STATE OF ARIZONA
DEPARTMENT OF WATER RESOURCES

# State Standard
# for
# Identification of and Development Within Sheet Flooding Areas

Under authority of ARS 48-3605(a), the Director of the Arizona Department of Water Resources (ADWR) establishes the following standard for identification of and development within sheet flooding areas in Arizona:

Communities that need to identify or regulate development within sheet flooding areas in Arizona to fulfill the requirements of local and county flood damage prevention ordinances and floodplain regulations shall use the criteria outlined in State Standard 4 entitled "Identification of and Development Within Sheet Flooding Areas" or an alternative procedure that results in greater level of flood protection.

For the purpose of application of these criteria, sheet flooding areas will include all sheet flooding areas which have been identified by a local floodplain administrator as having significant potential flood hazards, sheet flooding floodplains meeting the site identification criteria outlined herein with drainage areas more than 1/4 square mile or a 100-year estimated flow of more than 500 cubic feet per second. Application of these guidelines will not be necessary if the local community or County has in effect a Drainage, Grading, or Storm Water Ordinance which results in the same or greater level of flood protection as application of these guidelines would ensure. In addition, these guidelines are not applicable in FEMA-designated Special Flood Hazard Areas mapped with Base Flood Elevations and Base Flood Depths.

This requirement is effective {date to be determined, 2012}. State Standard 4 replaces State Standard 4-95 and State Standard Attachment 4-95, which were adopted January 1, 1995. All previous versions of the superseded standard and attachment should be discarded.

Copies of this State Standard can be obtained by contacting the Arizona Department of Water Resources or via the internet at the ADWR website.

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# Identification of and Development

# within

# Sheet Flooding Areas

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# 1 Introduction

Sheet flooding is a type of surface water runoff that occurs on broad, unconfined floodplains with low lateral relief. Sheet flooding can occur in urban, rural, and natural areas. Because sheet flooding occurs in areas that often lack defined stream channels, identifying sheet flooding areas may be more difficult than identifying riverine floodplains. Although types of sheet flooding have been identified in every geographic region of Arizona, floodplain management standards developed specifically for sheet flood areas are generally lacking. This State Standard is intended to provide criteria and guidance to promote sound floodplain management of these unique flood hazard areas.

This document details minimum floodplain management criteria for identification of, and development within, sheet flooding areas in Arizona. Different types of sheet flooding are defined, and identifying characteristics are given for each type. Flood hazards associated with sheet flooding are also described, and floodplain management standards and suggested development criteria are presented. Three levels of analysis for sheet flooding areas are presented which reflect increased levels of complexity and accuracy. Finally, example applications of this State Standard are provided to demonstrate its application.

# 2 Definitions and Identifying Characteristics

The term "sheet flood" was first used in scientific literature in 1897 by William McGee, a U.S. Geological Survey scientist working in the Arizona Sonoran Desert. Based on his observations on the Santa Rita Piedmont south of Tucson during a summer monsoon, McGee defined sheet flooding as a "broad expanse of unconfined runoff moving downslope." This general definition of sheet flooding is adopted for use in the State Standard, since it adequately envelops the more narrowly defined types of sheet flooding discussed elsewhere in this document.

**Figure 1. Low angle aerial photograph of a sheet flood in central Arizona, showing the broad unconfined flow, the lack of defined channels, and shallow inundation. Arrow indicates the general flow direction.**

The primary identifying characteristic of sheet flooding is that the majority of floodwater is conveyed over surfaces that lack well-defined channels (Figure 1). The "channels" that are

found in sheet flooding areas are typically very shallow, poorly defined, discontinuous, and/or highly interconnected. Even where such channels exist, most of a sheet flood is conveyed outside of the identifiable channels. For this reason, the potential for flood inundation and damage in sheet flooding areas may not be obvious landowners, development engineers, or floodplain managers.

**Definition of Sheet Flooding**: A broad expanse of unconfined runoff moving downslope.

## 2.1 General Characteristics of Sheet Floods

Like many types of flooding in the arid west, observations of sheet floods are relatively rare. Therefore, documentation of actual sheet floods is limited. The lack of defined channels, the broad shallow inundation area, and the short flow duration of many Arizona floods complicate attempts to systematically collect sheet flood data. However, sheet floods in Arizona are generally thought to have the following identifying characteristics:

- Appearance. Sheet floods occur over broad areas that lack a central, main channel, and consequently have a relatively uniform appearance across the inundation area.

- Hydraulic characteristics:
  - High width/depth ratio. Sheet floods typically have relatively low depths and large widths, yielding very high width/depth ratios, usually well in excess of 100.
  - Maximum depth and velocity. It is likely that there is an upper limit for depth and velocity in sheet floods on natural alluvial surfaces, since high flow depths and velocities would be erosive and would lead to formation of defined channels over time. To date, no maximum sheet flooding depths and velocities have been definitely established in the scientific literature. For the purposes of this State Standard, the maximum average depth for sheet flooding areas in Arizona is defined as three (3) feet over a cross section through the inundation area. In many cases, sheet floods will have average depths of one foot or less.
  - Froude number. Because it has relatively shallow depths and low velocities, most sheet flooding on natural surfaces should have subcritical Froude numbers (< 1.0). Sheet flooding on some steeper, smoother surfaces may approach critical depth.
  - Sheet flooding may or may not be gradually varied or steady, and may have a strong two-dimensional character.
  - Sheet flooding may have different hydraulic characteristics for sediment laden and sediment deprived flows.

- Flood properties. Water moving over a smooth stable surface does not move as a uniform film. If the surface is broad, the sheet differentiates into parallel streams of greater depth and relatively rapid flow, separated by shallower bands of relatively sluggish flow; and at the same time, both streams and intervening bands differentiate into series of transverse waves which move forward more rapidly than the body of the undifferentiated sheet.

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- Attenuation & Infiltration. Significant peak flow attenuation may occur as a sheet flood moves downslope, due to the large size of potential storage areas versus flow volume. In addition, a significant loss of flow volume may occur due to infiltration. Some sheet floods may completely dissipate due to infiltration or other loss mechanisms before ever leaving the sheet flooding area.

- Flow uncertainty. Because of the lack of defined channels and the high percentage of unconfined flow, the distribution of flow at any given point may change between subsequent floods, creating some uncertainty in both the flow location and rate. Subtle changes in land use, cover type, grading or other human and natural impacts to the land surface also may change the flow distribution between sequential floods, although the overall character of flooding within the sheet flooding area should be similar during subsequent flood events. Flow path uncertainty also complicates the delineation of watershed boundaries in sheet flooding areas.

## 2.2 General Characteristics of Sheet Flood Areas

While real-time observations of sheet floods may be rare, the characteristics of areas subject to sheet flooding can be observed at any time on aerial photographs, on topographic, soils, and geologic maps, or in the field. Combining observations from all of these data sources is recommended when identifying sheet flooding areas. Specific characteristics are described below for each data source.

**Key Identifying Characteristics of Sheet Flooding Areas**:
- ✓ No central main channel
- ✓ Wide shallow flow area
- ✓ Flat lateral terrain
- ✓ Uniform vegetation
- ✓ Uniform soils
- ✓ Smooth parallel contours

- Aerial photographs (Figure 2). Sheet flooding areas have the following characteristics that can be observed on aerial photographs:
  - The absence of a well-defined channel network over a relatively large land area. Defined channels can be identified on aerial photographs from the denser concentrations of bank vegetation and/or the bright appearance of sandy bed sediments, or in rare instances in Arizona, from flowing water.
  - The presence of a broad, poorly-defined distributary channel network, with mostly parallel rather than radiating channel segments. The poorly-defined channels are often discontinuous, and usually have very low or indiscernible channel banks.
  - The occurrence of a well-defined upstream channel that transitions into an area with poorly-defined or no channels. The transition is usually coincident with changes in topography, physiography, or land use.
  - Very uniform vegetative characteristics that extend laterally over an expansive area. Many natural sheet flooding areas are covered by grass, low brush, or desert scrub, with few large trees.
  - Soil characteristics may not be visible on aerial photographs due to vegetative cover. Where the ground surfaces are visible, the soil characteristics are usually very uniform within the sheet flooding area. In lower desert regions, very little surficial soil reddening or other signs of surface aging may be present.

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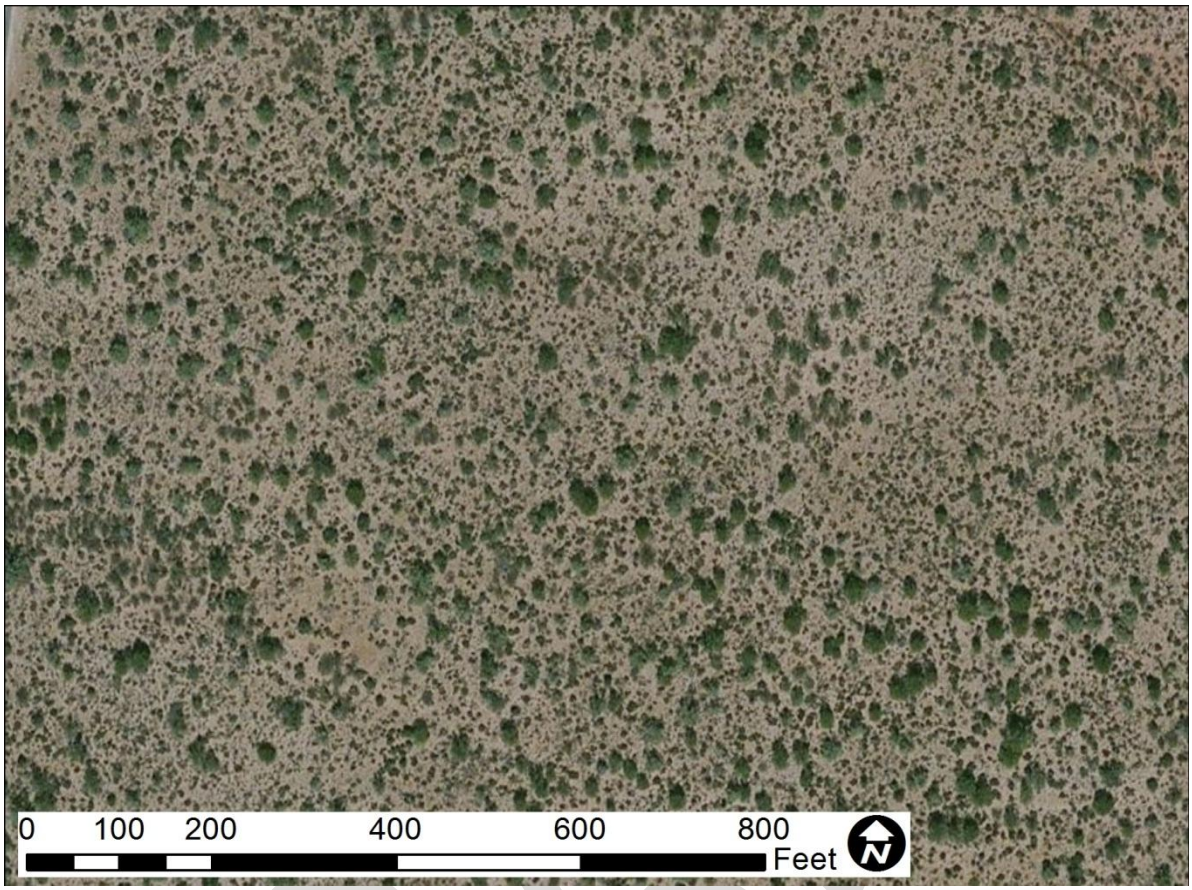


**Figure 2. Aerial photograph of sheet flooding area in Pima County (Lat. 32.064612, Long 110.686976). Note the lack of defined channels, the uniform terrain and topography, and lack of soil reddening or topographic relief. Careful inspection reveals a faint distributary network of very small channels.**

- Topographic maps (Figure 3). USGS topographic quadrangle maps or other topographic data provide the following types of information that can be used to identify areas subject to sheeting flooding:
  - Low lateral topographic relief. The lack of topographic relief perpendicular to the primary flow direction indicates a lack of confinement, as well as the ability for flooding to flow broadly over a large area.
  - Lack of deeply incised channels. Topographic contours bend upstream where they cross channels. If topographic contours do not bend sharply or at all in the upstream direction at channel crossing, it indicates low channel depths.
  - Smooth, parallel topographic contours. Sheet flooding areas tend to have planar topography with low lateral relief and no deeply incised channels. As a result, topographic contours through these areas tend to be very smooth, rather than crenulated. Parallel contours indicate the presence of a planar surface.
  - Low to moderate surface slope. Based on analysis of the State's physiographic characteristics, experience has shown that most sheet flooding areas in Arizona have surface slopes of less than three percent.
  - Lack of stream symbols. USGS topographic maps of sheet flooding areas either lack the standard blue USGS stream symbol, or have several brown-colored, parallel stream symbols that may terminate or not connect to any downstream channel.

