LA-UR-01-4359
Approved for public release; distribution is unlimited.

Title:

A CHARACTERIZATION METHODOLOGY FOR POST-WILDFIRE FLOOD HAZARD ASSESSMENTS

Author(s):

Stephen G. McLin
Mark E. Van Eeckhout
Everett P. Springer
Leonard J. Lane

Submitted to:

International Congress on Modelling and Simulation
MODSIM 2001, 10-13 December 2001
The Australian National University
Canberra, Australia

A Characterization Methodology for Post-Wildfire Flood Hazard Assessments

S.G. McLin[a], **M.E. Van Eeckhout**[a], **E.P. Springer**[a], **and L.J. Lane**[b]

[a] *Los Alamos National Laboratory, Los Alamos, NM, 87545, USA (sgm@lanl.gov)*

[b] *Southwest Watershed Research Center, USDA, ARS, 2000 E. Allen Rd, Tucson, AZ, 85719, USA*

Abstract: A combined GIS-HEC modeling application for floodplain analysis of pre- and post-burned watersheds is described. The burned study area is located on Pajarito Plateau near Los Alamos, New Mexico (USA), where the Cerro Grande Wildfire burned 17,353 ha (42,878 ac) in May 2000. This area is dominated by rugged mountains that are dissected by numerous steep canyons having both ephemeral and perennial channel reaches. Vegetation consists of pinon-juniper woodlands located between 1,829-2,134 m (6,000-7,000 ft) above mean sea level (m MSL), and Ponderosa pine stands between 2,134-3,048 m MSL (7,000-10,000 ft). Approximately seventeen percent of the burned area is located within Los Alamos National Laboratory, and the remainder is located in upstream or adjacent watersheds. Pre-burn floodplains were previously mapped in 1991–92 using early HEC models as part of the RCRA/HSWA permitting process. Numerous recording precipitation and stream gages have also been installed. These data provide essential information characterizing rainfall-runoff relationships before and after the fire. They are also being used to monitor spatial and temporal changes as forest recovery progresses. Post-burn changes in HEC-HMS predicted rainfall-runoff patterns are related to changes in watershed vegetation cover and hydrophobic soil conditions. Stream channel cross-sectional geometries were extracted from 0.3 m (1 ft) DEM data using ArcView GIS. Then floodpool topwidths, depths, and flow velocities were remapped using the HEC-RAS model. Finally, numerous surveyed channel sections were selectively made at crucial sites for model verification. Direct comparisons are made between alternative data acquisition and mapping techniques.

***Keywords*:** DEM; GIS; HEC-HMS; HEC-RAS; Floodplain Modelling

1. INTRODUCTION

Los Alamos National Laboratory (the Laboratory) was established in 1943 as a national research and development facility. It is located (35°52′N, 106°19′W) in north-central New Mexico (USA) about 97 km (60 miles) north-northeast of Albuquerque, and 40 km (25 miles) northwest of Santa Fe (Figure 1). Los Alamos has a semiarid, temperate mountain climate. This 111-square km (43 square mile) facility is situated on Pajarito Plateau between the Jemez Mountains on the west and the Rio Grande Valley to the east. The Plateau slopes east-southeast for more than 24 channel km (15 miles), where it terminates along the Rio Grande in White Rock Canyon. Topography ranges from 2,377 m (7,800 ft) above mean sea level (m MSL) along the western Laboratory margin to about 1,951 m MSL (6,400 ft) at the canyon rim. The Plateau is dissected by a system of gaged and ungaged watersheds that are dominated by ephemeral stream drainage. Here we define a gaged watershed as one having at least one rain gage (input) and one stream gage (output) so that the system response can be estimated [Dooge, 1959, 1973]. Some perennial channel reaches are also locally defined. All of these watersheds are elongated in the west-to-east flow direction along Pajarito Plateau, and are extremely narrow in the north-south direction. All total, there are 13 separate watersheds draining Laboratory lands that contain over 161 channel km (100 miles) requiring floodplain identification. These floodplains are defined at approximately 61 m (200 ft) intervals using topographic data obtained from a 0.3 m (1 ft) gridded digital elevation model (DEM). These data were obtained from a 1992 aerial photogrammetric survey of the Laboratory and surrounding areas.

