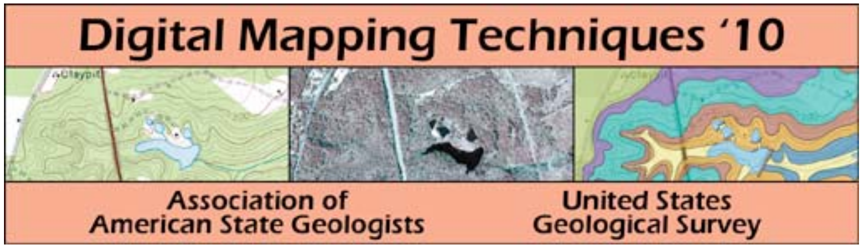

The following was presented at DMT'10
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The contents are provisional and will be superseded by a paper in the DMT'10 Proceedings.

See also earlier Proceedings (1997-2009)
http://ngmdb.usgs.gov/info/dmt/

Modeling Alluvial Fan Flood Hazards: A Derivative of Surficial Geologic Maps

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ABSTRACT

The factors that make alluvial fans desirable – relatively planar slopes, good surface drainage characteristics, and often excellent views – are formed by floods and debris flows that can negatively affect lives and property. The California Geological Survey (CGS) is integrating geologic maps that use the Classification of Surficial Materials developed by the USGS (Matti and Cossette, in preparation) with geologic assessments for a first-order assessment of the areal extent and relative magnitude of alluvial fan flooding hazards. These maps may be used to assist in avoiding hazardous areas and to design for proper flood and debris flow management facilities; they are not intended to satisfy FEMA requirements.

The general distribution and relative hazard of alluvial fan flooding is defined as: relatively high ≈ Late Holocene fan surfaces and historic channels and washes, or whole fan areas subject to historic and future migration of flow paths; moderate ≈ Late Pleistocene to Middle Holocene alluvial fan terraces, moderately incised and raised above younger channels and washes; and relatively low ≈ Early to Late Pleistocene relict fans elevated significantly above historically flooded surfaces. Maps incorporating these relative hazard designations, supplemented with the delineation of debris flow hazard areas and potential channel avulsion sites, may assist landowners, land-use planners, developers, and regulators in identifying the most hazardous areas prone to alluvial fan flooding in the pre-project design phase.

Figure 1: Streamflow Fan (San Bernardino County, CA)

Figure 2: Debris Flow Fan (Riverside County, CA)

WHAT IS ALLUVIAL FAN FLOODING?

Alluvial fan flooding is flooding that occurs on the surface of an alluvial fan (or similar landform) that originates at the apex of the fan and is characterized by high-velocity flows; active processes of erosion, sediment transport, and deposition; and unpredictable flow paths (FEMA, 2003). Modeling this type of flooding is significantly different than riverine type flooding, and requires a cooperative effort between geologists and engineers.

BACKGROUND

CGS is a technical consultant to and on the management team for the Alluvial Fan Task Force (AFTF), which is developing an inter-agency, multi-disciplinary effort aimed at providing planning and flood control departments guidelines for minimizing loss of life and property while preserving beneficial resources on alluvial fans. Currently, alluvial fan floodplains are mapped by FEMA in coordination with local flood control agencies where communities participate in the National Flood Insurance Program (NFIP). However, only a small percentage of these potentially hazardous areas have been mapped, and therefore CGS proposes an approach for land-use planners that may be used to establish a preliminary site assessment in the absence of FEMA data.

Two derivatives of surficial geologic maps are proposed for the AFTF: (1) Advisory maps that show areas that are underlain by Quaternary sediments that may include alluvial fans (Figure 5); and (2) A methodology to determine the relative hazard for alluvial fan flooding that is derived from surficial geologic maps and site reconnaissance (Figure 13). This relative hazard system is designed to assist landowners, developers, regulators, and the public in identifying those areas where quantitative studies are likely to document an alluvial fan flood hazard. Relatively High areas identified by this approach are most likely to be within a Special Flood Hazard Area (SFHA) and the Relatively Low areas are least likely to be within a SFHA. The Relatively Moderate areas may or may not be within a SFHA, but these are areas with a lower likelihood for alluvial fan flooding that those identified as Relatively High.

