IMPACTS OF CLIMATE INSTABILITY ON FLOOD MANAGEMENT DECISIONS OF THE RIO DE FLAG IN FLAGSTAFF, ARIZONA

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Wildfires in the western United States are driven by natural factors such as fuel availability, temperature, precipitation, winds, relative humidity, and others including insect infestation and anthropogenic influences (Westerling 2001). These climatic fluctuations affect natural factors on temporal and spatial scales. Climatologists have analyzed some of these natural factors and indicate prolonged periods of drought, hotter seasons and possible increased storm intensity for the North American southwest (IPCC 2008).

During periods of drought ponderosa pines become weak and more susceptible to tree loss due to death from frequent bark beetle infestation and extensive fires. As seen in recent years, about 4.8 million acres burned in Arizona and New Mexico between 1998 and 2007 with another 3 million+ acres of forest and woodland impacted by drought and bark beetle-caused mortality (Swetnam 2007), The loss of forest cover as a result of tree mortality and fire would lead to an increased amount of runoff and flooding during storm events falling on the headwaters of the Rio de Flag.

The lower portion of the Rio de Flag flows through the City of Flagstaff increasing the possibility of flooding and flood damage to local residence along the floodplain borders. The estimated cost of flood damage as a result of a 100-year flood event is approximately $93 million (USACOE 2000). The problem of flood hazard and its subsequent damage are exacerbated by the haphazard rerouting of the Rio de Flag through the City of Flagstaff.

Using hydro climatic indicators in climatic projections and known ponderosa pine forest system responses to drought and fire occurrences, I hypothesize that there is significant projected watershed instability within the Rio de Flag and put forward that the U.S. Army Corps of Engineers' recommended rerouting alternative 6B is under capacity and suggest in my paper that Poff and Tecle's alternative A12 be considered in its place.

STUDY AREA

The Rio de Flag is an ephemeral stream that originates on the southwestern slopes of the San Francisco Mountains. It is also a tributary of the San Francisco Wash feeding into the Little Colorado River. The Rio de Flag flows over various types of terrain: wide, flat valleys of the Fort Valley area; the steep, narrow canyons north of Flagstaff, and the wide, flat-bottomed canyons southeast of Flagstaff. The total drainage area of the Rio de Flag watershed is approximately 116 square miles, and the total drainage area above the City of Flagstaff is roughly 50 square miles. The Upper Rio de Flag Watershed encompasses 13,800 ha gathering surface flow from a number of parallel sub-basins that converge (Leao 2005) to a drainage area that ranges from approximately 12,356 feet to 6,800 feet in elevation (USACOE 2000).

The City of Flagstaff identified the Rio de Flag as one of the primary drainages contributing to flooding and as being a major damage center and problem area. Located within the City of Flagstaff and Coconino County, Arizona, the study area for flood damages is approximately 15 square miles. The floodplain encompasses the Rio de Flag upstream from the city limits to the Route 66 crossing just downstream of the Continental Estates housing development (USACOE 2000).

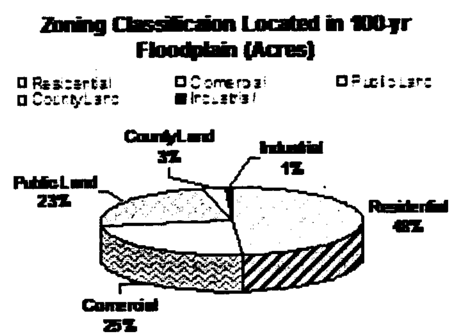

Figure 1. Source: City of Flagstaff Planning Department - 1998

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Flooding in Rio de Flag is related to snowmelt from the San Francisco Peaks in the winter and spring due to runoff (rain and/or snowmelt) from single or multiple storm events such as intense summer thunderstorms and dissipating tropical cyclones. The average annual precipitation for the Rio de Flag drainage area ranges from about 20 inches in Flagstaff to about 35 inches in the San Francisco Peaks, with a basin average of about 25 inches (USACOE 2000). About 74% of the National Forest lands in the Flagstaff/Lake Mary Ecosystem Area are ponderosa pine with 1% aspen, 11% piñon-juniper and 9% grassland (USFS 1999). The importance of ponderosa dominated ecosystems is their active watershed functions which for this paper, focuses on water absorption and soil stabilization. Currently, most tree mortality is centered in "stress-zones" such as drier south-facing slopes, transition areas between ponderosa pine and piñon-juniper areas and recent construction sites (USFS 2006). Prolonged drought conditions in the Southwest would change the fire regime in the ponderosa and mixed conifer dominated forest of the headwaters of the Rio de Flag, and increased fire disturbance in conjunction with other determining factors may cause severe tree mortality resulting in increased runoff and sediment loading to the Rio de Flag watershed.