The Cerro Grande wildfire began as a US National Park Service prescribed burn on May 4, 2000. It quickly spread out of control because of high winds and extremely dry conditions. The fire was contained on June 6, 2000, after consuming approximately 17,353 ha (42,878 ac), including 3,010 ha (7,439 ac) within the Laboratory. The fire continued to burn inside the containment line throughout July as seen in Figure 1.

In 1990 the Laboratory became a permitted hazardous waste treatment, storage, and disposal facility. Permit conditions stipulate that all Resource Conservation and Recovery Act (RCRA) facilities must delineate 100-year floodplain elevations within their boundaries [40 CFR 270.14(b)(11)(iii)]. These floodplains were originally mapped [McLin, 1992] using the US Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) computer-based Flood Hydrograph Package (HEC-1) and the Water Surface Profiles Package (HEC-2). These techniques are well-documented and routinely used for floodplain analyses [Hoggan, 1996]. Updated model versions [USACE, 2001a, 2001b] now include HEC-HMS (Hydrologic Modeling System) and HEC-RAS (River Analysis System). All floodplain boundaries are being remapped following the Cerro Grande wildfire because they have expanded. These changes are in direct response to fire-related modifications in the rainfall-runoff process due to reductions in watershed vegetation cover and development of hydrophobic soil conditions. As the forest around the Laboratory recovers over the next several decades, these floodplain boundaries are expected to recede slowly back toward their pre-fire boundaries at some undetermined rate.

2. HEC-HMS RAINFALL-RUNOFF MODEL

HEC-HMS is a single event, rainfall-runoff model that can be used to simulate real or hypothetical storm hydrographs in gaged or ungaged watersheds in response to user specified rainfall hyetographs [USACE, 2001a]. This model was used to forecast both pre- and post-burn flooding impacts associated with the Cerro Grande wildfire [McLin et al., 2001]. Output from the model includes the design storm hydrograph for individual subbasins. Hydrograph peaks are then utilized in the HEC-RAS model as input data to predict floodplain boundaries.