TYPES OF ALLUVIAL FANS

Alluvial fans are subdivided into three types based on their principal style of flooding and sedimentation: Streamflow Fans (Figure 1), Debris Flow Fans (Figure 2), and Composite Fans (Bull, 1977; and NRC, 1996). The type of alluvial fan and mode of deposition, whether it is built up from hyperconcentrated floods, debris flows, or both, will be unique for each fan. It is the position on an alluvial fan surface and the type of alluvial fan that determine the relative hazard to alluvial fan flooding for any site and the approach needed to identify and mitigate the hazard. For instance, alluvial fans that are built up by thick sequences of relatively young debris flow deposits are the most hazardous and require the most mitigative effort to protect life and property.

The debris flow hazard may be preliminarily assessed by identifying the dominant mode of alluvial deposition -- stream flow, debris flow, or composite – and then to determining where debris flow deposition has occurred in the Holocene. Debris flow hazards studies for Holocene debris flow fans may identify areas where debris flow may deposit sediment in active channels and result in avulsion where channels margins are low relative to debris flow volume. They may also identify debris flow terminal lobes where rapid aggradation may occur. For composite alluvial fans with incised channels, debris flow hazard studies may be used to identify channels that are easily overtaxed by relatively less frequent debris flows.

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MAPS OF QUATERNARY AGE ALLUVIAL FAN DEPOSITS - A PRE-PROJECT SCREENING TOOL

For the benefit of the land-use planner, maps that indicate areas underlain by surficial sediments (Figure 5) provide information about the potential for a proposed site to be located where alluvial fan flooding may occur, indicating a need for additional studies. These maps are based on published surficial geologic maps by the California Geological Survey, and the U.S. Geological Survey. Where published maps are unavailable, mapping will be conducted at 1:24,000 scale utilizing 1-meter NAIP imagery, USGS 7.5-Minute topographic maps, and shaded relief 10-meter Digital Elevation Models (DEM) (Figure 4 A-C).

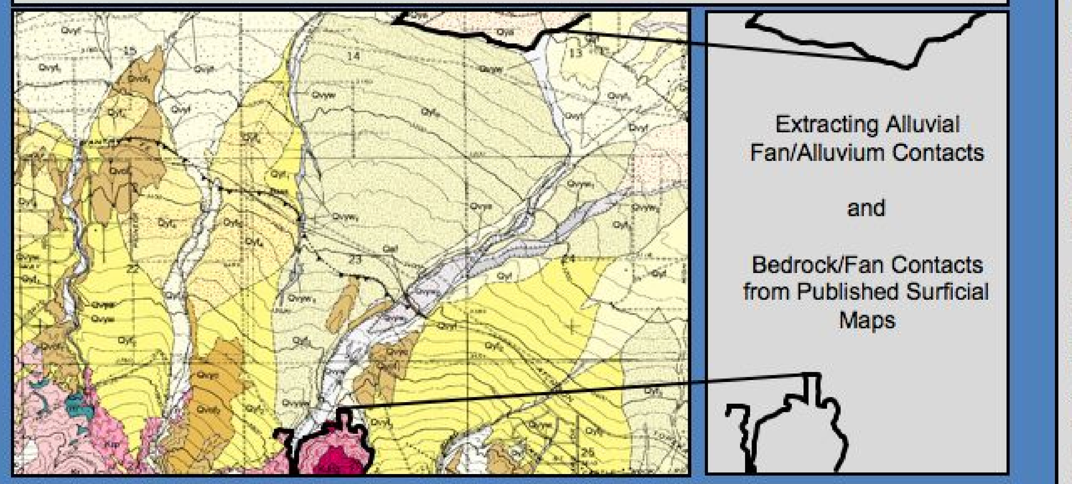


Figure 3:
Areas underlain by quaternary sediment that may include aggrading alluvial fan segments subject to alluvial fan flooding are mapped by extracting the bedrock contact with alluvial fan and alluvial wash deposits, providing the contact along the mountain front. The contact between alluvial fan deposits and axial valley deposits are also extracted and then the upper and lower contacts are merged to form polygons that represent all Quaternary age alluvial fan deposits.

