Post-fire Flood-risk Assessment of Sycamore Flat in the Arroyo Seco Watershed in Monterey County, CA

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Abstract

Risky land use decisions have led to large amounts of damages from flooding. Wildfires can potentially alter the risk of flooding by increasing the likeliness of high flow events due to multiple physical processes that increase the volume and intensity of runoff and erosion. In June and July of 2008, the Basin Complex fire burned 240,170 acres of the Arroyo Seco Watershed located in Monterey County, CA. Sycamore Flat is a developed flood plane of the Arroyo Seco River that is lacking a post-fire flood risk assessment that could improve the timeliness of the National Weather Service’s Flood warnings. A HEC-RAS model was developed by collecting and inputting survey data of the Arroyo Seco River and the adjacent flood plane, Sycamore Flat. The point of incipient flooding is 7100 cfs, with a recurrence interval (RI) of 1.9 yrs. Cross sectional geometries were adjusted to reflect 0.5 m increments of aggradation, and the relationship between aggradation and discharge (Q) was identified (y = 478.71x3 - 1760.7x2 - 1385.1x + 7087.3, R2 = 0.9997). A Log Pearson Type III analysis on historic peak flow data resulted in an aggradation to RI relationship (RI = 0.0222x3 + 0.0048x2 - 0.5175x + 1.9143, R2 = 0.9953). The results of this study, in combination with the monitoring of sediment accumulation in the watershed upstream, can be used by the NWS to more accurately indicate the point at which a serious threat exists. This could lead to an earlier evacuation, possibly saving lives or at least an earlier warning that will allow residents time to take actions that will minimize the loss of property.

Introduction

Most damages caused by natural disasters are from flooding and droughts (Lins 1999). Long-term trends in the California/Nevada region have shown a continuous increase in flood damages (Cartwright 2005). Although some research has shown trends of increasing precipitation, risky land use decisions is the main contributor to flood damages (Changnon 1996). Flood plains cover 2,000,000 km^2, but up to 90% of these areas are used by humans, primarily for urban development and agriculture (Tockner and Stanford 2002). Flooding is not a problem until a flood zone is developed.
Wildfires can potentially alter the risk of flooding by increasing the likeliness of high flow events due to multiple physical processes that increase the volume and intensity of runoff and erosion (DeBano 2000). Fires alter the evapotranspiration, soil-water storage capacity, and infiltration rates resulting in higher annual and peak streamflows (Gabet 2003, Moody and Martin 2001). In addition, the soils are more easily eroded after a fire due to rainsplash erosion, the creation of a hydrophobic layer, and decreased woody debris (Barro and Conard 1990, Gabet 2003). When the soil becomes heated during a fire event, a hydrophobic soil layer often develops at or just below the surface (DeBano 2000). This water repellent layer decreases the amount of infiltration, forcing an increased amount of water to move down the hillslope. If the hydrophobic layer forms just beneath the surface, the thin top layer becomes quickly saturated during rainfall events, resulting in high rates of erosion. In addition, the loss of vegetation due to fire decreases the interception of raindrops before they come into contact with topsoil (DeBano 2000). Fires also eliminate much of the roots and debris that once created storage units, thus decreasing the sediment’s travel time, although in some cases fire has resulted in an increase of woody debris created by the blowdown of burned trees (Swanson 1981). The large amount of loose sediment that is typical of post fire landscapes often form migrating sediment waves (Moody 2001). These waves locally aggrade the river, thus decreasing its capacity to transport water, while also altering the local slope of the channel (James 2006).

In Monterey County, CA, the Basin Complex Fire burned a large area in the Arroyo Seco Watershed (Fig. 1). This fire was started on June 21, before it combined with the Indians Fire to burn a total of 240,170 acres (BAER 2008). The Arroyo Seco Watershed is primarily dominated by chaparral ecosystems within a landscape characterized by the steep mountain slopes of the
rapidly rising Santa Lucia Mountain range. The majority of the land is part of the Los Padres National Forest, with smaller portions of the land belonging to state, county, and private entities. Sixty percent of the burn area has been rated moderate to high burn severity by a BAER team (BAER 2008).