METHODS

The primary method of research for this study was observational. This included extensive review of pertinent literature, communications with community action groups, written and verbal communications with concerned officials and experts in the study area and attended open house discussions on the reroute of the Rio de Flag. I also used published and unpublished data and other information on local vegetation and climate scenarios, ecosystem response to fire disturbance and utilized various articles, EIS reports, theses, books, and online media to make inferences about the impacts of a drier climate on the watershed system.

RESULTS

Some of the hydro climatic indicators of climate change are the shifts in snow and rain patterns, the decrease in spring snow pack and earlier snowmelt and runoff often all associated with increased temperatures which instigate drought conditions. To better understand how ecosystems function during these fluctuations we must gain knowledge of the history of different natural disturbance regimes over long periods. Such retrospective perspectives also provide a basis for assessing how and when human actions might interact with these processes (Williams et al., 1997).

Climate data was collected on the Colorado and Coconino Plateau in U.S. Geological Survey Scientific Investigation Report 2005-5222 which makes known that winter storms (Oct. – April) provide about 60% of the precipitation to the study area and summer storms account for the remaining 40% (Bills et al., 2007). U.S. Geological Survey Scientist Richard Hereford concludes with his data collection, from 1951-2006, that there has been an average daily increase in temperature of 1.7°F with an ongoing period of drought since 1996 to 2006. This data collection is based on a regional scale with only a few decades of data. To get landscape scale data on a millennial timescale I turned to a study using dendrochronology on the San Francisco Peaks analyzing tree-ring widths shown below.

In the arid American Southwest, variations in tree-ring widths from one year to the next have long been recognized as a source of information on past precipitation. Because the growth of most southwestern trees is primarily limited by moisture availability, most dendroclimatic reconstructions in the southwest are precipitation reconstructions (Salzer 2000). Salzer's study was done on a millennial timescale using dendrochronology (tree-ring analysis) and shows similar dry and wet periods dating back some 1400 years ago to the current early 21st century warming period. The analysis shows that the late 20th –early 21st century climate fluctuation to a drier/warmer state has never been met in magnitude over the past 1,400 years.

The IPCC's Third Assessment report highlights numerous models projecting Salzer's findings, being a warmer and drier climate for the southwestern United States. Seager et al. (2007) produced a multi-model ensemble showing mean precipitation minus evaporation (P-E) using 19 models from AR4. The multi-model shows a transition to a sustained drier climate for the southwestern U.S. (including all land between 125°W and 25°N and 40°N) that begins in the late 20th and early 21st century (Seager et al., 2007). The continued ensemble multi-model shows a mean P-E in this region around 0.3 mm/day in 2100 which put into perspective is 0.21 mm/day greater than the dust bowl drought in the 1930's and 0.17 mm/day greater than the 1950's drought in the southwest.

DISCUSSION

The effects of drought accompanied by warmer temperatures resulting from green house forcings might be expected to produce even greater effects on vegetation change than those of periodic, protracted drought alone (Breshears 2005). The projection of a prolonged period of drought is a key variable to forest health and watershed conditions. During periods of drought we have seen an increase in bark beetle outbreaks and increased forest fires which depending on severity, can create a rapid shift in ecotone as noted by the ponderosa pine (Pinus ponderosa) mortality in response to the 1950's drought (Breshears 2005). Breshears et al. found that of particular concern is regional-scale mortality of overstory trees, which rapidly alters ecosystem type, associated ecosystem properties, and land surface conditions for decades (Breshears 2005).

The bark beetle is native to ponderosa forests and trees are typically able to push them out with their sap but during periods of severe drought trees lose this ability and are killed as a result. Several years of drought and high tree densities combined to allow pine bark beetle populations to reach outbreak levels during 2002 – 2004. Data from aerial surveys recorded 2.1 million acres of piñon-juniper woodland and 1.3 million acres of ponderosa pine affected in Arizona and New Mexico (USFS 2009). The last major outbreak of these bark beetles on record in the southwest occurred during the 1950's drought.