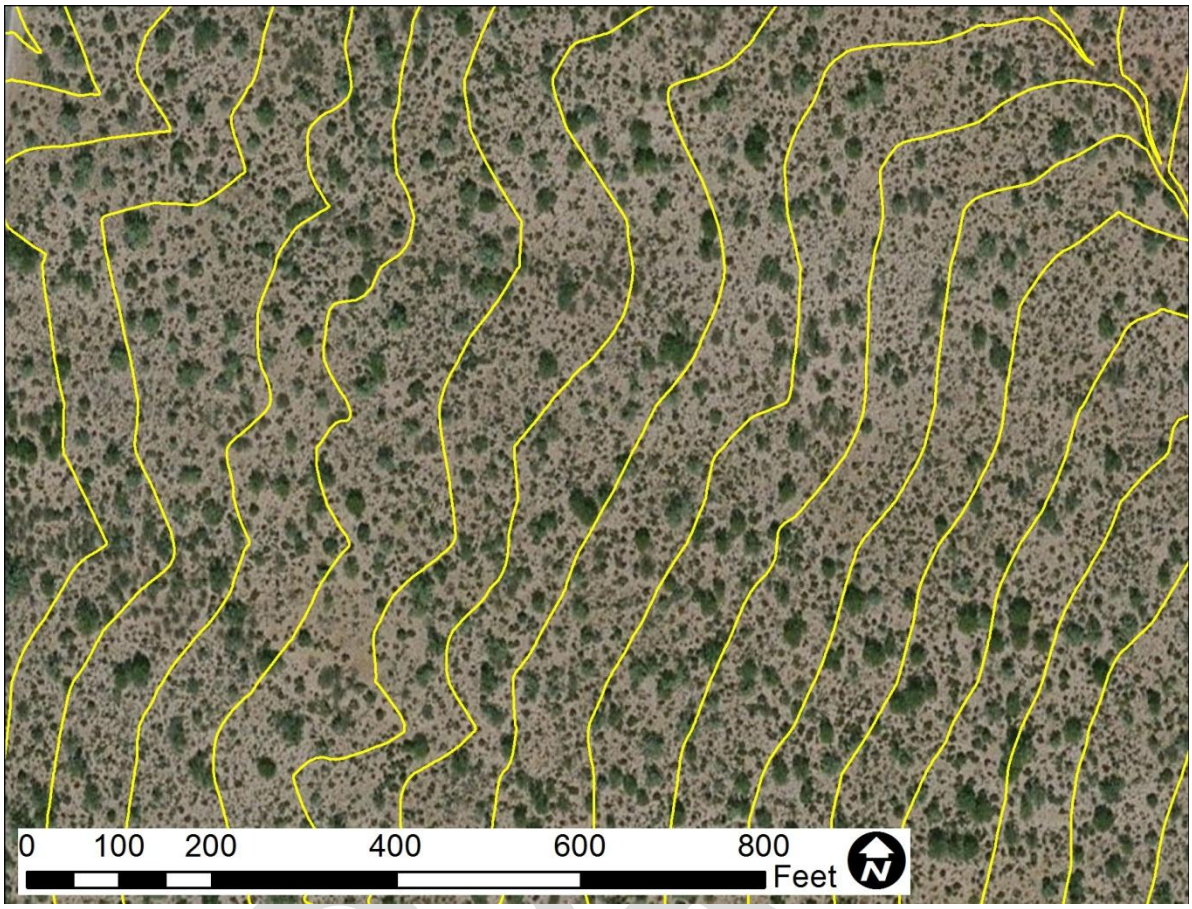


**Figure 3. Detailed (2 ft.) topographic mapping of sheet flooding area in Pima County (Lat. 32.064612, Long 110.686976). Note the lack of incised channels, and the smooth, parallel contours.**

- Soils and geologic maps (Figure 4). The Arizona Geological Survey (AZGS) and U.S. Geological Survey (USGS) have performed detailed surficial geologic mapping for some parts of Arizona. AZGS surficial geology maps are available online (www.azgs.az.gov/publications.shtml). Check with the regional USGS offices in Flagstaff, Tucson, and Phoenix for availability of USGS surficial mapping for other specific areas in Arizona. Detailed soils and geologic mapping may provide information useful for identifying sheet flooding areas, including the following:
  - Detailed soils mapping from the Natural Resources Conservation Service (NRCS) and the U.S. Forest Service (USFS) is available for most of Arizona. NRCS soils maps can be obtained online from the NRCS Soil Data Mart (http://soildatamart.nrcs.usda.gov) or viewed at the NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). USFS soils data may be available from individual USFS management unit offices in Arizona.
  - Detailed NRCS soils map unit descriptions normally do not refer to sheet flooding, but may describe soils in sheet flooding areas as occurring on floodplains, alluvial fans, or drainageways. NRCS soils in sheet flooding areas typically consist of loams or loam/sand derivatives. Note that while most sheet flooding areas are mapped as floodplains or alluvial fans, it does not necessarily follow that soils units described as floodplains or alluvial fans are subject to sheet flooding.

- Soil units in sheet flooding areas typically show minimal soil profile development, and consist of recently deposited sand-gravel-silt alluvium.
- AZGS and USGS surficial geology map unit descriptions will sometimes identify surfaces subject to sheet flooding. In general, sheet flooding will occur on the younger map units (mid- to late Holocene), which are often designated with Qy symbol. Note that not all geologically young surfaces are subject to sheet flooding.

**Figure 4. Detailed NRCS soils mapping for sheet flooding area in Pima County (Lat. 32.064612, Long 110.686976). Red box indicates the approximate area shown in Figures 2 and 3. Note that the entire area of interest is comprised of a single NRCS soil unit (#8: Bucklebar-Sahuarita Complex – sandy loam, fan terrace).**

- Field observations. Field-checking observations and conclusions made from aerial photographs, topographic mapping and soils/geologic mapping is highly recommended. It is important to not limit the field visit to just a specific property, but to expand the visit to include one or more traverses of the entire potential floodplain. The following types of field data are useful for identifying sheet flooding areas:
  - The key characteristic to verify in the field is the lack of defined channels capable of conveying a 2- to 10-year flood without overtopping.
  - Within a full transect of a sheet flooding floodplain, the vegetation, channel characteristics (if any), and topographic relief should be relatively uniform.
  - In many sheet flooding areas, potential channel features visible on aerial photographs may be difficult to locate in the field because of the lack of topographic relief, and the uniformity of the terrain and vegetation.
  - Because of the uniform terrain, locating specific areas in the field may be difficult unless there are constructed features such as roads, homes or fences that can be used as reference points.

**Figure 5. Example of sheet flooding in a natural rangeland area.**

## 2.3 Types of Sheet Flooding Areas

In addition to the general identifying characteristics listed in Section 2.2, identifying characteristics for the following types of sheet flooding areas are provided below:

- Urban Sheet Flooding
- Agricultural Sheet Flooding
- Alluvial Fan Sheet Flooding
- Sheet Flooding Caused by Tributary Flow onto Geologic Floodplains

### 2.3.1 Urban Sheet Flooding

Urban sheet flooding occurs where development has obscured natural drainage patterns or where drainage facilities are severely undersized, and flow is conveyed around buildings through streets, alleys, yards and parking areas. Urban sheet flooding is most common in areas that were developed prior to modern floodplain management practices, as well as in "wildcat" subdivisions that are typically developed with minimal or inadequate drainage infrastructure (Figure 6 and Figure 7). Urban sheet flooding is more problematic where development is dense, homes are built at grade, and a rectilinear development pattern is imposed on the natural topography.

Identifying urban sheet flooding areas differs from identifying natural sheet flooding areas in that many of the most diagnostic characteristics, such as drainage pattern, vegetation, and topography may be obscured or altered by development. Nevertheless, urban sheet flooding areas may be identified from the following information and characteristics:

- Local flood control and street maintenance personnel may have records of past floods or drainage problems, such as frequent ponding, poor drainage, home flooding, sediment deposition, or widespread damage to landscaping.
- Lack of defined natural channels, drainage easements, or drainage facilities in areas with relatively large watersheds.
- Construction of low berms around homes which may indicate landowner efforts to protect their sites from flooding.
- Identification of the general sheet flooding characteristics described in Section 2.2 on undeveloped surfaces upstream, downstream, and/or adjacent to the urban area.

Assessment & Management Issues for Urban Sheet Flooding

- Perimeter fences and walls cause flood problems when sheet flooding areas urbanize, particularly where they obstruct, divert, and/or concentrate flow.
- Road construction, maintenance, and other improvements can also cause adverse changes in sheet flooding areas by altering pre-development flow characteristics.
- Concentration of sheet flooding into narrow, defined corridors can cause scour, headcutting, and downstream damages due to increased flow depths and velocities.
- Regional flood control solutions may be needed to mitigate urban sheet flooding problems in densely developed area. Such flood control measures may be expensive, and may have complicated right-of-way, alignment, utility, and outfall problems.
- In densely developed urban sheet flooding areas, a Level 3 analysis, as described in Section 3, may be needed to accurately identify flood hazards and potential solutions. In many cases, this may require a two-dimensional, volume-accounting model, with storm drain modeling capabilities.

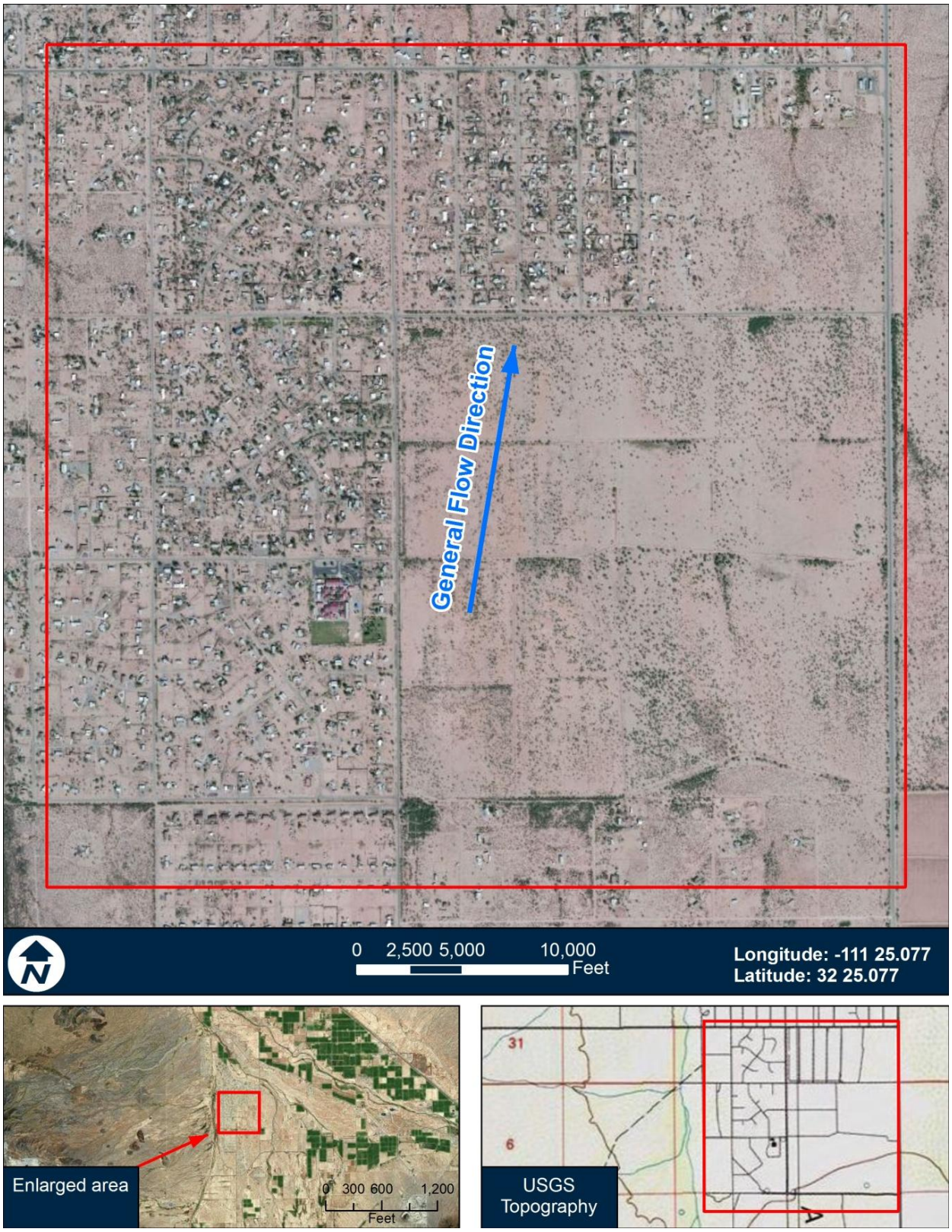


**Figure 6. Aerial photographs and topographic maps for urban sheet flooding area.**

**Figure 7. Aerial photograph and topographic mapping for a highly developed urban sheet flooding area in Tucson, Arizona. Red dots indicate known drainage complaints, one of the primary indicators that sheet flooding occurs in the area.**

### 2.3.2 Agricultural Sheet Flooding

Agricultural sheet flooding occurs on land surfaces that have been graded or leveled for agricultural use. The lack of topographic variation within the farm fields creates sheet flooding conditions. Identifying agricultural sheet flooding areas differs from identifying natural sheet flooding areas in that soil and vegetative characteristics may be obscured by grading or leveling for irrigation or farming. Figure 8 shows an agricultural sheet flooding area.