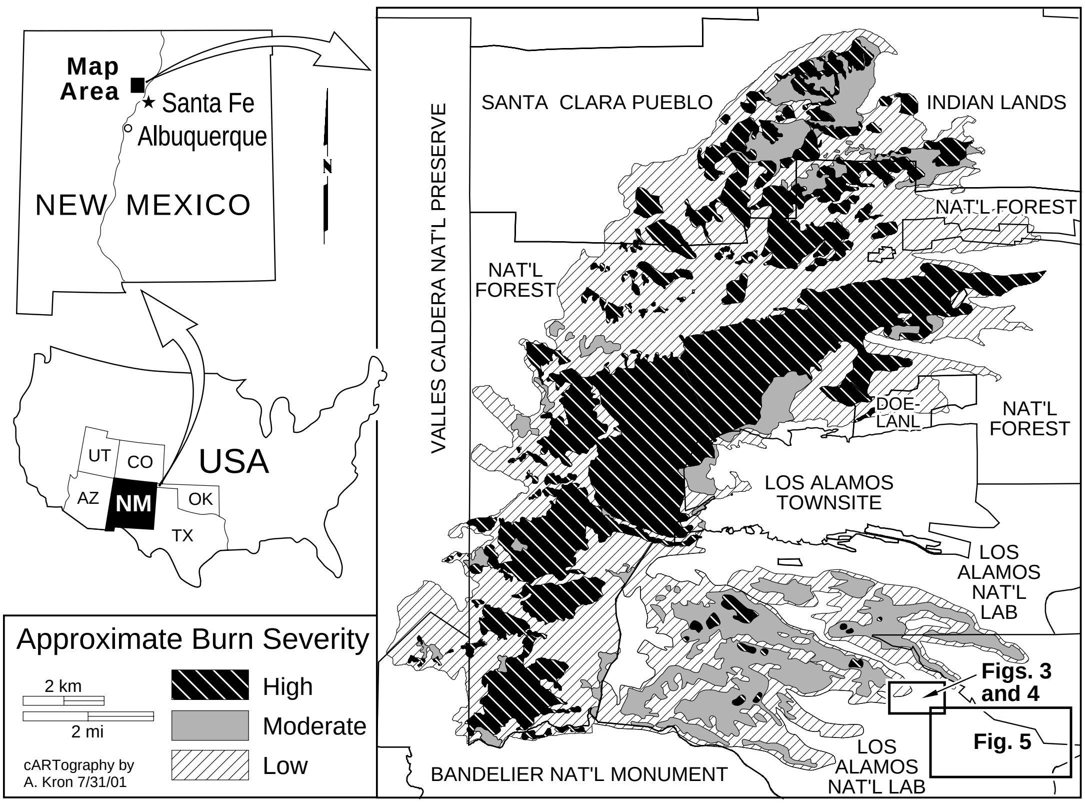

Figure 1. Location map of Los Alamos showing Cerro Grande wildfire burn area.

HEC-HMS can utilize five different unit hydrographs (UH) to simulate runoff. The SCS UH and SCS rainfall abstraction loss rate [SCS, 1993] were selected in this study to characterize the relationship between rainfall-runoff and peak discharge. The Muskingum method was selected to route computed flood flows through downstream subbasins because channel losses and flood-wave attenuation in individual watersheds have not been fully characterized. Hence these losses were assumed to be zero even though they are known to be relatively high in certain pre-fire stream channel reaches (e.g., those channel reaches with relatively thick alluvial deposits). Muskingum routing parameters were computed from average channel flow velocities using Manning's equation. In addition, level-pool reservoir routing was selected to move water through road culverts with high embankments and for flood detention structures.

Pre-fire SCS curve numbers (CN) were determined for all watersheds [McLin, 1992] and formed a starting point for post-fire simulations. These pre-fire CN values typically ranged from the mid-50s and 60s for wooded alpine forests, to 70s and 80s for mountain brush and pinon-juniper woodlands. These values were originally obtained using a quasi-model calibration procedure for ungaged watersheds [McLin et al., 2001].

The post-fire CN values were initially modified from original values using weighting factors based on the percent of subbasin areas that were burned. These burned areas were subdivided into low (57% of total burn area), medium (8% of total), and high (34% of total) severity burned areas as defined by the US Forest Service’s Burned Area Emergency Rehabilitation team [BAER, 2000]. This classification is qualitatively linked to changes in soil texture and infiltration capacity. High burn severity areas are located in those areas where the surficial soil structure has been altered. These soils typically have a hydrophobic layer that was formed during the fire. This layer is located approximately 6.4 mm (0.25 in) below the surface and is between 6.4 to 76 mm (0.25 to 3.0 in) thick. These hydrophobic soils develop when high temperature fires produce heavy volatile organics that migrate into soils and condense [Imeson et al., 1992; Dekker and Ritsema, 1994]. For the Cerro Grande wildfire, these hydrophobic soils are preferentially located on north-facing canyon slopes with heavy ponderosa pine forests. They occur on approximately 22% of the total burn area. Medium severity burn areas show little or no hydrophobicity and are concentrated on south-facing canyon slopes with sparser vegetation, on mesa tops, and in canyon bottoms. Low severity burn areas are generally located along the perimeter of more severely burned areas. This hydrophobic soil distribution is related to the distribution of fuels, temperature, and heavy winds during the fire.

Post-fire CN values of 65, 85, and 90 were assigned to the low, medium, and high severity burn areas, respectively. Unburned areas retained their original pre-fire CN values. A composite CN value was then computed for each subbasin using four burn severity weight factors and four estimated CN values. These weight factors were computed according to the fraction of burned area within each subbasin area (i.e., unburned, low, medium, or high severity). Each respective weight factor was multiplied by each respective CN value and the results were summed to obtain the composite CN value. Details of the HEC-HMS simulations are described in McLin et al. [2001].