Sycamore Flat is a developed floodplain in an inside bend of the Arroyo Seco River. The landowners have accepted the risk of flooding by building or buying homes here because they wanted to live in the scenic Arroyo Seco Watershed and the river’s active floodplain presented the most suitable place within the high relief landscape. Without proper warning, these homes could go unprotected and become completely ruined.
Accurate flood risks of the homes on Sycamore Flat are currently unknown because the recent Basin Complex wildfire has altered the conditions of which a general flood zone was previously estimated. The National Oceanic and Atmospheric Administration’s (NOAA) National Weather Service (NWS), is responsible for issuing flash flood watches for Monterey County (MCWR 2008). The NWS issues warnings based on rain and stream gages in the area, along with general reports that have been issued regarding watershed characteristics, including FEMA flood maps. In 1984, FEMA studied the area and formed flood risk maps for insurance purposes (FEMA 1984). At that time, it was concluded that the entire community of Sycamore Flat was within Arroyo Seco’s 100yr floodplain (FEMA 1984). Since the most frequent recurrence interval that was identified is 100 years, the actual flood frequency of the land within this zone is unknown. In the time since the FEMA map was made, the recent Basin Fire/Indians Fire Complex wildfires have altered the conditions that govern the flow and geometry of the Arroyo Seco River thus making the 1984 map an imprecise tool for current assessments. A more accurate assessment of the flood risk of Sycamore Flat is needed to provide its residents and the NWS with the information they need so that timely warnings can be made, and informed decisions can be made to best protect the people’s lives and their property.

What is the current flood risk of Sycamore Flat? Using the Hydrological Engineer Center River Analysis System (HEC-RAS) to model the current and predicted conditions is an effective way to fill the information gap left by fire and the previous flood risk assessment. HEC is the Institute for Water Resources division of the United States Army Corps of Engineers who began developing hydrologic analysis software in 1964, and has since evolved to become a standard tool in the engineering and flood insurance industries (HEC 1995). The model identifies the
relationship between discharge and surface water elevation, and produces three-dimensional models that provide visual representations that are effective communication tools. The results of this study provide NWS and the residents of Sycamore Flat with an estimate of the likeliness and severity of flooding that can be caused by a given discharge and aggradation.

Methods

To determine the effect of aggradation on flood frequency of Sycamore Flat, a HEC-RAS model was used with the results of an analysis of peak flow data. HEC-RAS is a step backwater model based on Manning’s Equation, given by the following equation:

\[ V = \frac{k}{n} R^{\frac{2}{3}} h^{\frac{1}{2}} \]

In this equation, \( V \) is velocity, \( R \) is hydraulic radius, \( S \) is channel slope, \( n \) is roughness factor, and \( k \) is for unit conversion. To provide the necessary data for input into the HEC-RAS model, several cross sections of the river and its floodplain were surveyed in November of 2008, and a DEM of the area was analyzed to identify river slopes. Grain sizes and vegetation of different areas of the cross-section were noted to estimate roughness factors. Incremental amounts of river channel aggradation where modeled in HEC-RAS, and hydrologic discharge at the point of incipient flooding of each scenario was identified. These discharges were then translated into
recurrence intervals using the Log Pearson Type III Distribution technique on historic peak discharge data, thus resulting in an aggradation-discharge relationship.

To provide the geometric data for the HEC-RAS model, eight cross sections of the river and its floodplain were surveyed. A benchmark was created on a small floodplain 2 meters to the right of the right edge of water next to the cliff. This benchmark was oriented by triangulation using a handheld compass on a distant crest in the horizon and on a tall distant Monterey Pine. Seven cross sections were found by collecting data points at breaks in slope across the river channel using a Total Station attached to a tripod, and two prisms that were each suspended by a rod. An additional cross-section was later added to increase the length of the study reach for a more accurate assessment. This cross section was found using a scope and rod method. Synthetic data points were added to each cross section to estimate the geometry of the floodplain using the information collected with the range finder, along with elevation data from Google Earth.

The geometric data were then adjusted to reflect a range of aggradations that could occur because of increased post-fire erosion rates and the formation of sediment waves. Each cross section was adjusted by adding increments of 0.5 m to the elevation of the thalweg, creating a flat-bottomed river. Additional cross sections were interpolated within the HEC-RAS software to better represent the actual river morphology.

The remaining model parameters include coefficients of contraction and expansion, slopes, and roughness factors. Standard coefficients of contraction and expansion were used.
Upstream slope and downstream slope where determined using ARC-GIS during an evaluation of a 1/3 arc sec (approximately 10 m) DEM obtained from the USGS Seamless Server. Slopes within the study reach are dependent on the elevation data individual cross sections. A visual assessment of grain size and vegetation, along with a consultation with literature of calculated roughness values (Barnes 1967) provided roughness values of $n_{\text{leftbank}}$, $n_{\text{channel}}$, and $n_{\text{rightbank}}$.

Historic discharges were analyzed using the Log Pearson Type III Distribution technique to identify recurrence intervals of discharge events. Historic discharge data were collected from a USGS gage downstream (USGS gage# 11152000, Arroyo Seco near Soledad, CA) because of its close proximity and similar watershed area. Skew was calculated on log-transformed data. An analysis of outliers was conducted on the historical peak flow data (USGS 1981) using the following equations:

$$X_H = X_M + K_N S \quad X_L = X_M + K_N S$$

In these equations, $X_H$ = high outlier threshold in log units, $X_L$ = low outlier threshold in log units, $X_M$ = mean logarithm of annual peak flows, $S$ = standard deviation, and $K_N$ = value of sample size $N$ from chart of one-side $t$ that detects outliers at the 10% significance level based on a normal distribution. A Log Pearson Type III Distribution excel sheet created by Fred Watson of California State University Monterey Bay was used to implement the technique.