Identifying characteristics of agricultural sheet flooding areas include:

- Agricultural sheet flooding areas may be identified from pre-development photographic or topographic data, using the general sheet flooding characteristics described in Section 2.2. However, in many parts of Arizona, agricultural development pre-dates the advent of aerial photography and pre-farming records are unavailable.
- Historical flood records are another way to identify sheet flooding in agricultural areas. Records of historical flooding may be obtained from long-term residents, road maintenance supervisors, or news accounts.
- Low lateral topographic relief perpendicular to the primary flow direction.
- Identification of sheet flooding characteristics on undeveloped surfaces upstream, downstream, and/or adjacent to the development, such as distributary or anastomosing channel patterns which are intercepted by agricultural areas with no identified drainage facilities.

Assessment & Management Issues for Agricultural Sheet Flooding

- Irrigation infrastructure, such as canals, field perimeter berms, laterals, and other similar structures may be the most topographically prominent feature in many agricultural areas. These structures obstruct, divert, pond and redirect runoff in ways that may have little connection with the natural topography.
- FEMA floodplain delineations in agricultural sheet flooding areas may reflect FEMA protocols regarding modeling practices for non-levee embankments, non-engineered structures, and privately maintained structures. Floodplain managers should be aware of the effect of such protocols on published floodplain delineations, relative to where actual flood hazards may occur in the vicinity of such structures.
- It is necessary to assess the flood hazards associated with failure as well as non-failure of non-engineered agricultural features to determine the regulatory flood elevation.
- Inundation resulting from breaches in irrigation canals, ponding areas, or stock ponds should be accounted for in flood hazard assessments.
- Ponding upstream of irrigation canals, berms and other features should be accounted for when determining flood depths.
- Urbanization of retired agricultural lands may require creation of a new regional drainage infrastructure.

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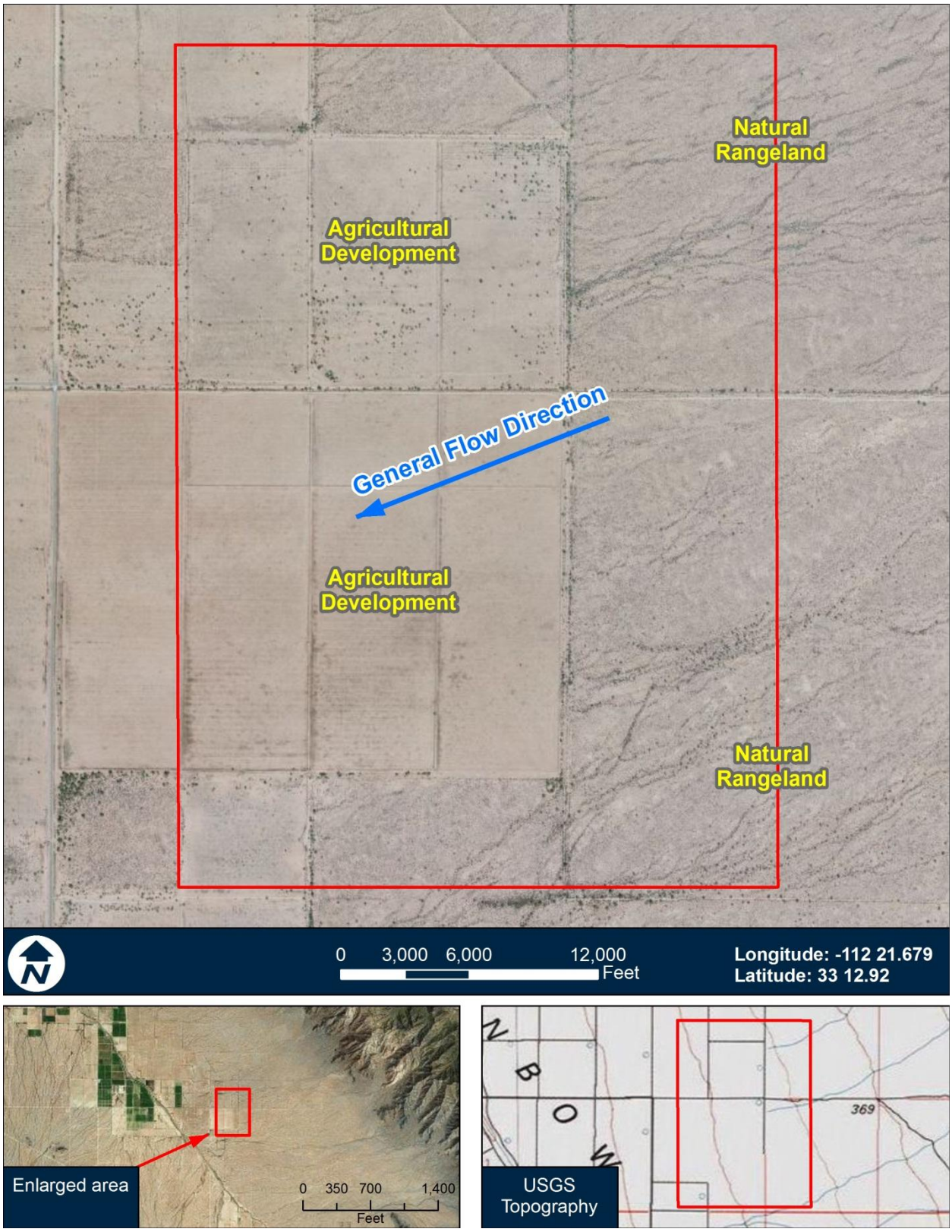


**Figure 8. Aerial photograph and topographic mapping for sheet flooding in agricultural area.**

### 2.3.3 Alluvial Fan Sheet Flooding

Alluvial fan sheet flooding is similar to other types of sheet flooding, except that it occurs on active alluvial fans. The most hazardous portions of some active alluvial fans also have unique flood hazards such as channel avulsions, debris flows, sediment deposition and net aggradation. However, other portions of many active alluvial fans include large areas of relatively shallow sheet flooding are not subject to those unique hazardous flood hazards, at least on engineering time scales. This State Standard applies only to the zone of sheet flooding on an alluvial fan, not the portions subject to ultrahazardous flood conditions. Figure 9 shows an alluvial fan sheet flooding area.

Alluvial fan sheet flooding typically occurs on the lower portions of the active fans, well below the hydrographic apex, and immediately downstream of where the fan channel network loses definition. The boundary between sheet flooding and channelized flow is gradual, rather than abrupt, and may vary with flood magnitude or even the flooding source. The sheet flooding surfaces tend to be dominated by runoff that originates from rainfall on the fan surface, rather than from the watershed above the hydrographic apex, although upper watershed floods may also transition to sheet flooding on the lower portions of many alluvial fans. Major avulsions are unlikely within the alluvial fan sheet flooding area, but potential changes in flow distribution caused by avulsions on upstream, more hazardous portions of the active fan should be accounted for in hydrologic assessments in the sheet flooding zone.

Identifying characteristics of alluvial fan sheet flooding include:

- The general sheet flooding characteristics listed in Section 2.2.
- Location on an active alluvial fan. Some resources for identifying active alluvial fans are provided by FEMA[1] and may be available at local floodplain management offices.

Assessment & Management Issues for Alluvial Fan Sheet Flooding

- Floodplain delineations on active alluvial fans require special delineation techniques. Refer to local floodplain management regulations and FEMA Guidelines, Appendix G for more detailed information.
- The FEMA FAN methodology is not an appropriate tool for analyses of alluvial fan sheet flooding in Arizona because it is based on an assumption of channelized flow.
- Estimating the 100-year discharge for active alluvial fan sheet flooding areas can be challenging due to the potential for upstream avulsions and flow path uncertainty. Refer to FEMA Guidelines and Section 7 for additional information.
- Sheet flooding portions of active alluvial fans are not "ultrahazardous," as that term is used in FEMA literature. Therefore, elevation on fill is usually an adequate method to mitigate the flood risk.

[1] FEMA Guidelines, Appendix G. Available at www.fema.gov.

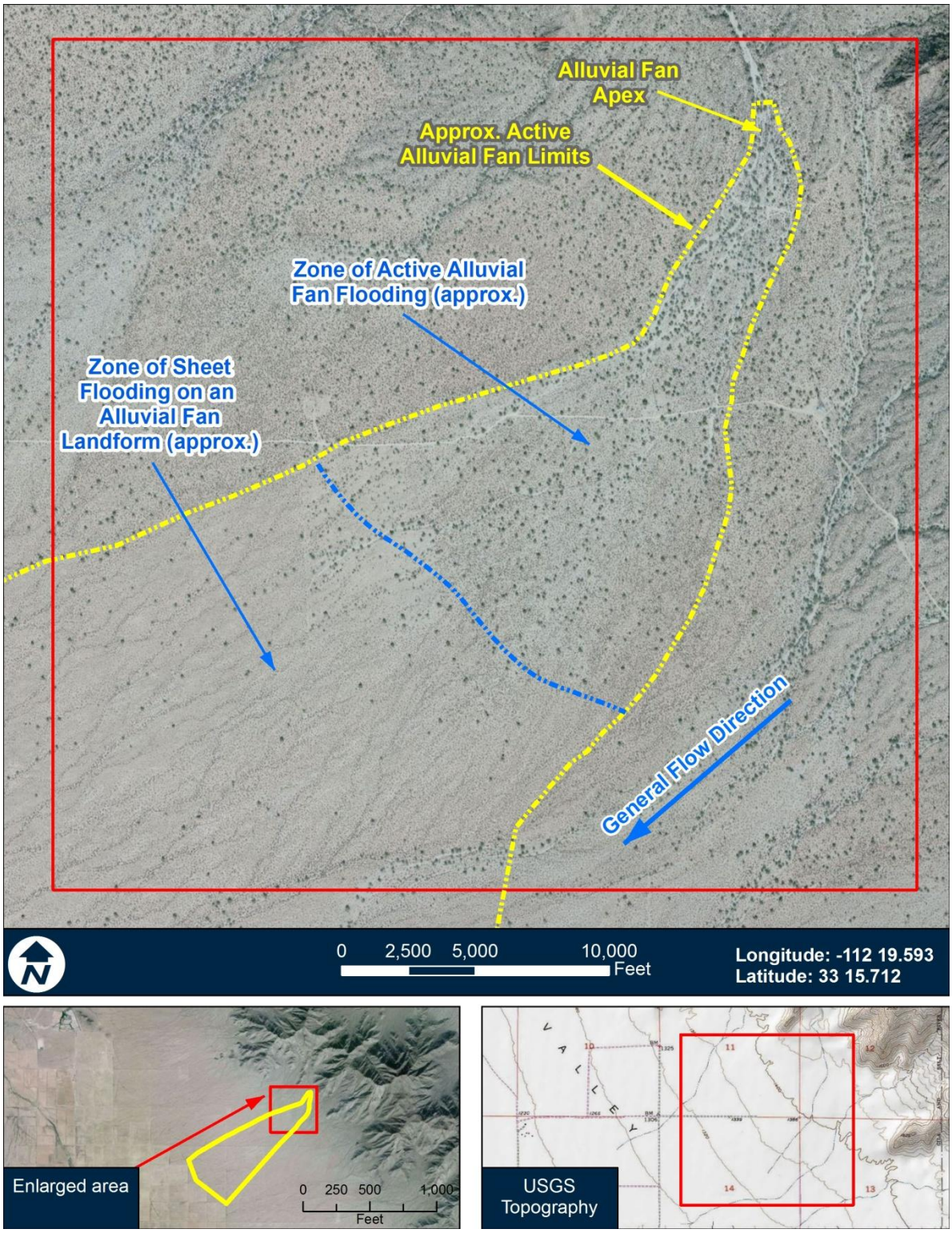


**Figure 9. Aerial photograph and topographic mapping of sheet flooding on an active alluvial fan.**

### 2.3.4 Sheet Flooding Caused by Tributary Flow onto Geologic Floodplains

Sheet flooding may occur where defined tributaries flow out onto the floodplain of a larger watercourse. If a major watercourse's floodplain is sufficiently large, and is characterized by planar, undissected topography, the tributary flow may transition to a sheet flood condition as it flows across the geologic floodplain before entering the main channel of the major watercourse. Sheet flooding on a geologic floodplain is more common where the major watercourse has experienced significant incision leaving its former floodplain perched as a terrace above its existing active floodplain. Sheet flooding on geologic floodplains is often a geologically temporary phenomenon, due to processes such as (1) headcutting of the tributary flow path, (2) lateral erosion along the major watercourse that removes the floodplain surface, or (3) overbank flooding from the main stem watercourse that changes the floodplain topography. Figure 10 shows an example of sheet flooding where tributary flow enters the floodplain of a larger watercourse.

In many cases in Arizona, agricultural development of the riverine floodplain creates or alters sheet flooding conditions, as described in Section 2.3.2 In other cases, agricultural development includes channels, berms, levees or other structures that attempt to control the tributary flow and prevent sheet flooding across the field areas. Small active alluvial fans are often found at the mouths of tributaries where they enter the geologic floodplain, lose confinement and deposit a significant portion of their sediment load.

Tributary sheet flooding on a geologic floodplain can be identified from the following characteristics:

- The general sheet flooding characteristics listed in Section 2.2.
- A lack of defined channels between the point where a well-defined tributary leaves the piedmont uplands and where it enters the main channel of major watercourse.
- A wide geologic floodplain with relatively flat topography adjacent to a major watercourse.

Assessment & Management Issues for Tributary Flow on Geologic Floodplain

- The effective floodplain may be controlled by flooding from the major watercourse, rather than the tributary sheet flooding. Both flood sources should be evaluated.
- The area near where the tributary enters the geologic floodplain may behave like an active alluvial fan.
- Urban or agricultural uses on the geologic floodplain may require application of urban or agricultural sheet flooding criteria.

