PIEDMONT FLOOD HAZARD ASSESSMENT FOR FLOOD PLAIN MANAGEMENT

for Maricopa County, Arizona

USER'S MANUAL

Version: April 2003

by H. W. Hjalmarson
Consulting Hydrologist

Appendix on Surficial geology
by Philip A. Pearthree
Arizona Geological Survey

Appendix on Flood hazard zones
and development standards
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ACKNOWLEDGMENTS

H. W. Hjalmarson, PE, consulting hydrologist under the direction of Joe Tram, Dave Johnson and Ted Lehman of the Flood Control District, originally prepared this user's manual. The manual was first released in draft format on December 8, 1997 for review and comment by engineers, hydrologists, geologists and other interested parties including FEMA.

Many hydrologists, engineers, geologists, soil scientists and flood-plain managers at the local, county, state and federal levels, in the consulting community and at universities have made direct and indirect contributions to the development of methods used in this manual. The original draft was reviewed by Stanley A. Schumm, Ph.D., P.G., Philip A. Pearthree, Ph.D., John E. Fuller, P.E. and Bill Jenkins, P.E. Additional comments by Mike Grimm of the Federal Emergency Management Agency have also been incorporated in the manual.

The often under utilized soils information for flood hazard assessment presented in U.S. Soil Conservation Service Reports *Soil survey of Aguila-Carefree area, parts of Maricopa and Pinal counties, Arizona* (1986) and *Soil survey of Maricopa County, Arizona, central part* (1977) contributed greatly to the methods in this manual. Soil surveys are an important part of the method to consistently and reproducibly delineate those areas subject to active flooding.

This first release of the Manual was reviewed by Philip A. Pearthree, Ph.D., John E. Fuller, P.E., and personnel of the Flood Control District. Important additions to the initial draft include *Appendix L. Surficial geologic mapping and piedmont flood hazards in Maricopa County* by Philip A. Pearthree, Arizona Geological Survey, and *Appendix R Flood hazard zones and development standards* by Ted Lehman, JE Fuller/Hydrology & Geomorphology, Inc. Many maps of surficial geology for parts of Maricopa County have been completed, that are very useful for piedmont flood hazard assessment, by the Arizona Geological Survey since the first draft of this Manual was released. Also, New FEMA Guidelines and Specifications have been released recently are incorporated in this first release of the Manual.

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INTRODUCTION

The objective of the Piedmont Flood Hazard Assessment for Flood Plain Management User's Manual (manual) is to describe a methodology for identifying and mapping flood hazards on piedmonts in Maricopa County. Portions of piedmonts in Maricopa County may be subject to unstable flow patterns and changes in channel position during floods, whereas flow paths in other areas are relatively stable. The manual considers relationships between piedmont flood hazards and piedmont landforms, describes how to identify areas with stable and potentially unstable channels, and presents examples of flood hazard analyses for three different piedmont areas in Maricopa County. The intended audience for the manual is a desert region flood specialist or a flood hazard assessment team with complimentary expertise in engineering, hydrology and geomorphology that is familiar with FEMA methods and the geomorphic framework of desert regions like Maricopa County.

This Manual provides methods to determine realistic risks on alluvial fans and other piedmont landforms to regulate development accordingly. The Manual exists because management of flood hazards in Maricopa County is complex and there are areas on piedmonts with uncertain flow path hazards. There are other piedmont areas where the flow path is certain but the channel bed and banks are movable as a result of high flow velocities and sediment movement. Some areas such as parts of active alluvial fans are considered undevelopable without major flood control structures to manage both the water and sediment. Other areas may be developed as safely as many riverine floodplain areas. This manual explains how contractors in Maricopa County should assess flood hazards on piedmonts, which include alluvial fans, to meet the *Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA, 2002) and Maricopa County requirements.

This introductory chapter provides an overview of the objectives of the manual and the terminology that is used in the manual. Landforms that are considered stable and unstable are briefly described followed by the use of flow and flood terminology that can be confusing. A discussion of important limitations and differences of the geomorphic and traditional engineering methods sets the stage for the approach. An overview and organization of the manual follow the general approach of the manual. A detailed glossary compliments the glossary of FEMA (February 2002). Tutorials for novice users are provided in several appendices.

The tutorials for the manual provide background on several aspects of the method, landforms, surface features and channel processes. The tutorials are placed in the appendices because once learned, users may not need the tutorials, and experienced users can ignore the tutorial appendices without interrupting their train of thought. Novice users of this manual should become familiar with the information in Appendices A to S before applying the methods in Chapters 2 to 5 of this Manual. Investigators conducting a flood hazard assessment to FEMA requirements should follow the Maricopa County guidelines in Appendix R before starting Chapter 5 of the Manual.

Some FEMA requirements under the community rating system for sites with uncertain flow paths and movable bed streams follow:

- Aggrading or degrading streams. A sediment transport model that includes the availability of sediment to the stream, and that accounts for its movement through the floodplain, is required. Modeling of these streams for CRS credit must look at present conditions and projections of future conditions based upon changes in the source of sediment and the floodplain. Mapping and management must be based upon the worst case of aggradation or degradation.

- Channel migration. The local history of migration must be reflected in the mapping process. For full credit, mapping must be based upon floodplain soils and historic channel migration that indicates the probable extent of future migration.

- Movable bed streams. One of the uncertainties about moveable bed streams concerns the changes in the stability of the channel over time. Throughout much of the arid and semi-arid regions of the United States, there is evidence that human activities over as short a time as a decade have drastically changed the nature of some streams. It is important to understand the causes of aggradation, degradation, and channel migration in order to project the future configuration of the channel.

- Alluvial fans. Follow guidelines in Appendix G *Guidance for Alluvial Fan Flooding analysis and Mapping, Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2001).

1.1 Objectives

The objectives of this manual are to identify

- How flood hazards on *piedmonts* (see glossary) in Maricopa County are related to landforms,

- How to go about performing an examination of specific sites for the identification of *unstable (active)* and *stable (inactive)* flood hazard zones and

- How to accurately and reproducibly delineate those areas subject to active flooding,

- Piedmonts areas that are safe for development while preventing development in high hazard areas.

In Maricopa County, areas of active flooding are considered floodway districts in order to maintain conveyance corridors for the transport of floodwaters and sediment down the piedmonts past development (See special flood hazard zone AAFF in Appendix R).

Areas where any flow path uncertainty can be ignored for the assessment of flood hazard are called stable areas in this manual. Detailed approaches to flood insurance studies that result in determination of 100-year flood elevations (FEMA, 1995) typically are for stable areas, where flood flows are confined by local topography that does not change substantially during floods. Flow paths and flood boundaries for these stable areas are considered predictable using traditional engineering methods and standard-step hydraulic methods like HEC-RAS (COE, 1995).

Unstable areas are where the flow path uncertainty *"is so great that this uncertainty cannot be set aside in realistic assessments of flood risk or in the reliable mitigation of the hazard"* (National Research Council, 1996). Traditional engineering methods generally are inappropriate for areas with changing flow paths and where abundant sediment from upslope source areas is being deposited on the piedmont.

Areas where there is flow path uncertainty can be defined using geomorphologic methods. Unstable areas typically are wholly or partly aggrading young geomorphic surfaces and have undeveloped or weakly developed soil profiles and wide and shallow sand channels. Approximate boundaries for these areas can be defined using geomorphologic analysis (Chapter 2 of Manual).

This manual translates useful *morphologic* and other technical information into engineering terms for appropriate use as follows:

- In conjunction with Drainage Design Manuals for Maricopa County, Volumes I and II,
- To improve identification of actual flood hazards,
- For flood hazard identification that typically starts with determining the scope of flood insurance studies outlined in Volume 1 Flood Studies and Mapping of the Guidelines and Specifications of Flood Hazard Mapping Partners (FEMA, February 2002), and
- This manual also provides useful information specific to landforms and flood hazards in Maricopa County to be used with FEMA Guidelines for Determining Flood Hazards on Alluvial Fans (FEMA February 23, 2001).

The NRC (1996) report on alluvial fan flooding provides some valuable perspectives on the definition of "active fans" and the flow instabilities that are typically encountered on active fans. According to that report, *"The term active means those locations where flooding, erosion, and deposition have occurred on the fan in relatively recent time, and probably will continue to occur on that part of the alluvial fan".* The NRC report further states that *"The term active refers to that portion of a fan where flooding, deposition, and erosion are possible. If flooding and deposition have occurred on a part of a fan in the past 100 years, clearly that part of the fan is active. If flooding and deposition have occurred in the past 1,000 years, that part of the fan can be considered to be active."*

The usefulness of geomorphic information in assessing flow path stability and potential for flooding was also considered in the NRC (1996) report: *"The evolution of the fan surface causes a difficult problem for the interpretation of field evidence concerning alluvial fan flooding and for the prediction of future flood risk. For example, if a part of a fan surface has not been disturbed by flooding or erosion for 15,000 years, its surface will have become weathered and covered by a soil-profile and vegetation. The surface of such a fan will be very different from the surface of a nearby channeled and actively evolving area. An important geomorphologic and hydrologic question for flood risk analysis is whether the older surface has evolved out of the flood zone or whether it simply has not been flooded for 15,000 years because random channel migration across the fan took the locus of flooding and sedimentation far from the site for that length of time."*

Generally speaking, the decision of whether to use engineering and/or geomorphic methods also depends on the level of accuracy required and the scale of the assessment. **Consult with the FCDMC about mapping requirements**. See also the first part of Appendix E for discussion of scale and accuracy.

1.2 Piedmonts

Most of Maricopa County is in the Basin and Range Physiographic Province where fault-block mountains are separated by intervening plains. The mountain ranges are consolidated rock and stream deposits generally cover valleys. Axial streams that head in adjacent mountains traverse the piedmont along the valley floor and drain the basins. Piedmonts, the broad, gently sloping and low relief plains located between mountain ranges and axial drainages, occupy much of Maricopa County.

The upper margins of piedmonts are located at the base of a mountain or mountain range (Figure 1.1). A piedmont is a part of an erosion-depositional system where sediment eroded from mountains is transported by a stream (*wash*) across the piedmont to (1) a valley where it is deposited, or to (2) an axial stream where it is transported out of the valley. Piedmont slopes range from less than 1 percent near the valley floors to more than 10 percent near the mountains. Typical piedmonts consist of *pediments* and *relict fans* on the upper slopes adjacent to the mountains and *alluvial plains* on the lower slopes adjacent to the valley floors or base level streams. *Active alluvial fans* (fans that are presently aggrading and eroding) can occur anywhere on the piedmont as shown in Figure 1.1. Lower portions of many piedmonts consist of alluvial plains, low-relief aprons of mostly fine-grained deposits with small, discontinuous channel networks. Many piedmonts in Maricopa County were formed by the lateral coalescence of separate alluvial fans into a landform called a *bajada*. The general features of alluvial fans, piedmont streams and rivers are briefly described in Appendix A.

Piedmonts in Maricopa County have areas of tributary stream channels (see the relict alluvial fans and pediments of Figure 1.1) and distributary stream channels (see the inactive alluvial fan of Figure 1.1). Floodwater enters the piedmont in channels from the tributary mountain streams and as overland flow along the mountain front and in embayments like the one shown in Figure 1.1. Floodwater may also originate from rainfall directly on the piedmont. Much of the flood flow crosses the piedmont slopes in defined channels of relict or inactive alluvial fans and pediments.

Active alluvial fans (the three small areas in Figure 1.1) function primarily as loci of deposition for sediment and detention and infiltration of floodwater, whereas the channels of pediments, relict fans and inactive alluvial fans function as transport corridors for sediment. Much of the deposited sediment on active alluvial fans can be remobilized by subsequent floodwater and redeposited down slope. A most significant difference between flood hazards on active alluvial fans and pediments, relict fans, and inactive alluvial fans is that paths of flow on active alluvial fans can change gradually or suddenly (avulse) during flooding. The paths of flow on pediments, relict and inactive alluvial fans typically can be considered fixed for purposes of flood hazard assessment.

Relict and inactive alluvial fans are remnants of old alluvial fans that are no longer subject to flooding and sediment deposition. These remnants are called *fan terraces* in NRCS soil survey reports (Camp. 1986), *erosion fan remnants* in a desert landform report for soil surveys by Peterson (1981), older alluvial surfaces in a flood hazard report of piedmonts by Field and Pearthree (1992), Pleistocene alluvial fans and terraces on surficial geologic maps (for example, Skotnicki and others, 1997) and a heterogeneous assortment of generally weakly consolidated slope-wash deposits by Cooley (1977). For this manual, relict fans are simply deposits with well-developed calcium carbonate in the soil profile and/or cemented conglomerate. Areas are classified as inactive alluvial fans where a sufficient amount of the remnant remains to be recognized as an alluvial fan landform as described in Chapter 2 of this Manual.

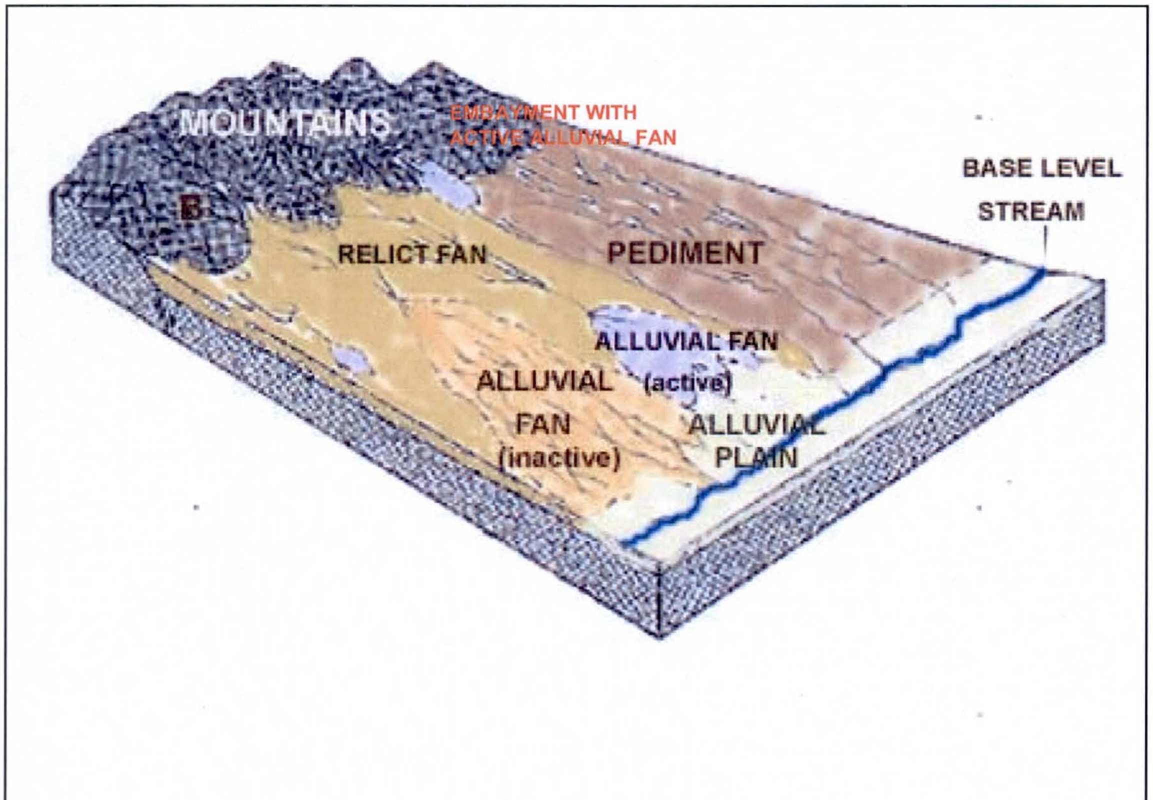


Figure 1.1. Isometric sketch of piedmont

Flood flow that enters active alluvial fans and alluvial plains becomes unconfined and can spread laterally at shallow depths. However, other characteristics of active alluvial fans and alluvial plains are quite different. Active alluvial fans typically have steeper slopes than alluvial plains. In addition, active alluvial fans are formed by material from the upper piedmont and mountains while alluvial plains are also formed by deposits along base level streams. Because the surfaces of active fans in Maricopa County commonly are composed of sand with gravel and scattered cobbles with only a few scattered boulders and some low vegetation, the surface is hydraulically rather smooth (Manning n <0.040) and flood flow velocities, based on observations of bed forms, are near or above the critical state in channels where slopes exceed about 2 percent.

1.3 Flow and flood terminology

The variety of terminology related to the flow of water over landforms to rivers and flow that leaves defined river channels can be confusing. For example, Hogg (1982) gives a good discussion of the numerous meanings of selected terms. Some of this confusion has been cleared in Arizona State Standard 4-95 for *Identification of and Development within Sheet Flow Areas.* With a few exceptions, this State Standard is used as a basis for definitions and identifying characteristics of flow types in this manual. The reader is encouraged to consult the glossary at the end of the manual for the meaning of terms and discussion some minor differences in the use of terms, such as sheet flood, between State Standard 4-95 and this manual.

1.4 Standards and Limitations

Flood studies must be accomplished in accordance with standards of FEMA, ADWR and the FCDMC. Standards for flood-hazard zones and development on piedmonts in Maricopa County are given in Appendix R of this Manual.

The frequency, magnitude and location of flood inundation and sediment deposition are of considerable interest for the welfare and safety of those occupying piedmonts. Precise definition of the occurrence and nature of these hazardous floods is complicated by several factors including unstable channel boundaries, uncertain flood flow-frequency relations and the threshold nature of basin sediment yield and transport. While generally accepted standard-step methods such as HEC-2 (COE, 1990b); unit-graph or hydrographic storm rainfall-runoff models such as TR-55 (NRCS, 1986) and HEC-1 (COE, 1990a); and sediment yield models such as RUSLE (Soil and Water Conservation Society, 1995) represent the engineer's current set of tools for characterizing flood conditions, these tools may be limited for specific sites on piedmonts. To overcome some of these limitations, geomorphologic tools are used to supplement engineering tools to produce a more reliable definition of the flood hazard.

To compensate for potential errors or limitations of predictions the engineer typically takes the conservative approach that uses an implicit or explicit factor of safety. Modern engineering uses several generalizations to depict, for example, runoff, peak discharge, channel behavior, sediment transport and sediment yield. These general relations may not be precise for specific sites because of differences in basin factors at specific sites and also because of the nonstationarity of climate and variability of storms. This conservative approach is recommended providing the conclusions reached are substantiated by field evidence. For example, the estimate of the 100-year flood peak discharge is not very precise for streams in Maricopa County (Thomas, Hjalmarson and Waltemeyer, 1997).

The realistic and rather simple engineering and geomorphologic tools presented in this manual for the assessment of unstable and stable flood hazards have limitations that will be discussed in the manual. This user's manual should be used with judgment based on knowledge of and experience with engineering methods and geomorphic processes of arid and semi-arid landforms.

1.5 Using evidence of past floods

Both engineers and geologists use information about past floods to estimate what future conditions might be. For example, the use of geomorphic evidence of past floods to estimate the future flood hazard is analogous to the use of gaged peak flow data to estimate the 0.01 probability flood. The engineer typically fits a probability distribution to past annual peak discharge data at a streamflow gage and the resulting flood frequency relation is used to estimate the magnitude of the 100-year flood that is then used to define the flood boundaries. In a like manner, the geomorphic evidence of past floods such as sediment deposition, surface texture, channel bank erosion and particle rounding and sorting is used to predict the nature and location of future floods. Thus, both the engineering and geomorphologic approaches use past information in different ways to make estimates of future conditions.

The difference in the engineering and geomorphologic approaches in the use of the 100-year peak discharge is significant but potentially useful. For example, the typical engineer must have a value of the peak discharge for the 0.01 probability flood to run the standard step model and produce flood boundaries in accordance with traditional riverine hydraulic methods. On the other hand, the geomorphologist does not need a value of the 0.01 probability flood to define flood limits of geologically recent floods. The geomorphologist examines drainage network characteristics and the extent of recent sediment deposits to define the cumulative area of geologically recent inundation (Pearthree and others, 1992; Klawon and Pearthree, 2000). The geomorphic approach does not rely on stable flow path geometry. Thus, the geomorphic approach becomes more useful for unstable landforms such as active alluvial fans and moveable boundary channels. The engineering and geomorphic approaches are complementary and more effective when used together (See Appendix B for additional discussion).

1.6 Approach

Procedures including those developed for interpreting the earth (Schumm, 1991), for characterizing incised channels (Schumm and others, 1988) and for identifying alluvial fans and alluvial-fan areas subject to flood hazard (NRC, 1996) form the basis for identifying flood hazards on piedmonts as outlines in this manual. The three stage method that progressively focuses on the definition of the flood hazard follows:

Stage 1 Recognizing and characterizing the kind and extent of piedmont landforms and showing these landforms on a map. The four main landforms on piedmonts of Maricopa County are pediments, relict fans, alluvial fans and alluvial plains. Procedures for identifying piedmont landforms are described in Chapter 2 of the manual.

Stage 2 Defining the nature of the piedmont landform environment and identifying unstable and stable components of the piedmont and showing these areas subject to various flood hazards on a map. For example, flood hazards of alluvial fan landforms in Maricopa County consist of fans with stable paths of flow and fans with unstable paths of flow. Procedures for identifying unstable and stable components of the piedmont are described in Chapter 3 of the manual.

Stage 3 Identifying and applying methods for defining and characterizing areas affected by the 100-year flood and showing these areas on a map. Realistic methods for definition of 100-year flood hazards are discussed in Chapter 4.

1.7 Overview and tasks

This Manual outlines a step-by-step procedure for characterizing piedmont landforms and associated flood hazards, especially areas subject to flooding on active and inactive alluvial fans. The method is modified from stages used by the National Research Council (1996).

- Chapter 1 is this introduction.

- Chapter 2 (STAGE 1 OF METHOD) is a description of how to identify and produce a map of the four major landforms - pediments, relict fans, alluvial fans and alluvial plains - on piedmonts. On many piedmonts in Maricopa County, existing surficial geologic maps and soil survey maps can be used to delineate different types of landforms.

  TASK Identify landform using procedures given in Chapter 2, characteristics outlined in Table 2.1 and steps outlined in Table 2.2 using available information such as surficial geologic maps or soil survey maps. Produce a map showing the topography, soils, surficial geology and significant features such as desert pavement and vegetation of the pediment, relict fan, alluvial fan and/or alluvial plain.

- Chapter 3 (STAGE 2 OF METHOD) is a procedure for identifying where the flood hazards are on pediments, relict fans, alluvial fans and alluvial plains and how to produce a map of these hazard areas.

  TASK Building upon the information developed in Stage 1 of the method, Identify stable and unstable areas using indicators given in Chapter 3 and Table 3.1 and selected characteristics of stable and unstable flood hazard areas given in Table 3.2. For alluvial fan landforms identified in Stage 1 define stable and unstable areas using steps given in Table 3.3. For active alluvial fans identify sources of sediment in the drainage basin. Produce a map showing areas subject to stable and unstable flood hazards with supporting field observations of significant factors such as the location and amount of sediment deposition, erosion, vegetation and flow path

- Chapter 4 (STAGE 3 OF METHOD) is a discussion of realistic methods for definition of 100-year flood hazards.

  TASK Characterize the 100-year flood hazards of piedmont landforms as outlined in Table 4.1 and described in Chapter 4. For stable areas characterize the 100-year flood using guidelines in FEMA, (2002) and appropriately supplemented with geomorphic methods (Appendix G of FEMA 2001 typically should not be used.) For unstable areas such as active alluvial fans estimate the 100-year flood hazards using geomorphologic methods possibly supplemented by traditional hydraulic methods. A map showing both stable and unstable areas subject to the 100-year flood is produced.

* Chapter 5 is the application of the procedure to three sites in Maricopa County.

> **TASK** Report findings and assumptions for the three stages as shown for the example sites in Chapter 5. An engineering report is produced that includes but is not restricted to the following items: (1) a discussion of how the map of the landforms, the map of the stable and unstable areas and a map of the 100-year flood were produced, (2) a discussion of how soil classification maps were used, (3) surveyed channel cross sections and stream profiles, (4) hydraulic computations including conveyance-slope estimates and (5) substantiation of conclusions reached with significant field evidence, assumptions and limitations.
>
> **Investigators conducting a flood hazard assessment to FEMA requirements Should follow the Maricopa County guidelines in Appendix R before starting Chapter 5.**

* There are three sections at the end of the manual-- acronyms, glossary, and references. The glossary is taken primarily from Alluvial Fan Flooding by the National Research Council (1996).

* Tutorials and miscellaneous methods based on published geomorphologic and engineering methods for assessing channel and landform stability are given in Appendices A to S. The tutorials are placed in the Appendices because experienced users may not need the tutorials. First–time users of the Manual should become familiar with the information in the Appendices.

To make best use of this Manual, the investigator should examine the many photographs and maps of landforms and surface features presented in the following chapters and appendices. Some photographs show a variety of landform features within a relatively small geographic area. The inclusion of a number of different but related landforms on a single photo permits the viewer to make direct comparisons of their shapes and relative sizes. Other photographs show detail of specific landforms or of important features such as desert pavement.

The investigator is encouraged to visit the three example sites and kick dirt. The South Mountain Park alluvial fan and the White Tank Park relict fan sites are in city and county parks, respectively. The third example site, Skyline Wash alluvial fan, is private land that may become developed. Comparison of landforms, examination of specific features and field investigation of the three sites will help the investigator to more easily visualize the various and interesting surface features of landforms in Maricopa County.

2

PIEDMONT LANDFORMS OF MARICOPA COUNTY

STAGE 1 OF METHOD

This chapter describes the major types of landforms that comprise piedmonts in Maricopa County. Piedmonts of Maricopa County are the gently sloping plains that lie between mountain ranges and axial drainages or playas of the Basin and Range Province. The four major piedmont landforms are relict fans, pediments, alluvial fans and alluvial plains. Flood hazards on piedmonts of Maricopa County are related to the four landforms as shown in Figure 2-1. Each of these landforms has distinctive topographic, surface, and soil characteristics, and the landforms can be reliably identified using several combined criteria. The description of the four landforms is followed by a discussion of several identifiers that are readily used to recognize the type of landforms. An example map at the end of this chapter shows the kind and extent of some piedmont landforms and represents the completion of Stage 1 of the Manual.

Several important distinguishing characteristics of relict fans, pediments, alluvial fans and alluvial plains are described in this section. In general, distinctive characteristics of pediments and relict fans are the products of erosion and distinctive characteristics of alluvial plains and many alluvial fans are the products of sediment accumulation. A summary of general characteristics of the four major landforms is listed in Table 2.1 and characteristics of (1) relict fans, (2) pediments, (3) alluvial fans and (4) alluvial plains are described in the remainder of this section.

In this manual, alluvial fans are subdivided into two categories that have distinctly different surface characteristics. Alluvial fans are *active* where stream deposition is common and stream systems are distributary or braided. Alluvial fans are *inactive* where stream deposition is less common and many stream systems are tributary. Thus, active fans are wholly or partly active depositional surfaces, and inactive fans are mostly erosion surfaces. Flow paths may change during floods on active fans, but flow paths on inactive fans typically are stable.

Many photographs and maps of landforms are presented so the inexperienced reader can become acquainted with the appearance of the landforms. The ability of evaluate surface features and define the landforms clearly is gained by experience. The reader should gain experience with landform identification by becoming familiar with the maps and aerial photos of this Manual and also by making field observations of geomorphic relationships and surface and soil characteristics especially at the three example sites.

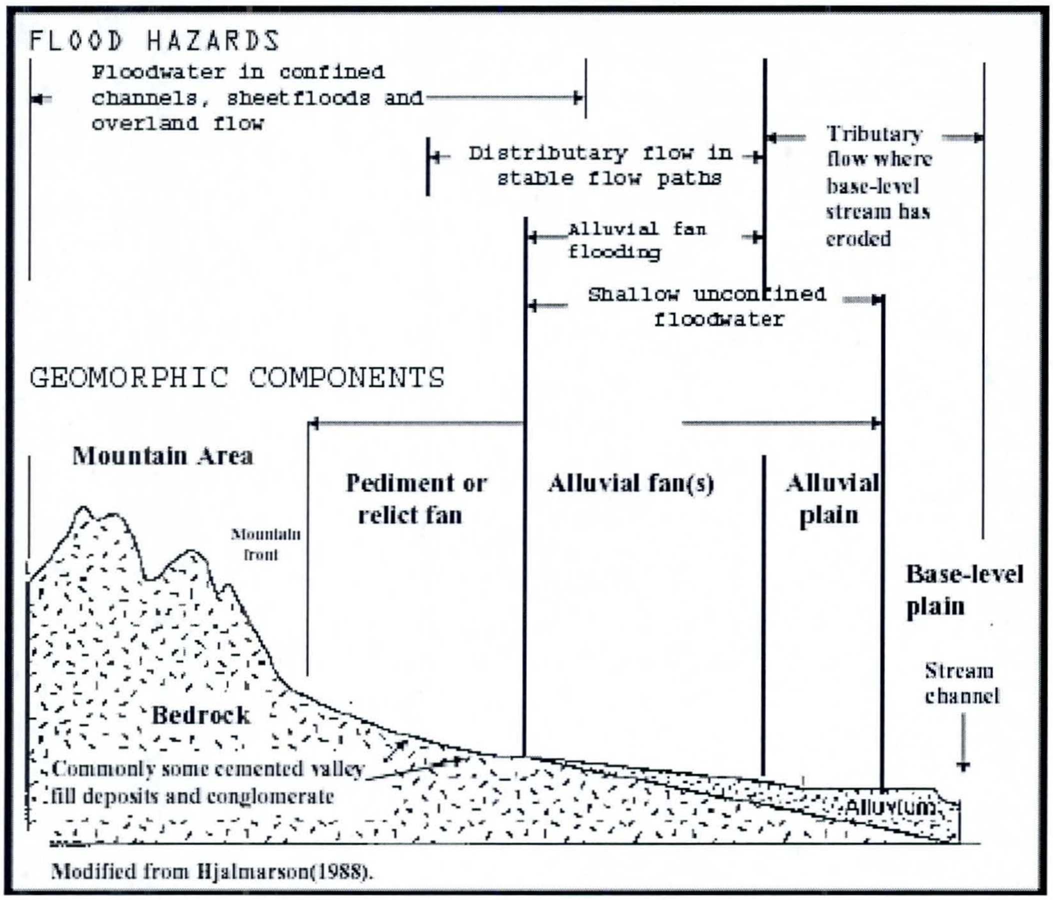


Figure 2-1. Typical flood hazards and landforms on piedmonts in Maricopa County.

Table 2.1 Component landforms, common soil types, typical geologic map units, and significant characteristics of piedmonts in Maricopa County.

Landform	Component Landform (common soil types)[1] *(typical geologic units)*[4]	Significant characteristics[2]
Relict Fan	Erosion Fan remnant (Mohall-Contine, Gunsight-Chuckawalla- Rillito, Pinamt, Tremant-Ebon- Momoli-Carefree, Eba-Pinaleno, Laveen, Mohave-Continental) (*Qo, Qmo, Qm)*	Typically incised channels in cemented conglomerate of cobbles and boulders. Drainage typically is tributary but small pockets of distributary channels may occur. Some relict fans have a ridge-valley morphology. Incised throughflow streams typically are more than 10 ft. deep and less than 20 ft. deep with steep banks. Desert pavement and rock varnish are common on flat interfluves. General slope typically is 1-6 percent.
	Inset Alluvial Fan (Carrizo, Gilman, Antho, Estrella, Glenbar) *(Qy, Qy2, Qy1)*	Generally small and confined between relict fan remnants. Fluvial deposit that can act like a floodplain with high potential for scour and fill. Much of the alluvial fan material may be from gulling of the relict fan and such material may be bouldery.
Pediment	Bedrock remnant (Gran-Rock outcrop, Gran-Wickenburg complex, Cherioni-Rock outcrop association) *(various bedrock units)*	Incised channels generally formed in bedrock and old soils. Drainage typically is tributary but distributary channels may be present especially on lower slopes. There are many first order tributary channels. Parent rock typically is granite with large granite boulders on the upper slopes near the mountains. The crests of transverse slopes are small and shoulders are steep. General slope typically 2-5 percent.
	Inset Alluvial Fan (Anthony-Arizo complex, possibly Eba-Pinaleno and Carrizo) *(Qy, Qy2, Qy1)*	Generally small alluvial fan confined between pediment. Fan typically widens like a partially opened fan and lower part typically narrows as distributary channels rejoin. Fluvial deposit that typically is actively aggrading and eroding with possible balance of sediment over past few hundred years.
Alluvial Fan	Active Alluvial Fan (Carrizo, Gilman, Antho, Brios, Estrella, Glenbar, Coolidge, Valencia, Torrifluvents, Maripo) *(Qy, Qyc, Qy2, Qy1)*	Fluvial deposits with little, if any, calcium carbonate development. Fan shaped in plan view with hydrographic apex at topographic break. Typically no desert varnish. Stream channels are wide with little incision or channels are very small. Active portions of alluvial fans in Maricopa County typically are a small part of an alluvial fan that is mostly inactive. General slope 1-10 percent.
	Inactive Alluvial Fan (Laveen, Anthony, Antho, Momoli, Mohave, Pinamt, and other soils of relict fans) *(Qm, Qm1, Qm2, Ql, Qly)*	Fluvial deposits with much carbonate in K soil horizon. Fan shaped typically with distributary network of incised-throughflow channels. Transverse slopes of interfluves are flat. Interfluves typically drained by small channels that are tributary to throughflow streams. Interfluve slopes are stable and throughflow streams typically are incised less than 3 ft.. General slope typically 1.5 - 4 percent.
Alluvial Plain	Piedmont Toe (Gilman, Estrella[3], Glenbar, Momoli, Denure, Antho, Contine, Mohall, Avondale) *(Qy, Qy2, Qy1, Qyf)*	Aggrading or rather stable fluvial deposit with little transverse relief and small throughflow channels. Channels typically are less than 1 ft. deep. Few tributary channels head on the surface. Little, if any, rock varnish but possibly some desert pavement. Can be channel incision of a few feet where there has been general head cutting of base- level stream. General slope is 0-3 percent.

[1] Soil complexes on NRCS maps include one or more of the soil types associated with the indicated landform.
[2] These characteristics may be observed on topographic maps, aerial photographs and by field inspection.
[3] Some of this soil is associated with alluvial fans by Camp (1986) and with alluvial plains in this manual. This soil is associated with alluvial plains for this manual because Estrella loam (Soil type 50) typically is at the toe of piedmonts, the slope is small and the landform does not meet the criteria for alluvial fans (NRC, 1996). This is an example of a few minor inconsistencies between this manual and NRCS soil surveys that have no effect on the reliability of the method.
[4] Surficial geologic map units commonly used by AZGS geologists to describe deposits associated with the various landforms.

2.1 Landforms

The four principal landforms are:

- **Relict fan** An erosion remnant of an old alluvial fan that was formed in a past geologic epoch and hardened by cementation. The original fan surface has been strongly modified by erosion, and in some cases the original fan shape has not survived disintegration or burial.

- **Pediment** A broad, flat or gently sloping, rock-floored erosion surface located at the base of an abrupt mountain front or plateau escarpment. Pediments are underlain by bedrock (occasionally by older alluvial deposits) that may be bare but more often partly mantled with a thin and discontinuous veneer of alluvium derived from the upland masses and in transit across the surface.

- **Alluvial fan** Sedimentary deposit located at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of streamflow and/or debris flow sediments and has the shape of a fan, either fully or partially extended.

- **Alluvial plain** A nearly level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or at the toe of an alluvial fan.

2.1.1 Relict fans

A relict fan is a remnant of an old alluvial fan that was deposited in a past geologic epoch and hardened by cementation and strongly modified by subsequent erosion. Many relict fans in Maricopa County are a heterogeneous assortment of strongly developed soils with abundant clay or calcium carbonate on ridge lines and weakly consolidated slope-wash deposits. Relict fan areas are the remaining parts of larger landforms that have eroded away or have been partially buried. The head of some relict fans is at a mountain front (commonly the Ebon or Cipriano soil series (Camp, 1986)) and is easily identified because the general slope change is abrupt at the mountain fronts. The typical lower slopes or toe of the relict fans is where the conglomerate is covered by recent fluvial material.

An alluvial fan that has survived disintegration by retaining its fan shape is classed as an alluvial fan. Conversely, a similar alluvial fan that has not survived disintegration and has not retained its fan shape is classed as a relict fan in this Manual. Several examples of alluvial fans and relict fans are shown later in this chapter and in Appendix C.

For informative descriptions of pedogenic soil development and calcic horizons. see Christenson and Purcell (1985), Machette (1985), Compton (1977), Field and Pearthree (1992) and Camp (1986). For informative descriptions of landforms in the Basin and Range Physiographic Province see Peterson (1981).

2.1.1.1 Transverse relief

Many relict fans have distinct rounded transverse hillside shoulders with concave foot slopes as shown in the first sketch of Figure 2.2. Relict fans with these ridges have a distinct *surface texture* and abundant calcium carbonate that commonly gives them a light appearance with boundaries that can be easily seen on color-infrared and other aerial photographs (A relict fan, pediment and alluvial fans are shown in Figure 2.3). The transverse relief, between 3 feet and 15 feet, usually can be seen on 7.5- minute series USGS topographic maps (Figure 2.4). Peterson (1981) used the term "ballena" for these broadly rounded ridges, describing them as follows:

> *"The typically broadly rounded shoulders meet from either side to form a narrow crest and merge smoothly with the concave back slopes. In ideal examples, the slightly concave foot slopes of adjacent ballenas merge to form a smoothly rounded drainage way."*

Channel banks or hillsides on more recently dissected relict fans have an abrupt break at the shoulder with steep back slopes along incised throughflow streams as shown at the left bank of the large channel in the second sketch of Figure 2.2. In these situations, more of the original fan surface is preserved in the relatively planar areas between drainages.

The larger channels that head in the mountains commonly are separated by wide interfluves that are cut by small tributary channels, which form on the relict fan. These tributary channels are V-shaped with narrow beds composed of little fluvial material. The larger throughflow channels that head in the mountains commonly have flat beds with exposed conglomerate nick points and boulders and cobbles.

An example of and incised channel with steep banks is shown in Figure 5.15 of the White Tank Park site in Chapter 5 of this Manual. Several examples of incised channels with both sharp and rounded shoulders can be seen on the White Tank alluvial fan along Olive about 1-½ to ½ mile east of the entrance to the White Tanks Park (Figures 2.10, 2.11, 5.11 and location map for photographs of Appendix J).

2.1.1.2 Surface texture

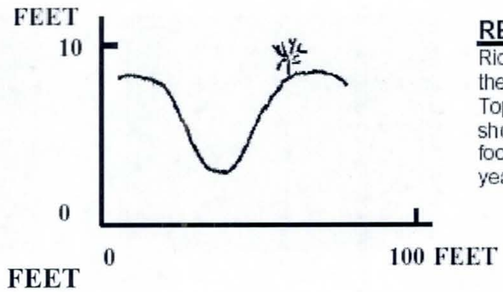
Surface texture is the appearance of the land surface when viewed from an aircraft, on a topographic map or on an aerial photo image. Much of the texture is the result of the the permeability of the soil and mantle rock, local topographic relief, vegetation type and density, and drainage patterns and density (see Appendix E). Typical surface textures associated with relict fans are shown in Figures 2.3, 2.4 and several figures in Appendix E.

2.1.2 Pediments

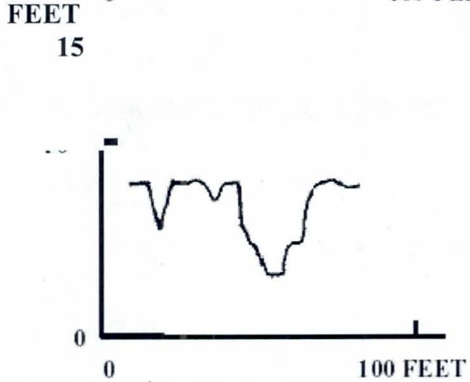
Pediments are developed on bedrock and are formed by weathering and erosion. Pediments of Maricopa County may resemble inactive alluvial fans and relict fans largely because the surface of pediments can be covered with sand and gravel a few inches to a few feet thick. The form of the surface reflects the slope and shape of the bedrock surface (Twidale, 1982, p. 190). Upper slopes of pediment surfaces commonly are bouldery and more gentle lower slopes are mantled with gravel, sand and silt.

Many pediments in Maricopa County are formed on granite or granite-like igneous rocks (Figure 2.5). For this user's manual, a pediment is where there are bedrock exposures, even if the exposures are scarce along incised channels. The pediment head is easily identified because the slope change at the toe of mountain fronts is abrupt. The toe of the pediment is defined or where the bedrock is sufficiently covered by fluvial deposits that is not visible along eroded channel banks and there are no large boulders on the land surface.

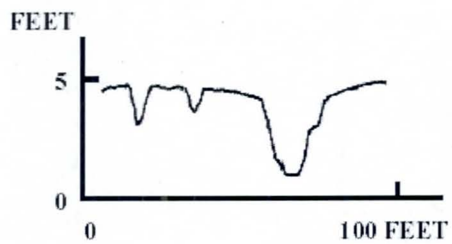
Granite pediments can be mistaken for alluvial fans because the pediments are weathered to large depths and have both tributary and distributary channel networks. Detailed geologic maps are an invaluable resource because areas of exposed bedrock are differentiated from surficial deposits. Exposed pediments are characterized by extensive bedrock areas with low topographic relief (typically 10 to 20 ft between channels and interfluve divides). Shallowly buried pediments are characterized by exposures of bedrock along incised drainages (see Skotnicki et al, 1997, for example). See Appendix F for a more detailed discussion of granite pediments in Maricopa County.



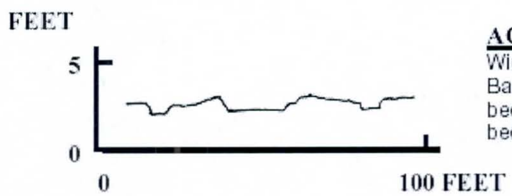
RELICT FAN
Ridges and valleys of some relict fans where the ridges have a general parallel appearance. Tops of ridges can be wider and flatter that shown here. Ridge shoulders are convex and foot slopes are concave. The level of the 100-year flood typically is well below the ridges.



RELICT FAN OR PEDIMENT
Incised channels where larger channels typically head in mountains and have flat beds with fluvial bed material. Bed material in larger channels can be boulders and cobbles where incised in relict fan of boulder conglomerate or where mountains and pediment are metamorphic or volcanic rock.



INACTIVE ALLUVIAL FAN
Incised channels where large flat bed channels typically head in the mountains and transport sediment from the upslope areas. The drainage network of the larger channels is distributary and of the smaller channels is tributary. Larger channels typically are lined with paloverde and/or mesquite trees.



ACTIVE ALLUVIAL FAN
Wide channels with low banks. Bed and Banks of active channnel can be higher than bed and banks of nearby channels. Channel beds typically are flat.

Figure 2.2. Sketches of transverse cross sections of piedmont landforms.

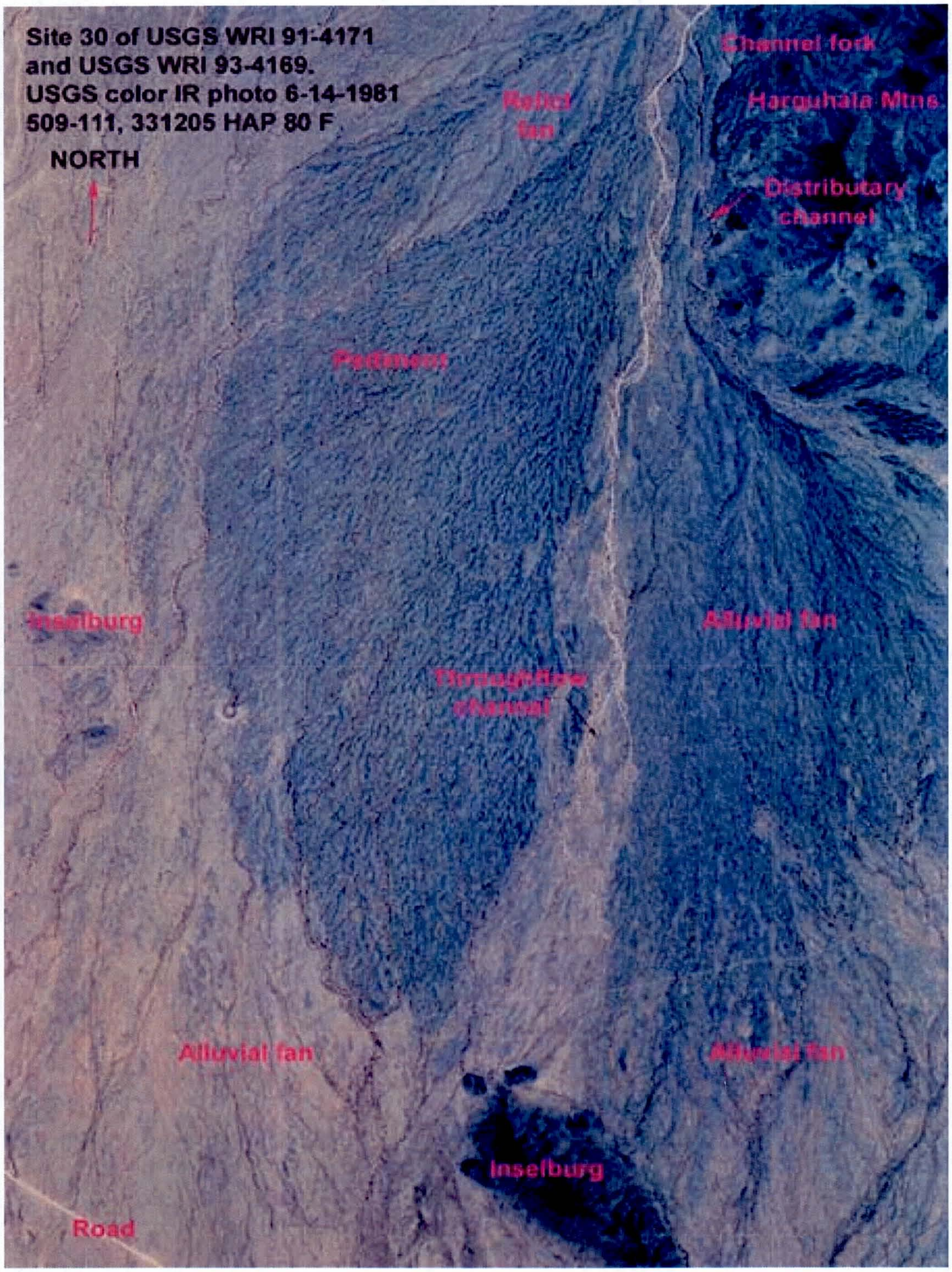
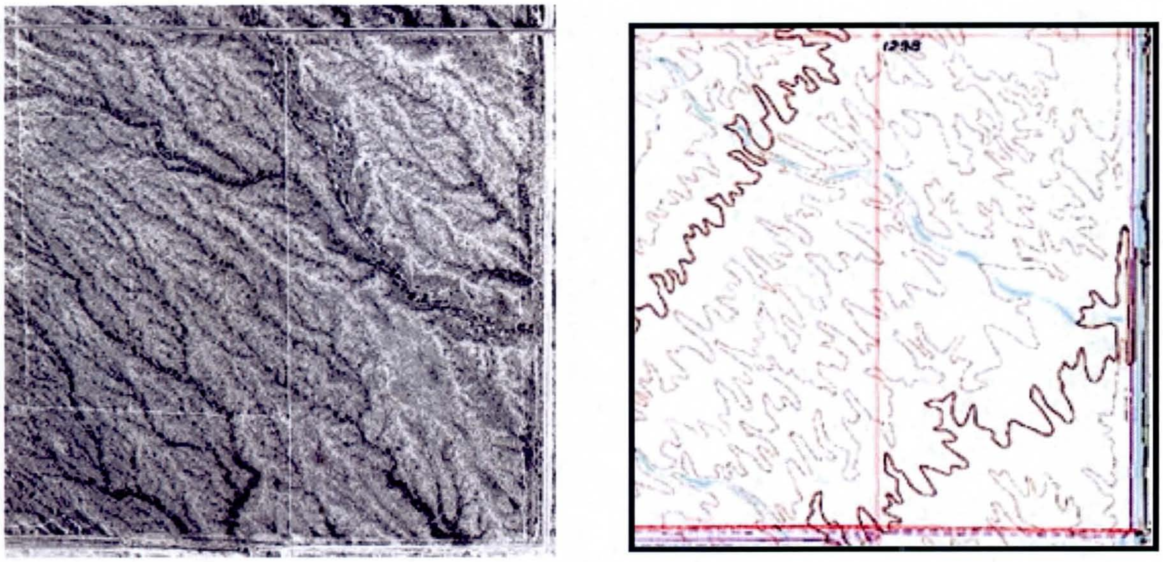


Figure 2.3. Color infrared aerial photograph of USGS site 30 showing surface features of alluvial fans, pediments and relict fans.



Scenes are about 1 mile^2. Topographic map is 7-1/2 minute with 10 ft contour intervals.
Aerial photo is digitized from a black and white glossy.

Figure 2.4. Aerial photograph and topographic map illustrating surface texture and appearance of relict fan.

2.1.2.1 Surface texture and drainage pattern

Near the mountains on upper slopes of pediments, the drainage pattern is tributary. Floodwater typically is confined to well-defined channels in these areas (Table 2.1). On the lower slopes, the drainage pattern can be a mixture of tributary, distributary and anastomosing. The defined channels on the lower slopes are less incised. The 100-year flood typically is confined to defined channels and adjacent small terraces of pediments. On lower slopes where the channel depths are small, the 100-year floodwater can spread over adjacent land.

For further discussion of the drainage pattern on pediments of Maricopa County, see Moss (1977), Rhoads (1986) and Hjalmarson (1978).

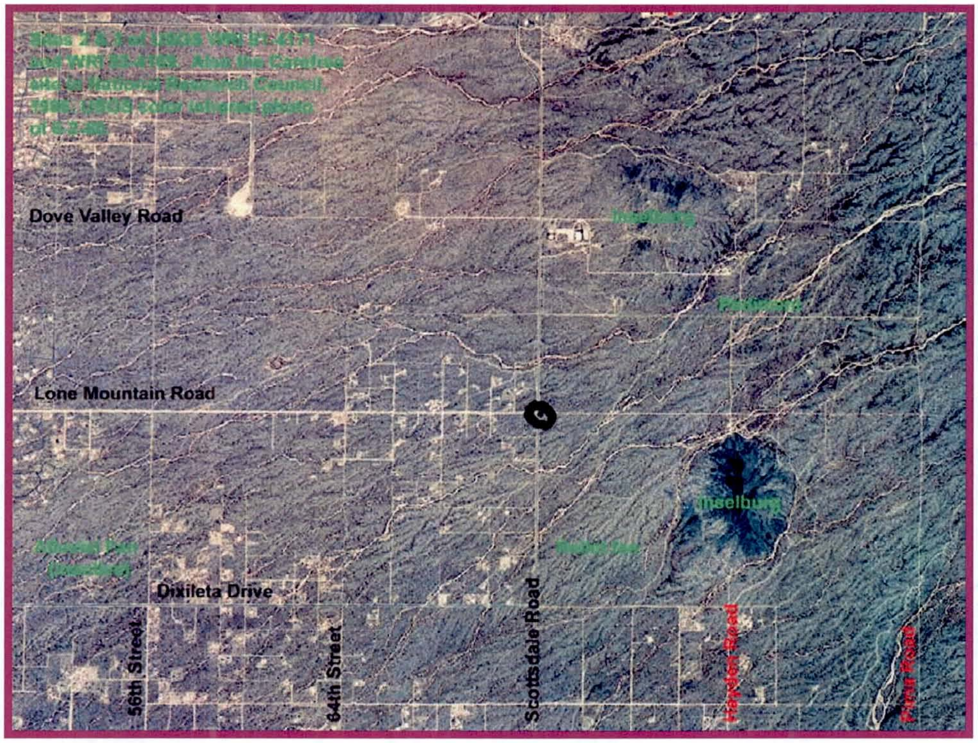


Figure 2.5. Pediment near Carefree

2.1.2.2 Drainage texture

Drainage texture is the relative spacing of drainage ways (rills, swales, washes, etc.). Drainage texture, as depicted by upslope crenulation count on contour lines of USGS 7.5-minute topographic maps, commonly increases upslope on pediments. According to Doehring (1970), the drainage texture of pediments is finer (more low-order drainage channels) in the upslope direction (Appendix D). Pediments commonly have many streams of various sizes from rills to streams with large incised channels, and many of these streams head on the pediment.

The transition at the upper slopes of pediments generally is easy to identify because the transition from the mountain to the alluvial plain is direct with a marked change in the slope of the land surface at the mountain fronts. The transition of the lower pediment slopes to alluvial plains and fans is more difficult to identify because the slope of the land surface is nearly constant or is changing only gradually. Drainage texture, however, typically changes at the transition as suggested by the regression relations in Figure D1b discussed in Appendix D (Doehring, 1970 and Hjalmarson and Kemna, 1991).

2.1.2.3 Relict fans and pediments

Many relict fans and pediments have similar flood characteristics. For example, relict fans and pediments typically have tributary drainage patterns and the 100-year flood is confined to defined channels and adjacent land. A significant difference is the *drainage texture* of relict fans typically decreases upslope and the drainage texture of pediments typically increases upslope (Hjalmarson and Kemna, 1991). The drainage texture (spacing of the low order drainage channels depicted by the crenulation count on contours of USGS 7.5 minute topographic maps) of relict fans, pediments and inactive alluvial fans is discussed later in this chapter and in Appendix D.

2.1.3 Alluvial Fans

Alluvial fans are common and extensive landforms on the piedmonts of Maricopa County. The purpose of this section of the Manual is to consider the genesis of alluvial fans and their morphologic features. The procedures outlined here supplement Stage 1 of Appendix G: Guidance for Alluvial Fan Flooding Analysis and Mapping of the FEMA Guidelines and Specifications for Flood Mapping Partners (2001).

An alluvial fan is *"a sedimentary deposit at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of fluvial and/or debris flow sediments and which has the shape of a fan either fully or partly extended."*(NRC, 1996). Alluvial fans on the piedmonts of Maricopa County have been deposited in Quaternary time when global climate has varied considerably. It is likely that periods of substantial alluvial fan deposition are tied to climatic variations that changed the amount of sediment supplied to streams from hillslopes or the ability of streams to transport sediment (Bull, 1991; Menges and Pearthree, 1989). In many upland areas in and adjacent to mountain ranges, streams are incised well below the highest levels of deposition that occurred in the early or middle Quaternary (Menges and Pearthree, 1989). Modern stream systems erode material from mountain and upper piedmont areas and deposit the detritus farther downslope below a topographic break, forming a rather evenly sloping cone called an alluvial fan. In Maricopa County, the apices of most active alluvial fans are located well downslope from the topographic mountain front.

The geologic history of a particular area is admittedly is beyond the scope of this manual, but it can be important. For example, the geologic history can be very important if landform and flood characteristics of alluvial fans and other landforms are transferred to sites in Maricopa County and visa versa. Characteristics of alluvial fans and other landforms described in technical literature may be different for sites in Maricopa County that have different geologic pasts.

Many alluvial fans in Maricopa County have active areas of flooding and sediment deposition inset in much older fans that are inactive and stable. Fans in Maricopa County are somewhat similar to fans in Death Valley that are formed mostly by water flood processes described by Hunt (1975) and Hunt and Mabey (1966). Fans in Death

Valley, however, have a greater tectonic influence. Alluvial fans in Maricopa County have fewer debris flows than fans along the western slopes of the Wasatch Mountains in Utah. Alluvial fans of different regions have general differences and general similarities. However, each alluvial fan has unique flood hazard characteristics.

Many alluvial fans in Maricopa County have evolved or matured to a general state of inactivity where much of the fan is drained by incised channels (see third sketch of Figure 2.2 and Figure 2.3). These channels may have tributary or distributary drainage networks, but in either case the flow paths may be considered stable for regulatory purposes. Other alluvial fans or parts of segmented alluvial fans are wholly or partly aggrading landforms where sediment is deposited by spreading floodwater and are subject to movement of flow paths (See fourth sketch of Figure 2.2). A procedure for distinguishing inactive and active alluvial fans is described in Chapter 3 of this Manual. The following procedures for recognizing and characterizing alluvial fans are derived from the National Research Council (1996) report *"Alluvial Fan Flooding".*

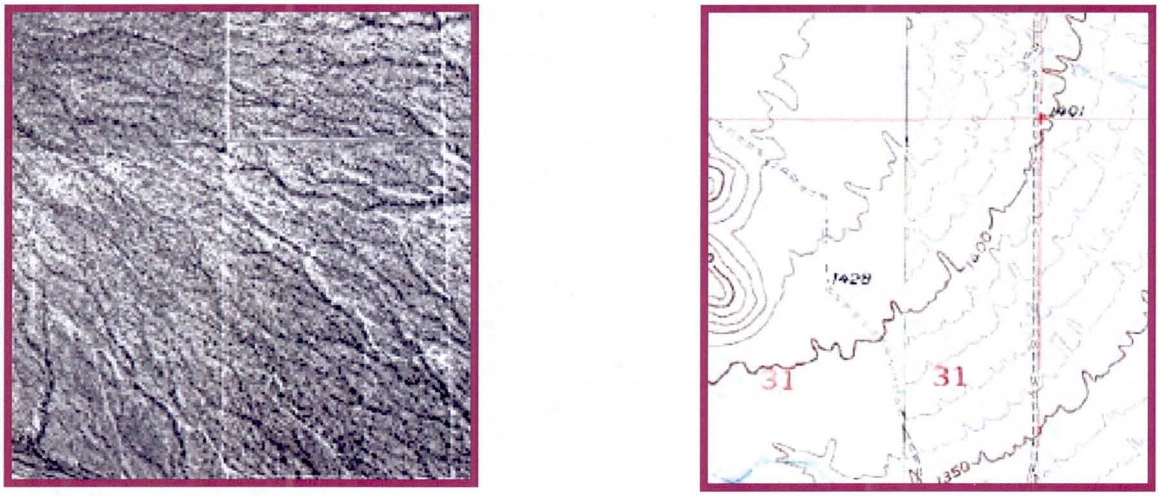
2.1.3.1 Composition and extent

An alluvial fan is a sedimentary deposit of loose, unconsolidated or weakly consolidated sediments. Alluvial fans are typically composed of gravel and sand layers or lenses, with minor silt and clay near their apices; farther downslope, fine-grained deposits are dominant and sand and gravel typically are minor constituents. Geologic maps that show the distribution of bedrock and surficial deposits are a primary data source for evaluating the extent of alluvial fan deposits. Small-scale geologic mapping (1:1,000,000 scale) covers all of Maricopa County (Cooley, 1967; Kamilli and Richard, 1998; Richard and others, 2000). Intermediate (1:100,000) and large (1:24,000) scale geologic mapping completed by the Arizona Geological Survey in since the late 1980's covers most of the county (for example, Demsey, 1988; Huckleberry, 1994. Published NRCS soil survey maps Camp (1986) and Hartman (1977) show soil types typically associated with sedimentary deposits (Table 2.1). Field reconnaissance should be done to verify that the landform is a sedimentary deposit.

2.1.3.2 Shape

Alluvial fans are landforms that have the shape of a fan either partly or fully extended. Modern and old flow paths radiate outward from the fan apex to [the perimeter of] the fan toe. Old flow paths can be eroded away or filled in by wind, rain and sheet flow. Active alluvial fans typically are concave upward in longitudinal profile but are convex upward in the transverse direction. The transverse convexity can be eroded away on older alluvial fans or lost by coalescence with adjacent alluvial fans.

Coalesced alluvial fans present special considerations for flood hazard assessment because floodwaters from different source areas commingle. A procedure for estimating the drainage boundaries of coalesced fans is given in section 2.3 of the Manual.



Scenes are about 1 mile^2. Topographic map is 7-1/2 minute with 10 ft contour intervals.
Aerial photo is digitized from a black and white glossy.

Note: Inactive alluvial fans like that shown above typically have with many incised channels heading on the landform as shown above. Inactive alluvial fans also have broad smooth ridges with widely spaced small channels. These Pleistocene landforms may have exposed cemented rock on the shoulders of channels. Shoulders of older washes tend to be rounded and shoulders of channels of recently dissected areas are angular.

Figure 2.6. Aerial photograph and topographic map illustrating surface texture and appearance of alluvial fan.

2.1.3.3 Topographic break

Heads of alluvial fans are located at a topographic break called the *topographic apex* (Figure 2.7). The topographic apex is the uppermost apex of the alluvial fan and may not be the present location where sediment deposition starts. The hydrographic apex is the highest location of an *active alluvial fan,* where the modern stream widens and corresponding flow depths decrease resulting in less power to transport sediment (See for example Figure 2.12). Below the hydrographic apex there is markedly more channel migration and sedimentation.

2.1.3.4 Surface texture

The surface texture of many inactive alluvial fans consists of undulating and parallel ridges and valleys of small channels. A close examination of the rounded ridges reveals a slight radiating pattern or spreading down slope. The rather smooth ridges are flat or rounded and the shoulders of the channels typically are smooth and rounded (See Figures 2.3, 2.6, 2.7. 2.9-2.11). Most of the texture is the result of the tributary channels that have developed over time on the abandoned fan.

The distinctive surface texture of active alluvial fans is much different than the texture of inactive alluvial fans (Compare the active fan shown in Figure 2.12 with the inactive fan in Figure 2.7. The texture of active alluvial fans typically is the result of the many braided channels, the movement of sediment and the scattered growth of vegetation. The active alluvial fans typically have a braided-stippled appearance. In other words, the appearance of active *alluvial fans* is because they are wholly or partly aggrading landforms where sediment is deposited by spreading floodwater and flow paths change.

For further discussion of surface texture as a tool for estimating the type of landform and the type of drainage pattern the investigator should refer to Appendix E. For the significance of the appearance of active and inactive alluvial fans for flood hazard assessment, the investigator's patience is suggested. The type of flood hazard is discussed in the next chapter of the Manual.

2.1.3.5 Drainage texture

Doehring (1970) observed that the drainage texture on alluvial fans with incised channels generally was constant along the axis of fans. Studies by Hjalmarson and Kemna (1991) also showed drainage texture of inactive alluvial fans was uniform in the upslope direction on 7.5-minute topographic maps. Drainage texture is a quantitative measure of surface texture and is described in Appendix D.

2.1.3.6 Topographic, geologic, and soils maps

Alluvial fans usually can be identified on standard 7.5-minute series of USGS topographic maps, which provide useful information to delineate alluvial fan boundaries. Information provided by surficial geologic maps and soils maps can also aid in identifying and delineating alluvial fans. Identifying characteristics of alluvial fans that are found on topographic maps include :

- Bifurcating intermittent stream symbols on maps depict distributary channels.

- Small wash or intermittent stream symbols that end abruptly in an area with smooth contours also may depict distributary flow on the fan surface.

- Broad areas of piedmont that are marked with the sand symbol (stippled pattern) may depict aggrading areas and possibly bifurcating channels.

- Relative drainage texture domains depicted by contour-crenulation counts (small rounded upslope projection of a contour line) provide excellent clues to the type of landform and potential alluvial fans (Hjalmarson and Kemna, 1991 and the Henderson Canyon example (National Research Council, 1996)). The drainage texture of active areas of distributary flow normally is uniform in the upslope direction.

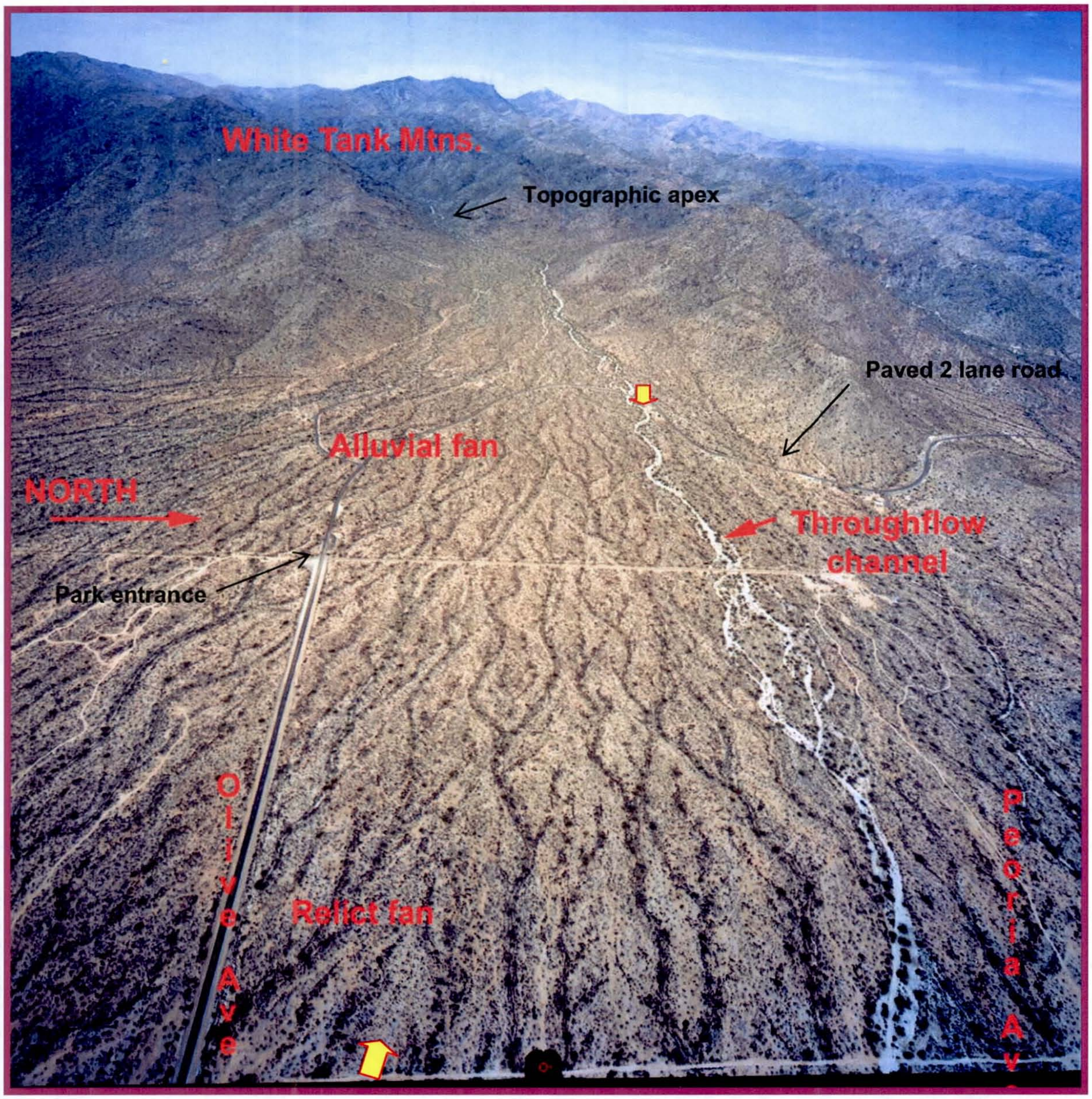
- Smooth contours that are parallel and either straight or convex pointing downstream in plan view indicate mild transverse relief that may result from bifurcating channels. Contours with relatively large and narrow crenulations may reveal remnants of inactive fans.

It is important to note that concentric semicircular contours that bow down slope do not necessarily depict an active alluvial fan. Many inactive alluvial fans that have developed tributary channels and presently are eroding have concentric semicircular contours that bow down slope. Eroding fluvial processes are active on these old surfaces and alluvial fan processes (aggradation) no longer are active. It is common, however, for inactive alluvial fans to host active alluvial fans. Thus, a portion of a semicircular contour that bows down slope that is smooth and bounded by relatively large and narrow crenulations may indicate bifurcating flow and the alluviation of an active alluvial fan.

Detailed surficial geologic maps and soil survey maps generally are presented at a scale of 1:24,000 and provide data that facilitate the recognition and delineation of active and inactive alluvial fans. Soils maps, for example, depict relatively strongly developed soils associated with the older deposits that dominate inactive fans in contrast to weakly developed soils associated with the young deposits of active washes and fans. In either case, soil map units or complexes of map units that have a general fan shape opening downslope are associated with alluvial fans. Surficial geologic maps explicitly differentiate and map deposits of different ages (Appendix L). Laterally extensive, fan-shaped surficial geologic map units depict the extent of alluvial fans of different ages. In the case of inactive or relict fans, surficial geologic maps depict the exposed extent of the deposits associated with the formerly active landforms.

