

Museum Fire and Post-Museum Fire Mitigation Efforts

On Sunday July 21, 2019, a forest fire known as the Museum Fire, erupted in the San Francisco peaks, north of Flagstaff, Arizona in a recreational area known as the Dry Lake Hills. Over the course of 23 days, the fire burned 1,961 acres in Coconino National Forest covered in pine and upland desert vegetation [1]. The monsoon season, which extends from mid-July to the end of September was delayed, causing dry conditions, and testing the skills and resources of first-responders, local citizens, government agencies, and engineers. Only 0.14 inches of rain had been recorded from the start of the monsoon season to the onset of the fire, falling far short of the annual average 1.71 inches of precipitation that falls during this time period [1]. Although no structures were destroyed in the fire and no lives were lost, the major impact from the fire was that it charred the lush vegetation and caused the soil to become hydrophobic [2]. Having experienced this same situation after the Schultz Fire in 2010 summer flashfloods immediately became the next challenge for the community of Flagstaff.

Under typical monsoon conditions, flooding should have been an imminent threat as was experienced following the Shultz Fire when rainfall event days after the fire flooded the downstream residents. However, the people of Flagstaff received a break because the monsoon seasons of 2019 and 2020 were the first and second driest years of precipitation activity on record for the community. The lack of significant monsoon storms provided time for the Coconino County Flood Control and the City of Flagstaff Stormwater Management group to plan and implement initial mitigations strategies. Government agencies also used the break in monsoon activity to study the impact of the new watershed characteristics on the neighborhoods below the burn scars. To analyze and visualize the influence of this fire-damaged area, new flood hazard mapping was completed in August of 2019 [3]. As part of the mapping project, three different flood models were created based on one inch, two inches, and three inches of rainfall events which correspond to a 2-to-5-year rainfall event, a 25-to-50-year rainfall event, and a 200-to-500-year rainfall event. These models utilized data collected on soil burn severity to predict the possible depth of runoff in affected neighborhoods [3].

These Coconino County flood models are based on the following assumptions about the conditions of the current drainage systems: all culvert and storm drains are assumed to be clogged; sediment bulking is not included; and a one-hour storm is modeled for each scenario [3]. Utilizing data based on water depth from these models, the agencies developed strategies for prioritizing the placement of sandbags and Jersey barriers along properties determined to be at high risk for flooding. Sandbag protection has been proven to have at least modest protection from flooding [4]. Based on these models and early identification due to the concentrated burned area in the Spruce Watershed, Spruce Avenue Wash was identified as the predominant corridor for drainage and flooding. Due to the wash being surrounded with homes on both sides for almost 1.5 miles of its total 4 miles length, mitigation steps that address flooding concerns were prioritized and implemented. The mitigation steps taken included the installation of Jersey barriers, the placement of sandbags, the addition of rain gauges, the installation of rock weirs, multiple live stream cameras, and the clearing of debris out of the channel [3]. These steps appeared to be initially successful based on the minor rain experienced.

In addition to mitigation strategies, Coconino County officials created partnerships with local citizens affected by stormwater run-off. Throughout 2019, 2020, and 2021, a series of pre-monsoon informational gatherings, titled, “Meets in the Streets,” were instituted [3]. These meetings, in May and June of each year, provided an informal forum in which community members could voice their flooding concerns to both county supervisors and city council members, engineers for the city and county, and sign up for emergency notifications through the national weather service. Throughout 2019 and 2020 government agencies urged the public to keep current sandbags in place and to take advantage of information concerning long-term mitigation currently in the planning phases.

The floodplain mapping, channel debris removal, installation of rain gauges, alluvial fan stabilization projects, channel stabilization, clearing of sediment in basins, and forest restoration that took place during 2019 and 2020 proved to be essential to the recovery from the monsoon flooding of 2021 [3].

On August 17, 2021, the City of Flagstaff saw unprecedented flooding throughout the streets, channels, and storm drains on the eastside of the city. Rain gauges in the watershed registered from 2 to 3.5 inches of rain in a two-hour period, with additional rain threatening the neighborhoods farther down the watershed [5]. Depending on the rain gauge in the Spruce Avenue Watershed this storm produced a 200-to-500-year reoccurrence rainfall event [5]. The flood event was combination of the high rainfall intensity and the Museum Fire burn scars. Streets within the flooding area became major corridors for transporting runoff. The Spruce Avenue Wash conveyed large amounts of runoff which was confined within the channel by sandbags and concrete vehicle barriers. However, at a culvert crossing for the channel at Linda Vista Drive, the runoff was too great to be contained. The runoff overtopped the double barrier culvert and flowed without restriction down the roadway to Grandview Drive. The runoff at the corner of Linda Vista and Grandview runoff was approximately 3 feet deep at this location [2].