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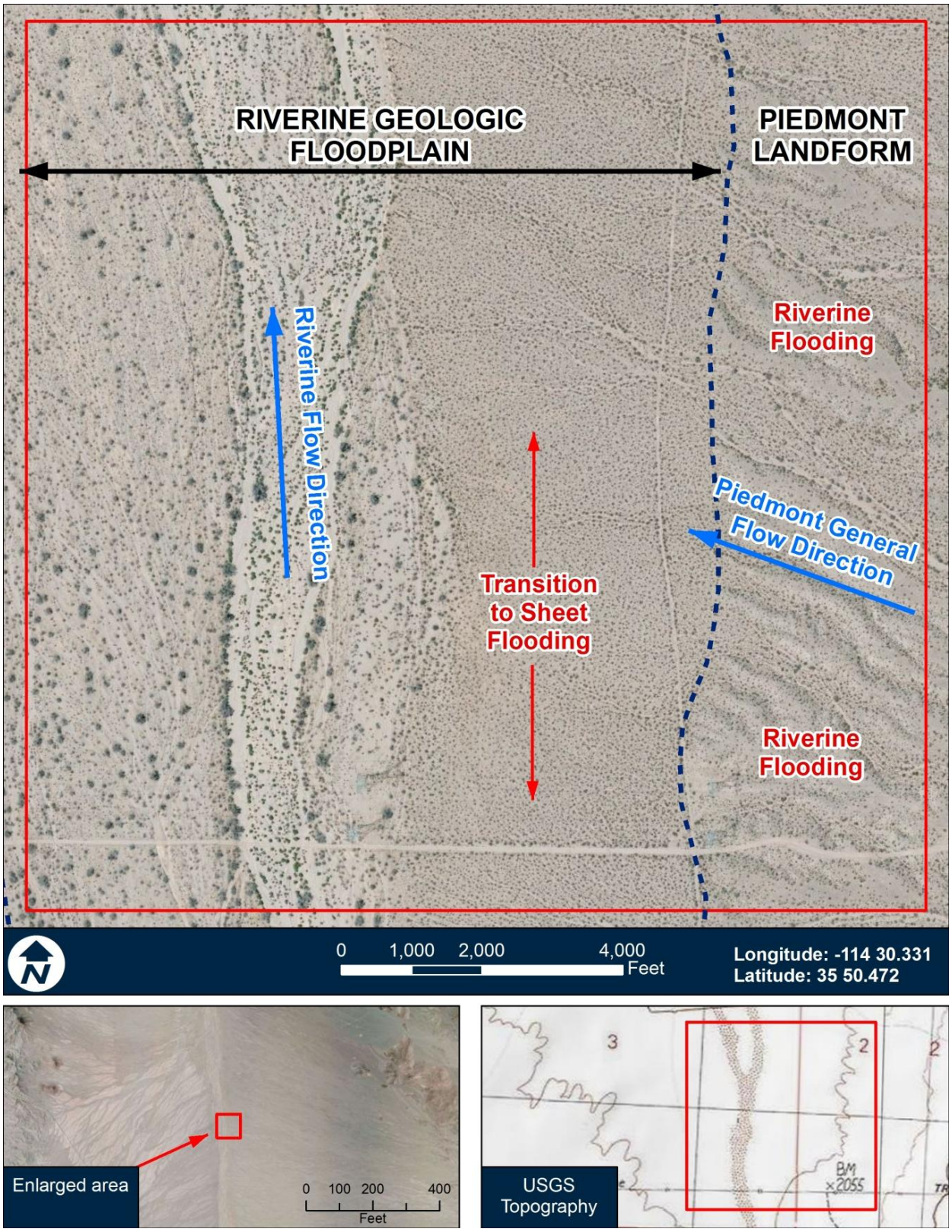


**Figure 10. Aerial photograph and topographic mapping of sheet flooding from unconfined tributary flow onto a geologic floodplain.**

## 2.4 Flow Types Related to Sheet Flooding

The following flow types related to sheet flooding are also described:

- Distributary Flow
- Anastomosing Flow

### 2.4.1 Distributary Flow

Distributary flow areas[2] are characterized by a channel pattern in which flow paths split in the downstream direction. A distributary channel is a stream branch flowing away from, and not immediately rejoining, the main stem of a watercourse. In distributary flow areas, the number of channel forks usually exceeds the number of channel confluences. Distributary flow areas include a range of flooding characteristics. On one end of the spectrum there are well-defined distributary channels that are hydraulically isolated from one another, and which may never rejoin the parent channels. On the other end of the spectrum are highly-interconnected, poorly-defined, and/or discontinuous channels where most of the flow in large floods is conveyed outside of defined channels. In the latter case, such distributary flow areas may be considered to be subject to sheet flooding. The spectrum of distributary flow types is transitional, and not all distributary flow areas experience sheet flooding. The occurrence of sheet flooding in some distributary flow areas may be a function of discharge magnitude, with small floods exhibiting more channelized flow characteristics, and larger floods exhibiting more unconfined, sheet flooding characteristics. Figure 11 shows a distributary flow area with a significant sheet flooding component.

Identifying characteristics of distributary flow areas include:

- Channels which divide in the downstream direction so that the number of flow paths conveying floodwaters increases in the downstream direction.
- Low, but distinguishable topographic relief perpendicular to the primary flow direction. Topographic relief is usually sufficient to create isolated islands during some floods within the overall floodplain.
- An increase in vegetative density along flow lines, with more uniform upland vegetation types found between low-flow areas which may extend laterally over an expansive area.
- Soils units mapped by the Natural Resource Conservation Service as floodplains, alluvial fan terraces, inactive alluvial fans, or alluvial fans.
- During small floods, most distributary channels are relatively stable, with flow distributions between splits governed by the hydraulics of the bifurcation point.
- During large floods, the distribution of flow between various existing distributary flow paths is subject to some uncertainty. Larger floods also may realign some distributary braids, or cause isolated or widespread bank erosion or sediment deposition, resulting in changes to channel capacity, location, or geometry. However, the overall characteristics of a distributary flow area generally are not altered by such changes.

Note that while distributary channel patterns are one of the common identifying characteristics of active alluvial fans, distributary flow areas also occur on non-alluvial fan landforms such as pediments and alluvial plains.

[2] See Hjalmarson and Kemna, 1991 for additional information.

**Figure 11. Aerial photographs and topography for a distributary flow area with potential sheet flooding.**

### 2.4.2 Anastomosing Flow

The term "anastomosing" refers to a pattern of highly interconnected, interwoven lines. When applied to runoff, anastomosing, also known as anabranching, describes a pattern of interconnected channels. Anastomosing systems tend to be more inter-branching than distributary flow areas, with less of an outward branching character. Sheet floods often have anastomosing characteristics, but not all anastomosing systems are subject to sheet flooding, since some rivers have anastomosing channel patterns. Riverine anastomosing is usually found in intermittent and perennial stream systems with net long-term erosion, in contrast to some braided streams which are characterized by active sediment transport and deposition, and which occur within well-defined riverine floodplains. Anastomosing flow differs from sheet flooding by the degree of flow line incision and separation in anastomosing systems. Figure 12 shows an anastomosing pattern in a sheet flooding area.

Identifying characteristics of anastomosing flow areas include:

- An anastomosing stream has branching, interlacing, and interconnecting flow paths, which produce a net-like or braided appearance.
- Anastomosing flow areas have slight topographic relief perpendicular to the primary flow direction.
- An increase in vegetative density may occur along flow lines in anastomosing flow areas, with uniform vegetative characteristics between flow lines, extending laterally over an expansive area.
- Flows may be anastomosing at low discharges, but may become more like sheet flooding at higher discharges as low divides are overtopped and flow paths coalesce.

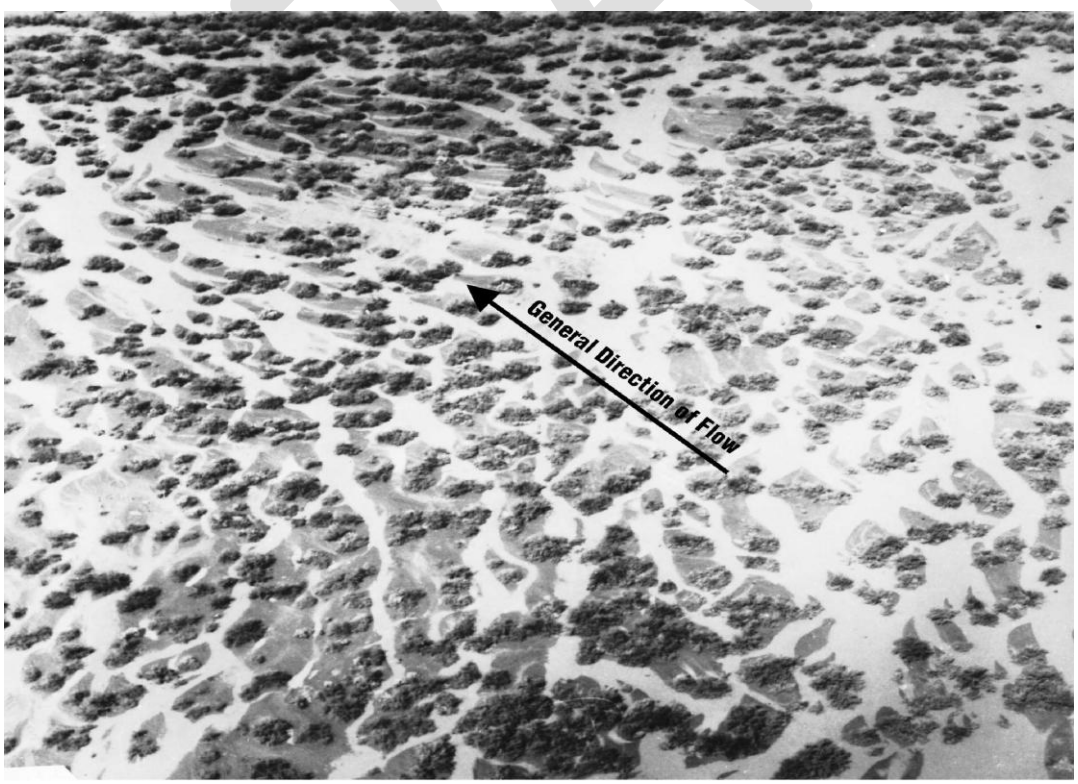


**Figure 12. Anastomosing flow in sheet flooding area. Queen Creek, AZ, October 1954**

## 2.5 Similar Flow Types That Are Not Sheet Flooding

This State Standard should not be applied to the following flooding or flow types that are similar to, but distinct from sheet flooding:

- Riverine Floodplains
- Braided Flow
- Perched Flow
- Overbank Flow
- Ponding
- Overland Flow

The differences between sheet flooding and each of these similar flow types are described in the following paragraphs.

### 2.5.1 Riverine Floodplains

The primary difference between riverine floodplains and sheet flooding areas is the presence of a defined main channel in a riverine floodplain. A riverine main channel generally has readily discernible stream banks, and distinct differences between channel bed sediments and floodplain soils, as well as differences between the channel, bank and floodplain vegetation. Key differences between riverine floodplains and sheet flooding areas are summarized in Table 1 and Figure 13.

**Table 1. Differences Between Riverine and Sheet Flooding Floodplains**

| Characteristics | Riverine Floodplain | Sheet Flooding Area |
|---|---|---|
| Main Channel | Main channel exists<br>Main channel contains 2- to 10-year (+)<br>Variety of channel types & patterns | No discernible main channel<br>Any single channel carries < 2-year<br>Low sinuosity, poorly defined channels |
| Channel Pattern | Many pattern types – braided, meandering<br>Pattern defined by single main channel | Typically distributary or anastomosing<br>No channels or many (sub)parallel channels |
| Floodplain Morphology | Distinct channel & floodplain surfaces<br>Consistent main channel morphology<br>Elevations increase away from thalweg<br>Topographically confined by river terraces | Uniform planar morphology<br>Irregular, discontinuous channels<br>No elevation increase across flow area<br>Laterally unconfined |
| Channel Banks | Well-defined banks<br>Riparian bank vegetation<br>Denser vegetation on banks vs. floodplain | Poorly defined or non-existent<br>Minimal bank vegetation<br>Uniform vegetation across flow area |
| Hydraulic Characteristics | Channel conveys most flow<br>Channel flow deeper, faster than floodplain<br>One dimensional flow<br>Overbank flow connected to channel | Most flow outside channels<br>Spatially similar flow depths & velocities<br>Strong two-dimensional flow component<br>Irregular water surface profile |
| Sediment/Soils | Loose, sand & gravel channel bed material<br>Finer grained floodplain sediment<br>Soil development on floodplains & terraces | Spatially uniform soils/sediment |
| Topographic Mapping | Contours bend in upstream direction<br>Lateral confinement of floodplain | Parallel contours with minimal crenulation<br>No lateral confinement |
| **Note: Braided, perched, and overbank flow are forms of riverine flooding (not sheet flooding) as discussed below.** | | |

Riverine floodplain management tools, such as those presented in State Standard 2, should be used for riverine floodplains.