2.1.3.7 Inactive and relict alluvial fans

Both inactive alluvial fans and relict fans may have similar surface textures (Compare Figures 2.4 and 2.6 for example.). The texture of both landforms is the result of erosion and the formation of tributary drainage patterns on the landforms. However, the channels on inactive alluvial fans are smaller and further apart that the channels on relict fans. Also, the channels of relict fans do not have the subtle radiating pattern exhibited by the channels on inactive alluvial fans. Another important difference between relict fans and alluvial fans is channels on alluvial fans may have a distributary pattern white the drainage pattern on relict fans is tributary. Interesting differences between inactive alluvial fan and the relict fan further down slope is shown in Figure 2.11.



Location of Figures 2.8 and 2.9. See Figure 2.10 for topography and Figure 2.11 for aerial photograph of this site. Aerial photo is digitized from a color glossy taken during August 2002.

Note: Inactive alluvial fans like that shown above typically have with many incised channels heading on the landform as shown above. Inactive alluvial fans also have broad smooth ridges with widely spaced small channels. These Pleistocene landforms may have exposed cemented rock on the shoulders of channels. Shoulders of older washes tend to be rounded and shoulders of channels of recently dissected areas are angular (See for example Figure 2.8).

Figure 2.7 Oblique photograph looking west at White Tanks Park alluvial fan.

Figure 2.8. Throughflow channel on White Tanks Park alluvial fan.

Figure 2.9. Wide-flat interfluve of old alluvial fan covered with desert pavement with some desert varnish and scattered saguaro cacti. Dominant plants are creosote and saltbush. Gravely surfaces of old alluvial fans and relict fans with a shallow calcic soil horizon commonly are dominated by creosote and saltbush shrubs like in the scene above.

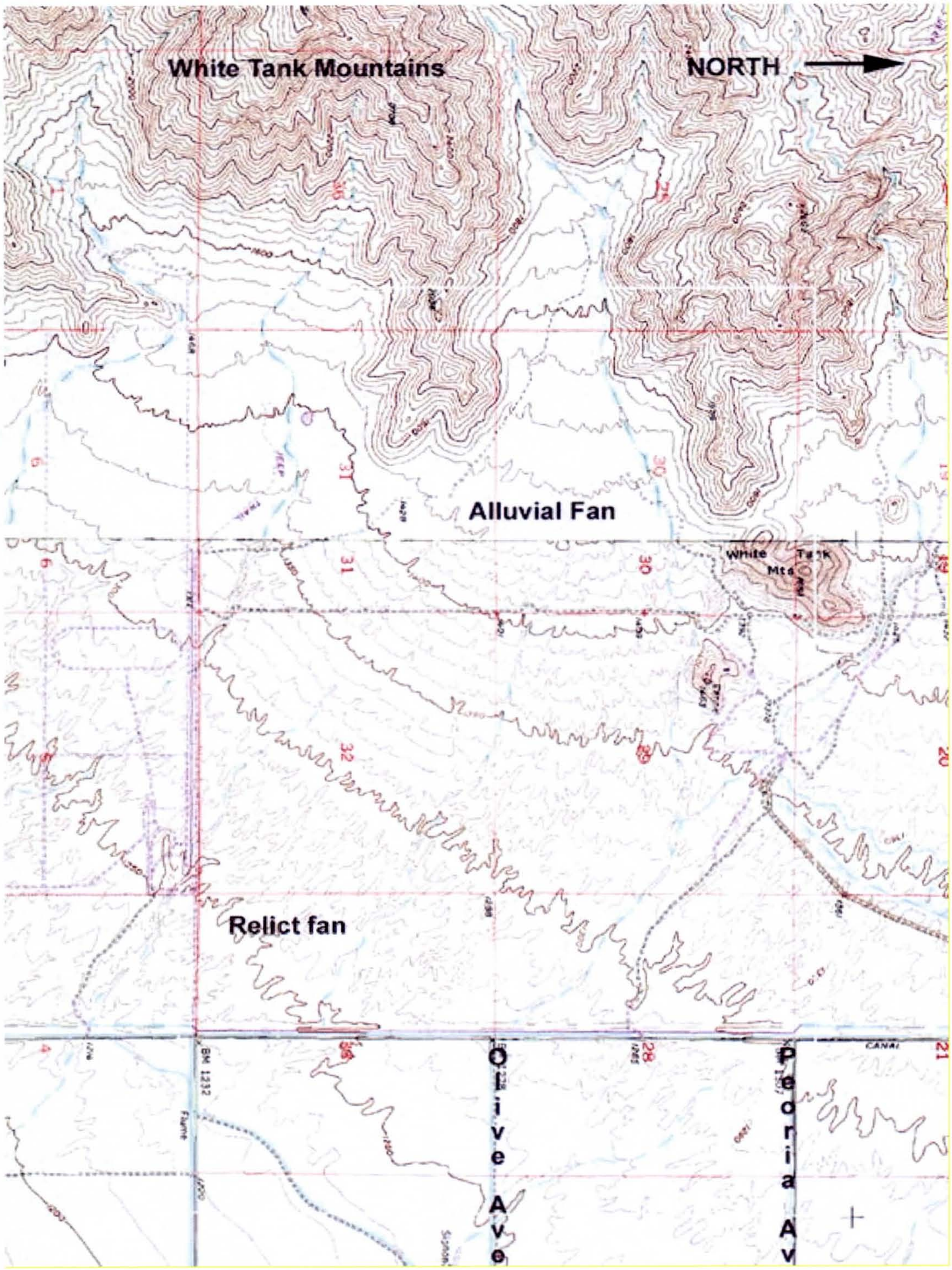


Figure 2.10 Topography of White Tank Park alluvial fan.

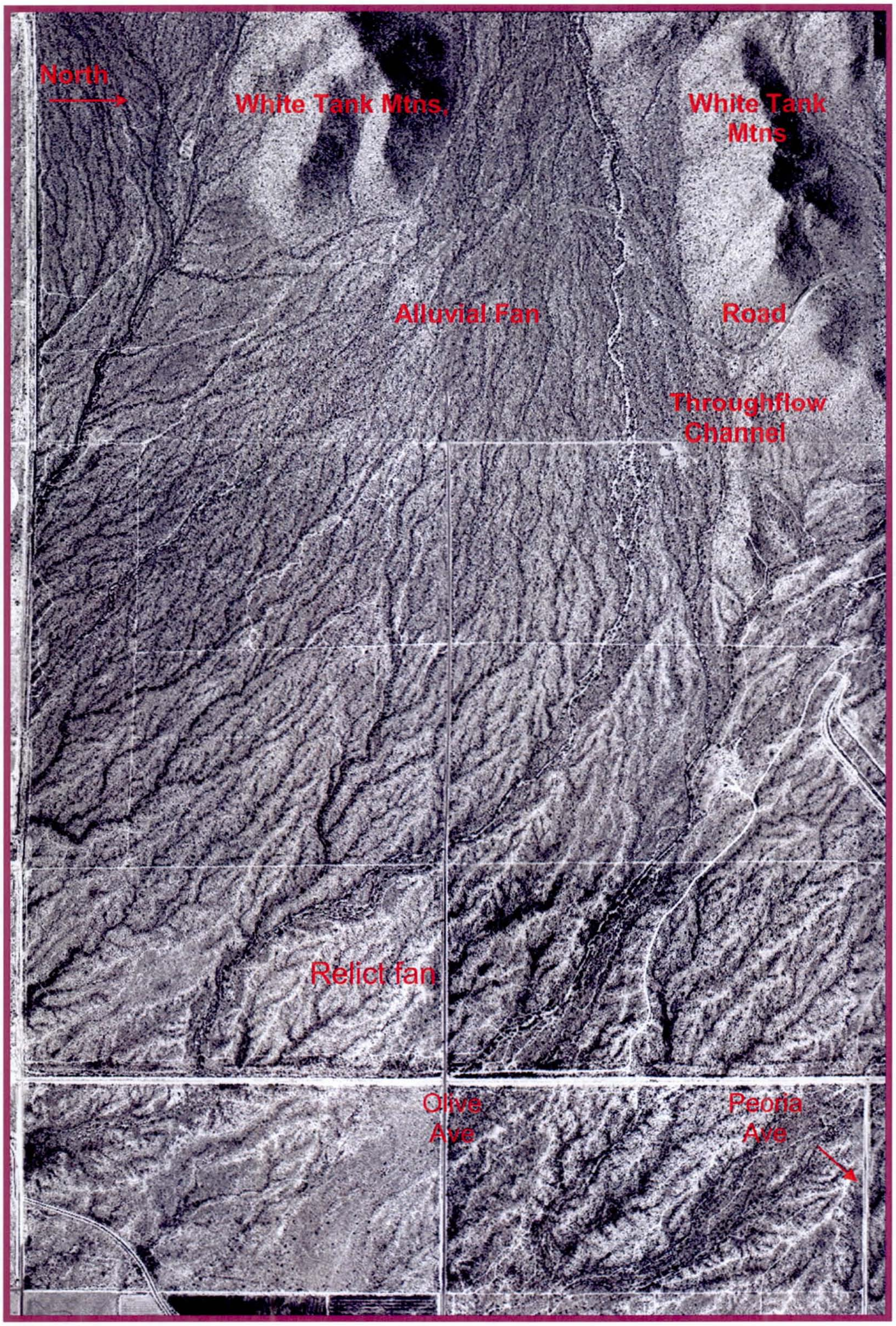
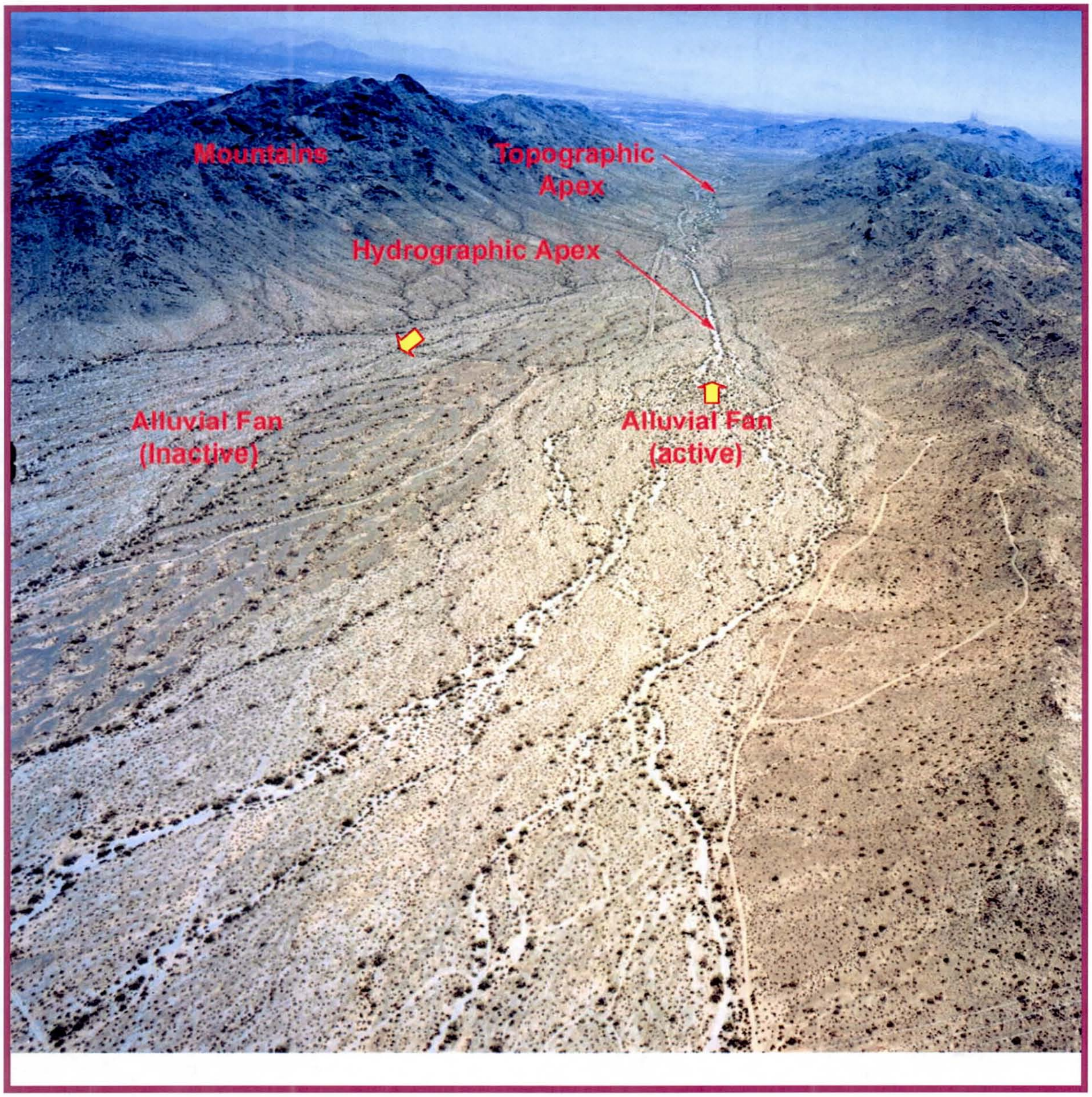


Figure 2.11 Aerial photograph of White Tank Park alluvial fan.



Location of Figures 2.13 and 2.14. Digitized from color glossy taken during July 2002.

Note: The inactive alluvial fan on the left of the scene has smooth interfluves with widely spaced small channels. The darkened part of the old alluvial fan is very old desert varnish. The light colored active alluvial fan on the right of the scene has several distributary channels with a mound of recent alluvium below the hydrographic apex. See Appendix I for many additional photographs of this site.

Figure 2.12 Oblique photograph looking east at South Mountain Park alluvial fan.

Figure 2.13 Throughflow channel on inactive alluvial fan

Figure 2.14 Throughflow flow path on active alluvial fan

2.1.4 Alluvial plains

The lower portions of many alluvial fans coalesce into a smooth and nearly level surface called an alluvial plain (Figures 1-1, 2-1, 2-3 and 2-10). An alluvial plain is either a relict floodplain of a base level stream or a very low gradient (< 0.5 percent) fan built onto the basin floor (Peterson, 1981). Alluvial plains may abut defined channels at the basin floor or they may transition into floodplains (the basin floor) of base level streams. The upper and lower boundaries of alluvial plains can be indistinct with intricately mixed sediment from upslope areas of the piedmont and base level stream. Fortunately, precise boundaries typically are not necessary for flood hazard definition because the flood hazard of alluvial plains, adjacent alluvial fan toes and adjacent floodplains of base level streams is typically from shallow sheetflooding except where there is channel incision from lowering of the base level stream. Manual users are encouraged to use NRCS soil maps (see Table 2.1 for soil types) and detailed surficial geologic maps to define alluvial plains based on sediment composition and soil type.

An example of alluvial plain flooding is shown in the Figure 2.15 below. See Appendix G for several photographs and maps of alluvial plains and flooding on alluvial plains.

Figure 2.15 View looking east at flooding on June 23, 1972 in Scottsdale.

2.2 Identification of piedmont landforms

A procedure for identifying relict fans, pediments, alluvial fans and alluvial plains is described in this section. The type of landform is identified using indicators such as surface texture, rock varnish, desert pavement, soil development, cementation of deposits, drainage pattern and channel shape. The steps and indicators of this method of flood hazard assessment are based on several publications and sources including those used by Christenson and Purcell (1985), Hjalmarson and Kemna (1991), Field and Pearthree (1992), CH_2M Hill (1992), Hjalmarson and Tram (1996) and the National Research Council (1996).

The type of landform is defined, but not necessarily named, on most NRCS soil survey maps and AZGS surficial geologic maps. NRCS soil survey maps and AZGS surficial geologic maps are available for much of Maricopa County. The investigator will need some knowledge and experience with the use of soil surveys and surficial geology maps (See Appendix I). Soil and geology maps may not have the level of detail needed for a detailed flood hazard assessment. Thus, the investigator may need to refine the boundaries of landforms shown on available published maps.

To identify piedmont landforms the investigator should first obtain topographic maps, geologic maps, soil maps, aerial photographs and any technical reports such as journal articles on the geomorphology, geology, soils, vegetation, and flooding in the project area in order to determine the general morphology and location of the landform(s) along the piedmont and in the drainage area. The second step is to use topographic maps, geologic maps, soil maps and aerial photographs to define/refine the morphology of the drainage basin and the piedmont landforms in order to recognize the landform at the level of detail needed for the flood hazard assessment. The third step, like the second step, is a continuation or refinement of the identification of the landform(s) using a field inspection of the channels and land surfaces in order to determine the composition, morphology, boundaries and location of the landforms. These three general steps for piedmont landform identification are shown in Table 2.2.

All landform identification should also include field inspection of the particular site, because similar appearing landforms on aerial photographs may, in fact, be quite different. A field examination involves walking (or driving) over the surface of the landform and along stream channels and examining cut banks, road cuts and other exposures; vegetation type and location; surface characteristics such as desert pavement, rills, desert varnish; soil development; and topography. Maps of these features are produced along with detailed field notes. A good starting point for landform identification is the location of the particular site of interest on the typical desert profile showing mountains and the piedmont (Figure 2.1).

Table 2.2 Steps for identification of piedmont landforms for assessment of flood hazards.

Recognizing landforms	Data information source
1. Define general setting (Geology, tectonics, soils, surficial geology, relief)	Geologic, topographic, aerial photos, soil maps. General reference.
Type of landform.	Detailed surficial geology maps, soil maps and geology maps
2. Define physical setting and type of landform.	
Geomorphology of source area (relief, slopes, feeder channel geometry, vegetation distribution, size of source area, drainage pattern)	Topographic maps, aerial photographs.
Geomorphology of piedmont (size, relief, slopes, channel geometry, vegetation type and distribution, surface color and soil)	Topographic maps, soil maps, aerial photographs.
Location of landform (Is there a topographic break? Is it at a mountain front? Is it at an isolated remnant or *inselberg*? Is it inset on a larger landform?)	Topographic maps and aerial photographs.
3. Verify and refine landform characteristics and boundaries.	Field work using geologic maps and soil survey maps.
Composition and age (bedrock or a sedimentary deposit, soil development, desert varnish, desert pavement, surface color and caliche)	
Morphology (plan view shape, drainage pattern and spacing, channel incision and geometry, ridges and valleys)	Field work using topographic maps and aerial photographs.
Location of landform (Is it at a topographic break? Is it at a mountain front? Is it an isolated remnant or *inselberg*? Is it inset on a larger landform?)	Fieldwork using topographic maps and aerial photographs.

Several indicators are especially helpful in determination of the type and extent of landforms on the piedmont. Some of the indicators have been shown in previous photographs of pediments, relict fans, alluvial fans and alluvial plains in section 2.1 of this Manual. These "office" and "field" indicators are used to recognize pediments, relic fans, alluvial fans and alluvial plains within sections 2.2.1 to 2.2.15.

2.2.1 Surface texture on aerial photographs and topographic maps

Pediments, relict fans, alluvial fans and alluvial plains have a distinctive appearance when viewed from an aircraft, on a topographic map or on an aerial photo image. Several examples of surface texture of the four landforms are shown in preceding section 2.1. Surface texture of the three example sites that are part of this Manual is also described in Chapter 5 of the Manual. Additional discussion of using surface texture for landform identification and mapping in Maricopa County is given in Appendix E. Surface texture is useful for landform identification as well as defining the boundaries of landforms.

2.2.2 Surface color and relative color differences

- A light surface color seen on aerial photographs usually indicates a young surface that has been recently eroded or subject to sediment deposition. Active alluvial fans, alluvial plain areas and sand channels typically have a light or relatively light surface appearance.

- A dark surface color results from weathering of the surface stones. A very dark surface typically indicates an old surface of desert varnish, desert pavement or oxidized soil common to relict fans, mountain slopes and some old alluvial fans.

- Many active alluvial fans have a light surface (or a relatively light surface) with a radiating drainage pattern.

- Many relict fans and some old alluvial fans have a dark surface of desert varnish with a dendritic drainage pattern.

2.2.3 Channel and small valley size on aerial photographs

Stereo pairs of aerial photographs used in conjunction with topographic maps and field measurements of channel geometry are useful for defining the amount and extent of channel incision and small valleys associated with incised drainages. Old-stable landforms such as relict fans and pediments clearly have greater amounts of channel incision than young-aggrading landforms such as active alluvial fans (See Table 2.1).

2.2.4 Drainage texture on 7.5 minute topographic map

Relative drainage texture domains depicted by contour-crenulation counts (small rounded upslope projection of a contour line) are used to quantitatively distinguish between pediments, relict fans and old alluvial fans as described in Appendix D.

2.2.5 Drainage pattern

- A tributary drainage pattern is characteristic of relict fans and pediments.
- Some streams build an alluvial fan, a sloping radiating deposit, which focuses at the point called the *hydrographic apex* where active fluvial sediment deposition starts. A distributary drainage pattern is characteristic of alluvial fans.
- Some streams build alluvial plains, a gently sloping rather smooth deposit, which is formed as floodwater spreads over base-level plains as *sheet flow*.
- Some throughflow streams serve as sediment and water transportation corridors between the mountains and base-level streams. These transport channels commonly form where there has been recent base-level lowering.
- Some streams head (begin) on relict fans, pediments and inactive portions of alluvial fans. These streams are tributary to throughflow and base-level streams.

2.2.6 Shape and appearance of contours on 7.5 minute topographic map

- Fan shaped, concentric and semicircular contours that bow down slope may depict an alluvial fan if there is little channel incision as indicated by small or widely spaced contour crenulations.
- Smooth contours that are straight and parallel (or slightly convex pointing downstream in plan view) indicate mild relief and possibly active sediment deposition in recent geologic time. Such contours indicate young (active) alluvial fans or alluvial plains.
- Concentric semicircular contours that bow down slope may also depict a relict fan if the contour *crenulations* are large (indicating at least 3 ft. depth of dissection) and the drainage pattern that has developed on the landform is *dendritic* or tributary (typically observed on aerial photographs). Eroding fluvial processes are active on most of these relict surfaces and alluvial fan processes (aggradation and erosion) no longer are active except where an active fan has formed within an old fan. An inactive alluvial fan may host an active alluvial fan (Table 2.1).
- A portion of a semicircular contour that bows down slope that is smooth and bounded by relatively large and narrow crenulations may indicate bifurcating flow and alluviation of a young (active) alluvial fan.

2.2.7 Location on piedmont

Throughflow streams typically pass from their steeply graded mountain canyons to incised channels of pediments and relict fans and deposit sediment and spread floodwater on alluvial fans and alluvial plains where they lose topographic confinement. The typical position of the landforms is shown in Figure 2.1.

2.2.8 Topographic break

A topographic break is where confined flood flow becomes less confined and is able to migrate more freely. Less confinement can lead to greater channel width, lesser flood flow depths and more sediment deposition. Inset fans and pockets of braided channels are common along throughflow streams where there is a topographic break. Old alluvial fans that were partly or wholly aggrading also are common below topographic breaks. A special kind of topographic break where a young alluvial fan has formed is called a hydrographic apex.

2.2.9 Desert pavement

A concentration of pebbles and cobbles on the land surface is known as desert pavement (Compton, 1977). Desert pavement is best seen in the field and is indicative of old surfaces (relict fans and pediments) formed by the removal of fine grained material by wind, soil creep and sheet flow. Desert pavement usually forms on inactive surfaces where there are pebbles and cobbles in the deposits. Desert pavement can also form on young coarse-grained alluvial fans (Christenson and Purcell, 1985). Thus, desert pavement development is not always a reliable indicator of surface age and type of landform. The mantled layer (commonly a single layer) of closely spaced pebbles typically is found on relict fans, portions of alluvial fans that are not active and occasionally on alluvial plains. Areas such as active alluvial fans and stream channels that are prone to flooding typically do not have desert pavement. Desert pavement can resemble stream channel armoring except the stones are not *imbricated*.

2.2.10 Desert varnish

Desert varnish is one of the best indicators of surface stability and the age of piedmont landforms in Maricopa County because it is easily observed and reliable. Dark brown and blackish layers of clays and manganese and iron oxides form on the surface of stable rocks over thousands of years. Although the dark appearance of rock varnish is not precisely related to age, the simple presence of rock varnish on piedmonts in Maricopa County is indicative of old surfaces such as those of relict fans. For example, a very dark varnished desert pavement may be present on very old-flat interfluves of relict fans (Figure 2.16). Soluble surfaces of carbonates and friable rocks such as granite that weather rapidly do not support varnish.

For additional information on rock varnish, see Liu and Dorn (1996), Dorn and Oberlander (1982) and Dorn and others (1989).

Figure 2.16. Varnished desert pavement that is a few thousand years old.

2.2.11 Surficial geology

Geologic maps and reports are an excellent source of information on the type of landform as described in Appendix L. Surficial geologic maps differentiate deposits of different ages on piedmonts and delineate their lateral extent. Thus, these maps provide information on the distribution of pediments, relict fans, and inactive and active fans. The criteria that are used to differentiate and map surficial deposits include many of the indicators listed in this section, including relative topographic position, drainage patterns and incision, vegetation assemblages, surface topography, desert pavement and rock varnish development, surface color, and soil development. The surficial geology of most of eastern Maricopa County has been mapped at 1:24,000-scale, and much of this map information is available in digital format at the AZGS. Some of the landform boundaries may need refinement to meet the required detail of the flood hazard assessment, so all landform boundaries should be field checked using the techniques described in this Manual.

2.2.12 Soils

Soil survey reports and maps of the NRCS are an excellent source of information on the type of landform. Soil survey reports typically identify the landform associated with mapped soil units (Camp, 1986 and Hartman, 1977). Common soil types corresponding to piedmont landforms of Maricopa County and surrounding areas are noted in Table 2.1. A major advantage of published NRCS soil surveys is the mapping is consistently accomplished in accordance with standards. A disadvantage for new users of the published NRCS soil surveys is that the reports are written for a wide range of uses and are not specifically for landform identification and flood hazard assessment. Users of soil surveys are encouraged to get assistance from NRCS soil scientists. Many of the soil boundaries need refinement to meet the required detail of flood hazard assessment. All NRCS soil boundaries should be field checked using the techniques given in this Manual.

2.2.13 Vegetation

Vegetation type and distribution, as seen on good quality aerial photographs, can also be a reliable indicator of landform. For example, saguaro cacti, jumping cholla, creosote bush and saltbush are seldom on very active alluvial fans and are typically on old surfaces of relict fans and pediments. Isolated saguaro cacti and creosote bush do however, occur on parts of unstable landforms and thus are not a stand-alone definitive indicator. Creosote bush, for example, is on several alluvial plains subject to sheet flow. Abundant mature saguaro cacti may be found on relict fans, pediments and inactive alluvial fans adjacent to the unstable land of wholly or partly aggrading landforms where sediment is removed or deposited by spreading floodwater on which there are very few saguaros.

Many distributary channels of old (inactive) alluvial fans and pediments are lined with abundant paloverde trees and bushes. The native riparian vegetation affords resistance to bank erosion and channel migration but is present because the land is stable. Desert trees and bushes tend to be scattered about on active alluvial fans suggesting the absence of stable flow paths.

2.2.14 Channel shape and capacity

A field examination of the form and size of throughflow and tributary channels can reveal important indicators of the type of piedmont landform (and also the flood hazard discussed in the next chapter). Most throughflow streams are flat bottomed with a bed of deposited sediment (Figure 2.17) that is remobilized during floods. Most tributary streams that head on the piedmont are somewhat V-shaped with a narrow channel bottom and little, if any, deposited sediment. Some throughflow streams are channels that have cut to form gullies. According to investigators such as Graf (1982) and Hedman and Ostercamp (1982), the active channels are in the bottom and the form and size of these gullies is not related to discharge except in a very general sense. The user should be aware that the gullied depth (Figure 2.17) for piedmont streams of Maricopa County probably is related to factors such as changes of vegetation cover and not necessarily flood discharge. However, general relations between channel capacity and flood frequency are useful for identification of relict fans, pediments, alluvial fans and alluvial plains.

There are general relations of bank full capacity and recurrence interval for piedmont landforms in Maricopa County. For example, based on the author's experience, the 100-year flood nearly always is less than bank full capacity for relict fans with convex side-slopes shoulders and concave foot slopes. The bank full capacity of throughflow streams traversing most pediments is more than the 50-year flood and the 100-year flow is confined between defined ridges. The bank full capacity along distributary channels of inactive alluvial fans typically in more than the 5-year flood and seldom is more that the 25-year flood. Throughflow channel capacity of active alluvial fans and inset alluvial fans typically are about the 2-year flood and seldom are more than about the 10-year flood.

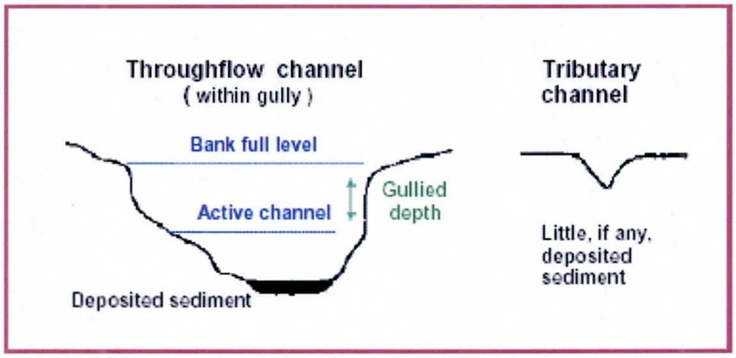


Figure 2.17. Cross sections of throughflow and tributary channels showing deposited sediment.

The capacity of tributary streams that form on piedmont landforms is variable and may be related to the drainage pattern on relict fans and pediments (Table 2.1). Where first and second order streams of relict fans and pediments have a parallel appearance, the bank full capacity typically is greater than the 50-year flood. For more radiating dendritic patterns the bank full channel capacity is much less and typically is more than the 10- year flood. On pediments the 100-year floodwater that over tops banks usually is confined to adjacent overflow areas. On smooth-flat relict fans, the 100-year floodwater can spread over wide areas as sheet flow and the sheet flow may become concentrated down slope. Therefore, if the investigator knows the recurrence interval for a particular peak discharge, he or she can roughly estimate the type of landform.

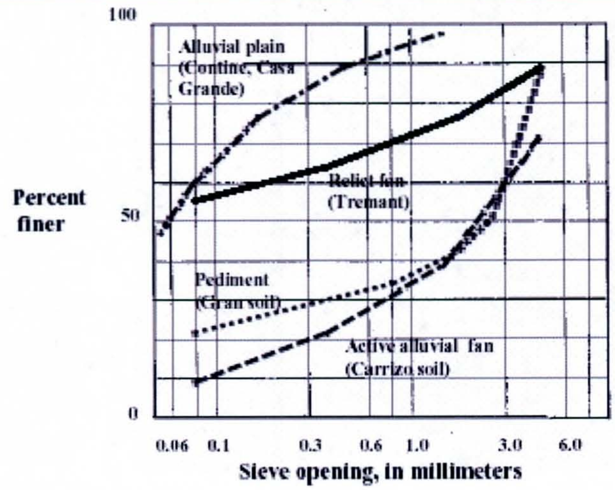
2.2.15 Sediment

The sediment in alluvial plains generally has a much finer distribution of grain size than the surface material of alluvial fans, relict fan and pediments (Figure 2.18a). Although the particle size of material on a landform is not necessarily used as an indicator to predict the type of landform, landforms do exhibit some common sediment characteristics that are used for this manual.

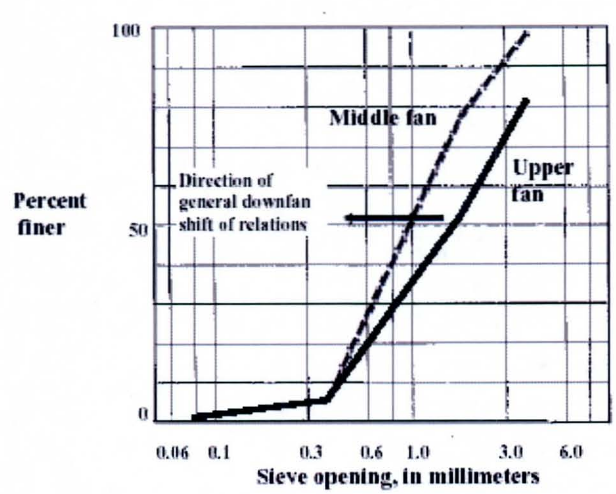
A few useful relations of soil particle size follow:

- Several relict fans have a grain size distribution like that shown for the Tremant soil in Figure 2.18a).
- Material of relict fans ranges from clay to boulders and characteristics vary possibly because relict fans are formed by both debris flow and water flow deposits and these deposits have different characteristics (Bull, 1964).
- The grain size shape and distribution of weathered pediment material is related to the parent material and is dependent on the underlying rock type.
- Sediment in young (active) alluvial fan deposits ranges in size from clay to boulder and tends to be somewhat sorted partly because recent deposits in Maricopa County are typically from water floods.
- There typically is a general increase in sorting down active fans and a shift in the grain (*clast*) size, such as the median grain size (D_{50}) as shown in Figure 2.18b.

It is important to note that alluvial fans that are wholly or partly aggrading can be composed of a wide range of material size. Most young (active) fans in Maricopa County have coarse sand with some gravel and scattered cobbles near the hydrographic apex. The lower or outer parts of the fan may be composed of fine sand, silt and clay with small tongues of coarser material such as Carrizo soil. These distal fan areas (toes) coalesce and transition into alluvial plains with a similar material size and heterogeneity as the active fan toes. A simple quantitative example of how sediment might be distributed along an active alluvial fan is in *Sediment grain size along an idealized active alluvial fan* in Appendix Q.



a. Indicative graphs for major landforms with corresponding NRCS soil type.



b. Active alluvial fan at southern end of White Tank Mountains. Samples were collected about 3 to 6 inches below the surface that appeared light colored on aerial photographs.

Figure 2.18. Cumulative graphs of material size versus frequency indicative of landforms in Maricopa County.

2.2.16 Additional information

There is a considerable amount of useful published information on the stratigraphy of alluvial fan deposits that is also useful for landform identification. While much of this literature is for specialists in fluvial deposits and sedimentary geology, some is useful for the stability assessment of this Manual.

According to many geologists, alluvial fan deposits are recognized mostly by their physical characteristics (Nilsen, 1987; Blair, and McPherson, 1994). Several physical indicators are used because each indicator is not necessarily unique. Exposures of unconsolidated sediments in active fan channels can be examined in the field and samples of sediment can be collected and analyzed. Major physical indicators of active alluvial fan deposits found in the stratigraphic record are as follows:

- The deposits are located relatively close to their source area with a limited radial length.
- Deposition is dominantly by unidirectional, high-energy fluid flow, on steep slopes.
- The deposits are typically very poorly sorted and may have a great range in grain size.
- Clasts are poorly rounded, reflecting the short distance of transport. An exception to the common angular clasts is where the alluvial fan material is second or third generation sediments derived from relict fans.
- The deposits are compositionally immature and have a great range in composition, depending upon the types of rocks present in the source area.
- The deposits are characterized by major changes in lateral and vertical facies, particularly in the downfan direction.
- The deposits are characterized by rapid downfan decrease in both average and maximum clast sizes.
- The deposits generally contain very small amounts of organic matter because of the oxidizing conditions of sedimentation.
- Facies are predominantly planar-bedded associated with upper-regime water flow.
- The depositional bodies have a lenticular or wedge-shaped geometry and typically form clastic wedges.
- The deposits may be characterized by a radial sediment dispersal system.

For other useful information on the identification and dating of alluvial fan deposits from the stratigraphic record, see Bull (1987), Blissenbach (1954), Massari (1996), Blair and McPherson (1992), Blair, Clark and Wells (1990) and Hereford (1996). The map of surficial geology that includes deposits of specific floods, along the Colorado River in the Grand Canyon by Hereford shows the detail possible using geologic methods.

2.3 Special landform boundary and drainage considerations

Traditional landform mapping is based mostly on manual (visual) interpretation of aerial photographs, topographic maps and ground observation. Ground observations serve to define the composition of landforms. The precision of landform boundaries depends on both the requirements of the particular flood hazard assessment and the nature of the boundary. Some boundaries of landforms are not distinct and may be a few tens of feet wide and other boundaries are not unique and must be estimated. Boundaries of landforms are shown on a base map approved by the FCDMC (See Appendices E and R for additional information about maps).

To best define the boundaries of landforms the investigator should be familiar with topographic maps, the 3-D aspects of topographic maps and stereo viewing of aerial photographs. For example, the investigator should be familiar with the shape of contour lines at ridges and how to draw a drainage divide on a topographic map. The investigator should also be familiar with stereo viewing of landform features. Optical 3-D viewing using pairs of aerial photos affords quick comparison of the shape and Arial extent of landforms and rapid detection of subtle landform features and boundaries.

For areas of little topographic relief, 7.5-minute topographic maps may not show important features such as distributary channels on piedmonts which leave the drainage area. Detailed topography at a scale of 1 inch = 100 to 500 ft with contours at 1 or 2 ft. intervals should be considered for areas of low relief. Also, high resolution aerial photographs are a necessity to see important drainage features.

The boundaries of mountains, pediments and relict fans typically are easy to define. However, the definition of boundaries for alluvial fans and alluvial plains that are associated with a particular upslope drainage basin is not straightforward. Generally speaking, if the investigator needs landform boundaries associated with a particular drainage area and there is commingling of floodwater from two or more drainage basins, the boundaries must be estimated using approximate methods. Also, indistinct boundaries where deposited alluvium is blended or interfingered cannot be precisely defined.

Boundaries that are difficult to precisely define include the following:

- Between coalesced alluvial fans where distributary channels are shared by fans.
- Between alluvial plains where sheet flow of adjacent drainages commingles.
- Between the toe of pediments and the start of some inactive alluvial fans.
- Between the toe of many alluvial fans and the start of alluvial plains.
- A few drainage basin boundaries.

2.3.1 Drainage basins

Some drainage basins on piedmonts may have small-active streams that cross the topographic divide well above the apex (Figure 2.19A). Although not common, small distributary channels on piedmonts can enter or leave a drainage basin. Where these channels convey a small portion of the total flood flow, the amount of discharge crossing the topographic divide can be estimated and added to or subtracted from the peak discharge at the apex.

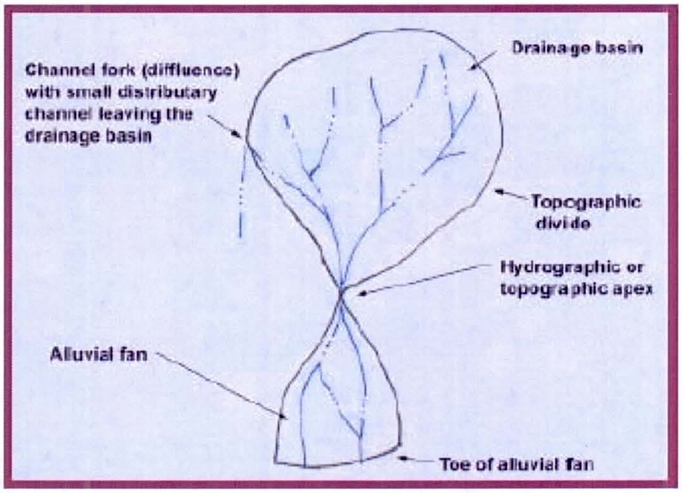
A diffluence in a drainage basin with one channel in the basin and the other channel crossing the drainage divide into an adjacent drainage basin (Figure 2.19A) may seem illogical or impossible to some engineers and hydrologists. Many engineers and hydrologists have not experienced these phenomena because it commonly is not discernible on 7.5-minute topographic maps and is difficult to define on aerial photographs. The drainage divide may appear to be improperly identified and the question--How can a drainage divide have a channel crossing it?--may seem vexing. The fact is that channels within drainage basins on piedmonts do fork and the channels can become widely separated and drain into different intermountain basins.

Conditions at small earthen dams or stock watering ponds on piedmont slopes also should be considered. The area of the stock-water pond may only contribute to the downstream channels when there is flow through the spillway. The affect of the stored flood flow on the 100-year flood should be assessed. Also, flood flow at some stock watering ponds can he diverted across the drainage divide as described above.

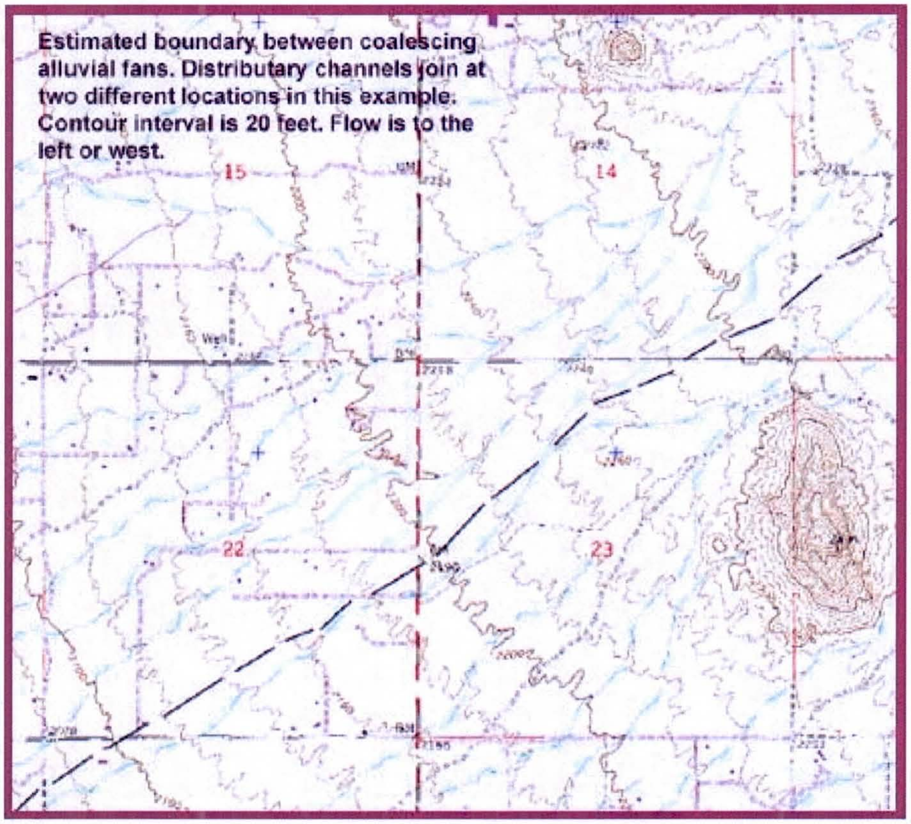
2.3.2 Boundaries along coalescing alluvial fans

There are two important kinds of alluvial fans with distributary channels that when coalesced with similar alluvial fans types have uncertain boundaries. These are active alluvial fans and some inactive alluvial fans with distributary channels.

Before the boundaries of alluvial fans with distributary channels are defined, the hydrographic (active fan) apex is located (see section 2.1.3.3). All direct runoff from precipitation within the topographic divide of the drainage basin will be drained by the stream at the apex if the overall drainage system is tributary. If the drainage area above any particular point of interest on the piedmont can be defined, the investigator should check that no channels cross the defined ridge line (topographic divide) by using orthophotoquad maps, aerial photographs, and possibly a field inspection.



A. Sketch of small distributary channel crossing a topographic divide



B. Estimated drainage boundary for coalescing alluvial fans

Figure 2.19. Special drainage basin and alluvial fan boundary considerations.

After the apex is located, the boundaries of the alluvial fan can be defined. Starting at the apex, the ridge lines are defined on each side of the apex. The ridge lines are on the shoreward side of the outermost channels. Ridge lines, commonly are along ridges of interfluves separating defined distributary channels, are the boundaries of many degrading or relatively stable alluvial fans (Figure 2.19B). Trough lines form the boundaries of some coalesced alluvial fans especially where fans are aggrading.

Deposited debris of a single alluvial fan commonly has a trough along the boundary of the fan.

Where tributaries to the alluvial fan are severed the boundaries are continued on the opposite bank of the tributary. The potential drainage divides may appear to cross over into an adjacent alluvial fan (Figure 2.19B). Areas of coalesced alluvial fans with overlapping channels are separated by a probable boundary that bisects the defined ridge lines for the two areas. The potential divides tend to be perpendicular to the topographic contours and split any X-shaped confluence-diffluences where the channels from each fan join and then divide. The "probable" boundaries are estimated defined from the apex to the toe of the alluvial fan.

In addition to using the topographic ridge and trough lines to define the boundaries of the alluvial fans, the drainage texture, surface texture, soils, surficial geology, vegetation, desert varnish and other indicators can be used as discussed previously. The boundaries of many fans correspond to the boundaries of drainage-texture and surface texture domains. Soil maps that delineate recent depositions of soil also may assist in boundary definition. Changes in vegetation density and the amount of desert varnish also are indices of the boundaries of alluvial fans.

2.3.3 Boundaries along toes of alluvial fans

The toes of alluvial fans with distributary channels (active and some inactive alluvial fans) are defined using several factors. The toe cannot extend beyond the base-level stream. The toe also cannot extend beyond where the stream patterns change from distributary to tributary over the width of the alluvial fan. Also, the toe ends where the flood flow is unconfined across the width of the alluvial fan and becomes sheet flow; sheet flow marks the start of an alluvial plain. The presence or absence of confined flow can be difficult to define especially where channels gradually become smaller and less significant down slope. Like the lateral boundaries, it may not be feasible to define precisely a narrow boundary at the toe. The toes of many alluvial fans are irregularly shaped as the distributary channel system changes to tributary channels of sheet flow at various distances below the apex. The washes and plains that form the base level represent the downstream limit of the toe. Soil color and sediment character also may change, indicating lower or upper limits of recent sediment deposition or a different source of sediment such as the base level stream. Lastly, the profile of the piedmont may show a rapid decrease in slope that corresponds to the approximate location of the toe. The toe is located on the basis of the above considerations, and the boundary is drawn approximately parallel to the contours connecting the potential divides.

2.3.4 Drainage boundary on alluvial plains

Normally, only rough estimates of drainage boundaries can be made on alluvial plains and such estimated boundaries may not be practical. Floodwater of adjacent drainages commingles and relatively small obstructions can affect the flow paths of sheet flow and sheet floods on alluvial plains. The nature of flooding on alluvial plains is shown in Appendix G of the Manual where there are several examples of sheet flow that is diverted by small obstructions and roads. The investigator should also consult the Glossary for sheet flow and sheet flooding and Arizona State Standard 4-95 (1995) for a description of sheet flooding.

2.3.5 Boundary between toe of some pediments and start of inactive alluvial fans

The transitional zone between some pediments and inactive alluvial fans with distributary channels is wide and difficult to define. Drainage texture characteristics can be used to estimate the boundary because the drainage texture of old alluvial fans is different than pediments (Appendix D and Hjalmarson and Kemna (1991)). The drainage texture of inactive alluvial fans with distributary channels is rather constant and the drainage texture of pediment increases upslope. The drainage texture, as depicted of USGS 7.5 minute topographic maps commonly changes in the transitional zone between the inactive alluvial fan and the upslope pediment.

2.3.6 Summary

Some landform boundaries can only be estimated and the investigator should utilize the many indicators described in this chapter for the definition. Several indicators that are shown on topographic maps, aerial photographs and by field inspection should be used. For example, landforms have distinct surface texture and relict fans commonly are paved with dark desert varnish. These and other identifiers commonly change at the boundaries of landforms and can be used to map the boundaries.

2.4 Summary

Relict fans, pediments, alluvial fans and alluvial plains are the four major landforms of piedmonts in Maricopa County. Each landform can be recognized using identifiers such as desert pavement, surface color, vegetation type and location, desert varnish, transverse relief, drainage texture, drainage pattern, composition, sediment particle size and amount of soil development. The identification of landform type is reliable when several identifiers point to a particular type of landform.

Soil survey reports by the Natural Resources Conservation Service provide valuable information on the type of landform and fluvial processes. These often under utilized reports show soils information on 7.5-minute orthophoto maps. Most soil types correspond to morphology and landform types. Use of NRCS reports *Soil survey of Aguila-Carefree area, parts of Maricopa and Pinal counties, Arizona* (1986) and *Soil survey of Maricopa County, Arizona, central part* (1977) will contribute greatly to the identification of landform type and the overall assessment of flood hazards on piedmonts.

Published geologic maps of the Arizona Geological Survey (See Appendix L) are also a valuable source of information with implications for piedmont flood hazard assessment.

An example map of a mountain and the down slope piedmont landforms is shown in Figure 2.20. For this particular example the landforms were identified in the soil survey report (Camp, 1986) and verified using procedures in this chapter of the manual. For typical studies the aerial photographs, any surficial geology and all the indicators will accompany the map of the landforms. The mapped landforms shown in Figure 2.20 are the result of stage 1 of this method and provide the geomorphic basis for the flood hazard identification (Section 1.7).

Some of the indicators of landform type such as rock varnish and desert pavement are also indicators of landform age or surface stability discussed in the next chapter of this manual.

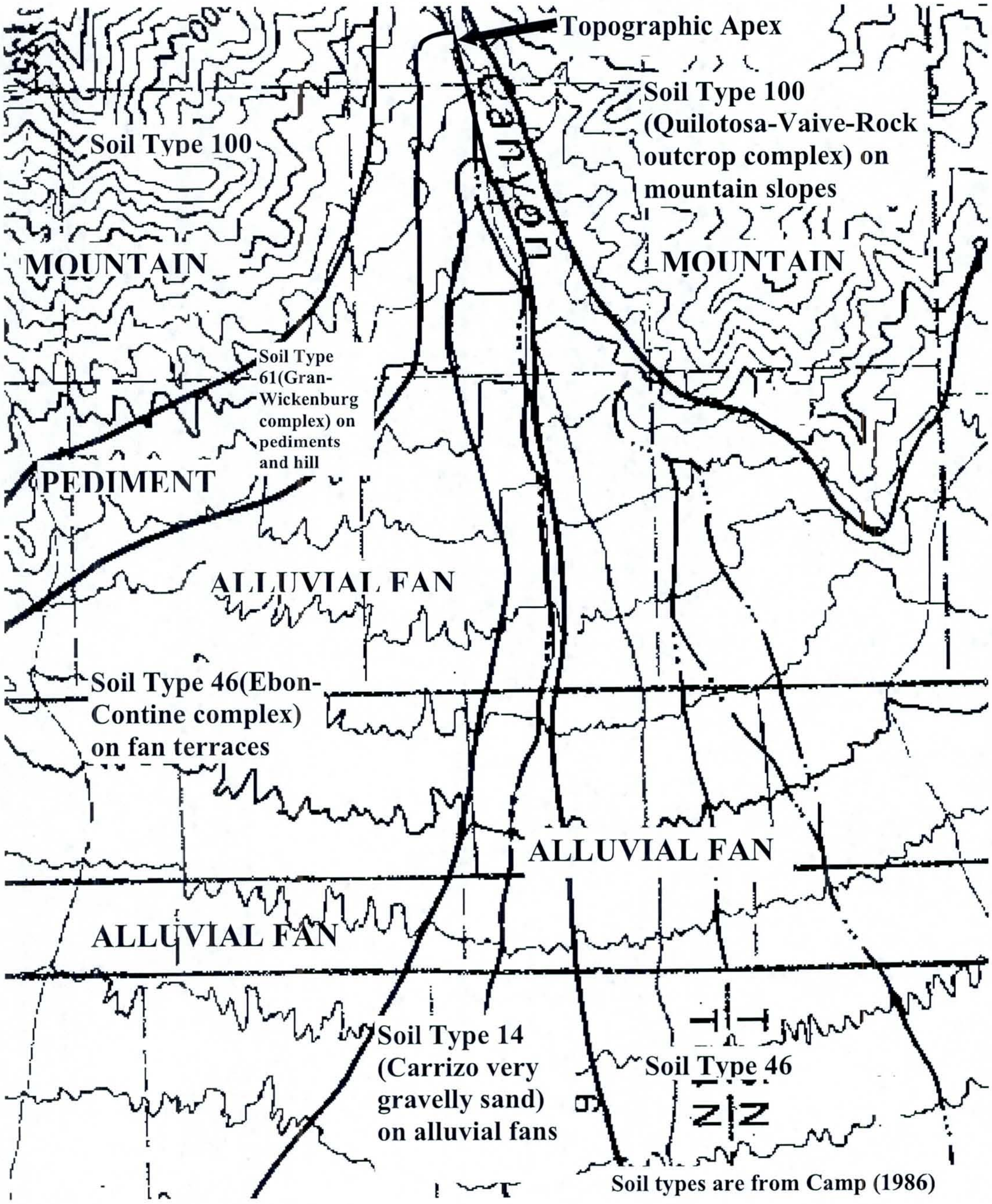


Figure 2.20. Example map of soil, topography and landforms that represents the completion of stage 1 of the method.

3

IDENTIFICATION OF STABLE AND UNSTABLE AREAS ON PIEDMONTS OF MARICOPA COUNTY

STAGE 2 OF METHOD

This chapter describes a procedure for identifying the nature and location of flood hazards on the four major piedmont landforms. These flood hazards are broadly classed as areas with either stable or unstable flow paths. Stable and unstable flood hazards are first defined. Indicators that should be used to define stable and unstable areas are defined next. Flow path stability is closely related to various piedmont landforms discussed in Chapter 2, so this chapter concludes by considering the nature of flood hazards on relict fans, pediments, inactive and active alluvial fans, and alluvial plains.

Areas where flow path uncertainty and any uncertainty in hydraulic factors such as channel geometry and roughness can be ignored for the assessment of flood hazard are called stable areas in this manual. Areas are considered unstable if the flow path uncertainty *"is so great that this uncertainty cannot be set aside in realistic assessments of flood risk or in the reliable mitigation of the hazard"* (National Research Council, 1996). Stable and unstable areas are defined as follows:

- **Stable** The relative state of the location, geometry and roughness of a channel, network of channels or landform where any changes of flow path, geometry and roughness during floods are likely to be minor and can be set aside in realistic assessments of flood risk.

- **Unstable** The relative state of the location, geometry and roughness of a channel, network of channels or landform where major changes of flow path, geometry and roughness are possible during floods and cannot be set aside in realistic assessments of flood risk.

Application of traditional engineering methods and standard-step hydraulic methods like HEC-RAS (COE, 1995) to determine 100-year flood elevations (FEMA, 1995) is appropriate where the flow paths and flood boundaries are considered to be relatively stable. Many movable bed streams have stable or certain flow paths during some finite period. These streams commonly have relatively minor changes of geometry and roughness during floods that are set aside in realistic assessments of flood risk.

Common stable areas are:

- Hillside
- Relict fan
- Pediment
- Inactive alluvial fan
- Throughflow channel with a movable bed
- Some sheet flow and split flow areas

In areas where substantial changes channel geometries and positions may occur during floods such that the assumption of stable flow boundaries is not valid, traditional flow modeling methods do not adequately describe flood hazards. Active alluvial fans are classed as unstable because channel positions and flow paths may change substantially during floods. Unstable areas may also include distributary channels below active alluvial fans where the distribution of flow in the channels is uncertain. In these situations, the overall distributary network may be relatively stable, but there is substantial uncertainty regarding the detailed distribution of flow in any particular flood. It is important to recognize that unstable areas (uncertain flow paths and uncertain distribution of flow) have definable limits such as the valley edges or the limits of the particular landform where the flow paths reside.

Some sheet flow and split flow areas may be considered to have an uncertain distribution of flow where the hydraulic geometry, grade and roughness are relatively stable but small obstructions or small amounts of scour or fill associated with the generally shallow flow depths can significantly alter the distribution of flood flow. The uncertainty of the flow distribution for these otherwise stable areas may or may not be set aside depending on site conditions. Several examples of the effects of obstructions on the flow distribution of sheet flooding on alluvial plains are shown in Appendix G.

Common unstable areas are:

- Active alluvial fan
- Some multi-channel areas below active alluvial fans
- Alluvial plain with active sedimentation
- Multi-channel pocket along a throughflow channel
- Area of recent sediment deposition and erosion
- Split flow channel where flow is wide and shallow
- Areas of low relief where minor development such as roads can divert floodwater and cause significant erosion in areas otherwise not susceptible to flood hazard.

As used in this Manual, the terms stable and unstable are relative states of hazard on the landform. Obviously, all piedmonts of Maricopa County are undergoing change as a result of long-term erosion and deposition. Where the change is slow and progressive and effects such as channel movement are also slow, the landform is considered relatively stable. Where the changes may be sudden and there is a reasonable possibility that dramatic effects such as channel *avulsion*s may occur during the 100-year flood regulatory period, the landform is considered unstable. A landform can also be considered potentially unstable if slow, progressive change results in a sudden event such as the rapid evacuation of accumulated debris from a mountainous drainage basin to the piedmont. For excellent discussions of natural processes and man's activities associated with perceptions of the relative state of landforms see Schumm (1994) and Graf (1977).

The procedures described in this chapter use many of the readily observable indicators described in Chapter 2 to assess landform stability. These indicators are used to delineate areas of potential flooding on each of the landforms. Many of the stability indicators are simple measures of relative surface age and weathering like desert pavement and rock. As in Chapter 2, Manual users are encouraged to consult existing data resources such as soils maps and surficial geologic maps.

More sophisticated dating techniques such as the radiocarbon and optical dating used by White and others (1996) are beyond the scope of this manual. The digging of observation/test trenches for studying surface geology and soils is also beyond the scope of this manual.

3.1 Identification of stable and unstable areas

The purpose of this section is to describe how to identify stable and unstable flood hazard areas of piedmont landforms. The procedure described here is complementary to the procedure used to identify landform types in Chapter 2 of the Manual because most of the indicators used to identify the type of landform such as surface texture, surface geology, rock varnish, desert pavement, cementation of deposits, drainage pattern and channel shape are also used to identify stable and unstable areas. Several additional indicators of flow path stability are introduced in this chapter.

A few indicators of stable and unstable areas of landforms along with landform age and the approximate recurrence interval when channels are filled are shown in Table 3.1. The information in Table 3.1 serves as both an introduction and summary to this chapter of the Manual. These and other indicators of the nature and location of flood hazards on piedmonts in Maricopa County will be discussed in detail in the remainder of this chapter.

3.1.1 Basis of indicator method

The nature and extent of piedmont flooding is estimated using several indicators. All flow path and hydraulic stability properties of a particular landform cannot be accurately predicted, but a reliable assessment of stability can be made where several indicators point to a particular stability condition. Pediments, relict fans, inactive and active fans, and alluvial plains each have discrete sets of properties that relate to the character of flooding on these landforms. Thus, these properties can be used to evaluate the stability of flow patterns on the respective landforms. Much of the information essential to defining stable and unstable areas of flooding is obtained by field examination of the piedmont. Other important information is obtained from topographic maps, soil surveys, aerial photographs, surficial geologic maps and reports of flooding. This is the scientific basis of the determination of stable and unstable areas.

Table 3.1 Selected indicators of stable and unstable areas

INDICATOR	LANDFORM AGE[1]	LANDFORM STATE[2]	FLOOD FREQUENCY[3]	SIGNIFICANCE FOR IDENTIFYING LANDFORM AND STABILITY (TYPICAL)
Morphology				
ridge & valley	O	S	--	On relict fans and pediments.
Throughflow Channels[4]				
incised > 10 ft.	O	S	$> Q_{100}$	On relict fan surfaces where side-slope shoulders are convex and foot slopes are smooth and concave.
incised < 3 ft.	I	S	$> Q_5$	On inactive fans where transverse foot slopes are steep and shoulders are smooth and convex and summits between channels are smooth and flat.
incised < 2 ft.	Y	U	Q_2	On unstable surfaces where banks are steep and channel width-depth ratio > 10 at bank full stage.
incised <1 ft.	Y	?	any	On alluvial plains with smooth surfaces and very little cross-drainage relief
Drainage pattern				
tributary				
parallel channels	O	S	$> Q_{50}$	On relict fans and pediments where ridges between first and second order streams are parallel.
dendritic channels	I	S	$> Q_{10}$	On relict fans and pediments and inactive areas of alluvial fans.
distributary	I,Y	?	--	On active and inactive alluvial fans and, in places, on granite or granite-like pediments
faint with wide areas between flow paths	Y	U	any	On alluvial plains where the slope is not great enough to override any influence of minor topographic irregularities.
Vegetation				
Creosote bush	O	S	$> Q_{50}$	Predominant vegetation on stable calcium carbonate rich soil.
	I,Y	?	any	Not the predominant plant.
Saguaro	O	S	$> Q_{50}$	On stable surfaces.
Desert trees	I,O	MS, S	$> Q_5$	Along channel banks.
	Y	U	any	Scattered over area.
Soil development				
Reddish color	I,0	MS	?	On pediments, relict fans, inactive alluvial fans and alluvial plains and may indicate the surface is stable.
B horizon	O	S		May indicate the surface is stable.
Weak B horizon	I	S		Can form in a few thousand years.
Calcic horizon	O	S		Crystals on gravel indicates surface has been stable for hundreds of years.
Desert varnish				
None	?	?	?	May indicate the surface is unstable. Does not form on granite or limestone and where ground cover vegetation is dense.
Some	O, I	MS, S	$>Q_{10}$	Varnished rocks may be reworked from older upslope surfaces such as bedrock. Also, surface may be removed by erosion.
Much	O	S	$> Q_{100}$	Varnished boulders and larger cobbles with few varnished smaller stones.
Desert pavement	O	S	$> Q_{50}$	Dense "pavement" with smooth surface.

1 Y=young (<500 years), I = intermediate (>500 and <10,000 years), O = old (>10,000 years) and ? = inconsistent indicator of age.
2 S = stable (flow paths not expected to change over regulatory period), MS = moderately stable (flow paths may change in places during regulatory period of 100 years), U = unstable (flow paths expected to change in places during large floods) and ? = not a consistent indicator of state.
3 Approximate recurrence interval at bank full level. May include small adjacent overflow areas.
4 Values are for drainage basins less than 5 mi^2.

3.1.2 Indicators of stable and unstable areas

The paths of flood flow on piedmont landforms in Maricopa County are considered stable or unstable based on the indicators described below. Investigators should always bear in mind that any one indicator, or even several indicators, may erroneously suggest that an area is either stable or unstable. Therefore, investigators should employ most or all of the following indicators to assess stability of piedmont fluvial systems.

1. Flow path movement

Stable areas. If there has been no channel movement, formation of new channels, and/or fresh mudflow or debris flow deposits on the landform or portions of the landform as depicted by comparison of old and recent aerial photographs and topographic maps then the landform may be stable. A fundamental indicator of flow path movement, especially when also applied to similar surrounding areas, is the movement of throughflow channels over a period of a few tens of years (There is good photo coverage of Maricopa Co. from the early to mid-1950's.). Flow paths may be stable if no throughflow channel movement is observed from comparison of good quality recent and historical aerial photographs and if there are no documented eyewitness accounts or geologic evidence of recent channel movement, formation of new channels, and/or mudflow or debris flow deposits on the landform or portions of the landform. The length of the historical record is fairly short, however, so it is very important that other indicators also point to stable surface conditions before flow paths are considered stable.

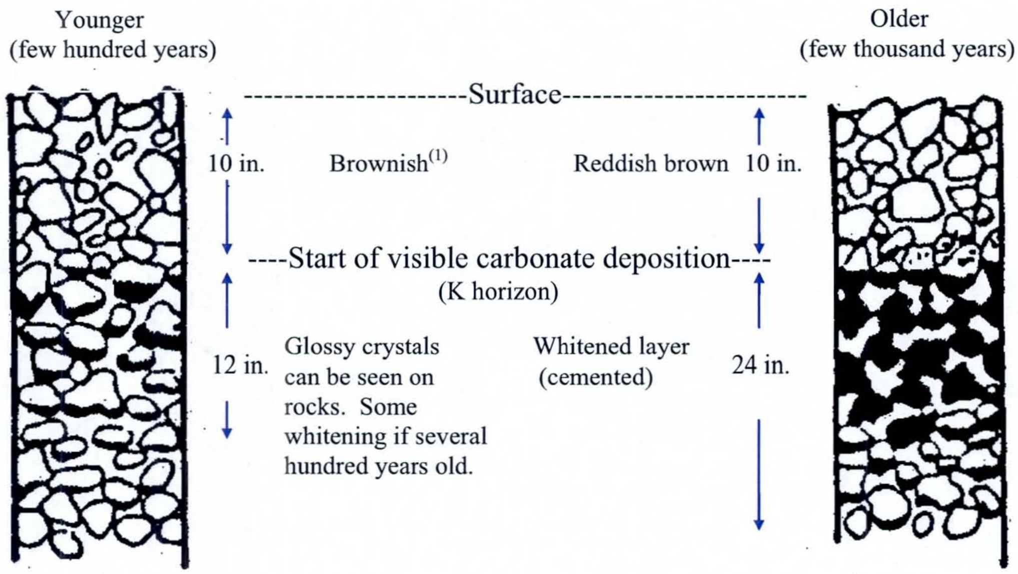
Unstable areas. An area obviously has unstable flow paths if there is documented movement, abandonment or formation of new throughflow channels on aerial photographs, by land surveys and topographic maps.

Several recent studies of active alluvial fans in Maricopa County have demonstrated dramatic historical channel changes. Field (1994) and CH_2M Hill (1992) found evidence for significant channel movement in the upper part of the White Tank Fan, which is located on the western slopes of the White Tank Mountains. Investigations of Tiger Wash alluvial fan in westernmost Maricopa County documented the development of several large new channels during a large flood in 1997 (Klawon and Pearthree, 2000).

2. Soils (carbonate zones)

Stable areas. Visible calcium carbonate development along the banks of stream channels strongly suggests the channel is stable (See Figure 3.1). An obvious soil carbonate zone like that shown in part A of Figure 3.1 is an excellent indicator of a stable surface adjacent to the channel. A well developed soil with reddish-brown sandy clay *loam* (Figure 3.2 and Table 3.1) or clay texture a few inches below the surface is also a good indicator the surface of the landform is stable (see Appendix L). Development of obvious carbonate and clay horizons in soils implies that the surficial deposits have not been subject to substantial erosion or deposition for at 10,000 years

A. Typical Calcium carbonate accumulation in gravely material indicated by black shading
(Thicknesses are typical and can vary)



(1) Recent surface deposits such as those along active stream channels and on active alluvial fans will be light colored--commonly light gray or tan--because the weathered coating has been removed by erosion and residence time has been too short for new oxidation to be visible.

B. Photograph of conglomerate along incised channel of inactive alluvial fan

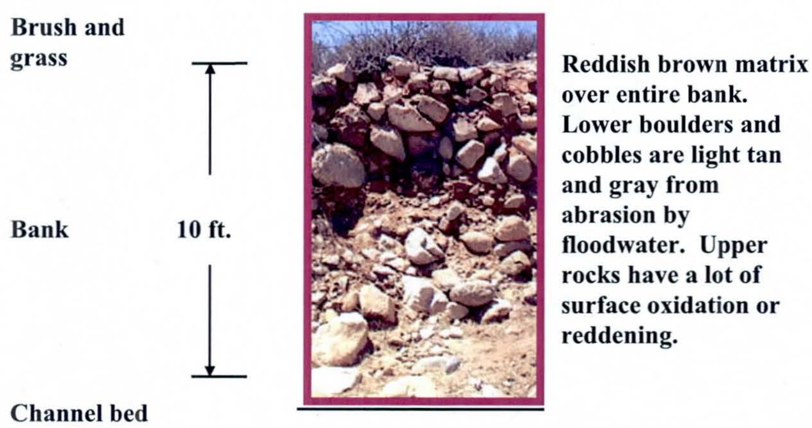


Figure 3.1 Sketch of typical calcium carbonate development and photograph of typical conglomerate at White Tank Park site.