Denser tree stands also play a role in the weakening of trees as they compete for the little available moisture and nutrients remaining in the soil (USFS 2009). These denser tree stands benefit the spread of bark beetle infestation and as the weaker trees die, millions of new snags form and present a threat of spotting. Once trees fall, a fire in these large fuels would burn longer and hotter, damaging soils and adversely affecting the site in the long-term (USFS 2006). The dynamics of fire occurrence create conditions that decrease the rate of infiltration into soil thus causing an increase in surface runoff and sedimentation and result in large-scale flooding as an immediate post-fire concern (Leao 2005 & DeBano 2009). Leonard DeBano, a professor in the School of Natural Resources at the University of Arizona found in his earlier work (1996) that there are two major factors that affect the hydrologic response of a watershed to fire, fire severity and the magnitude and timing of precipitation following fire.

According to the U.S. Geological Survey, a 100-year flood event is determined through a process called frequency analysis, which estimates the probability of the occurrence of a given precipitation event. The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year. This however does not consider forest conditions, disturbances and future climate changes.

The approved flood management alternative 6B is expected to handle a 100-year return flood under existing forest and climate conditions. Currently the capacity to carry discharge varies considerably along the Rio. At Meade Lane, south

Table 1.The processes of the hydrologic cycle most affected in forest fires are those that are controlled by vegetation and the soils of the watershed which are listed below (DeBano 2009).

Processes and pathways most affected by fire (vegetation & soils of watershed)	Process description and changes
Interception	Reduced as a result of destroying both the vegetation canopy and the organic litter on the soil surface
Infiltration and Percolation	Reduced as a result of the formation of a water-repellent soil layer or plugging soil pores with fine ashy material
Evapotranspiration	Results from the loss of vegetation
Soil Moisture Storage	Reduced as result of above processes
Overland Flow of Water	Increased as a result of above processes

of "The Narrows" at the Museum of Northern Arizona, the capacity is 4,800 cfs. In the center of town where the channel was realigned to its present position between the Flagstaff Public Library and City Hall, the capacity drops to about 200 cfs (Wilcox et al., 2002). If there is a significant hydro climatic shifts or a decrease in forest health, specifically influential to the Rio de Flag watershed, alternative 6B could be considerably under capacity.

Duncan Leao, a graduate student in the Forestry Dept. at NAU, generated peak discharge hydrographs for 2, 5, 10, 25 and 100-yr storm events under three AMC's (antecedent soil moisture conditions). In these hydrographs, he also included current vegetation condition, thinning treatment, and three levels of wildfire scenarios for the Rio de Flag watershed. The wildfire scenarios consists of one-fourth, half and the entire area of the watershed being burned. Leao's model for a 100-year storm over the three wildfire scenarios produced peak discharges that ranged from 28-230 m3/sec (~980-8,050 cfs) under dry to wet AMC's (Leao 2005).

The U.S. Army Corps of Engineers used an upstream high flow value of 240 cfs and a downstream high flow value of 1,421 cfs. When compared to Leao's 100-year hydrographs, generated under specific conditions and focused just on the upper portion of the watershed which would include the upstream portion of the flows, we see a large variation in predicted flows and flow capacities by as much as 6 times.

Based on historical records, flooding within the City of Flagstaff may occur during any season of the year (USACOE 1997), this uncertainty along with the uncertainty of possible forest disturbances resulting from climate change needs to show some weight in the decision making process. This uncertainty should be approached through adaptive management practices and should consider retaining option value by employing sequential decision analysis to improve later decisions using insight gained from earlier choices. This approach should only include project alternatives that can easily be upgraded, altered or retrofitted to suit the needed improvements to apply new found knowledge.

The U.S. Army Corps of Engineers' chosen rerouting alternative 6B does not fit the project profile of adaptive watershed management. Alternative 6B proposes to replace the detention basin at Thorpe Park with a trapezoidal channel which would be closed channel modifications along residential areas and calls for the addition of a detention basin at the Clay Avenue Wash with a concrete channel and closed channel modifications in specific sections of the watershed. These suggested stream channelization alternatives are not easily adaptable to changes in flow as closed channels cannot be easily modified to increase maximum input. Without the ability to modify, the adaptive management approach may not be considered as the best working approach. Alternative 6B not only fails to fit the project profile of adaptive watershed management but according to Poff and Tecle (2004) it fails to consider the requests of the community and multi-objective use which would have resulted in the creation of alternative A12.

Alternative A12 would include two detention basins (Thorpe Park & Clay Avenue Wash) and suggests a greenbelt with levees constructed to merge unobtrusively with the natural landscape on both sides of the stream channel running through town from the Thorpe Park detention basin to areas downstream of the Rio de Flag Water Reclamation Plant (Poff & Tecle 2004). This alternative would be better suited in adaptive management practices since the construction of the project permits uncomplicated access allowing reasonable ability to modify the channel once decisions have been reflected upon. The suggested alternative A12 also does not cover any of the channels therefore allowing for the influence of varying climatic condition's on flows to be better managed.

