
ASFPM Arid Regions Committee

Introduction

Up to one third of the remaining developable land area in western United States lies on alluvial fan landforms (Anstey, 1965). Therefore, accurate delineation of flood hazards on these unique landforms is critically important to the health of the National Flood Insurance Program. The goals of this white paper are to encourage ASFPM member communities and FEMA to continue their long history of continuously improving tools for delineating and managing alluvial fan floodplains, and to increase the number of alluvial fan floodplain delineations in ASFPM communities. As with all the activities of ASFPM, our underlying goal is to provide better tools to help protect the lives, property and well-being of the American public.

A History of Successes

Hazards associated with alluvial fan flooding were brought into the national spotlight following catastrophic debris flows on alluvial fans in Southern California in the 1970’s. These disastrous floods highlighted the fact that alluvial fan flooding was substantively different than riverine flooding, and therefore required different mapping and management tools. FEMA responded by implementing a methodology developed by the USGS (Dawdy, 1979). The Dawdy-based method offered two key improvements in alluvial fan floodplain delineation technology. First, it recognized that alluvial fan flooding is very different from riverine flooding. Second, it recognized that flow path uncertainty is a key aspect of alluvial fan flooding. From 1979 to late 1980’s, the Dawdy method was used to map alluvial fan floodplains throughout the West. The Dawdy method is now implemented as the FAN program and is described in Appendix G of the FEMA Guidelines.

In 1995, FEMA contracted with the National Research Council (NRC) to evaluate their alluvial fan floodplain delineation practices. After deliberating for nearly a year, and visiting numerous alluvial fans and interviewing dozens of communities throughout the United States, the NRC technical committee issued their report Alluvial Fan Flooding (1996), which suggested a number of improvements to FEMA’s alluvial fan floodplain delineation methodology. The NRC recommendations included the following: (1) recognition that not all alluvial fans are alike, (2) distinction of active and inactive alluvial fans, (3) incorporation of geologic data into the fan identification and mapping process, and (4) use of a three stage delineation process.

Recent Developments

Since publication of the NRC report in 1996, and the revised FEMA Appendix G Guidelines in 2002, the three-stage alluvial fan floodplain delineation process has been
applied to alluvial fan landforms throughout the United States. In addition, the Flood Control District of Maricopa County (Arizona) published its draft *Piedmont Flood Hazard Assessment Manual* (PFHAM) in 1998, which implements the NRC and FEMA recommended three-stage alluvial fan delineation process. More than 30 alluvial fan floodplain delineations have been completed in Maricopa County alone using the Maricopa County manual. More recently, the State of California commissioned an Alluvial Fan Task Force, which adopted an integrated planning and analysis approach which closely parallels the approach recommended in the NRC Report. Within FEMA, the mapping community recently transitioned from the MapMOD program to RiskMAP, for which some of the main themes include use of the following: (1) better technology, (2) better mapping, (3) risk-based mapping, and (4) multi-disciplinary approaches. In addition, FEMA is currently evaluating overall reform of the NFIP, seeking to improve our ability to prevent flood losses, better protect lives and property, and improve floodplain management practices.

**Need to Update Alluvial Fan Floodplain Delineation Techniques**

Given FEMA’s call for better technology and mapping as part of their RiskMAP program, and the experience gained by local communities like the State of California and Maricopa County, Arizona in alluvial fan floodplain delineation, the Arid Regions Committee now calls on its members to encourage FEMA to update its alluvial fan floodplain delineation procedures. ASFPM’s report, *National Flood Programs and Policies in Review* (2007), specifically noted that the existing alluvial fan floodplain delineation techniques inaccurately depict the actual flood hazard. The following are reasons that now is the time for such an update:

- **Time.** It has been 14 years since publication of the NRC report and eight years since FEMA adopted the current version of Appendix G. We have learned much over the past 14 years that could be applied to alluvial fan flood hazard evaluations. Every technical methodology needs periodic updates. The alluvial fan floodplain delineation methodology is no exception.

- **Experience.** The current three-stage alluvial fan delineation methodology has been applied many times over the past decade. As with any new procedure, the more it is applied, the better we know its shortcomings and needs. One of the key shortcomings identified by most stakeholders is the existing methodologies’ inability to generate engineering data suitable for structure design. We should leverage our experience to shore up existing gaps and weaknesses, as well as exploit any opportunities to better manage flood hazards.