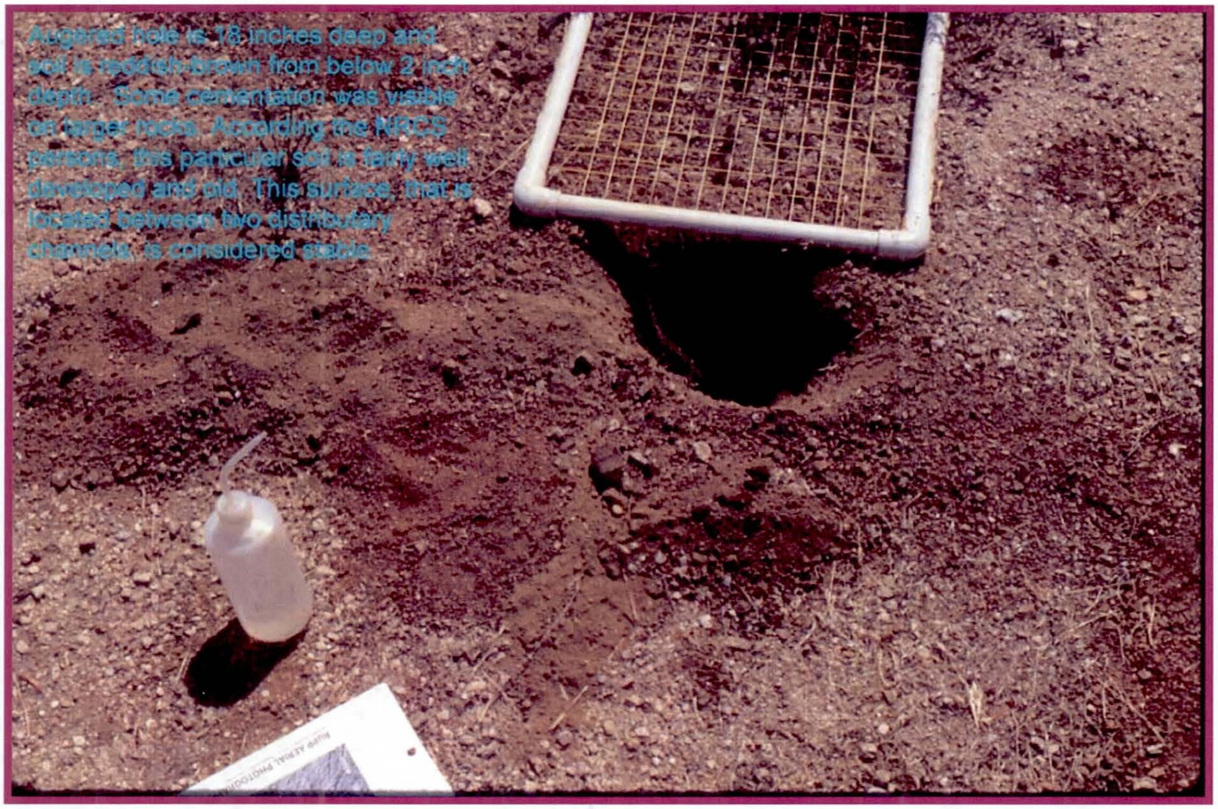


Figure 3.2 View of dark reddish-brown older soil.

(Gile and others, 1981; Bull, 1991; Pearthree, 1989). Soils on relict fans and many inactive fans typically have a lot of calcium carbonate accumulation reflecting the stabilility of these surfaces.

An example of a cemented channel bank that is slowly eroding because of a large gravel pit that was constructed downstream is shown in Figure Skyline 12 of Appendix H. Examples of stable soil are shown in Figures 27-30 for the South Mountain Park alluvial fan of Appendix I. A good example of a nearby stable channel bank is shown in Figure 26 for the South Mountain Park alluvial fan of Appendix I.

Unstable areas. The lack of developed soil as indicated by little clay accumulation, oxidation or reddening in the upper few inches and little or no calcium carbonate development suggests the surface is young and may be unstable. A surface that is geologically very young has been subject to fluvial deposition in the past few thousand years and may be unstable.

Examples of unstable soils are shown in Figures Skyline 20 to Skyline 23 of Appendix H.

3. *Surface geology*

Surficial geologic maps and reports that are available for much of Maricopa County are an excellent source of information on the nature of flooding (Appendix L). Surficial geologic maps typically show several subdivisions of Holocene (less than 10,000 years old) and Pleistocene (greater than 10,000 years old) piedmont deposits, and thus may be used to delineate areas of relatively recent deposition on piedmont that may be subject to inundation and unstable flow paths. Many surficial geologic maps have accompanying reports that include an interpretation of potential flood hazards associated with various surficial geologic map units. The boundaries of the map units shown on surficial geologic maps may need refinement to meet the requirements of the flood hazard assessment. All boundaries should be field-checked using the techniques given in this Manual. Users of surficial geologic maps are encouraged to consult w/ AZGS or USGS geologists regarding there flood hazard implications.

Stable areas. Using geologic maps, relatively narrow corridors of young deposits incised into Pleistocene deposits commonly are stable. The greater the topographic relief between young and old deposits, the more confident the investigator can be regarding stability of the drainage way. For example, if the 100-year flood would be contained by topographic relief at the boundary between young and old deposits, the drainage way may be considered to be stable. If unstable areas such as active alluvial fans are bounded by Pleistocene deposits with substantial topographic relief, the boundaries likely are stable. Flow paths in some areas covered by Holocene deposits may be fairly stable. For example, alluvial plains typically are covered by Holocene deposits, but channels are small and discontinuous and channel positions may be relatively stable during floods.

Unstable areas. Piedmont areas covered with Holocene deposits may subject to inundation and unstable flow paths during floods. Wide, fan-shaped areas of Holocene deposits associated with distributary channel networks are associated with alluvial fans that have been active in the past 10,000 years and may be active at the present. The lower portions of active fans may gradually transition down slope into alluvial plains. Both active fans and alluvial plains are covered by young deposits, but the potential for flow path instability is much greater on active fans.

Any differences between NRCS soil survey maps and surface geology maps must be resolved. Some differences between soil survey maps and the AZGS surficial geology maps relate to the greater detail of the AZGS maps.

See soil development in Appendix L for further discussion of relative age of piedmont alluvial surfaces.

4. Soil survey reports

Soil survey reports and maps of the NRCS are an excellent source of information on stable areas but some experience is needed to interpret the soil characteristics. Many of the soil boundaries need refinement to meet the required detail of flood hazard assessment. All NRCS soil boundaries should be field checked using the techniques given in this Manual. Users of soil surveys are encouraged to get assistance from NRCS soil scientists.

Any differences between NRCS soil survey maps and surface geology maps must be resolved. Generally, any differences between soil survey maps and the AZGS surface geology maps is related to the greater detail of the AZGS maps.

Stable areas. Soils on fan terraces and hills typically are old with a lot of calcium carbonate and stable. Common soil types of stable areas include Eba-Pinaleno, Laveen, Gran-Wickenburg complex, Anthony, and many others.

Unstable areas. Common soil types of unstable areas include Carrizo, Gilman, Brios, Estrella, Torrifluvients and many others.

5. Desert pavement and rock varnish

Rock varnish is one of the most obvious indicators of surface stability and old age of piedmont landforms in Maricopa County because it is easily observed and reliable. Dark brown and blackish layers of clays and manganese and iron oxides form on the surface of stable rocks over thousands of years. A varnished desert pavement of tightly packed gravel and cobbles clearly suggests a stable landscape (See Appendix I for further information).

Rock varnish is not an indicator of stability on granite or limestone gravel because soluble surfaces of carbonates and friable rocks such as granite weather rapidly and do not support varnish.

It is important to remember that stable areas covered with desert pavement and desert varnish typically are subject to local sheet flow.

Stable areas. Desert pavement normally forms on stable areas that are rather old and inactive where there are pebbles and cobbles in the deposits. Pavement development is not always a reliable indicator of a stable surface, but when pavement is accompanied by a developed darkly varnished surface gravel or a strong calcium carbonate soil horizon and an upslope tributary drainage network, the surface probably is stable (Figures 2.9 and 2.16).

The paved surface of the inactive alluvial fan of the White Tanks Park site (Figure 3.3) is an example of a stable surface covered with desert pavement.

Unstable areas. The lack of desert pavement typically suggests a piedmont surface is unstable. Exceptions are granite landforms where surface weathering may not produce a desert pavement that can be easily seen.

Deposition of fresh sediment or evidence of erosional degradation of desert pavements may be indicators of instability. An example of freshly deposited rock debris on desert pavement is shown in Figure 3.4 where floodwater and rock debris overtopped the left bank of a small distributary channel on an inactive alluvial fan on the west slopes of the Saddleback Mountains in Maricopa County. The estimated recurrence interval of the flood was between 50 and 100 years and the flow paths did not change. However, the capacity of the distributary channel was less than the 50-year flood and deposited mounds of rock debris in the throughflow channel appeared to be remobilized during flood flow.

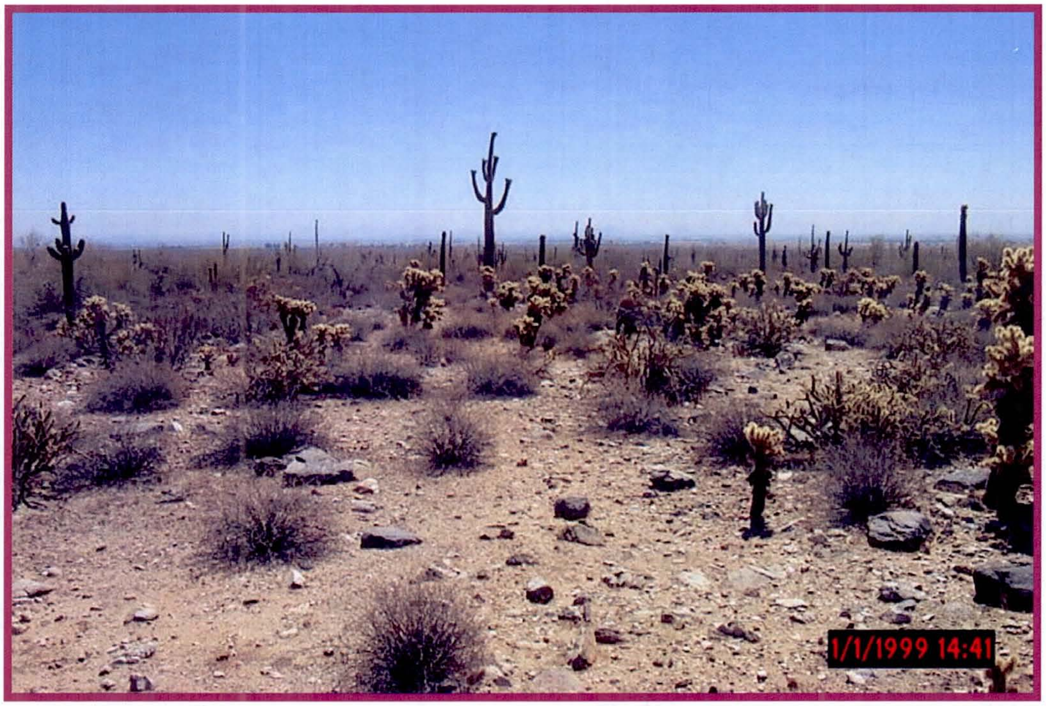


Figure 3.3. View looking east at desert pavement on White Tanks Park site.

The conveyance capacity of the channel may have been reduced as rock mound(s) passed the overflow reach shown in Figure 3.4. It is possible the rock mounds move as debris flows. Similar deposited mounds can be observed in the throughflow channel of the White Tanks Park site (Appendix J).

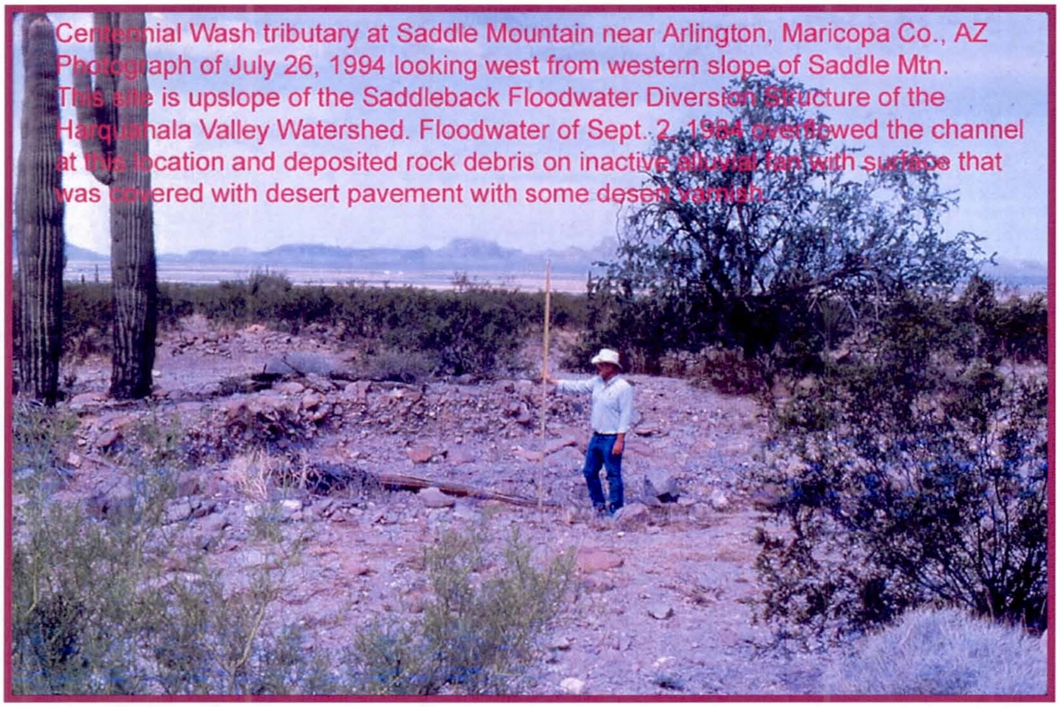


Figure 3.4. View looking west across a throughflow distributary channel. Rock debris overtopped the left bank and was deposited on desert pavement about 100 ft. down slope of the channel. Floodwater spread over the paved area as sheet flow.

6. Surface color

Stable surfaces. Surfaces of old fans may appear orange, gray, or white because of development of desert pavements and rock varnish and the colors of the underlying soil. Old surfaces with well-developed clay soil horizons typically are orange in color. Very old surfaces with strong calcic horizons and poorly preserved or nonexistent argillic horizons typically are gray or white in color.

Unstable surfaces. A light surface color seen on aerial photographs usually indicates a young surface that has been recently eroded or subject to sediment deposition. Active alluvial fans, alluvial plain areas and sand channels typically have a light or relatively light surface appearance. Light tan or gray colored rock is indicative of recent abrasion during sediment transport.

7. Surface texture on aerial photographs and topographic maps

Stable areas. A rather dark ridge and valley surface texture with transverse relief of about 5 to 20 feet and with rounded shoulders and troughs is indicative of a stable surface. The relict fan shown in several photographs in Appendix K is an example of the surface texture of a stable area.

Unstable areas. A rather light stippled surface texture commonly with a salt and pepper appearance from scattered trees and bushes is indicative of an unstable surface. A speckled- braided texture also is associated with an unstable surface (See the active alluvial fan areas in Appendices E and K, the alluvial fan in Figure C1 and the braided channels in Figure C4 for good examples). Some rather dark stippled appearing surfaces are also associated with an unstable surface as shown in Figure 3.5 below.

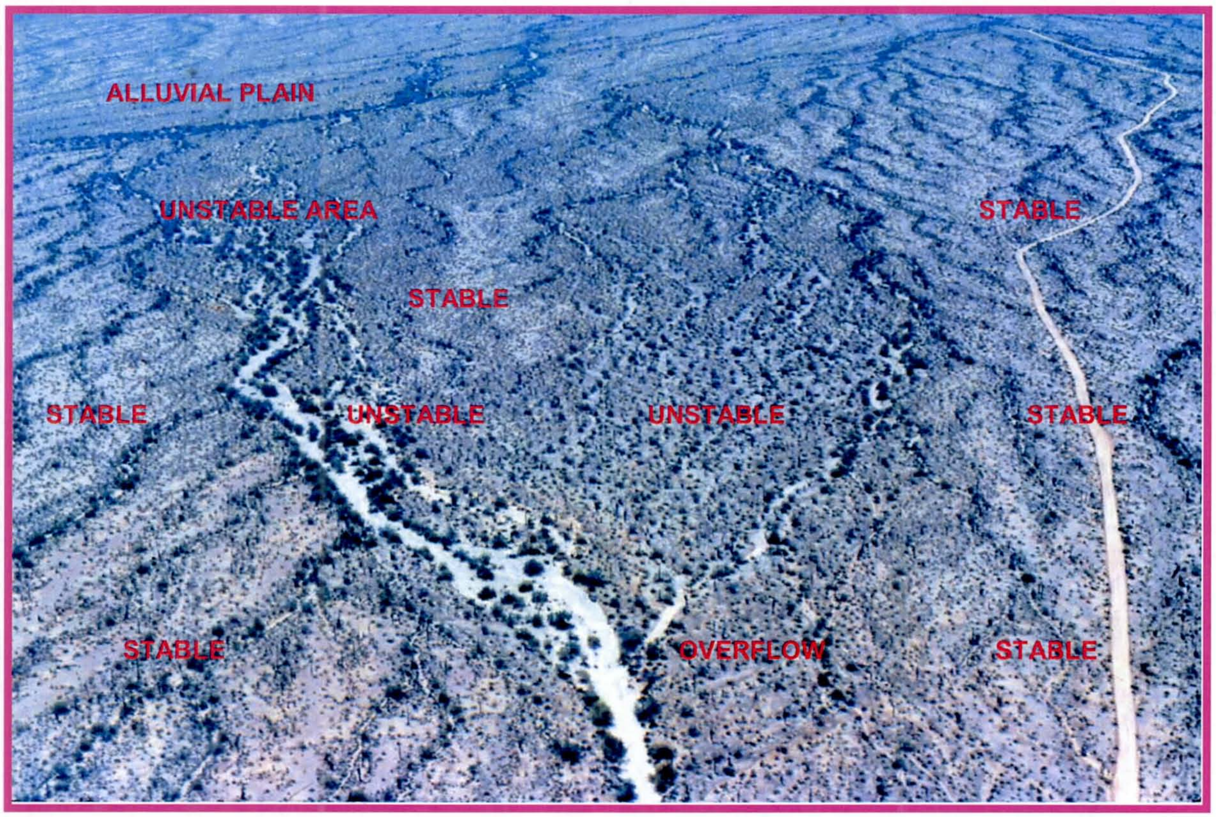


Figure 3.5 Relatively dark stippled texture of unstable area inset in an inactive alluvial fan.

8. Drainage pattern

Stable areas. Tributary drainage patterns commonly are indicative of piedmont areas with stable surfaces. Some stable areas have distributary drainage patterns but these patterns are not always a reliable unique indicator of stable areas.

Unstable areas. Unstable channels tend to have many forks and joins with a distributary drainage pattern. Channels that form a braided pattern tend to be wide and areas separating the channels tend to be low and easily inundated by large floods. Unstable areas may also have a poorly defined drainage pattern.

9. Channel capacity

Stable areas. If the investigator knows the recurrence interval for a particular peak discharge, he or she can estimate the type of landform. In general, piedmont channels that convey infrequent floods (>50-year flood) without overflow on adjacent interfluves tend to be stable.

The use of the large channel capacity is conservatively cautious. Lesser discharges may also be contained between stable ridges of stable areas. For example, the 25-year flood may overflow developed soil with a surface armored with desert pavement. The duration of overtopping may be only a few minutes, flow velocities may be less than 5 ft/s and overtopping may occur only a few times over a century. Such infrequent overflow would not be a realistic cause of instability. Thus, sites with lesser channel capacities may be stable but additional assessment is needed for the determination.

Unstable areas. The presence of throughflow channels and banks that are perched above the adjacent land when viewed across the channel profile are an indication the landform is unstable. Also, a landform may be unstable if the estimated 100-year flood overtops the banks of throughflow channels and inundates much of the landform including many of the ridges and interfluves separating the channels.

Transverse mounding (perching) of piedmont channels, when viewed across the landform, tend to have unstable paths of flow. These areas commonly are young (unweathered) and light colored surfaces that are aggrading.

Deposits are mounded across active alluvial fans unless there has been erosion and/or co-mingling with adjacent active alluvial fans.

10. Channel shape

Stable areas. V-shaped channels with a narrow channel bottom commonly are stable. Throughflow channels with a small width-depth (about <30) tend to be stable.

Schumm (1961) developed a technique that can be used to distinguish between stable and unstable ephemeral-channel cross sections (Appendix M of Manual). A channel is considered stable is data from measurements of channel geometry and bed and bank material samples at several cross sections consistently plot in the stable region of the relation between channel width-depth ratio and percent silt-clay along the wetted perimeter published in USGS Professional Paper 352C (Schumm, 1961).

Hjalmarson and Tram (1995) investigated the stability of a network of distributary throughflow channels near Carefree using the hydraulic geometry relations by Schumm (1961) and found the flow paths to be stable.

Unstable areas. Throughflow channels have large width-to-depth ratios, typically more than 50, are characteristic of channels formed in noncohesive material that is unstable. Unstable channels may be poorly defined with large width-to-depth ratios.

The depth generally represents the distance from the thalweg to the height of the active channel within which the bed material is mobile. Channel width is the distance between the top of the banks. The width-depth ratio is for the bank-full stage in the active channel.

A channel is considered unstable if data from measurements of channel geometry and bed and bank material samples at several cross sections consistently plot in the unstable region of the relation between channel width-depth ratio and percent silt-clay along the wetted perimeter published in U. S. Geological Survey Professional Paper 352C (Schumm, 1961) (Appendix M of Manual). See Hjalmarson and Tram (1995) for an analysis of a network of distributary throughflow channels on an unstable landform.

Discussion of channel depth of incision. According to Field (1994) historical aerial photographs, surficial features, and limited subsurface trenching on five fluvial dominated alluvial fans in Arizona demonstrate that channel abandonment occurs along bends and/or where bank heights are low. Several large floods on the fans during the photographic record produced no significant channel changes and may have actually inhibited future diversions along certain reaches by eroding channel beds and increasing bank heights. One of the five fans studied by Field was the White Tank Fan described above where the channels in the upper active fan are generally incised < 2 ft. with a width-depth ratio >10 and the channel of the lower inactive fan are incised about 3 ft. with a width-depth ration <10. These channel and other fan characteristics are in good agreement with the flood hazard indicators in Table 3.1 of this manual. The channel and fan characteristics of Field's other sites are also in agreement with the indicators of this manual.

11. Vegetation

Stable areas. Characteristically stable landforms in Maricopa County are sparsely covered with scattered large trees except along the banks of throughflow channels where large paloverde, ironwood, and/or mesquite are abundant.

Piedmont channels lined with native trees such as paloverde tend to be stable. Stable surfaces commonly, but not always, have creosote bush, saltbush and some saguaro cacti. An example of a stable distributary throughflow channel lined mostly with paloverde trees is shown in Figure 3.6. The bed is subject to scour and fill but the tree-lined banks of the small channel are stable.

Stable areas commonly are dominated by creosote bush and saltbush because they grow well on gravely high-calcium carbonate areas (See for example Figures 2.9, 5.26a and L4). Creosote bush is not a stand alone indicator because it grows almost any place on piedmonts of Maricopa County. Very unstable areas typically have little creosote.

Figure 3.6. Throughflow distributary channel with stable banks lined mostly with paloverde trees.

Unstable areas. The scattering of large trees such as paloverde over the landform with the absence of distinctly abundant trees along the banks of throughflow channels suggests unstable conditions. Trees that are scattered over much of an area suggest some local flow path movement or the absence of defined flow paths during the life of the trees or frequent enough overflows and sheet flooding to supply the water needs of the trees. Thus, scattered trees do not always mean that flow paths are unstable.

12. Particle size of the bed material

Stable areas. Sediment particles presently transported in stable throughflow channels typically do not decrease in size down the channels. Also, there is not much general increase in sorting of bed material down stable channels.

Measurements of the particle size of the bed material at many sites along networks of throughflow channels in Maricopa County show a uniform distribution of particle size along the defined channels. The uniform particle size indicates the mobile bed material passing the apex is conveyed through the network of defined distributary channels (See Figure 3.7 for photograph of sampled cross section). The uniform bed material suggests the system of distributary channels is not aggrading.

Figure 3.7. View looking upstream at throughflow channel with mobile bed and stable banks.

Unstable areas. Studies of fluvial processes have shown that a lessening of soil texture down slope is typical of aggrading alluvial fans (Blissenbach, 1954). Such a relation is a useful index of flow path stability because aggrading landforms typically have unstable paths of flow. Mapped NRCS soil units with index particle size distributions for component soils along piedmont slopes can be used to assess stability (See Hjalmarson and Tram (1995)). Both the maximum and average clast size of the sediment deposits decreases down the fan (See for example Blissenback (1954) and Hjalmarson and Tram (1995)).

The investigator is invited to read more about bed material size along piedmont channels in Hjalmarson and Tram (1995).

13. Donoring

Stable areas. Channel banks of more stable channels in sandy immobile material typically are much finer material (Waite Osterkamp, oral communication, 1994). During rising runoff water seeps into the sand banks which act as a filter on the inflowing water and the suspended sediment particles of silt and clay plaster the sandy bank with a mud cake (figure 3.8). This donoring process is clearly indicated by the uniform progression with depth of the D_{50} to D_{90} values toward the deeper "parent" material (45-90 cm depth) as shown by the data for the sites shown in Figures 3.6, 3.7 and 3.8. The sand banks have become plastered with silt and clay that is a stabilizing mechanism for paloverde trees and other vegetation. The resulting mud-caked vegetation covered banks have "aged" and become cohesive to create an overall stability of the channels. In other words, the grain size distribution of the bank material indicates plastering of the banks with fine sediments as described by Schumm (1961). This plastering of the channel banks indicates a bank stability that might not be expected in the normally dry and sandy environment of a network of distributary channels.

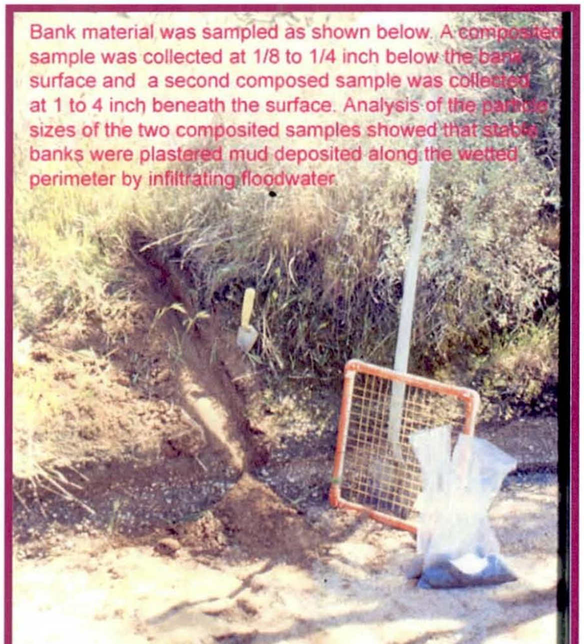


Figure 3.8 Sampling bank material for particle size analysis.

Measurements of the proportion of silt and clay in the channel banks should be made in straight reaches between any bends. Samples of banks material are collected as shown in the photograph on the right.

Unstable areas. Unstable channels of aggrading areas exhibit little donoring of suspended material along the wetted perimeter of channels. The texture of bank material of unstable channels grades little, if any, with depth perpendicular to the bank surface.

14. Shear stress

Stable areas. A channel may be considered stable if measurements of vane shear (Figure 3.9) corresponding to computed tractive power at many cross sections consistently plot in the non-erosive region of Figure 52 of Natural Resources Conservation Service TR-25 (Appendix N of the Manual). In other words, channel banks that have a high unconfined compressive strength relative to the tractive power of the flood water are considered non-erosive or stable according the a relation published in TR-25 of the NRCS.

Microbiotic soil crust surfaces may increase surface stability based on a few measurements of surface shear stress along channels in Maricopa County. The crusts are a possible indication of surface stability in arid and semi-arid deserts. These darkened surfaces are composed of cyanobacteria, lichens and mosses (Belnap, 1995) and may require hundreds of years to establish a soil cover. According to Belnap, recovery after surface disturbances is hampered by large amounts of moving sediment. Disturbed crusts in Maricopa County may recover in a few years and new crusts may form in 10 to 20 years. The presence of large areas of microbiotic soil crusts suggests recent surface stability for a few tens of years and possibly for a few hundred years.

Preliminary research along a few channels in Maricopa County suggests a small increase in surface stability because of native grasses and microbiotic soil crusts. Conversly, wetting of the surface material may decrease surface stability.

Unstable areas. A channel may be considered unstable if measurements of vane shear (Figure 3.9) corresponding to computed tractive power at many cross sections consistently plot in the erosive region of Figure 52 of Natural Resources Conservation Service TR-25 (Appendix N of the Manual). In other words, channel banks that have a low unconfined compressive strength relative to the tractive power of the flood water are considered erosive or unstable according the a relation published in TR-25 of the NRCS.

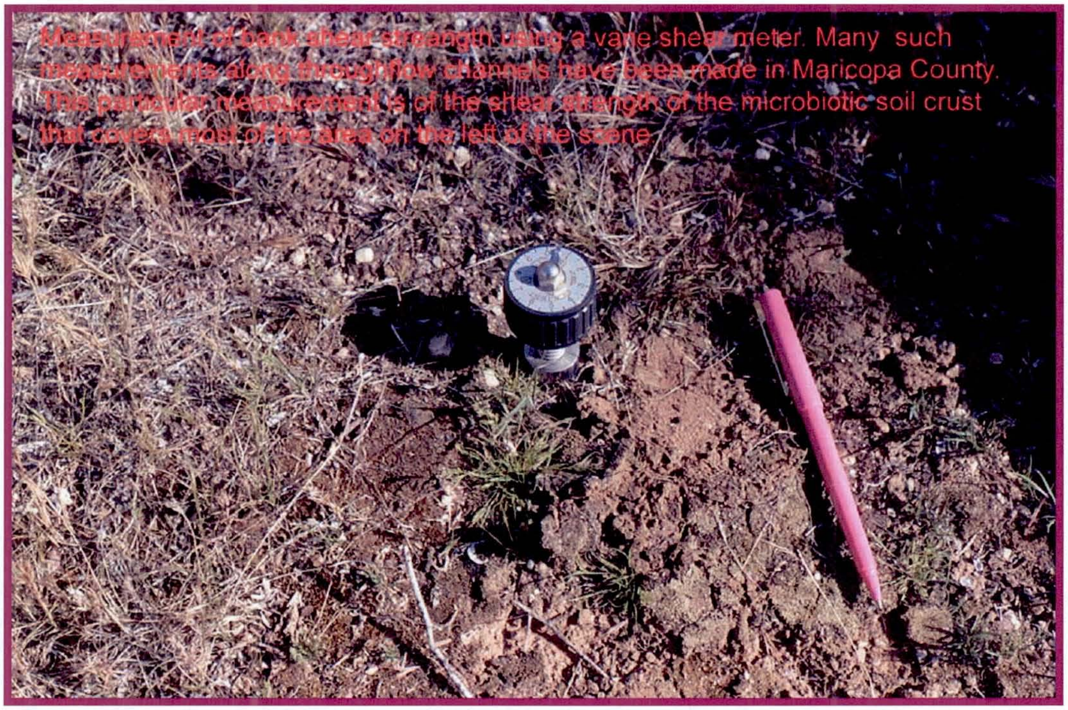


Figure 3.9 Measuring shear stress on channel bank.

3.15 Drainage basin

Stable areas. The absence of an abundant supply of unconsolidated medium to coarse granular sediment above the hydrographic apex suggests the alluvial fan is not active. For example, the supply of fan building material may have decreased with time as active channels incised into a relict fan. An alluvial fan may not be very active if (1) there is not a supply of material along the steep slopes of the drainage basin and (2) the profile of channels incised in relict fans to depths of more than 10 ft. is smooth. A smooth channel profile suggests there is no significant head cutting and associated limited supply of eroded material for fan building.

Unstable areas. The drainage basin of very active alluvial fans typically is bowl shaped where first and second order streams drain quickly to the hydrographic apex (See for example Blair and McPherson (1994) and McPherson and Blair (1993)). Active fans are also associated with high relief drainage basins (See for example Hjalmarson and Kemna (1991), Anstey (1965) and Blair and McPherson (1994). Loose debris accumulates within the basin upstream of the hydrographic apex until large floods transport the debris to the alluvial fan. A supply of material above the hydrographic apex is needed for active fan building.

Two sources of fan building material are typical of active alluvial fans in Maricopa County. The first is material derived from channel incision, or head cutting, into relict fans. This source is below the mountain front and commonly between the topographic and hydrographic apices. The second source of material is from sediment production in the mountainous drainage basin. Loose debris typically accumulates along the beds and banks of stream channels until the debris is transported by large floods to the alluvial fan. For most active alluvial fans in Maricopa County a supply of loose material along the basin channels is visible on good quality aerial photographs.

16. Computed degree of flood hazard

This method is considered a good check of stability of alluvial fans.

Stable areas. A quantitative method of estimating the degree of flood hazard of alluvial fans was developed by Hjalmarson and Kemna (1991). The higher the degree of hazard the less the stability of the alluvial fan (Hjalmarson, 1994). An alluvial fan can be considered stable for computed degrees of flood hazard of 1 to 8. See Appendices O and P for the method.

Unstable areas. An alluvial fan can be considered unstable for computed degrees of flood hazard of 9 and 10. See Appendices O and P for the method (Hjalmarson, 1994).

3.1.3 Words of caution

Prediction of the nature and location of flood flow based on the geomorphic characteristics of various parts of a piedmont can be tenuous. Similar effects or equifinality can be caused by different processes (Schumm, 1991). Large events such as massive sediment laden floods can be obscured by subsequent erosion and burial. Debris flow deposits can be remobilized by water floods and redeposited down slope. The evolution of a landform surface, especially the surface of an alluvial fan, can cause a difficult problem for the interpretation of field evidence concerning flooding and for the prediction of future flood risk (NRC, 1996).

Assessments of flow path stability are reliable if most or all of the indicators discussed above point to the same condition of stability. If a set of indicators is mixed certain indicators may be given more weight. For example, soil characteristics and surficial geology are very important indicators of surface stability. Also, any observations of historical flow path movement indicate that the landform is unstable. Methods given in Appendices M, N and O that are based on general relations and thus subject to chance variation, so they may be given less weight if they conflict with other indicators. A mixed set of indicators should be carefully examined for obvious errors and likely causes of the mix, such as the absence of recent floods. Where indicators for a particular site are mixed and it is not obvious if the landform is stable or unstable, more sophisticated methods or detailed investigations than those described in this manual may be needed to assess stability.

A particular mixed set of indicators might occur because of the variable nature of summer thunderstorms that produce most of the large floods on piedmonts in Maricopa

County. For example, all indicators except the observed flow path movement for a particular site might suggest a landform is unstable. The absence of flow path movement may simply be the result of random chance that the site did not experience large floods for the period of photographic record. Measurements of flow path movement using a larger sample of surrounding landforms with similar characteristics, such as the same type of soil and drainage characteristics, might be a more reliable indicator. For this particular example, a general relation that showed flow path movement may be a more reliable indicator than the observed lack of movement at the particular site. This technique is reliable if the site in question and the sample has similar characteristics.

3.1.4. Discussion of flow paths and stream piracy

New paths of flow where channels are incised are formed by the long known general process of stream piracy (Shelton, 1966, p. 138 and fig. 134). There is simple stream piracy (capture) on some alluvial fans such as site 30 of Hjalmarson (1994) (Also see Figure 2.3 of Manual) and the Tiger Wash site studied by Field (1994) in western Maricopa County and described in Appendix L. Field (1994) discusses how channels of fans in Maricopa County bifurcate "...through a process of stream capture in which over bank flow from the main channel accelerates and directs head ward erosion of a smaller channel heading on the fan. According to Field (1994), the pulsing nature of sediment transport and deposition by short-lived floods along piedmont streams is critical in the migration process, because the greatest amount of over bank flow is generated where bank heights are lowest.

The upslope overtopping of low channel banks and corresponding inflow and erosion of the head of a nearby channel certainly is a convincing explanation for gradual/sudden channel avulsion/bifurcation because the head of all channels ends before a divide is reached (the progressively decreasing drainage area above the channel head in not able to provide runoff to sustain head ward channel cutting). Stream piracy, the taking of the drainage basin of one stream (prominent stream) by another stream (pirate stream), can occur for several reasons including one or more of the following: (1) the pirate stream has a steeper gradient near the point of capture, (2) the course of the pirate stream is in more easily eroded rock, (3) the erosion potential, associated to the sediment load, of the pirate stream is larger, and (4) the channel of the prominent stream is aggrading. Items (1) and (4) are characteristics of site 30 in a USGS study (Hjalmarson, 1994).

It is important to be aware that sediment debris is deposited on alluvial fans in a complex manner. Deposits from large floods can be remobilized, transported down fan and redeposited (See the Rudd Creek, Utah site in National Research Council, 1996). The flow velocities may be high and possibly unstable (Hjalmarson and Phillips, 1997). Hooke and Rohrer (1979) found that higher discharge floods tend to flow down the axis of the fan while lesser floods can be turned to the sides of the fan. Hooke and Rohrer also found that for gentler slopes the floods are more easily diverted to the flanks. A literature review of documented floods on alluvial fans shows a variety of fluvial processes and areas of inundation during single large floods.

Although the processes of channel diversion are different on debris-flow fans, a literature review of documented avulsions demonstrates that flow on debris-flow fans is also commonly diverted into preexisting channels. These findings suggest that the location of future channels on alluvial fans may be more predictable than previously thought, although information on the frequency of diversions is still limited.

3. 2 Relict fans

Relict fans generally are stable landforms where inundation occurs as flow in and adjacent to defined channels and as local overland sheet flow (Table 3.2). The geometry and roughness of the channels, the network of channels, and the adjacent land surfaces typically can be considered stable for assessments of flood risk.

Along incised throughflow streams the steep banks may have some instability, although the banks of many incised channels are well cemented and are formed in coarse gravelly material with moderate stability. The floors of the throughflow channels typically are fairly flat and composed of only coarse sediment because of the high flow competency. The well-developed soils, abundance of rock varnish and common desert pavement are indicative of old and stable surfaces, implying that the floodwater from upslope mountains has been conveyed past these stable surfaces in throughflow streams for thousands of years.

Relict fans characteristically have well-developed tributary drainage networks incised in Pleistocene sediments separating throughflow channels, but in some places relict fans are also traversed by incised, stable distributary channel networks. Both tributary and stable distributary throughflow channels are not perched above the adjacent land and typically are incised more than 3 ft. below adjacent Pleistocene fan surface.

The 100-year flood typically is confined to defined channels and low terraces adjacent to channels of throughflow streams and floodwater seldom looses energy and deposits much sediment. On some relict fans, 100-year floodwater also is confined within tributary streams that head on the fan. On other relict fans that are dissected by incised throughflow streams the 100-year floodwater from rainfall directly on the fan may be unconfined and spread over wide-flat interfluves as sheets before becoming tributary flow.

3.3 Pediments

Pediments are stable landforms where inundation occurs as local overland sheet flow and flow in and adjacent to defined channels (Table 3.2). The geometry and roughness of the channels, the network of channels, and the adjacent land surface typically can be considered stable for assessments of flood risk.

Table. 3.2 Selected characteristics of stable and unstable flood hazards of piedmont landforms.

Landform	Component Landform (State)	Significant stability and flood characteristics
Relict Fan	Erosional Fan remnant (Stable)	Remnants of broad coalescent plains or bajadas that have been incised by streams for thousands of years. The presence of large areas of varnished desert pavement and soils with substantial clay or carbonate suggests the surface of this landform is very stable in many places and flood flow has been conveyed past these stable areas for thousands of years. The 100-year flood is confined to throughflow channels and small over bank areas adjacent to the defined channels.
	Inset Alluvial Fan (Unstable)	These typically bouldery fluvial deposits can have a great aggradation and erosion potential and are unstable. The 100-year flood can spread over much of these areas.
Pediment	Bedrock remnant (Stable)	Nearly all of these landforms are eroding and stable. Relatively small areas along larger channels subject to scour and fill. The 100-year flood typically is confined to defined channels of throughflow streams and streams that head on the pediment.
	Inset Alluvial Fan (Unstable)	These fluvial deposits resemble flood plains except the inset fan may be subject to more erosion and deposition than typical flood plains. Inset deposits of sediment can be the "apex" of distributary channels.
Alluvial Fan	Active Alluvial Fan (Unstable)	Fluvial deposit with little or no calcium carbonate soil development, no insitu rock varnish development, and seldom any desert pavement. The surface typically is a light tan or grey color that is indicative of recent abrasion of the weathered surface during sediment transport. Some areas not recently eroded or that have received sediment may be darkened by weathering. Typical channels are poorly defined with large width-to-depth ratios and may have a braided pattern in addition to a general radiating pattern below the hydrographic apex. Typical clasts are angular, sorted and unweathered. Both the maximum and average clast size of the sediment deposits decreases rapidly down fan. Deposits are mounded across the fan unless there has been erosion and/or co-mingling with adjacent alluvial fans.
	Inactive Alluvial Fan (Stable)	Fluvial deposit with much carbonate in K soil horizon, reddish upper soil horizon, desert pavement, rock varnish, incised throughflow channels, trees along the throughflow channels and developed tributary drainage systems that head on the fan surface. Very old inactive alluvial fans that have lost their shape are relict fans.
Alluvial Plain	Piedmont Toe (Generally stable but some areas may be unstable.)	Rather stable or possibly aggrading fluvial deposit with little transverse relief except where channels are incised as the result of lowering of base-level stream. Floodwater of the 100-year flood may spread over large areas like that shown in Appendix G. Areas with low slopes, lack of flow confinement, little aggradation and developed caliche soil that resists erosion are stable. Areas may be unstable where there is much aggradation. Where channels are incised the gully walls may be unstable and head cutting may progress upslope.

Channel banks typically are stable and hill slopes are relatively stable. The banks of throughflow streams may be locally steep and unstable when undercut. Only relatively small areas along larger channels are subject to active scour and fill. Most pediment areas are undergoing slow long-term erosion, but may be considered stable for purposes of flood hazard assessment. The 100-year flood typically is confined to defined channels of throughflow streams and streams that head on the pediment but some sheet flow is typical on lower slopes.

Several examples of exposed bedrock on pediments in Maricopa County are shown in Appendix F.

3.4 Alluvial fans

Alluvial fans in Maricopa County consist of active areas with potentially unstable flow paths and inactive areas with stable flow paths. The indicators of flow path stability described earlier in this chapter allow the investigator to distinguish stable (inactive) and unstable (active) flow areas on alluvial fans in Maricopa County. The procedures outlined here are consistent with Stage 2 of Appendix G in Guidance for Alluvial Fan Flooding Analysis and Mapping of the FEMA Guidelines and Specifications for Flood Mapping Partners (2001). By systematically following the FEMA guidelines, criteria and definitions given in *Alluvial Fan Flooding* (NRC, 1996), and the guidelines in the Manual, reliable estimates of the spatial extent of active areas of alluvial fans in Maricopa County can be made.

There are many active and inactive alluvial fans in Maricopa County. Many of the inactive alluvial fans are old with a tributary drainage network over much of the fan. Many of the active alluvial fans are part of older fan complexes that have both active and inactive parts. There are only a few young alluvial fans that are active over their entire surface. Many active parts of fans are lighter colored than older parts because of less weathering, soil development, desert pavement, and rock varnish, although some active parts of fans may appear dark because of greater vegetation density. Active parts of alluvial fans in Maricopa County typically have distributary channel networks surrounded by extensive young deposits, which indicate that these areas are subject to active sediment deposition and erosion. Inactive parts of alluvial fans may be subject to flooding but flow paths are not changing and there is no significant active sediment deposition. Indicators of stable and unstable alluvial fans are given in Table 3.2 and the steps for defining the type of alluvial fan and active and inactive areas are given in Table 3.3.

Active fans in Maricopa County typically are relatively small (larger than a few tens of acres) fluvial deposits that have the characteristics of unstable flow areas as follows:

- Little or no clay or calcium carbonate soil development.
- No in situ rock varnish development, and seldom any desert pavement.
- Some areas not recently eroded or that have received sediment may be darkened by weathering.
- Distributary or braided channel pattern.
- Typical channels are poorly defined with large width-to-depth ratios
- Angular to sub angular, sorted and unweathered light tan or gray gravel (See for example Hereford and others (1996)). The poorly rounded clasts reflect the short distance of transport.
- Both the maximum and average clast size of the sediment deposits decreases down the fan (See for example Blissenback (1954) and Hjalmarson and Tram (1995)).
- Deposits are mounded across the fan unless there has been erosion and/or co-mingling with adjacent active alluvial fans.

In order to feel confident about a determination of fan activity or inactivity, most or all indicators should point toward a particular type of stability class. Discrepancies among the indicators should be resolved as part of the assessment. An outline for defining and characterizing the alluvial fan environment is given in Table 3.3.

3.5 Alluvial plains

These landforms can generally be considered stable because of low slopes (usually less than 1 % but always less than 3%), low rates of aggradation, and fairly stable flow paths. Most alluvial plains are drained by small, shallow stream channels spaced at 100-500 ft. intervals that head on upslope piedmont and mountain areas. Channels may be continuous, but it is also common for channels to fade out downstream in expansion reaches. Channels typically are at or close to the level of the surrounding plain, so there is little transverse relief. Most alluvial plains are subject to laterally extensive, shallow sheet flooding from rainfall directly on the area or from runoff that is conveyed to the upslope edge of the plain in throughflow channels. Major floods spread over the large-smooth areas between channels at depths of 1 ft. or more (Rhoads, 1986; Klawon and Pearthree, 2000; see Appendix G).

Table 3.3. Steps for defining and characterizing alluvial fans.

CHARACTERISTIC	DATA SOURCE	FUNCTION (Define on topographic map)
Type of fan?		
Alluvial, debris flow, or composite?	Field work	Examine morphology, facies assemblages and other evidence of sedimentary processes
Ideal, composite, or segmented?	Topographic maps & field work	Make profiles along fan.
Incised/not incised?	same as above	Throughflow and local channels.
Drainage patterns	Topographic maps & aerial photos	Tributary, Distributary and/or Anastomizing?
What parts of fan are active(< 10,000 years) and/or inactive? If practicable, use time scales less than 10,000 years.		
Depth of incision	Topographic maps & fieldwork	(Depth of incision <2ft, about 3ft, 3 ft-10 ft, >10 ft)
Flow path movement	Aerial photographs	Rate of movement and proportion of channels.
Fan surface morphology	Topographic maps & field work	(Bar & channel, smooth, deeply dissected)
Desert pavement & desert varnish	Aerial photos & field work	(None, weak, moderate, strong development)
Soil characteristics	Soil maps and field work (trenching)	(B-horizon development and $CaCO_3$)
Is the drainage basin typical of those found above active alluvial fans?		
Sediment supply	Soils maps, aerial photos and field work	(Abundant, moderate or little medium to coarse grained sediment on steep basin slopes or along channel incised in relict fan)
Basin shape	Topographic map	(Rounded or elongated)
Drainage pattern	Topographic map and aerial photos	(Uniform or non-uniform length of first and second order channel segments)

Most of the large floods on alluvial plains are sheet floods or simply a sheet of unconfined floodwater moving down slope. Most of the flood flow is not concentrated into well-defined channels and flood waters from different piedmont throughflow channels coalesce. Except for aggrading areas and areas of base level lowering and head cutting along throughflow channels, flow paths are rather certain for alluvial plain. Because there is little topographic relief on alluvial plains, however, relatively small obstructions can affect the flow paths of sheet flow and sheet floods. There are several examples in Appendix G of sheet flow that was diverted by small obstructions and roads. The investigator is encouraged to also consult the Glossary for sheet flow and sheet flooding and Arizona State Standard 4-95 (1995) for a description of sheet flooding.

3.6 Summary

This chapter describes a number of indicators of flow path stability in various piedmont landforms. Many of these indicators should be observed and documented in the field, whereas others may be evaluated using existing soils maps, surficial geologic maps, topographic maps, and recent and historical aerial photographs. These indicators should be used together to assess the stability of piedmont landforms. There is a strong correlation between the landform type and the stability of flow paths on the landform. For example, relict fans and pediments are old landforms dominated by erosional processes, and flow paths are quite stable. Active fans are young landforms dominated by depositional processes, and flow paths have the potential to change dramatically during floods. Stability is the relative state of hazard on the landform.

The indicators used in this Manual produce reliable assessments of landform type and flood hazards for most cases.

A simple example map of stable and unstable flood hazards is shown in Figure 3.11. Figure 3.11 is the result of stage 2 of the method.

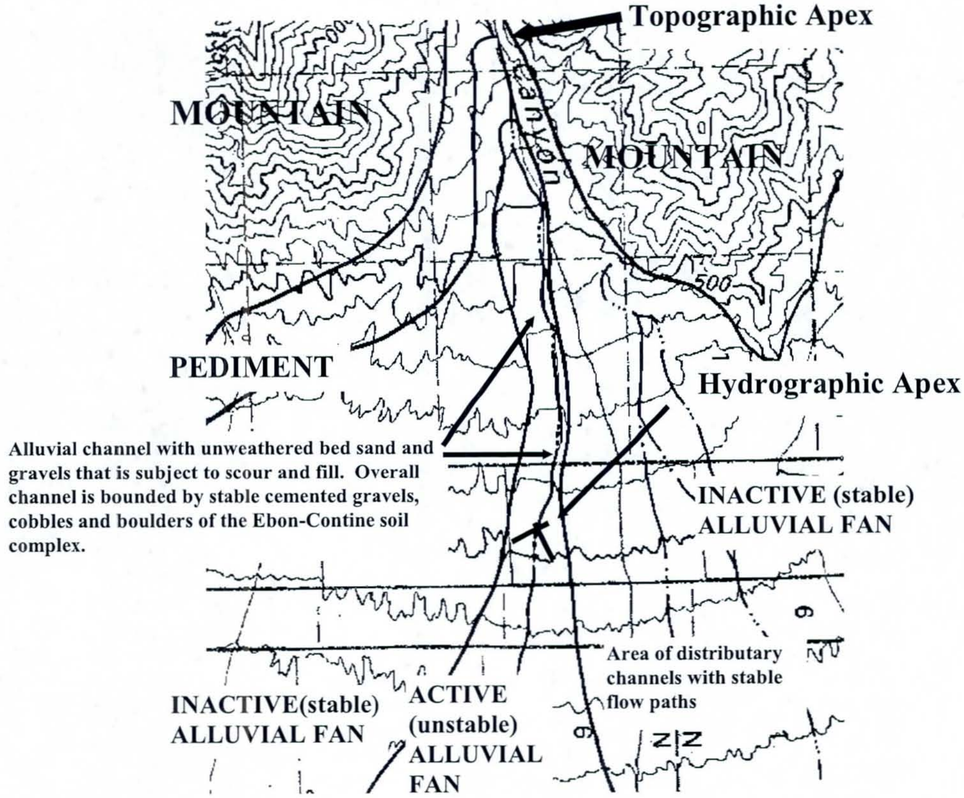


Figure 3.10 Example map of landforms and stable (inactive) and unstable areas.

4

DEFINITION OF 100-YEAR FLOOD HAZARDS

STAGE 3 OF METHOD

This chapter is a discussion of flood hazards in Maricopa County and realistic methods for defining these hazards for flood plain management. Clearly, before the 100-year flood hazard is assessed, it is important to properly identify the type of landform(s) as described in Chapter 2 of this Manual and to define the nature and location of flood hazards (stable and unstable areas) of the particular landform as described in Chapter 3 of this Manual. Traditional engineering methods are preferred for the definition of 100-year flood hazards at stable areas as defined in Chapter 3. Geomorphic methods are preferred for the definition of the flood hazard at unstable areas.

There are distinct differences in areas subject to flooding on relict fans, pediments, active alluvial fans, inactive alluvial fans and alluvial plains. Where flow paths are stable and flow is reasonably confined, standard hydraulic engineering methods such as backwater computations are used to define the elevation (or depth), velocity and extent of the 100-year flood. These backwater computations use a specific peak discharge estimated for the 100-year flood. This 100-year peak discharge and the accounting of energy losses from surface friction and hydraulic expansion form the foundation of the engineering methods. An accounting of flow energy is performed along the flow path. Where there are changing channel conditions and other unstable conditions, the accounting of flow energy is uncertain and geomorphic methods are used mostly to supplement the traditional engineering methods. For active alluvial fans and alluvial plains where the flow is unconfined and/or there is substantial sediment accumulation, or channel positions may change during floods, normal backwater profile computations for flood definition may be inappropriate. Geomorphic methods are used to assess flood hazards on active alluvial fans.

Geomorphic methods generally are superior to traditional engineering methods for hazard definition on unstable areas such as active alluvial fans because of the complexity of flood flows in these systems. The problem is that the geometry of the active-fan surface changes during flooding because of scour, fill and flow path movement below the hydrographic apex. Floodwater and sediment spread over wide areas at shallow depths and at high velocities. The state of flow may be supercritical or sub critical or changing in time and space during flooding. There is evidence that flood flow tends to follow the preflood channels but there is also geologic evidence that flow paths change over long periods. Thus, because during many floods the flow paths change, flow depths are shallow, flow is somewhat unconfined and expanding and sediment is deposited, remobilized and transported further down slope, the precise amount of the flood peak discharge at the hydrographic apex or the precise channel geometry within the bounds of the fan are less important than in stable areas. It is more important to delineate the active alluvial fan area using geomorphic techniques because the hazard within these bounds is severe.

Traditional engineering methods are applicable to the defined channels of relict fans, inactive alluvial fans and pediments. Hydraulic methods given in Volume II of the Drainage Design Manual for Maricopa County (1996) and *Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2002) are appropriate for most reaches although some attention to sediment, scour and bank erosion is needed.

Traditional hydraulic methods may also be used for stable (inactive) alluvial fans and weathered granite pediments where there are many channel forks and joins. The proportion of flow that splits at the channel forks may change some from one flood to the next or during a flood (the distribution of discharge may be dependent on the frequency of the particular flood peak discharge). For most of these forks there is some bed scour during high flow. A solution for flow splitting on these landforms is the use of traditional hydraulic methods like those described in the Arizona State Standards of Practice Report for Lateral Migration and Channel Degradation (June 7, 1995) to estimate the amount of bed scour at channel forks. A site that exhibits the stable characteristics outlined in Chapter 3 is a candidate for channel conveyance-slope methods to estimate the level and extent of the 100-year flood. In general, physically based methods that consider site processes and hydraulics, in particular channel geometry, grade and roughness and channel bed and bank material are preferred.

The precise definition of flood characteristics on alluvial plains is difficult mostly because of the spreading of floodwater over large areas at shallow depths. Unlike the flow on many alluvial fans, flow entering alluvial plains typically is lower regime. In the rapid expansion of tranquil flow, a major hydraulic issue is the uncertain loss of head to surface roughness and eddies. Flood depths can be estimated using methods given in the Arizona State Standard for Identification of and Development within Sheet Flow Areas (SSA 4-95).

Traditional engineering methods are least applicable for definition of flood levels (or depths), velocities and boundaries on active alluvial fans of Maricopa County because the paths of flow may change as a result of sediment deposition and erosion as previously discussed. Also, the rapid expansion of both tranquil and rapid flow is a major issue where there are no known practical hydraulic solutions to the precise definition of flood depths, velocities and boundaries. The most severe hazard on many active alluvial fans is from avulsions and sediment deposition and to a lesser degree from inundation. For additional discussion of engineering and geomorphologic methods see Pearthree (1991).

4.1 Methods for defining 100-year hazards

For active alluvial fans the most severe hazard is from sediment deposition, high velocities, flow path movement and erosion (NRC, 1996). Floodplain maps should attempt to show both the flood hazard involving inundation and the hazards associated with sediment deposition, bank erosion and avulsions. Because the definition of 100-year flood characteristics must be legally and politically defensible, the engineering and geomorphologic methods should also be documented and defensible.

The general approach is to use standard hydraulic methods where applicable and to supplement the computed flood profiles, velocities and boundaries with a geomorphic assessment (See Table 4.1). For unstable areas, the flood hazard assessment is accomplished using geomorphic methods and possibly supplemented with appropriate hydraulic methods.

4.1.1 Relict fans and pediments

On relict fans and many pediments (including the portions upslope of the weathered granite discussed in Appendix F of this Manual) the floodwater typically is confined to narrow channels (See for example Figure 4.1). There is also shallow overland flow on the slopes of pediments and relict fans (see *Overland Flow* in State of Arizona Standard 4-95) and sheet flooding on flat interfluves of some relict fans (see *Natural and Urban Sheet Flow* in State of Arizona Standard 4-95).

Normal backwater profile computations using the standard step method for flood definition are appropriate for these areas. In addition to the traditional hydraulic conditions, the fieldwork should focus on identification of any distributary channels, inset alluvial fans and potential stream piracy (See section 3.1.4 for discussion of stream piracy). In general, stream piracy should be considered only where floodwater of large floods could presently enter the pirate channel because piracy may not progress at an engineering time scale.

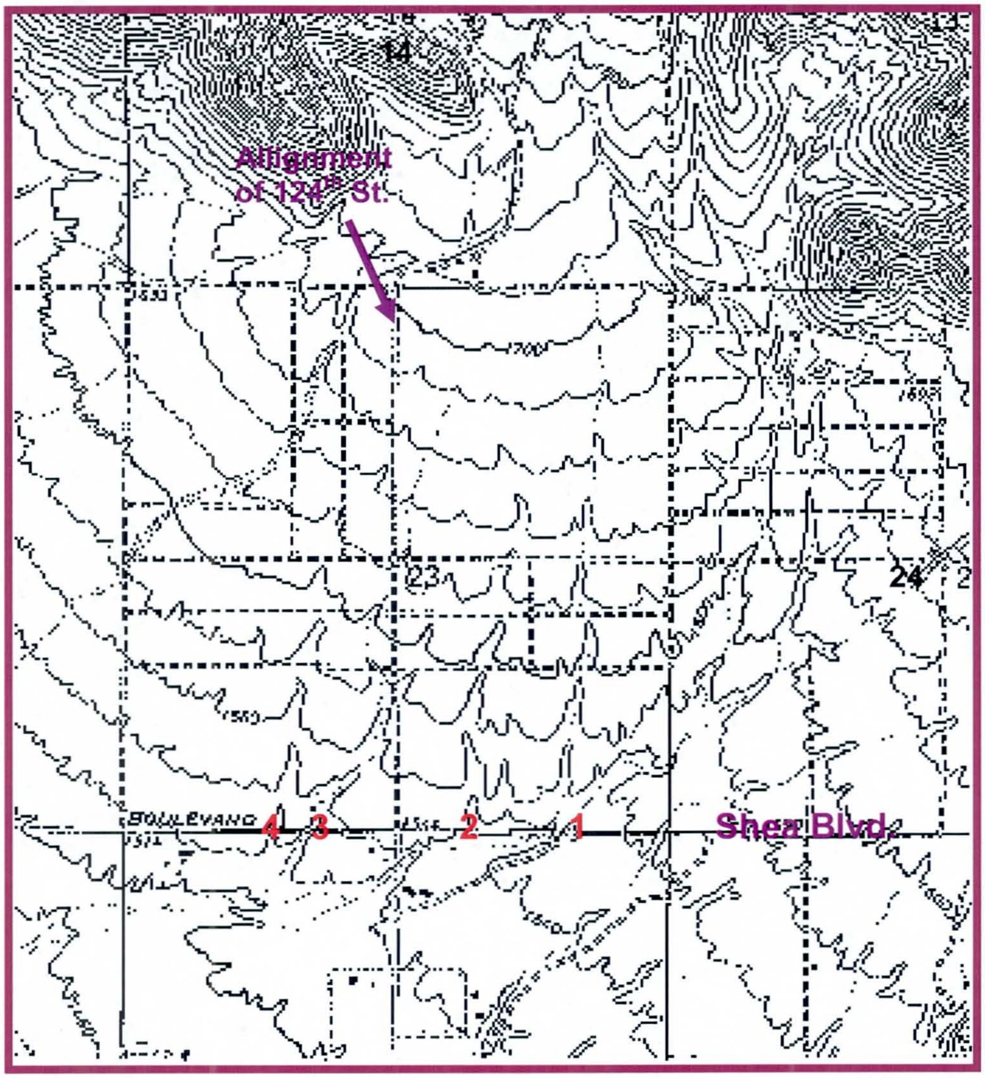
The 100-year flood hazard on weathered granite pediments with distributary flow paths that are described in Appendix F of this Manual is assessed using methods for inactive alluvial fans as described below.

4.1.2 Distributary channel networks on inactive alluvial fans and pediments

On inactive alluvial fans and those weathered granite pediment areas described in Appendix F of this Manual, floodwater typically is along incised channels and adjacent stable land (See for example Figure 4.2). There typically are smooth-flat and/or stable ridges that separate the incised channels and these ridges are above the level of major floods from rainfall in the mountains and upper piedmont.

Table 4.1 Defining and characterizing 100-year floods on piedmont landforms of Maricopa County.

CHARACTERISTIC	DATA SOURCE
1. Drainage basin (water and sediment source area) area	Topographic maps, aerial photos and field inspection
Flood frequency relations (topographic apex)	Drainage Design Manual, Vol. I, Hydrology
Channel capacity at basin mouth	Field work and surveying
Debris flow potential/frequency	Field inspection
Sediment supply and grain size characteristics	Field work/soil survey reports/ aerial photos
2. Define the type of landform as given in Chapter 2 of this Manual.	
3. Define stable and unstable areas of flood hazard as given in Chapter 3.	
Where has historic flooding occurred? (Examine photos, vegetation, soils, pavement and varnish)	Historic aerial photos/ soil maps/ vegetation/ geologic mapping/ flood reports
Examine geometry and composition of channels (width, depth, gradient, deposits in banks)	Field work/ surveying/use methods of this Manual
4. Define areas of confined and unconfined flow on the particular landform	
Characterize flow during historic events	Aerial mapping/ field mapping
Characterize prehistoric flows--map deposits	Aerial photos/ field mapping
Determine the type of processes suggested by deposits (Give reasons why deposits suggest water flood or debris-flow processes.)	Fieldwork
5. For any stable channels define 100-year profiles	Traditional hydraulic methods
6. Estimate debris flow potential and areas of hazard	Geomorphic mapping/soil maps/ aerial photos/field work
7. Estimate areas of erosion hazard	same as item 6 above
8. Estimate areas of sedimentation hazard	same as item 6 above



Station	Stream and location	Drainage area (sq. mi.)	Peak discharge (cfs)	Unit Q (csm)
1	Shea Wash, SE 1/4 sec. 23, T. 3 N., R. 5 E.	1. 79	945	528
2	Shea Wash trib No 3, SE ¼, sec. 23, T. 3 N., R. 5 E.	.09	86	956
3	Shea Wash trib No 2, SW ¼, sec. 23, T. 3 N., R. 5 E.	.14	103	736
4	Shea Wash trib No 1, SW ¼, sec. 23, T. 3 N., R. 5 E.	.12	80	667

Floodwater for storm of June 22, 1972 was confined to defined channels. Indirect measurements of peak discharge made by USGS. According to the NRCS (Camp, 1986) the Ebon soil is on fan terraces. Channels are incised between 3 and 15 ft.

Figure 4.1 Example of flooding on relict fan.

For FEMA requirements see Appendix G in *Guidance for Alluvial Fan Flooding analysis and Mapping, Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2002).

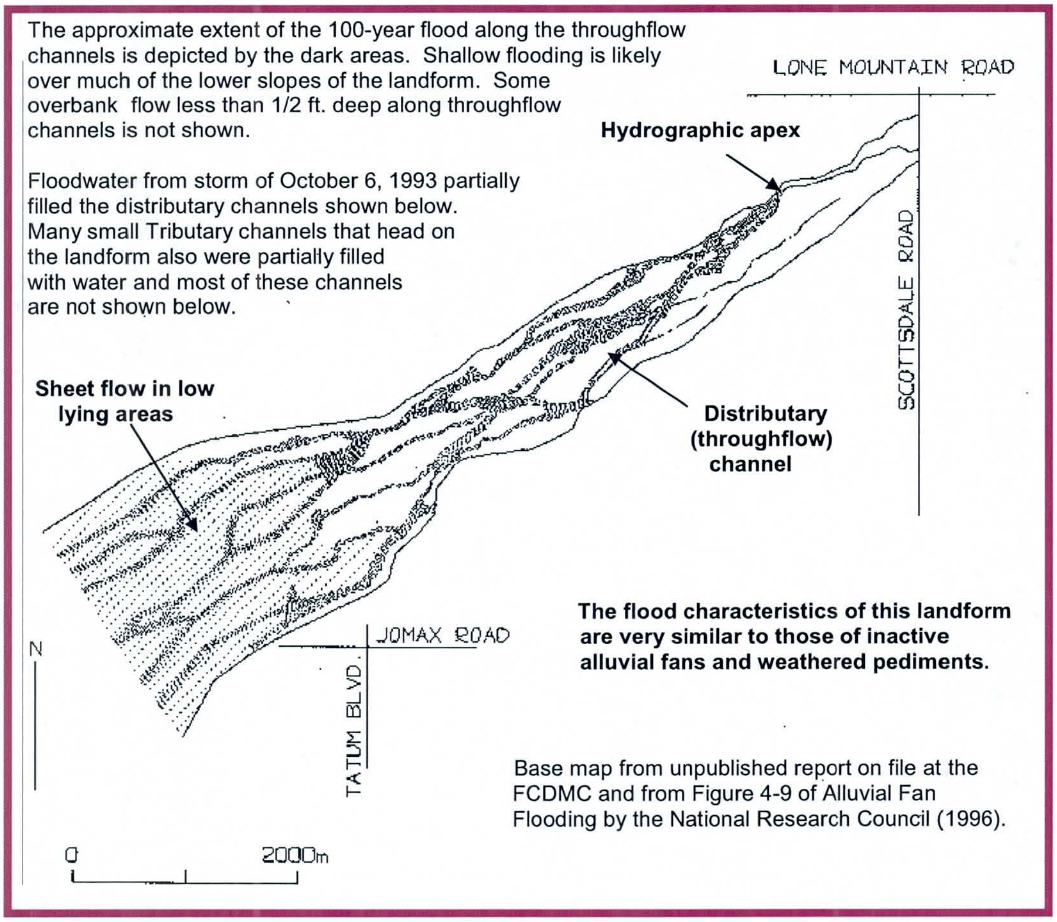


Figure 4.2. Example of flooding on an area with incised distributary channels near Carefree.

Normal backwater profile computations using a model such as HEC-RAS (COE, 1995) that computes profiles through stream junctions (channel forks and joins) are appropriate for many throughflow channels. These precise profile computations may require a great number of cross sections because 100-year floodwater in the many distributary flow paths traverses long piedmont slopes at shallow depths. Where precise computations of water surface profiles using energy or momentum based methods are unwarranted, the use of channel conveyance and slope estimates for definition of flood boundaries may be satisfactory and cost effective. Thus, flood boundary definition using ratings based on channel conveyance may be appropriate for some networks of distributary channels.

Both the rating curve and normal profile methods have a built in safety factor because the peak discharge is apportioned through the network of channel reaches by assuming that the flood peaks coincide at all forks and joins. The natural attenuation of flood peaks that results from channel storage and the unequal timing of peaks in the separated channels below splits and above joins is ignored in this method. This accounting of peak flow is based on the simple assumption that the joining of separated flood peaks is at the peak discharge. This method reduces the impact of underestimating the magnitude of flow in separated distributary channels. The impact reduction can be significant below joins because of the flashy nature of piedmont floods and the associated attenuation of peaks as floodwater spreads into a network of channels. The risk to homes along these stable networks of distributary channels may be significantly reduced by use of this conservative accounting method.

Development of inactive alluvial fans should recognize that throughflow channels convey both flood flow and sediment. Development that is set back from these channels and does not interfere with the water and sediment transport can have long term environmental benefits.

Delineation of major tributary streams that head on the inactive fans or weathered pediments is important to maintain an open flow path to the throughflow streams. Tributary streams typically drain areas much less than 1 mi^2 and flow depths are typically less than 1 or 2 ft. Streams draining such small areas may not be identified as subject to FEMA flood hazard delineation but may fall under state and county regulations. For example, the State of Arizona Standard for watercourse bank stabilization (SSA 7-98) includes all watercourses with drainage areas more than 1/4 mi^2 or a 100-year discharge estimate of more than 500 ft^3/s (See Arizona Revised Statute 48-3605(a)).

In addition to the definition of traditional hydraulic conditions, the fieldwork should focus on identification of any areas of sediment deposition and impending stream piracy. Flood flow on some inactive fans becomes unconfined on lower slopes like that for the Carefree alluvial fan (NRC, 1996). For unconfined sheet flow see *Natural and Urban Sheet Flow* in State of Arizona Standard 4-95.

4.1.2.1 Rating curve method for allocating split flow

For distributary channel networks where the channel in which water-surface profiles are being computed splits into 2 or more separate channels, each channel must be considered a separate reach. This is demonstrated using the fork in Figure 4.3 where the total discharge is split into unknown components in the right and left channels. It is desired to determine the stream profile and the distribution of flow in the left and right channels.