3. HEC-RAS FLOODPLAIN MAPPING

For the modeling efforts described here, stream channel cross-sections at varying locations were obtained from the Laboratory's computer-based graphical information system (ArcView GIS). For this study, cross-sections are located approximately every 61 m (200 ft) along each reach. Topographic data are automatically extracted from a triangulated irregular network (TIN) that is created from the DEM database. This procedure minimizes channel-surveying tasks. The data extraction process is performed for each cross-section following the pre-selected channel reach pathway. Each point along the cross-section forms an (x, y, z) topographic point that is geo-referenced to the New Mexico State Plane coordinate system. A typical 30 m (100 ft) long cross section contains between 15 and 50 data points. These cross-sectional features are exported to the HEC-RAS model using HEC-geoRAS, an ArcView extension capability developed by the USACE-HEC.

In order to verify this data extraction process, approximately 1% of all channel sections were surveyed using a network of precision benchmarks. Differences between 51 surveyed and DEM low-point elevations from channel sections are shown in Figure 2. These elevation differences (i.e., surveyed minus DEM elevations for identical points) are normally distributed and appear random. They have a mean difference of 0.34 m (1.11 ft) and a standard deviation of 0.64 m (2.11 ft). These differences range from +1.81 m (5.92 ft) to –1.19 m (–3.89 ft). The affect of these

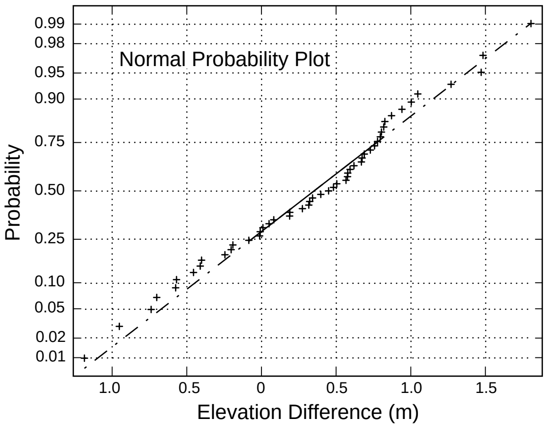

Figure 2. Probability plot of elevation differences.

elevation differences on the floodpool mapping process is presently unknown.

The independently executed HEC-RAS model employs a HEC-HMS hydrograph peak to simulate a water surface elevation at each channel section using a steady, gradually varied flow approximation. Here the water surface elevation is computed as a function of channel distance using an iterative standard-step method [USACE, 2001b]. The model computes a pair of left and right overbank floodpool coordinates for each section that identifies where the DEM land surface and computed floodpool intersect. Coordinate pairs from adjacent channel sections are imported back into ArcView GIS and linked together using the geo-referenced New Mexico State Plane coordinate system. These linked coordinates define the floodplain over the entire channel reach. Parameter estimation procedures and construction of input data files for pre- and post-fire conditions are described by McLin et al. [2001].

The idea of merging HEC-RAS modeling capabilities with ArcView mapping and geographic features is appealing because surveying requirements can be selectively minimized. This is especially important if the floodplain mapping area is extensive. However, several factors can affect the final shape of the floodplain as illustrated below. Figure 3 shows the 100-yr, 6-hr HEC-RAS floodplain after being imported back into the ArcView database. Note that the floodpool appears somewhat angular and discontinuous. Figure 4 shows the same location after interpretative hand smoothing of the floodpool. Dramatic differences are obvious and can be attributed to the following: (1) localized channel modifications made between model simulations represented by each figure; (2) reductions in hydrograph peaks associated with the installation of an upstream flood control structure; and (3) interpretative hand smoothing of the floodpool.

