to each subwatershed. For all models, precipitation is stored as flat text files in a "precip" directory that is nested in the workspace location defined in the watershed delineation step under subdirectories named for the watershed delineation and watershed discretization.

Model Simulation Creation: Model simulations may be created following the precipitation definition step for K2, or after the watershed parameterization step for SWAT if the model will be driven by weather station generated daily rainfall values. Creating K2 simulations minimally requires defining a simulation name, and

selecting a watershed discretization, a parameterization of that discretization, and a precipitation file created for that discretization. Optionally, parameter multipliers may also be defined for K2. For SWAT, similar steps are required, but additional selections must also be made. The user may elect to forgo selecting a precipitation file (and also a daily temperature file) and instead generate daily precipitation (and temperature) using a user-selected weather station. The user must also define the start and end date of the simulation since SWAT is a continuous model. Optionally, the user may define subbasin adjustment factors, groundwater parameters, crop types, and a results output timestep (the model runs on a daily timestep regardless of the results output timestep). Model simulations are stored as flat files in a directory named for the simulation name that are nested in the workspace location defined in the watershed delineation step under subdirectories named for the watershed delineation and watershed discretization.

Model Execution: Model execution is performed by selecting a watershed discretization and a simulation already created for that discretization. Model execution is separated from model simulation creation to provide the user the ability to edit model input files following simulation creation but prior to model execution. This capability allows the user to rerun existing simulations limitlessly if changes are made to the simulation outside of AGWA.

Model Results Visualization: Model results visualization is performed by selecting a watershed discretization, importing/re-importing completed simulations, and selecting model outputs to map onto the watershed discretization. A variety of outputs can be displayed for any upland or channel model element including major water balance components and fluxes. K2 can also display hydrographs for simulations. Both models can calculate differences between two simulations as either an absolute difference or a percent difference.

APPLICATIONS

Landscape Change Assessment: AGWA was originally designed to assess the effects of landscape change on runoff, erosion and sediment yield. AGWA can use the National Land Cover Dataset (NLCD) for parameterization so it can assess the effect of the most recent NLCD version or look at change between NLCD versions. AGWA has been used to assess landscape change on runoff and water quality in Arizona, New York, Virginia, Oregon, Texas, Kenya, Jordan, Mexico and other locations (Miller et al. 2002; Kepner 2008a; Yang and Li 2011; Baker and Miller 2013; Abulla and Eshtawi 2007; Norman et al. 2010).

AGWA has also been used to forecast the impact of potential future changes related to growth and climate change (Kepner et al. 2008a; Kepner et al. 2008b). In recent studies, Burns et al. (2013) and Barlow et al. (2014) developed a methodology to characterize the hydrologic impacts of future urban growth through time. Future growth is represented by housing density maps generated in decadal intervals from 2010 to 2100, produced by the US-EPA Integrated Climate and Land-Use Scenarios

(ICLUS; Bierwagen et al., 2010) project. ICLUS developed future housing density maps by adapting the Intergovernmental Panel on Climate Change (IPCC) social, economic, and demographic storylines to the conterminous United States. To characterize the hydrologic impacts of future growth, the housing density maps were reclassified to National Land Cover Database 2006 land cover classes and used to parameterize SWAT using AGWA. Burns et al. (2013) conducted this effort in the international San Pedro Basin in southeast Arizona and did not find a substantial impact on average surface runoff or on sediment yield at the watershed outlet for all scenarios. However, over smaller subwatersheds where development was concentrated the hydrologic changes are more significant. Barlow et al. (2014) found similar results in the South Platte Basin that contains the greater Denver, Colorado metro region.

Rangeland Assessment: Effective rangeland management requires the ability to assess the potential impacts of management actions on soil erosion and sediment yield at both the hillslope and watershed scales. Many of the current tools for assessing and evaluating the effects of rangeland management practices on soil and water resources originally were developed for traditional cropland agricultural practices. These tools and models assumed a uniform vegetation distribution and surface cover across the landscape, which was inadequate to represent typical rangeland conditions. A Decision Support Tool (DST) that incorporates ecological concepts and rangeland management practices, uses readily available data, and was developed to represent rangeland hydrologic and erosion processes by integrating the RHEM and KINEROS2 models and developing parameterization approaches for AGWA (Goodrich et al. 2011). RHEM is used to model runoff and erosion from hillslope modeling elements. AGWA, via the KINEROS2 watershed model, executes RHEM for all hillslopes within a watershed. Runoff and sediment are then routed through channels draining the hillslopes, enabling rapid watershed scale assessments.

AGWA has been used in research in the USDA Grazing Lands Conservation Effects Assessment Project (Weltz et al. 2011). AGWA can evaluate the runoff and erosion impacts from several rangeland best management practices (BMPs) including, brush removal, watering locations, prescribed grazing, retention/detention ponds, and prescribed fire. AGWA can be used to evaluate the relative change in runoff and erosion resulting from a suite of BMPs at the hillslope, grazing allotment and watershed scales.