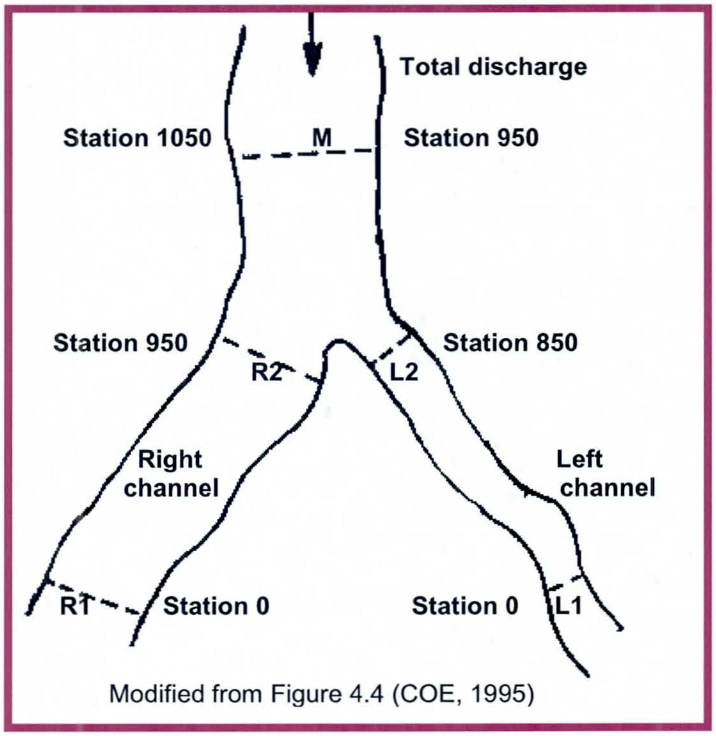


Figure 4.3. Example of split flow at a channel fork.

The problem is that the division of the flow into the right and left channels is not known and the HEC-RAS (COE, 1995) model assumes the user has determined the correct flow in each channel. To use HEC-RAS to compute water-surface profiles the division for sub critical flow is accomplished as follows.

The right and left channels are calibrated by establishing a stage-discharge relation for section M (Figure 4.3). For example, beginning at section R1 and working up the right channel, the water surface profiles for various discharges are computed up to M. A minimum of three discharges is needed that span the correct discharge for the right channel. For this example four discharges were used for each channel as shown in Table 4.2. The rating, computed water-surface elevation at M versus discharge (See computations in Table 4.2), is plotted as in Figure 4.4, with a solid line. A similar rating is established at section M for the left channel, and plotted with a dashed line in Figure 4.4. The crossing of the two curves determines the proper subdivision of the total discharge into the right and left distributary channels. For further information on the use of this technique see Computation of Water-Surface Profiles in Open Channels (Davidian, 1984).

4.1.2.2 Cross-sections

Cross sections used for normal backwater profile computations should be representative of the channel reach between them and should span the width of landform that includes the channels which might convey the 100-year flood. If there is any doubt about which channels may convey floodwater, the cross sections should span the channels across the entire width of the landform between the boundaries defined in Chapter 3. Cross sections are placed at intervals along the network of channels that will subdivide the distributary channels into a series of sub reaches of relatively uniform geometry and roughness. Cross sections may be located at contour lines of a detailed topographic map because the shallow flow is approximately perpendicular to contours and the section shape may be estimated from the map information. Cross sections should be located above and below all forks and joins of the network of channels such that the fork or join is in the middle of the sub reach (see Figure 4.3). In general, cross sections should be established in accordance with procedures in water-surface profiles user's manuals such as HEC-2 (U.S. Army Corps of Engineers, 1990) and WSPRO (Shearman, 1990) and the Guidelines and Specifications for Study Contractors (FEMA, 1995).

Table 4.2. HEC-RAS output for sub critical flow split using rating method.

RAS Plan: Rating.split 6/4/96

Reach	River Sta.	Q Total (cfs)	Min Ch Elev. (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude No.
Right	1050	200	92.00	93.78		94.36	0.0157	6.12	32.68	18.71	0.82
Right	1050	200	92.00	93.70		94.34	0.0182	6.42	31.14	18.68	0.88
Right	1050	200	92.00	93.63		94.33	0.0205	6.68	29.96	18.65	0.93
Right	1050	200	92.00	93.73*		94.35	0.0173	6.32	31.65	18.69	0.86
Right	950	160	90.00	91.90		92.62	0.0198	6.80	23.53	12.76	0.88
Right	950	145	90.00	91.79		92.46	0.0198	6.57	22.07	12.71	0.88
Right	950	130	90.00	91.67		92.29	0.0197	6.32	20.58	12.67	0.87
Right	950	150**	90.00	91.82		92.51	0.0198	6.65	22.56	12.73	0.88
Right	0	160	71.00	72.90	72.74	73.62	0.0200	6.82	23.46	12.76	0.89
Right	0	145	71.00	72.78	72.63	73.45	0.0200	6.60	21.98	12.71	0.88
Right	0	130	71.00	72.66	72.52	73.29	0.0200	6.35	20.46	12.66	0.88
Right	0	150	71.00	72.82	72.67	73.51	0.0200	6.67	22.48	12.73	0.88
Left	950	200	92.00	93.62		94.33	0.0211	6.73	29.71	18.65	0.94
Left	950	200	92.00	93.77		94.36	0.0158	6.14	32.57	18.71	0.82
Left	950	200	92.00	93.96		94.44	0.0115	5.54	36.10	18.79	0.70
Left	950	200	92.00	93.72*		94.34	0.0174	6.33	31.60	18.69	0.86
Left	850	40	90.00	91.75		92.18	0.0199	5.26	7.60	4.70	0.73
Left	850	55	90.00	92.16		92.67	0.0200	5.73	9.60	4.87	0.72
Left	850	70	90.00	92.55		93.13	0.0199	6.08	11.51	5.02	0.71
Left	850	50**	90.00	92.03		92.52	0.0200	5.59	8.94	4.81	0.72
Left	0	40	73.00	74.75	74.42	75.18	0.0200	5.27	7.59	4.70	0.73
Left	0	55	73.00	75.16	74.75	75.67	0.0200	5.74	9.59	4.87	0.72
Left	0	70	73.00	75.55	75.04	76.12	0.0200	6.09	11.49	5.02	0.71
Left	0	50	73.00	75.03	74.64	75.51	0.0200	5.60	8.94	4.81	0.72

The subdivision of cross sections should be accomplished based on channel geometry. Each of the channels that potentially may convey flood flow should be subdivided to facilitate the analysis of the amount and distribution of flood flow in the network of channels. The computer program should be capable of tabulating hydraulic characteristics for the subsections at many elevations for each cross section (see for example WSPRO (Shearman, 1990)). Across some channel networks the roughness of defined channels is markedly less than the roughness of adjacent land and the subdivision should define the roughness differences. Well-defined channels with low roughness may have critical-flow conditions and the adjacent rougher land with shallower flood flow may have sub critical-flow conditions. Thus, the computer program should be capable of managing values of Q at both critical and normal depths for the sub areas at several water-surface elevations. Where defined throughflow channels are relatively small and meander there may be additional roughness from the meanders as floodwater rises above the defined banks of the small channels and "short circuits" or passes over the meanders.

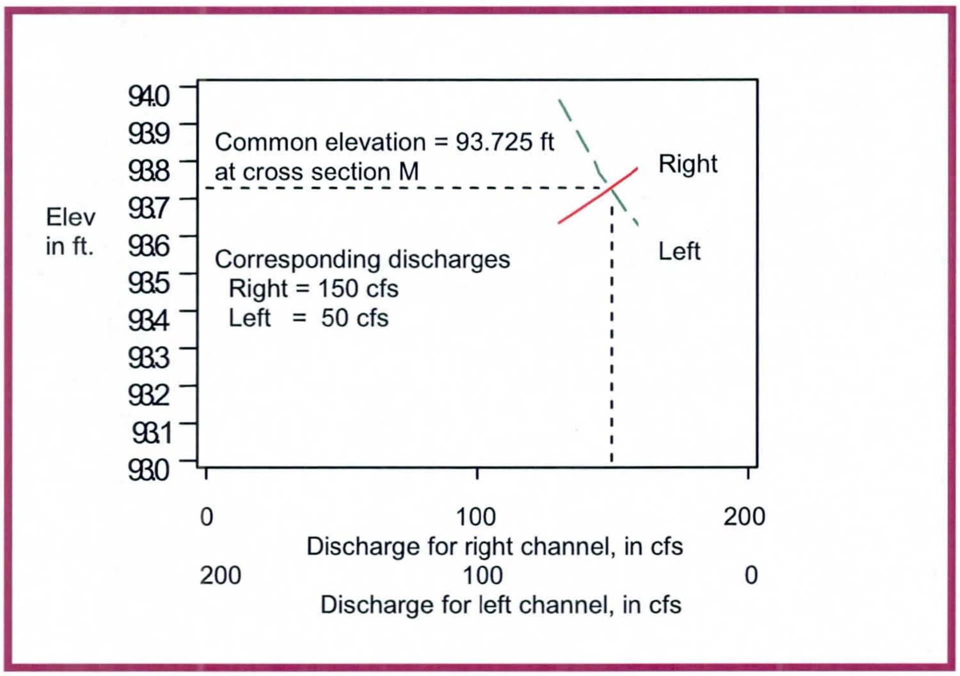


Figure 4.4 Distribution of flow at split using the rating method.

Such "short circuits" are likely on granite pediments in Maricopa County. Thomsen and Hjalmarson (1991) discuss subdivision of cross sections and the estimation of roughness coefficients for streams in Arizona.

4.1.2.3 Channel conveyance-slope method

Some networks of distributary channels convey flood flow in many small channels that have many forks and joins (see for example the distributary channels is Figure 4.2). In order to define the extent of flooding, each of the channel segments must be defined as a separate reach with a unique peak discharge. Many computations of flow apportionment at the forks and joins and many standard step-backwater or step-forewater computations for the many individual reaches are needed. The problem is these computations are time consuming, expensive because of the data requirements and possibly unnecessary especially where flow depths and velocities are not very hazardous. The channel conveyance-slope method greatly simplifies the data and computation requirements and should be considered for these areas.

Flow apportionment based on channel conveyance and slope may be used for these less hazardous networks (networks composed mostly of small channels) of stable distributary channels. The peak discharge is apportioned through the network of channel links (reaches) by assuming the flood peaks coincide at all divides and joins. A single cross section for each of the distributary channels below each fork (See for example sections R2 and L2 in Figure 4.3) is used. By assuming lower regime flow velocities and a uniform water level at the head of the distributary channels, flow is easily apportioned using channel conveyance and slope. The estimates are further simplified where the slope difference along the channels is small and can be ignored. The resulting estimated peak discharge and corresponding channel conveyance (or even channel area where channel roughness is uniform) are used to estimate flood boundaries for each reach. This technique can produce reliable and low-cost delineation of the location and extent of flooding on distributary networks of channels especially if the throughflow channels are kept free of obstructions.

This approximate technique may be used for distributary channel networks on inactive alluvial fans and those granite pediment areas described in Appendix F of this Manual, where the hazard is not very great. The major steps for apportioning 100-year flood peak discharge and estimating the flood boundaries using the conveyance-slope method follow:

1.-- Define the 100-year peak discharge above the hydrographic apex (see Figure 4.2 for an illustration of an hydrographic apex above a complex network of distributary channels. The hydrographic apex and boundaries of the landform were defined in Chapter 3. The 100-year peak discharge is estimated using the drainage basin area and flood-frequency relation using sources given in Table 4.1.

2.-- Define the throughflow and major tributary watercourses throughout the landform on a detailed topographic map. The flow paths and should lie within the bounds of the landform defined using methods in Chapter 2.

3.-- Estimate limits of flooding along each distributary channel. High ridge lines separating the channels can be defined on detailed topographic maps. The width of flooding should be within the flood limits defined in Chapter 3 of this Manual.

4.-- Identify each distributary channel reach that has a channel fork or join at the upstream end and a channel fork, join or outlet at the downstream end.

5.-- Select a cross section near the middle of each reach that represents the hydraulic conditions of the reach. The cross section must represent channel conveyance below any fork at the upper end as discussed in the previous paragraph and in USGS report Computation of Water-Surface Profiles in Open Channels (Davidian, 1984). Although not the rule, several sub reaches may be needed for some reaches if hydraulic conditions change significantly along the reach.

6.-- Define areas and sub areas of cross sections.

7.-- Select Manning's *n* for the areas and sub areas.

8.-- Compute and tabulate conveyance and discharge for the area and/or sub areas of the cross sections and define the stage-discharge relation above and below all channel forks. The distribution of wide-shallow flow approaching a channel fork can be used in conjunction with the channel capacities below the fork to apportion peak discharge at the fork. Engineering judgment is needed for the apportionment of flow at forks because the splitting of peak discharge is related to both the distribution of the wide-shallow flow approaching a fork as well as the channel capacities below the fork.

9.-- Apportion or route the peak discharge at the channel forks using the rating curves for each reach of distributary channel and the assumption the water surface is horizontal across head of each channel fork and the slope of the channels is the same as discussed above. The distribution of peak flow for this simple technique is based on the assumption that the joining of separated flood peaks is at the peak discharge. The peak discharge is apportioned through the network of channel reaches by assuming that the flood peaks coincide at all forks and joins (Figure 4.5.a). Any reduction of peak discharge below the apex from channel storage and transmission losses to infiltration into the channel beds is assumed to offset tributary inflow for this simple example. Allowance should be made for inflow from any large tributaries.

10.-- Estimate the flood boundaries on the detailed topographic map using conventional engineering techniques (Figure 4.5.b).

4.1.2.4 Soil and surface characteristics

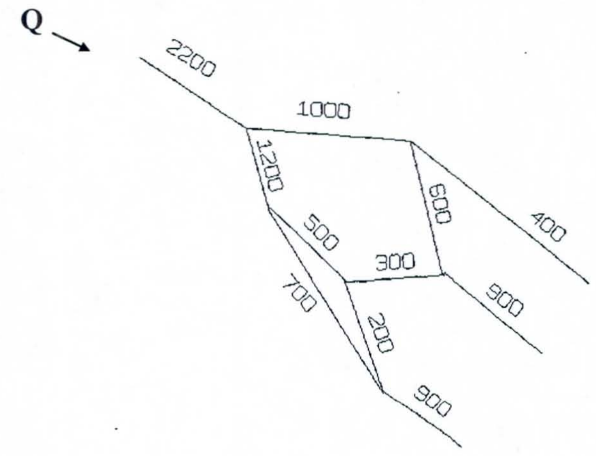
The apportionment of flow at all forks has some uncertainty as previously discussed. Because of this uncertainty, the verification of the computed flood limits by briefly examining the soils and surface characteristics along each of the individual reaches is recommended for all sites in Maricopa County. Present soil and surface characteristics are related to past and future flooding, so the use of this information can be a low-cost, physically based means of supplementing the hydraulic computations. Physically based methods like soil and surface age may be more reliable in dealing with uncertainty than methods based on assumptions of the nature of uncertainty (See for example Figure 3-10 of NRC, 1996).

Soil development and surface characteristics should be used to supplement the delineation of flood boundaries using the hydraulic methods (See Table 4.1). These soil and surface characteristics are the same as those used in the stability assessment outlined in Chapter 3 of this Manual, but more detailed analyses and soil descriptions by a soil scientist or arid region geomorphologist may be required. There is a correlation between the age of soil and the areas flooded along the channels (NRC, 1996, p. 111; Cain and Beatty, 1968; Klawon and Pearthree, 2000). Sediment deposited within the general bounds of the 100-year flood should be young and unweathered.

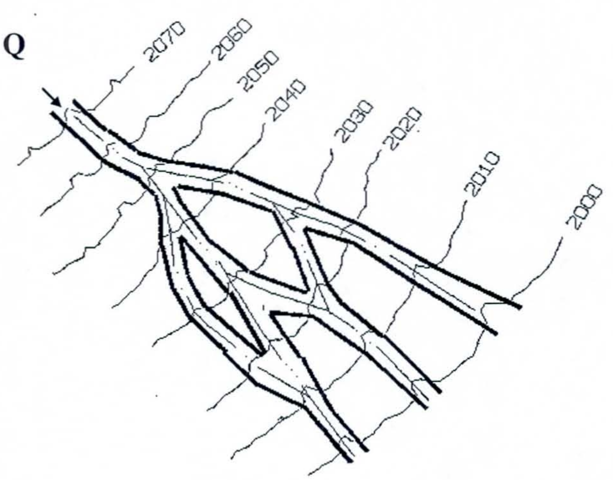
4.1.2.5 Discussion

The precise and approximate techniques for allocating peak discharge and defining flood boundaries may be modified to account for infiltration, attenuation and tributary inflow effects. Large networks of distributary channels with small drainage basins may have a relatively large component of tributary peak discharge from within the channel network that should be included in the hydrology. For example, a significant portion of the total storm runoff on October 6, 1993 at the Carefree, Arizona site (Figure 4.2) was from within the bounds of the network of distributary and tributary channels (NRC, 1996) and below where flow was last confined. For some networks of distributary channels, it may suffice to assume the runoff directly from the inactive alluvial fans and granite pediment areas offsets the loss of incoming peak discharge at the hydrographic apex to infiltration. For example, in the simple example given in section 4.1.2.3 (step 9) the tributary inflow was assumed to offset losses to infiltration along the throughflow channels.

The numerous distributary channels function to convey water and sediment through and from the inactive alluvial fans and weathered pediments. Those areas along throughflow channels subject to inundation by floods up to the 100-year flood might be set aside as floodway districts in order to maintain conveyance corridors for the transport of the floodwater and sediment down the piedmonts past development. Development that is set back from these throughflow paths may help maintain the natural sediment and runoff balance and prevent unwanted channel scour and sedimentation within and downstream from these areas.



a. Distribution of 100-year peak discharge



b. Estimated flood boundaries on detailed topographic map

Figure 4.5. Sketch of stable distributary flow paths showing distribution of 100-year flood peak discharge and estimated flood boundaries.

4.1.3 Active alluvial fans

The major hazard on active fans in Maricopa County is potential changes in flow paths due to either sudden or long-term sedimentation and erosion where a site may become buried or become part of a new active channel. The temporary inundation by floodwater traditionally associated with *riverine* hazards may be a lesser hazard on active alluvial fans.

The 100-year peak discharge at the hydrographic apex is only a partial measure of the flood hazard. Traditional step backwater methods of defining profiles and flood boundaries for the 100-year flood have little meaning because the floodwater typically becomes unconfined and spreads in various flow paths at uneven levels. The paths of flow may change during flooding as a result of sedimentation and erosion. Deposited sediment is remobilized and redeposited down fan by subsequent floods. On some fans large floods may transport and deposit large amounts of debris that eventually are translocated by smaller, less sediment-laden floods. The resulting morphology may appear deceptively simple and invite an overly simplified probabilistic depiction of the hazard (as that developed by Dawdy, 1979).

The natural path of floodwater over alluvial fans in Maricopa County is not random during a time span of a few hundred years (CH_2M Hill, 1992 and Pearthree, 1991). For active fans like those in the County, the preflood topography influences the location of major flooding (NRC, 1996). Nonetheless, alluvial fans or portions of alluvial fans in Maricopa County that are active are subject to infrequent flashy sediment laden torrents.

4.1.3.1 Flood hazard management on active alluvial fans in Maricopa County

The active alluvial fan is an area of great potential risk and danger to development and life. In the absence of major engineering measures to mitigate the fluvial hazard, this entire area is reserved in order to receive sediment and floodwater without altering and thereby increasing the distribution of hazard across the fan to inactive areas and to areas down slope.

> The high hazard area should be regulated similar to the floodway district in the typical riverine floodplain.

An important requirement in the final definition of flood hazard involves a review of the distinction between active and inactive areas on the fan. The topography of the fan, in particular the relation between the stream channel and the fan surface, is re-examined using the best available maps. Using the best estimate of the 100-year peak discharge, the capacity of the channel at and below the hydrographic apex is next examined. If the channel(s) is so incised that the 100-year flood cannot break out of its channel(s), the fan must be further evaluated before it is considered active. A fan surface that is above the level of the 100-year flood may not be active.

In the identification of stable and unstable areas, Chapter 3 of this Manual, an alluvial fan is considered active if there is recent evidence of flow path movement and other disturbance by flooding during the Holocene geologic epoch. In the absence of a finer time scale, the past 10,000 years is a convenient and practical period to use as discussed in Chapter 3 of Manual. Use of this period is expected to result in a satisfactory and conservative assessment of the flood hazard for most alluvial fans.

Fans with a nonstationary flood hazard typically evidenced by recent movement of the hydrographic apex may need further assessment of activity. Many stream channels in Arizona are incised as a result of geologically recent climate change or anthropogenic impacts (Cooke and Reeves, 1976; Hereford and Webb, 1992; Waters, 1985; and NRC, 1996). Fans with recent channel incision that make portions of the fan less active may require a precise dating and field assessment of the fan surface by a qualified soil scientist or geologist in order to define the flood hazard. The 100-year flood test described above should be applied to these less active areas. A more detailed examination of the fan stratigraphy as discussed in section 3.4.3 of Manual may be needed. These less active fans or less active portions of fans are a special case and require supportive documentation of site conditions and interpretations by qualified soil scientists, geologists and engineers.

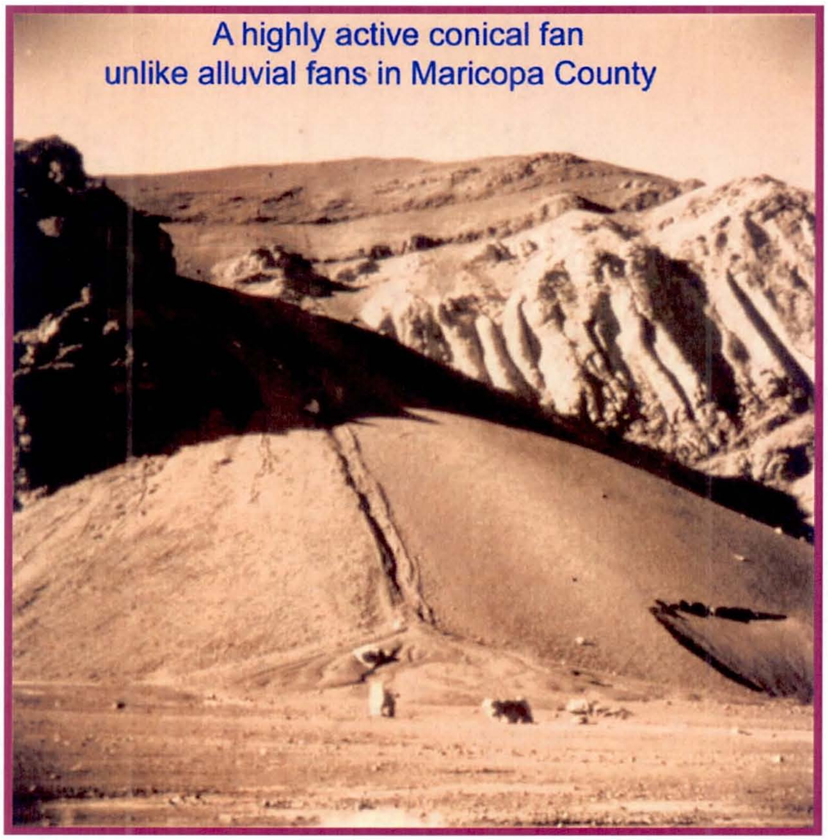
The evaluation should also include a detailed field examination of the drainage basin and supply of fan building material. Very active fans have an abundant supply of unconsolidated medium to coarse granular material along the steep slopes and channels of the drainage basin. Active fans may also have a material supply along incised channels of relict fans. A fan may become less active as the rate of channel incision in the relict fan has lessened over time. Such decreased fan activity may be difficult to demonstrate but the lack of an abundant supply of fan building material suggests a low activity. The channel beds above the hydrographic apex of active alluvial fans typically are composed of unconsolidated sand, gravel, cobbles and scattered boulders.

Alluvial fan surfaces that: (1) are classed as active using indicators of Chapter 3, (2) are generally above the level of the 100-year flood, and (3) do not have an abundant supply of sediment above the hydrographic apex are not considered very active. The user should be aware that an "abundant sediment supply" is related to the size of the alluvial fan that is located below the sediment supply. For example, a sediment supply may be considered abundant for a small alluvial fan and less than abundant for a large alluvial fan. In this regard, Hjalmarson and Kemna (1991) found that fans with large drainage basins relative to fan areas are more active than fans with relatively small drainage basins. These areas of low activity may be defined using methods given in this Manual and possibly supplemented using methods by Hjalmarson and Kemna (1991) (Appendix O).

Mitigation of hazards on active alluvial fans is beyond the scope of this Manual but in general, hazards on fans with a low level of activity might be mitigated using less than major engineering measures. Any engineering measures should not increase the flood hazard at other locations on or below the active fan.

4.1.3.2 Fans with random flow paths

For the very few alluvial fans in Maricopa County that may not exhibit obvious preferred flow paths, the assumption of absolute uncertainty where the floods might occur on the fan surface may be made. This special case where there are no channels on the fan meets the requirements in Appendix G in *Guidance for Alluvial Fan Flooding analysis and Mapping, Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2002) but should be used only as a last resort. Random flow paths, as suggested for fans like that shown in Figure 4.6 are considered unlikely in Maricopa County.



The active alluvial fan shown above may closely meet the assumption of random flow paths associated with the FAN computer program (Section G.2.3.2 of FEMA, 2001). However, few, if any, alluvial fans in Maricopa County are like the alluvial fan shown above.

Figure 4.6. Fan unlike those in Maricopa County

4.1.3.3 Supercritical flow velocities and *translatory wave* considerations

Flow velocities at the hydrographic apex may be supercritical and flow may expand as unconfined flow over the fan surface (McPherson and Blair, 1993). Flow velocities may remain supercritical and possibly unstable along the upper fan as evidenced by an observed sheet flood with migrating waves in the active deposition lobe of a fan (Blair and McPherson, 1994). Oblique expansion waves (Chow, 1959) may form where the channel banks widen and the waves may continue down the fan. Where the channel width-depth ratio is large and Froude numbers are greater than 1.6, the flow may be unstable causing large-wide translatory waves (Hjalmarson and Phillips, 1997). High flow velocities, sheet flood and translatory waves are common documented characteristics of alluvial fan flooding (NRC, 1996).

There is no known practical step forward method to precisely define the water-surface profile or a method to define the single-event fan profile for the hazardous conditions described above. With active sediment transport deposition where slopes are both steep and mild, many assumptions of channel and sediment conditions are needed. An example of such assumptions for channel slope and width is given by French (1995) in his estimate of the channel profile where the slope changed from steep to mild. Quantitative estimates like the hypothesized approach used by French should consider accounts of actual floods like those of Blair and McPherson (1994).

4.1.3.4 Published examples of geomorphic hazard assessments

Examples of a few geomorphic assessments of flood hazard that reflect to some degree the probability of the design or regulatory flood have been published. The major advantage of geomorphic assessments is they are physically and process based. A major disadvantage of geomorphic methods may be that traditional expressions of flood event probability are limited. A major advantage of traditional hydraulic engineering methods in the United States is that the flood event probability is estimated and then converted to computed elevations and mapped boundaries. A major disadvantage of this traditional method is that assumptions of channel stability, friction and eddy losses and flow-path location may be severely limited on active alluvial fans.

Useful examples of fluvial hazard assessments with maps of hazard zones for are found in CH_2M Hill (1992), Kellerhals and Church (1990), Thurber Engineering Ltd. (1983), Whitehouse and McSaveny (1990) and Field and Pearthree (1992).

Examples of illustrated accounts of flow path stability and/or severity of flood hazard are provided in Hjalmarson (1994) (See section 8.4 of this Manual), Hjalmarson (1978), Hjalmarson and Tram (1995), Hjalmarson and Kemna (1991) (See section 8.3 of this Manual), Klawon and Pearthree (2000), Pearthree (1991), and Rhoads (1986).

Examples of geologic maps of flood deposits with corresponding age designations that are especially useful for conditions in Maricopa County are found in Blair and McPherson, Blair and McPherson (1994), Hunt (1975), Hunt and Mabey (1966) and Wells (1977).

4.1.3.5 Published examples of modeled hazard assessments

Examples of modeling debris or water flows on alluvial fans are given in Anderson-Nichols and Co.(1981) and O'Brien and Fullerton (1990).

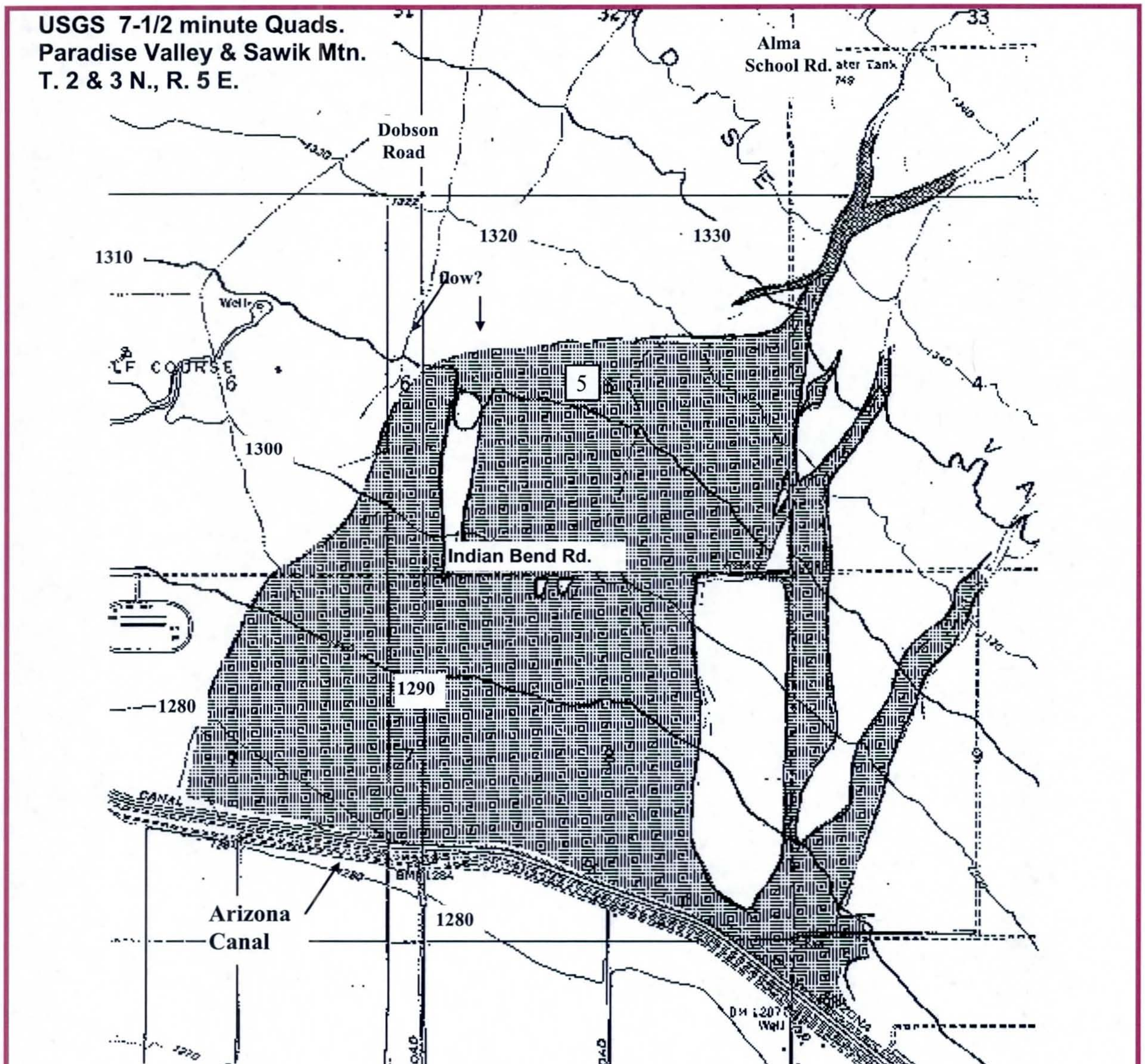
An example of a laboratory model and short term and long-term flood risk is discussed in Zarn and Davies (1994).

4.1.4 Alluvial plains

Alluvial plain flooding typically is shallow and unconfined (see *Anastomosing Flow* and *Agricultural Sheet Flow* in State of Arizona Standard 4-95). Flow paths of the shallow flow follow the general grade of the land slope but are easily affected by obstructions such as roads (See for example Figures 4.7 and G7 in Appendix G and Figures 4.8 and G1 in Appendix G). The rapid spreading of flood flow shown in figure 4.7 was accompanied by a significant decrease of flood depth. Separated flow, uneven flow levels, varying surface roughness and complex eddies complicate any precise definition of flood characteristics. There is no known convenient and practical method of computing water surface profiles for the flow conditions depicted in Figures 4.7 and 4.8. Because the land is generally smooth with slopes usually less than 1 percent, estimated flood depths are used for flood plain management.

For most alluvial plains the flooding hazards should be defined using the FEMA *Shallow Flooding* methods given in *Guidelines and Specifications for Flood Hazard Mapping Partners* (FEMA 2002) and also in Arizona SSA 4-95 (1995) Identification of and Development within Sheet Flow Areas.

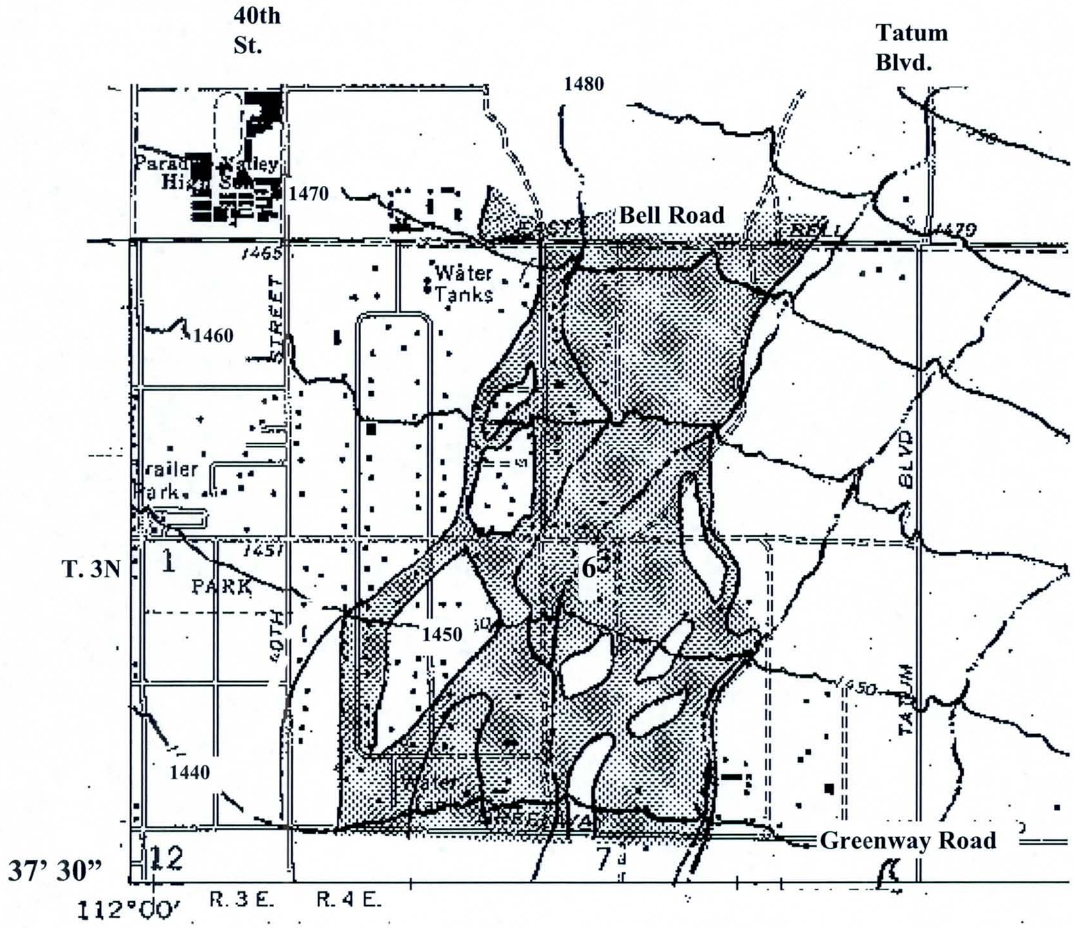
Deposited sediment (typically sand, silt and clay) can be a problem on alluvial plains. Sediment may be deposited in tongue shaped sheets as sheet floods spread out below channels. Local low bars of sand with some gravel may be deposited below locations where flow spreads and the slope lessens.



Flood of June 22, 1972. Most floodwater was from Shea Wash that crosses Shea Blvd. in the SE 1/4 sec. 23, T. 3N., R. 5E. Shea Wash (Site 22 of Hjalmarson and Kemna, 1991) is an active alluvial fan with the hydrographic apex 4 miles upstream of Indian Bend Road and 3/4 mile downstream of Shea Blvd. at sec. 26, T. 3N., R. 5E. The drainage area for the alluvial fan is 2.33 mi^2. The peak discharge at the fan apex was 1,300 ft^3/s with a unit peak discharge of 560 ft^3/s/mi^2 . Four indirect measurements of peak discharge at tributaries on a relict fan in the drainage basin were made by the USGS at Shea Blvd.. The area down-stream of the apex to the Arizona Canal is about 5.46 mi^2. The total area above the Arizona Canal in the scene is about 7.79 mi^2. Based on USGS aerial photographs of the flood, most of the runoff was from the drainage basin above the fan apex. The corresponding recurrence interval for this flood was about 25 yrs.

The average slope is 0.0053 with little transverse relief . The average spacing between the small channels upslope of Indian Bend Road is about 500 ft.. Below Indian Bend Road there are fewer than 5 small crenulations per mile of width across the alluvial plain. The dirt roads have some effect on the flow paths but the swale-like areas indicated by the contours have little discernible effect on flow paths. The entire mapped area of flooding was inundated at the time the photographs were take on June 22, 1972.

Figure 4.7 Example of major flooding on an alluvial plain.



Flood of June 22, 1972. General land slope is 0.0066 with about 1000 ft. spacing between the small 1 ft. deep channels. The water is moving along the general maximum slope gradient but not always normal to the contours. Roadways and road berms and other small obstructions have an affect on the flow paths. Many small islands are not shown. Flow depths appear to be about 1/2 ft. or less except in the small channels. A below ground swimming pool in the flooded area of the scene was not inundated. According to the NRCS (Camp, 1986) the Gilman soil is on flood plains and alluvial fans and is subject to shallow flooding. The hazard of water erosion is slight and the hazard to dwellings and small commercial buildings is severe. The surface is considered stable.

Figure 4.8 Example of flood flow on an alluvial plain in north Phoenix.

4.2 Summary

Standard hydraulic engineering methods such as step-backwater and step-forewater computations are used to define the profile, velocity and extent of the 100-year flood for flow confined to stable channels within relict fans and pediments. Floodway areas that include the limits of recent channel movement between stable banks should be delineated and reserved for the conveyance of floodwater and sediment. See for example the channel upstream from point A of Figure 4.9.

Where there are changing channel conditions, geomorphic methods are used in conjunction with traditional engineering methods. Floodway type areas that are reserved for the conveyance of floodwater and sediment which include the limits of recent channel movement between stable banks should be delineated. See for example the channel between points A and B of Figure 4.9.

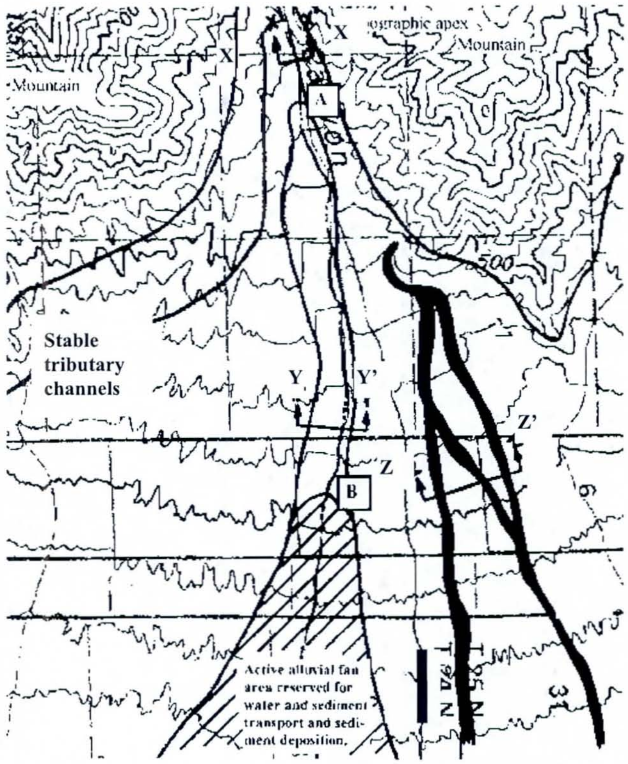
For active alluvial fans and alluvial plains the flow is unconfined and normal backwater profile computations for flood definition are inappropriate. Geomorphic methods, possibly supplemented by traditional hydraulic methods, are used to define the flood hazard areas of active alluvial fans.

Only major engineering measures can be used to mitigate the fluvial hazard on fully active fans. On more stable fans, minor engineering measures may be used to mitigate the hazard providing the hazard at other locations remains at acceptable levels. In the absence of engineering measures, the surface of active alluvial fans is reserved in order to receive and/or convey sediment and floodwater without altering and thereby increasing the distribution of hazard across the active fan and to areas down slope. See for example the active alluvial fan shown in Figure 4.9.

For networks of distributary channels that convey flood flow in many small channels that have many forks and joins the channel conveyance-slope method described in section 4.1.2.3 is a practical means for apportioning 100-year flood peak discharge and estimating the flood boundaries (Figure 4.2). See for example the distributary channels shown in Figure 4.9.

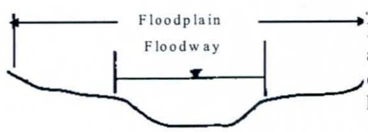
Land considered stable under natural conditions might be subject to considerable erosion if flow is concentrated by development. Stable or inactive alluvial fan areas, especially areas with little transverse relief, may become active if roads and other development direct flood flow from active onto inactive fan areas.

Investigators conducting a flood hazard assessment to FEMA requirements should follow the Maricopa County guidelines in Appendix R before starting Chapter 5 of the Manual.



Cross section X-X'

Representative cross section for stable cut in fan terrace and pediment above point A.



Banks and some of bed outcrops are gravel, cobbles and boulder s cemented by caliche. Traditional hydraulic methods used.

Cross section Y-Y'

Representative cross section of unstable sand bed channel confined between stable banks

Ebon-Contine soil(fan terrace) on banks. Bed is unweathered sand and gravel typical of active(modern) washes. Geomorphologic methods used and unstable area between stable banks is reserved for the conveyance of water and sediment.

Cross section Z=Z'

Cross section of stable distributary channels on fan terrace. Defined channels are reserved for the conveyance of water and sediment.

<u>This figure is the progression of Figures 2.6 and 3.2.</u>

Figure 4.9 Example of 100-year flood hazards.

5

APPLYING THE ASSESSMENT TO EXAMPLE SITES

Two of the three readily accessible sites used to demonstrate the assessment method are located within parks in Maricopa County. The first site is in Phoenix South Mountain Park and the second site is in the White Tank Park and the third site is at Skyline Wash located at the southern end of the White Tank Mountains. Methods described in Chapters 2 to 4 form the basis of the flood hazard assessment for each of the sites. The investigator is reminded that geologic maps, soil surveys, topographic maps, aerial photographs and field observations are the fundamental sources of information used for the assessment. Some flexibility of writing style and technical content is demonstrated but the three-stage approach (1. Recognize and characterize piedmont landforms, 2. Define the nature of the landform environment, and 3. Define the 100-year flood hazards) is closely followed.

5.1 The South Mountain Park alluvial fan.

The field inspection of this site is made to:

1. Verify the type of landform, described as an alluvial fan by the NRCS, using methods in Chapter 2 and steps in Table 2.2

2. Identify active and inactive areas using methods in Chapter 3

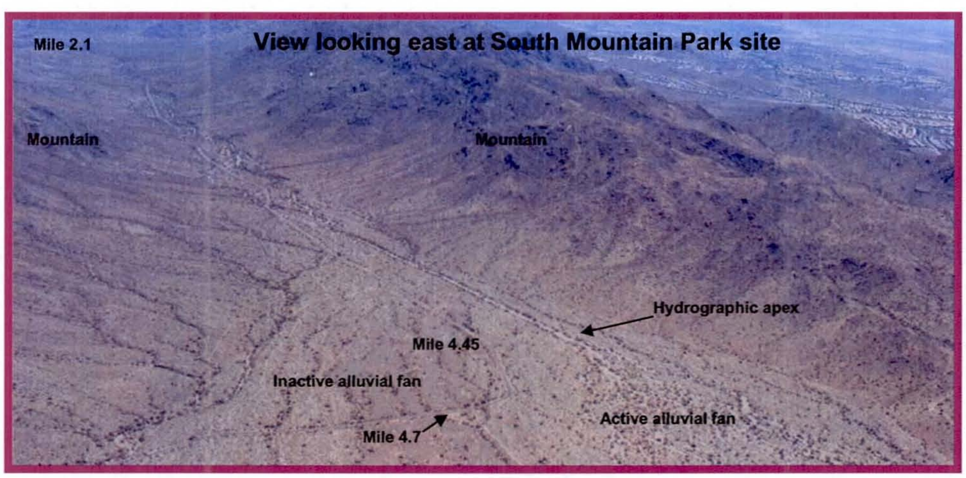
3. Estimate flood hazards, as described in Chapter 4, based mostly on geomorphologic methods using an estimate of the 100-year peak discharge at the hydrographic apex and at any major tributaries.

The investigator should have USGS 7.5-minute topographic maps of the Laveen and Lone Butte Quads, or the equivalent, and should have consulted the NRCS Soil Survey of Maricopa County, Arizona by Hartman (1977). Copies (small scale) of the soil survey maps for this site are included in this Manual. The investigator should consider reading this section of the Manual and obtain any needed referenced material before making a field inspection of the site.

The South Mountain Park site is located in an embayment at the west side of the Phoenix Mountains (Figures 5.1 and 5.2). The landform is accessed on the San Juan Road that starts at the old park entrance, the rock guard house, (mile 0) and crosses a saddle and enters the drainage basin at mile 2.1. The photograph on the right is a view looking west at road to the San Juan overlook at about mile 1.9. The South Mountain Park drainage basin is beyond the drainage divide in the background of the scene at about mile 2.1.

At mile 2.5 the incised main channel can be viewed from a pullout-parking area on the left (south) where the channel is deeply cut into pediment material mapped by Hartman (1977) as the Cherioni-Rock (CO) outcrop complex. At mile 2.6 the road crosses a small tributary from the right or north.

The topographic apex is approximately at mile 3.5. A major tributary from the north is crossed at mile 3.8 where cemented cobbly-bouldery conglomerate is visible on the right bank to the right or upstream of the road. At milepost 4.0 the road is on the fan terrace mapped by the NRCS as Carrizo-Ebon complex on alluvial fans (Hartman, 1977, shown as CeD in Figures 5.1 and 5.2). The lower mountain slopes located about 1/4 mile to the right are gravely-bouldery material with some bedrock outcrops and are covered in places with cholla that is typical of the Ebon soil in Maricopa County. At mile 4.45 are the hydrographic apex and the FCDMC streamflow gage about 400 ft. to the left (south) of the road. The surface of the old alluvial fan material to the right (north) is covered with varnished desert pavement. To the south of the road the material generally is younger and the varnish on the desert pavement becomes much lighter as one nears the gage and channel. A narrow parking area located to the southwest of the roadway at mile 4.7 can be used for a field inspection of the alluvial fan and the FCDMC gages (See photograph below).



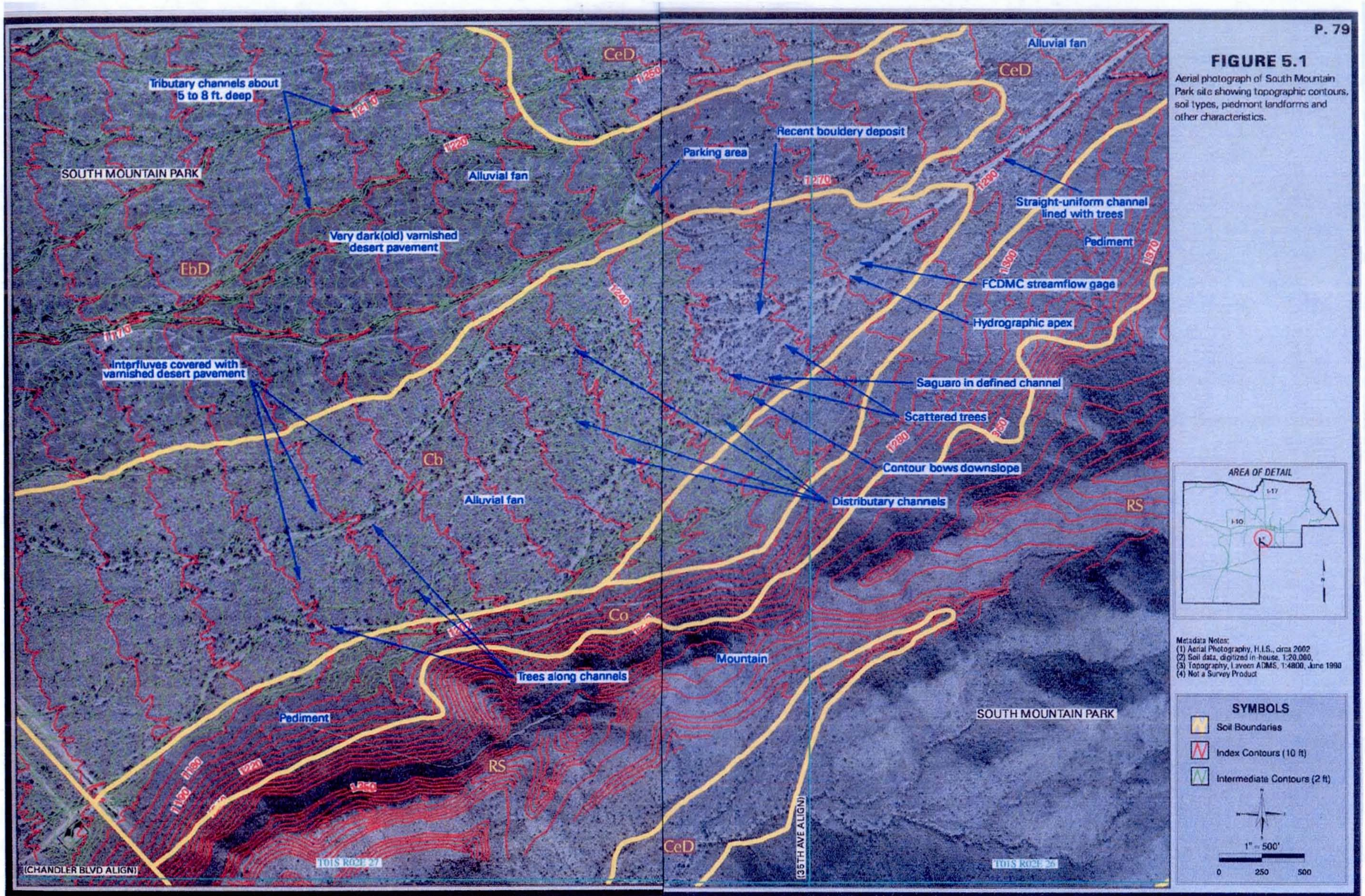
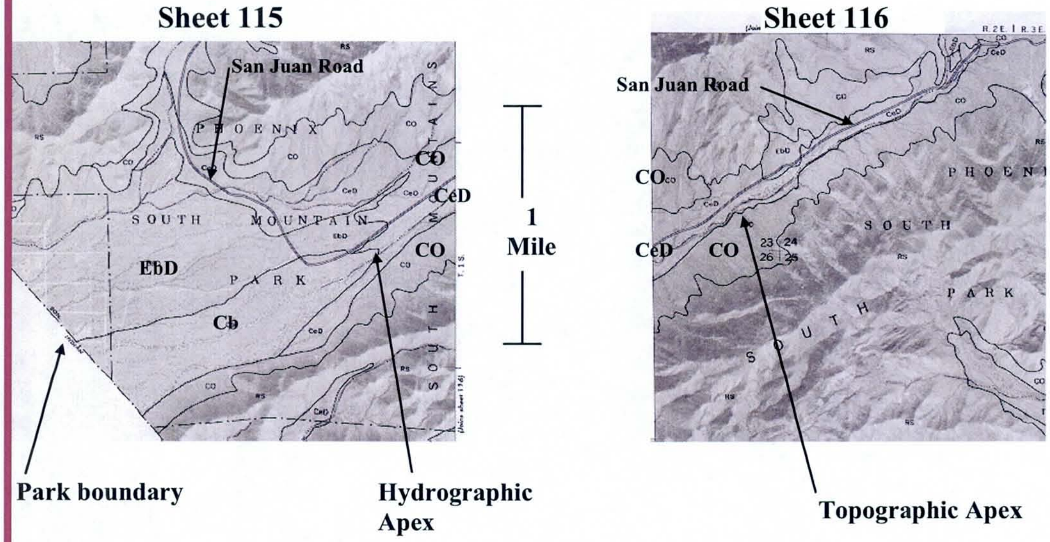


FIGURE 5.1

Aerial photograph of South Mountain Park site showing topographic contours, soil types, piedmont landforms and other characteristics.



Source of base map: NRCS Soil Survey of Maricopa County, Arizona by Hartman(1977).

Figure 5.2 Mapped Soils

5.1.1 Type of landform

In regions like central Arizona where there is relatively little geological recent tectonic activity and mountain uplift, the loci of deposition of most active alluvial fans shifts downslope from the mountain fronts. According to Bull (1977, p. 252) the fanhead trench can be "...removed as a possible area of deposition and the degree of soil-profile development will provide clues as to the length of time since the fanhead area last received deposits." These general conditions apply to the South Mountain Park site where there is a trench draining the surrounding mountain slopes. The trench divides into a few distributary channels a few hundred feet below the FCDMC streamflow gage (Figure 5.1). The area of distributary channels appears surrounded by land covered with dark gravel that is visible in Figure 5.1 and in the field. This widespread varnished desert pavement suggests the landform and surface exposure age are very old because the landform has been incised and no longer receives sediment as discussed by White and others (1996) (See also section 2.2.10 of this Manual). The distributary channels are surrounded by an abandoned deposition surface (a relict fan) where the erosion rate (if any) has been small.

The investigator is invited to examine the many photographs of the South Mountain Park site in Appendix I.

Erosion and runoff in inter rill areas of the relict fan may have increased as grass may have been replaced by shrubs during the past 100 years as described by Abrahams, Parsons and Wainwright (1995). Fine sediment is found under the shrubs that form islands where the shrubs regenerate, especially in the middle and lower fan area. The shrub islands are surrounded by desert pavement near the distributary channels and desert varnish a few tens of feet shoreward of the channel banks where it appears difficult for new shrubs to establish. These islands of fines are aeolian in origin and are surrounded by desert pavement. These islands at the South Mountain Park site are somewhat similar to the conditions at Walnut Gulch (Abrahams, Parsons and Wainwright, 1995).

The vegetation along the distributary channel banks, located to the south and west of San Juan Road, is paloverde, ironwood and mesquite. Below the hydrographic apex, the trees are scattered over an area of distributary channels (See section 2.2.13 and Appendix E of this Manual for the significance of scattered vegetation). Creosote bushes are scattered over the entire fan including the channels and ridges where there is typically carbonate in the soil. There are also saguaro cacti on the varnished ridge land between the channels. A few living and a few fallen saguaros (see general location on Figure 5.1) are also in the less active channels: saguaros seldom are found in active channels where there is scour and fill. The saguaro cacti and creosote bushes in some of the channels and on the adjacent land are uncommon in Maricopa County and suggest the landform is rather stable. About 1,500 ft. below the hydrographic apex most of the trees are along the channels suggesting stable flow paths.

The drainage area above the hydrographic apex is about 2.0 mi^2 with a relief ratio of about 0.12. The 100-year peak discharge is about 2,600 ft^3/s using methods by Thomas, Hjalmarson and Waltemeyer (1997) for flood regions 12 and 13. The basin is steep bedrock on three sides, somewhat bowl shaped and with many first order streams directly entering the main channel. These basin conditions are ideal for generating flash floods.

The Phoenix South Mountain Park landform (soils EbD and Cb, Figures 5.1 and 5.2) was identified as an alluvial fan based on the composition, morphology and location of the landform using methods of Chapter 2 in this Manual and descried below. For this particular site, the landform could be reliably identified using the NRCS soil survey (Hartman, 1977) and the USGS 7.5 minute topographic maps. A field inspection of the channels, road cuts and surface was made to verify the identification. Indicators observed on aerial photographs and in the field consistently verified the landform is an alluvial fan.

5.1.1.1 Composition

The landform is constructed from deposits of coarse, angular gravel sediments that can be observed in road cuts and along cut banks of washes. The angular material is typical for alluvial fans and clearly suggests a source area a short distance upslope. Along the southern part of the fan there is an accumulation of recent loose unconsolidated to weakly consolidated coarse sediments especially within two thousand feet of the hydrographic apex shown in Figure 5.1 (See section 2.1.3.1 for general discussion). The material is mapped as Carrizo gravely sandy loam soil on alluvial fans by the NRCS (Hartman, 1977) (Cb on Figure 5.2).

The northern part of the landform is an old deposit of angular gravel, cobbles and small boulders that is cemented. The coarse material observed along cut banks is imbricated suggesting fluvial process rather than debris flow process. Evidence of debris flows has not been found on the landform. The surface is rather smooth and flat and is covered with desert pavement and generally dark rock varnish. This material is mapped as Ebon gravely loam on old alluvial fans (EbD in Hartman, 1977 and on Figure 5.2). The upper part is mapped as the Carrizo-Ebon complex on alluvial fans.

5.1.1.2 Morphology

The landform has a partly extended fan shape bounded by the toes of the adjoining mountains (See sections 2.1.3.2, 2.1.3.4 and 2.1.3.5 for general discussion). The highly crenulated contours shown on the available 7.5-minute series USGS topographic maps (Laveen and Lone Butte Quads) have a slight convex shape in the downslope direction (See also Figure 5.1).

The contours on the south part of the landform (soil type Cb), where there are many distributary channels below a single-straight channel, bend more sharply downslope for a distance of about two thousand feet below the end of the single channel. The upper fan is convex upward in the transverse direction and this transverse mounding is apparent when viewed across in the field. The contours of the lower part of the landform are rather straight with several small crenulations that depict the small-incised channels. The aerial photograph (Figure 5.1) clearly shows a fan shaped braided channel network in the upper fan and a few tree lined distributary channels separated by several small undissected areas along the south side in the mid and lower fan.

5.1.1.3 Location

The landform is located at an old *topographic apex* (Figure 5.2) where flood flow that was confined between mountain slopes became laterally unconfined. The hydrographic apex is located about 1 mile below the topographic apex, where the approximately 90 ft. wide and 5 ft. deep channel looses lateral confinement. The profile of the channel shows a slight decrease of grade below the hydrographic apex because of the deposited sediment (Figure 5.3). The piedmont landforms are shown on Figure 5.1.

5.1.2 Stable and unstable areas of the alluvial fan

Most of the alluvial fan clearly is stable (inactive) with old developed soil covered with varnished desert pavement (See Chapter 3 for general discussion). These soils are the

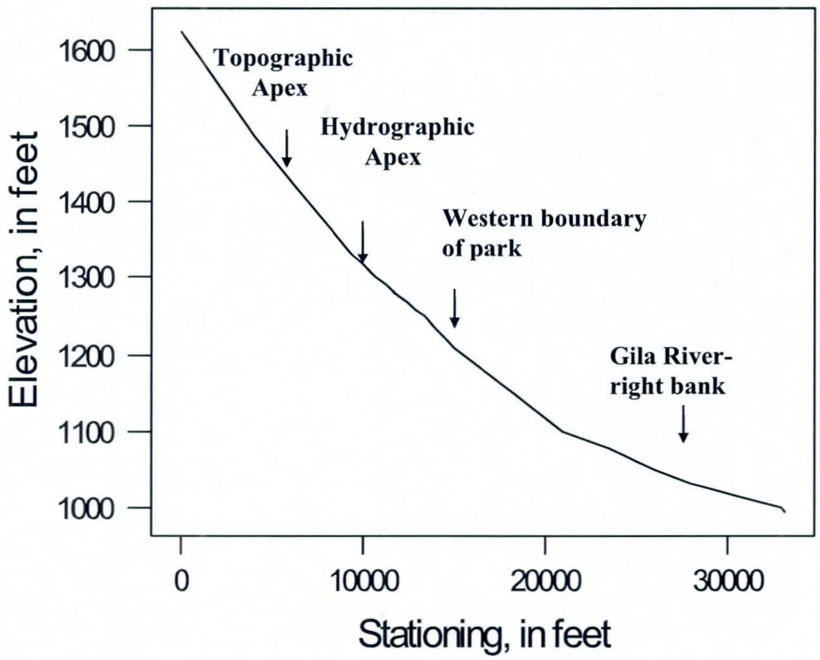


Figure 5.3. Profile of stream channel through active part of alluvial fan.

Ebon gravely loam (soil type Ebd) and the Carrizo-Ebon complex (soil type CeD). The throughflow tributary channels are cut about 5 to 8 ft. into the cemented conglomerate of these inactive areas. Several small tributaries head on the inactive fan. There is a potentially active alluvial fan in the upper part of soil type Cb (Carrizo) where there is recent sediment deposition and filling of small channels (See Table 2.1 for common soil types). Channel boundaries depicted on aerial photographs of 1936 and 1990 were examined by CH_2M HILL (1992). Channels in 1953, 1958 and 2002 are also shown in Scene 32 of Appendix I. A comparison of these stream channels revealed no significant change in the channel location. This lack of flow path movement suggests that (1) movement, if any, is small and not discernible on the aerial photographs, (2) there was no movement because there were no large floods during the 67-year period (1936-2002), or (3) movement does not occur because the fan is not aggrading and not active.

5.1.2.1 Fan Building at the South Mountain Park site

The primary sedimentation processes that build alluvial fans may be short-lived rare rock slides, debris flows and sheet floods that actively transport rock to the fan site (Blair and McPherson, p. 454, 1994). Sediment typically flows though a channel from an upland drainage basin to the fan site. Fan building events may result when basin sediment accumulation reaches a critical mass that can be moved during major floodwater or major accumulation of water within soil masses. Where fluvial processes are dominant, as in nearly all of Maricopa County, basin sediment accumulation is facilitated where periods of little or no basin runoff are long.

For example, at the South Mountain Park site, the slow accumulation of sediment in the incised basin channels is suggested because many years with little or no runoff are common and the mean annual flood is very small. At the USGS streamflow gage no. 09512200, located in the adjacent drainage to the east, the 2-year flood (19 ft^3/s) is a small portion of the 100-year flood (4,740 ft^3/s) suggesting that there are long periods where runoff is insufficient to transport sediment from the basin. Because the drainage basin above the South Mountain Park site shares a drainage divide with the drainage basin for USGS gage 09512200, the flood characteristics are probably similar. Thus, infrequent large floods are likely to transport sediment that has accumulated in the basin channels over long periods, and deposit this sediment on the alluvial fan of the South Mountain Park site.

5.1.2.2 Selected observations along the potentially active area

Evidence of channel scour and fill are clearly visible in cut bank exposures of the distributary channels (soil type Cb) from the hydrographic apex to near the Park boundary to the west (Figure 5.4). There is more bed and bank scour along the distributary channels of the right (north) side of the active alluvial fan. There is also some scour and fill along the left channels but not to the extent as on the right side where a few old trees have recently exposed roots. Just below the hydrographic apex a short distance below the FCDMC streamflow gage (See Scene 11 of Appendix I) the first channel bifurcation (fork) is from overflow into a channel on the right. This channel has recently (probably less than few hundred years before present based on the steep cuts in places along the banks) scoured and is headcutting into the main channel on the left. Most of the bedload from the drainage basin has been in the main channel and the flow that spills over the low right bank has carried less sediment. The overflowing floodwater on the right has picked up a new bed load by scouring a deeper channel for several hundred feet down the fan. This scour appears to be the final phase of stream capture that will progress during future floods. The distribution of floodflow at this first fork is expected to continue changing with a progressive, or possibly sudden, increase in flow to the right.

There are several closely spaced distributary channels in the upper two thousand feet of this part of the fan (soil type Cb). The generally unweathered angular and cobbly-bouldery bed material is considerable evidence of recent floodflow over much of the

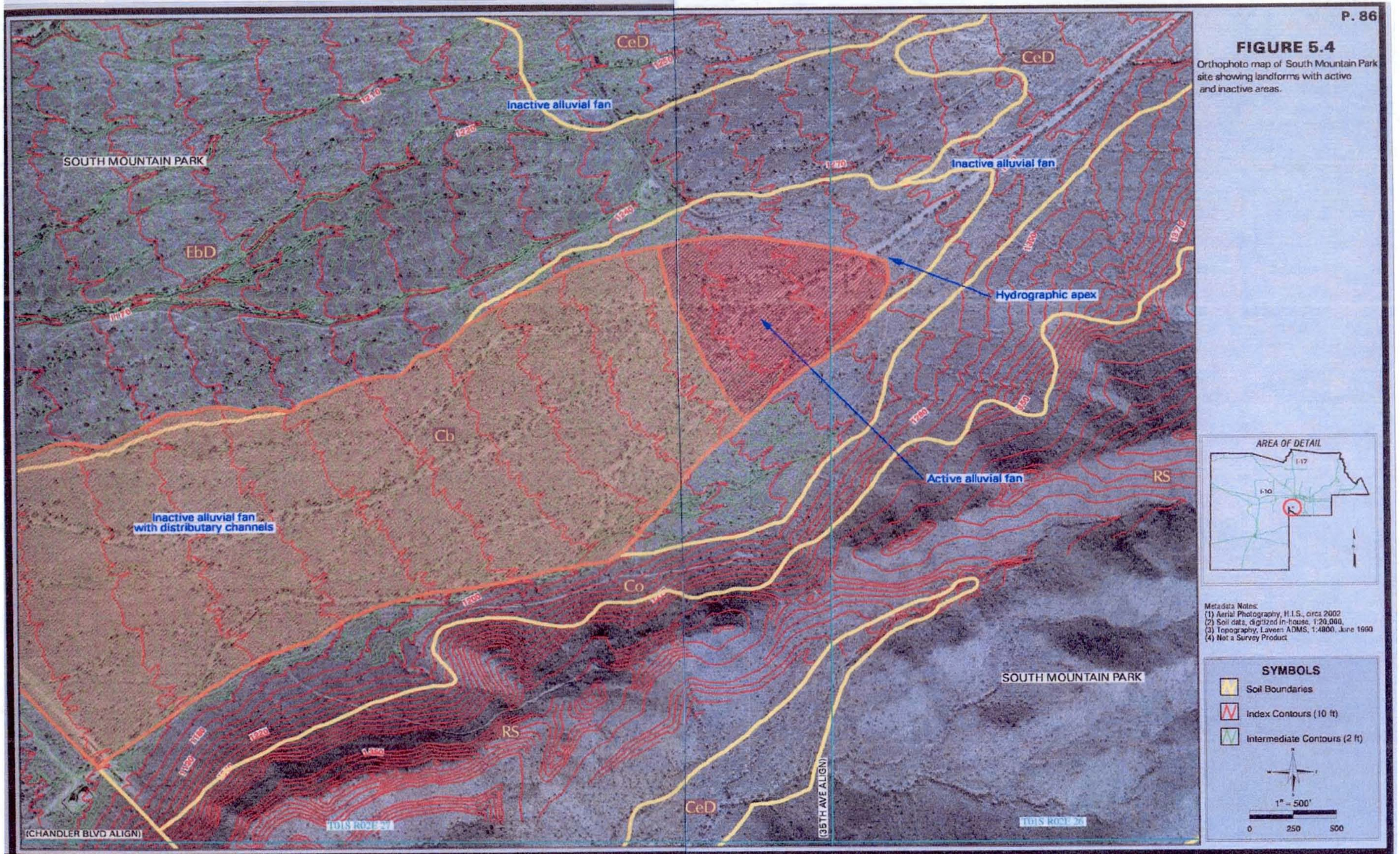


FIGURE 5.4

Orthophoto map of South Mountain Park site showing landforms with active and inactive areas.

area that is about one thousand feet wide in the middle and lower slopes (Figure 5.4). Some of the interfluves have lightly varnished stones and there are several saguaro cacti and large paloverde and ironwood trees. On the upper part of the fan trees are scattered over much of the fan suggesting (1) some local flow path movement or the absence of defined flow paths during the life of the trees or (2) frequent enough overflow and sheet flooding to supply the water needs of the trees. This evidence suggests the flow paths may change on the order of a few tens of feet as a result sediment deposition and erosion. The large clast size of the bed material and the recent deposits also suggest large floods cause much of the sediment transport, deposition and movement because small floods do not have the stream power to transport such material. The absence of fines in these coarse deposits indicates subsequent smaller flows and direct rainfall and sheetflow have remobilized and transported the smaller material down the distributary channels.