(Reference: Surficial Geologic Map of the Fifteen Mile 7.5-Minute Quadrangle (USGS, 2001))

Figure 4(A-C): Where published surficial geologic maps do not exist, areas underlain by Quaternary sediment are mapped by observing fan geomorphic features from 7.5-minute USGS topographic maps, 2005 1-meter resolution NAIP imagery, and USGS 10-meter (posted) DEM (National Elevation Dataset). These data provide a means to approximate both the bedrock/alluvial fan contact, and the lower alluvial fan/axial valley deposit contacts.

B-AF: Bedrock - Alluvial Fan Contact
AF-AV: Alluvial Fan – Alluvium Contact

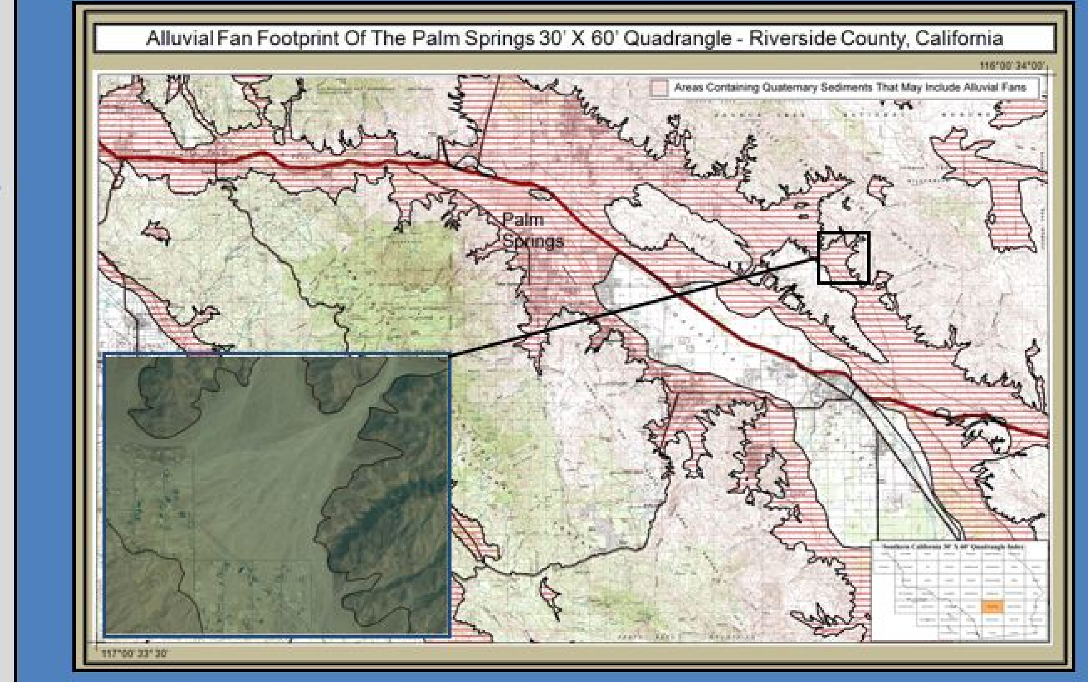


Figure 5: Draft version of an AFTF advisory map for the Palm Springs 30'X60' Quadrangle. As indicated in both examples above, these maps will be derived from published surficial geologic maps, and mapping bedrock-fan and fan-alluvium boundaries based on geomorphology. These advisory maps will be published for the entire AFTF 10-county study area and used to identify areas where additional studies may be necessary.