Figure 5 shows a second channel reach with pronounced angular and discontinuous floodpools. These irregular features are a result of the ArcView GIS representation of the imported HEC-RAS floodpool. Note that the original HEC-RAS cross-sections and floodpool topwidths are preserved in the hand-smoothed representation of the floodplain. The ArcView GIS floodpool is created from rasterized data computed from the intersection of the land and water surface TINs.

4. DISCUSSION AND CONCLUSIONS

The successful integration of modern GIS databases and hydrologic models is an emerging technology [Maidment and Djokic, 2000]. Most federal, and many State, facilities already have significant GIS topographic coverage. This paper describes an application of HEC-HMS and HEC-RAS floodplain models to complex terrain using ArcView GIS extracted topographic data. These models are recognized by the EPA, USACE, and others as the best available technology for floodplain definition in ungaged watersheds. Combining these models with a GIS capability represents a refinement in their continued use. However, the results presented here suggest that the ArcView GIS floodpool-mapping algorithm may need some refinement.

The SCS curve number method was used in this study to predict runoff. The relative merits of this empirical approach versus physically based representations have been openly debated in the literature for years. However, Loague and Freeze [1985] have shown that physically based models generally do not predict runoff any better than the relatively simple approach used here. In addition, extension of physical models to ungaged watersheds retains many limitations of simple approaches. Furthermore, the SCS method has the advantage that future changes in land use patterns (e.g., pre- and post-fire watershed alterations or urbanization) are easily addressed.

Finally, the elevation differences between surveyed and DEM points shown in Figure 2 are worrisome. The implication is that excessive floodplain modeling errors may be inadvertently introduced into an already uncertain rainfall-runoff process. Error quantification addressing this issue is currently underway.

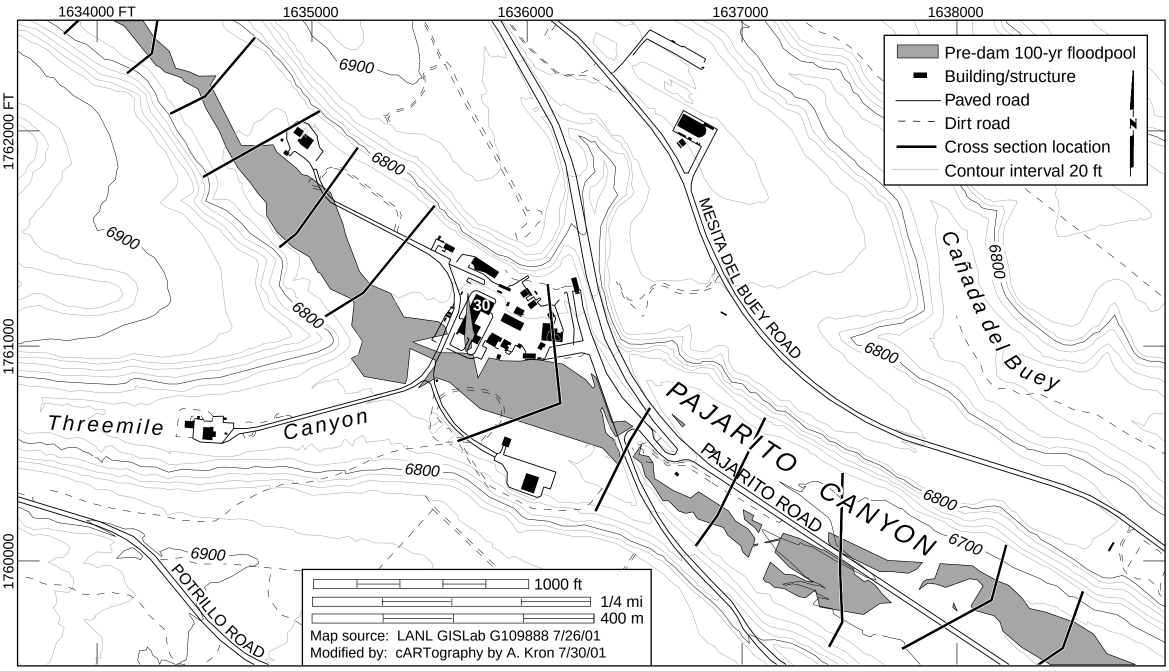

Figure 3. ArcView floodplain map for Area 1.