CONCLUSIONS

The peak discharges from a 100-year return period storm event over all types of watershed treatments exceeded 31 m^3/sec (~1,085 cfs), notably, the peak discharge over the most severely burned area could be 2-6.6 times greater (depending on AMC) than the historic 1923 flood (Leao 2005). Natural disturbance factors such as fire regime and hydro climatic indicators such as drought implications need to be more thoroughly considered in determining the recommended rerouting plan.

The proper flood control project for the Rio de Flag should include a management plan that does not solely depend on frequency analysis of historic precipitation events but rather it should consider the possibilities of projected changes in climate and fire disturbance. Accounting for watershed disturbances in conjunction with frequency analysis of storm events is a proactive inclusive process which may compensate for the increase in capacity variation from the calculated 100-year flow.

In 2005, the rate of forest thinning was just under 405 ha/year or approximately 3% of the total forested watershed area (Leao 2005). If we continue to greatly expand forest thinning along the watershed we could help decrease the probability of high intensity fires resulting in decreased runoff and lower probability of flooding. It is also necessary to do controlled burns in conjunction with the thinning to assure surviving trees will have increased vigor due to less competition. This in turn results in less susceptibility to bark beetle attack by ridding the weak stands of trees that were growing on highly susceptible sites (DeGomez 2004). Monitoring is also recommended and necessary to evaluate the progress of a project to ensure effective decisions have been made. This can be done with the addition of active gauging stations along the Rio de Flag so climatic variability will be recorded within the watershed to provide useful information pertaining to the correlation between stand loss, peak discharge and climatic changes.

The U.S. Army Corps of Engineers' project proposal alternative 6B, does not consider the supported predictions of a changing climate's ability to alter the flow regime of the Rio de Flag watershed. The USACOE's proposed closed channel modifications do not have the ability to handle flows outside of the 2009 FSEA calculated 100-year flow. This insufficient emphasis on uncertainty and the irreversibility in the USACOE's recommended alternative 6B can have long-lasting consequences. Even assuming perfect certainty about the costs and benefits of alternative actions, there needs to be reflection on past project decisions. An activity which yields positive returns in the short-run and negative thereafter but cannot be terminated should perhaps not be undertaken in the first place. Hence, if the City of Flagstaff has chosen alternative 6B as a short-term solution this could create long-term problems.

Poff and Tecle have demonstrated grounds on the community level to reject alternative 6B and I have shown grounds for rejection based on its inability to adapt to watershed disturbances. The better alternative to managing the Rio de Flag watershed under anticipated natural and climatic disturbances is best applied through adaptive management practices and consideration of Poff

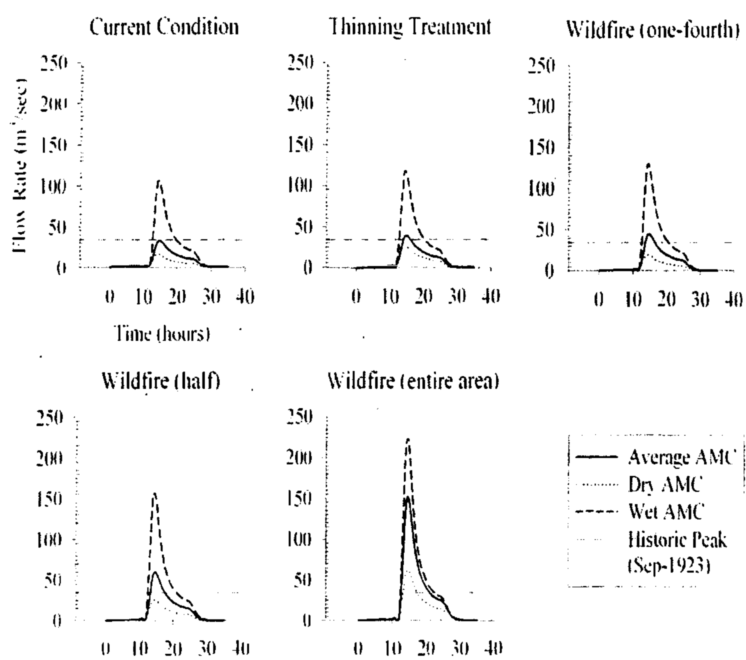

Figure 2. Five generated hydrographs from a 100-year storm event under 5 treatment scenarios with 3 antecedent soil moisture conditions (Leao 2005).

and Tecle's alternative A12 would allow the City of Flagstaff to handle what should be, anticipated additional flow requirements.

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