After the event, impact of this storm was evident. Streets were impassable, storm drains and culverts were clogged, yards were overwhelmed by mud and debris, and 24 homes flooded. Killip Elementary School was also flooded with 6 inches of water throughout the school forcing closure.[5] The path of the flood through Flagstaff's low-income community caused widespread mud and sediment deposition throughout the neighborhoods of Sunnyside and Grandview. 11 tons of sediment was removed from this location [2]. The City of Flagstaff estimated that the damage to public and private property amounted to 3.3 million dollars [5].

Three Levels of Response

The economic physical and emotional recovery from the Museum Fire/Flood Event has required the cooperation of multiple entities from both the private and public sector. The commitment of government, civic and private resources are needed to ensure that everyone affected by the flood has the assistance for recovery and prevention. The three levels of response include the following: initial flood response, intermediate flood recovery, and long-term planning.

Both the City of Flagstaff and Coconino County took immediate steps to help mitigate the effects of the flooding on the city and the community. The focus of mitigation taken by the local government

agencies to increased resilience and facilitated recovery. The first step was the implementation by local government of the Museum Flood Area Emergency Alert Process based on a threshold approach [6]. When rainfall was measured at 0.25 inches in 15 minutes, city and county officials began monitoring drainages and water flows. When rainfall was measured at 0.40 inches of rainfall in fifteen minutes, notifications were given to Mount Elden Estates downstream of the burn scars, using county and city social media. At 0.75 inches of rainfall in 15 minutes, emergency alerts were posted to cellphones of residents in flood-prone areas. As a result of this three-stage process, swift action was taken during this twenty-minute flooding event on August 21st. Many roads were closed, public announcements were posted on social media, flooding was surveyed, and emergency responders were alerted. [2].

After the flood waters receded, the city and the county took swift action to initiate recovery efforts. Major debris and mud were removed, clogged infrastructure was addressed, roadway restoration was initiated, and residents of flooded homes were contacted to determine how best to aid them in their recovery efforts [8].

Since the flood, long-term plans have been under discussion, and fire-flood projects are being implemented. The groundwork in addressing the flooding concerns of local citizens and proposals for future projects took place at the 2021 Museum Flooding Summit held in Flagstaff, Arizona on August 28, 2021. Representatives from the United States Forest Service, the Army Corps of Engineers, Flagstaff Unified School District, the Arizona Department of Water Resources, the Federal Emergency Management Agency, the Arizona Geological Survey, and the Arizona Department of Transportation participated. Along with the government agencies, seven consulting engineering firms were present to contribute their expertise in order to identify practices that would most effectively address the changing contexts affecting the infrastructure in Coconino County. The need to pursue federal, state, and local funding sources was discussed due to the high cost of flood mitigation. In addition, flood hydrology, mitigation ideas, next steps in recovery and prevention as well as lessons learned from the 15,000-acre 2010 Schultz Fire were discussed [7]. An analysis of the Shultz fire yielded the following: a framework

for designing feasible long-term mitigation during a temporary hydrologic regime, a focus on minimizing rather than preventing damage, and a recognition of the importance of key relationships in fire/flood response, resilience, and recovery. [3]. This summit not only facilitated the interaction of government agencies with engineering firms but became a way for communicating ongoing flooding mitigation to the citizens of Flagstaff. Continuing to establish a call-line to communicate flood information to residents was a major action taken by summit participants, a step that has the potential to strengthen public and private partnership.

Private homeowners contributed to flood mitigation by the placement and maintenance of sandbags. In the aftermath of the flooding, debris removal by local citizens, neighbors helping one another, and assessing damage characterized this stage of recovery. Citizens were encouraged to add and maintain their own sandbags, to stay informed of the latest information on flooding response and prevention, and to participate in public meetings in person or via social media.

Exploring Strategies for Coordinating and Maximizing Resources for Recurring Flooding

The current strategies for maximizing resources for recurring flooding in the area are a result of floodplain management mitigation efforts by both Coconino County and the City of Flagstaff. The County and City are working to create a long-term infrastructure that will foster the resilience and recovery of residents that have experienced losses due to flooding events. The City of Flagstaff and Coconino County received \$6.5 million in funding from the federal government. \$3.5 million has been allocated to remediate the burn scar and \$3 million has been earmarked for mitigation efforts [8]. Both are working together to ensure that long-term mitigation efforts are realized. This funding source is the first step in ensuring this goal.

The systematic strategies being implemented by the local agencies to ensure that the communities affected by flooding have reliable drainage infrastructure is a way that local governments are maximizing resources for recurring flooding. Both are maximizing flood prevention through the implementation of multiple different mitigation efforts throughout the watershed. The following are the projects in the works

for mitigation efforts: Museum Fire sediment reduction project the NRCS Emergency watershed protection project, the Mt. Elden Estates flood mitigation project, the Mt. Elden Estates NRCS exigency project and the forest alluvial fan stabilization project [3].