DERIVING RELATIVE HAZARD INFORMATION FROM SURFICIAL GEOLOGIC MAPS AND SITE ASSESSMENTS

THE ROLE OF SURFICIAL GEOLOGIC MAPS IN ASSESSING ALLUVIAL FAN FLOODING

Surficial geologic maps of alluvial fans provide a record of the long-term flooding history (Pelletier et al., 2005), that are a function of tectonic processes, climate change, and various feedback mechanisms (Bull, 2007). The use of surficial geologic m aps and geomorphology in flood hazard analyses on alluvial fans was formally recognized by the National Research Council (1996) and by FEMA in their Guidelines and Specifications for Mapping Partners (2003). FEMA guidelines must be followed in all cases , yet the aerial extent of FEMA mapping on alluvial fans is limited to where there is community participation in NFIP.

Planning departments and developers , up to this point, have had little available map-based communication of the hazard on alluvial fans other than Flood Insurance Rate Maps (FIRM) that are not available for most undeveloped alluvial fan areas. To addres [illegible]

THE RELATIVE POTENTIAL OF ALLUVIAL FAN FLOODING

The recent work in Clark County Nevada by House (2005, 2007) and Robbins et al., (2008) identifies that the general distribution of alluvial fans and the relative potential for alluvial fan flooding is a function of the age and geomorphic position of alluvial fan surfaces. Surficial geologic maps identify areas with flood and debris flow deposits of various ages, including modern drainage systems, their flow paths, and drainage divides (Robbins et al, 2008). The relative age of alluvial sediments, coupled with the identification of debris flow deposits, provides a method for making a preliminary estimate of the relative hazard to alluvial fan flooding at a given location.

Geologic studies may be required to perform preliminary assessments. Surficial geologic maps may be used to address the types of alluvial fan deposits and the relative ages of sediments on alluvial fans to provide a preliminary assessment of the relative potential for alluvial fan flooding. Additional information from site assessments, such as the potential for avulsion and debris flows, should also be considered in the assessment of alluvial fans. These preliminary studies may be conducted for a local area for pre-project assessment, or for entire fan regional planning. Surficial geologic maps coupled with site assessments may be used to develop a preliminary ranking or an area of study as:

Relatively High –Channels and washes (youngest Holocene <500 years or so), or whole fan areas subject to historic and future migration of flow paths
Relatively Moderate – Alluvial fan terraces that are moderately incised and raised above surrounding historic channels and washes. These areas are considered to have a moderate hazard. Fan terrace surfaces that are narrow interfluves surrounded by or interwoven with historic channels should be included with the High areas.
Relatively Low – Relict fans, or adjacent surfaces of deeply entrenched fan heads containing well-developed soils that are elevated above active washes
Debris Flow Hazard Area – Areas where Holocene age debris flow deposits have been mapped based on geomorphic and geologic evidence, or where debris flows are anticipated.
Uncertain due to Disturbance – Areas where disturbances to natural flow patterns have occurred and the relative hazard cannot be reliably mapped at or below the disturbed areas.