5.1.2.3 Summary of active and inactive areas

Most of the alluvial fan is inactive based on (1) the old developed soil that is covered with varnished desert pavement, (2) the throughflow tributary channels are cut about 5 to 8 ft. into cemented conglomerate, (3) several small tributaries head on the inactive fan and (4) the comparison of stream channels shown on aerial photographs revealed no significant change in the channel location for a 55 year period.

There is an active alluvial fan inset in the southern part of the inactive fan located in the upper area defined as soil type Cb. This fan is considered active based on (1) the recent deposited coarse sediment in the upper part of this area, (2) the cross-profile mounding of this sediment (3) the several wide-shallow distributary channels in the upper part of this area and (4) the recent deposition that has filled some of the small channels and redistributed conveyance across the fan.

In the lower part of the area defined as soil type Cb there are distributary channels separated by stable interfluves that are covered with varnished stones. The desert pavement in this area is lighter and less developed than on the surrounding inactive fan areas (soil types EbD and CeD). The larger channels are incised 2 to 3 ft. This area with distributary channels is younger than the inactive areas of soil types EbD and CeD but there is no evidence of recent flow path movement. On this basis the area is considered inactive but subject to varying distribution of discharge in the several channels because of the nonstationary hydraulic conditions at the first fork and flow path movement, although probably small, at the active alluvial fan upstream. This relatively inactive alluvial fan area is mapped separately from the other inactive alluvial fan area because of these conditions (Figure 5.4).

5.1.3 Estimated 100-year flood hazards

Methods given in Chapter 4 are used and discussed in this section. Some of the methods used to characterize the flood hazard are not specifically described in Chapter 4 and demonstrate the flexibility of the method.

5.1.3.1 Characteristics of recent deposited sediment

At first glance the material along the active distributary channels may appear like a recent debris flow but there are no classic remnants characteristic of debris flows (For examples of debris flows see Whipple and Dunne (1992), National Research Council (1996) and Costa (1988)). Some classic characteristics that are missing include (1) marginal levees of coarse material, (2) muddy deposits, (3) cemented non-friable deposits and (4) obvious inverse grading. Deposited sediment along the distributary channels is coarse and angular. In a few places, recent material is deposited on microbiotic crusts (See last paragraph in section 3.4.3 for general discussion) and in other places, there is local scour and some cutting of old banks. In general, however, the location of the active flow paths, as defined by the recent deposited sediment, appear to not change much except during very large flood flows where the stream power can move the large stones. Within several hundred feet below the hydrographic apex there is a propensity for unconfined flows as floodwater, typically at or near supercritical velocities (based on hydraulic modeling), spreads laterally and looses energy.

Along the major channels of the drainage basin above the hydrographic apex, there is an ample supply of coarse sediment from bank failure (Figure I2). These major channels are incised several feet into cemented conglomerate that has sloughed into the channel. The cementing obviously limits the supply. Some of the recently moved stones that are deposited on the active fan have a calcium carbonate coating that suggests remobilization from this nearby source. Some of the angular material of the active alluvial fan appears to be second or third generation sediment derived from the relict fan.

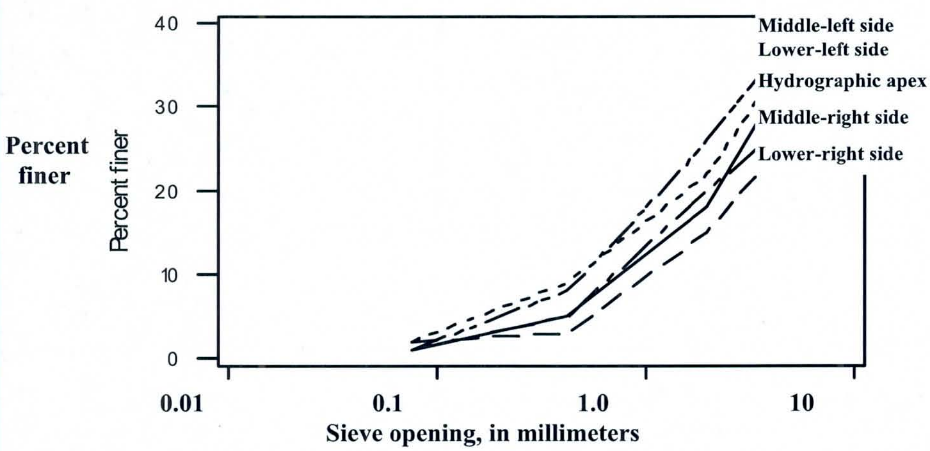
The mean particle size is medium gravel (about one cm) along the active distributary channels based on samples collected on June 24, 1997. Samples were collected at several locations across the channels with a shovel at approximately 2-6 inch depths. Samples at each location were composited. There was no obvious increase of gravel particle rounding from the hydrographic apex to the lower crest stage gages. About 40 percent of the material was coarse gravel (greater than about 2 cm), cobbles with a few small boulders. About 20 percent of the particles were sand and about one or 2 percent were silt and clay (Figure 5.5). Because the sediment apparently was deposited several years ago, undoubtedly by a large flood(s), many of the smaller particles have been remobilized by subsequent floods and translocated downstream beyond the park boundary. Most of the fines have been washed from the coarse bed and bank material leaving the present deposit of angular-coarse gravel and cobbles.

Where there are fluvial processes the sediment texture typically decreases downslope on aggrading alluvial fans because the flow competency decreases as floodwater spreads (Blissenbach, 1954) (See also Appendix Q *Sediment grain size along an idealized fan* of this Manual). This relation is useful because aggrading alluvial fans have unstable flow paths. At the South Mountain Park fan there is no discernible change in particle size along the throughflow channels of the active fan (Figure 5.4).

The competency of water flows to transport the non-cohesive and uncemented coarse bed material is briefly evaluated using the following equation, in metric units, from Blair and McPherson (1994):

$$\gamma DS = 0.056d^{1.213}$$

where γ = specific weight of the fluid, = 1,000 kg/m^3,
D = average flow depth, in meters,
S = grade(slope), in m/m, and
d = diameter of entrained gravel clast, in mm.



Sieve opening (mm)	Percent finer at indicated sample location				
	lower fan		middle fan		gage
	left side	right side	left side	right side	--
4.750	36	26	38	28	34
2.000	22	15	26	20	18
0.425	9	3	8	5	5
0.075	2	2	1	1	1

Figure 5.5. Cumulative sediment size-frequency graphs for South Mountain Park alluvial fan.

At the South Mountain site, the channel grade at the apex is 0.017 (about 1 degree) and at the 100-year flood, the flow depth is about 1 m (Figure 5.6). From the above equation, the diameter of the entrained gravel clast is 11 cm (about 4 inches). Clearly, because most of the sediment is smaller than 11 cm, most of the rock can be moved by large floods past the apex to the active alluvial fan. The above equation is one of several competency equations available in technical literature and is not necessarily recommended for all sites in Maricopa County.

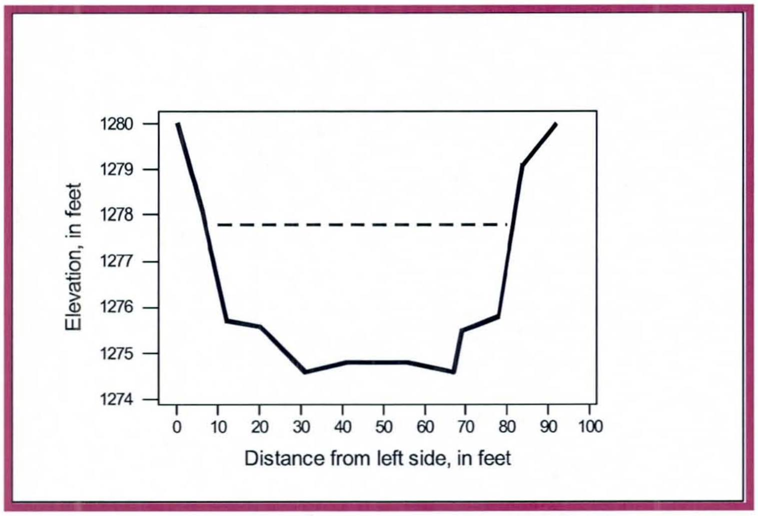


Figure 5.6. Cross section about 200 feet upstream of the hydrologic apex showing the approximate level of the 100-year flood.

5.1.3.2 Shear strength along the channels

Bank stability of channels in cohesive soils can be roughly evaluated using shear strength in the tractive power approach of TR-25 (USDA, 1977). At the South Mountain Park site the banks are incised in cemented conglomerate and only short reaches have developed cohesive bank material. Thus, only a rough measure of bank stability is made from shear strength estimates at this site. Twenty-three estimates of material shear strength were made along the channels from the hydrographic apex to the lower crest stage gages.

The surface shear strength of the silty areas along the right bank at the hydrographic apex is about 800 lb/ft^2 based on a few measurements on June 25, 1997 with a Torvane shear device (CL-600A) by Soil Test. The measured shear of the microbiotic crust on the flat-smooth surface a few feet shoreward on the right overbank was between 1,000 and 1,200 lb/ft^2. At the lower section of crest-stage gages, the average measured shear on the microbiotic crusts at several locations was about 1,000 lb/ft^2 with a range of 700 to 1,240 lb/ft^2. The measured shear strength below the crusts was about 50 to 60% of the crust shear strength. The measured shear along the bank surface in the few places where the surface appeared stable and there was donoring (Hjalmarson and Tram, 1995 and Chapter 3 of Manual) was 460 to 600 lb/ft^2 . The bank shear at 1/2-inch depth below the surface was about 50% of the surface shear.

The measured shear stress of the silty places along the banks, range of 460 to 800 lb/ft^2, is almost 1/2 the shear stress of other sites in Maricopa County with stable banks but about 2 or 3 times the shear stress of sites in Maricopa County with active alluvial fans (unpublished data by Winn Hjalmarson and Joe Tram on file at the FCDMC). The shear strength of the microbiotic crusts, range of 700 to 1,240 lb/ft^2, is in agreement with other piedmont sites in Maricopa County. The approximate 50% increase of shear strength resulting from the crusts also is in agreement with other sites in Maricopa County. The large amount of microbiotic crusts along the distributary channels suggests the fan has been stable for several years. The cohesive strength, however, developed from donoring was not great and was limited to only a few locations.

During major floods, the stability affects, if any, of microbiotic crusts are uncertain (See *Shear Stress* in Chapter 3). However, awareness that measurements of shear stress are affected by the crusts is important.

5.1.3.3 Infrequent fan building events

Estimates of flow path movement are inherently difficult in the arid southwestern United States where at specific sites there are many years of no flow with few flood events of large magnitude that transport sediment to the fan. There is evidence on some alluvial fans of flow paths moving considerable distances over short periods of time (a few hours) but such movement is infrequent. Thus, the comparison of flow paths (where space is regarded as a continuous variable as depicted on aerial photographs) at different observable times (where time is regarded as a discrete variable) has a relatively short time scale while the process being modeled has long time scale during at least the Holocene Epoch. If flow path movement were relatively frequent and uniform in space then estimates of flow path movement, if any, could be estimated using discrete intervals with some reliability. Thus, because flow path movement, if any, on a particular space such as the South Mountain Park site is infrequent the detection and characterization of movement in terms of transverse and lateral rates is tenuous.

The problem can be demonstrated using elementary probability. For example, if the movement of a single flow path in the network of distributary channels resulted from floods equal to or greater than the 50-year flood then the probability of movement in 40 years (the discrete interval between aerial photographs of the flow paths) is:

$$P_m = 1 - (1 - 1/50)^{40} = 1 - 0.45 = 0.55$$

but if flow path movement was less frequent and the result of perhaps the 200-year flood, then the probability of any movement in 40 years is:

$$P_m = 1 - (1 - 1/200)^{40} = 1 - 0.82 = 0.18$$

Thus, the same average rate of movement (for example feet per year across the alluvial fan) may result for both cases but the detection of movement is likely in the first case and unlikely in the second case. The average rate is used here to demonstrate that detection of flow path movement is much more difficult using discrete time intervals if the causation is infrequent. Obviously, an average rate of movement has little meaning for the assessment of flood hazards where movement is sudden and infrequent.

Clearly, alluvial fan processes in Maricopa County may produce variable flow paths in space and time. This variability can be observed continuously or more commonly at discrete intervals of time. There are several processes, each of which produces change at different time and space scales. For example, a debris-laden flow may be a low-frequency high-magnitude event that produces large spatial variance for small areas over very small intervals of time. On the other hand, erosion of interfluval areas by sheetflow from direct rainfall is a high frequency (low magnitude) event that produces small space variance over very long time intervals and over large areas. Many such processes are at work on the South Mountain Park alluvial fan. In addition, the imprint of past processes of different geologic epochs that produced the relict fan has an influence on processes today.

As we focus on the active and inactive areas and flood characteristics of the South Mountain Park alluvial fan we are challenged by the several processes and in particular the apparent infrequent occurrence of recent debris laden floods on the southern 1/3 of the fan (the area defined by soil type Cb and the active and inactive alluvial fans). Because the fan building floods are infrequent and not precisely known, we might be inclined to ignore the different ages of the surface material. For example, for the characterization of alluvial fan flooding for flood insurance studies we might impose rigid constraints (Dawdy, 1979) over the entire fan because of our limited understanding of the processes rather than use process-based indicators that reflect some understanding of the processes. Although our understanding of flow path movement at the South Mountain Park fan is limited, it is clear that a large part of the fan is inactive and that part of the fan which has experienced recent sediment deposition, can in the interest of being conservative, be considered active. It is a difficult task indeed to estimate hazards associated with a large boulder laden debris torrent with an unknown but infrequent recurrence interval of perhaps a few hundred years.

5.1.3.4 Summary of 100-year flood conditions

Several characteristics indicate that the south side of the alluvial fan is active. The clasts on this part of the fan are unweathered and angular and thus suggest recent transport. The radial sediment dispersal system below the hydrographic apex and the mounding across the upper fan are also characteristic of an active alluvial fan. There is an ample supply of coarse sediment along the large channels in the drainage basin (Figures I2, I12 to I15). There is no doubt the active fan area shown in Figure 5.4 is subject to sediment deposition, change in channel conveyance and some flow path movement. The frequency of fan building flood events is uncertain, however, and may be on the order of a few hundred years. Secondary processes including direct rainfall and sheetflow and water floods from the drainage basin have remobilized and transported the smaller grains down the fan.

Characteristics of the recent deposits that suggest the south part of the fan is not very active are (1) the channel deposits are sorted and contain a small range in grain size, (2) the downfan deposits are rather uniform in both average and maximum clast size and (3) there are weathered (developed soil) areas between the distributary channels in the upper fan. About 1,500 ft. below the hydrographic apex there is no evidence that suggests the tree lined flow paths have moved for many (perhaps a few thousand) years.

5.1.3.4.1 General map of 100-year flood conditions

A map of unstable flood-hazard areas (UFP) where flow paths are considered unstable is shown in Figure 5.7. Area UFP starts at the hydrographic apex and includes the several distributary channels where there has been recent sediment deposited. The sediment forms a general mounding across the fan that can be easily seen in the field and where the trees are scattered across the fan surface below the hydrographic apex. At the downstream part of area UFP, an eroding surface is indicated because there is no mounding across the fan.

Area UFP is considered subject to alluvial fan flooding as described by the National Research Council (1996) and the level of activity is low, especially for the downstream part, as described Chapter 4. Area DF is considered a stable area of distributary channels where the amount of 100-year floodflow in each of the channels is dependent on the upstream flow paths that are unstable and where channel capacity may be changing.

The boundary common to areas DF and UFP is about 2,000 ft. below the active area where there is active sediment deposition and erosion (Figure 5.4). The boundary is placed conservatively far down the fan to (1) assure that the flow paths entering area DF can be considered stable, (2) to assure that floodflow is spread over much of the common boundary and (3) to allow for the natural apportionment of 100-year floodwater in the several channels. Because of the interlacing network of numerous small distributary channels between the common boundary of areas DF and UFP and the hydrographic apex there is ample opportunity for floodwater to spread across the downstream end of area UFP.

Because there are only a few islands separating the many distributary channels, the water surface elevation is assumed uniform at the downslope end of area UFP. For a uniform water surface elevation for the100-year flood (See Figure 5.8a) the floodwater entering area DF is apportioned in the distributary channels using channel conveyance. At elevation contour 1190, located a few feet below the boundary common to areas DF and UFP, the distribution of conveyance across the 1092-ft. wide fan is shown in Figures 5.8b and 5.8c.

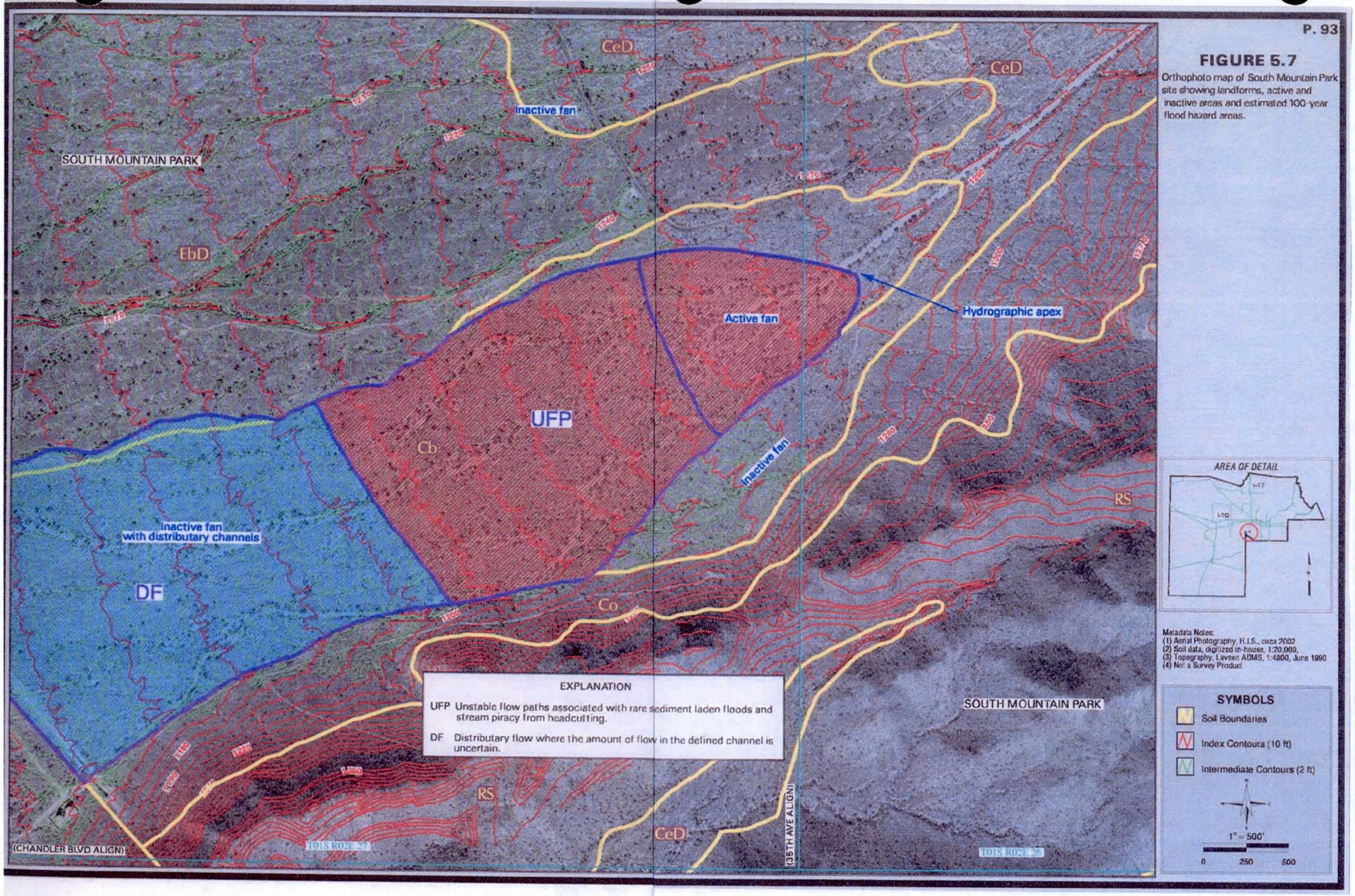


FIGURE 5.7

Orthophoto map of South Mountain Park site showing landforms, active and inactive areas and estimated 100-year flood hazard areas.

5.1.3.4.2 Estimate of active and inactive areas for 100-year flood conditions

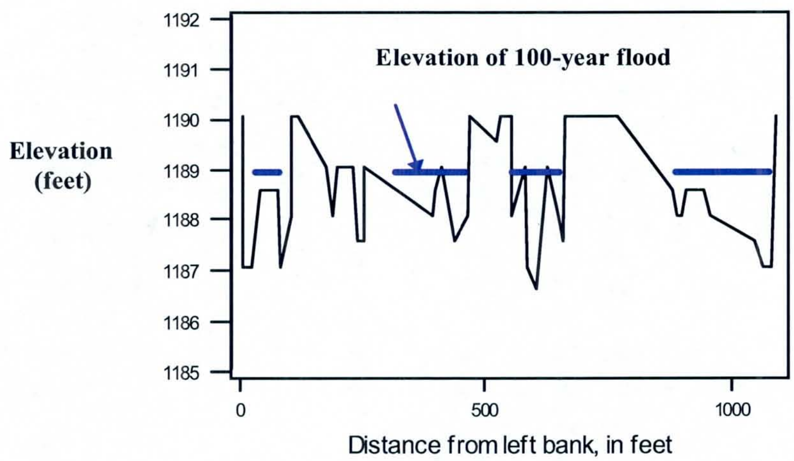
The cross section and approximate distribution of the above conveyance is shown in Figure 5.8. About 65 percent of the area at the cross section is inundated by the 100-year flood. The cross-section geometry was defined using topographic map contour data (See Figure 5.1) and the conveyance for the subareas was defined using WSPRO (Shearman, 1990). The total capacity of the channel network at the cross section is about 3 to 4 times the magnitude of the 100-year flood before floodwater spreads over the adjacent inactive fan areas.

Areas DF and UFP (Figure 5.7) are within soil type Cb that is Carrizo gravely sandy loam found in stream channels, low terraces near stream channels and on alluvial fans (Hartman, 1977). Flooding in the area defined by soil types EbD and CeD is sheetflow and flow in defined channels. Flooding on most of the other land is from overland flow and flow in defined channels draining mountainous areas. Standard hydraulic engineering methods are recommended for all areas except DF and UFP. Geomorphologic methods are satisfactory for area UFP.

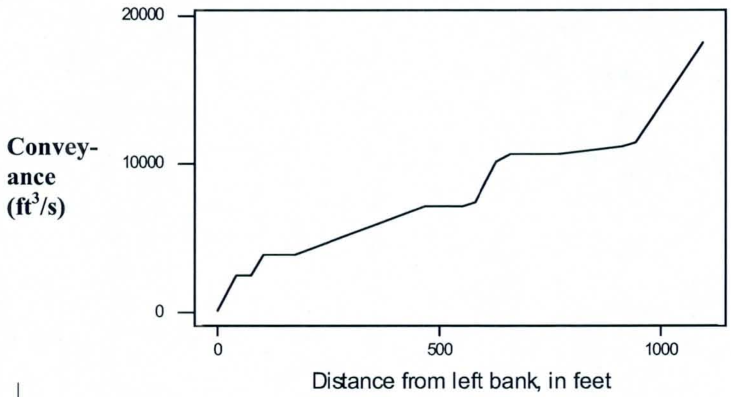
Methods described in section 4.1.2 for inactive alluvial fans are appropriate for area DF. These methods were not applied to this example and the results would be similar to the area with distributary channels shown in Figures 4.5 and 4.8. The discharge in the several small channels could be estimated from the distribution of channel conveyance shown previously at elevation contour 1190. Because the flow entering area DF from area UTP is wide and shallow and therefore has a somewhat uncertain distribution of discharge in the several channels, the approximate channel conveyance-slope technique described in section 4.1.2.3 is considered appropriate. The use of soil characteristics described in section 4.1.2.4 to substantiate and refine the estimated flood boundaries for the conveyance-slope estimates is very important for this site.

The investigator is invited to also examine the surface texture of the active alluvial fan by referring to Appendix E and Figures E2A and E2B. Also, comparison of the active alluvial fan with the Reata Pass alluvial fan (Appendix K) may be informative. A review of Figure 2.12 is also suggested.

a. Elevation of 100-year flood



b. Approximate distribution of conveyance across fan



c. Computed conveyance

Distance from left bank (ft)	Conveyance(ft^3/s)
0	0
0-40	2354
40-75	231
75-102	1306
102-530	3215
530-580	213
580-625	2861
625-660	523
660-910	528
910-945	231
945-1092	6721

Figure 5.8. Cross-section at upper end of area DF at elevation contour 1190 showing the level of 100-year flood and distribution of channel conveyance.

5.1.3.4.3 Check of the estimated 100-year flood conditions

A rough check of the assessment can be made using methods by Hjalmarson and Kemna (1991) described in Appendix O of this Manual. This check of the assessment uses a relation between flood-hazard degree and physiographic characteristics of the alluvial fan and the drainage basin. The USGS report *Flood Hazards of Distributary-Flow Areas in Southwestern Arizona* must be consulted for an explanation of the method and the following results:

> Equation 9 on page 54 of Hjalmarson and Kemna is appropriate for estimating the degree of flood hazard at the South Mountain Park site. The area of the distributary flow area (DFA) extends beyond the Park boundary onto the Gila River Indian Reservation and corresponds to soil type Cb (Figures 5.1 and 5.2)
>
> $$B = 6.21 - 0.62DD + 25.6MRDA - 1.19H + 2.70K$$
>
> where
>
> B = flood-hazard degree,
> DD = ratio of the area of the alluvial fan (DFA) divided by the area of the drainage basin,
> MRDA= mean relief ratio of the drainage basin,
> H = average contour sinuousity of four to six contours evenly spaced within the DFA, and
> K= average contour-band widths of four to six contours evenly spaced within the drainage basin.
>
> The values of the independent variables are DD = 0.33, MRDA = 0.12, H = 2.06 and K = 0.32. The estimate flood-hazard degree is B = 7.5.

According to Hjalmarson and Kemna, a degree of 8 corresponds to a network of distributary channels where most ridges can be overtopped by the 100-year flood but the location of the channels is stable. Hjalmarson and Kemna classed this flow condition as unstable because the distribution of flow across the DFA may be uncertain. This condition corresponds to area UPF (Figure 5.5). A flood-hazard degree of 7 corresponds to stable flow paths where less than 1/2 of the stable ridges is above the 100-year flood (Table 1 of Hjalmarson, 1994). This area closely corresponds to area DF (Figure 5.5). Thus, the single rather simple numerical rating of 7.5 supports the flood hazard assessment using methods given in this Manual.

5.2 The White Tank Park relict fan.

The White Tank Park site is located on the east piedmont of the White Tank Mountains mostly between the alignments of Peoria and Olive Avenues. The upper part of the site is in a small embayment where there are remnants of relict debris flows. The site is accessed at the park entrance (mile 0) on west Olive Ave near the center of the inactive (relict) fan (Figure 5.9). The primary area of interest is located west of the eastern park boundary.

Photograph on the right is a view looking west along Olive Ave. The park entrance is about one mile west of this location. The White Tank Park site is to the north of Olive Ave. Dip in road is at wash in relict fan. The channels on the relict fan in this area have a shape similar to top sketch in Figure 2.2 of the Manual. The surface texture of this relict fan is described in section E2 of Appendix E and in Figures E3A to E3C. Drainage texture is discussed in section E3.

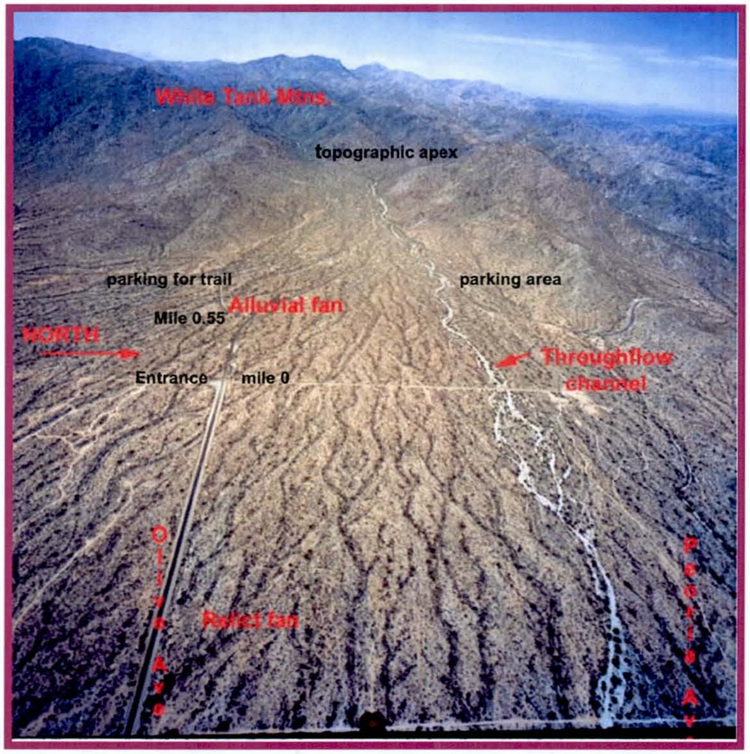
The field inspection of this site is made to: (1) verify the type of landform, described as an alluvial fan by the NRCS, using methods in Chapter 2 and steps in Table 2.2; (2) identify active and inactive areas using methods in Chapter 3; and (3) estimate flood hazards, as described in Chapter 4, based mostly on geomorphologic methods using only a rough estimate of the 100-year peak discharge at the hydrographic apex and at any major tributaries. The investigator should have USGS 7.5 minute topographic maps of the Waddell and White Tank Mtns. SE Quads., or the equivalent, and should have consulted the NRCS Soil Surveys of Maricopa County, Arizona by Hartman (1977) and Camp (1986). Copies (at a small scale) of the soil survey maps for this site are included in this Manual. The investigator should consider reading this section of the Manual and obtain any needed referenced material before making a field inspection of the site.

5.2.1 Embayment area

The embayment area can be accessed by proceeding 0.55 mile beyond the park entrance and turning left on the paved road. The parking on the right (mile 0.62) is the head of a trail that leads to the topographic apex of the relict fan. The trail is along the right bank side of the incised channel about 1/2 mile from the trailhead. The topographic apex is about 1 mile from the trailhead at an elevation of about 1,800-ft.

The drainage area at the topographic apex is about 3.0 mi^2 with a corresponding 100-year flood peak discharge of about 3,400 ft^3/s (Thomas, Hjalmarson and Waltemeyer,

1997) (Other appropriate methods of estimating peak discharge such as the FCDMC Hydrology Manual could also be used). Based on channel conveyance-slope estimates, this discharge is confined to the large incised channel along the left side of the embayment at the toe of the bedrock mountain. At the topographic apex (See photograph below), the estimated level of the 100-year discharge is within a couple of feet of the top of the right bank. Evidence of historic floodwater overtopping the right bank was not observed. The channel capacity is greater than the 100-year discharge in the embayment area.



Large angular boulders with some visible imbrication in places are exposed along the banks of the channel (Photograph 3, Appendix J). The exposed rock is cemented a few feet below the land surface. There are remnants of an old terrace about 8 to 10 ft. above the streambed in a few places. These banks and terraces can be readily observed a short distance to the north of the trail about 1/2 to 3/4 mile from the trailhead.

The surface of the landform that lies just below the mountains is covered with varnished boulders and cobbles that indicate the landform is old and stable (Photographs 14 and 15, Appendix J). There are several old debris lobes a few feet high and several tens to a couple of hundred feet long (The lobes are located to the west of the area shown in Figure 5.9). These few lobes have snouts of large boulders and are similar to the debris lobes on the relict part of the Henderson Canyon alluvial fan near Borrego Springs, California (National Research Council, 1996, Figure 4.4). The debris mounds have inverse grading and many of the fines have washed from the debris matrix.

Of fundamental importance is this surface is old and stable. Some the details about the debris lobes are not needed for the assessment but are presented because such lobes are not common in central Arizona. Because the mounds are old (apparently early or pre-Holocene) the characteristics are not precisely like fresher deposits described by Costa (1988) or the clast poor, matrix rich lobes described by Blair and McPherson (1994). The lobes also may be similar to the sieves described by Hooke (1967). Clearly, the active channel has incised into old fluvial (water and debris flow) deposits.

The interested investigator is invited to decide precisely what the lobes are like.

5.2.2 Area below the mountain front

The mid- and lower-relict fan can be viewed along Olive Ave. starting at the Beardsley Canal about 2 miles east of the park entrance (to the east of the area shown in Figure 5.9). Many small tributary channels head on the fan surface. The interfluves are covered with desert pavement and there is a well-developed carbonate zone about 1 ft. below the surface. The throughflow channel can be examined by continuing straight at mile 0.55 mile beyond the park entrance, crossing the wash at mile 0.75 and parking on the right at the restrooms and picnic tables (mile 0.82) (See Figure 5.9).

About 4.10 mi^2 is drained by the incised channels at the road crossing near the restrooms. The corresponding 2-, 10-, and 100-year flood peak discharges are about 100, 820 and 4,400 ft^3/s (Thomas, Hjalmarson and Waltemeyer, 1997). The investigator is reminded that the precise amount of peak discharge is not needed for this assessment unless it is determined that profiles are needed for the 100-year flood in stable channels. For example, a 100-year discharge of about 5,600 ft^3/s was independently estimated and used to define the limits of the 100-year flood discussed later in this Manual. The investigator should keep in mind the peak discharge is not needed to determine the type of landform and stable and unstable areas.

Channel incision is progressing upslope as evidenced by a large head cut. The bouldery sediment produced by the incision has produced downstream deposition at the inset alluvial fan. This “out-of-phase” effect of channel incision is further described by Schumm, Harvey and Watson (1988).

5.2.3 Type of landform

Using procedures in Chapter 2, landform was identified as an alluvial fan with an incised channel composed of a head cut and a relatively small downstream channel area of active aggradation and erosion. Sediment in this aggrading channel area has spread laterally over adjacent land. The lower part of the area was identified as a relict fan.

See Appendix J, Appendix E and Section 2.1.3.4 of the Manual for additional information on the White Tanks Park site.

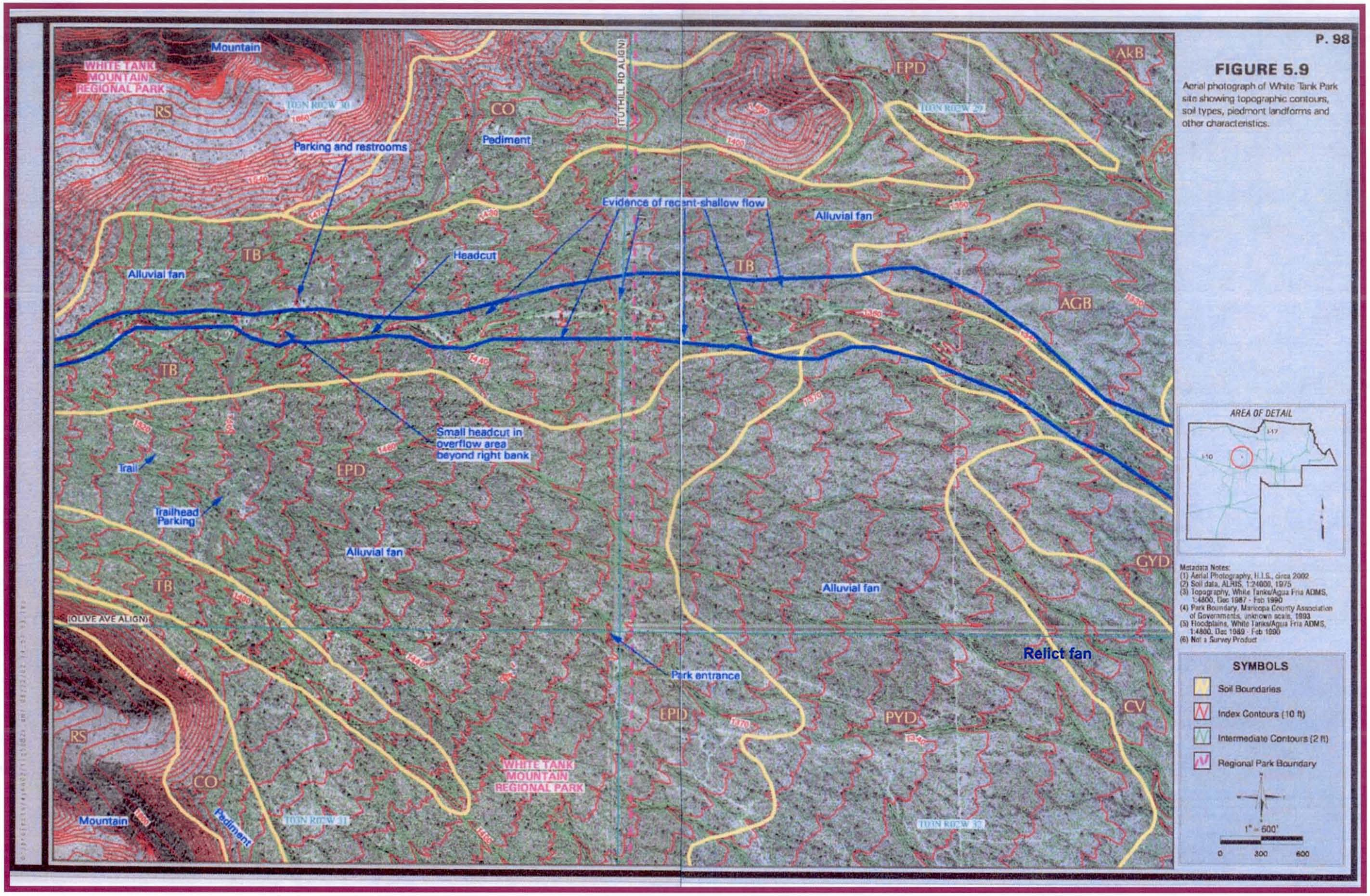


FIGURE 5.9

Aerial photograph of White Tank Park site showing topographic contours, soil types, piedmont landforms and other characteristics.

5.2.3.1 Composition

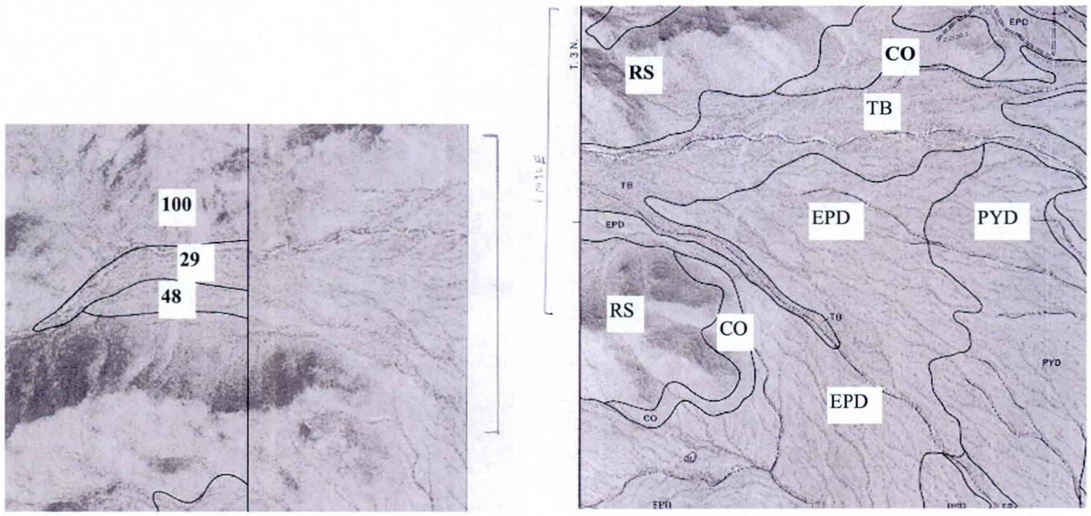
The area along the incised channel was classed by Hartman (1977) as torrifluvents (map unit TB) consisting of young unconsolidated gravely, cobbly and stony alluvium on young alluvial fans (Figure 5.9). Camp (1986) classed the adjoining area to the west as a fan terrace (map unit 29) that is calcareous a few inches below the surface (Figure 5.9). Cemented gravely, cobbly and stony alluvium can be observed along most of the channel. Young unconsolidated gravely, cobbly and stony alluvium was observed along the channel near and to the east of the eastern park boundary (Figure 5.9). This narrow area of unconsolidated material resembles an inset alluvial fan (See Table 2.1) but it is classed here as an alluvial channel that is both aggrading and eroding.

Much of the upper area is mapped by both Hartman (1977) and Camp (1986) as the Ebon-Pinamt complex (soil type EPD and 48, respectively) (Figures 5.9 and 5.10) of old alluvial fans that form on the piedmont along the base of the White Tank Mountains. The middle area is mapped by Hartman as the Pinamt-Tremant complex (PYD) of gently to steep sloping land of old alluvial fans. The lower area is also mapped as an old alluvial fan (CV, AGB, GYD) that is nearly level to gently or moderately sloping.

Thus, except for the young unconsolidated gravely, cobbly and stony alluvium along the incised channels, the entire area is identified by the NRCS as an old alluvial fan. The vegetation is creosote bush, paloverde, bursage with some cholla cactus. There is cementation at depth below the upper reddish-yellowish subsoil. The surface is covered with desert pavement that is varnished. The upper area is bounded by the Cherioni-Rock outcrop complex (CO) (a pediment at the base of the mountain front) and rock outcrop (RS) of the White Tank Mountains.

5.2.3.2 Morphology

The landform has a partly extended fan shape with the upper part bounded by the toes of adjoining mountain slopes. Below the mountain front the fan widens and coalesces with adjacent relict or inactive alluvial fans. The highly crenulated contours shown on the available 7.5-minute series USGS topographic maps (Waddell and White Tank Mtns. SE Quads) have a distinct convex shape in the down slope direction to about 1 mile east of the mountain front (see Figure 5.9 and the above listed USGS topographic maps). Where the convex shape is lost the landform has the appearance of a relict fan.



Sheet no. 44 of NRCS soil survey by P. D. Camp (1986)

Sheet no. 19 of NRCS soil survey by G. W. Hartman (1977)

Figure 5.10. Soil types.

5.2.3.3 Location

The site is located next to the mountain front like typical relict and inactive alluvial fans (See Figures 1.1 and 2-1). The topographic apex is at a topographic break at the top of the embayment. The present channel is incised at this location. There is no hydrographic apex within the park boundaries.

5.2.4 Active and inactive areas of the alluvial fan

Active and inactive areas are identified using methods in Chapter 3.

5.2.4.1 Inactive area

Most of the alluvial fan is inactive with old developed soil covered with varnished desert pavement (Figure 5.11 and Scene 16 of Appendix J). These soils are mostly the Ebon-Pinamt complex. The throughflow tributary channel is cut nearly 10 ft. in places into the cemented conglomerate. Several small tributaries head on the inactive fan. The landform clearly meets the criteria of a stable area as defined in Chapter 3 of this Manual.

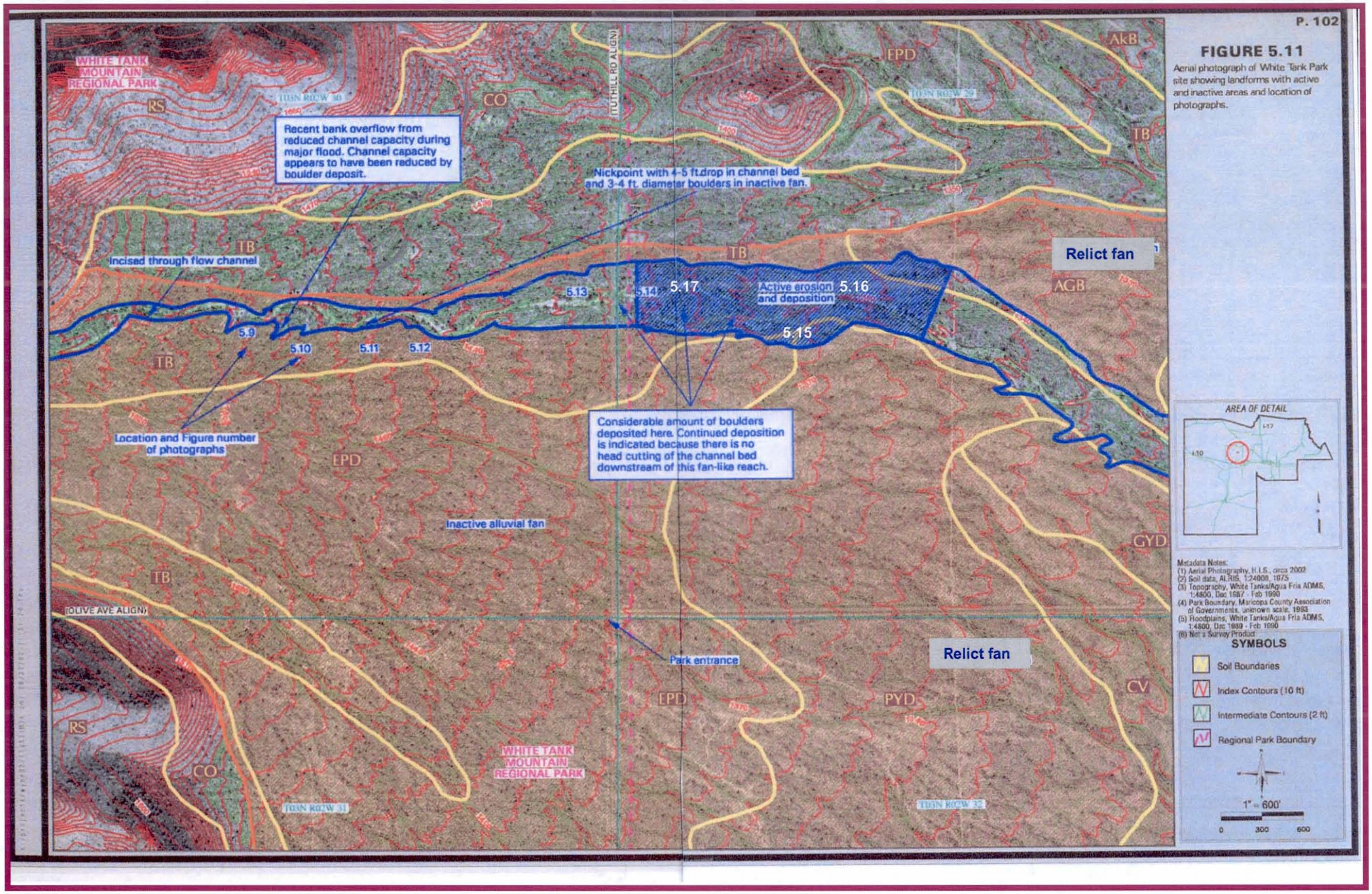


FIGURE 5.11

Aerial photograph of White Tank Park site showing landforms with active and inactive areas and location of photographs.

5.2.4.2 Active areas along throughflow channel

The long narrow aggrading area starting near the eastern park boundary and extending downstream about 600 ft. resembles an inset alluvial fan using procedures in Chapter 2 (See Figure 5.11, 5.16, 5.17 and E3C). Although this area is aggrading in places and starts at a topographic break, it does not have the shape of a fan. Rather, it is an area where upslope head cut sediment is deposited and subsequently moved further downstream during floods of various magnitudes. The aggrading/eroding part of this area meets the criteria of an unstable area, like that of an inset alluvial fan, given in Chapter 3 or the braided channels in Figure C4 of this Manual. Fluvial hazards along the throughflow channel are shown in Figure 5.12 to 5.17 (See Figure 5.11 for location of photos). The investigator should examine the landform in the field and not rely on the photographs alone. For example, a field examination of the nick point and likely eventual stream piracy mentioned in Figure 5.13 shows the importance of using this method.

Figure 5.12. Photograph of right bank below roadway showing relict boulder conglomerate.

The boulder position on the right shows imbrication and boulder angularity suggests a nearby source of material--probably the White Tank Mountains. Of significance for present flood plain management is that the relict channel bank is steep and has been cut by recent flow and only large amounts of stream power can move the large-angular rock. The rod interval is 0.5 ft.

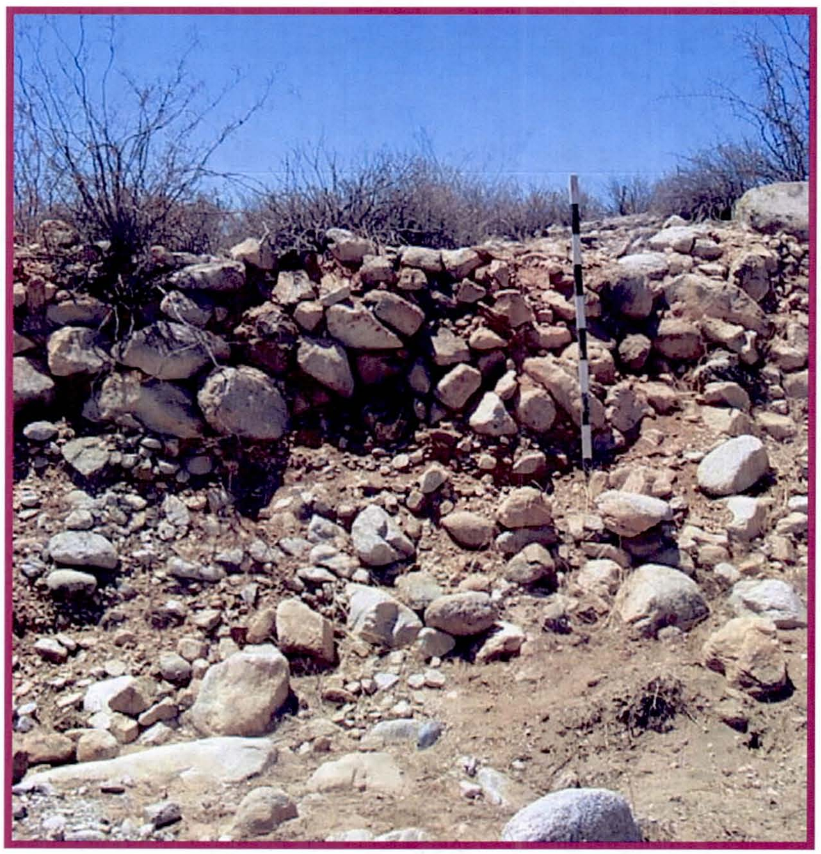


Figure 5.13. Photograph of right bank where the active channel bends to the left above the park restroom building shown in the background.

Bank erosion and overtopping from pileup has occurred along the right bank and can be expected during large floods. Several feet beyond the bank and out of view is a nick point that forms the head of another channel on the inactive alluvial fan. This nick point, which is a location on the profile where there is an abrupt change of elevation (Schumm and others, 1988), is slowly eroding head ward and may eventually intersect the bank shown in the scene. The rate of nick point movement is related to the amount and frequency of overflow from the active channel in the scene. Factors such as the boulder deposit in the center of the scene must be considered in an estimate of when stream piracy may occur. For example, the boulder deposit has reduced channel conveyance at this location and may be moved downstream by large floods and thereby reducing the amount of bank overtopping at that location.

Figure 5.14. Photograph looking upstream at nick point of entrenched channel.

There is a 4 to 5 ft. drop of bed elevation at the nick point shown above and the 3 to 4 ft. boulders are from the cemented conglomerate of the inactive alluvial fan. The conglomerate is resistant to erosion to depths of at least several feet and thus a slow rate of arroyo growth may be expected for a 100-year regulatory period. The rate of head cutting may increase when the large boulders in the scene are washed downstream perhaps to be deposited in the aggrading area shown in photographs 5.15 and 5.16.

Figure 5.15. View looking south at right bank a few hundred feet downstream of the nick point where the channel is about 8 to 9 ft. deep.

The upper 4-ft. of bank shown by the orange flag above is composed of angular boulders that are smaller than the boulders of the lower material. The lower material may be more erosion resistant than the upper bank but the difference, if any, is not considered for flood assessment for the 100-year regulatory period.

Figure 5.16. View looking downstream and east at the overflow area on right side of the channel where there is recent aggradation.

The overflow channel profile and the inactive alluvial fan profile are the same in this scene and flood flow can spread laterally a few hundred feet. The lobe-like boulder deposit is a few hundred feet below the breakout from the arroyo.

Figure 5.17. View looking downstream at main channel of aggrading area located several feet east of the Park boundary.

This formerly entrenched channel shown above has filled with the material shown in the scene. The profile of the channel and the inactive fan are nearly the same and floodwater can spread a few hundred feet to the north and south. The small branching channels of the left and right of the scene rejoin several hundred feet beyond the scene. Other braided appearing reaches are located downstream along the throughflow channel. Floodwater in these smaller downstream reaches spreads in a few channels and then becomes confined only to spread again further downstream.

5.2.5 Drainage basin

The drainage basin above the road crossing is 4.10 mi^2 with a long-narrow tributary area on the north. The basin is about 4 miles long with a width of about 1-mile. The general shape is elongated and not bowl shaped like mountainous basins above many active alluvial fans. The drainage of the first and second order streams is not quick and does not coincide at the topographic apex. Because there is not an abundant supply of unconsolidated sand, gravel and cobble material in the basin and the basin is not bowl shaped, active fan building is not expected at the mountain front based on the basin characteristics.

5.2.6 Characteristics of recent deposited sediment

Much of the stony sediment along the aggrading/eroding part of the throughflow channel is transported from the relict alluvial fan by infrequent large floods.

5.2.7 The 100-year flood

The computed boundaries of the 100-year flood are shown in Figure 5.18. These boundaries are from a traditional step backwater computation using a peak discharge of about 3,200 ft^3/s at the restrooms and 3,500 ft^3/s at the park boundary. The area of active erosion and deposition (Figure 5.11) closely agrees with the computed 100-year flood boundaries. Three small geomorphic hazard areas that lie outside the traditional 100-year flood boundaries are shown in figure 5.18. There has been recent flow in these areas possibly as the result of reduced channel conveyance from temporary filling of the channel with coarse sediment.

The safe setback distance for development is also shown in Figure 5.18. The setback allowances were for a Level 1 analysis given in the "Watercourse System Sediment Balance" State of Arizona Standards SSA 5-96. It is interesting that for this site the three small "geomorphic" hazard areas that lie outside the bounds of the 100-year flood limits are within the setback limits. This supports the use of the setback limits defined by the Arizona Department of Water Resources.

Floodwater on the inactive alluvial fan is in defined tributary channels.

5.2.8 Summary

Most of the landform is old with small tributary streams that form on the inactive fan. The inactive fan is eroding slowly and is stable. Along the throughflow stream there is active head cutting and sediment deposition. The computed 100-year flood boundaries represent the minimum fluvial hazard. There should be setback from the incising reaches to allow for bank failure and channel widening.

Aggrading areas and areas adjacent to these areas along the throughflow channel from the park boundary to at least 600-ft, downstream are especially hazardous. The channel geometry of this area can change during flooding and development can be buried by sediment debris. Some of the aggradation near the park boundary is very recent and suggests that sediment deposition may spread to adjacent land as upstream head cutting continues to supply sediment. The safe setback distance for development along this aggrading area is at least that defined in State of Arizona Standards SSA 5-96 and shown in Figure 5.18.

This site is a great example of a stable landform that is easily accessed from the Phoenix area. The investigator is invited to visit the site and see for yourself what is causing the surface appearance on aerial photographs and topographic maps. A hike down the channel from the road crossing near the bathroom facilities will reveal a great example of a head cut in boulder conglomerate. A longer hike up the inactive alluvial fan to the topographic apex will reveal old debris lobes that are not very common in Maricopa County but more common in the Death Valley area.

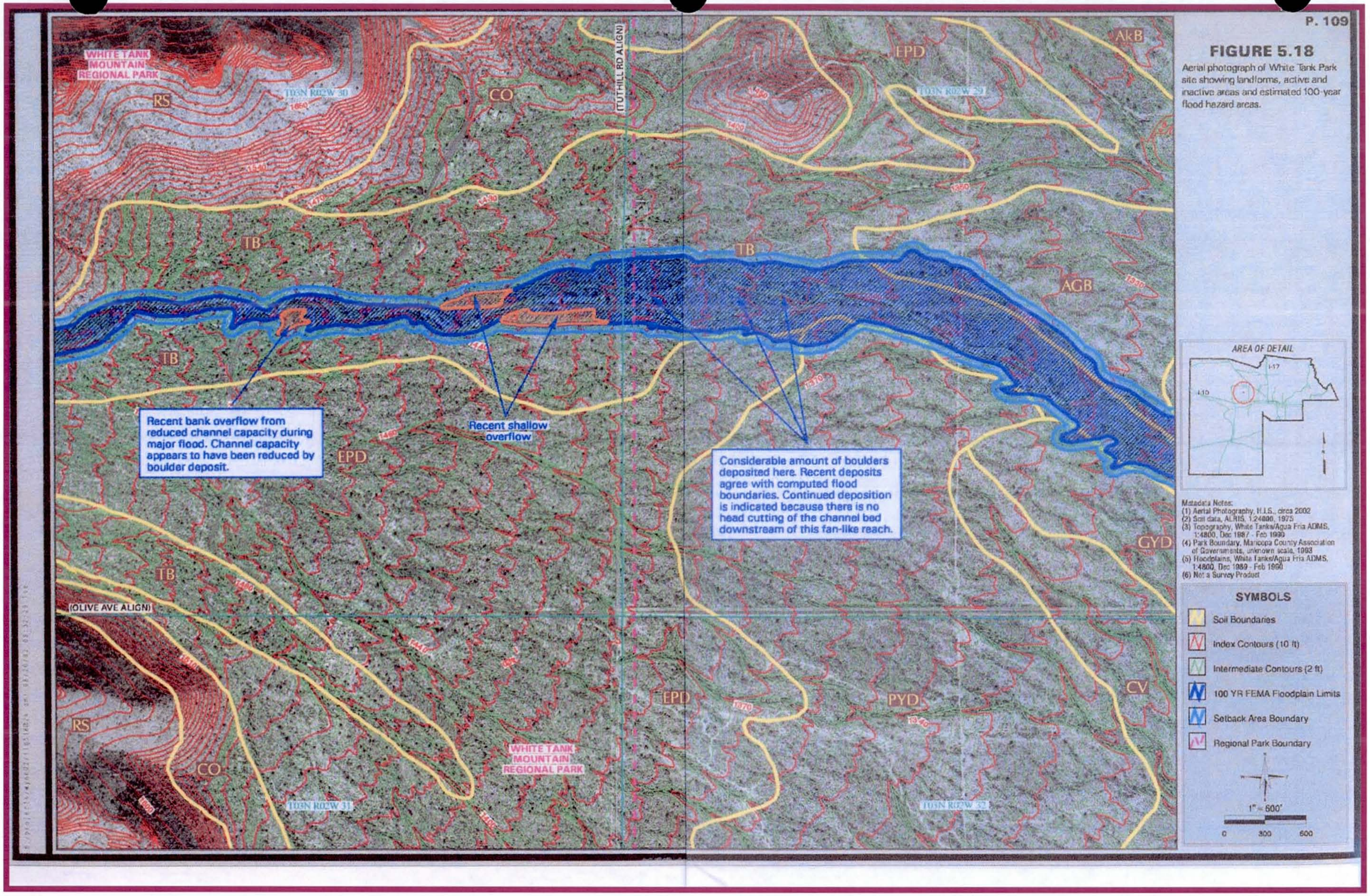


FIGURE 5.18
Aerial photograph of White Tank Park site showing landforms, active and inactive areas and estimated 100-year flood hazard areas.

5.3 The Skyline Wash alluvial fan.

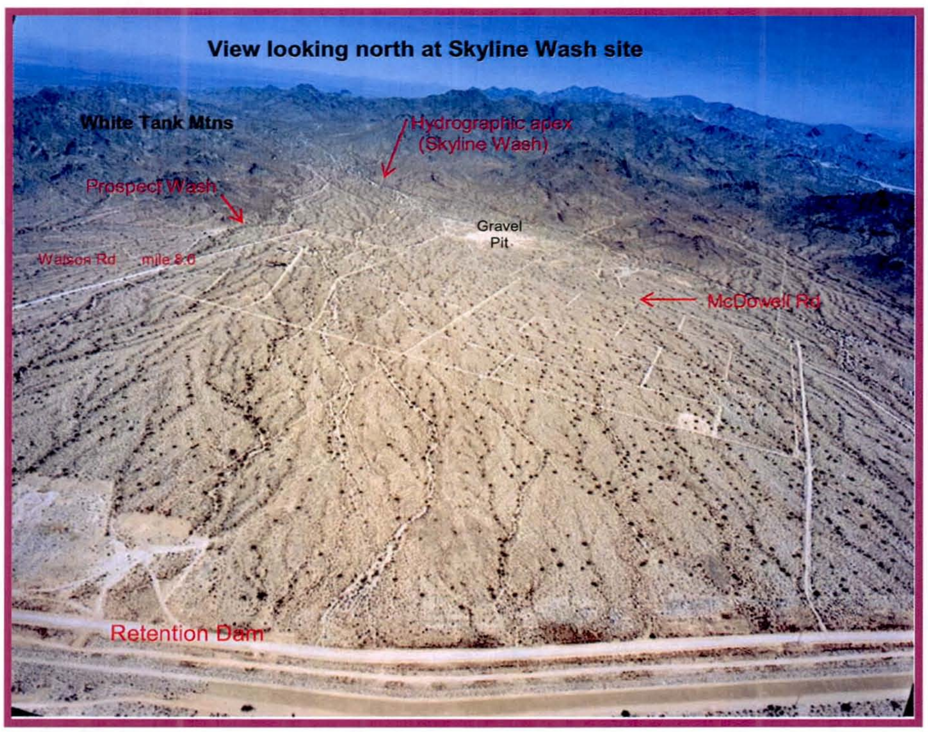
5.3.1 Introduction

The Skyline Wash alluvial fan is located in a wide embayment on the southern piedmont of the White Tank Mountains. The site is to the north of Interstate Highway 10. Runoff from the drainage basin is retained above I-10 at FDCMC Buckeye Flood Retaining Structure No. 3 that is readily visible when looking north from I-10. The drainage basin heads in the rugged White Tank Mountains. The alluvial fan is bounded by Prospect Wash on the west and Rattler Wash on the east. There is an old gravel pit on the alluvial fan that complicates this assessment. The toe of the Skyline Wash alluvial fan is cut by I-10 and the Buckeye No. 3 flood retention structure.

A four-wheel drive vehicle is recommended for access in the active parts of the fan and in the active channels at this site especially in the channels to the north of McDowell Road. Nearby areas are being developed and access may become restricted. Please obey all signs and respect the environment and private property.

5.3.1.1 Road log (September 2002)

The Skyline Wash site is accessed from I-10 by turning south at Jackrabbit Trail (Exit 121). At mile 1.8 turn west (right) at Yuma Road. Proceed west for about 4.5 mile (mile 6.3) and turn north at Watson Road. Proceed north 2 miles (mile 8.3) to McDowell



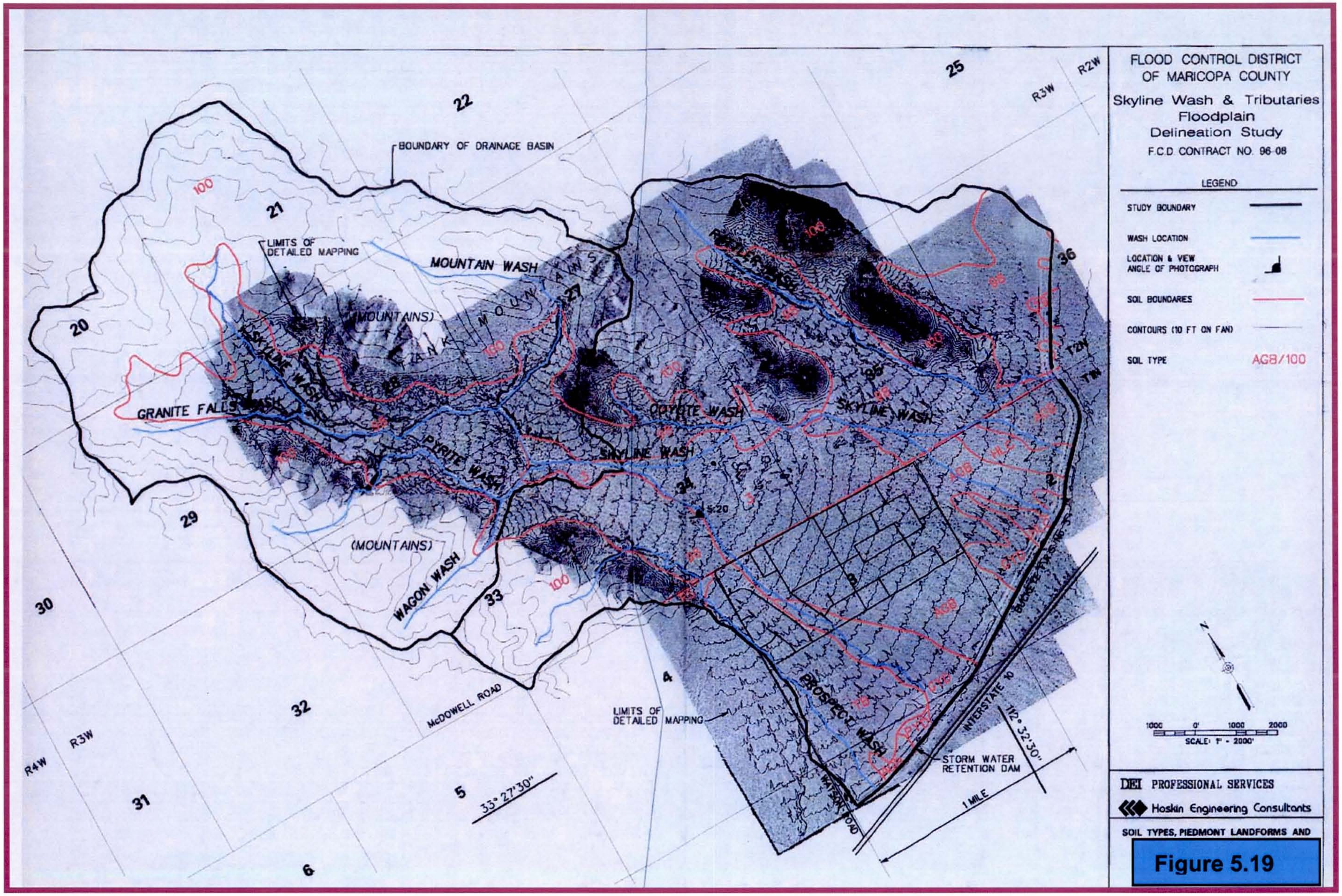
Road and make note of the following: (a) pass under I-10 at about mile 7.0, (b) the storm water retention dam on the right (mile 7.2) that blocks floodwater from the Skyline Wash fan and other drainage basins, (c) at mile 7.3 the lower fan can be accessed on road to the right and (d) at mile 8.0 the road crosses Prospect Wash where the gully is cut into rather young alluvium (NRCS soil type TB) and the depth of incision is restricted in places by bedrock (old cemented conglomerate like material) that forms the bed. Turn east (right) at McDowell Road. A relict fan (NRCS soil type 98) with desert pavement and desert varnish is on the left. Proceed 0.1 mile onto the western edge of the active alluvial fan (See Figure on the next page). The upper part of the fan area (to the left) is mapped as drainage ways and flood plains by the NRCS (Camp, 1986). The lower fan area is mapped as alluvial fan that is 1 to 3 miles from the mountains (Hartman, 1977).