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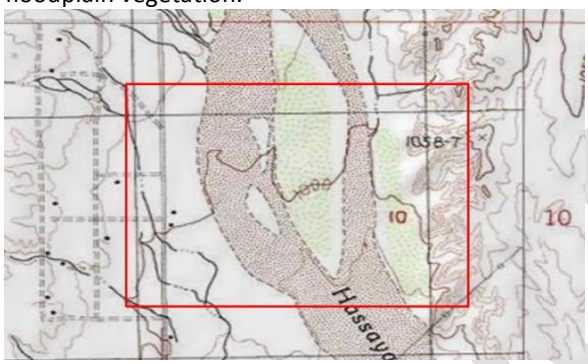
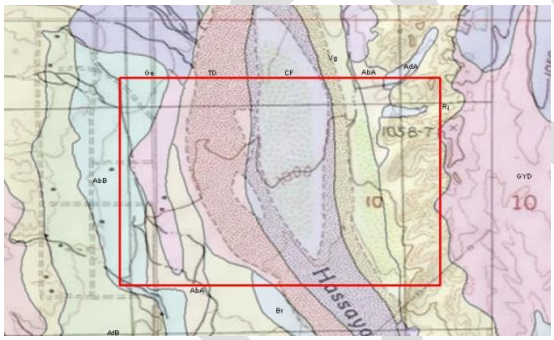
Aerial photo of riverine floodplain with defined main channel, showing contrasting channel, bank and floodplain vegetation.

Aerial photograph of sheet flooding area showing uniform morphology and vegetation



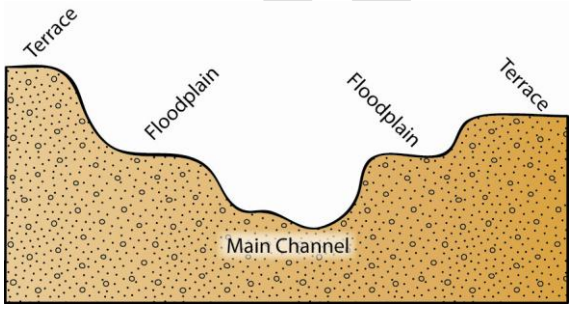

Topographic map of riverine floodplain showing lateral confinement, main channel incision, defined bank locations, and topographic map symbols for stream channels.

Topographic map of sheet flooding area showing lack of lateral confinement, no incision, minimal contour crenulations, and parallel contours.

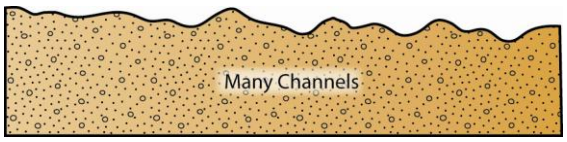



Soils map of riverine floodplain showing mapping of separate channel and floodplain soil units.

Soils map of sheet flooding area showing uniform soils delineation.




Typical cross section for riverine floodplain showing lateral containment, channel and floodplain surfaces.




Typical cross section for sheet flooding area showing lack of confinement or defined channels.

**Figure 13. Comparison of riverine and sheet flooding floodplain characteristics.**

### 2.5.2 Braided Flow

Braided flow occurs within a well-defined channel or floodplain where flow is divided into separate, but coalescing flow paths created by shifting patterns of sediment deposition. Braided flow is common on steep river systems that have high sediment loads. Braided flow is generally not considered a form of sheet flooding, although on occasion sheet flooding has been called "braiding" by some authors, probably because some sheet flood inundation areas are interrupted by many low small islands of vegetation or hummocky terrain (Figure 1; Figure 12), which sometimes resemble separate braids of flow. However, the term "braiding" is more correctly used to describe a riverine channel pattern. Braided river systems tend to have more directly connected flow paths than do sheet flooding areas, which tend to have poorly-defined, discontinuous channels. Braided systems also tend to convey most of their flow over defined channel beds that are readily distinguished from the adjacent, elevated floodplains. An example of a braided river channel is illustrated in Figure 14.

Braided flow can be identified from the following characteristics:

- Multiple flow paths located within a well-defined river channel or flow corridor.
- Flow paths separated by low, recently deposited bars of unconsolidated alluvium.
- Confinement of the braided area by elevated floodplains, terraces, or uplands.
- Lack of distinct, well-defined channels or upland vegetation within the braided area.
- Distinct differences in vegetation and soil characteristics between the braided area and adjacent floodplains, terraces or uplands.

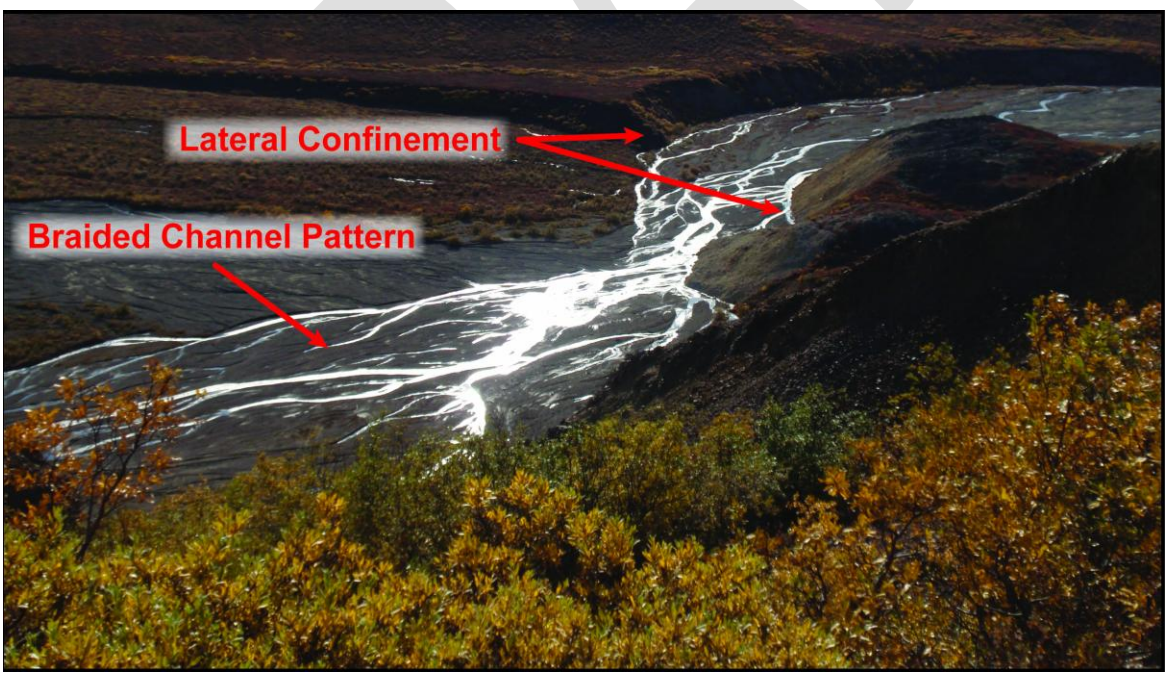



**Figure 14. Example of braided channel pattern (riverine). Note the topographic confinement of the riverine flow corridor, with braiding created by deposition of bed sediment.**

Riverine floodplain delineation and management techniques, such as those presented in State Standard 2, should be used for braided watercourses.

### 2.5.3 Perched Flow

Perched flow originates along well-defined riverine systems where overbank flooding becomes hydraulically separated from the main flow path, usually at a higher elevation than the main channel. In such cases, flow develops hydraulic characteristics unique from the main channel. Some perched flow paths may have similar characteristics to sheet flooding, e.g. high width-depth ratio, no defined channel, and uniform vegetation, but perched flow is a riverine process. For this State Standard, perched flow is not considered to be sheet flooding, because it usually occurs in a riverine environment. Perched flow is identified by hydraulic modeling or from post-flood observations. An illustration of perched flow is shown in Figure 15.

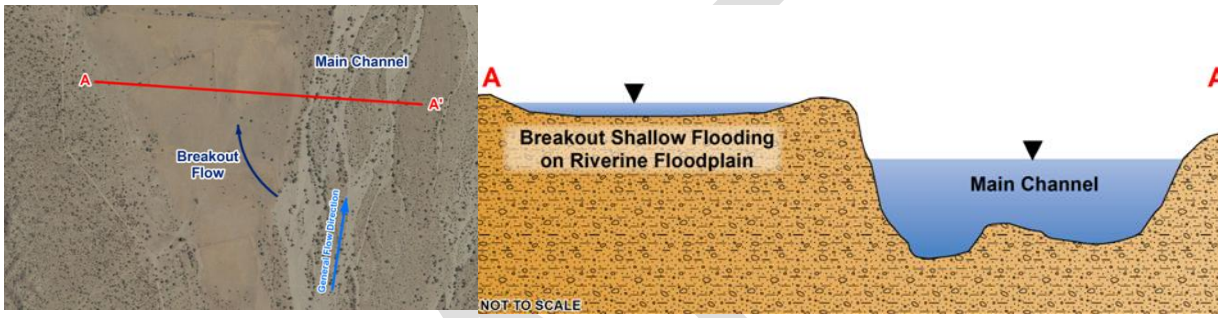



**Figure 15. Illustration of perched flow on a riverine floodplain.**

### 2.5.4 Overbank Flow

Flow in the overbank portion of the floodplain of a riverine system is not sheet flooding, even where it is wide and shallow. Overbank flooding is derived from and hydraulically connected to the main channel, whereas a sheet flooding area does not have a well-defined main channel. Overbank flooding areas can be distinguished from sheet flooding areas by inspection of aerial photographs and topographic maps to identify a main channel, or by comparing riverine hydraulic modeling results with field observations, as shown in Figure 16.

**Figure 16. Example of broad shallow overbank flooding along Big Chino Wash in Yavapai County, January 2005 (left) with a matching dry weather image (right) showing the well-defined main channel.**

### 2.5.5 Ponding

Ponding occurs where a natural floodplain is obstructed, creating a temporary or permanent impoundment for runoff. Ponding can occur in sheet flooding areas or any other type of floodplain, but ponding itself is not a form of sheet flooding. An example of ponding at a canal embankment is shown in Figure 17.

**Figure 17. Ponding upstream of the Central Arizona Project canal embankments.**

### 2.5.6 Overland Flow

Overland flow is the movement of water resulting from rainfall on hill slopes prior to entering any type of defined channel such as a rivulet, swale, or channel. Overland flow is a component of the rainfall-runoff process, in which the rainfall excess moves a short distance over the land surface from the point of rainfall impact to a defined conveyance. Sheet flooding is a flood process in which flood waters are conveyed over broad landform surfaces on which channel conveyance is relatively insignificant. The development standards detailed in Section 3 of this document should not be applied to overland flow areas. Overland flow is illustrated in Figure 18.

Identifying characteristics of overland flow areas include the following:

- Overland flow occurs over relatively short distances, generally less than 400 to 1,000 feet, between the point where surface runoff begins and where it enters any type of defined conveyance. The drainage areas for overland flow are commonly less than 0.25 $mi^2$, the lower threshold for sheet flooding as defined for this State Standard.
- Overland flow is most commonly identified near the watershed divides, rather than at the outlet of a watershed, and usually occurs at depths of much less than 6 inches.
- Overland flow usually is a site drainage concern, rather than a regional flood problem.

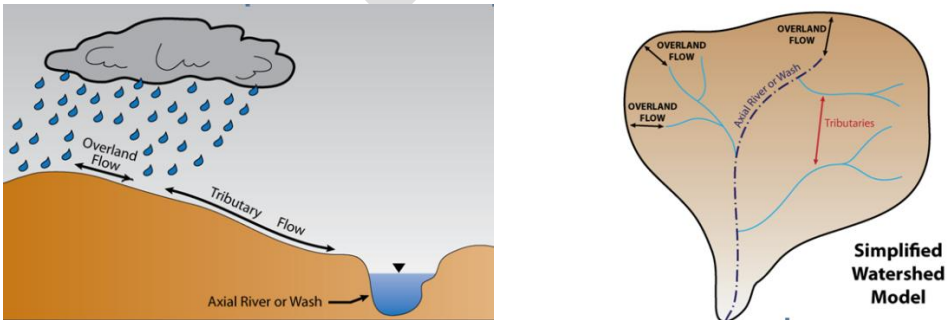



**Figure 18. Sketch showing where overland flow occurs within the watershed.**

# 3 Methods of Flow Analysis

A three-level analysis method has been established to identify the flood hazards impacting development in sheet flooding areas. The higher levels of analysis are intended to provide more accurate hydraulic data, but may require more expertise in hydrology and hydraulics, and greater expense. The three level methodologies outlined below are to be applied only in sheet flooding areas, as defined in Section 2, that have drainage areas greater than 0.25 square miles, base flood discharges greater than 500 cfs, or areas of concern identified by the local floodplain manager.

- **Level 1** is the minimum acceptable level of regulation and analysis, and can be used where only limited site and flood data are available, and where only basic site improvements are proposed, the watershed is not urbanized, and the contributing drainage area is less than 10 square miles.

- **Level 2** requires a basic understanding of hydrology and hydraulics, and is appropriate for single lot development where some flood and site data are available, no significant backwater conditions or obstructions exist, and the drainage area is less than 30 square miles.

- **Level 3** analysis should be used if the proposed development will impact more regional floodplains, or for complex sheet flooding areas exists, as outlined below. Level 3 methodologies are required for watersheds larger than 30 square miles, subdivisions, in highly urbanized areas, and where existing development or structures may significantly impact the natural flow characteristics of the sheet flooding area.