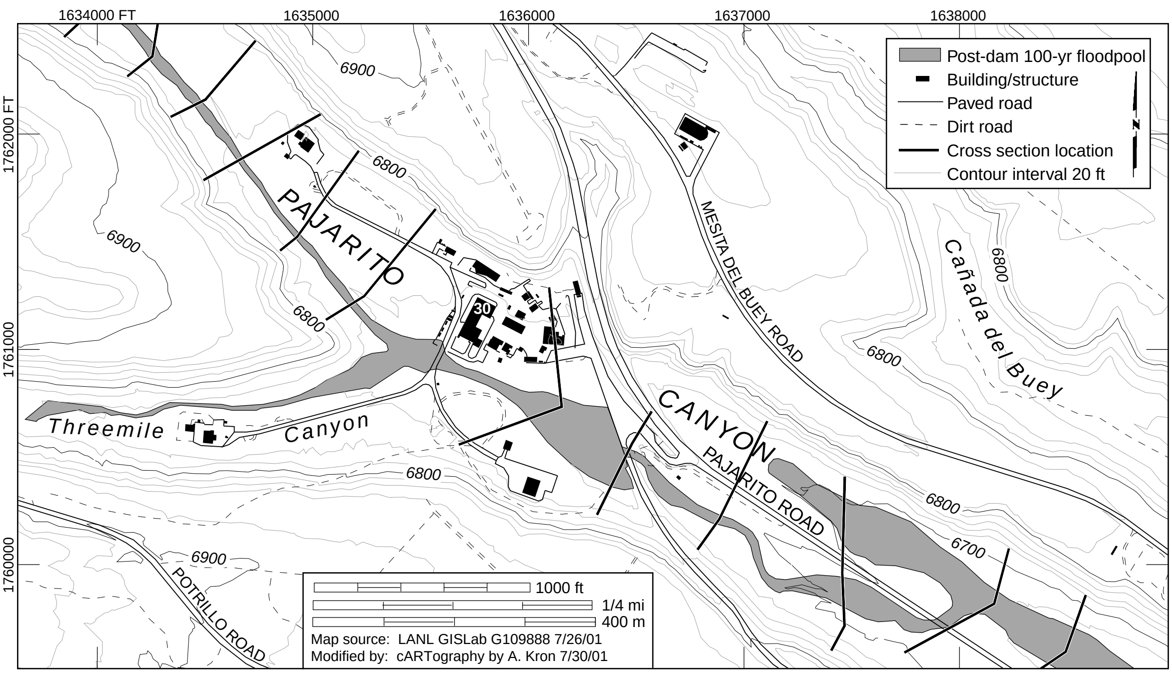

Figure 4. Smoothed floodplain map for Area 1.