The hydrographic apex is about 0.6 mile upstream to the left or north of McDowell Rd. The apex can be accessed by driving up the first active channel using 4-wheel drive. The hydrographic apex is located in a reach about 150 ft long where flow is in one 200-ft. wide channel confined by bedrock banks. The channel above the apex can also be accessed by vehicle. Large amounts of sediment are in the channels and floodplains above the hydrographic apex.

5.3.1.2 Background and materials for field inspection

The field inspection of this site is made to: (1) verify the type of landform, described as an alluvial fan and as drainage ways and flood plains by the NRCS, using methods in Chapter 2 and steps in Table 2.2; (2) identify active and inactive areas using methods in Chapter 3; and (3) estimate flood hazards, as described in Chapter 4, based mostly on geomorphologic methods using only a rough estimate (a level 2 estimate as defined in State of Arizona Standard 2-96) of the 100-year peak discharge at the hydrographic apex and at any major tributaries. The user should have USGS 7.5 minute topographic maps of the Valencia and White Tank Mtns. SE Quads, or the equivalent, and should have consulted the NRCS Soil Surveys of Maricopa County, Arizona by Hartman (1977) and Camp (1986).

During a field examination of this site, an error in the placement of boundary lines for soil type was found. The mapped soil types (Hartman, 1977) and the location of the floodwater retardation structure apparently were incorrectly displaced 1,000 feet to the west along the east side of the site south of McDowell Rd. The published soils maps that include this error are shown in Figure 5.19. The corrected soils maps are shown in Figure 5.23. The NRCS state soil scientist confirmed that this correction appears to be correct. As discussed in section 2.2.12 the state soil scientist is available to assist users with published soil surveys.


FLOOD CONTROL DISTRICT OF MARICOPA COUNTY
Skyline Wash & Tributaries Floodplain Delineation Study
F.C.D. CONTRACT NO. 96-08
LEGEND
STUDY BOUNDARY
WASH LOCATION
LOCATION & VIEW ANGLE OF PHOTOGRAPH
SOIL BOUNDARIES
CONTOURS (10 FT ON FAN)
SOIL TYPE
AG8/100
SCALE: 1" = 2000'
DEI PROFESSIONAL SERVICES
Hoskin Engineering Consultants
SOIL TYPES, PIEDMONT LANDFORMS AND
BOUNDARY OF DRAINAGE BASIN
LIMITS OF DETAILED MAPPING
MOUNTAIN WASH
SKYLINE WASH
GRANITE FALLS WASH
PYRITE WASH
WAGON WASH
COYOTE WASH
PROSPECT WASH
(MOUNTAINS)
STORM WATER RETENTION DAM
INTERSTATE 10
MCDOWELL ROAD
1 MILE
33° 27'30"
112° 32'30"
R4W
R3W
R2W
Figure 5.19

Geologic mapping and the assessment of flood hazards have been accomplished for parts of the White Tank Mountain piedmont by Field and Pearthree (1992). This geomorphic analysis and mapping, that includes the Skyline Wash alluvial fan, is used to refine the assessment of the 100-year flood hazard. In addition, the degree of flood hazard was estimated at four alluvial fans located nearby on the western piedmont of the White Tank Mountains (Hjalmarson and Kemna (1991) and Hjalmarson (1994). These fans demonstrate the variety of active and inactive areas of alluvial fans in the area. The user should consult Appendix L and obtain any other needed referenced material before making a field inspection of the site.

Excellent aerial photographs with topographic contours at 2 ft. intervals were available at a scale of 1 inch=200 feet (DEI Professional Services, November 10, 1997). Aerial photos of March 10, 1953 and March 31, 1976 were used for the assessment of flow path movement.

5.3.2 Type of landform

Landform clearly is an alluvial fan with a topographic apex in an embayment based on the following composition, location and morphology.

The investigator is encouraged to consult Figures E1A to E1D and the discussion of this site in Appendix E (section E2, Active alluvial fans) and also the several photographs of this site in Appendix H. A discussion of ***Mapping scale and map detail*** using surficial geology maps for this site is in section L4 of Appendix L of the Manual.

5.3.2.1 Composition

Antho-Carrizo complex (Hartman, 1977) and Antho-Carrizo-Maripo complex for adjacent upslope unit (Camp, 1986) (Figure 5.19). Soil is on floodplains and drainage ways according to Camp and on alluvial fans according to Hartman. The mapping by Camp is to the north of McDowell Rd. where the drainage ways are more defined and, in places, on apparent old conglomerate (Figure 5.20). The cemented material that forms the channel bed in Figure 5.20 is very old and the unconsolidated material including the sub-angular boulders along the banks is young. The mapping by Hartman is to the south of McDowell Rd where there are few defined throughflow channels and most channels are wide with low banks. The soil types agree with the common types for alluvial fans in Table 2.1.

5.3.2.2 Morphology

The landform has a shape of a partly extended fan that is readily seen on the USGS Valencia, AZ Quad. 7.5 minute series topographic map. The transverse cross sections along the lower fan are similar to the typical cross section for active alluvial fans shown in Figure 2.2. The channels in the upper fan are distributary (See Chapter 2).

Figure 5.20. Photograph looking upstream along channel on right (west) side of Skyline Wash alluvial fan.

5.3.2.3 Location

The topographic apex is approximately at an elevation of 1,510 ft near the upslope end of young unconsolidated sediment (NRCS soil type 3 (Camp, 1986)) at the edge of the fan terrace. There is more that one topographic apex depending on which tributary channel is selected. There is a slight slope decrease at this location (Figures 5.21 and 5.22) and there is some widening of the channel.

The hydrographic apex is located in the NW1/4 of section 34, T. 2 N., R. 3.W at a topographic break where there is an abrupt widening of the banks (Figure 5.19). The precise location of the hydrographic apex cannot be seen on the Valencia Quad.

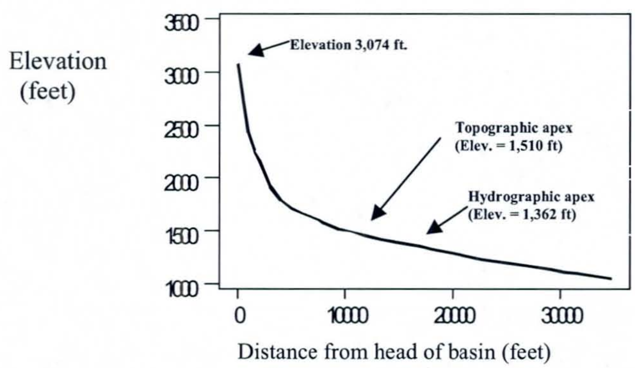


Figure 5.21. Elevation profile of stream channel at Skyline Wash landform.

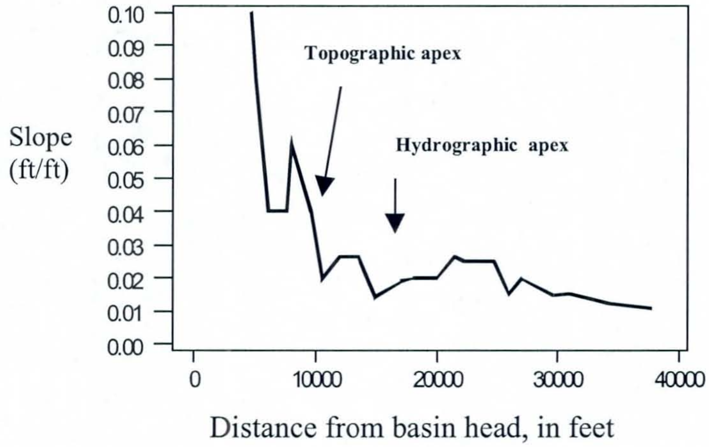


Figure 5.22 Profile of channel slope along center of the Skyline Wash alluvial fan.

The alluvial fan is on the upper piedmont at a location similar to the uppermost alluvial fan shown in Figure 1.1 of the Manual.

5.3.3 Active and inactive areas of the alluvial fan

Initial clues that indicate the alluvial fan has both active and inactive areas are gleaned from the soil survey reports and the surface texture shown on the aerial photo of the site and the 7.5-minute series topographic map (See Appendix E for several photos and discussion of surface texture of this site).

The distribution and size of the contour crenulations changes both across and down the fan. For example, at and upslope of the 1,300 ft. contour there are several distinct crenulations that suggest defined and possibly stable channels. Another example is down slope of the 1,300-ft. contour there are few crenulations in the middle of the fan suggesting active sediment deposition (See section 2.2.2) or possibly eolian effects.

Note

> **It is important to realize that the channels depicted by the crenulations may be tributary, distributary and/or throughflow channels. Aerial photographs and a field examination are used with the topographic maps to define the channels. In this regard, contour crenulations that appear to represent channels may represent other features such as a group of debris flow mounds.**

The drainage basin is bowl shaped where much of the drainage quickly reaches the hydrographic apex. Many active alluvial fans have bowl-shaped drainage basins.

The corrected NRCS soil survey is shown in Figure 5.23. Both of the NRCS soil surveys (Hartman, 1977 and Camp, 1986) report that much of the alluvial fan is composed of Antho, Carrizo and Maripo soil types that are associated with young sediments. About 20 percent of the area above McDowell Rd. that is mapped as unit 3 is Carrizo soil along drainage ways. About 30 percent of the area (soil type AGB) south of McDowell Rd. is Carrizo soil that is in channels that form a braided pattern across large bodies of Antho soils. Camp (1986) describes the Carrizo soils as severely limited for urban use because they are subject to flooding. In the lower fan area, there are fingers of relict fans (soil types 98, GYD and HCL) that separate the areas of younger sediments. These old sediments include small areas of Carrizo and other younger soils along drainage ways. The more stable parts of the surface of soil types GYD and HCL are gravelly loam (desert pavement).

5.3.3.1 Source of sediment

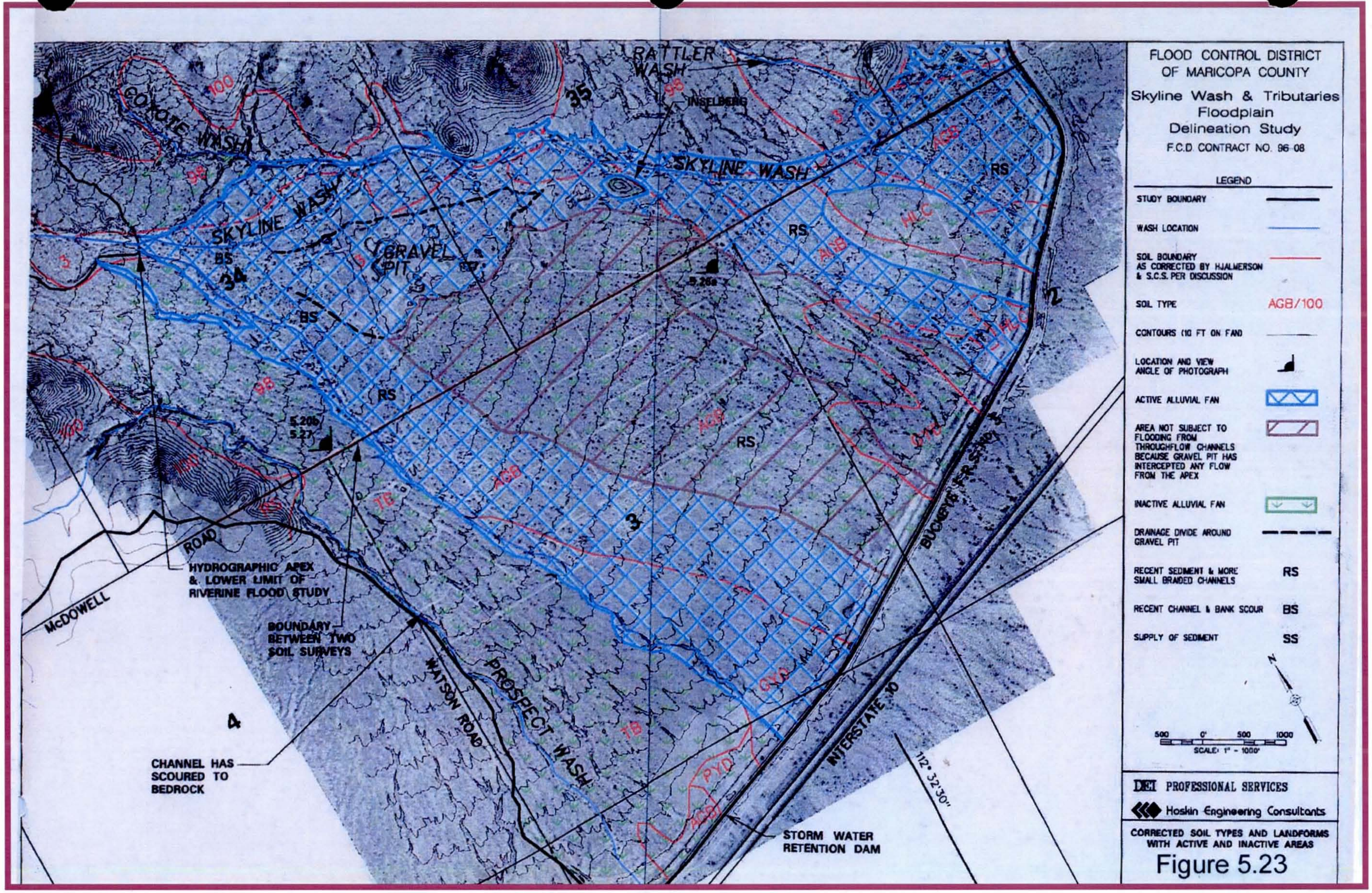
A large amount of loose sediment is visible along the larger drainage channels upslope of the hydrographic apex using aerial photographs (Figure 5.23 and Figure C4 of Appendix C). Much of this very gravely and sand debris is along the western drainage channels. This unconsolidated material can be transported to the fan mostly because flood flow velocities are great along the steep channels (See section 3.15 of the Manual for additional discussion).

The supply of accumulated debris is the Carrizo soil that is a large portion of soil type 3 and a small portion of soil type 98 described by Camp (1986). Channel slopes above the hydrographic apex exceed 2 percent (Figures 5.21 and 5.22) and many channel beds have rather wide reaches with scattered trees. These characteristics were verified by a field inspection of the channel material. A general description of the Carrizo soil, a common soil on alluvial fans in the southwest, is given in Camp (1986).

5.3.3.2 Flow path movement

Flow path movement was evaluated using an Army Map Service aerial photograph of March 10, 1953 (Number 220 at about 1" = 1150 ft.) on file at the FCDMC. A second aerial photograph of March 31,1976 on file at Landiscor Aerial Information in Phoenix, AZ was also used. The recent photography of Nov. 10, 1997 is of excellent quality while the 1953 photograph is slightly faded. The detail on the 1953 photograph is satisfactory. Detail in the 1976 photograph was very clear.

The gravel pit is shown on the 1953 photograph with a haul road heading southeast to a military landing strip. Unconsolidated material has been removed from the pit to depths of more than 10 ft. in several places before bedrock was encountered. The sand and gravel operation continued after 1953 because the gravel pit appears slightly larger in the 1976 photograph. Since 1976 the gravel pit has enlarged to the north and has completely intercepted a large throughflow channel near the central axis of the fan. Other much smaller throughflow channels were also intercepted by the gravel pit.


FLOOD CONTROL DISTRICT OF MARICOPA COUNTY
Skyline Wash & Tributaries Floodplain Delineation Study
F.C.D. CONTRACT NO. 96-08
LEGEND
STUDY BOUNDARY
WASH LOCATION
SOIL BOUNDARY AS CORRECTED BY HJALMERSON & S.C.S. PER DISCUSSION
SOIL TYPE
AGB/100
CONTOURS (10 FT ON FAN)
LOCATION AND VIEW ANGLE OF PHOTOGRAPH
ACTIVE ALLUVIAL FAN
AREA NOT SUBJECT TO FLOODING FROM THROUGHFLOW CHANNELS BECAUSE GRAVEL PIT HAS INTERCEPTED ANY FLOW FROM THE APEX
INACTIVE ALLUVIAL FAN
DRAINAGE DIVIDE AROUND GRAVEL PIT
RECENT SEDIMENT & MORE SMALL BRAIDED CHANNELS
RS
RECENT CHANNEL & BANK SCOUR
BS
SUPPLY OF SEDIMENT
SS
500 0' 500 1000
SCALE: 1" = 1000'
DEI PROFESSIONAL SERVICES
Hoskin Engineering Consultants
CORRECTED SOIL TYPES AND LANDFORMS WITH ACTIVE AND INACTIVE AREAS
Figure 5.23
RATTLER WASH
INSELBERG
COYOTE WASH
SKYLINE WASH
SKYLINE WASH
GRAVEL PIT
HYDROGRAPHIC APEX & LOWER LIMIT OF RIVERINE FLOOD STUDY
BOUNDARY BETWEEN TWO SOIL SURVEYS
McDOWELL ROAD
WATSON ROAD
PROSPECT WASH
CHANNEL HAS SCOURED TO BEDROCK
STORM WATER RETENTION DAM
INTERSTATE 10
BUCKEYE F.R.S. No. 1
112° 32'30"
5.20b
5.27
5.26a

Other than the large impact of the gravel pit, no major changes of the flow paths were observed. Some channel erosion in the upper fan was apparent during the 44-year period. Some channel filling with more development of narrow networks of braided channels also was visible along the sides of the fan. New sediment deposition was along the west channel south of McDowell Rd. and along the eastern two channels that split a few hundred feet north of McDowell Rd. Channel scour with widening was visible below the hydrographic apex along the eastern two channels that presently bypass the gravel pit. Some scour along the west channel below the apex also was apparent.

The throughflow channel on the west side appears to have scoured and widened below the hydrographic apex above McDowell Rd. About 0.2 mile downstream of McDowell Rd. there appears to have been some sediment deposition since 1953. More recent small braided channels are visible below McDowell Rd. in the 1997 photograph.

Below the hydrographic apex, the two throughflow channels on the east appear to have widened a small amount and possibly down cut. Down cutting is restricted by exposed bedrock (apparently cemented relict material) that is readily observed in the field. A new channel is cutting from the northern throughflow channel across to Coyote Wash. There is considerable evidence of active bank erosion along the steep banks. About 0.5 mile below the apex, the channel on the east appears unchanged. About 0.2 mile above McDowell Rd, this channel forks where recent sediment deposition is apparent. There is recent filling and development of small braided channels along both of the forks to the detention dam downstream. There appears to be more sediment deposited along the eastern fork.

The gravel pit clearly has intersected the large fourth channel near the center of the fan below the hydrographic apex. Other much smaller throughflow channels also were intersected by the pit. The gravel pit intersects flow across the eastern two-thirds of the alluvial fan and diverts it to the large throughflow channel on the east side of the fan.
A couple of other small throughflow channels pass between the large throughflow channel on the west of the fan and the west edge of the gravel pit. These small throughflow channels appear in the three aerial photographs to convey only small amounts of overflowing floodwater. Based on the field inspection, only relatively small amounts of flow can enter the fan near the west side of the pit and east of the large throughflow channel. The present geometry and roughness conditions below the apex suggest that only very shallow flow of major floods can enter this area.

5.3.3.3 Vegetation

A mix of areas with channels lined with trees or areas with scattered trees are visible on the aerial photographs. For example, the scattered paloverde trees over much of the center and west of the upper fan below the hydrographic apex suggests the fan is unstable (Table 3.1 and Section 3.1). Within this area, however, are at least two faint channels lined with trees that suggest some stability. About 1,500 ft below the hydrographic apex the channel on the west is lined with trees to about 3,500 ft below the hydrographic apex just below McDowell Rd. suggesting this reach is stable. On the east side of the fan below the hydrographic apex, the trees are mostly along the channel also suggesting that this channel has not moved for several years.

5.3.3.4 Channels

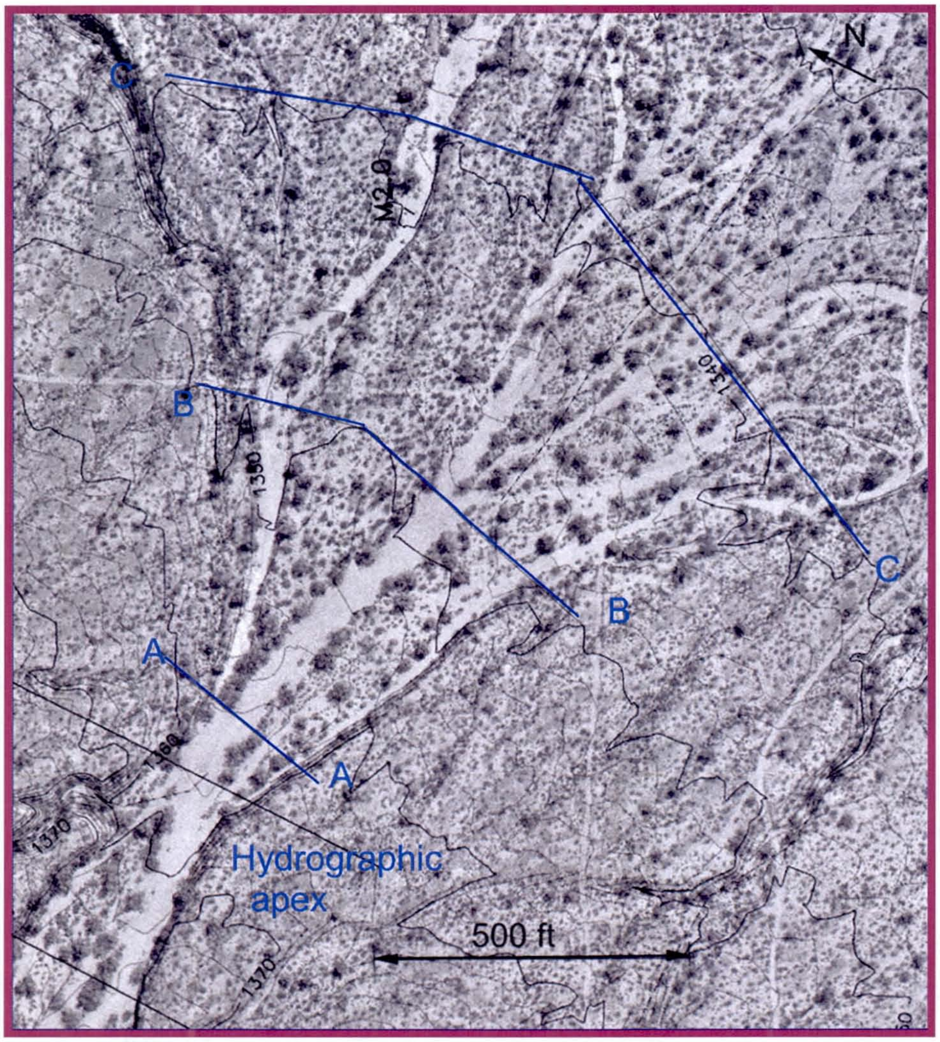
Four rather large throughflow channels are below the hydrographic apex. The most distinct throughflow channels are along the edges of the upper fan (See Figures 5.23 and 5.24). Below McDowell Rd., the channel on the west progressively becomes less distinct (Figure 5.23) where there are several channel forks and the channel depths decrease. Along the eastside of the fan the two channels join and form a single channel that has several small tributaries including Coyote Wash. A few hundred feet upstream of McDowell Rd. the east channel splits into two distinct flow paths. A fourth rather large channel in the upper fan enters the gravel pit area and becomes indistinct on the aerial photographs (Figure 5.23).

In the upper alluvial fan many channels are wide with low banks like those shown for cross sections BB' and CC' (Figures 5.24 and 5.25). Many channel cross sections shown in fan sections BB' and CC' are similar (after allowance is made for scale differences of the abscissa and ordinate) to the cross section in Figure 2.2 for typical active alluvial fans. The large and fairly deep channel on the west of the fan shown in cross section CC' is more typical of an inactive alluvial fan (See third cross section in Figure 2.2). South of McDowell Road the throughflow channels for soil type AGB are or become less than 2 ft. deep suggesting the fan is unstable (See Table 3.1).

5.3.3.5 Gravel pit

As previously mentioned, the rather large throughflow channel is head cut where it enters the gravel pit. The head cutting is progressing upstream at roughly 10 ft/year and the channel near the pit has scoured about 5 or 6 ft. This head cutting will progress upstream toward the hydrographic apex and the rate of progression is expected to increase as more throughflow is intercepted. A small alluvial fan has developed in the pit below the head cut channel. Large amounts of sediment will be deposited in the pit as more throughflow enters the pit. Flow exits the gravel pit area a few hundred feet upslope of a small inselberg (Figure 5.23).

The gravel pit has intersected floodwater that under natural conditions would have entered the shaded area below the pit (Figure 5.23). This area below the pit is removed from natural throughflow except where the dirt subdivision roads have intersected flow that under natural conditions probably would remain to the west of the shaded area. Both the north-south and east-west roads have an impact on the distribution of flood flow south of McDowell Rd. These roads intersect the generally southeast natural flow in the numerous small channels. Some flow and sediment is diverted into the shaded area mostly by the east-west roads near the center of section 3. This diversion can be seen on the aerial photographs with the detailed topography and in the field.



(Base map of 11/10/97 at 1" = 200 feet and 2' contour interval from DEI Professional Services)

Figure 5.24. Cross sections located below the hydrographic apex of the Skyline Wash alluvial fan.

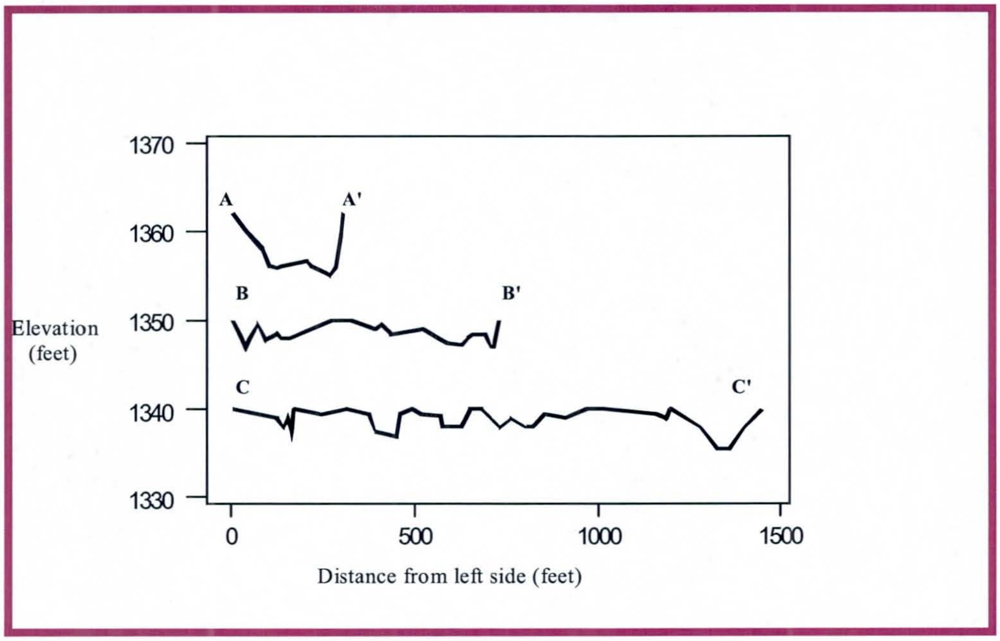


Figure 5.25 Cross sections located at the 1362, 1350 and 1340 ft. topographic Contours shown in Figure 5.24 below the hydrographic apex.

5.3.3.6 Surface age indicators and soil development

The profiles of soil exposed along cut banks in soil types 3 and AGB show little development suggesting the surface is young and unstable (Table 3.1 and Section 3.1). Profiles along cut banks in soil types 98, HLC and GYD show some calcium carbonate.

There is little desert pavement on much of the fan. Some desert pavement with a generally light desert varnish is on many of the interfluves in soil types 98, HLC and GYD. Typical desert pavement and desert varnish on the stable areas of the Skyline Wash alluvial fan is shown in Figure 5.26.

There are many small areas of microbiotic crusts on the more stable areas of the fan (Figure 5.27). These crusts are an indication of surface stability for short periods (See section 3.1.2). Microbiotic crusts may not an indicator of surface stability for more than a few tens of years.

a. View looking upslope at desert pavement with some desert varnish on interfluves of soil type GYD.

b. View looking down at desert pavement at west side of fan about 100 ft. north of McDowell Rd on soil type 98.

Figure 5.26. Views of desert pavement with some desert varnish on stable parts of fan.

5.3.3.7 Distribution of sediment along the fan

Sediment samples were taken at three sites along the western throughflow on April 28, 1997. The samples were across the channel near the hydrographic apex (apex sample), across the channel a few feet upstream of McDowell Road (upper sample) and 3,000-ft downstream across a large distributary channel (middle sample). Several samples were taken at each site at about 3-6 inch depth and composited. The particles were angular and sub angular and a change in rounding down the fan was not obvious. The percent of sediment greater than the sieves at the three sites is shown in Table 5.1 and in Figure 2.18b.

Table 5.1 Distribution of particle size at the upper, middle and lower sites along the west side of the fan.

Sieve No.	Sieve size	Percent greater than indicated size		
	mm	Middle site	Upper site	Apex site
4	4.7	2.623	17.361	17.677
10	2.0	21.311	39.583	43.561
40	.42	95.082	88.889	91.540
200	.074	99.672	99.306	99.747

The darkened surface is composed of microbiotic, lichens and mosses (Belnap, 1995) and may require hundreds of years to establish. The presence of large areas of microbiotic crust is a reliable index of surface stability for a few tens of years and possibly for a few hundred years. There are many small crusted areas on the alluvial fan. There appears to be more crust on the relict fans (soil types 98, HLC and GYD). Some of this crust to the left and above the pen is covered with a thin veneer of recent sediment.

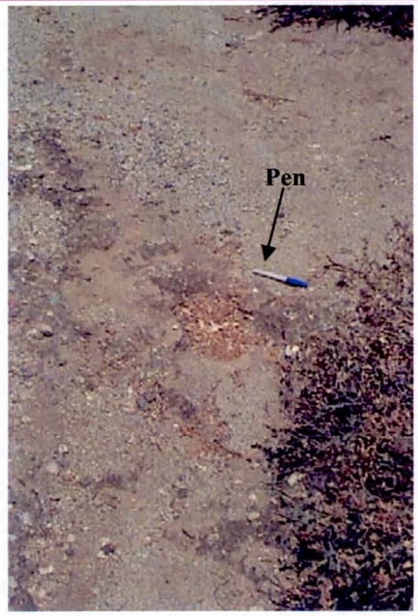


Figure 5.27. Microbioticic crust in small first order channel on soil type 98 about 100 ft. north of McDowell Road on west side of fan.

The upper and apex samples are very similar and suggest there is no deposition in the reach. There is much less large material in the middle sample, suggesting there is deposition of coarser material (mostly larger than coarse sand (>.42mm)). Apparently, there is enough stream power to move the silt and clay past the lower site. Thus, the west part of the fan (Soil type AGB) appears to be aggrading below McDowell Road. Above McDowell Road, the sediment is moving on through in the confined channel (See Figure 5.20).

Sediment samples also were collected along the central axis of the fan on July 10, 1998. These samples were in the less active appearing area between the east and west throughflow channels from just north of McDowell Rd. to near the fan toe upstream of the flood retaining structure. Samples were composited for three sites located across the fan at McDowell Road, about 1/2 mile down slope of McDowell Rd. and at the third site about 1 mile below McDowell Rd. These samples were collected at 2-14 inch depths in soil type AGB. No calcium carbonate or much reddening from oxidation was observed at these depths. A small down-fan decrease in the proportion of sand particles is apparent (Figure 5.28) thus suggesting alluvial fan processes like those discussed in Appendix Q of this manual. It is uncertain how much the distribution of sediment in this less active area has been affected by secondary processes of remobilization and redeposition along fan. The greater proportion of gravel near the fan toe above the retention dam (Figure 5.28) may be the result of secondary processes where the finer material has been translocated down fan.

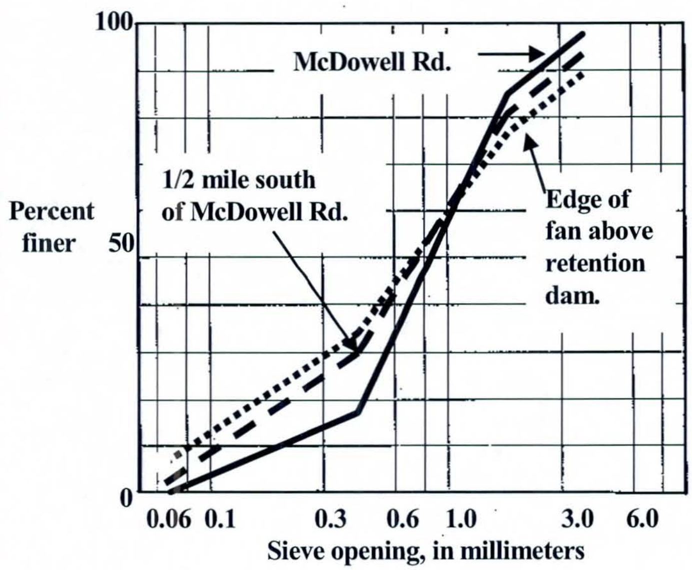


Figure 5.28. Cumulative graph of material size versus frequency along central axis of fan where there is little evidence of recent throughflow.

5.3.3.8 Summary of active and inactive areas

The channels on the east and the west sides of the fan have recently eroded to bedrock in places and the banks, especially along the east channels, have eroded and widened. Thus, the sides of the fan are more active than the center of the fan. The center of the fan, however, is also considered active, although much less active than both sides of the fan, in the absence of the gravel pit that intersects flood flow. Thus, the area below the pit is shown as active (Figure 5.23) mostly to be conservative on the side of caution and remind the user of the hazard. If the gravel pit were not present, much of the alluvial fan would be considered active based on (1) the young soil (types 3 and AGB), (2) the several small throughflow channels that are visible across the upper fan on the 1953 and 1976 aerial photographs and (3) the generally scattered appearance of the trees below the apex.

The large gravel pit, however, intercepts throughflow that would have entered the middle of the fan defined by soil types 3 and AGB. Thus, throughflow that normally would have entered the center of the fan is presently diverted across the fan to the large channel on the east side of the fan. The "shadow" area below the pit affected by this intersection and diversion is shown in Figure 5.23.

The dirt subdivision roads at and to the south of McDowell Rd. have interfered with the natural flow paths. Because of the small relief across the fan in this area, shallow flood flow in the western throughflow area has been diverted to the east along the roadways for a few hundred feet. The numerous small ridges and channel depressions were smoothed when the roadways were bladed. These smoothed roads efficiently convey shallow flow to the east. Some minor erosion has occurred along the roads. Thus, small amounts of floodwater presently enter the western edge of the "shadow" area below the gravel pit.

Inactive areas generally correspond to soil types 98, GYD and HCL. In the lower east part of the fan above the retention dam, the inactive areas only roughly correspond to the soil types. The inactive areas shown in Figure 5.23 are based mostly on the older appearing surface features including the desert pavement (Figure 5.26a), the predominance of vegetation along the channels and the developed tributary drainage network on the fan surface.

The inactive area in the southeast part of the fan that corresponds to soil type HLC has little relief a few hundred feet south of McDowell Rd. Flow paths appear stable in this area but the area appears subject to sheet flow.

5.3.4 Estimated 100-year flood hazards

The stable and unstable areas are the basis for the 100-year floods hazards. The stable and unstable areas are reviewed and modified as necessary by incorporating an estimate of 100-year conditions. The peak discharge for the 100-year flood is estimated using methods by Thomas, Hjalmarson and Waltemeyer (1994). This level 2 estimate of estimate of the peak discharge of the 100-year flood (See State of AZ standard 2-96) is sufficiently precise for this morphologic assessment. More precise estimates of the 100-year peak discharge using level 3 methods should be used for water surface profiles. Channel conveyance is next evaluated for the upper fan to demonstrate the varying distribution of discharge across the fan during a major flood. The impact of the gravel pit and the subdivision roads are then considered to produce a map of the 100-year flood hazards. The stable and unstable areas are the basis for the 100-year floods hazards.

5.3.4.1 Peak discharge and channel conveyance considerations

The magnitude of the 100-year flood is used to evaluate and demonstrate the potential flow spreading and flow path movement below the hydrographic apex. Stable geometry and roughness are assumed for these idealized computations. Channel conveyance is estimated at three cross sections in the upper fan and the average channel slope for each section is determined. The channel capacity for the 100-year flood and flow path stability is then examined using conveyance-slope estimates. This particular channel conveyance based demonstration of flow spreading is not required for defining and characterizing areas affected by the 100-year flood as defined in Chapter 4 of this manual.

Peak discharge for 100-year flood

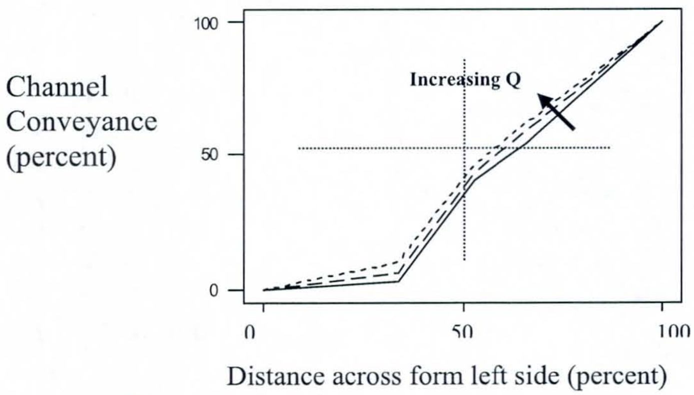
The magnitude and frequency of floods from the 3.93 mi^2 drainage basin above the hydrographic apex was estimated using methods by Thomas, Hjalmarson and Waltemeyer (1994) for flood region 12. The peak discharge of the 100-year flood is 5,030 ft3/s for the rugged basin with a mean basin elevation of about 1,850-ft. This level 2 method of estimating of the peak discharge of the 100-year flood (See State of AZ standard 2-96) is sufficiently precise for this demonstration.

Based on this regional method of estimating the magnitude and frequency of floods, the estimated peak discharge is not very precise. This imprecision is inherent in any estimate of the peak discharge of the 100-year flood. The average standard error of prediction for flood region 12 is 39 percent (Thomas, Hjalmarson and Waltemeyer, 1994). For the Skyline Wash alluvial fan, this standard error corresponds to a range of peak discharge from 1,960 to 6,990 ft3/s. This imprecision, that is often overlooked in traditional analyses, should be considered when using the geomorphic methods for this or any other site in Maricopa County.

Channel conveyance below hydrographic apex

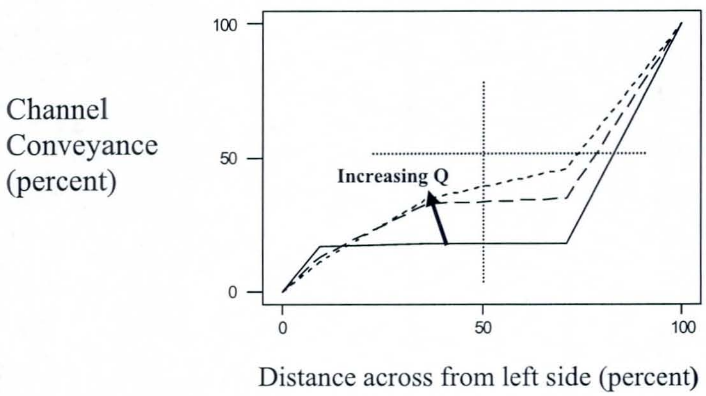
Cross sections used are shown in Figure 5.24. Cross section AA' is at elevation contour 1,362, section BB' is at contour 1,350 ft and section CC' is at contour 1,340 ft. Cross sections are along the contours because the flow typically is perpendicular to the ground slope. On the average, the ground slope is approximately the same as the hydraulic grade and both are perpendicular to the elevation contour. Cross sections AA', BB' and CC' are shown in Figure 5.24. The total channel conveyance corresponding to the contour elevations is 160,000, 45,500 and 68,300 ft3/s for sections AA', BB' and CC' respectively. The distribution of conveyance across the fan is shown in Figure 5.29. High flow conditions depicted by the dotted line correspond to the 100-year flood.

Cross section AA'



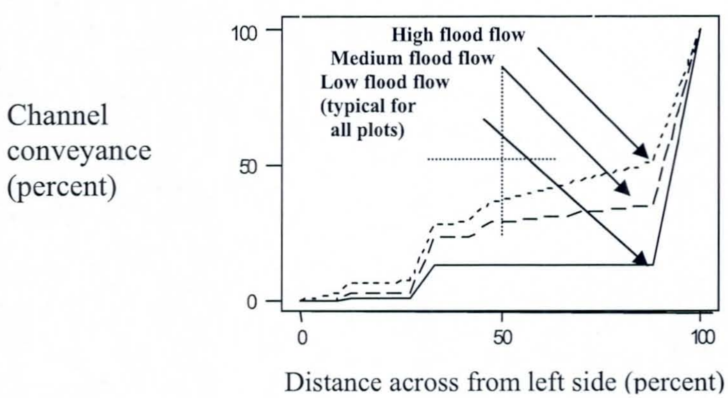
The distribution of channel conveyance (K) for the low, medium and high flows remains rather constant as discharge increases. Except for the brushy & rocky left bank, the distribution of K is rather uniform across the channel.

Cross section BB'



Water surface is assumed to be horizontal at the 1350-ft elev. contour. For low flows most of the K is on the right side with a small portion on the left side and none in the middle. The distribution of K becomes uniform as discharge increases.

Cross section CC'



Water surface is assumed to be horizontal at the 1340-ft elev. contour. For low flows most of the K is on the right side with a small portion in the left-center and none in the middle. The distribution of K does not change significantly as discharge increases.

Figure 5.29. Distribution of channel conveyance at cross sections below the hydrographic apex.

Flow paths and flow spreading

At cross section AA' the conveyance is rather evenly distributed across the channel for all floods. Thus, as the amount of flood discharge changes the distribution of discharge remains rather uniform and unchanging if the roughness, geometry and slope remain constant. The 100-year peak discharge of 5,030 ft^3/s is easily contained between the bedrock banks.

At cross section BB' most of the conveyance for small floods is in the right channel. As flood discharge increases the conveyance becomes more evenly distributed across the section. For bank full conditions across the fan, the channel capacity is roughly 6,400 ft^3/s or 27 percent more than the 100-year discharge of 5,030 ft^3/s. This channel capacity is within the standard error of prediction for the 100-year flood (a peak discharge of 1,960 to 6,990 ft^3/s) that was discussed previously. Clearly, land within the entire cross section could be inundated by the 100-year flood. In addition, because the distribution of conveyance changes with discharge, it appears likely that floodwater can spread across the fan at section BB' in varying amounts.

At cross section CC' part of the flood flow becomes separated in the right channel and remains separated for high flows. The bank full capacity is about 9,600 ft^3/s or about 90 percent more than the 100-year peak discharge. Overtopping of defined banks by the 100-year flood appears likely in the center and left side of the fan. Apparently a large portion of 100-year floodwater becomes separated and confined along the channel at the right of the fan.

For the assumed stable channel conditions, the hydraulic conditions represented by cross section BB' control the distribution of floodwater across the upper fan and thereby control the distribution of floodwater for the entire fan. The distribution of flow changes with increasing and decreasing discharge and the entire upper fan can be inundated. Thus, flow paths are somewhat unstable even for the highly idealized condition of stable geometry. Some flow path stability is evident at the right end of cross section CC' and when flow reaches this channel the flow is confined and separate from the flow to the left (east). for some distance downstream.

5.3.4.2 Infrequent fan building events

Evidence of recent large floods with large amounts of scour and fill was not found. The coarse sand and gravel sediment with a few cobbles and scattered boulders that is in the larger channels above the hydrographic apex is a large source of sediment for fan building.

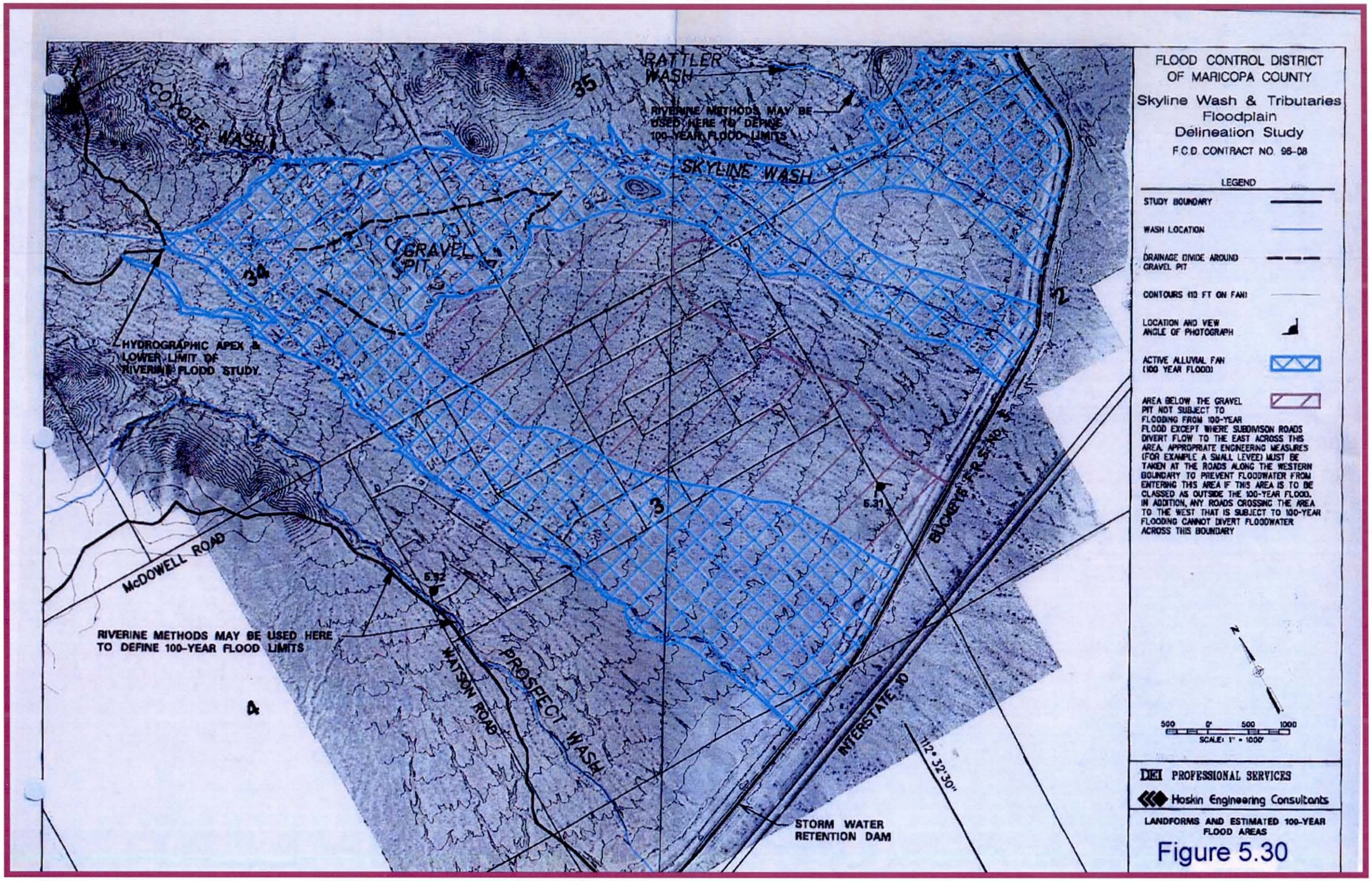

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY
Skyline Wash & Tributaries
Floodplain
Delineation Study
F.C.D. CONTRACT NO. 96-08
LEGEND
STUDY BOUNDARY
WASH LOCATION
DRAINAGE DIVIDE AROUND GRAVEL PIT
CONTOURS (10 FT ON FAN)
LOCATION AND VIEW ANGLE OF PHOTOGRAPH
ACTIVE ALLUVIAL FAN (100 YEAR FLOOD)
AREA BELOW THE GRAVEL PIT NOT SUBJECT TO FLOODING FROM 100-YEAR FLOOD EXCEPT WHERE SUBDIVISON ROADS DIVERT FLOW TO THE EAST ACROSS THIS AREA. APPROPRIATE ENGINEERING MEASURES (FOR EXAMPLE A SMALL LEVEE) MUST BE TAKEN AT THE ROADS ALONG THE WESTERN BOUNDARY TO PREVENT FLOODWATER FROM ENTERING THIS AREA IF THIS AREA IS TO BE CLASSED AS OUTSIDE THE 100-YEAR FLOOD. IN ADDITION, ANY ROADS CROSSING THE AREA TO THE WEST THAT IS SUBJECT TO 100-YEAR FLOODING CANNOT DIVERT FLOODWATER ACROSS THIS BOUNDARY
N
500 0' 500 1000
SCALE: 1" = 1000'
DEI PROFESSIONAL SERVICES
Hoskin Engineering Consultants
LANDFORMS AND ESTIMATED 100-YEAR FLOOD AREAS
RATTLER WASH
COYOTE WASH
SKYLINE WASH
RIVERINE METHODS MAY BE USED HERE TO DEFINE 100-YEAR FLOOD LIMITS
GRAVEL PIT
HYDROGRAPHIC APEX & LOWER LIMIT OF RIVERINE FLOOD STUDY.
35
34
3
2
4
McDOWELL ROAD
WATSON ROAD
PROSPECT WASH
INTERSTATE 10
STORM WATER RETENTION DAM
112° 32'30"
5.31
5.32

Figure 5.30

5.3.4.3 Summary of 100-year flood conditions

The gravel pit effectively intercepts throughflow across the center of the fan (Figure 5.30). The amount of intercepted flood flow will increase with time because of the head cutting along the large throughflow channel. The potential volume in the pit for sediment deposition is more than 500 times the predicted annual sediment yield of the drainage basin using a method by Flaxman (1972). Flood peaks will be attenuated in the pit mostly because of detention storage in several low-lying areas. This means that the pit will effectively intercept water and sediment for many years. Floodwater and sediment entering the pit are redirected to the east side of the fan.

West side of fan

The throughflow area along the west side of the fan is subject to scour, fill, and channel avulsion. Much of this area will be inundated by a 100-year flood. This west area is very active.

Shadow area

Before development the approximately western two-thirds of the shadow area was active and the approximately the eastern one-third of the shadow area was inactive. The gravel pit has intersected floodwater that under natural conditions could have entered most of the shadow area below the pit (Figures 5.23 and 5.30). The dirt subdivision roads, however, have intersected some flood flow that under natural conditions would have remained to the west of the shadow area. As previously stated, these north-south and east-west roads have an impact on the distribution of flood flow in the shadow area at and south of McDowell Rd.

Soils in much of the shadow area are easily eroded where flow is concentrated. Some of the most severe recent erosion along subdivision roads in the shadow area is shown in Figure 5.31. This erosion is from local runoff. Erosion along the east-west subdivision roads is much less severe than that shown in Figure 5.31. However, the potential erosion where flood flow is concentrated along roads in the shadow area (soil type AGB) is great.

During major flooding, throughflow floodwater and some sediment will be directed down the roads toward the east. Floodwater along the roads will be shallow but prolonged flooding may erode channels along the roads. Slopes along the rather smooth subdivision roadways exceed 1 percent and shallow flow velocities are near critical. The erosion potential is rather high and scour like that shown in Figure 5.31 could occur. Thus, appropriate engineering measures (for example a small levee) must be taken to prevent floodwater from entering this area if this area is to be classed as outside the limits of the 100-year flood.

Any engineering measures should allow for sediment deposition along the west side of the fan. Many acre-feet of sediment debris are expected during the 100-year flood. In addition, because this is an active alluvial fan, engineering measures should not impact the active areas outside the defined shadow area. As previously discussed, the gravel pit (considered a significant engineering measure) has altered the flow distribution across the fan. There is evidence this impact may not be large mostly because little throughflow has entered the middle part of the fan for possibly 1,000 years (See Field and Pearthree, 1992).

Figure 5.31. View looking north at erosion from concentrated runoff along subdivision road where local runoff has eroded channels into soil type AGB.

However, because of the nonstationarity effect of the gravel pit such as the progressive head cutting at the inflow channel to the pit, engineering measures should provide an ample factor of safety to allow for unknown trends (See section 3.6 of manual). Over time, less floodwater is expected along the west side of the fan and more floodwater is expected along the east side of the fan as more floodwater is intercepted by the gravel pit as discussed in section 5.3.3.5.

East side of fan

The channel bed and banks north and east of the gravel pit also are eroding. The eroded bed and bank material along with the sediment yielded from the drainage basin also has been deposited along the east side of the fan below the gravel pit. Because of the filling of the channels generally below McDowell Rd. the low-lying inactive fan area (See Figure 5.23) on the southeast part of the fan is included in the 100-year flood limits. There is evidence this area has been inundated by large floods but there is no evidence of sediment deposition and associated flow path movement. Because floodwater is progressively diverted to this area by the gravel pit (See section 5.3.3.5), some additional water and sediment are expected on the lower east side of the fan.

There is active head cutting along the defined channels that cross the fan to the north of the gravel pit. A new channel that cuts across to Coyote Wash is forming near the northern boundary of the 100-year flood limits. There is evidence of active bank erosion along the steep banks. This entire area is subject to high velocity floodwater and channel movement and formation.

Traditional 100-year flood boundaries in the 100-year flood zones shown in Figure 5.30 will not be reliable. Any flood elevations and flood limits computed from step backwater methods such as HEC-RAS are considered only rough approximations because of the uncertain flow paths and channel instability as previously discussed. Clearly, the distribution of flow below the hydrographic apex is uncertain and the channel geometry in the upper fan is unstable and changing.

The shadow area is not very active. Much of the shadow area was not very active before the gravel pit was constructed. After the gravel pit was constructed and before the subdivision roads, the shadow area was inactive because there were no throughflow channels in the area. Because the subdivision roads divert throughflow from the active area to the west into the shadow area, the shadow area is considered active. The activity is very low at the present (August 2002) but a large flood may erode channels into the area and divert throughflow into the area from the west. This problem can be easily corrected with a small-engineered levee or other minor-engineered measure.

Thus, a minor engineering measure would prevent alluvial fan flooding in the shadow area. The area would then be subject to hazards common to steep-erodible tributary streams (Figure 5.31).

5.3.4.4 Rough check of the estimated 100-year flood conditions

A check of the assessment can be made using methods by Hjalmarson and Kemna (1991) described in section Appendix O of this Manual. This check of the assessment uses a relation between flood-hazard degree and physiographic characteristics of the alluvial fan and the drainage basin. A sample computation using this Skyline Wash site is shown in Appendix O. The computed flood-hazard degree supports the flood hazard assessment using methods given in this manual.

5.3.5 Brief comments on hazard assessment for adjacent landforms.

5.3.5.1 Prospect Wash

Prospect Wash heads in the mountains to the west of the Skyline Wash basin. The deep-narrow channel crosses soil type 98 (Camp, 1986) at the toe of a mountain. The channel then crosses soil type TB (Hartman, 1977) to the west of the Skyline Wash fan. The relict fan material above the McDowell Rd. alignment is stable. The much younger torrifluvients (type TB) are not very consolidated and are stratified. The channel of Prospect Wash is deeply cut (gullied) into both landforms and down cutting in the torrifluvients is restricted in places by bedrock (Figure 5.32). The channel generally is incised more than 10 ft to about 1/2 mile above the retention dam where incision decreases to less than 4 ft. The channel meets the stable criteria given in this manual mostly because of the depth of incision (See Chapter 3) and 100-year floodwater typically is confined in the channel. Traditional hydraulic methods (rigid-boundary flood analysis) will produce approximate flood elevations and boundaries. Setbacks are appropriate for management of 100-year flood hazards. A setback from the steep-erodible banks is important along this wash because there is active bank erosion in places.

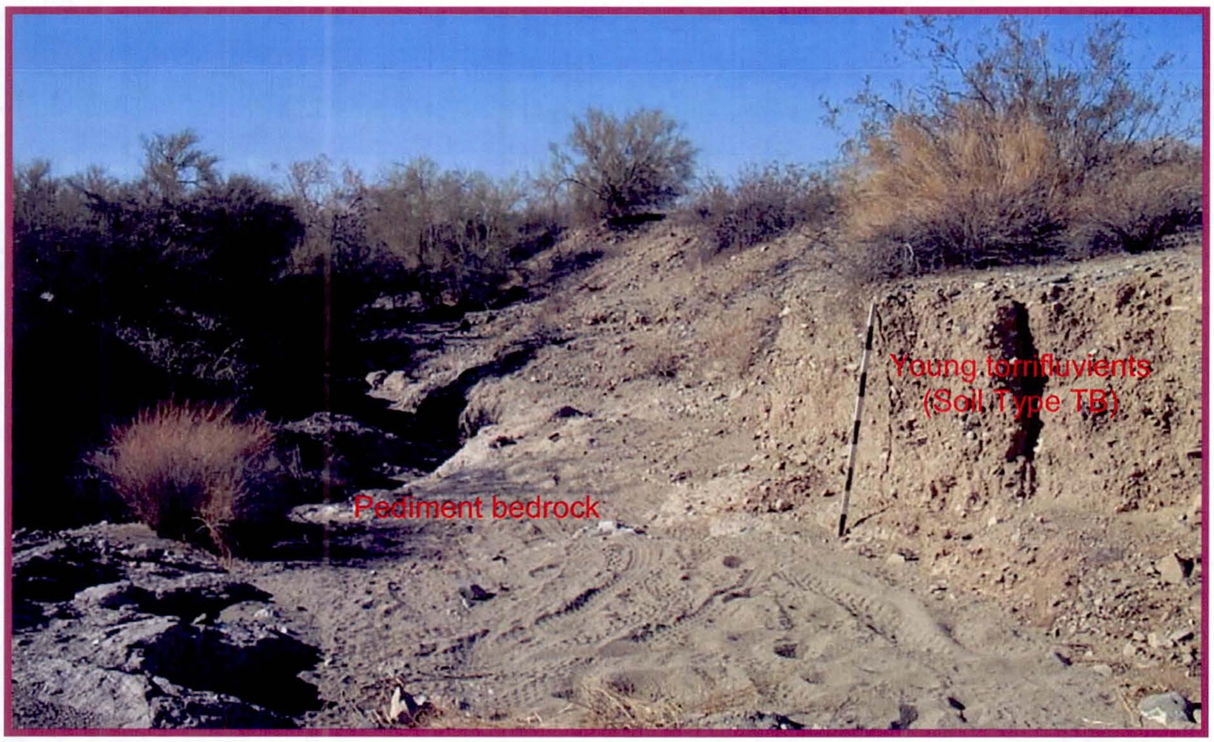


Figure 5.32. View looking south from below Watson Road at channel of Prospect Wash.

5.3.5.2 Coyote Wash

Coyote Wash heads in the mountains and crosses a relict fan (type 98) before joining the eastern channel of the Skyline Wash alluvial fan. The channel is rather stable and traditional hydraulic methods apply above the throughflow channel that forms the east boundary of the Skyline Wash alluvial fan.

5.3.5.3 Rattler Wash

Rattler Wash heads in the mountains to the east of the Skyline Wash drainage basin. The upper channels are in the bedrock mountains. Below the mountains the channel is deeply cut into relict fan (soil type 98) with cemented banks. Incision is more than 10 feet. Near McDowell Rd., incision and confinement are lost and the wash forms the east end of the active Skyline Wash alluvial fan. A few hundred feet above McDowell Rd. the channel is stable and traditional hydraulic methods are appropriate. Near McDowell Rd., the 100-year flood spreads over a wide area (soil types 3 and AGB).

5.3.5.4 Skyline Wash above hydrographic apex

At and to about 1/2 mile above the hydrographic apex the within the channel is unconsolidated and coarse (soil type 3) and is easily moved by the high flood velocities. There typically are several small channels along the watercourse and floodwater spreads over wide areas at rather shallow and variable depths. Channel roughness varies across the channel mostly because of the scattered vegetation that in places is aligned parallel with the paths of flow (See Figure 6A of Phillips and others (1998) for the effects of aligned vegetation). This area is bounded by relict fan material (type 98) that is consolidated and somewhat stable. Because flow is generally confined, traditional hydraulic methods can be used to produce a rough estimate of the 100-year flood limits. The channel bed geometry is not stable and subdivision of cross-sections to define alpha (the velocity head coefficient) is complex. In general, channels can move between the consolidated banks of soil type 98.

About 1/2 mile above the hydrographic apex the channels are cut into relict fan (type 98) and are much narrower and stable. These channels typically are more than 10 ft. deep with rather stable banks. Flow typically is confined and traditional hydraulic methods can be used to define the limits of the 100-year flood. Setbacks should be used because the banks are steep and subject to some movement.

In the upper reaches above the relict fan, the channels are confined between steep bedrock canyons. The channels typically are incised and stable.

6

ACRONYMS

ADWR	Arizona Department of Water Resources
AZGS	Arizona Geological Survey
BLM	U.S. Bureau of Land Management
FEMA	Federal Emergency Management Agency
FCDMC	Flood Control District of Maricopa County
HEC	Hydrologic Engineering Center
NFIP	National Flood Insurance Program
NRC	National Research Council
NRCS	Natural Resources Conservation Service
COE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

7

GLOSSARY

(Source typically Alluvial fan flooding, National Research Council, 1996)

Active Those locations where flooding, erosion, and/or deposition have occurred on the landform such as an alluvial fan in relatively recent time(the historic period), and probably will continue to occur on that part of the landform.

Alluvial Pertaining to or composed of alluvium, or deposited by a stream or running water.

Alluvium A general term for clay, silt, sand, gravel, or similar unconsolidated detritus material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semi sorted sediment in the bed of the stream or its floodplain or delta, or as a cone or fan at the base of a mountain slope; esp. such a deposit of fine-grained texture (silt or silty clay) deposited during time of flood.

Alluvial Fan (FEMA 2002) The sedimentary deposit located at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of streamflow and/or debris flow sediments and has the shape of a fan, either fully or partially extended. These characteristics can be categorized by composition, morphology, and location.

Alluvial Fan Flooding (FEMA 2002) The flooding that occurs on an alluvial fan as defined above. The term alluvial fan flooding encompasses both active alluvial fan flooding and inactive alluvial fan flooding. Alluvial fan flooding can include distributary flow, sheet flow and sheet flooding.

Alluvial Fan Flooding (Active) (FEMA 2002) Flooding that occurs only on alluvial fans and is characterized by flow path uncertainty so great that this uncertainty cannot be set aside in realistic assessments of flood risk or in the reliable mitigation of the hazard. An active alluvial fan flooding hazard is indicated by three related criteria: (1) flow path uncertainty below the hydrographic apex; (2) abrupt deposition and ensuing erosion of sediment as a stream or debris flow loses its ability to carry material eroded from a steeper, upstream source area; and (3) an environment where the combination of sediment availability, slope, and topography creates an ultra hazardous condition for which elevation on fill will not reliably mitigate the risk.

Alluvial Fan Flooding (Inactive) (FEMA 2002) Flooding that is similar to traditional riverine flood hazards, but occurs only on alluvial fans. Inactive alluvial fan flooding is characterized by flow paths with a higher degree of certainty in realistic assessments of flood risk or in the reliable mitigation of the hazard. Unlike active alluvial fan flooding hazards, an inactive alluvial fan flooding hazard is characterized by relatively stable flow paths. However, like areas of active alluvial fan flooding, inactive alluvial fan flooding, may be subject to sediment deposition and erosion, but to a degree that does not cause flow path instability and uncertainty.

Alluvial plain A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or an alluvial fan.

Alluvial plain flooding A type of flood hazard that occurs only on alluvial plains. It is characterized by sheet flow (Arizona State Standard 4-95), sediment deposition and channel erosion where the base-level stream has lowered.

Anastomosing The branching and rejoining of channels to form a netlike pattern.

Approximate Study (FEMA 2002) A flood hazard study that results in the delineation of floodplain boundaries for the 1 percent annual chance (100 year) flood, but does not include the determination of BFEs or flood depths.

Attribute A characteristic of a geographic feature described by numbers, characters or images.

Avulsion A sudden cutting off or separation of land by a flood or by an abrupt change in the course of a stream, as by a stream breaking through a meander or by a sudden changes in current, whereby the stream deserts its old path for a new one.

Base map A rectified map containing geographic features such as roads for locational reference.

B horizon A mineral horizon of a soil, below the A horizon, sometimes called the zone of accumulation and characterized by one or more of the following conditions: an alluvial accumulation of humus or silicate clay, iron, or aluminum; a residual accumulation of sesquioxides or silicate clays; darker, stronger, or redder coloring due to the presence of sesquioxides- a blocky or prismatic structure.

Bajada A broad, continuous alluvial slope or gently inclined detritus surface, extending along and from the base of a mountain range out into and around an inland basin, formed by the lateral coalescence of a series of separate but confluent alluvial fans, and having an undulating character due to the convexities of the component fans- it occurs most commonly in semiarid and desert regions, as in the southwestern United States. A bajada is a surface of deposition, as contrasted with a pediment (a surface of erosion that resembles a bajada in surface form), and its top often merges with a pediment.

Buffer Zone An area of specified distance (radius) around a map item or items.

Calcic horizon A secondary calcium carbonate accumulation in the lower B-horizon that occurs as coatings on clasts and as lenses in fine-grained sediment matrices; it is at least 15 cm thick and contains 15 percent or more calcium carbonate.

Channel (FEMA 2002) A naturally or artificially created open conduit that periodically or continuously contains moving water or which forms a connecting link between two bodies of water.

Clast An individual constituent, grain, or fragment of a sediment or rock, produced by the mechanical weathering (disintegration) of a larger rock mass.

Contour crenulation An uphill kink or barb in a contour line but not a gentle bend of the line(Doehring, 1970). The uphill kink typically represents gullies or first order streams.

Debris flow A mass movement involving rapid flowage of debris of various kinds under various conditions; specifically, a high-density mudflow containing abundant coarse-grained materials and resulting almost invariably from an unusually heavy rain.

Dendritic A tree-like pattern, typical of most drainage networks.

Desert pavement Surfaces of tightly packed gravel that armor, as well as rest on, a thin layer of silt, presumably formed by weathering of the gravel. They have not experienced fluvial sedimentation for a long time, as shown by the thick varnish coating the pebbles, the pronounced weathering beneath the silt layer, and the striking smoothness of the surface, caused by obliteration of the original relief by down wasting into depressions.

Desert varnish A dark coating (from 2 to 500 microns thick) that forms on rocks at and near the Earth's surface as a result of mineral precipitation and eolian influx. The chemical composition of rock varnish typically is dominated by clay minerals and iron and/or manganese oxides and hydroxides, forming red and black varnishes, respectively. With time the thickness or the coating increases if abrasion and burial of the rock surface do not occur. As a result, clastic sediments on alluvial fan surfaces that have been abandoned for long periods of time have much darker and thicker coatings of varnish than do younger deposits.

Digitizing A process of converting an analog image or map into a digital format usable by a computer.

Distributary flow Diffuse flow where there is a distinct channel fork at an out flowing branch of a stream. Areas with distributary flow typically are composed of channel forks, joins and outlets. Active alluvial fans and granite pediments typically are characterized by distributary flow (Hjalmarson).

Distributary flow area Term was used by Hjalmarson and Kemna (1992) to describe a network of multiple bifurcation and rejoining of drainage channels on active and inactive alluvial fans in Arizona that have a distributary drainage network.

Embayment A recess or indentation in the mountain front forming an open bay-like formation typically composed of sediment derived from the surrounding mountain slopes. This definition is for this manual and is in the context of the mountains and valleys of Maricopa County.

Eolian Pertaining to the wind; esp. said of rocks, soils, and deposits (such as loess, dune sand, sand some volcanic tuffs) whose constituents were transported (blown) and laid down by atmospheric currents, or of landforms produced or eroded by the wind, or of sedimentary Structures (such as ripple marks) made by the wind, or of geologic processes (such as erosion and deposition) accomplished by the wind.

Flood (FEMA 2002) A general and temporary condition of partial or complete inundation of normally dry land areas from (1) the overflow of inland or tidal waters or (2) the unusual and rapid accumulation or runoff of surface waters from any source.