- **New and Improved Tools.** The engineering tools available for evaluation of alluvial fan flooding have been improved, and new tools have been developed in the past 14 years. These tools include improvements in two-dimensional modeling, new geologic dating techniques, and new debris flow prediction and modeling tools.
Management & Mitigation Issues

An update of FEMA Appendix G would also be consistent with the larger goals of the NFIP. Better floodplain delineation tools for active alluvial fans not only enable NFIP member communities to better manage their flood hazard, but also it provides opportunities for FEMA to determine whether the hazards are properly rated for insurance purposes. Furthermore, better hazard identification tools for alluvial fans may allow FEMA and NFIP member communities to deal directly with coverage for erosion, sedimentation, and debris flow hazards which occur on active alluvial fans.

Recommendations

The Arid Regions Committee strongly believes that we should build on FEMA’s long history of continuous improvement of their alluvial fan floodplain delineation tools, and therefore offer the following recommendations for updating the current alluvial fan floodplain delineation methodology:

Recommendation #1: Any changes in the approved methodologies for alluvial fan floodplain delineation and management should recognize the following foundational principles:

- Floodplain delineation techniques and management techniques for active alluvial fans must address the potential for flow path uncertainty.
- Floodplain delineation techniques on alluvial fans should account for potential changes in topography, channel pattern, and fan processes over reasonable engineering time scales, rather than relying on single event, fixed-bed modeling.
- Not all alluvial fans are the same. Different tools and approaches may be required for different fans. Floodplain delineation techniques should account for differing watershed characteristics, alluvial fan flooding processes, and physical characteristics of the alluvial fan.

Recommendation #2: Any new methodology should recognize that there are different types of active alluvial fans. Currently, Appendix G recognizes that there are different types of flooding on alluvial fan landforms (G.2.2.4), but does not include any finer distinctions among types of active alluvial fans. Furthermore, the current methodology does not distinguish different types of flood zones that correspond to the differing types of flooding on alluvial fans. Specifically, the guidelines should distinguish the following:

- Debris flow fans. In general, debris flow fans will have significantly greater flood hazards than fans subject only to water floods.
- Fluvial (streamflow) fans. Many active fans in tectonically inert areas are subject only to water floods, which typically have less catastrophic types of sedimentation than debris flow fans.
- Channelized fans. Fans with channels that can convey larger floods (by frequency) are generally subject to less flow path uncertainty than fans whose channels have very low bankfull capacities.
• Sheet flooding fans. Fans subject to avulsive, channelized flow have significantly greater flood hazards than fans which are dominated by shallow, low velocity sheet floods.

**Recommendation #3**: Any new methodology should allow higher hazard portions of fans to be distinguished from lower hazard portions of fans. Currently, the effective methodology does not adequately distinguish degrees of hazard within an alluvial fan floodplain. We now know that the degree of hazard is a function of watershed characteristics (drainage area, flow rate, flow frequency, sediment production, wild fire risk, debris flow potential, etc.), fan surface characteristics (slope, sediment size, soil characteristics, fan area, topographic relief, etc.), and the hydraulic characteristics of flow (depth, velocity, etc.). Implicit in this recommendation is that a method for quantifying alluvial fan flood hazards is needed. The following types of hazards should be distinguished on active alluvial fans:

- Flow path uncertainty
- Channel avulsions
- Debris flow
- Sediment deposition
- Scour and erosion
- High flood depth & velocity
- Shallow sheet flooding

**Recommendation #4**: The terminology used in Appendix G and the NFIP should be clarified and made internally consistent. An example of contradictory or confusing language is in the definition and descriptions of active alluvial fans. According to the language in Appendix G, active alluvial fans can either be areas in which “elevation on fill would not reliably mitigate the flood risk” (high threshold), or areas of sheet flooding (low threshold), or areas that would have been inundated in the past 100 or 1,000 years (low threshold). It is difficult to reconcile inclusion of areas of shallow sheet flooding on fluvial, non-debris flow fans that experience low flow depths and velocities with the active alluvial fan flooding descriptor of “ultrahazardous.” In such areas, if the rate of sedimentation is low, it is likely that elevation on fill would reliably mitigate the risk, even though the fan may be “active” in recent geologic time (i.e., aggrading, albeit slowly). In addition to clarifying such potential contradictions, the text should be edited to remove, to the extent that is feasible, non-quantitative adjectives from definitions, such as “high,” “abrupt,” “so severe that,” etc.