Post-fire Assessment: Since 2011, AGWA has been used by Burn Area Emergency Response (BAER) teams to evaluate post-fire effects on runoff and erosion. Fires that used AGWA include the Wallow (AZ-2011), Las Conchas (NM-2011), Little Bear (NM-2012), Mountain (CA-2013), Mile Marker 28 (WA-2013), Silver (CA-2013), Elk/Pony (ID-2013), and Rim (CA-2013) fires. The AGWA project currently has an agreement with the Bureau of Land Management to assist the Department of Interior on BAER activities. AGWA results of post-fire hydrological and erosional watershed response are being included in BAER assessments and presented at public meetings. Parameterization procedures have been develop to evaluate the effect of

burn severity on runoff and erosion parameters (Goodrich et al. 2012), which supports the use of burn severity maps (Figure 2) to assess fire impacts at a watershed scale. BAER teams are interested in identifying areas of concern both within the burn area (Figure 3) and

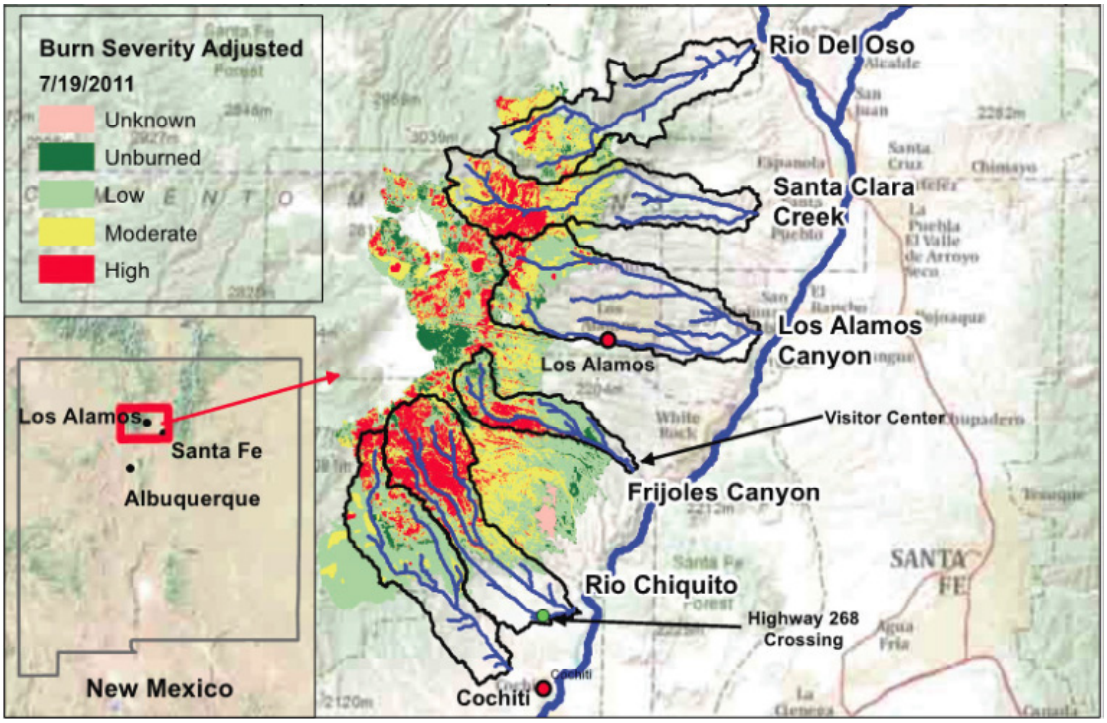

Figure 2: Burn severity map for the Las Conchas fire New Mexico, July 2011 (from Goodrich et al. 2012).

downstream, such as increased risk of flooding (Figure 4). Since wildfire severity impacts post-fire hydrological response, fuel treatments can be a useful tool for land managers to moderate this response. Sidman et al. (2015) conducted a spatial modeling approach that couples three models used sequentially to allow managers to model the effects of fuel treatments on post-fire hydrological impacts. Case studies involving a planned prescribed fire at Zion National Park and a planned mechanical thinning at Bryce Canyon National Park were used to demonstrate the approach. Fuel treatments were modeled using FuelCalc and FlamMap within the Wildland Fire Assessment Tool (WFAT). The First Order Fire Effects Model (FOFEM) was then used to evaluate the effectiveness of the fuel treatments by modeling wildfires on both treated and untreated landscapes. Post wildfire hydrological response was then modeled using KINEROS2 within AGWA. This approach provides a viable option for landscape scientists, watershed hydrologists, and land managers hoping to predict the impact of fuel treatments on post-wildfire runoff and erosion and who want to compare various fuel treatment scenarios to optimize resources and maximize mitigation results.

Built Environment Assessment: The K2 model can be used to predict runoff and peak flows in a built environment (Kennedy et al. 2013). Additionally, new tools

have been designed for AGWA to parameterize K2 for built environments. The GI/LID (Green Infrastructure/Low Impact Development) tool will allow users to assess the impacts of LID practices on flooding and stormwater capture (Korgaonkar et al. 2014). The K2 model can represent the effect of water harvesting, detention/retention basins, pervious surfaces, and channel modification. Tools have also been developed that allow the user to describe the characteristics of a home lot, with and without LID practices and to manually define the flow network within an urban watershed. The impact of different combination of LID practices can be assessed and compared to obtain the "optimal" design.