Flood Boundary and Floodway Map (FBFM) (FEMA 2002) The floodplain management map issued by FEMA that depicts, based on detailed flood hazard analyses, the boundaries of the 1 percent annual chance (100 year) and the 0.2 percent annual chance (500 year) floodplains and, when appropriate, the regulatory floodway. The FBFM does not show flood insurance risk zones or BFEs.

Flood flow Frequency Curve (FEMA 2002) A graph showing the number of times per year on the average those floods of certain magnitudes are equaled or exceeded.

Flood Hazard Mapping Program (FEMA 2002) The program undertaken by FEMA to conduct FISs and prepare reports and maps delineating flood hazards in flood prone communities throughout the United States.

Fluvial Of or pertaining to or living in a stream or river; produced by river action, as in a fluvial plain.

GIS Geographic information system. An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies.

Hydraulic Computer Model (FEMA 2002) A computer program that uses flood discharge values and floodplain characteristic data to simulate flow conditions and determine flood elevations.

Hydraulic Methodology (FEMA 2002) Analytical methodology used for assessing the movement and behavior of floodwaters and determining flood elevations and regulatory floodway data.

Hydrograph (FEMA 2002) A graph showing stage, flow, velocity, or other properties of water with respect to time.

Hydrographic apex The head or highest point on an active alluvial fan. Note: This definition is consistent with the definition on p. 25 of National Research Council (1996).

Hydrologic Analysis (FEMA 2002) An engineering analysis of a flooding source carried out to establish peak flood discharges and their frequencies of occurrence.

Hydrology (FEMA 2002) The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground.

Imbricated Overlapping or shingling of pebbles in the watercourse(H. W. Hjalmarson).

Inactive Those locations where flooding, erosion, and/or deposition have not occurred on a landform such as an alluvial fan in relatively recent time, and probably will not occur on that part of the landform.

Inselburg A prominent isolated residual knob or hill partly buried by the debris derived from and overlapping its slopes(Hjalmarson and Kemna, 1993).

Interfluve The area between rivers; esp. the relatively undissected upland or ridge between two adjacent valleys containing streams flowing in the same general direction.

Isoline A line on a surface connecting points of equal value.

Lithology The description of rocks, esp. sedimentary clastics and esp. in hand specimen and in outcrop, on the basis of such characteristics as color, structures, mineralogic composition, and grain size.

Loam A rich, permeable soil composed of a friable mixture of relatively equal and moderate proportions of clay, silt, and sand particles, and usually containing organic matter (humus) with a minor amount of gravelly material. It has somewhat gritty feel yet is fairly smooth and slightly plastic. Loam may be of residual, fluvial, or eolian origin, and includes many loesses and many of the alluvial deposits of flood plains, alluvial fans, and deltas.

Loamy Said of a soil (such as a clay loam and a loamy sand) whose texture and properties are intermediate between a coarse-textured or sandy soil and a fine-textured or clayey soil.

Morphology The external structure form, and arrangement of rocks in relation to the development of landforms; the shape of the Earth's surface; geomorphology.

Pediment A broad, flat or gently sloping, rock-floored erosion surface or plain of low relief, typically developed by sub aerial agents (including running water) in an and or semiarid region at the base of an abrupt and receding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but more often partly mantled with a thin and discontinuous veneer of alluvium derived from the upland masses and in transit across the surface. The longitudinal profile of a pediment is normally slightly concave upward, and its outward form may resemble a *bajada* (which continues the forward inclination of a pediment).

Piedmont (adj .) Lying or formed at the base of a mountain or mountain range; e.g. a *Piedmont* terrace or a *piedmont* pediment. (n.) An area, plain, slope, glacier, or other feature at the base of a mountain; e.g. a foothill or a bajada.

Pixel (FEMA 2002) The smallest discrete element that makes up a digital image. (Short for "picture element".)

Ponding (FEMA 2002) The result of runoff or flows collecting in a depression that may have no outlet, subterranean outlets, rim outlets, or manmade outlets such as culverts or pumping stations.

Probability The quantification of risk.

Regulatory Floodway (FEMA 2002) A floodplain management tool that is the regulatory area defined as the channel of a stream, plus any adjacent floodplain areas, that must be kept free of encroachment so that the base flood discharge can be conveyed without increasing the BFEs more than a specified amount. The regulatory floodway is not an insurance rating factor.

Relict A landform that has survived decay or disintegration (such as an *erosion remnant)* or that has been left behind after the disappearance of the greater part of its substance (such as a *remnant island).*

Relief ratio The average slope of a drainage basin; the ratio of maximum relief to basin length.

Resolution 1. Resolution is the accuracy at which a given map scale can depict the location and shape of geographic features. The larger the map scale, the higher the possible resolution. As map scale decreases, resolution diminishes and feature boundaries must be smoothed, simplified, or not shown at all. For example, small areas may have to be represented as points.
2. Distance between sample points in a lattice.
3. Size of the smallest feature that can be represented in a surface.
4. The number of points in x and y in a grid or lattice (e.g., the resolution of a U.S. Geological Survey one-degree DEM is 1201 x 1201 mesh points).

Riverine Pertaining to or formed by a river. Situated or living along the banks of a river; e.g. a "riverine ore deposit."

Riverine Flooding (FEMA 2002) The over bank flooding of rivers and streams.

Rock varnish *See desert varnish.*

Scanning The process of capturing data in raster format with a device called a scanner. Some scanners also use software to convert raster data to vector data.

Scour (a) The powerful and concentrating clearing and digging action of flowing air or water, esp. the downward erosion by stream water in sweeping away mud and silt on the outside curve of a bend, or during time of flood. (b) A place in a stream bed swept (scoured) by running water, generally leaving a gravel bottom.

Sediment (FEMA 2002) Fragmental material that originates from the weathering of rocks and is transported by, suspended in, or deposited by water or air or is accumulated in beds by other natural occurrence.

Shallow Flooding (FEMA 2002) Unconfined flows over broad, relatively low relief areas, such as alluvial plains; intermittent flows in arid regions that have not developed a system of well defined channels; over bank flows that remain unconfined, such as on delta formations; overland flow in urban areas; and flows collecting in depressions to form ponding areas. For National Flood Insurance Program purposes, shallow flooding conditions are defined as flooding that is limited to 3.0 feet or less in depth where no defined channel exists.

Sheet flood A broad expanse of moving, storm-borne water that spreads as a thin, continuous, relatively uniform film over a large area in an arid region and that is not concentrated into well defined channels; its distance of flow is short and its duration is measured in minutes or hours. Sheet floods usually occur before runoff is sufficient to promote channel flow, or after a period of sudden and heavy rainfall. According to Hogg (1982) a sheet flood is simply a sheet of unconfined floodwater moving down a slope. This definition implies a sheet flood is less frequent than a sheet flow.

The Committee on alluvial fan flooding of the National Research Council (1996) was more specific when they defined sheet flood as "a broad expanse of moving, storm-borne water that spreads as a thin, continuous, relatively uniform film over a large area in an arid region and that is not concentrated into well defined channels; its distance of flow is short and its duration is measured in minutes or hours. Sheet floods usually occur before runoff is sufficient to promote channel flow, or after a period of sudden and heavy rainfall." An excellent description of sheet flooding on an alluvial fan in Colorado is given by Blair and McPherson (1994) suggests characteristics comparable to one of the earliest and most interesting documented sheet floods in southern Arizona (McGee, 1897). These definitions and descriptions generally compliment the definition and description of sheet flooding given in Arizona State Standard 4-95 (1995).

Sheet Flow An overland flow or down slope movement of water taking the form of a thin, continuous film over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills. Also, the more restrictive definition and characteristics given in Arizona State Standard 4-95 (1995) can be used for alluvial plains of piedmonts. This flow typically is short lived with a limited travel distance. Most surface runoff starts as overland flow and commonly enters rills before it concentrates in channels. Natural overland flow is characterized by several lateral down slope concentrations of flow rather than uniform sheet flow (Emmett, 1970). See *Sheet Runoff.*

Sheet Runoff (FEMA 2002) The broad, relatively unconfined down slope movement of water across sloping terrain that results from many sources, including intense rainfall and/or snowmelt, overflow from a channel that crosses a drainage divide, and overflow from a perched channel onto deltas or plains of lower elevation. Sheet runoff is typical in areas of low topographic relief and poorly established drainage systems. See *Sheet Flow.*

Slope A measure of change in surface value over distance, expressed in degrees or as a percentage. For example, a rise of 2 meters over a distance of 100 meters describes a 2% slope with an angle of 1.15. Mathematically, slope is referred to as the first derivative of the surface.

spatial analysis The process of modeling, examining, and interpreting model results. Spatial analysis is useful for evaluating suitability and capability, for estimating and predicting, and for interpreting and understanding. There are four traditional types of spatial analysis: 1) topological overlay and contiguity analysis, 2) surface analysis, 3) linear analysis, and 4) raster analysis.

Special Flood Hazard Area (SFHA) (FEMA 2002) The area delineated on a National Flood Insurance Program map as being subject to inundation by the base flood. SFHAs are determined using statistical analyses of records of river flow, storm tides, and rainfall; information obtained through consultation with a community; floodplain topographic surveys; and hydrologic and hydraulic analyses.

Stable The relative state of the location, geometry and roughness of a channel, network of channels or landform where any changes of location, geometry and roughness can be set aside in realistic assessments of flood risk.

Stratigraphy (a) The branch of geology that deals with the definition and description of major and minor natural divisions of rocks (mainly sedimentary, but not excluding igneous and metamorphic) available for study in outcrop or from subsurface, and with the interpretation of their significance in geologic history: It involves interpretation of features of rock strata in terms of their origin, occurrence, environment, thickness, lithology, composition, fossil content, age, history, paleogeographic conditions, relation to organic evolution, and relation to other geologic concepts. (b) The arrangement of strata, esp. as to geographic position and chronological order of sequence.

Swale (a) A slight depression, sometimes swampy, in the midst of generally level land. (b) A shallow depression in an undulating ground moraine due to uneven glacial deposition. (c) A long, narrow, generally shallow, trough-like depression between two beach ridges, and aligned roughly parallel to the coastline.

Throughflow streams Are streams that head in the mountains and cross piedmonts to base level streams or to depositional landforms on lower piedmont slopes (H. W. Hjalmarson).

Topographic apex The highest point on an alluvial fan and some granite pediments in Maricopa County where flow is last confined.

Translatory wave A gravity wave that propagates in an open channel and results in appreciable displacement of the water in a direction parallel to the flow.

Uncertain distribution of flow Means that the distribution of flow at channel splits (forks) is not precisely known because the channel geometry may change with time and because of hydraulic model limitations such as common assumptions of steady flow or a horizontal water level above the split (H. W. Hjalmarson).

Uncertain flow path Means that the perceived, historical channel or network of channels cannot be relied on to convey the base flood without the creation of new flow paths or the abandonment of existing flow paths.

Unstable The relative state of the location, geometry and roughness of a channel, network of channels or landform where any changes of location, geometry and roughness cannot be set aside in realistic assessments of flood risk.

Wash (a) A term applied in the western U.S. (esp. in the and semiarid regions of the south west) to the broad, shallow, gravelly or stony, normally dry bed of an intermittent or ephemeral stream, often situated at the bottom of a canyon; it is occasionally filled by a torrent of water. (b) Loose or eroded surface material (such as gravel, sand, silt) collected, transported, and deposited by running water, as on the lower slopes of a mountain range, esp. coarse alluvium.

Watershed (FEMA 2002) An area of land that drains into a single outlet and is separated from other drainage basins by a divide.

Water Surface Elevations (WSELs) (FEMA 2002) The heights of floods of various magnitudes and frequencies in the floodplains of coastal or riverine areas, in relation to a specified vertical datum.

Wave Height (FEMA 2002) Vertical distance between the wave crest and the wave trough.

Wave Runup (FEMA 2002) Rush of wave water up a slope or bank.

8

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Appendix A. General features of piedmont alluvial fans and streams and rivers.

Nearly all streams draining desert mountains above piedmonts in Maricopa County flow only in direct response to rainfall. Desert floods on piedmonts result from large amounts of intense thunderstorm rainfall in the steep headwater areas. When this happens, the normally dry channels can suddenly host dangerous, debris-laden torrents. Typical floods are characterized by a rapid rise and cessation of discharge that are dramatically referred to as flash floods. Piedmont streams typically flow only a few hours each year.

Mountainous areas upslope of the piedmont plains typically have V-shaped valleys that are well drained and composed mostly of bedrock and colluvium. The stream channels are typically steep, scoured, and rocky. The flood plain is narrow or nonexistent. The system of stream channels in the mountains is tributary, and the peak discharge of large floods typically increases as the drainage area increases.

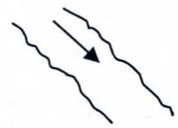
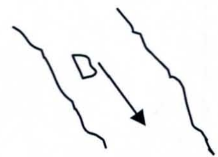
Piedmont plains are transition areas between mountains and base-level plains. A piedmont plain consists of pediments, alluvial fans, or relict fans. The lower part of the piedmont transitions to an alluvial plain. A pediment is an erosional surface cut on rock and usually covered with a thin layer of alluvium. The upper elevation limit of a pediment is commonly at the mountain front. Alluvial fans are composed of material deposited by streams typically emerging from mountains or pediments; thus, the upper elevation limit of alluvial fans may be at the mountain front or at the lower part of a pediment. Alluvial fans are active where stream deposition is common and stream systems are distributary and braided appearing. Alluvial fans are inactive where stream deposition is less common and most stream systems are tributary. Thus, active fans are wholly or partly depositional surfaces, and inactive fans are mostly erosional surfaces.

Flood flow on pediments and relict fans commonly is confined to tributary channels separated by stable ridges that are above the level of large floods. Flood flow on active alluvial fans commonly is unconfined in a distributary system of small channels separated by low and unstable ridges that are often overtopped during large floods. The size and location of channels on active fans can change during flooding.

Desert floods in rivers of base level streams are in direct response to rainfall or snowmelt. Typical streams in base-level alluvial valleys have a defined main channel with an adjacent flood plain. During large floods, floodwater may spill over the banks of the main channel onto the flood plain. Flood discharge can be decreased by infiltration as the flood wave moves downstream over sandy alluvial channels. Large amounts of debris are carried down the channels, and the shapes of the channels generally change during flooding. Channels scour and fill during flooding, and channel banks wetted by floodwater often collapse after flooding.

Important general features of piedmont alluvial fans and streams and base-level streams are summarized in Table A1.

Table A1. General features of alluvial fans, streams and base-level streams

FEATURE	ALLUVIAL FAN		STREAM		BASE-LEVEL STREAM
	Active	Inactive	Unstable	Stable	
Plan view shape					
Radial length	<1 to 10 miles		<1 to 20 miles		5 to >100 miles
Cross profile					
Geomorphic setting	Piedmont		Piedmont		Valley
Aggrading?	Yes	No	Yes	No	No
Propensity for unconfined flows	High	Moderate	Low	Low	Low
Flood plains present?	No	Few	Yes	Yes	Yes
Radial slope	1.5° to 25°	1° to 5°	0.5° to 5°		< 1°
Typical sediment mode	Sand to Boulders. Angular.	Sand to Cobbles. Angular.	Sand to Cobbles with some Silt and Boulders. Some rounding.		Silt to Cobbles with some Clay and Boulders. Rounded.
Relative basin size	Very small to small	Small to moderate	Small to moderate		Moderate to large
Sediment gravity flows?	Common	Some	Occasional		Rare
Increasing water discharge down slope?	No	Maybe	Yes	Yes	Yes
Flood flow velocity supercritical?	Yes	Maybe	Maybe		Yes in main channel for larger floods. Maybe for small floods.
Unstable flood flow?	Yes where slope is >3°		Yes where slope is >3°		No

Appendix B. Perspectives of engineers and geomorphologists

It is perfectly consistent to be unsure and recognize that perhaps another method will produce reliable results and guide development away from hazardous areas.

The following three issues related to floodplain management and this manual are discussed in this appendix:

- Manning n versus surface texture.
- The 0.01 probability flood.
- Structural and non-structural perspectives for mitigation.

Manning n versus surface texture

The estimate of Manning roughness for natural channels is a fundamental part of the traditional engineering methods of producing FEMA flood boundary maps. The selection of the roughness coefficient is an art that requires familiarity with the geometry and roughness features of the stream channel. Criteria for the selection of roughness coefficients are described in several hydraulics texts. Several publications also provide photographs and details on channel geometry for many types of channel where the Manning n was verified. Clearly, the location of the resulting flood boundaries is directly dependent of the estimate of Manning n that is an art.

The use of surface textures and tones from visual interpretation of aerial photographs is an important part of determining landform type and also the type of flood hazard. In a manner similar to the estimate of Manning n, an estimate of landform type or flood hazard is made based on experience. The characteristics of surface features have been published in a few geomorphology reports and in this Manual.

It is important to recognize that both the estimated value of Manning n and the location of the boundary of a particular type of flood hazard are uncertain. Both estimates are dependent on the experience of the engineer or geologist.

The 0.01 probability flood

The three-stage geomorphologic assessment of this Manual generally is concerned with relatively short spans of time of decades to a few hundred years (the historic period). It is not concerned with how the mountains were formed or whether relict alluvial fans were formed 1 or 10 million years ago because these issues concern periods of time beyond the scope of present and projected flood hazards. It is important, however, to distinguish among the three basic materials--bedrock, relict valley fill deposits and recent fluvial deposits--because whether an area is unstable or stable depends largely on the underlying rock and sediments.

FEMA has concluded that the law requires the purchase of flood insurance in areas subject to floods that can reasonably be determined as 1%-annual-chance flood events. We've agreed to use the 0.01 probability flood as the regulatory flood. The traditional means of using the 100-year flood is to first define the 100-year peak discharge using flood-frequency methods. We then define the geometry and roughness coefficients along the stream and compute water level profiles along the stream using a standard-step model such as HECRAS. We engineers transfer these estimated flood elevations to maps. This is the traditional engineering approach of producing FEMA flood boundary maps.

The difference in the engineering and geomorphologic approaches in the use of the 100-year peak discharge is significant. For example, the typical engineer must have a value of the peak discharge for the 0.01 probability flood to run the standard step model and produce flood boundaries in accordance with traditional riverine methods. On the other hand, the geomorphologist does not need a value of the 0.01 probability flood to define flood limits of geologically recent floods. The geomorphologist examines recent deposits to define the water level boundary, profile and/or discharge. It is important to note that the geomorphic approach does not rely on stable flow path geometry. Thus, the geomorphic approach becomes more useful as the amount of landform instability increases. For arid piedmont areas like Maricopa County where many streams have years with no flow and some landforms are unstable, the use of probability distributions may be invalid (Hjalmarson and Thomas, 1992) and the use of fixed geometry methods to define flood limits may also introduce great error.

Perhaps the greatest difference in the perspectives and concerns of engineers and geomorphologists is the span of time of interest. Engineers typically are concerned with the present, near past and near future while geologists and geomorphologists are additionally interested in the far past and far future (Schumm, 1991). Except for problems such as hazardous waste, engineers commonly are concerned with conditions for the next 50 to perhaps few hundred years while the geologist commonly is interested in the past millions of years. This problem is being overcome as more engineering prediction is being accomplished using earth science information.

This manual is concerned primarily with the regulatory or base flood with a recurrence interval of 100-years. To approach this end, time scales up to about 10,000 to 15,000 years that represent the Holocene geologic epoch may be used. For the short term, old maps and aerial photographs may be available to provide a good historical record that can be used to predict for decades. For the long term, soil development, desert pavement and desert varnish may be used. For intermediate spans of time, empirical relations can be used to predict the direction of change and, to a lesser degree, the magnitude of change. These are generally statistical or threshold relations between, for example, channel morphology and some independent variable such as discharge. The resulting relations can be used in an attempt to predict stream response to altered conditions for decades and perhaps centuries. Because it may not be practical to precisely use a 0.01 probability for flood regulation, evidence of inundation, sedimentation and channel movement may span longer periods, and therefore the probabilities will be smaller, to be conservative on the side of caution as discussed previously.

Structural and non-structural perspectives for mitigation

Identification of unstable channels and flow paths can be viewed from both structural and non-structural perspectives for mitigation. The structural advocate might recommend that there is no need to identify unstable flow paths in favor of "total" structural control of an incised channel or an unstable alluvial fan. On the other hand, because the unstable channel and changing flow paths are part of a *fluvial* system in a state of quasi-equilibrium that can be quantified, the non-structural advocate might recommend avoidance or "setback" and no effort to stabilize the channel or flow paths. The limited-time approach may use costly structures while the unlimited time approach may be in direct conflict with land use and development pressures. This manual attempts to identify the nature of piedmont flood hazards to enable an enlightened or compromise approach to land development and use between these diverse positions.

Some engineers, geomorphologists and flood plain managers share a biased perception of floods on piedmonts such as *alluvial fan flooding* because the term conjures up images of debris flows, loss of life and destruction of property. Attention has been on the published accounts of spectacular sediment and flow dynamics over a few minutes and hours at the expense of less dramatic (longer time span) processes and landform conditions. Unbiased estimates of future flood hazards should consider several factors of process dynamics (Schumm, 1991) such as the rate of basin (source) debris accumulation, debris-flow potential and the redistribution of deposited sediment by local rainfall.

Baker (1994) described extreme stereotype positions on flood hazard definition held by engineers and geomorphologists. Baker points out that because flood damages continue to rise the effectiveness of conventional flood science that uses idealized mathematical models and theoretical generalization of flood frequency is doubtful. He points out that the models should be calibrated using geologic and hydrologic data. A geomorphologic approach to understanding floods uses indices of real processes that are recorded in sediments and landforms. Baker concludes that geomorphic flood hazard analysis provides insight to understanding the problem.

The use of geomorphic evidence of past floods to predict the future flood hazard is analogous to the use of streamflow gage data to estimate the 0.01 probability flood. A probability distribution typically is fitted to past annual peak discharge data at a streamflow gage and this flood frequency relation is used to estimate the magnitude of the 100-year flood that is then used to define the flood boundaries. In a like manner, the geomorphic evidence of past floods such as sediment deposition, surface texture, channel bank erosion and particle rounding and sorting is used to predict the nature and location of future floods. Thus, both the engineering and geomorphologic approaches use past information to make predictions.

Summary.--The above diverse methods and viewpoints can be used together to produce a better definition of the true flood hazard. The geomorphic approach can be used to compliment the conventional engineering approach that uses idealized but consistent models such as HEC-1, HEC-RAS and flood frequency methods outlined in Bulletin 17B (U. S. Water Resources Council, 1981). Thus, the engineering and geomorphic approaches are complementary and more effective when used together.

An example of the application of both approaches in the City of Fort Collins, CO is given by Grimm (1996).

Appendix C. Additional photographs of piedmont landforms in Maricopa County.

A few additional photographs of relict fans, pediments, alluvial fans and alluvial plains are shown in this appendix. For a complete description of piedmont landforms see Chapter 2 of this Manual.

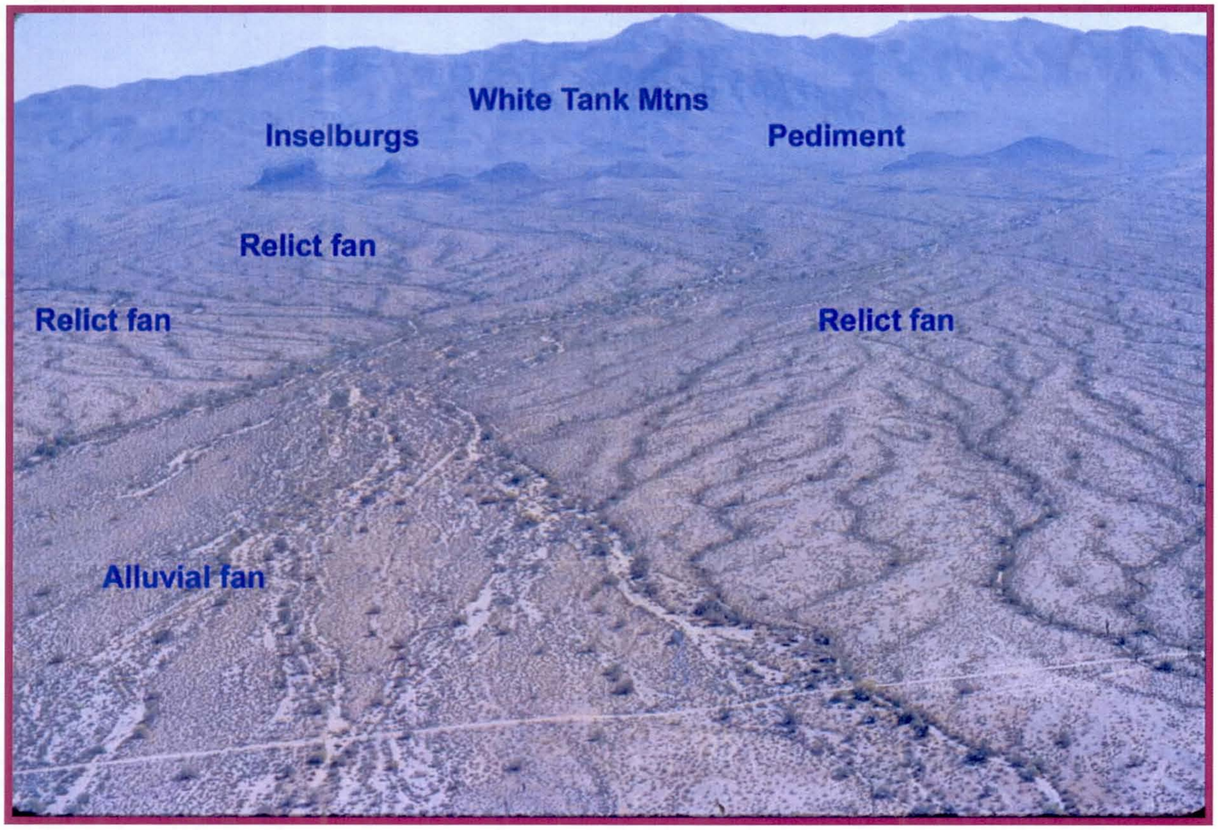


Figure C1. View looking east at west slope of the White Tank Mountains. This is site 39 (secs. 3 & 4, T. 2 N., R. 4 W.) of USGS WRI 91-4171 and WRI 93-4169.

The above photograph (Figure C1) shows a variety of landform features within a relatively small geographic area. The investigator is invited to make comparisons of the shapes, surface texture, tributary and distributary drainage patterns and relative sizes of the landforms.

The photograph on the following page (Figure C2) also shows a variety of landform features within another relatively small geographic area. The dark appearing surfaces that take hundreds to thousands of years to form on varnished rocks are easily seen on the color infrared aerial photograph. The lighter surfaces of recent deposits on unoxidized sand, gravel and boulders commonly delineate active alluvial fans. Desert varnish on stable stones of large relict fan surfaces are a reliable indication of the absence of significant flood flow during the past few thousand years.

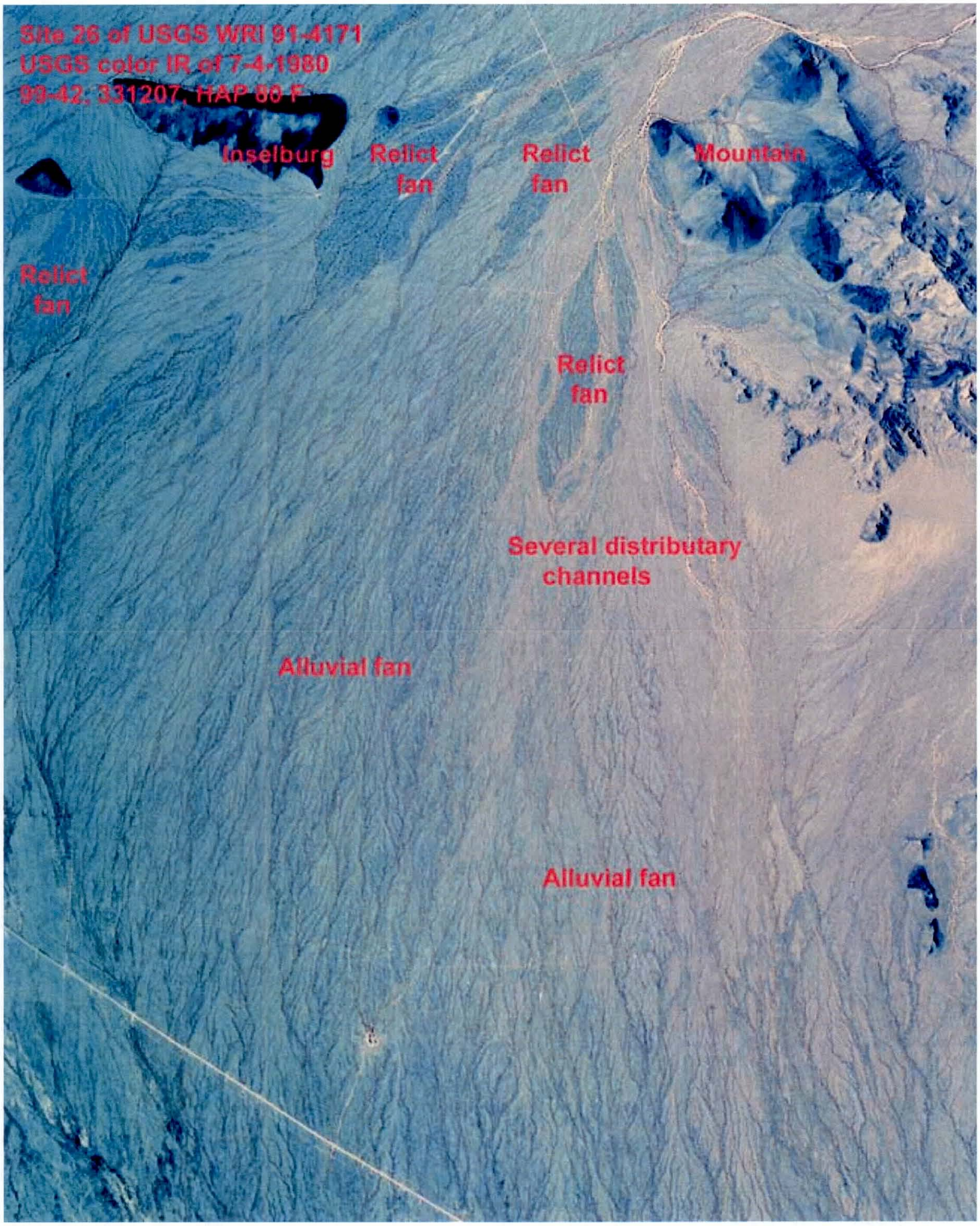


Figure C2. Color infrared aerial photograph of USGS site 26 showing relict fans, alluvial fan and alluvial plain. (Apex in sec. 3, T. 3 N., R. 9 W.)

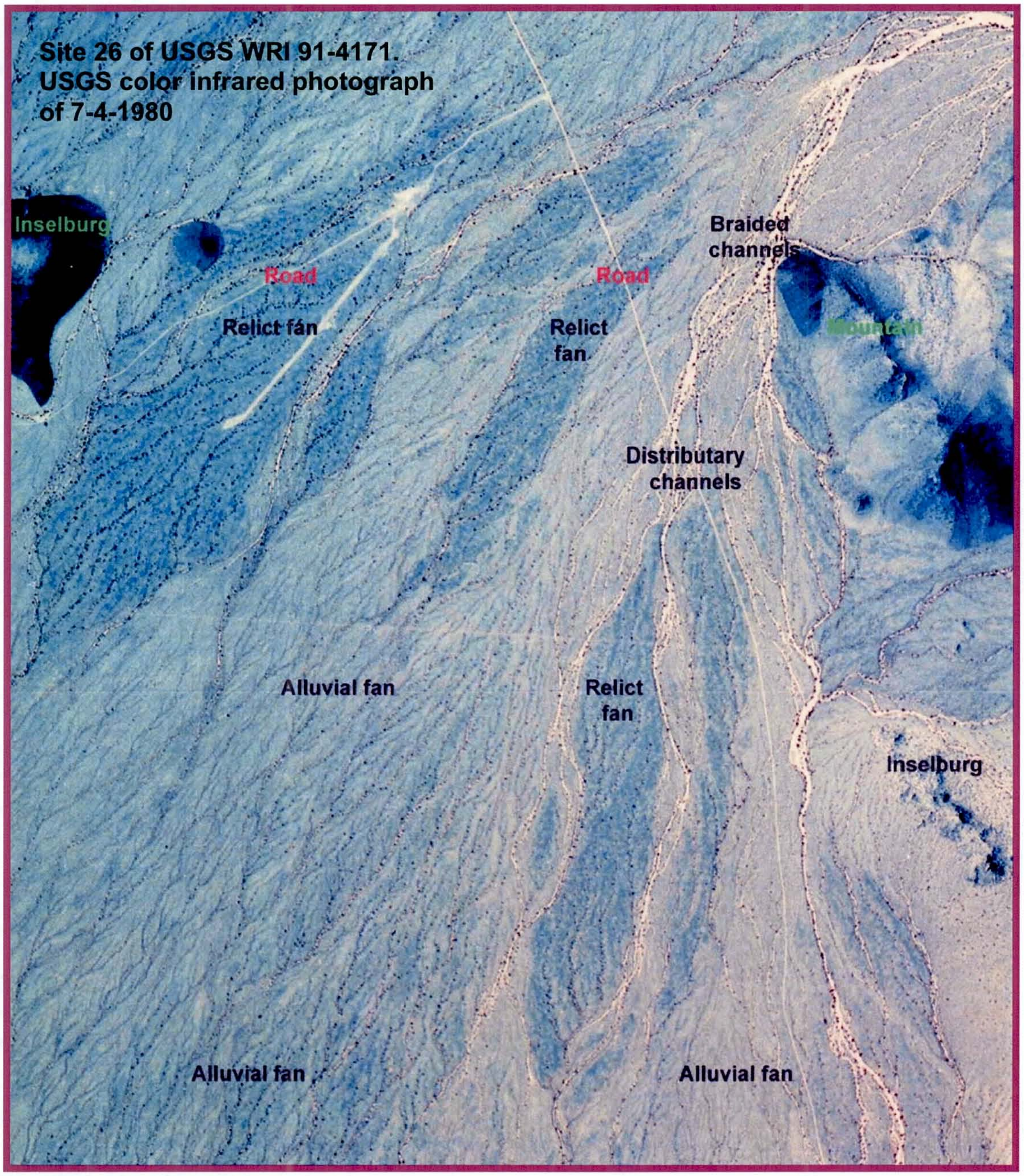


Figure C3. Detail of relict fan and distributary channel area of site 26. (Apex at upper right of scene is in sec. 3, T. 3 N., 9 W.)

The dark color of the relict fans (Figure C3) is from a dense layer of desert pavement and desert varnish. The lighter colored part of the alluvial fan has several distributary stream channels. The darker colored part of the alluvial fan has tributary stream channels. Also note the differences in surface texture of the landforms.

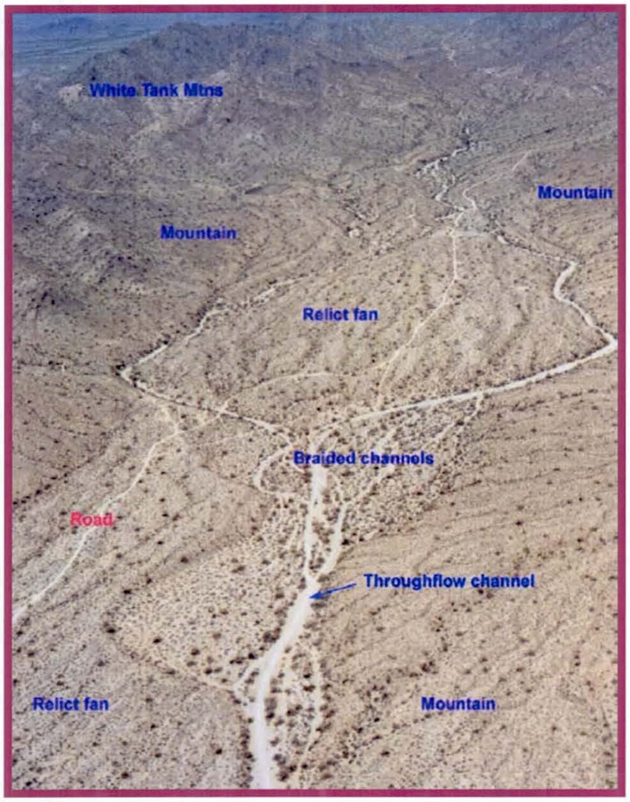


Figure C4. Braided channels

The small area of braided channels in the photograph to the left (Figure C4) is within the drainage basin of the Skyline Wash site. Braided channels like those in the photo are an interlacing or tangled network of several small branching and reuniting shallow channels separated from each other by branch islands or channel bars. These braided channels commonly appear to be part of a single channel and in plan appear to be strands of a complex braid (Bates and Jackson, 1980, p. 79).

This "pocket" of braided channels should not be confused with the distributary channels of an inactive alluvial fan where the stable interfluves are above the channels.

Appendix D. Drainage texture

Drainage texture is the relative spacing of drainage ways (rills, swales, washes, etc.). Much of the surface texture (Appendix E) is the result of drainage texture. Differences in drainage texture are related to the underlying types of geologic material and the types of landform. A technique of quantifying drainage texture using measurements of contour crenulations on USGS 7-1/2 minute topographic maps is described in this Appendix.

Drainage texture is a quantitative means of defining surface texture using the spacing of low order drainage channels as depicted by the crenulation count on contours of USGS 7.5-minute topographic maps. The use of drainage texture has advantages over the visual based surface texture technique because drainage texture can be defined with little experience. The user does not need to become acquainted with the appearance of the landforms on maps and photographs.

Relative drainage texture domains depicted by contour-crenulation counts (small rounded upslope projection of a contour line) provide excellent clues to the type of landform (Hjalmarson and Kemna, 1991). Drainage texture is measured as the number of low-order drainage channels (crenulations) along uniform widths of contour lines on topographic maps (See example in Figure D1a). The spacing of low order drainage channels is depicted by the crenulation count on contours of USGS 7.5-minute topographic maps. The drainage texture can be used to distinguish relict fans, pediments and inactive alluvial fans as shown in Figure D1b.

Old alluvial fans have a characteristic drainage texture that differs from the drainage texture of other landforms. A marked change in the drainage texture occurs between pediments and old alluvial fans. There is also a marked change in the drainage texture between old alluvial fans and relict fans (Doehring (1970 and 1971) and Hjalmarson and Kemna (1991))...

Drainage texture is determined as follows:

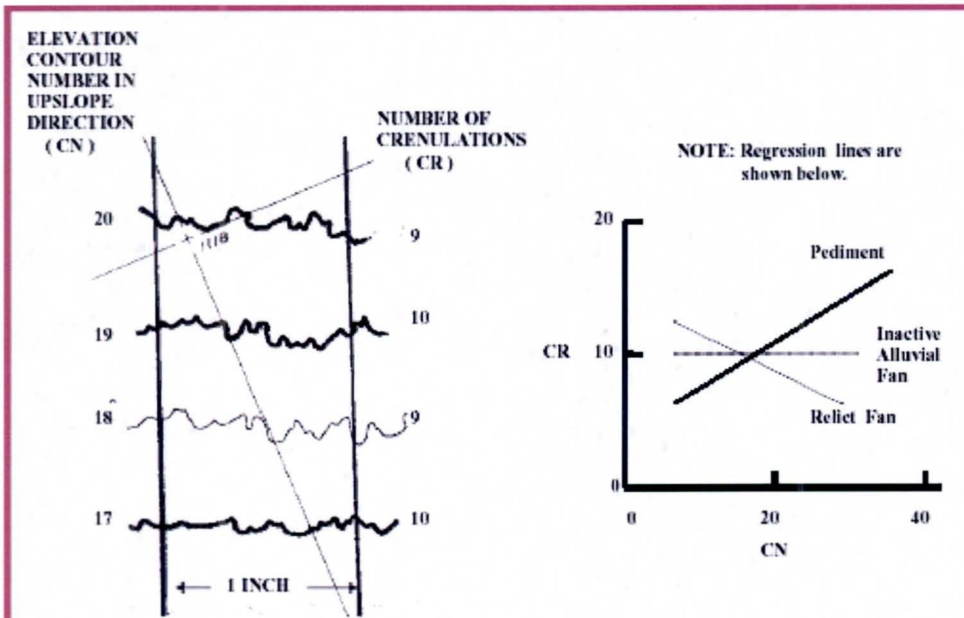
(1) Draw 1-inch-wide transects approximately normal to the trend of at least 10 consecutive contour lines on 7.5-minute topographic maps,

(2) note that contour crenulations are not uniformly mapped on all 7.5-minute topographic maps and therefore transects should be on single maps if adjustments for differences between maps are to be avoided,

(3) number the contours starting with the most down slope contour,

(4) count the number of contour crenulations for each contour,

(5) plot and evaluate a relation between the number of crenulations and the contour number.



a) Elevation contours along 1-inch wide strip drawn on topographic map.

b) Drainage texture relations from statistical regression.

Figure D1. Drainage texture and drainage texture relations for relict fans, pediments and inactive alluvial fans (from Hjalmarson and Kemna, 1991).

Drainage texture is a useful indicator of the boundary between some pediments and inactive alluvial fans with distributary channels. The drainage texture of inactive alluvial fans with distributary channels is rather constant and the drainage texture of pediment increases upslope. The boundary is in the transitional zone between the inactive alluvial fan and the upslope pediment.

The difference in the drainage texture of relict fans and pediments has an effect on the overland flow elements of HEC-RAS and slope lengths of TR-55 and RUSLE. Another difference is some old alluvial fans and relict fans, unlike most pediments, have broad rather smooth areas with little tributary channel incision between throughflow channels.

Appendix E. Surface texture and photographs and maps

Surface texture is the appearance (visual spatial surface characteristics) of the land surface when viewed from an aircraft, on a topographic map or on an aerial photo image. Much of the texture is the result of the surface geology, in particular the permeability of the soil and mantle rock, and fluvial processes that can be observed in the arid environment where vegetation does not obscure the surface drainage features. However, some of the texture is the result of vegetation type and density and these features can also be related to fluvial processes. We have learned to use surface texture as a tool for estimating the type of landform, the type of drainage pattern and the type and degree of flood hazard.

Much of the surface texture we are looking at is influenced by surface roughness or irregularities of geometry. Surface roughness is the second derivative of an elevation map and surface slope is the first derivative. We see texture associated with changes in the land slope (roughness) rather than the land slope itself. However, surface slope influences texture by influencing the formation of drainage ways. The permeability of the mantle rock and fluvial processes that caused the surface roughness commonly produced visible patterns or the texture.

There are two objectives of this appendix.

- To briefly provide information about the use of film and digital photographs and topographic maps.

- To supplement descriptive information related to surface texture of landform types and associated fluvial processes.

Surface characteristics or features are used to separate distinguishable things such as vegetation cover and drainage patterns into categories such as type of landform or active and inactive surfaces. Visual characteristics typically are gleaned from aerial photos and related to direct field observation and measurement. The texture of a landform is the aggregate of distinctive qualities observed on aerial photos and topographic maps and measured in the field. Generally speaking, aerial photos are more effective for identifying landforms and types of flood hazard because drainage ways, ridges, recent sediment movement and vegetation are easily seen. We are looking at the grain of spatial variation of the land cover (surface features) on the landform.

Textural analysis is typically performed by acquiring photographs and topographic maps, interpreting the photos using surface texture and shades and marking landform boundaries, field checking the landforms and boundaries and integrate the interpretation by showing the landforms, flood hazard zones, flow path changes, etc on a rectified base map and accompany this mapping with a discussion. Traditional analysis is the visual interpretation of film photographs using stereoscopes and lenses or the interpretation of paper topographic maps based on years of experience and insight.

We've learned by field inspection that landforms and drainage networks have distinctive image patterns or texture. Digital photography, GIS mapping, spectral remote sensing and digital image enhancement are changing how we perform textural analysis. This manual recognizes that our traditional map analysis procedures are changing but focuses on the visual interpretation of film and digital photographs.

The selection of the photographs and maps and the type of textural analysis is dependent on the particular application. Use of the best practical technology for texture analysis at a particular site is strongly encouraged.

E1. Photographs and maps

A few important factors related to surface texture of landforms and channel networks and changes in channel networks in Maricopa County are:

- Base maps and rectification of aerial photographs
- Photograph or map scale
- Resolution of the aerial photographs
- Image type
- Image differences

Base maps and rectification of aerial photographs

Rectified photographs are preferred but not necessary providing the features and boundaries are transferred to a rectified base map. A USGS Digital Orthophoto, map scale 1:24,000, is the minimum base map standard for the FIRM because these maps are geographically referenced, positionally accurate, reproducible, and inclusive of the necessary features and attributes that make maps useful documents for floodplain management.

Photograph and map scale

Landforms typically are identifiable on good quality aerial photographs at 1:100,000 to 1: 5,000 scale with the USGS scale of 1:24,000 for the 7.5 minute quadrangle series being optimal for most purposes. Smaller landforms such as inset alluvial fans may be best examined at 1:5,000 scale. Larger landforms such as relict fans along a mountain front might best be viewed at a much smaller scale. Large scales may be a reasonable for identifying channel movement, channel formation and smaller landforms (small inset fans?) that might be "absorbed" in pixels or fuzzy resolution at the smaller scales. The ideal scale to view surface texture is also related to the experience and judgement of the engineer. The engineer should be able to draw landform and hazard boundaries on the aerial photograph.

Multiple map scales should be considered depending on the objective of the engineer. At a small scale details of smaller objects are not observed. At a large scale details of larger objects might be difficult to see because only part of the object is seen. At a small scale much more of an object can be seen. Thus, the task of selecting the optimal scale to view surface texture of features of varying size can be simplified by using two or more map scales.

The optimal map scale for the FIRM may differ from the optimal scale for landform and hazard identification. For example, a base map at 1"=200 ft (1:2400) might be used by a land developer to show lot boundaries, streets and so forth. Where smaller scale photographs or maps are used for landform or flood hazard identification, the boundaries should be transferred to the smaller scale base map. Manual rectification using fixed landmarks may be necessary to transfer unrectified information from the smaller scale photographs to the base maps.

All mapping should be field checked.

Resolution of aerial photographs

The optimal resolution for landform or flood hazard identification is related to the size, shape and shading of the surface features of interest. Resolution is the accuracy at which a given map or photograph scale (or pixel size) can depict the shape and location of the geographic features. Generally speaking, greater resolution is possible on larger scale (or smaller pixels) maps and photographs. Scale involves the resolution at which an object is viewed. The most useful resolution or scale is related to the "texel grid" or size, shape and shading of the surface features we are looking at.

Generally speaking, images of the USGS and NRCS at the map scales previously discussed are useful for both present and historic time periods.

Resolution should be sufficient to capture the changes in shading across the land surface. Shading is related to surface geology and changes in elevation. Small stream channels, of a few feet wide, where sediment is actively transported typically are a lighter shade than the surrounding land surface. Undulating elevation changes across the piedmont surface produce patterns of shading distinctive of particular landforms. Therefore, the resolution should depict the surface roughness (second derivative of an elevation map) and surface shading (second derivative of shading) of the landforms.

Digitized images have a break even point between scanning resolution and cost or ease of handling the data volume. Pixels greater than 20 to 30 ft. typically are to large and require extensive field verification. Low resolution (large pixels) results in the jagged appearance of the raster images. There is no absolute or best smaller pixel size but generally speaking, higher resolution produces higher quality images. Pixels of about one ft result in large volumes of data that can be cumbersome for present computers to use for large areas. A pixel size of 5 to 10 ft generally is useful for landform and hazard identification using present technology. However, greater resolution may produce useful information and thereby reduce the amount of field verification.

The optimal resolution varies partly because the contacts between landforms and hazards zones vary from gradational to sharp. The contact between the toe of an active alluvial fan and an alluvial plain typically is fuzzy and wide. Conversely, the contact between a pediment and inset alluvial fan is very sharp. Judgment based on experience with desert landforms is needed to efficiently map the landforms and flood hazards. Traditional mapping is based on ground observation, which serves to establish the surface characteristics, and photo-interpretation based on the sharpness of the contacts observed in the field.

Image type

Black and white glossy photographs of the USGS and NRCS, or comparable quality, are traditionally used because they have good spatial detail. Color infra red film photographs are useful for distinguishing transpiring vegetation and light and dark tones associated with loose sand, desert pavement and desert varnish. Digital photographs are becoming more and more useful as we learn about image enhancement and computer pattern-recognition capabilities. As stated previously, this manual uses visual interpretation of film and digital images but automated analysis in GIS is encouraged if the capabilities are available.

Image type is an important consideration for detection of channel change. Land surface and cover change involves both gradual and sudden change in channel movement and vegetation cover. For example, recent research using digital photographs has produced spectacular color enhanced computer generated maps of changes in surface material resulting from floods.

Image differences

Images of the same area taken at different times are different. The clarity and shading of the patterns associated with surface roughness and surface material are affected by the camera angle and the position of the sun when the aerial photographs were taken. Viewing angles and sun angles affect tone contrast.

When flow path and land cover changes are examined by comparison of multidate images, it is important to remember that the images have different reflectance values. The images should be normalized by either mental or computer enhancement to make the appearance of the unchanged areas the same.

E2. Surface texture of landforms at sites in Maricopa County

The three sample sites of this User's Manual are used to demonstrate the surface texture associated with braided channels, active alluvial fans, inactive alluvial fans and relict fans. The appearance of the spatial surface characteristics is the direct result of drainage channel patterns, relief and relief patterns, surface roughness, surface material such as sand deposits from sheet flow and vegetation type, density and distribution. Many hydrologists and engineers are familiar with the hydraulic significance of river channel patterns such as meandering and braided. Like these two kinds of river patterns, patterns on piedmont surfaces also have useful characteristics. The significant landforms and surface texture at the three sites follows:

Relict fans

Both the Skyline Wash (Figures E1A – E1D) and White Tank Park (Figures E3A – E3C) sites have large relict fan areas. The relict fans of Skyline Wash are along the sides of an active alluvial fan and abut mountain slopes. The relict fan area of the White Tank Park site is on the lower slopes of an inactive alluvial fan. Thus, the position on the piedmont of the relict fans at the two sites is different. However, the surface texture of the relict fans at both sites is similar. Also, the surface texture of nearly all relict fans in Maricopa County is similar.

Inactive alluvial fans

The White Tank Park and South Mountain Park (Figures E2A and E2B) sites have two great examples of inactive alluvial fans. The inactive alluvial fan at the White Tank Park site is below the topographic apex, is bounded by mountain slopes, and forms the entire upslope part of the site. The inactive alluvial fan, that is the major landform at the White Tank Park site, loses its shape on the lower slopes that are classed as relict fan areas. The inactive alluvial fan of the South Mountain Park site is along the north side of an active alluvial fan and is bounded by mountain slopes on the north side. The two inactive alluvial fans are at slightly different positions on the piedmont and have similar surface features including similar surface texture.

Active alluvial fans

There is a rather large active alluvial fan at the Skyline Wash site and a small active alluvial fan at the South Mountain Park site. The fan at the South Mountain Park site is composed of a mound of angular silt, sand, cobbles and small boulders. The mound of alluvium can be viewed in the field by walking around and across the alluvial fan. The Skyline Wash active alluvial fan is less mounded but also has considerable angular silt, sand, cobbles and small boulders. The fresh sandy alluvium of the Skyline alluvial fan can be viewed by both walking and driving across the fan and along the several distributary channels. Both fans have flow paths that divide and join with low banks and wide beds. Both active alluvial fans also have scattered trees below the hydrographic apices that become increasingly aligned along defined channels down slope. The surface texture of both active alluvial fans is similar.

Alluvial plains

The rather smooth appearance of alluvial plains is shown in the background of Figure 3.9 and in several figures of Appendix G.

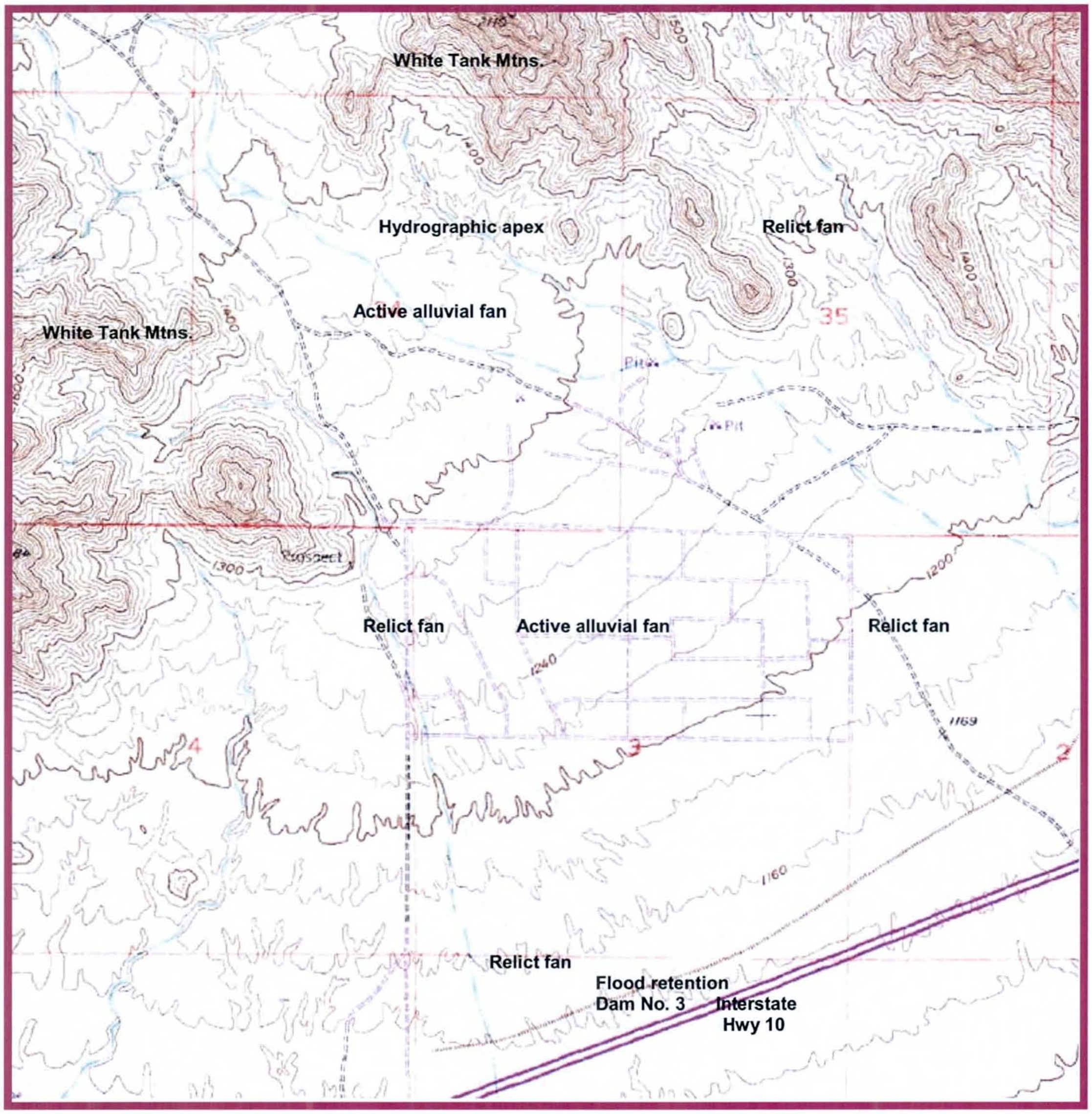


Figure E1A. Topographic map of Skyline Wash alluvial fan

The appearance of the contour crenulations is related to the type of landform.

Relict fans: The relict fans are old with rather deep valleys (small channels) and the ridges between the valleys are rounded and rather parallel. The crenulations typically are distinct and rounded with an alternating ridge-valley-ridge-valley appearance. Refer to Figure 2.2, 2.3 and 2.4.

Active alluvial fans: The crenulations are relatively small and wide suggesting wide channels with low banks as shown in Figure 2.2.

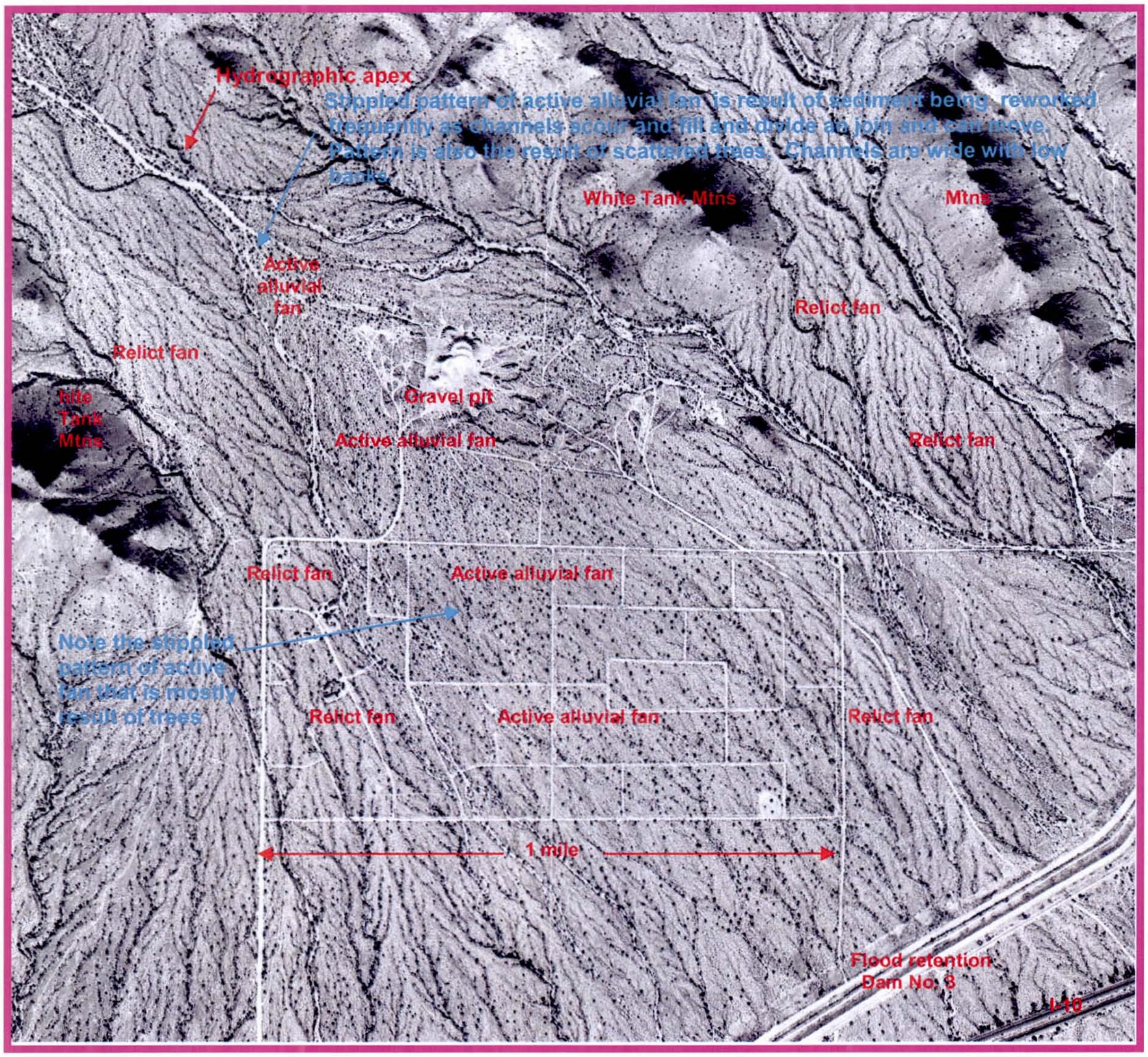


Figure E1B. Aerial photograph of Skyline Wash alluvial fan

The spatial surface characteristics are the direct result of large- and small-scale drainage patterns, surface roughness, surface material such as sand deposits from sheet flow and vegetation type, density and distribution and the relief of the terrain. For example, the hill sides of the relict fan areas in the above photograph are cut into numerous short noses or longer spurs by side slope drainage ways and short side valleys. These in turn are cut by yet smaller drainage ways and rills. Also, the grainy like speckled pattern on the relict fan is associated with the trees along the drainage ways.

Figure E1C. Oblique aerial photograph of Skyline Wash alluvial fan

The above rather smooth ridge-valley texture of the relict fan areas on the sides of the active alluvial fan is from a long period of erosion that produces that produces the undulating ridge-valley pattern with smooth ridges and valleys. Note the lines of trees along the stable valleys. The shading along the side slopes of the ridges is related to the sun angle when the photo was taken.

The above active alluvial fan has a salt-pepper stippled pattern below the hydrographic apex. The pattern gradually changes in the foreground to more of a ridge-valley pattern where trees tend to be along the channels. This changing pattern indicates there is less flow path movement in the lower part of the active alluvial fan.

A color infrared aerial photograph of the Skyline Wash site on the following page shows the active alluvial fan with distributary and braided channels (Figure E1D). The light colored area of braided channels is the result of recent sand movement. The reddish-brown speckles are Palo Verde and Mesquite trees that are alive and transpiring.

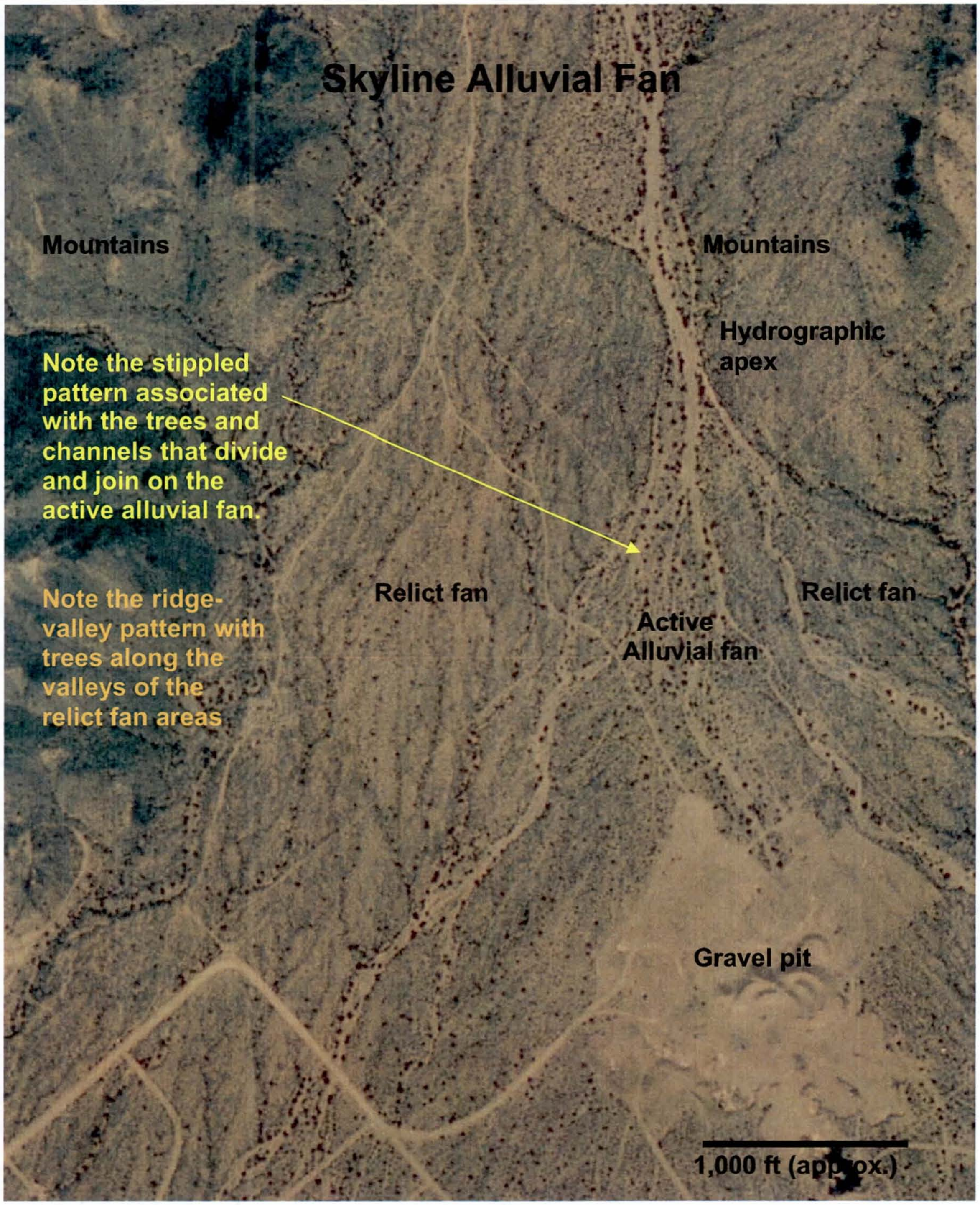


Figure E1D. Color infrared aerial photograph of Skyline Wash site.

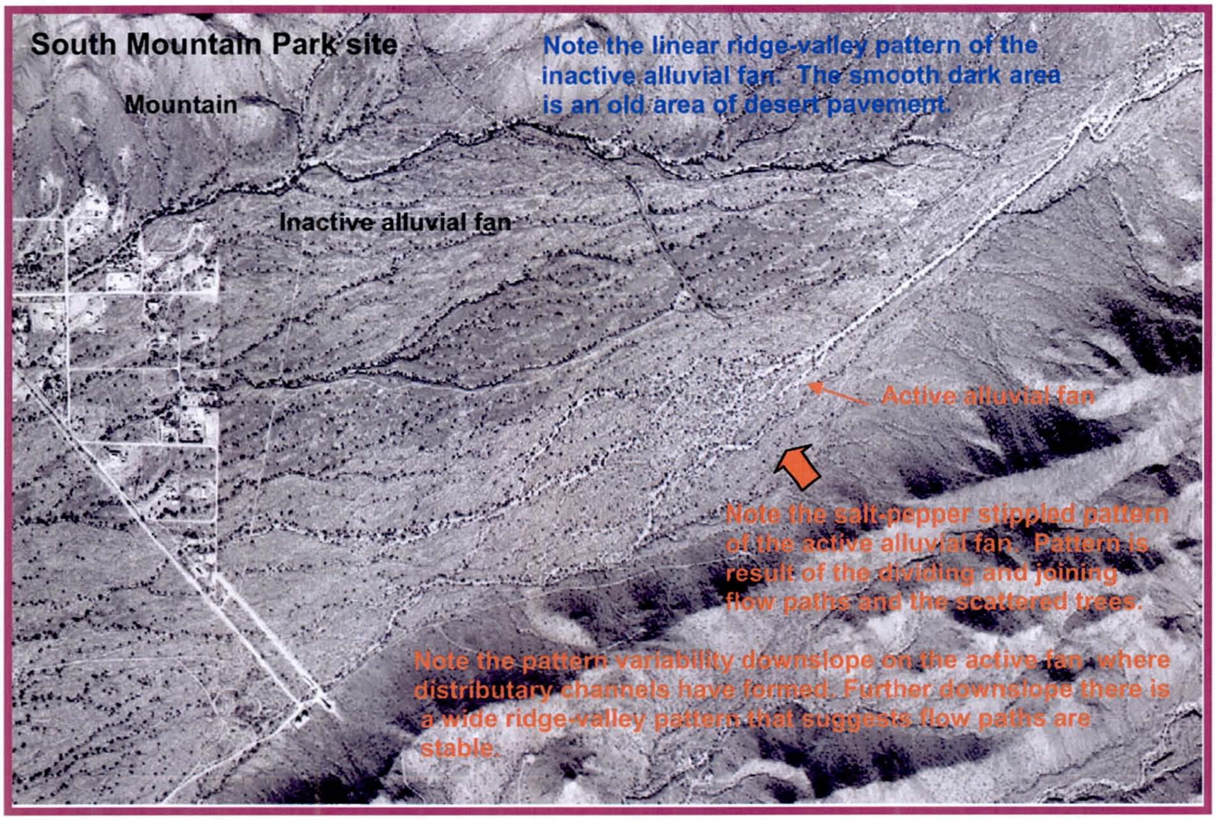


Figure E2A. Aerial photograph of South Mountain Park site.