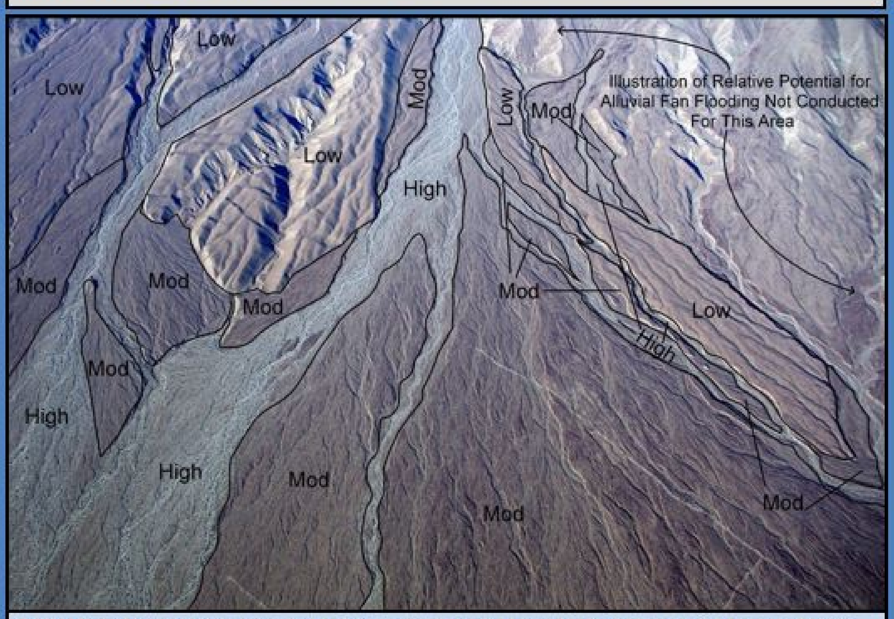


Figure 6: Illustration of a the relative hazard to alluvial fan flooding on an alluvial fan in the Santa Rosa Mountains, Riverside County, CA.

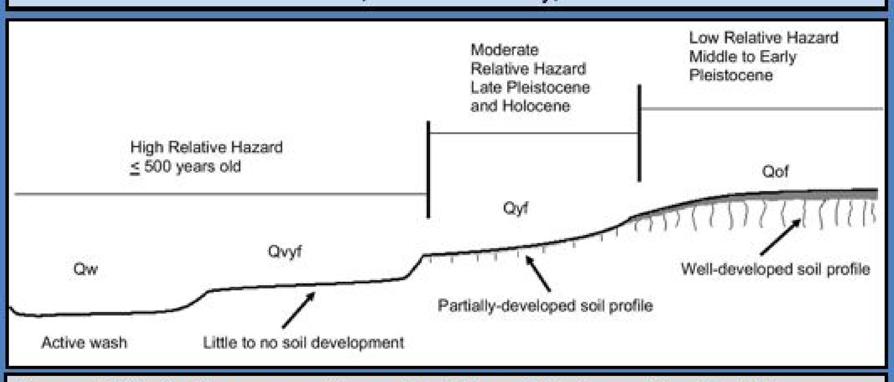


Figure 7: Illustrative geomorphic profile of the relative hazard to alluvial fan flooding, surficial mapping nomenclature based on Matti and Cossette (USGS), in preparation.