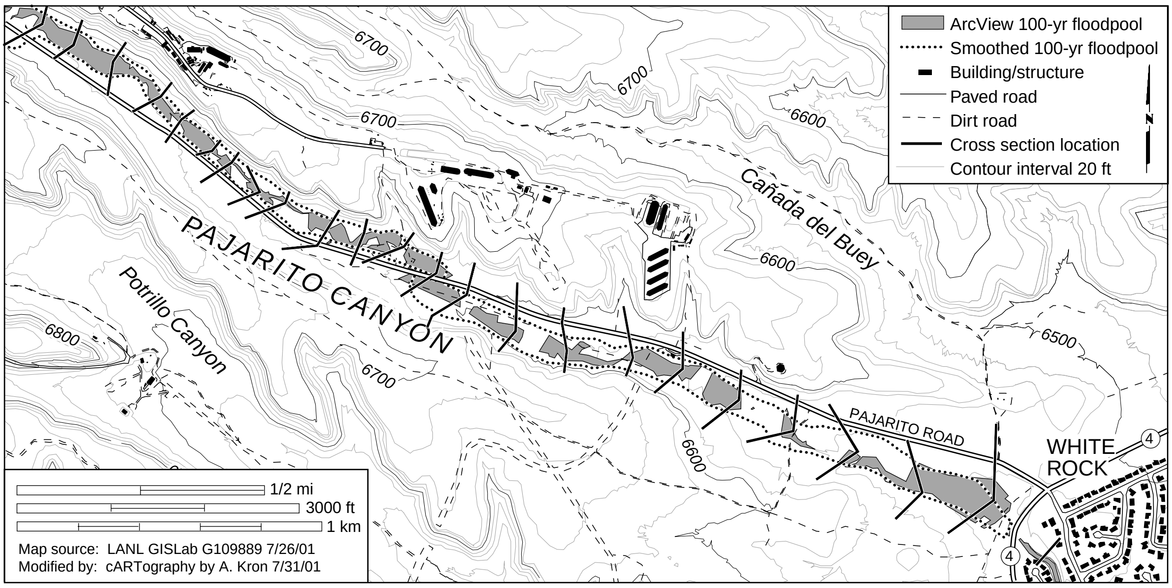

Figure 5. ArcView and smoothed floodplain map for Area 2.

5. ACKNOWLEDGEMENTS

This work was funded by the Environment, Safety, and Health Division and the Facilities and Waste Operations Division at Los Alamos National Laboratory through Post-Fire Emergency Response funds.

6. REFERENCES

BAER, Burned Area Emergency Rehabilitation Plan for Cerro Grande Fire, see http://www.baerteam.org/cerrogrande/, US Forest Service web site, 2000.

Dekker, L.W., and C.J. Ritsema, How water moves in a water repellent sandy soil. 1. Potential and actual water repellency, *Water Resources Research*, 30(9), 2507–2517, 1994.

Dooge, J.C.I., A general theory of the unit hydrograph, *Journal of Geophysical Research*, 64(1), 241–256, 1959.

Dooge, J.C.I., *Linear theory of hydrological systems*, USDA Agricultural Research Service, Technical Bulletin No. 1468, US Government Printing Office, Washington, DC, 117–124, 1973.

Hoggan, D.H., *Computer-Assisted Floodplain Hydrology and Hydraulics*, McGraw-Hill, 676 pp., New York, 1996.

Imeson, A.C., J.M. Verstraten, E.J. van Mulligen, and J. Sevink, The effects of fire and water repellency on infiltration and runoff under Mediterranean type forest, *Catena*, 19, 345–361, 1992.

Loague, K.M., and R.A. Freeze, A comparison of rainfall-runoff modeling techniques for small upland catchments, *Water Resources Research*, 21(2), 229–248, 1985.

Maidment, D., and D. Djokic, *Hydrologic and Hydraulic Modeling Support with Geographic Information Systems*, Environmental Systems Research Institute Press, 216 pp., Redlands, CA, 2000.

McLin, S.G., *Delineation of 100-year floodplain elevations at Los Alamos National Laboratory*, Los Alamos National Laboratory, report LA-12195-MS, 51 pp., Los Alamos, NM, 1992.

McLin, S.G., E.P. Springer, and L.J. Lane, Predicting floodplain boundary changes following the Cerro Grande wildfire, *Hydrological Processes*, 15(15), in press. 2001.

SCS, *National Engineering Handbook*, USDA Soil Conservation Service, Section 4, Hydrology (NEH-4), US Government Printing Office, Washington, DC, 1993.

US Army Corps of Engineers (USACE), *HEC-HMS Hydrologic Modeling System, User's Manual for Version 2.11*, Report CPD-74A, Hydrologic Engineering Center, Davis, CA, 2001a.

US Army Corps of Engineers (USACE), *HEC-RAS River Analysis System, User's Manual for version 3.0*, Report CPD-68, Hydrologic Engineering Center, Davis, CA, 2001b.