**Recommendation #5**: Improve the technical guidance for delineation of active alluvial fan flood hazards. Specifically, better guidance on what constitutes a composite method (Table G-1) is needed, as well as how use of a composite method fits with the apparent (and contradictory) prohibition of using “hydraulic analytical methods” on active alluvial fans. In addition, more detailed description of the types of analyses required to support a LOMR request for an active alluvial fan floodplain. In addition, clarification should be provided if some Appendix G methodologies are intended only for inactive fans. Many
LOMR/CLOMR submittals are woefully deficient because of the lack of clarity regarding what is required, resulting in multiple reviews and frustrated applicants.

**Recommendation #6:** Any new methodology should formally recognize specific key processes that are known to occur on active alluvial fans. These processes include the following:

- **Flow Path Uncertainty.** Flow path uncertainty, by avulsion or other mechanisms, is the key defining characteristic of active alluvial fan flooding. Methods to quantify the risk and role of flow path uncertainty on flood hydrology, hydraulics, sedimentation, and erosion are needed.

- **Hydrograph Attenuation.** Significant flow attenuation occurs on many active alluvial fans between the hydrographic apex and the toe. Because of this attenuation, use of the full apex discharge downstream of the apex may be overly conservative, particularly near the toe of an alluvial fan. Also, because of the degree of flood storage that occurs on active alluvial fans, the impact of development in such storage areas drastically increases peak discharges, adversely impacting downstream areas, a fact which is not adequately captured by using the full apex discharge for the entire fan.

- **Infiltration.** Infiltration on alluvial fans is well documented in the literature. The potential role of infiltration in hydrograph attenuation should be quantified and incorporated into hydrologic and hydraulic models as appropriate.

- **Sheet Flooding.** Sheet flooding is the dominant flood process on the mid- and distal-fan areas of many active (fluvial) fans. Use of floodplain delineation models that do not recognize the presence of sheet flooding will inaccurately depict the true flood hazard. These sheet flooding areas are subject to flow path and flow rate uncertainty, but generally do not present the same level of risk as channelized flooding and/or debris flow hazards. That is, any uncertainty in shallow, low velocity sheet flooding areas may be able to “be set aside” in the assessment of the hazard.

- **Sediment Transport.** The impact of sediment load on peak discharge, channel capacity, avulsion potential, flow attenuation, and channel stability should be considered in the hazard delineation methodology.

- **Debris Flow.** For alluvial fans subject to debris and mud flows, the impacts on flood hazards should be considered relative to watershed characteristics, including the geology, sediment production rates, wildfire potential, seismic hazard, and other triggering mechanisms.

**Recommendation #7:** Conduct regular training to increase awareness of alluvial fan floodplain hazards and keep abreast of advances in technology. This training should be targeted at FEMA and local community floodplain reviewers, floodplain management agencies, and development engineers. The target audience should be taught to recognize alluvial fan landforms, as well as how to delineate flood hazards on active alluvial fans. In addition, training in the use of new tools needed to quantify active alluvial fan flood
hazards is needed, such as two-dimensional modeling, geomorphic mapping, and recognition of debris flow hazards.

**Recommendation #8.** Initiate a consistent review process to assure that the presence of alluvial fans is not missed in the review and floodplain delineation process. This could be applied only in communities known to have active alluvial fans or could be applied on a broader scale. Currently, there is a high potential for alluvial fan flood hazards to be missed in the delineation and review process. There have been a number of well-documented cases where the threat of alluvial fan flooding existed, but was missed entirely in the delineation and review process.

**Recommendation #9.** Investigate the frequency of alluvial fan avulsions. FEMA and NFIP member communities should specifically investigate the physical mechanisms that lead to alluvial fan avulsion, and quantify the frequency with which avulsions occur on debris flow and fluvial fans. This investigation will determine whether avulsion risk is sufficient to warrant consideration in floodplain delineation and engineering mitigation evaluations. This investigation could also be used to assess the accuracy and applicability of statistical/probabilistic approaches.

**Recommendation #10.** Investigate other methods to quantify flow path uncertainty. Other agencies have developed methods to evaluate uncertainty using Monte Carlo simulations or USACE risk-analysis procedures. Some of these approaches may be applicable to alluvial fan floodplain delineation studies.

**Recommendation #11.** Collect better documentation of alluvial fan floods. Communities should be encouraged to document actual alluvial fan floods using ground and aerial photography, video, pre- and post-flood matching photographs, high water marks, flood inundation limit mapping, weather records, and flood damage reports. A central repository for historical flood documentation should be established and maintained for future reference and scientific evaluation.

**Recommendation #12.** FEMA should explore linkages between improved floodplain delineation tools for alluvial fans and insurance/management concerns. Better understanding of the nature and type of alluvial fan flooding will result in better assignment of risk for insurance purposes and better management of the actual hazards.