Flood-inundation mapping of a steep, gravel desert stream in Death Valley National Park, California

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Extended Abstract

Introduction

In desert landscapes, flooding can result in dramatic changes to streams. However, the frequency, magnitude, and geomorphic effects of floods in such environments are less understood compared to wetter environments (Tooth, 2000). In desert landscapes, steep slopes and sparse vegetation result in runoff and flashy flood peaks, often lasting for only a few hours. Many floods are the result of isolated, convective thunderstorms that cannot be predicted easily in advance and frequently occur at night. Therefore, direct observations or measurements of streamflow during floods often are limited, with data collection mostly occurring after the event. In ephemeral streams, limited vegetation within channels and on overbanks result in large stream velocity and higher probability for erosion during flooding. Moreover, flood occurrence in desert streams is often highly variable and some sites may go for years without streamflow, complicating flood frequency analyses. Finally, data sets in desert environments are often short and have few long-term, systematic collection sites.

Grapevine Canyon, located in the northeast part of Death Valley National Park in the Mojave Desert of California, drains the steep, sparsely vegetated slopes of the Grapevine Mountains. The stream channel is very steep, with an average 0.05 slope and drainage area of about 48 square miles. Channel material is predominately gravel. Except for short reaches supported by springs, the stream is ephemeral and only flows in response to heavy rainfall. The canyon is also the site of Scotty's Castle, a historic ranch and popular tourist attraction in the national park. Several buildings, a road, parking lot, and bridge occupy the canyon bottom. On October 18, 2015 an intense thunderstorm produced nearly an entire year's worth of rainfall in just a few hours. The resulting flash flood caused substantial damage to several buildings, roads, powerlines, and water infrastructure. In some locations, several feet of sand, gravel, and cobble were deposited, while elsewhere up to 10 ft. of channel incision occurred and new channels were created. The area is expected to be closed to the public until at least 2020, and cost $50 million to repair.

To help the National Park Service better understand the potential of future flooding and associated risk to historic park structures in Grapevine Canyon, the U.S. Geological Survey mapped current flood-inundation boundaries for the 4, 2, 1, 0.5, and 0.2-percent annual exceedance probability (AEP) streamflows.

Methods

Streamflow measurements in Grapevine Canyon were limited to two, post-flood indirect measurements (1968 and 2015) and an estimated streamflow (1976). Two streamgages were installed at the site (in Grapevine Canyon and Tie Canyon, a tributary canyon) in 2016, however, as of April 2019, no streamflows have occurred. The existing data were not enough to perform a site-specific flood frequency analysis, therefore regional peak streamflow regression equations for the desert regions of California were used to estimate the 4, 2, 1, 0.5, and 0.2-percent AEP streamflows (Gotvald and others, 2012). The estimated discharges ranged from about 3,900 to 41,300 cubic feet per second. The October 18, 2015 flood was estimated to be between a 4 and 2-percent AEP streamflow.

In addition to the lack of hydrologic data, the study area also lacks high resolution topographic data. In July 2016, a terrestrial laser scanner (TLS) was used to collect ground based lidar at 38 locations. The TLS locations were then surveyed to georeference each scan, and the collected data were combined into a 3-dimensional point cloud of the area. Over 83 million topographic points were collected during the TLS survey. From this point cloud, filtering was used to eliminate extraneous data such as vegetation, fences, powerlines, and atmospheric interference to create a digital terrain model of the area.

Finally, friction losses due to roughness of the channel bed and vegetation must be accounted for when modeling streamflow. When streamflows are directly measured, roughness can be computed via Manning's equation, however, in the absence of direct measurements, roughness must be estimated. Three approaches were used in this study to estimate channel roughness. First, the site was visually compared to other locations where the roughness has been directly computed (Phillips and Ingersoll, 1998). Secondly, the roughness was estimated using tables for channel material and adjusting for channel irregularities, obstructions, and vegetation (Chow, 1959). Finally, five Wolman style pebble counts were performed to determine channel bed particles sizes, and roughness was estimated using the measured particles size in empirically derived equations (Rickenmann and Recking, 2011).

The combination of the hydrologic, topographic, and roughness data were used to create a one-dimensional HEC-RAS hydraulic model. A total of 539 cross-sections were extracted from the digital terrain model over the approximately 5,000 ft. model reach. Model calibration was limited to the 2015 flood event high-water marks due to the lack of streamflow since that event and the large channel changes that occurred because of the 2015 flood, limiting the applicability of previously collected data.

Results and Conclusions

The model results indicated that at the highest computed streamflows, inundation would cover nearly the entire canyon bottom, impacting several historic buildings, parking lots, and roads. However, the main building of Scotty's Castle would not be inundated by any computed floods as it was built on a higher terrace. At the 0.2-percent AEP streamflow, a bridge and embankment could be overtopped by almost 6 feet of total depth.

Even at lower computed streamflows, some infrastructure would be inundated. Sections of the road and parking lot were inundated by every modeled streamflow as they are located directly within the stream channel. One building was situated in the direct path of streamflow as channel changes caused by the 2015 flood, have redirected the main channel toward the building. Additionally, at the 2 AEP, the bridge and embankment would be overtopped.

Model results must be viewed with an understanding of several assumptions and uncertainties. Except for areas with very dense vegetation and at the constriction of the bridge, the entire modeled reach computes as super-critical flow with very high velocities which have been questioned as unrealistic in other steep channel computations (Jarrett, 1984; Costa and Jarrett, 2008). The channel is subject to unknown erosion and deposition during floods. Since topographic data was limited to post flood conditions, using such data could result in over or under estimates of actual channel dimensions and inundated areas.

Due to the lack of site specific hydrologic data, regional regression equations were used to compute the AEP streamflows. This also adds uncertainty as the difference in computed streamflows between the latest (2012) and previously published equations (1977) are a 10-50% decrease in streamflow.

Finally, focusing on streamflow in main channels did not account for flooding potential from small tributaries, gullies, or overland flow. In the 2015 flood, many smaller channels flowed, however, drainage is mostly non-existent at Scotty's Castle, with several channels simply ending at building walls or parking lots.

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