The three levels of flow analysis methods described in this State Standard are intended to assist floodplain managers determine base flood elevations and/or base flood depths in sheet flooding areas. Other State Standards and floodplain management guidance documents should be consulted to determine other site development requirements such as erosion setbacks, foundation scour protection, sediment impacts, or site plan requirements.

**FREEBOARD REMINDER**:
Depths determined do NOT include freeboard. In Arizona, a minimum of one foot (1') of freeboard is required by Arizona Revised Statutes but the local permitting jurisdiction may have additional freeboard requirements. Freeboard is a factor of safety above the flood level for purposes of floodplain management (e.g. the minimum height of the lowest floor of a structure). Freeboard compensates for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood.

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## 3.1 Level 1 Methodology

Level 1 requires the minimum level of site analysis, and no hydraulic or hydrologic analyses other than estimating the contributing watershed area. The drainage area to the proposed building site must be determined to apply the Level 1 methodology. In some cases, delineating watershed boundaries in sheet flooding areas can be complicated, particularly where watershed divides are not well defined and where distributary flow areas exist within or upstream of the development site. More detailed guidance on delineating watershed boundaries in sheet flooding areas is provided in Section 7. However, note that the accuracy of the watershed delineation need only be sufficient to identify the correct drainage area category indicated in Table 2.

**Table 2.**
**Level 1 Base Flood Depth Estimates**

| Drainage Area (mi2) | Base Flood Depth (inches) | Freeboard Requirements |
|---|---|---|
| 0.25-1.0 | 12 | The Base Flood Depths listed in this Table do NOT include freeboard. In Arizona, a minimum of one foot (1') of freeboard is required by Arizona Revised Statutes but the local permitting jurisdiction may have additional freeboard requirements. |
| 1.0-5.0 | 18 | |
| 5.0-10 | 24 | |
| 10-30 | Level 2 or 3 Analysis Required | |
| >30 | Level 3 Analysis Required | |

**Limitations**. The Level 1 methodology should not be applied if any of the following conditions exist:

- The upstream watershed area exceeds 10 square miles.
- The development is a multiple lot subdivision or a commercial development.
- The proposed building site is located in a highly urbanized area.
- Structures are located downstream of the proposed building site that would create backwater or ponding conditions. Such structures might include elevated roadways, culverts, canals, berms, levees, or walls.
- Obstructions are located upstream of the proposed building site that will concentrate flow, potentially eliminating the sheet flooding condition.

If such conditions exist, it is recommended that Level 2 or Level 3 methodologies be applied.

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## 3.2 Level 2 Methodology

The Level 2 methodology requires slightly more engineering knowledge and site data than Level 1, but is intended to produce conservative development criteria in a cost effective manner. For the Level 2 methodology, a Manning's rating[3] (or equivalent) is performed.

**Limitations**. The Level 2 methodology should not be applied if any of the following conditions exist:

- The predicted 100-year average flow depth exceeds 3.0 feet.
- Structures are located downstream of the proposed building site that would create significant backwater or ponding conditions. Such structures might include elevated roadways, culverts, canals, berms, levees, or walls.
- Obstructions are located upstream of the proposed building site that will concentrate flow, potentially eliminating the sheet flooding condition.
- The proposed development is a multiple lot subdivision or commercial site over ½ acre or with multiple buildings.

If such conditions exist, Level 3 methods are applicable.

To apply the Level 2 methodology, the following data are needed:

- Discharge (100-year)
- Topography (cross sections of building site and sheet flooding area)
- Roughness Coefficient (Manning's "N" value)
- Slope (valley slope)

Information regarding the Level 2 required data is provided below.

### 3.2.1 Discharge

The 100-year discharge may be estimated using the methodologies described in ADWR State Standard #2 (SS2), State Standard #10 (SS10), or other more detailed methods as required by the local floodplain manager. Drainage areas should be estimated conservatively to account for all possible sources of runoff, as described in Section 7.

### 3.2.2 Topography

Site and watershed topography should be obtained from the best available information. Topography should adequately describe ground contours for both the site and the total

**FREEBOARD REMINDER**:
Depths determined do NOT include freeboard. In Arizona, a minimum of one foot (1') of freeboard is required by Arizona Revised Statutes but the local permitting jurisdiction may have additional freeboard requirements. Freeboard is a factor of safety above the flood level for purposes of floodplain management (e.g. the minimum height of the lowest floor of a structure). Freeboard compensates for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood.

[3] Use of Manning's equation assumes that uniform flow conditions exist. Floodplain managers should verify likelihood of uniform flow, prior to applying Level 2 method of analysis.

sheet flooding area affecting the building site. For most natural sheet flooding areas, topography from USGS topographic quadrangle maps may be used, unless more detailed data are available, but should be supplemented by documented field data whenever possible. For more complex sheet flooding areas, cross section topography should be obtained from detailed mapping, survey data obtained during a site visit, or estimated from aerial photography and field-verified. Field observations can be used to estimate channel widths, bank heights, and site characteristics. For urban sheet flooding areas, descriptions of cross section topography should document all areas where flow would be blocked by buildings, fences, or other obstructions.

A Level 2 Manning's rating cross section should meet the following criteria:

- Extent. The cross section should extend across the entire sheet flooding area, not just the proposed development parcel. The discharge used in the Manning's rating should be based on the entire drainage area upstream of the full cross section extent.
- Alignment. The cross section should be oriented perpendicular to the primary direction of flow, i.e., parallel to the topographic contours. In some cases, the cross section alignment may require multiple segments in order to be perpendicular to flow.
- Detail. The cross section should be sufficiently detailed to reflect the basic topographic characteristics of the sheet flooding area.

### 3.2.3 Roughness Coefficient ("N" value)

Table 3 lists roughness coefficients acceptable for use in sheet flooding areas. The Manning's N value selected should adequately account for vegetation, sediment size, blocking of flow by flood debris, and variations in channel geometry. Several publications describe techniques for estimating N values (Arcement and Scheider, 1984; Thomsen and Hjalmarson, 1991). If the Manning's rating results in a Froude number greater than 0.95, a higher N value should be used, or a Level 3 analysis should be performed.

**Table 3.**
**Recommended Manning "N" Values for Sheet Flooding Areas**

| Surface | N Value | Range |
|---|---|---|
| Concrete | .013 | .010 to .013 |
| Bare Sand, Compacted | .015 | .010 to .016 |
| Gravel | .024 | .012 to .03 |
| Desert Brush | .055 | .035 to .080 |
| Natural Rangeland | .070 | .040 to .320 |
| Dense Grass | .240 | .170 to .300 |
| Bermuda Grass | .350 | .300 to .480 |

### 3.2.4 Slope

Slope used in the Manning's rating should be the valley slope or channel slope, whichever is less. Slope may be measured from USGS topographic quadrangle maps or measured during a site visit. Slope should be measured parallel to the overall direction of flow, perpendicular to the topographic contours, and should represent the broader area surrounding the development, rather than the building site alone.

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## 3.3 Level 3 Methodology

The Level 3 methodology consists of detailed hydrologic and hydraulic analysis using computer models and advanced engineering tools. Level 3 hydraulic modeling should consider the potential for a strong two- or three-dimensional character to flooding, since one-dimensional modeling of water surfaces, depths, and flow paths may not be appropriate in many sheet flooding areas. Application of two-dimensional models may not be cost-effective for smaller developments, and may require acquisition of detailed topographic mapping and/or field surveys.

Level 3 analyses are required for the following types of sheet flooding areas:

- Highly urbanized areas.
- Multi-unit subdivisions.
- Sheet flooding areas where the natural flow characteristics have been significantly altered by development or other man-made structures.
- Areas with average flow depths greater than 3 feet, as computed by Level 2 analysis.

Selection and application of appropriate modeling techniques should be made by a qualified registered professional engineer. More information on Level 3 methodologies can be obtained from the following sources:

- Local floodplain administrators
- State and federal floodplain management agencies
- Engineering publications
- Other Arizona State Standards, such as:
  - SS2: Requirement for Floodplain & Floodway Delineation in Riverine Environments
  - SS3: State Standard for Supercritical Flow
  - SS9: State Standard for Floodplain Hydraulic Modeling
  - SS10: State Standard for Hydrologic Modeling Guidelines

**FREEBOARD REMINDER**:
Depths determined do NOT include freeboard. In Arizona, a minimum of one foot (1') of freeboard is required by Arizona Revised Statutes but the local permitting jurisdiction may have additional freeboard requirements. Freeboard is a factor of safety above the flood level for purposes of floodplain management (e.g. the minimum height of the lowest floor of a structure). Freeboard compensates for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood.

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# 4 Example Application

**Problem Statement**. A single lot residential development proposed on a rural 1-acre parcel. The development plan calls for a detached home and carport, with no perimeter fences or walls. Determine the base flood depth and required regulatory flood elevation using the Level 1 and Level 2 methodologies[4] presented in Section 3.1 and Section 3.2.

- **Site Description**. The building site is covered by tall grass and brush typical of desert landscapes, and is located on a broad, gently sloping piedmont surface at an elevation of about 4,200 feet above sea level. There are no well-defined channels located across the valley floor, although the some indistinct, discontinuous low flow channels were identified on the aerial photographs and were field verified.
- **Mapping**. Recent aerial photography of the region is available from several internet-based sources. There are no detailed topographic maps for the area other than 7.5-minute USGS topographic quadrangle maps (20-ft. contour interval). NRCS detailed soils mapping indicate that most of the valley bottom is mapped as a single soil unit which is classified as floodplains, drainageways and inactive alluvial fans. There are no detailed geologic maps for the area.
- **Drainage Area**. The drainage area to the site measured at ~2.0 square miles using USGS topographic mapping and aerial photographs.
- **100-Year Discharge**. The 100-year (1%) discharge was estimated at 2,100 cfs using the State Standard 2 Level 2 methodology (Region 12).
- **Site Topography**. Cross section topographic data were determined using a hand-level survey made during site visit.
- **N Value**. 0.055 (Table 3)
- **Valley Slope**. 0.009 ft./ft., measured on USGS quadrangle map for the area surrounding and including the development site.
- **Local Freeboard Requirement**. The local floodplain management ordinance requires one foot of freeboard above the base flood depth.

**Analysis**. The first step in the analysis is to determine if the site might be located in a sheet flooding area. Using aerial photographs and USGS topographic maps (Figure 19), the following characteristics indicative of sheet flooding were identified:

- Lack of a defined main channel capable of conveying significant runoff.
- Lack of continuous, incised or well-defined channels.
- Lack of lateral topographic confinement (no terraces or upland areas)
- Smooth, parallel contour lines with no drainage channel symbols.
- Uniform vegetative and soil characteristics across a broad surface.

These characteristics were confirmed by site visit, and it was concluded that the site was subject to sheet flooding, and that the State Standard 4 methodology was applicable.

[4] The Level 3 methodology is beyond the scope of this State Standard and is not included in this example.

**Figure 19. Site map for Example 1.**

**Level 1 Results**. The Level 1 methodology consists of estimating the drainage area and using Table 2 to determine the base flood depth. The watershed area was estimated at 2.0 square miles using USGS topographic mapping and aerial photographs. The Level 1 analysis indicates the following (Figure 20):

- Base Flood Depth (BFD): 18 inches
- Freeboard Added: 12 inches
- Total Elevation: 30 inches

The Level 1 methodology can be applied to the proposed building site because none of the following limiting conditions described in Section 3.1 are present:

- The watershed area is less than 10 square miles.
- The proposed development is not a subdivision or commercial development.
- The site is located in rural area with no downstream or upstream obstructions.

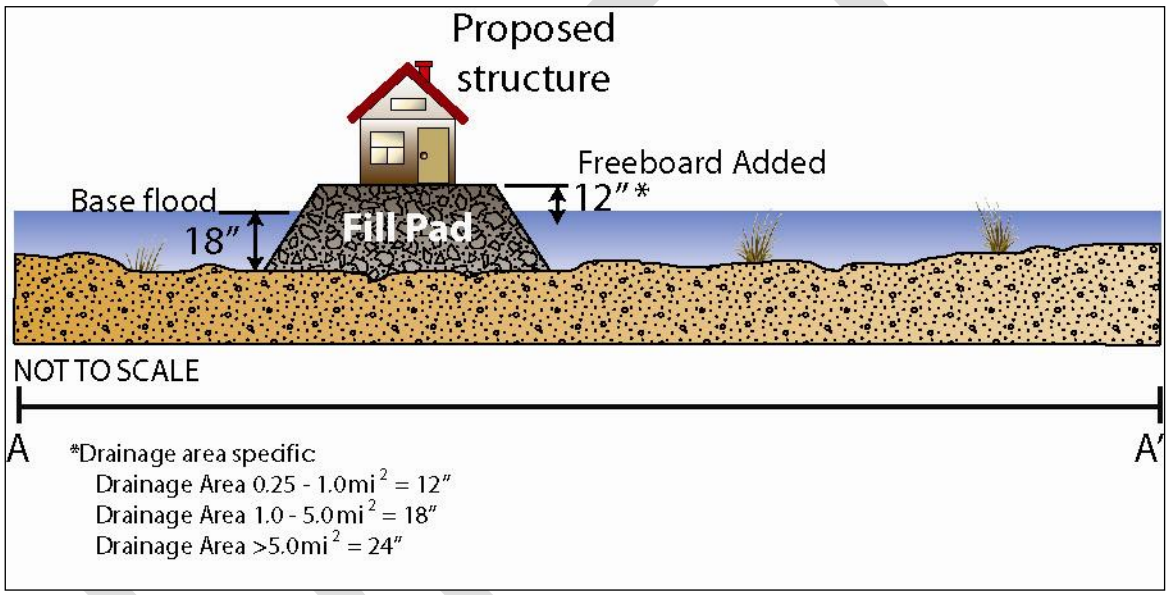


**Figure 20. Level 1 results for the example problem site.**

**Level 2 Analysis**. The Level 2 methodology consists of estimating the base flood depth using a Manning's rating. To apply Manning's equation, the following information is required:

- Drainage Area. The watershed area was conservatively estimated at 2.0 square miles using USGS topographic mapping and aerial photographs, making sure to account for possible upstream distributary flow areas and poorly defined watershed boundaries.
- Discharge. The 100-year discharge at the site was estimated at 2,100 cfs using the State Standard 2 Level 2 methodology.
- Topography. Site topography available from USGS topographic maps (Figure 19) was determined to be insufficient to develop cross section data, and was therefore supplemented using a hand-level survey of the area through the building site.
- Cross Section. In this case, a single cross section (Figure 19) was sufficient to characterize the flow conditions. The cross section extended 2,600 feet across the

piedmont surface to capture all of the sheet flooding runoff from the upstream 2.0 square mile watershed, and was oriented perpendicular to primary flow direction.