Assessing The Potential For Fluvial Avulsion

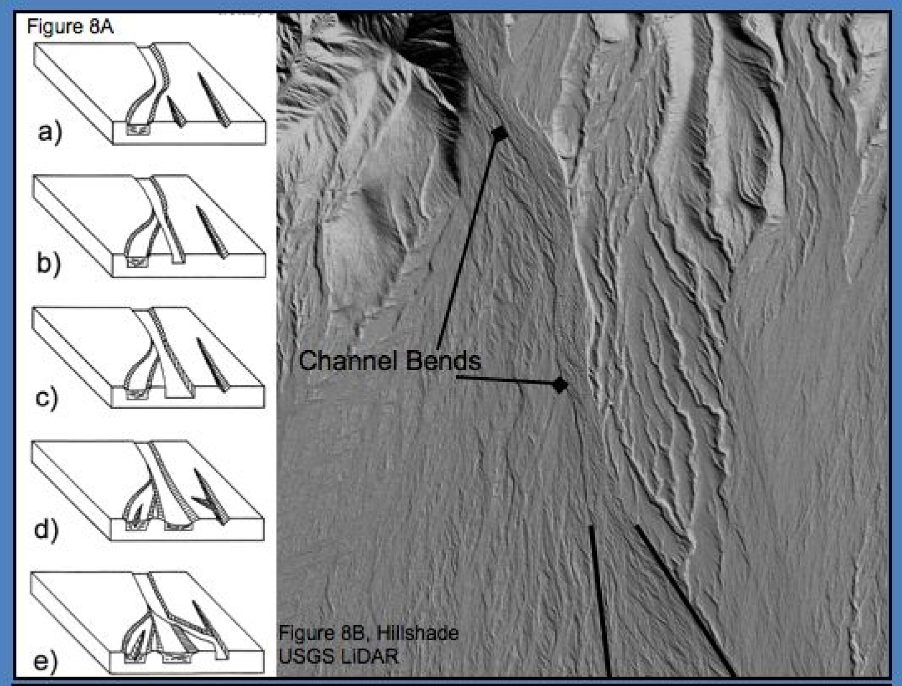


Figure 8 A&B:
Fluvial avulsion tends to occur on alluvial fans that are dominated by water floods or flooding hyperconcentrated with sediment. They tend to occur at channel bends, where channel banks are low relative to channel width, and in areas that are aggrading, causing channel bed elevations to increase relative to channel banks. They may also occur due to stream piracy where overland flow causes incision and headward erosion into active channels, thus causing a redirection, or redistribution of flow on the fan. Figure 8A (Field, 2001) describes the processes avulsion via stream piracy.

Assessing The Potential For Debris Flow Avulsion

Figure 9 A&B:
Alluvial fans that are dominated by debris flow processes, whether debris flow fans, or composite fans , tend to contain incised channels due to fluvial erosion processes.
Debris flows may travel down these channels for a limited distance until the channels are overtaxed by the sheer volume of the flow. As with fluvial avulsion, debris flow avulsion tends to occur at channel bends, but can occur much more frequently at the fan apex and proximal portions of the fan. Figure 9A above shows a debris flow that occurred on an alluvial fan in Inyo County, CA (Photo: Ken Babion, 2008). Figure 9B is an aerial view of the same alluvial fan showing where the debris flow avulsions occurred at the channel bends (Photo: Caltrans, 2008).

Assessing The Potential For Debris Flow

For preliminary indication of the potential for debris flow on an alluvial fan the focus of study should be to identify the dominant mode of alluvial deposition - stream flow, debris flow, or composite, and then to identify where debris flow deposition has occurred in the Holocene epoch because this is indicative of processes occurring under the current climate regime (Giraud, 2005). Identification of alluvial fans with Holocene debris flows deposition from a pre-project screening standpoint may then be used as the impetus for quantitative analysis of debris flow volumes during the project phase of a development.

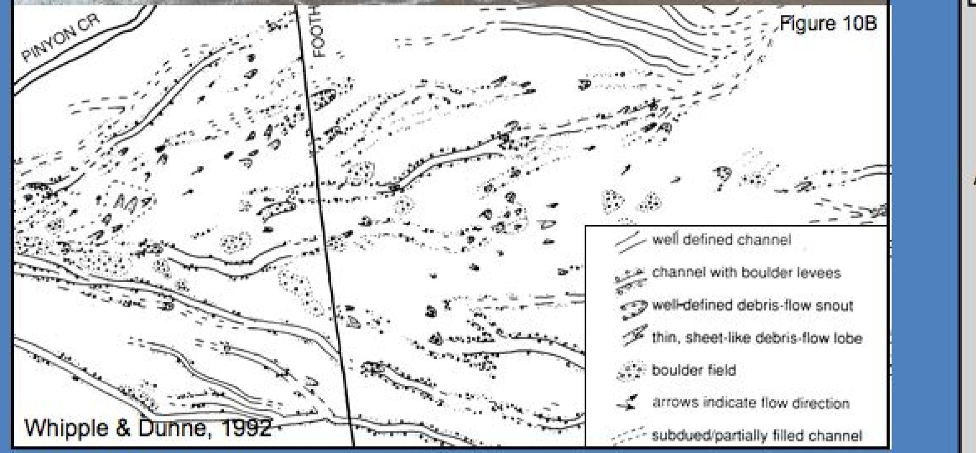


Figure 10 A&B:
The geomorphic expression of debris flows has been documented by many workers in the field. Whipple and Dunne (1992) found that the roughness of alluvial fan surfaces dominated by debris flow processes is controlled by the viscosity of debris flows. Fan apices and proximal areas tend to contain rougher surfaces expressed as channels with boulder lined levees, terminal snouts and boulder fields, due to higher viscosity debris flows. Whereas lower viscosity flows tend smooth the lower fan surfaces by depositing less viscous debris further downfan in low lying areas and channels.