The alluvial fan stabilization project in Flagstaff is being led by the Coconino County Flood Control District. The goal of the alluvial fan project is to improve the ability to receive runoff and sediment from the watershed area above, spread it out, and reduce the flow and velocity of stormwater [9]. Without this stabilization, 70 percent of the Museum area watershed could reach peak flows 100 times greater than before the Museum fire [10]. Engineers are proposing the stabilization of six different alluvial fans ranging from the headwaters of the watershed to the edge of Flagstaff city limits. Project participants point to the fact that the Vernon Creek watershed in Utah has been fully restored by the utilization of alluvial fan stabilization to repair erosion and sediment issues [9].

Another major long-term project being completed is the Killip School Regional Detention Basin Project [10]. The detention basins are being constructed to detain floodwater during a flooding event and then drain the water over a period of 36 hours. This basin was designed based on attenuating the most flow possible while still draining in 36 hours compared to meeting a specific runoff event [2]. This approach is more forward looking and flexible and not based only on the past data of the Rational Method [11]. Not only will the detention basins serve the community during floods but will also serve as new play fields for Killip Elementary School. Research shows that 92% of flood damage cost can be saved by using storage-based facilities and that these systems are the most effective for flood mitigation [12].

Discussion of Success and Challenges of Museum Flood Response

A forest fire followed by a 500-year storm could have caused a major disaster for the City of Flagstaff and Coconino County. To date, no lives have been lost, but 24 homes were flooded. The proactive mitigation efforts taken by the City of Flagstaff and Coconino County during the “non-soons” of 2019 and 2020 were a major factor in preventing what could have been a historic tragedy. Lessons learned from the Shultz Fire Flood ten years before were applied to the Museum Flood Response Plan, saving lives and preventing catastrophic property damage. In contrast, the response of Houston, Texas,

officials was less than proactive. The Houston area saw three greater-than-100-year rain events in a span of five years. Officials were unprepared for the flooding from these storms. Flood control officials would not admit that another 500-year event could happen on the heels of the last devastating storm. Hurricane Harvey was a painful dose of reality. Fueled by climate change, it brought unprecedented amounts of rain to the city, flooding more than 9,000 homes and businesses. Many lives were lost, and Houston citizens lost billions to property damage [13]. Although the Flagstaff area is not prone to hurricanes, it is vulnerable to dangerous flooding from monsoon storms. Planners and citizens can't afford to look backward as planners in Houston did, to try to predict storm events, but must look forward to the unpredictability climate change is bringing to flood forecasting [14]. Planners in Coconino County and City of Flagstaff must continue to take a proactive stance with their flood mitigation efforts despite the fact that no existing hydrology model is capable of making reliable flash-flood forecasts in watersheds affected by urbanization [15].

While local officials have experienced success with flood mitigation strategies and developing communication with local citizens, not everyone is satisfied with current efforts. Some citizens, especially in the historically blue-collar Sunnyside neighborhoods, feel they have been left out of the recovery process. After the flooding event, the residents wanted the same protection measures as the subdivisions upstream of the flooding. When interviewed, they alleged that no response to their requests for flood mitigation help was given to them by community officials. This perceived inequity can create the opportunity for the local government agencies to develop more strategic communication strategies so that all stakeholders can develop a vision for participation in the flood mitigation process [16]. With increased participation, government agencies can have a more informed approach to the improvement of city infrastructure and the public will benefit by increased assessed values on their property and a sense of ownership on-going projects. In addition, increasing the communication opportunities between engineers and public stakeholders could contribute to a common vision [11]. While the community felt positive about the response of the local officials, not every citizen is going to be satisfied by mitigation efforts. Officials in the City of Flagstaff and Coconino County now have an opportunity to deepen and strengthen

their partnership with local citizens by exploring ways to involve them in the many decisions needed for effective flood mitigation.

Conclusion

The Museum Fire Flooding was an unprecedented event in the City of Flagstaff history. Fortunately, no lives were lost and only one home totally destroyed. From a purely engineering standpoint, mitigation measures taken in the two years previous to the 2021 flood were successful. These proactive strategies were the key to preventing catastrophic loss. During those dry years, strengthening the partnership between public entities and private citizens was facilitated through social media communication and invitations to participate in the planning process. However, there is more work to be done to build flood resilience, especially in under-served neighborhoods in the Flagstaff community. A shared vision and a sense of ownership can be developed by making the planning process more inclusive. In addition, helping people link to available city, county, state, and federal resources is also essential to flood recovery.

Finally, looking forward to the effects of continuing climate change, rather than backward to historical meteorological data, can facilitate the development of hydrological models and mitigations that anticipate future challenges more realistically. Thus, mitigation will focus on the system's ability to rebound after a major event [11]. Because of the ever-changing environmental, social, and technical elements confronting all designers of flood mitigation strategies, building strong connections with all stakeholders is essential to making design choices that are suitable, sustainable, robust, cost-effective, and equitable.

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