- Roughness Coefficient. A Manning's N value of 0.055 was selected from Table 3 to reflect a conservative estimate for tall, dense grass and brush.
- Slope. The piedmont slope of 0.009 ft./ft. in the vicinity of the building site was measured from the USGS topographic maps.

**Level 2 Results.** Using these data, the Level 2 analysis indicates the following, as illustrated in Figure 21:

| | |
|---|---|
| Base Flood Depth: | 6.0" inches (0.5 feet) |
| Freeboard Added: | 12.0" inches (1.0 foot) |
| Total Elevation: | 18.0" inches (1.5 feet) |

The Level 2 methodology can be applied to the proposed building site because none of the following limiting conditions described in Section 3.2 are present:

- The predicted base flood depth is less than 3.0 feet.
- The proposed development is not a subdivision or commercial development.
- The site is located in rural area with no downstream or upstream obstructions that would create significant backwater conditions or flow concentrations.

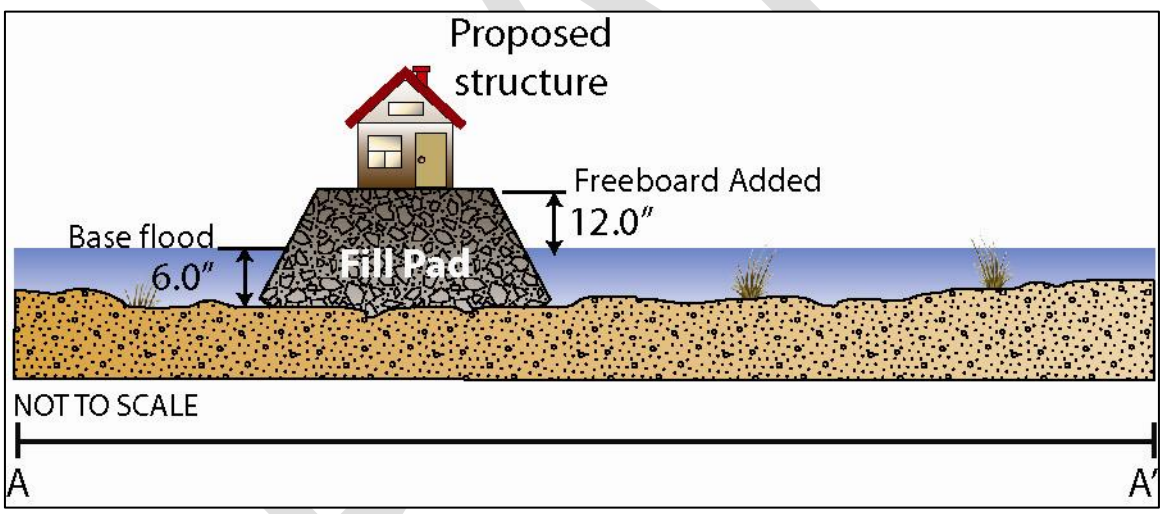


**Figure 21. Level 2 results for the example problem site.**

**Level 3 Results**. The Level 3 methodology consists of detailed hydrologic and hydraulic analysis using computer models and advanced engineering tools. Application of detailed two-dimensional models probably would not be cost-effective for the single lot rural development described in this example, since it would probably require acquisition of more detailed topographic mapping and/or field surveys.

The advanced computer modeling required to estimate a design discharge and flow hydraulics for this example is not described here.

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# 5 References

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Woolhiser, D.A. "Simulation of Unsteady Overland Flow." In K. Mahmood and V. Yevjevich, eds. *Unsteady Flow in Open Channels*. V. II. P. 502. 1975.

## 5.1 Annotated Bibliography

Following is a brief annotated bibliography of key articles on sheet flooding, listed chronologically, starting with McGee 1897, who coined the term "sheet flooding."

McGee, W.J. 1897. Sheetflood Erosion. Geologic Society of America Bulletin. 8: 87-112

- McGee 1897 contains the first known use of the term "sheet flood" in scientific literature. William J. McGee a geologist working for the United States Geologic Survey used the term sheet flood to describe an aspect of flooding he witnessed firsthand in the Sonoran District of south-western Arizona.

Davis, W. M. 1938. Sheetfloods and Streamfloods. Geologic Society of America Bulletin. 48: 1337-1416

Ives, R.L. 1938. Desert Floods in the Sonoyta Valley. American Journal of Science. 5th Series; 32: 349- 360

- Ives 1938 contains the second well documented first-hand observation of a sheet flood that occurs in scientific literature.

Blissenbach, E. 1954. Geology of Alluvial Fans in Semiarid Regions. Geologic Society of America Bulletin. 65: 175-190

- Blissenbach 1954 writes that there are three depositing agents on alluvial fans: sheet floods, stream floods and streams.

Rahn, P.H. 1967. Sheetfloods, Streamfloods, and the Formation of Pediments. Annals of the Association of American Geographers. vol. 57, no.3, p.593-604

- Rahn 1967 contains the third well documented first-hand observation in scientific literature of a sheet flood. Rahn describes and photographs sheet flooding in southwestern Arizona during the summer of 1963.

Hogg, S.E. 1982. Sheetfloods, Sheetwash, Sheetflow, or …? Earth Science Reveiws. Vol. 18, p.59-76

- Hogg 1982 contains an in-depth review of the various terms used for 'sheet flood' since McGee first used the term in 1897. Hogg defines the three terms sheet flood, sheet flow and sheet wash (p. 59) as: "A sheet flood is a sheet of unconfined flood water moving down a slope. The frequency of a sheet flood is relatively low while its magnitude is relatively great. Sheet flow is defined as relatively high-frequency, low-magnitude overland flow occurring in a continuous sheet and is restricted to laminar flow conditions. Sheet wash, a term of geomorphic origin, is considered to be redundant and is superseded by the more meaningful term rain wash defined as the washing action of rain on slopes."

Blair, T.C. 1994. Alluvial Fans and their Natural Distinction from Rivers based on Morphology, Hydraulics Processes, Sedimentary Processes, and Facies Assemblages. Journal of Sedimentary Research. Vol. A-64, No. 3 (July 1994), p. 450-489

- Blair 1994 contains thorough descriptions of sedimentary sheet flood deposits as well as sheet flood facies in the sedimentary record.

Blair, T.C. and McPherson J.G. 1994. Chapter 14: Alluvial Fan Processes and Forms. Geomorphology of Desert Environments: edited by Abrahams A.D. and Parsons A.J., Chapman & Hall, 1994 1st ed.

- On page 368 Blair and McPherson expand on Hogg's 1982 definition of sheet flood by defining it as "a broad expanse of unconfined runoff moving downslope (McGee 1897). The flow event is of relatively low frequency and high magnitude (Hogg 1982), while the flow itself is generally shallow and short-lived and has a limited travel distance. Sheet flooding is produced by catastrophic discharge, most commonly from high-intensity rainfall, combined with the absence of channelized drainage."

Field, J. 2001, Channel avulsion on alluvial fans in southern Arizona. Geomorphology. vol. 37 (2001) 93-104.

- Field 2001 draws a correlation between sheet flooding areas on alluvial fans and the increased potential for channel avulsion in those areas.

PCRFCD 2007. Fact Sheet: Sheet Flood Hazard Areas. Pima County Regional Flood Control District.

- Pima County defines Sheet flooding areas as (p. 2) "… areas that are flat or have a low slope and where there are no or few well defined washes or where washes are not large enough to contain all of the water delivered during storm events. As a result, flood waters flow in a broad sheet across the entire ground surface. For this reason, sheet flooding is likely to affect all or most of your property." Sheet flood depths can range several inches to several feet in depth depending on location. (p. 2). PCRFCD then defines requirements for building in sheet flow floodplains. (p.3)
- Homes and other structures in Pima County that are not elevated have been flooded by water less than six inches deep. Sheet flooding has been known to undercut building foundations, causing potentially significant building stability problems, and rip out fences with posts buried in 2 feet of concrete and move them over 100 feet away. In addition, even shallow moving water exerts a tremendous amount of force on objects that obstruct its movement. (p.2)

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# 6 Suggested Development Criteria for Sheet Flooding Areas

To assist local floodplain managers regulate development in sheet flooding areas, the following development criteria are suggested for consideration. These can criteria can be included in local floodplain ordinances, grading and drainage manuals, policy documents, and/or drainage master plans. **The development criteria outlined below are not required as part of this State Standard and are provided for information purposes only**.

Sheet flooding areas have unique flood hazards for which sound floodplain management practices are needed. Structures in sheet flooding areas can be damaged by flood inundation, hydrodynamic forces on structure walls, scour undermining structure foundations, or sediment deposition, even where average flow depths are less than one foot. Some types of development in sheet flood areas may concentrate flow and alter flow conditions on downstream properties. Accessory development features such as fences, perimeter walls, or roads can have significant impacts on downstream flood hazards. Concentration of flow may result in channel (arroyo) formation and initiate headcuts that could propagate upstream and damage property and structures. Alternatively, channel incision caused by concentration of sheet flooding can damage downstream and adjacent properties. Alteration of flow characteristics in sheet flooding areas may also alter important wildlife habitat, groundwater recharge, or receiving water quality characteristics. To address these and other floodplain management concerns, the following development criteria are suggested for consideration by local floodplain managers.

**FREEBOARD REMINDER**:
Depths determined do NOT include freeboard. In Arizona, a minimum of one foot (1') of freeboard is required by Arizona Revised Statutes but the local permitting jurisdiction may have additional freeboard requirements. Freeboard is a factor of safety above the flood level for purposes of floodplain management (e.g. the minimum height of the lowest floor of a structure). Freeboard compensates for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood.

## 6.1 General Minimal Development Criteria

Based on the criteria and information outlined above, the following development are suggested for all sheet flooding areas in Arizona:

- CFR 60.3(c)11 –adequate drainage paths around structures in AO Zones
- Grade building sites to direct nuisance runoff away from buildings.
- Protect the building foundation and related facilities from scour damage.
- Account for potential impacts of structures on flooding on adjacent properties.
- Regulate walls and fences to reduce flow diversion and encroachment.
- Development in sheet flooding areas should not concentrate flows or eliminate flow paths in a manner that changes the flow rate or flow distribution on adjacent parcels.

## 6.2 Supplemental Development Criteria

The following criteria are suggested for development in all types of sheet flooding areas:

- Development in, or modification of, the floodplain is generally discouraged. Development should be located outside the 100-year floodplain wherever possible. If site characteristics require that some development occur within the floodplain, the floodplain modifications should be the minimum possible, in order to lessen impacts to the natural water and sediment-transport capacity of the floodplain.
- Where sheet flooding is concentrated by development, post-construction (full build-out) condition 100-year hydraulic data should be used to establish the parameters for scour-protection design.
- Buildings constructed in sheet flood areas should be aligned parallel to the primary flow direction in order to limit flow obstruction and allow for flow-path continuity.
- Zoning densities higher than one residence per acre (1 RAC) are not suggested in designated sheet flooding areas, unless drainage studies that analyze potential concentration of flow and downstream impacts are completed or regional flood control facilities are constructed.
- Regional planning should be conducted to identify flow corridors to safely convey and accommodate sheet flooding and facilitate appropriate types of development, transportation alignments, open space and regional flood control measures.

In addition, the following development criteria are suggested for specific types of development in sheet flooding areas:

### 6.2.1 Walls & Fences

In general, construction of walls and fences should be avoided on floodprone properties wherever possible, unless they are part of an engineered flood hazard mitigation plan. The following criteria apply to construction of walls and fences in sheet flooding areas:

- Fences and walls should be prohibited where they block defined flow corridors and channels. Fences that obstruct flooding can trap flood debris, and cause erosion or diversion of flow.
- Prior to construction, any wall or fence proposed on any floodprone property should be reviewed and approved by the local floodplain management authority. The proposed wall or fence should not create an adverse impact on adjacent properties.
- Open fence types, such as pipe rail, split rail, or barbed wire are suggested where fencing is necessary within the floodplain. Solid fences and walls should be set back at least 25 feet from property boundary lines to minimize flow concentration. Block walls, chain link, field fence, mesh, no-climb, and chicken-wire are not considered open fencing types.
- Solid walls and fences may be constructed on property boundary lines in some cases if they are elevated above the base flood elevation, are designed to collapse under hydrostatic pressure, convey flow through the wall, or completely span any defined channels without adversely impacting adjacent parcels. Solid interior or courtyard walls may be allowed immediately downslope or upslope of a structure if the wall does not provide any additional encroachment, as measured perpendicular to the direction of flow.