Assessing Debris Flow Stratigraphy

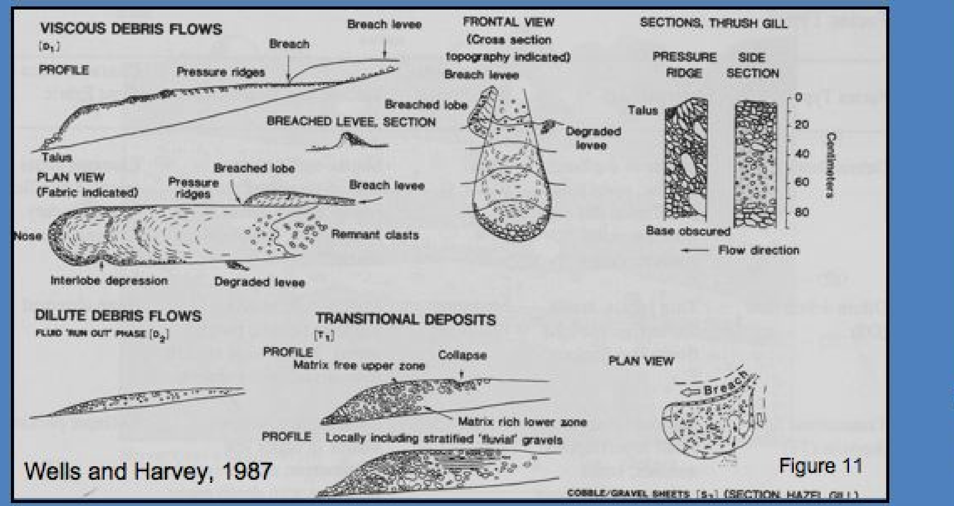
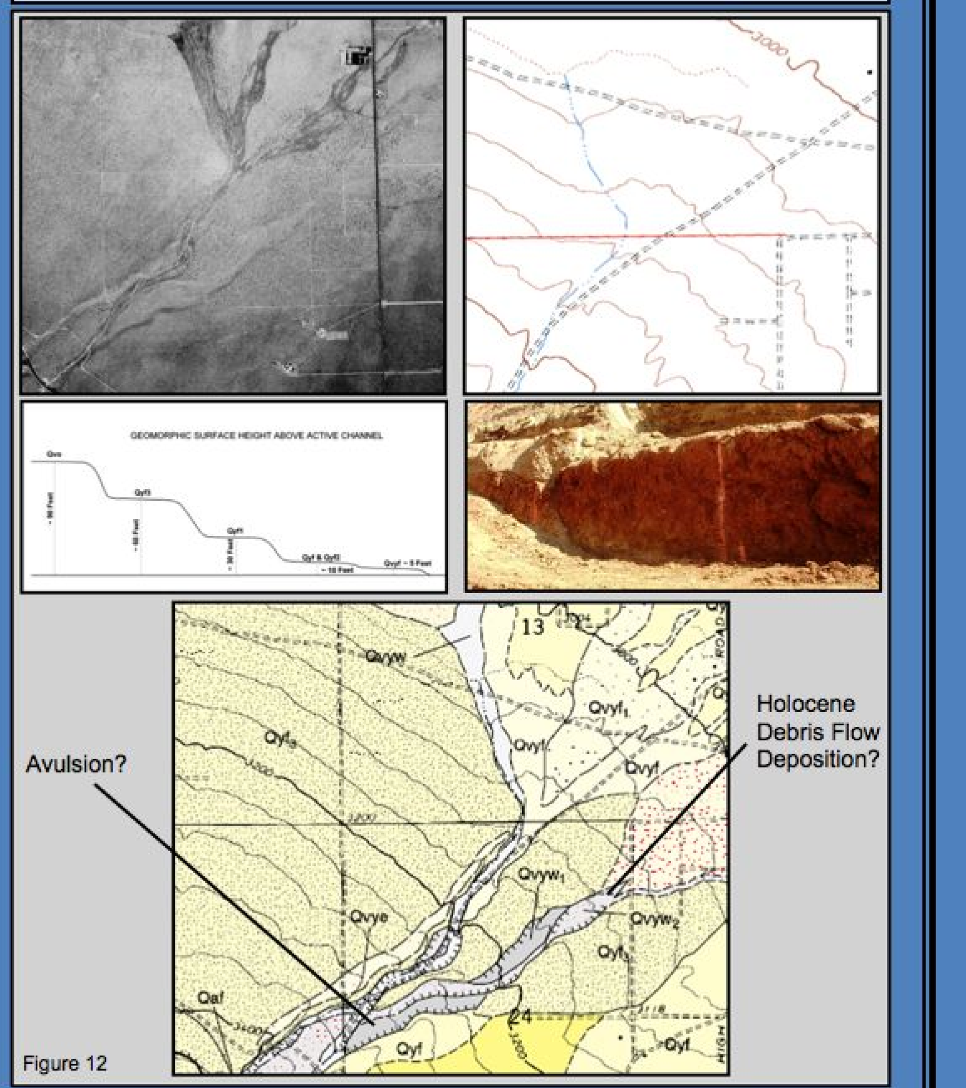
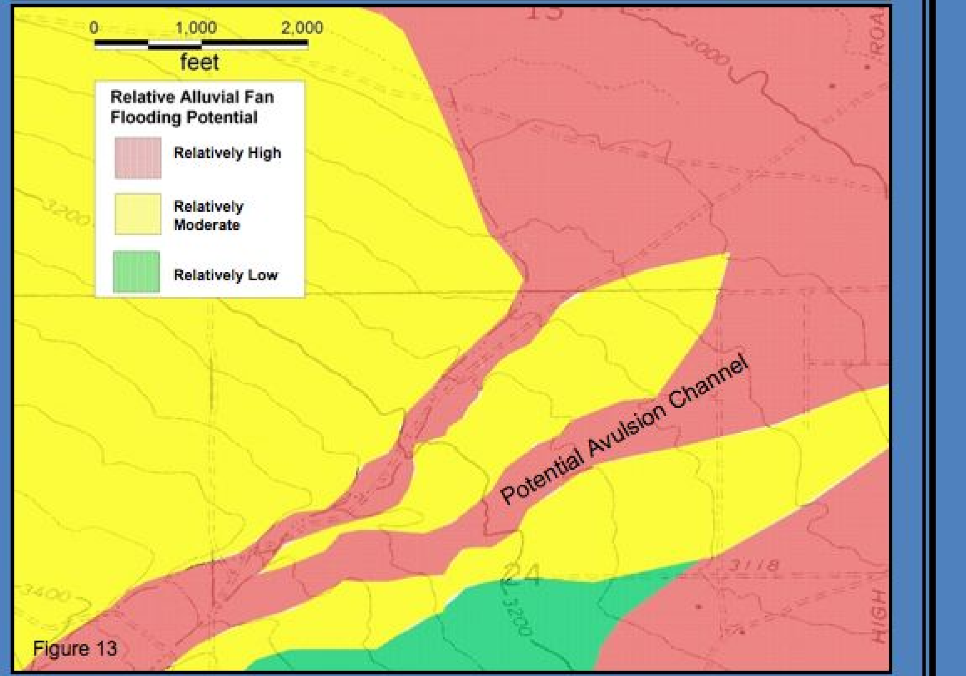


Figure 11:
Subsurface profiles of debris flow deposits indicate that they are commonly matrix supported, inversely graded at their base, and normally graded at the top. They are also characterized by a lack of bedding (usually massive) and a lack of clast imbrication.

Summarizing the Approach





Summary
From a land-use planning standpoint, the general distribution of alluvial fans and the relative hazard to alluvial fan flooding may be derived from surficial geologic maps coupled with field assessments of avulsion and the potential for Holocene debris flow deposition. The derivatives of surficial geologic maps for this purpose include advisory maps that show areas underlain by Quaternary alluvial fan deposits, and maps that indicate the relative hazard to alluvial fan flooding as relatively low, relatively moderate, and relatively high. These maps may be used to assist in avoiding hazardous areas and to design for proper flood and debris flow management facilities; however, they are not intended to satisfy FEMA requirements.