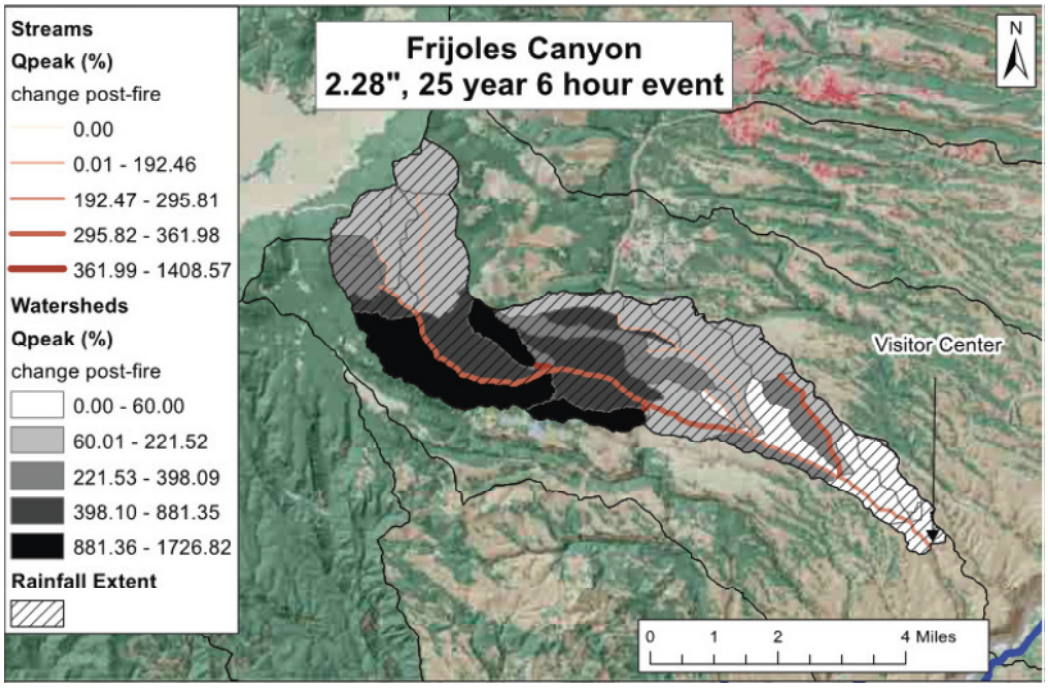

Figure 3. Percent change in pre- and post-fire peak runoff rates (streams and adjacent contributing areas) for the 6-hour, 25-year design storm as simulated by AGWA/KINEROS2. The diagonal shading indicates spatially uniform application of rainfall over the entire watershed (from Goodrich et al. 2012).

CONCLUSIONS

AGWA is a GIS-based hydrologic modeling tool that supports many aspects of watershed assessment and analysis including identifying areas at risk based on current or future conditions, evaluating effectiveness of LID (built environments) and BMP (range environments) practices, and supporting post-fire assessments. Future research will include incorporating the ability to model nitrogen and phosphorus loads in built environments. More LID practices (e.g. swales, bioretention facilities, infiltration basins, and filter strips) will be included in the GI/LID tool. Improvements are being made in the post-fire parameterization to better represent temporal changes associated with post-fire recovery.

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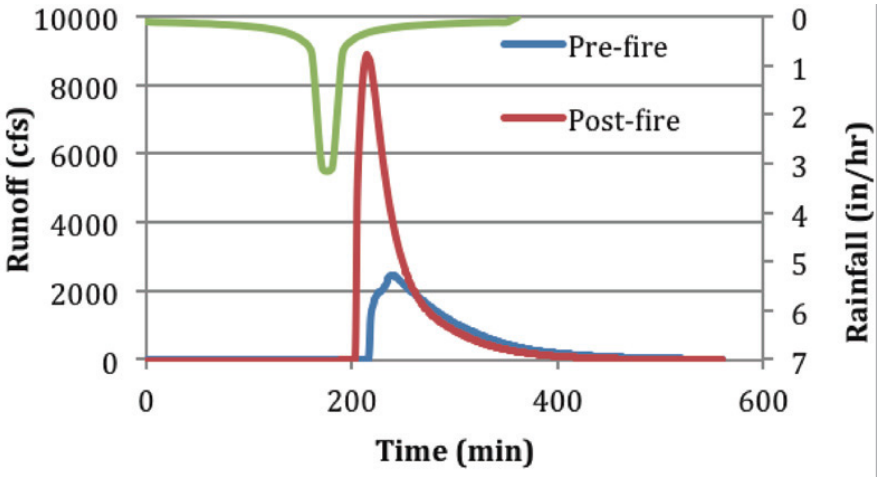

Figure 4. Simulated pre- and post-fire hydrographs at the Frijoles watershed outlet adjacent to the Bandelier National Monument Visitor Center for the 6-hour, 25-year design storm of 58 mm (2.28 in.) (from Goodrich et al. 2012).

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