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- Walls and fences intended to pass drainage should be designed to account for blockage of openings by vegetation and floating debris, and should be able to withstand hydrostatic pressure and scour caused by flow impingement.

### 6.2.2 Single Lot Development

In general, development in floodprone areas should be avoided. Where development in sheet flooding areas is allowed, the following development criteria are suggested:

- Development should be located on the highest ground available within the property limits. However, sheet flooding may occur over such a broad expanse that a single parcel may not have a significant portion which is less flood prone than any other portion.
- Site grading and building pad locations should allow for continuity of drainage for all recognizable flow paths.
- Homes should be aligned parallel to the primary flow direction to minimize the potential flow obstruction.
- Manufactured housing must be anchored to prevent flotation and overturning.
- Building pads should be protected against scour damage.
- Zoning densities higher than one residence per acre (1 RAC) are not suggested in designated sheet flooding areas unless Level 3 drainage studies that analyze potential concentration of flow and downstream impacts are completed or regional flood control facilities are constructed.
- For single-lot development in the sheet flooding areas, flows should not be concentrated beyond a typical shallow swale around the structure. Swales should daylight and broaden to the natural flow conditions on the downstream side of the proposed structure and not create adverse impacts to adjacent properties.

### 6.2.3 Major Development

Major developments include legal subdivisions, developments greater than three acres with proposed densities greater than one residence per acre (1 RAC), or industrial/commercial developments. For major developments in sheet flooding areas, the following standards are suggested:

- Development should not divert or concentrate flow on adjacent properties, unless concentrated flow is conveyed in a drainage facility or natural channel with demonstrated capacity for the base flood discharge.
- Drainage studies prepared for major developments should evaluate the hydrologic impacts at the point where the sheet flooding enters a drainage facility or natural channel with demonstrated capacity for the base flood discharge.
- Drainage design in sheet flooding areas should limit flow concentration and preserve unconfined sheet flooding corridors wherever possible. Where flows are concentrated or channelized, appropriate scour and erosion protection should be applied to the channelized areas. Concentrated flows should be returned to the natural flow condition prior to exiting the property.
- Regional drainage master plans are suggested where urbanization is expected in sheet flooding areas. The drainage master plans should demonstrate that the roadway

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network is integrated into the overall flood conveyance and mitigation strategy, and that it does not adversely impact adjacent lands.

- Due to the abrupt changes that can occur with sediment transport in alluvial fan sheet flooding areas, drainage infrastructures such as channelization and collector channel systems should be avoided unless a sediment transport analysis demonstrates such infrastructure will be stable and will not propagate head cutting or excessive deposition off-site from the drainage improvements.

### 6.2.4 Road and Utility Crossings

The following criteria are suggested for road and utility crossings in sheet flooding areas:

- Sheet flooding over roadways with no drainage structures may prevent emergency vehicle access. Sediment deposition on road crossings in sheet flooding areas may also hinder or delay property access long after flood waters recede.
- Roadway alignments should be designed so that runoff collected by the roadway is conveyed to its historic flow path to the maximum extent possible. Roadways should be designed so as to not divert sheet flooding, unless it can be shown that the diversion will minimize impacts on the natural flood processes.
- Streets in sheet flooding areas should be oriented perpendicular to the primary flow direction to prevent flow concentration and diversion. Unpaved streets in sheet flooding areas that are not perpendicular to the primary flow direction often capture and concentrate runoff, and may evolve into regional drainageways or have significant maintenance problems.
- Roadway surfaces should be designed to be as close to natural grade as possible to minimize obstruction or diversion of flooding. Both elevated and sub-grade roadways may divert, obstruct, or channelize sheet flooding.
- Roadway crossings should be designed so the roadway alignment is perpendicular to the watercourse in order to minimize disruption to the floodplain. Wherever possible, crossings should be located at the narrowest part of the flow corridor. New roads should be aligned to minimize placement of pavement within flow corridors.
- For drainage design purposes, if a hydraulic rating is used to determine flow distribution at a flow-split, the analysis should explicitly consider the impact of possible future changes in flow distribution on downstream peak discharge. In some cases, this may result in flow split estimates that sum to more than 100% of the upstream flow rate at a given flow bifurcation. For complicated distributary flow areas, a split accounting system may be needed to develop reasonable flow rates that are not overly conservative or that underestimate potential peak flow rates. If no hydraulic modeling is provided, the full 100-year discharge upstream of the split should be used on all downstream channels.
- Roadway crossings should be designed to minimize downstream scour, minimize the risk of erosion of roadway approaches, and maintain sediment balance up to the bank-full discharge. Scour protection is required to assure structure stability.
- In most sheet flooding areas, multiple widely spaced culverts will be necessary to minimize adverse impacts and flow concentration.
- Culvert crossing designs should account for the need for and facilitate sediment and debris maintenance.

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- Regional drainage master plans are suggested where urbanization is expected in sheet flooding areas. The drainage master plans should demonstrate that the roadway network is integrated into the overall flood conveyance and mitigation strategy, and that it does not adversely impact adjacent lands.
- At-grade roadway crossings are generally appropriate in sheet flooding areas due to the difficulty in spanning the floodplain, unless dictated otherwise by local all-weather access requirements.
- Significant backwater conditions may occur in sheet flooding areas upstream of roadways with drainage structures that are not sized for the 100-year flood. Flood depths resulting from these backwater conditions may exceed depths indicated by the natural geomorphology or field conditions. Required lowest floor elevations for development upstream of elevated road crossings should consider the potential for backwater to increase flood elevations.

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# 7 Delineating Watershed Boundaries in Sheet Flooding Areas

The following information is provided to assist floodplain managers with the complicated task of delineating complex watershed boundaries in sheet flooding and distributary flow areas:

## 7.1 General Watershed Delineation

By definition, sheet flooding areas do not have well defined watershed divides. Many sheet flooding areas are located within or downstream of distributary drainage systems (Figure 22), where streams split into two or more disconnected segments in the downstream direction. Therefore, determining the watershed area for sheet flooding areas is complex. Because flow paths divide in the downstream direction, not all flow from the upstream drainage area may reach a specific concentration point in a distributary or split flow area. Conversely, some runoff from "adjacent" watersheds may add flow at some concentration points. The following guidelines are suggested for delineating watershed boundaries for concentration points downstream of or within distributary and sheet flood areas:

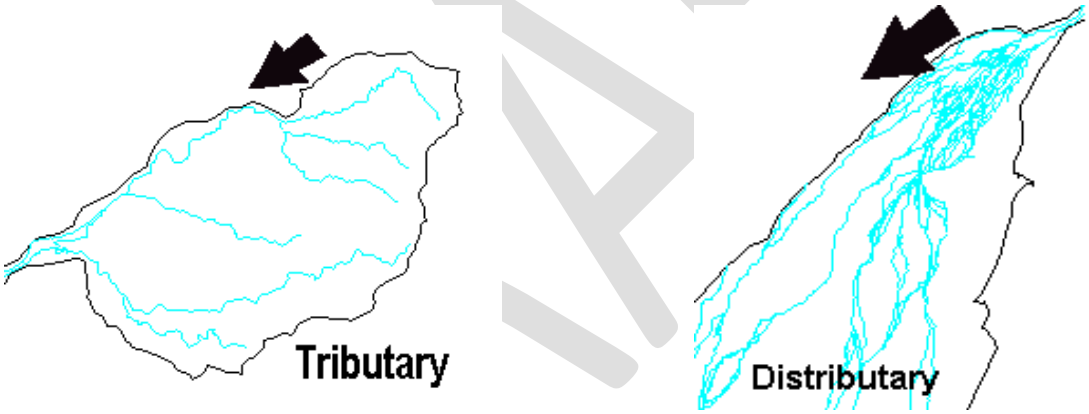


**Figure 22. Example of tributary (left) and distributary (right) drainage patterns.**

- ***Automated Watershed Delineation Tools***. In general, the use of automated watershed delineation tools is discouraged in areas with potential for distributary or split flow. If GIS or other automated watershed delineation tools are used, the drainage area boundaries should be carefully checked to identify places where additional flow might enter (or leave) the watershed. Specific hydrologic/hydraulic analyses may be needed at each point where flow splits cause runoff to enter or leave the watershed.
- ***Aerial Photographs***. In areas where vegetative patterns are preserved and soil characteristics are apparent, use of aerial photographs, rather than topographic maps, is suggested as the primary base map for watershed delineation. In many cases, flow splits are more easily identified on aerial photographs than on topographic maps. USGS topographic quadrangle maps do not have sufficient accuracy and detail for

mapping of complex distributary flow area watersheds. A combination of topographic mapping on an aerial photograph base is the best medium for watershed delineation.

- ***Field Verification***. Whenever possible, watershed boundaries in distributary flow areas should be field checked to look for potential flow splits, evidence of historical overflows, and potential stream piracy locations.
- ***Two-Dimensional Modeling***. Use of two-dimensional watershed modeling tools may be useful for verifying watershed divides and flow paths since many do not require an explicit watershed delineation, and may in fact circumvent the need for watershed delineation as a modeling task.
- ***Coordination***. If distributary and split flow conditions are encountered, the engineer should request review of the watershed delineation and hydrologic modeling approach with the appropriate review agencies.
- ***Conservative Estimates***. In most cases, and for relatively simple flow splits, the watershed area should be conservatively estimated to include inflow from splits that contribute runoff at the watershed boundary and to exclude splits that remove flow from the watershed. The long-term consequence of under-estimating the watershed area and design discharge is generally more significant than the consequence of possibly over-estimating the watershed area and design discharge.
- ***Simple Flow Split Areas***. For relatively simple flow splits along watershed divides, the engineer should delineate the main watershed and any contributing watersheds separately, so that the relative contribution from each potential flow source can be evaluated.
- ***Complex Distributary Flow Areas***. In complex distributary flow areas which have multiple interconnected flow bifurcation points, a high percentage of overbank and/or sheet flood, and a potential for channel avulsions, watershed delineation requires understanding of the local and regional geomorphic processes, and may require special expertise to complete the delineation. For Level 1 analyses, the most conservative watershed delineation should be used.

## 7.2 Proportioning Flow Between Established Splits

Unless a flow split is controlled by a well-maintained engineered hydraulic structure, such as a weir or diversion dam, the distribution of flow between channels downstream of a flow split may be uncertain and/or subject to change. Sedimentation, scour, vegetative growth, debris, urbanization, and encroachment may change the existing conditions sufficiently to alter the flow distribution over time, or even during a single flow event. Therefore, discharge estimates downstream of flow splits must account for potential future changes in the upstream flow distribution. The following guidelines are suggested for estimating design discharges downstream of flow splits:

- ***Watershed Area***. The watershed delineation guidance listed in Section 7.1 should be applied.
- ***Hydraulic Rating of Split Flow Points***. Guidance for hydraulic ratings is provided in Section 7.1. In general, the design discharge estimate should account for potential future changes in channel topography, roughness, allowable encroachment, and debris impacts.

- ***Hydrograph Timing***. Where there are significant differences in watershed size and/or geometry, the timing of the hydrographs from the main watershed and the split flow watershed should be compared. If the timing of the peaks is significantly different, potential split inflows may not significantly change the design discharge.
- ***Contributing Area***. The contributing area of the split flow and main watershed should be compared. Where the main watershed is significantly larger than the split flow contributing area, in most cases it is simpler to just add the split flow watershed to the main watershed, rather than evaluate the split flow contribution. Where the main watershed is significantly smaller than the potential split flow contributing area, hydraulic and geomorphic evaluation of the split flow point is required, or the corridor capacity approach (below) should be applied.
- ***Selecting Concentration Points***. In some cases, where flow splits recombine, evaluation of flow splits can be avoided by judicious selection of concentration points in the watershed model. If concentration points can be selected upstream of the flow bifurcation and downstream of the flow junction, and no flow paths escape between, then the evaluation of the split flow is avoided and becomes a simple question of routing and hydrograph attenuation.
- ***Safety Factor***. A safety factor should be applied to the discharge computed for each split channel such that the total discharge of all downstream channels sums to more than 100 percent. The safety factor used should reflect the relative uncertainty and potential for future change at the flow bifurcation point.
- ***Historical Trends***. Review of historical and recent aerial photographs may provide clues to geomorphic factors that indicate the long-term trend of flow distribution. For example, stream piracy may lead to formation of a flow split in which the steeper flow path becomes dominant over time and the flatter flow path is eventually abandoned. Such information can be used to estimate appropriate safety factors.
- ***Attenuation Losses***. In distributary flow areas that convey a high percentage of flooding as overbank or sheet flood, attenuation losses such as transmission loss and hydrograph routing effects (floodplain and channel storage) can be significant and may be modeled when estimating downstream flow rates. However, if no regulations exist to prevent future development from altering existing conditions and removing flow attenuation areas, use of routing losses should be carefully considered.
- ***Tributary Inflows***. The hydrologic modeling should account for tributary and local inflows that contribute runoff in the reach between the flow split location and the concentration point.

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