Multiple simulations were run using a steady mixed flow analysis on all geometries in HEC-RAS, including the original geometry and each degree of aggradation until the point of incipient flooding of each scenario was identified. These discharges were then translated into recurrence intervals using the Log Pearson Type III Distribution technique on historic peak discharge data, thus resulting in an aggradation-recurrence interval relationship.
Results

The resulting topographic cross sections are shown on a photo layer in Fig. 1. Surveying error was insignificant (max error = 0.02 m).
An analysis of historical peak flow data with 95% confidence intervals using a Log Pearson Type III Distribution resulted in Figure 2. The data is considered normal because of the calculated skew of -0.63. An analysis of outliers resulted in the omission of none of the peak datums.

Figure 2. Frequency plot with confidence intervals in log scale from the USGS Arroyo Seco River near Soledad gage peak flow data.

All simulations were run using constant parameters. Upstream and downstream slopes were found to be 0.003. Identified roughness values used are $n_{\text{leftbank}}$ (0.04), $n_{\text{channel}}$ (0.025), and $n_{\text{rightbank}}$ (0.04). A steady mixed flow analysis of the observed geometry resulted in a discharge...
of 7100 cfs, or recurrence interval of 1.9 years at the point of incipient flooding. The model was then run with a discharge using each aggradation geometry so that the point of incipient flooding was found with each scenario, resulting in an aggradation-discharge relationship (Fig. 4). These results were then translated into an aggradation-recurrence interval relationship using the Pearson Type III Distribution technique (Fig. 5).

Figure 3. Model plot of a discharge of 7100 cfs with original observed conditions. Represents the point of insipient flooding.
Figure 4. Graph of resulting discharges from the modeling of an array of aggradation geometries at the point of incipient flooding ($y = 478.71x^3 - 1760.7x^2 - 1385.1x + 7087.3$, $R^2 = 0.9997$). Flooding becomes imminent with any discharge with 2.5 m of aggradation.

Figure 5. Graph showing the aggradation-recurrence interval relationship resulting from the modeling of an array of aggradation geometries at the point of incipient flooding ($y = 0.0222x^3 + 0.0048x^2 - 0.5175x + 1.9143$, $R^2 = 0.9953$).
Conclusion

The HEC-RAS steady flow analysis that was used in this study adequately depicts real world scenarios within the accuracy that is necessary to properly influence the timing of the issuance of flood warnings by the NWS. The relationship between aggradation and discharge was identified with minimal error, so that the outcome of future scenarios can be predicted with an increased accuracy.

The peak annual discharge data from the USGS gage# 11152000 are minor overestimates of the actual peak discharges at Sycamore Flat due to the downstream location of the gage. The tributaries that enter the Arroyo Seco below Sycamore Flat are minimal additions to the flow at the downstream USGS gage, and do not significantly effect the analysis that was done during this study.

The recurrence intervals that were calculated in this study are likely to occur more frequently than calculated from historic data due to post-fire effects. It is known that post-fire run-off rates are likely be larger than they were before the area was burned, but there is considerable variation in the measured effects of fire on the magnitude of flow in individual watersheds. Previous studies in the Western United States have shown large differences in the post-fire effects on flow, but most have found a strong positive correlation. Because of this, the 1.9-year rainfall event that has historically resulted in a 1.9 year discharge (and a stage of the point of incipient flooding as shown from this HEC-RAS model of Sycamore Flat), will now likely produce a discharge with a magnitude that is larger than the estimated 1.9 year flow in the years after an area has been burned.
It is unknown how much, if any, aggradation will occur in the future. Like hydrologic post-fire run-off rates, a variety of watersheds have incurred various degrees of increased erosion rates following fire. This variation is due to differences in watershed characteristics, and the amount and intensity of rainfall that was received during the years following a fire. The Arroyo Seco Watershed received light to moderate rainfall during the past 2008-2009 rain season. A survey of the Arroyo Seco upstream of Sycamore Flat by a CSUMB hydrology class found that no aggradation had occurred. The potential for aggradation is still present, but will decrease with time as the watershed recovers.

The results of this study, in combination with the monitoring of sediment accumulation in the watershed upstream, can be used by the NWS to more accurately indicate the point at which a serious threat exists. This could lead to an earlier evacuation, possibly saving lives or at least an earlier warning that will allow residents time to take actions that will minimize the loss of property.