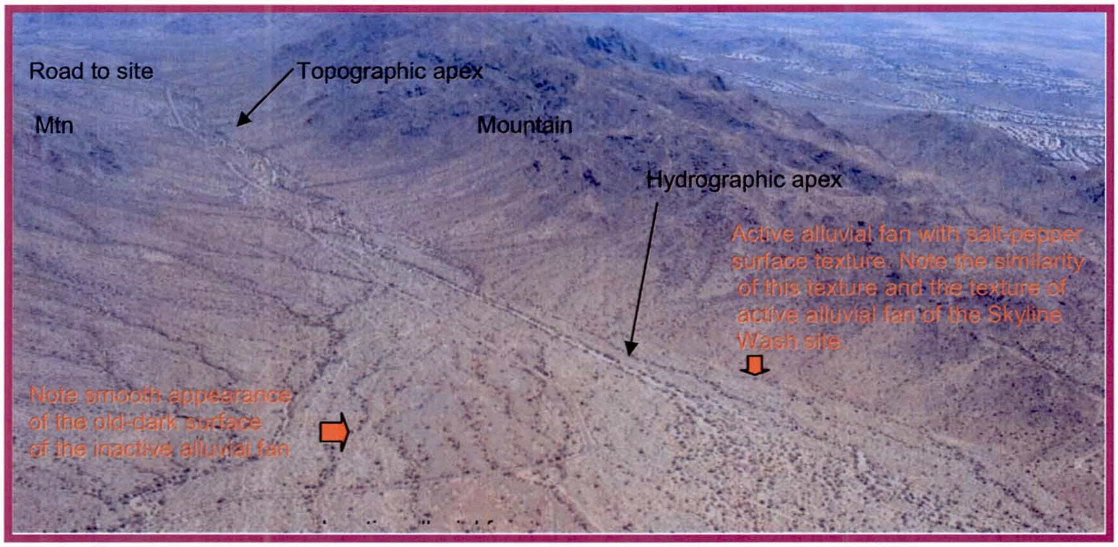


Figure E2B. Oblique aerial photograph of South Mountain Park site.

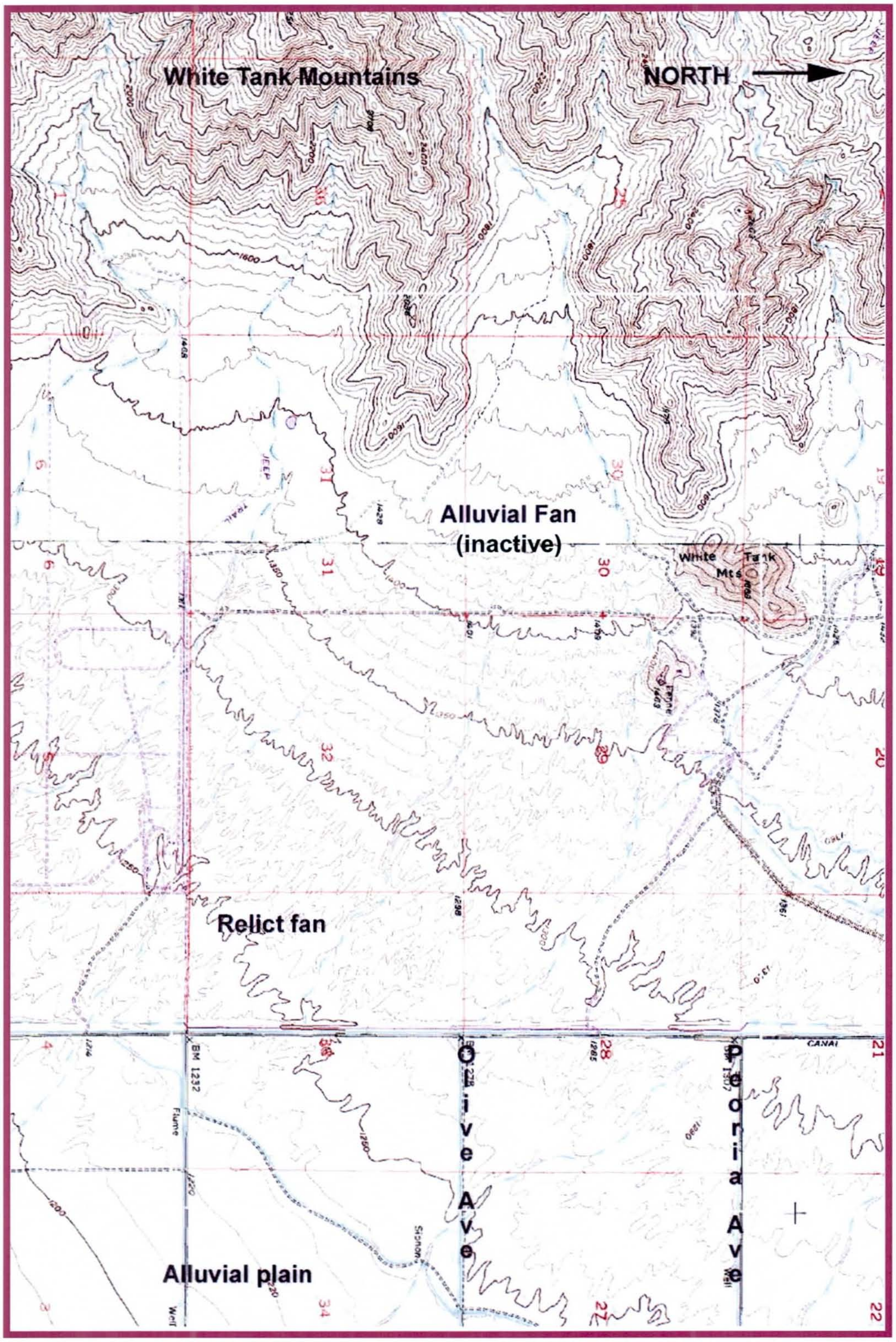


Figure E3A. Topographic map of White Tank Park site.

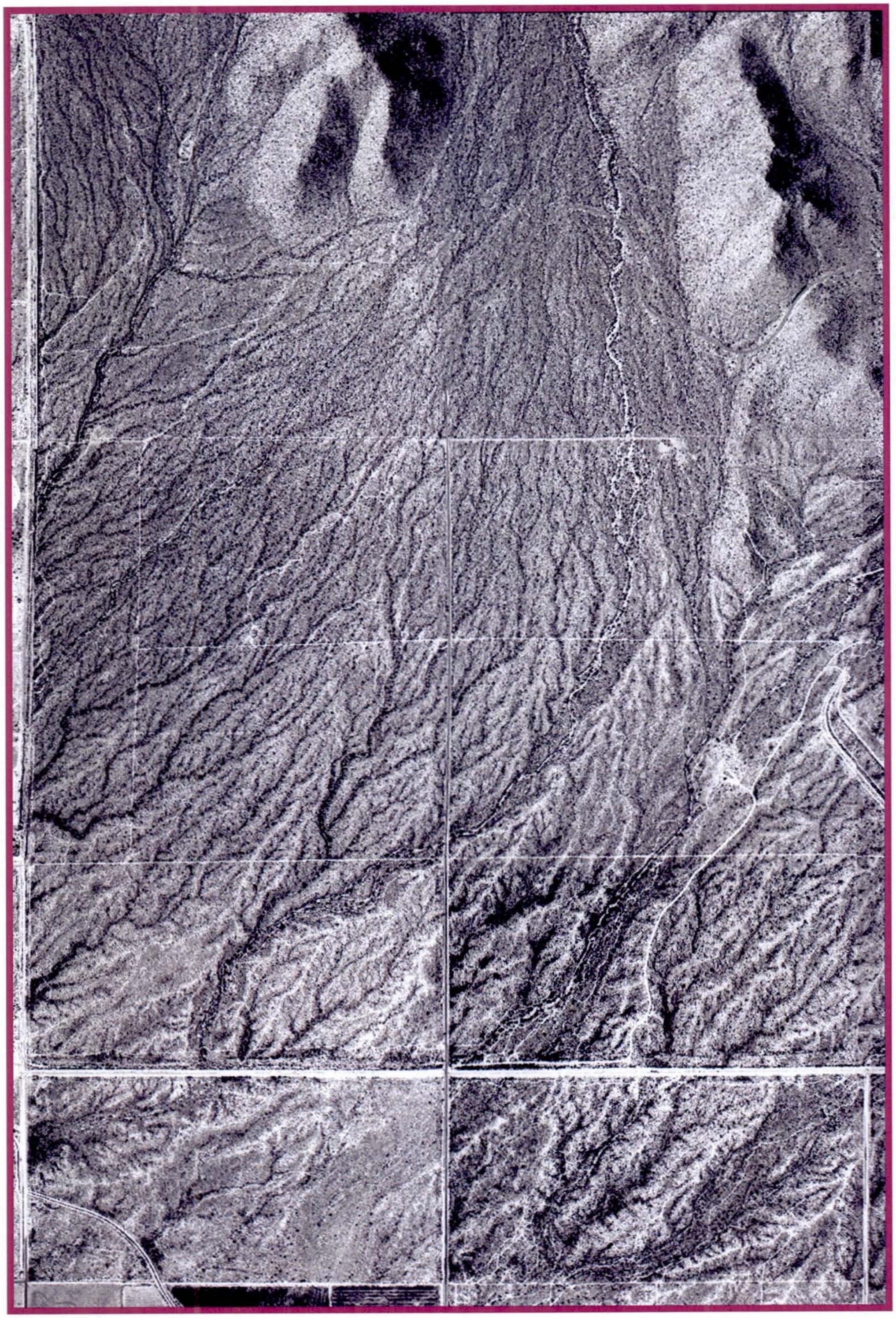


Figure E3B. Aerial photograph of White Tank Park site.

Why is surface texture of the relict fan and inactive alluvial fan shown in Figures E3B and E3C different? To fully answer this question a field inspection of the White Tanks Park site is recommended. However, we can use the aerial photos in the two scenes to discuss some of the surface features that produce the texture differences.

We are reminded that surface texture is a qualitative general visual appearance of the light and dark tones of the surface features. It is not necessarily the detailed characteristics of the surface features. However, we should be aware of the light and dark tones associated with loose sand, desert pavement, desert varnish, trees, recent sheet flow, washes with sharp shoulders, washes with rounded shoulders, hilly terrain and so forth. In other words, we should have some understanding of why the texture of the relict fan and inactive alluvial fan in Figures E3B and E3C are different.

Most investigators would probably agree the relict fan appears to have more topographic relief than the inactive alluvial fan. A quick look at Figure E3A will verify that the relict fan is more hilly. Most relict fans are hilly terrain with somewhat parallel hills and valleys (small drainage ways) that have rounded toe slopes and shoulder crests. Many relict fan areas, like those at the White Tanks Park site, consist of wide shoulders and back slopes where the summit (crest), foot slope, and toe slope areas are minimal. Conversely, many inactive alluvial fans, also like those at the White Tanks Park site, consist of mostly wide-flat summits that separate relatively small washes that head on the fan surface.

Hill slopes that are wide and straight along the topographic contour are indicative of inactive alluvial fans and not relict fans. The hill sides of relict fans are apt to be cut into numerous short noses or longer spurs by side slope drainage ways and short side valleys. These in turn may be cut by yet smaller drainage ways and rills. Thus, in plan view, the side slopes of a hill or mountain ordinarily form a wavy, crenulated, or digitate pattern (like fingers or toes).

Many back slopes along throughflow channels that cross both relict fans and inactive alluvial fans drop directly into the channels. These typically are areas of head cutting and gulling. The throughflow channel of the White Tanks Park site is a good example of head cutting into cemented rock. Head cutting is restricted by very large cemented boulders.

There is a distinctive speckled-braided surface texture in the braided channel area along the throughflow channel of the White Tank Park site. The geometry of this braided channel area is subject to scour and fill and is locally unstable. There are many examples of similar pockets of alluvium along throughflow channels in Maricopa County.

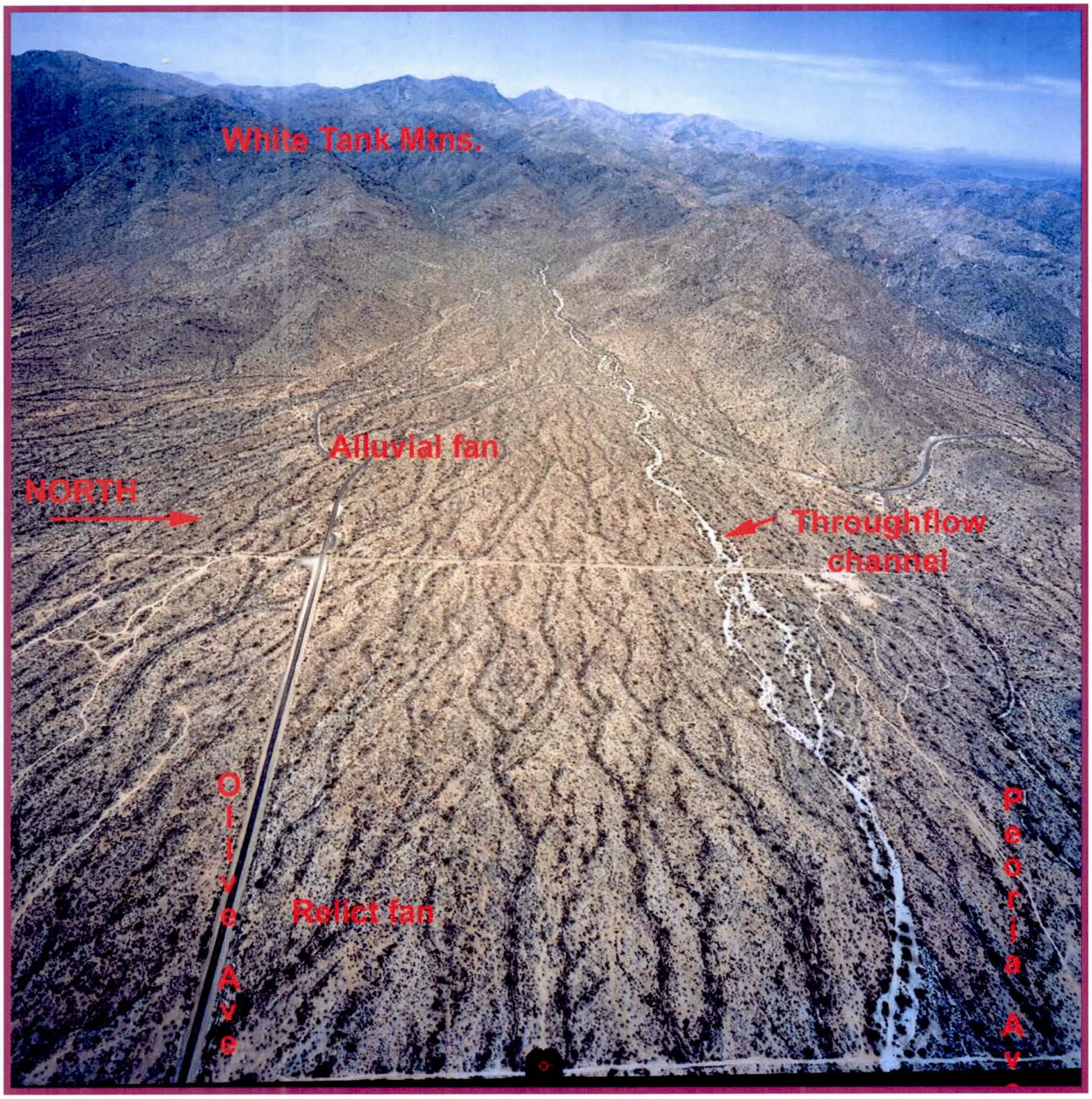
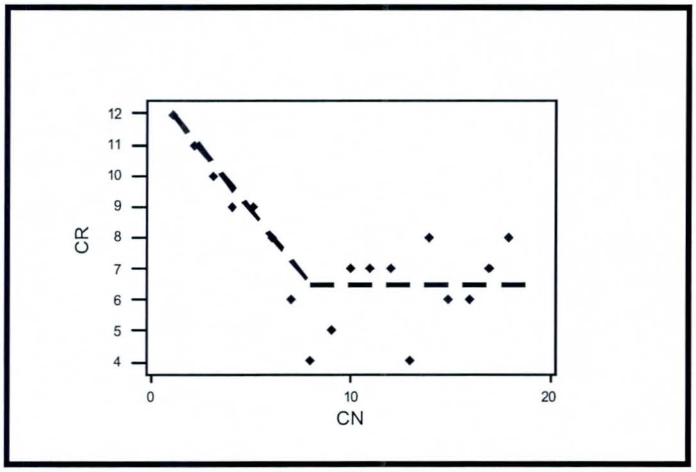


Figure E3C. Oblique aerial photograph of White Tank Park site.

E3. Additional information related to surface texture

Much of the surface texture that we see is the result of drainage texture described in Appendix D. Drainage texture is the relative spacing of drainage ways (rills, swales, washes, etc.). Differences in drainage texture are related to the underlying types of geologic material and the types of landform. A technique of quantifying drainage texture using measurements of contour crenulations on USGS 7-1/2 minute topographic maps is described in Appendix D.

The drainage texture relation for the White Tanks Park site is on the right (See Figure E3 of this appendix). The upper part of the site where the contours are fan shaped has a drainage texture typical of an inactive alluvial fan (See Figure D1). The lower part of the site, below about 1,350 ft elevation, has a texture relation of a relict fan.



Surface texture and changes of surface texture on an active alluvial fan at the northeast end of the McDowell Mountains are shown in Appendix K. Changes of surface texture associated with shallow flow that moved surface litter and surface alluvium and removed or covered grasses are shown. Lateral movement of an alluvial channel is documented using aerial photographs.

Surface textures and tones from visual interpretation of aerial photographs that correlate with landform type are given in Chapter 2 of the Manual.

Visual surface textures and tones that correlate with type of flood hazard are shown Chapter 3 of this Manual.

A good example of the surface texture of a granite pediment is shown in Figure F4 of Appendix F. Another example of a pediment surface texture is shown in Figure 2.3.

Finally, the investigator is invited to visit the Skyline Wash, White Tanks Park and South Mountain Park sites to see for yourself what is causing the surface appearance. Many photographs of these three sites are shown in Appendices H, I and J of the Manual.

Appendix F. Pediments

A few photographs of a pediment near Carefree are presented in this appendix. A discussion of granite pediments and some controversy related to landform identification in Maricopa County follows the photos.

Pediments typically are formed by back-weathering erosion of the mountains. Granite pediments are formed by in situ weathering and down-weathering. The weathered pediment material is moved down slope by alluviation and stripping where there are alluvial fans, bajadas and alluvial plains.

Some pediments have been tilted and in places tilted by normal faults (Cooley, 1977). Some deposits on pediments are cemented conglomerates. According to Twidale (1982), pediments of Arizona are planate rock surfaces or "rock pediments". Twidale reports that "McGee (1897) recorded his amazement on encountering these forms in Arizona late last century. They were different from anything previously recorded:"

> *At first sight the Sonoran district appears to be one of half-buried mountains, with broad alluvial plains rising far up their flanks, and so strong is this impression on one fresh from humid lands that he finds it difficult to trust his senses when he perceives that much of the valley-plain area is not alluvium but planed rock similar or identical with that constituting the mountains...*
>
> *During the first expedition ...it was noted with surprise that the horseshoes beat on planed granite or schist or other hard rocks in traversing plains 3 or 5 miles from mountains rising sharply from the same plains without intervening foothills (McGee, 1897, pp. 90-91).*

Some distributary channel networks on granite piedmonts reside on weathered granite and not on alluvium. Inset fluvial deposits have formed at topographic breaks and these deposits are separated by weathered granite interfluves that have developed soil. The fluvial deposits are along some active drainage ways below the apex and upslope of a network of distributary channels incised to depths less than 3 ft. Scour and fill of the fluvial deposits during floods may influence the formation of the distributary channels in the weathered granite down slope. Studies of these stream networks in Maricopa County show little or no movement of flow paths for the past 50 years (National Research Council, 1996 and Rhoads, 1986).

The following photographs are of sites 2 and 3 of USGS WRI 91-4171 and WRI 93-4169 and also the Carefree alluvial fan in Alluvial Fan Flooding of the National Research Council (1996, pages 102-111). The investigator is encouraged to consult these reports for additional information on these sites. The two USGS reports refer to alluvial fans as distributary-flow areas and to both topographic and hydrographic apex as a primary diffluence. Much of the other terms are the same.

Figure F1. Small distributary channel formed in an inset alluvial deposit within a pediment.

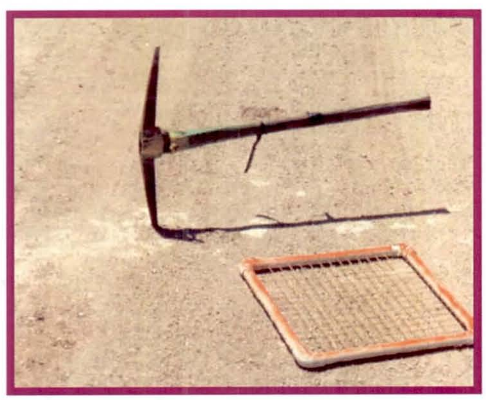
The bed is subject to scour and fill but the banks are fairly stable except at bends. The flow paths typically are stable. Throughflow channels typically have flat-sandy bottoms like that shown on the photo.

Figure F2. Bedrock bed of small distributary channel.

The bed is stable and locally controls the channel grade.

Figure F3. Exposed bedrock on interfluve between distributary channels on the Carefree pediment.

The presence of such bedrock has a stabilizing affect on the flow paths.



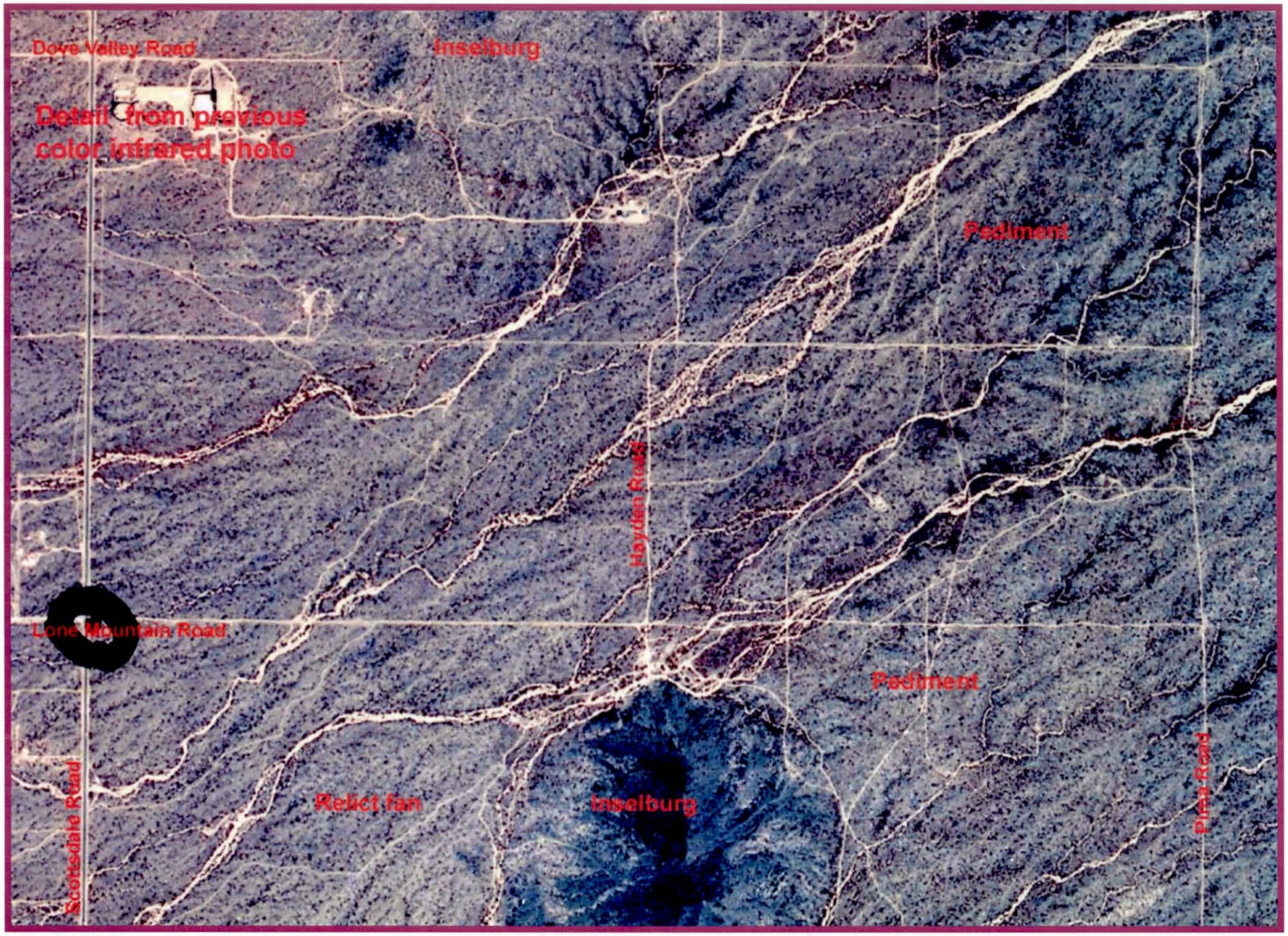


Figure F4. Aerial photograph of pediment near Carefree.

Granite pediments

Davis (1938, p. 1361) recognized the weathering similarities of igneous rocks but he also was clear that granite rocks weather differently than other igneous rocks in arid climates. Davis, in his contrasting of *sheetfloods* and streamfloods on weathered granite, points out that both are engaged in erosion, transport and deposition but sheetfloods are more engaged in erosion and transportation. Davis shows an example of the concentrating of sheetflooding at a highway culvert and the resulting streamflooding at the culvert with a distributary channel network below. This manmade conversion of sheetflood into streamflood and then back to sheetflood is similar to some natural drainage networks on granite piedmonts in Maricopa County.

Most pediments are thought to form by back-weathering erosion of the mountains and pediments with accompanying alluviation on lower slopes where there are alluvial fans, bajadas and alluvial plains by lateral planation or by deep weathering and stripping. Granite areas, and possible other igneous rock areas, are formed by in situ weathering and down-weathering and the transition from the pediment to the alluvial fan-like area is a function of the depth of underlying weathered granite. These fan-like areas commonly have inset fluvial deposits that form the core of the fan-like area at and closely below the apex. When exposed to percolating water or the fluctuating water surface of aquifers, granite can weather to great depths. Recorded depths of weathering are from 50 m to more than 200 m in humid regions and 40 to 50 m in semiarid regions (Twidale, 1982, p. 71). Moss (1977) found weathering of granite at the Union Hills sand pits in Maricopa County to depths of 37 ft. and to depths of 90 ft. at a drill hole.

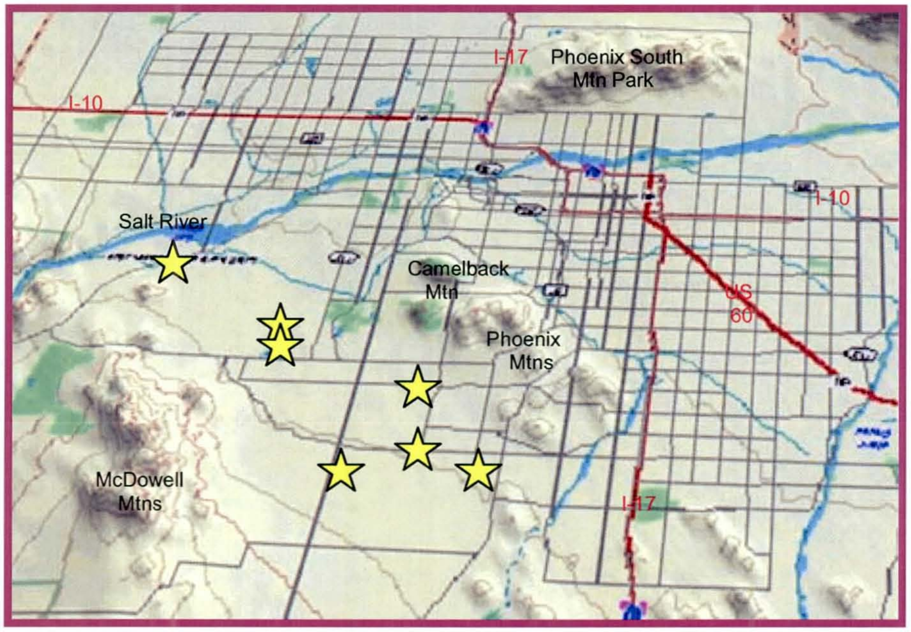
According to Twidale (1982, p. 190) the slope of granite pediments of the world varies between 1/2° to 7° (0.87 to 12.4 percent) but they typically are inclined at 1/2° to 2-1/2° (0.87 to 4.4 percent). The grade of pediment slopes in Maricopa County is in the mid to upper range of these typical values. In addition, slope changes along the profile of granite pediments and piedmonts of Maricopa County are typical where most profiles are slightly concave upward and other profiles are uniform or rectilinear.

Granite piedmonts may be at the root of the disagreement about the distinction of pediments and alluvial fans among geomorphologists. For example, the discussion and reply between V. C. Miller (1971) and D. O. Doehring (1971) over the definition of pediments and alluvial fans and the discrimination of them (Doehring, 1970) may be the result of in situ weathering. In situ weathering of granite produces fan-like areas of distributary channels; and, as Doehring suggests, a distributary drainage network forms where weathering depths are more than about 50 ft. (Doehring, 1970. p. 3109). Miller appeared to discount the discrimination problem simply because a pediment is an erosion surface and an alluvial fan is a depositional surface. Mammerickx (1964) observed that the stream pattern of not-so-deep dissection (less than 3 feet) was distributary (braided is the term used by Mammerickx) while the stream pattern for deeper dissection was not distributary.

In conclusion, users of this manual should be aware of the above controversy surrounding granite pediments in Maricopa County. Landforms commonly thought to be alluvial fans by FEMA appear to be weathered residual granite or a mix of weathered residual granite and fluvial deposits. The stream pattern of these controversial areas is distributary and flow paths are stable (See the Carefree example site in National Research Council, 1996). Channels are incised less than 3 ft. and are lined with paloverde and mesquite trees. The flood hazard assessment (Stage 3 in Chapter 4) and use of hydraulic models as described in this user's manual is not significantly affected by this controversy.

Appendix G. Alluvial Plains

Several photographs of flooding on the upper, middle and lower parts of alluvial plains in Maricopa County are shown in this appendix. These accounts show that flooding typically is shallow and unconfined and covers broad areas as sheet flooding. Receding floodwater typically leaves thinly deposited alluvium over large areas. The sites are shown on the following oblique 3D index map.

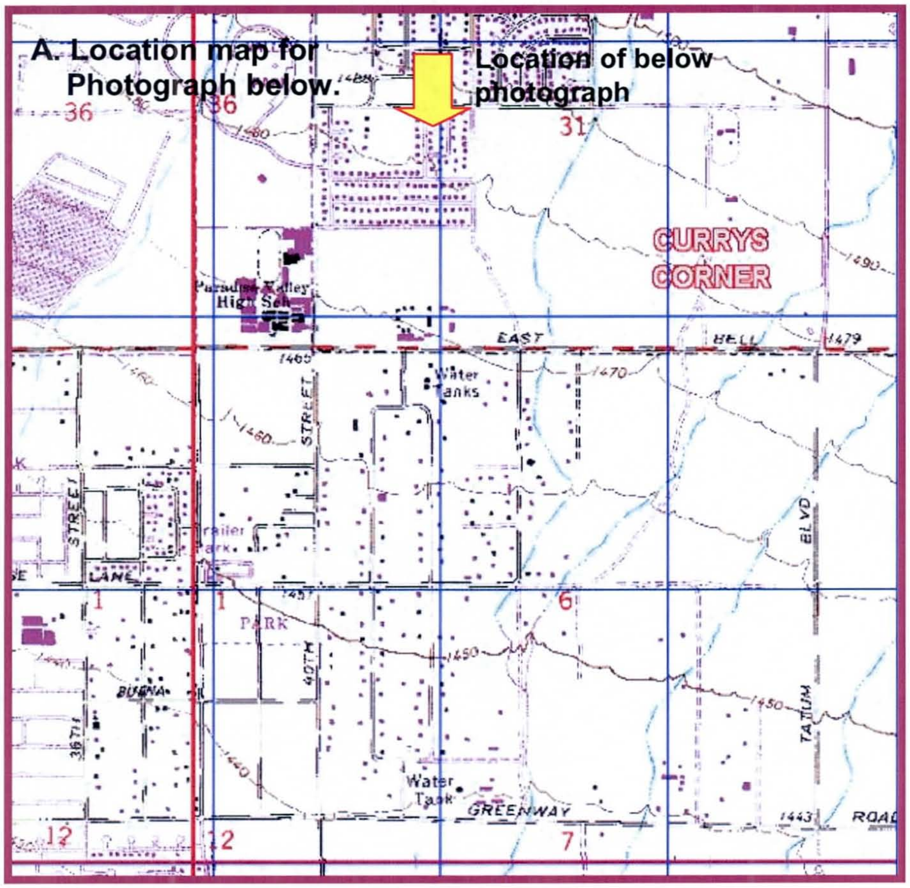


View of Phoenix area looking south showing location (yellow stars) of photographs in this appendix.

On June 22, 1972 nearly 4 inches of rain fell on the Phoenix Mountains. Heavy rain also fell on the McDowell Mountains. Much of the floodwater spread over broad areas of the alluvial plains along the base of the piedmonts of the Phoenix and McDowell Mountains. Much of the floodwater entered Indian Bend Wash and drained south to the Salt River.

Large areas of the alluvial plains were covered with homes. Many homes were damaged by sheet flow that generally was less than 1-1/2 ft. deep. The flow paths were influenced by streets, curbs, buildings and berms. Many berms around recent (1972) housing developments were breached.

Alluvial plains are rather flat and smooth with a gradient typically less than 0.5 ft/ft. There typically are widely spaced small washes a few feet wide and a foot or more deep that traverse the plains. Some washes head on the plains. The small drainage washes generally are a few hundred feet apart.



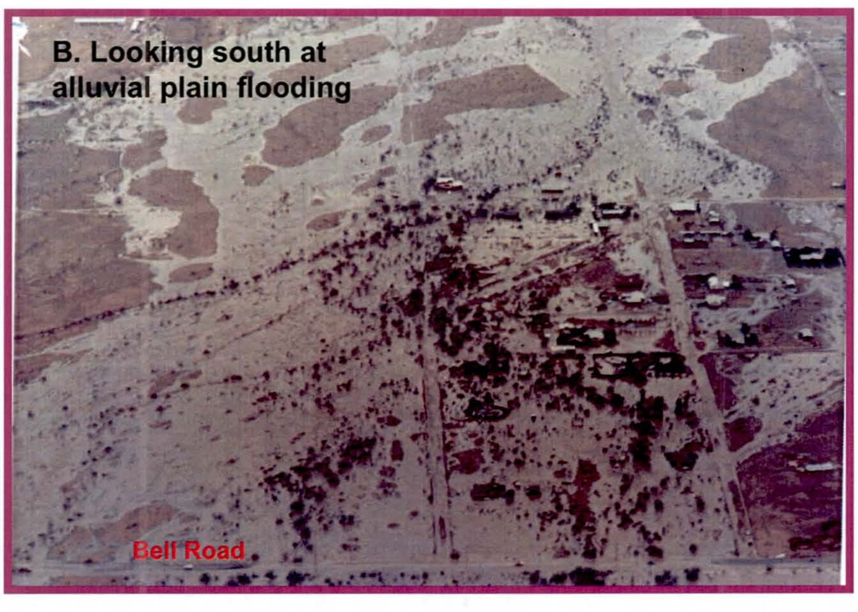


Figure G1. Alluvial plain flooding on June 22, 1972 along 44th Street between Bell Road and Greenway Road.

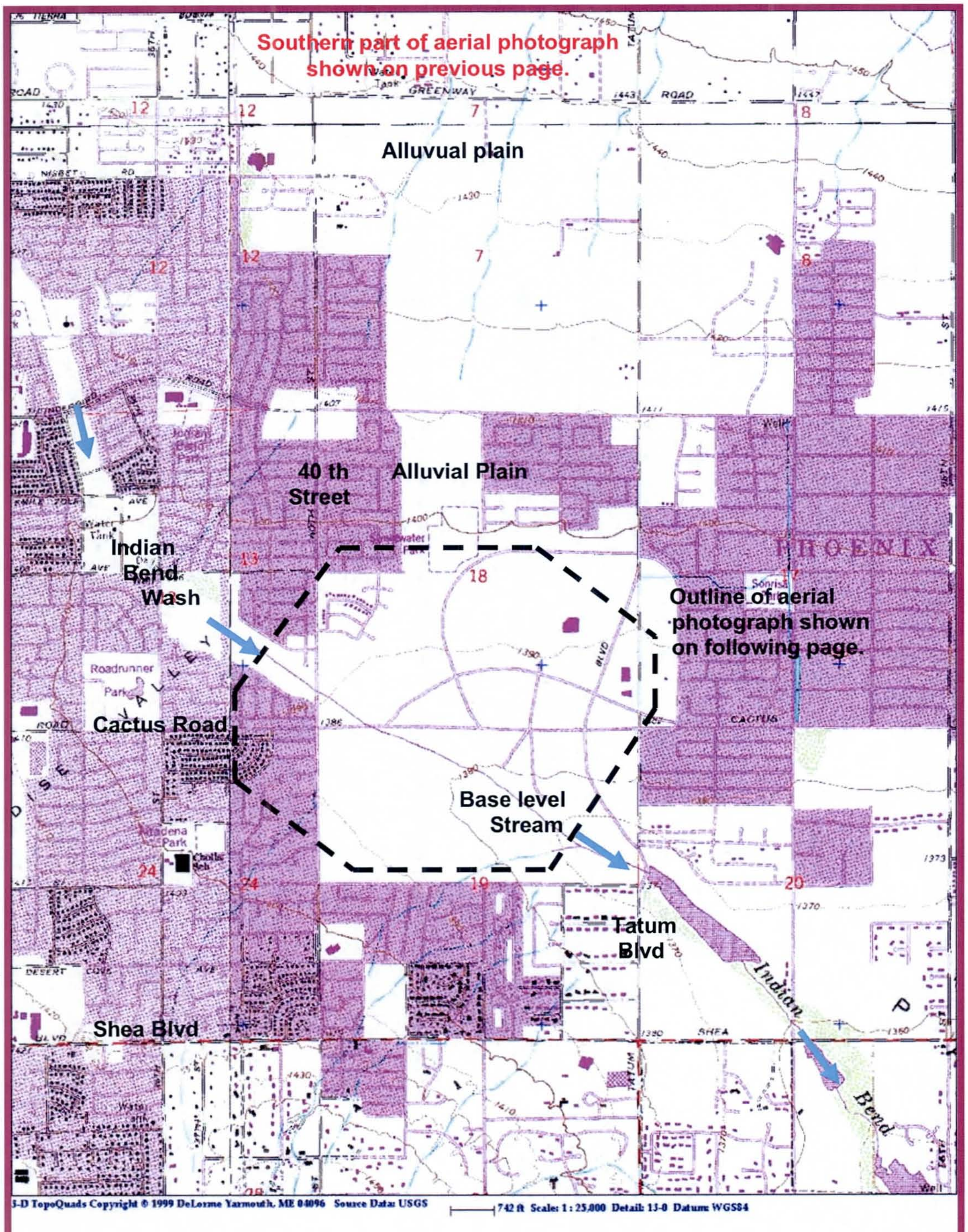
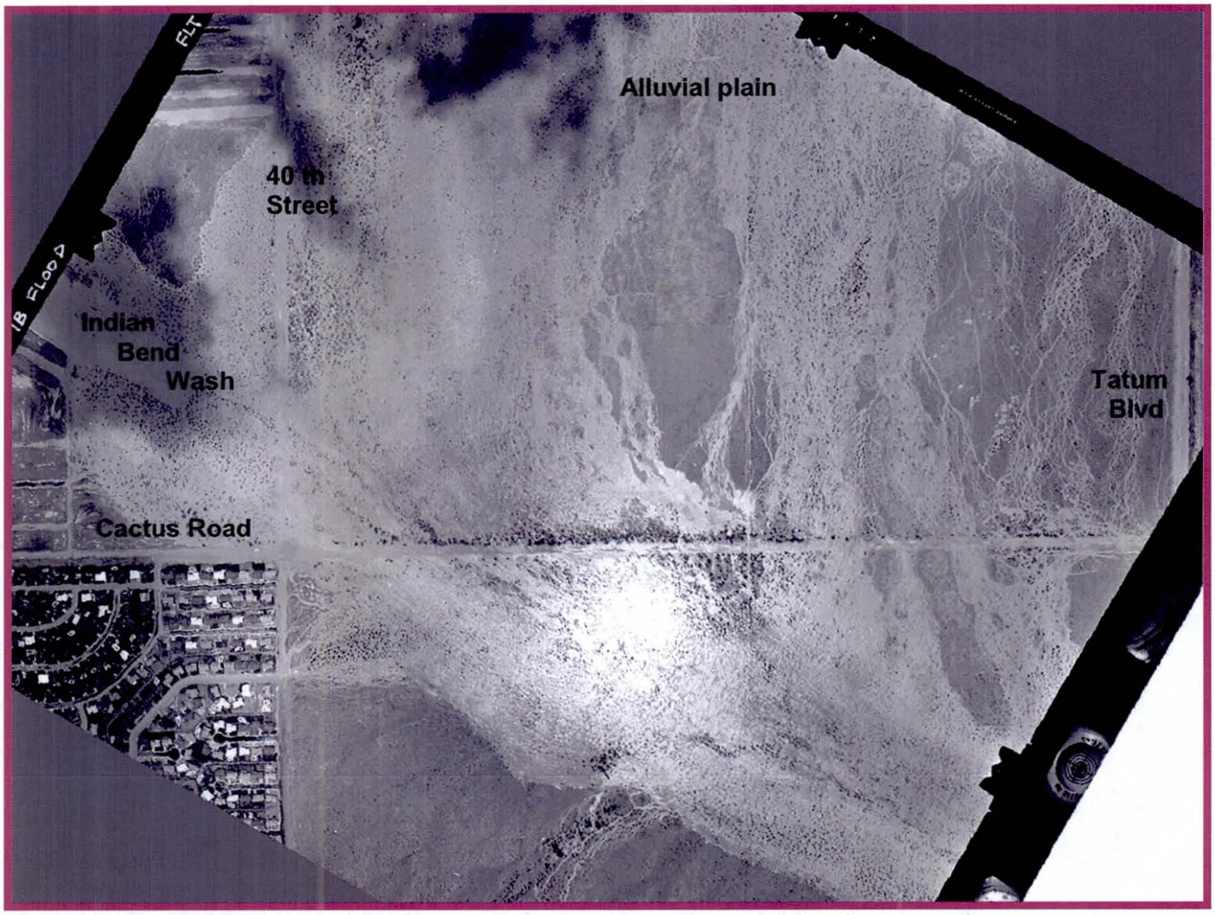


Figure G2. Topographic map showing location of aerial photographs of alluvial plain flooding.



Note: See previous figure for topography and location of this photograph.

Figure G3. Aerial photograph of June 22, 1972 flooding on alluvial plain and base level stream in vicinity of Cactus Road and Tatum Blvd.

The floodwater in the above scene has spread over a mile width of the alluvial plain at Indian Bend Wash that is the base level stream. Similar alluvial plain flooding covered broad areas from this location to the western slopes of the McDowell Mountains a few miles to the east (See Figure G9 that was taken on the following day). Sheet flooding was about 0.5 to 1 ft deep. Flow in the small widely spaced channels of the alluvial plain was on the order of 3 ft. deep.

You're invited to examine the photos of this appendix that show how floodwater of a major storm spread over alluvial plains and commingled. Please note how relatively small obstructions can affect the flow paths of sheet flow and sheet floods on alluvial plains. There is little topographic relief on the alluvial plains and there are several examples of sheet flow that is diverted by small obstructions and roads. The investigator is encouraged to also consult the Glossary for sheet flow and sheet flooding and Arizona State Standard 4-95 (1995) for a description of sheet flooding.

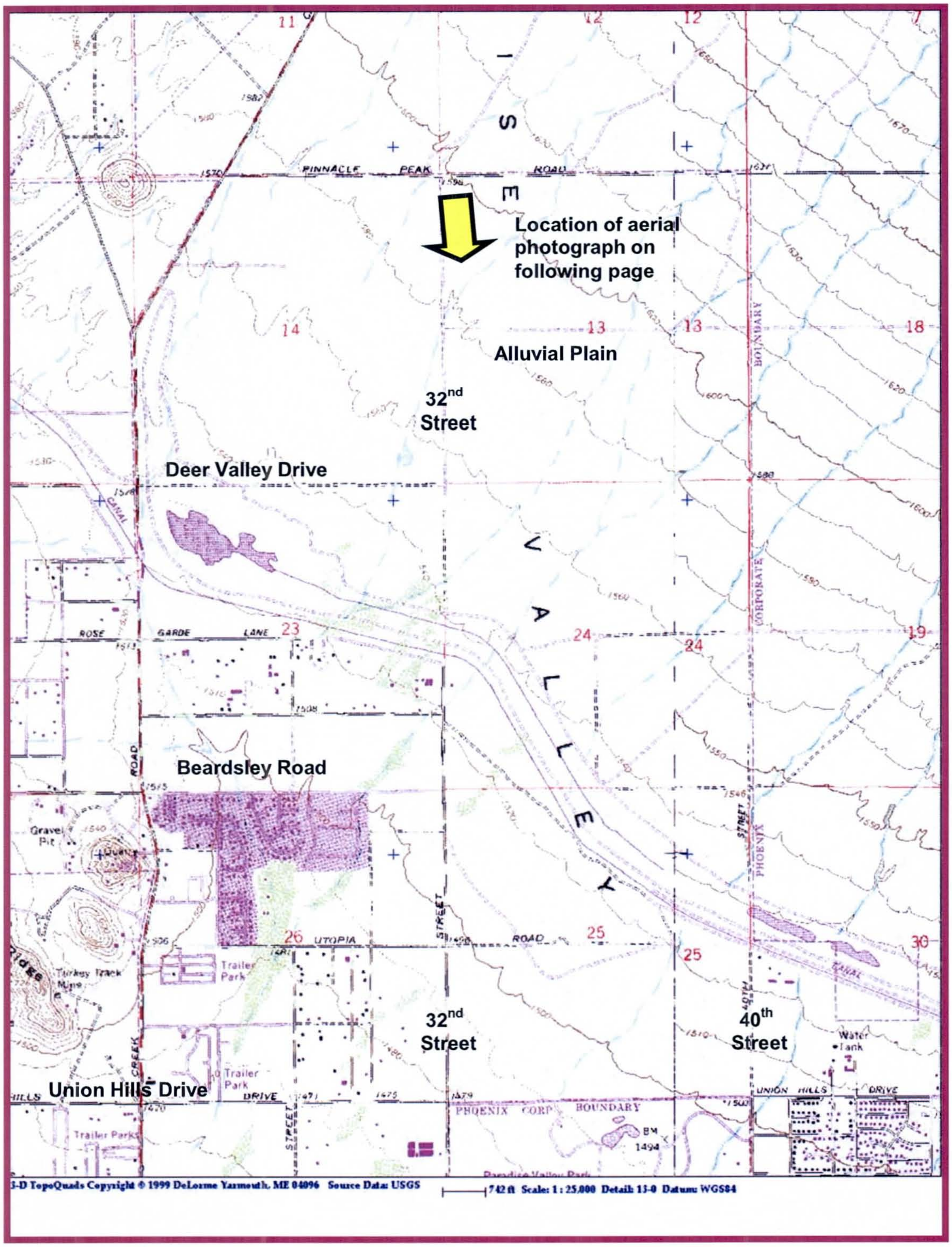


Figure G4. Topographic map showing location of aerial photographs of alluvial plain flooding along north 32nd Street near Beardsley Road.

Figure G5. Looking south along 32nd Street near Beardsley Road at alluvial plain flooding on June 22, 1972.

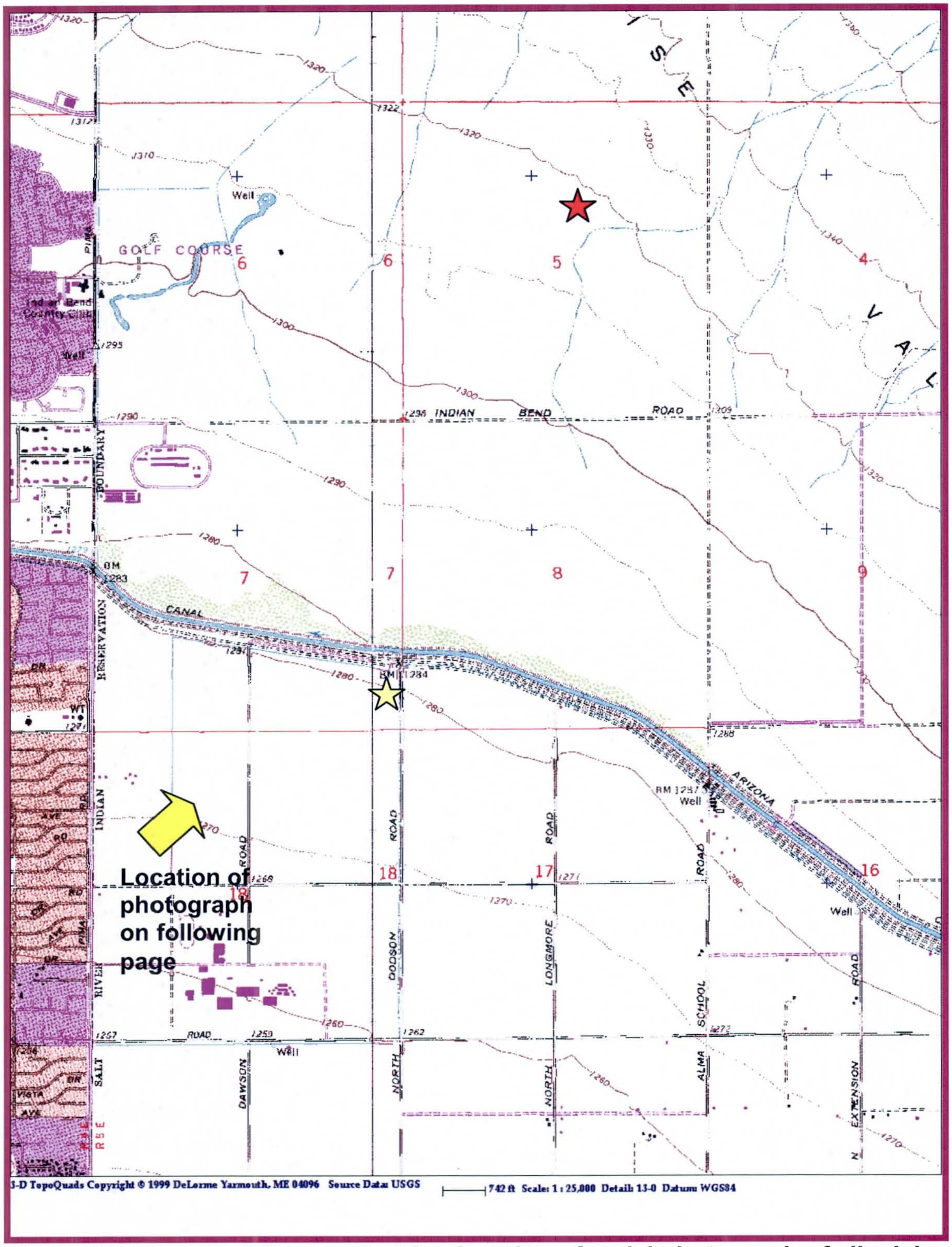


Figure G6. Topographic map showing location of aerial photograph of alluvial plain flooding in Alma School Road and Indian Bend Road area.

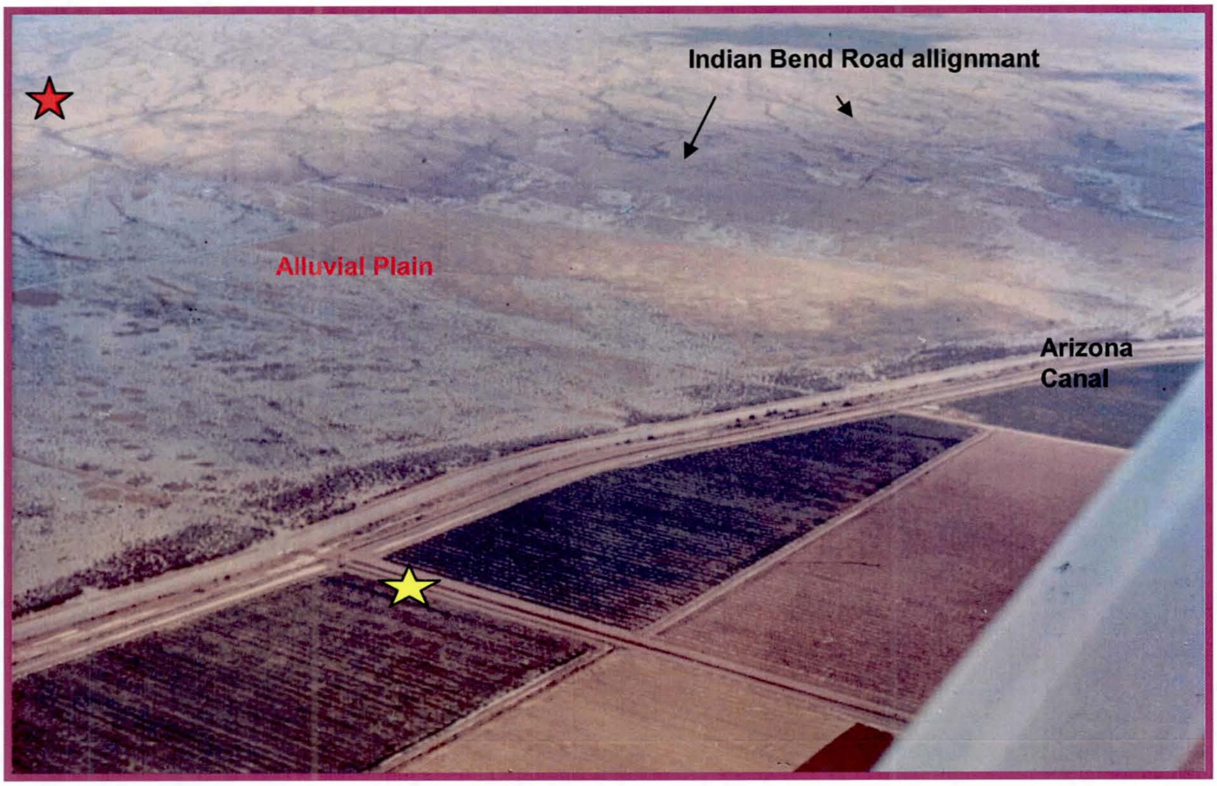


Figure G7. Looking northeast in vicinity of Alma School and Indian Bend Roads at alluvial plain flooding on June 22, 1972.

Figure G8. Looking west along Pinnacle Peak Road about 0.1 mile east of Scottsdale Road at deposited alluvium from flood the previous day.

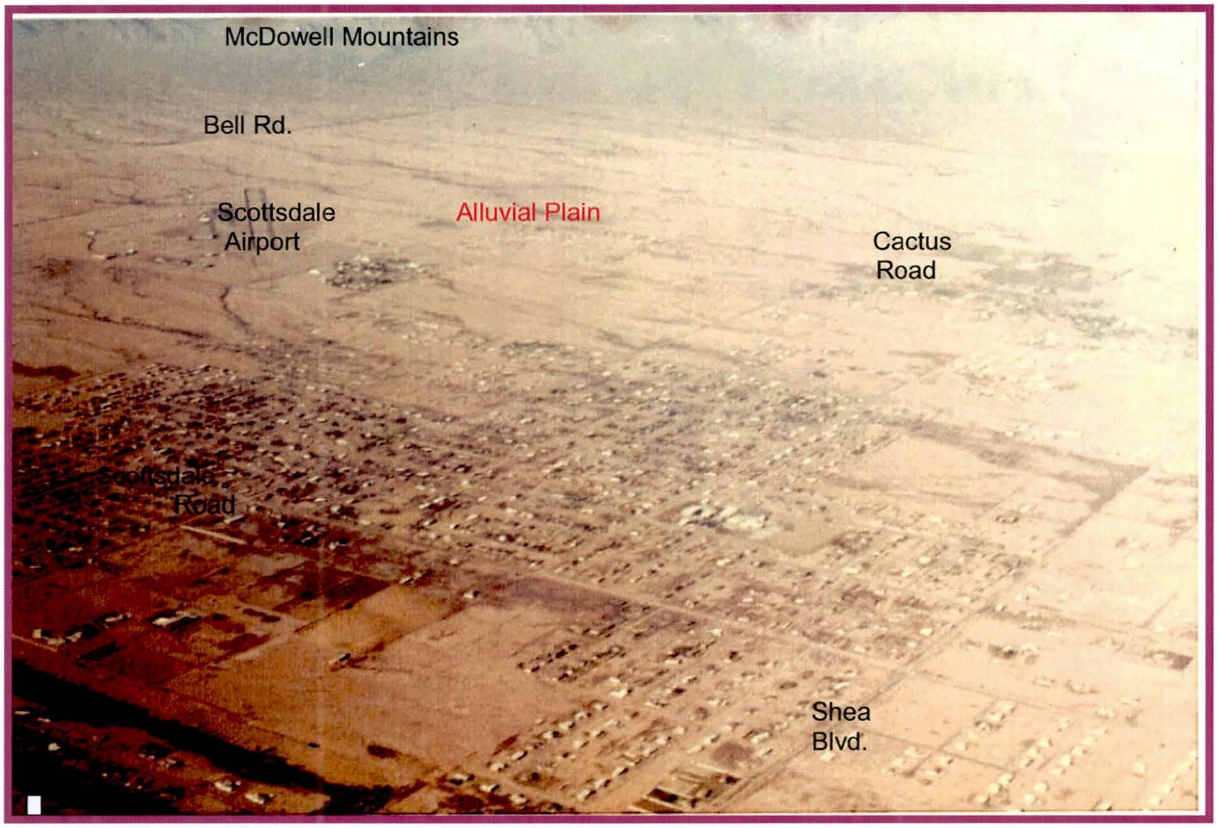
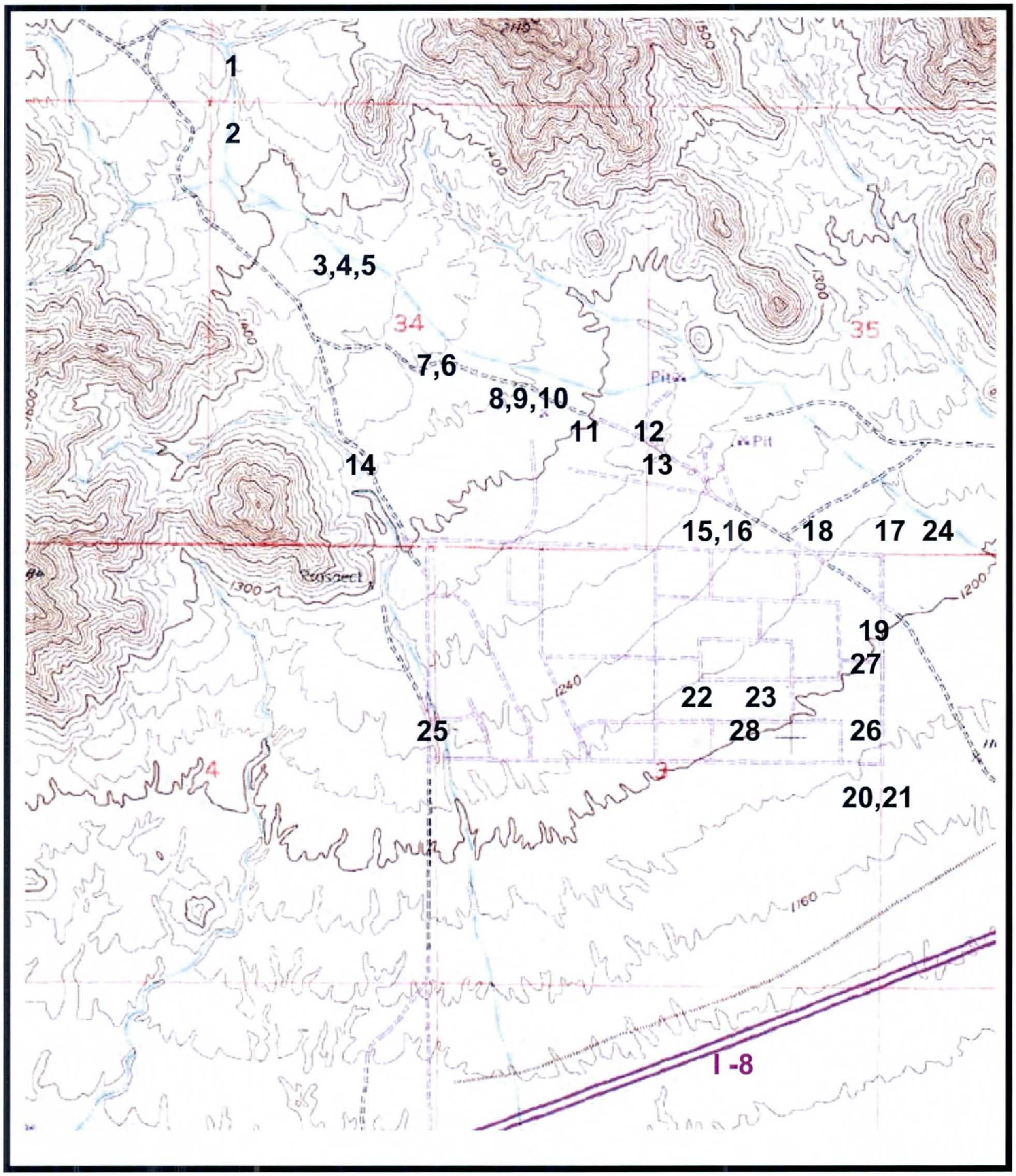


Figure G9. Oblique aerial photograph looking northeast at alluvial plain area that was covered with sheet flow (tan area) the previous day (June 22, 1972).

Figure G10. Looking east along Shea Blvd. just east of Pima Road at dip crossing and receding floodwater from flood peak of previous day.

Appendix H. Skyline Wash alluvial fan



The location of photographs of the Skyline Wash site that are in this appendix are shown above.

Skyline 1.

Scene: Looking downstream and south at main channel with bedrock at left end of survey rod. Rod intervals are 6 inches. There is a vegetated overflow area on the right composed of variously sorted stream alluvium including dumps of cobbles and angular boulders.

Landforms: Throughflow alluvial channel. Mountains in background.

Comment: The large amount of stream alluvium stored along this and upstream channels of this drainage basin is a major source of material for potential remobilization and redeposition on the alluvial fan downstream.

Further Reference & Sources: For additional information on debris accumulation above active alluvial fans see page 38 of National Research Council (1996).

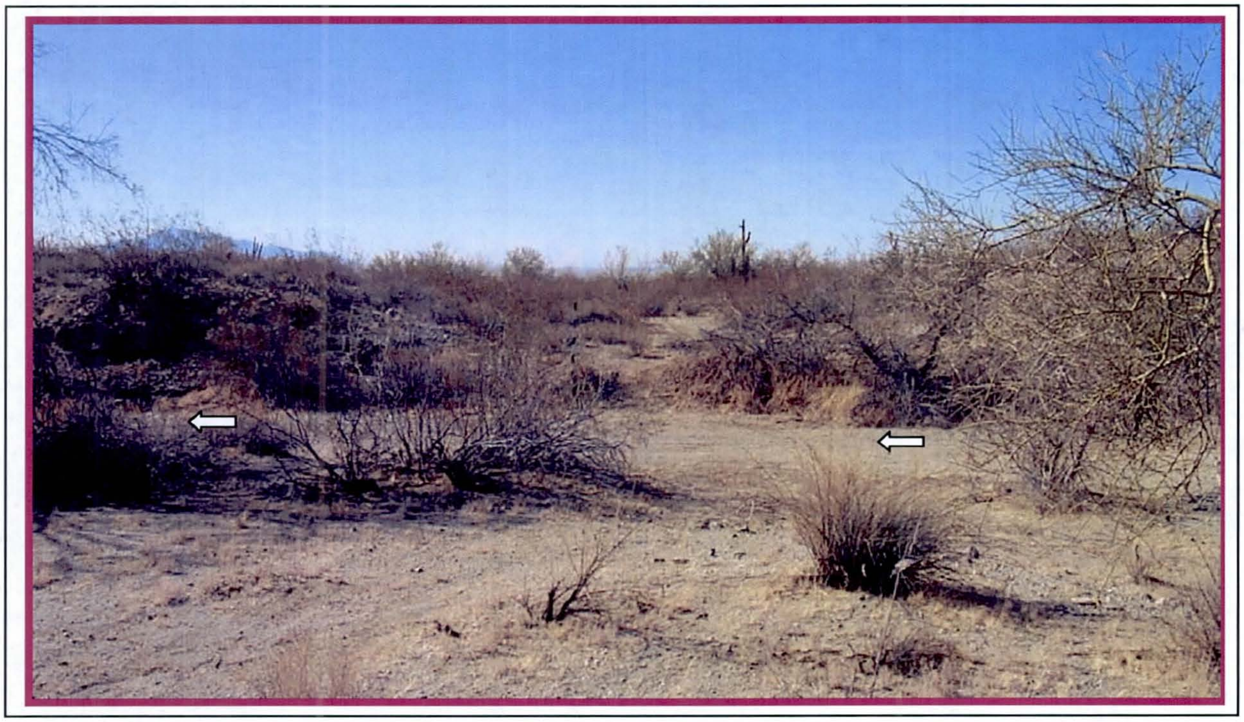
Skyline 2.

Scene: Looking downstream at channel fork to the left of the main channel. The vegetated area in the center is composed of variously sorted stream alluvium including dumps of cobbles and angular boulders.

Landforms: Braided part of throughflow channel. Mountains in background on the right of scene.

Comment: The slope of this braid is much greater than the slope of the main channel to the right of the scene. The channels rejoin upstream of the hydrographic apex about feet downstream.

This scene is at the upper end of the braided channel "pocket" shown in Figure C4.



Skyline 3.

Scene: Looking downstream and south where floodwater has spilled over the 2 ft high right bank of a small braided channel (flow direction in braid indicated by arrows). Scene is about 200 ft to the west of the main channel at the hydrographic apex.

Landforms: Braided part of throughflow channel composed of stream alluvium. Relict fan in center background composed of calcareous gravelly sandy material. Soil of relict fan is well developed as indicated by the brown oxidation and the amount of calcium carbonate in the upper 2 ft.

Comment: Large floods have spilled over the right bank of the braid and formed a swale like flow path in the relict fan at this location. Further downstream where there is tributary storm runoff from the nearby hill slopes the channel is incised near where it joins the west side of the alluvial fan. The 100-year flood may spill over the bank of this braid into this distributary channel. Head cutting with incision into the right bank is possible.

Further Reference & Sources: Photograph Skyline 4 is about 200 feet to the east (left) of scene.

Skyline 4.
Scene: **Looking downstream along right or west bank at the hydrographic apex.**
Landforms: **Throughflow channel**
Comment: **Bank is composed of cemented rock and is stable. Much of the channel bed is soft sand with gravel and scattered cobbles.**
Further Reference & Sources: **Photograph Skyline 5 is to the left of this scene.**

Skyline 5.
Scene: **Looking downstream from hydrographic apex at upper end of the active alluvial fan. Flood flow is unconfined at this location.**
Landforms: **Throughflow channel with active alluvial fan in background.**
Comment: **Much of the channel geometry in this scene is unstable and flow paths change. There are many dumps of cobbles and boulders in the upper fan. The few large saguaro and several large trees suggest that parts of the alluvial fan have not scoured greatly for many years.**
Further Reference & Sources: **Photograph Skyline 4 is to the right of this scene.**

Skyline 6.
Scene: Looking downstream in active area of alluvial fan
Landforms: Active alluvial fan. Estrella Mountains are in far background.
Comment: Photo below is to the west or right of this scene.

Skyline 7.
Scene: Looking downstream at active area of the alluvial fan.
Landforms: Active alluvial fan.
Comment: Flow paths are braided appearing and there are many dumps of angular rock. Much of the bed is soft sand with gravel.
Further Reference & Sources: Scene is to the right of scene in photograph Skyline 6 above.

Skyline 8.
Scene: **Looking upstream and north from active area of alluvial fan.**
Landforms: **Active alluvial fan. Mountains of drainage basin in background.**
Comment: **Lots of angular rock.**
Further Reference & Sources: **Photographs 9 and 10 taken at this location.**

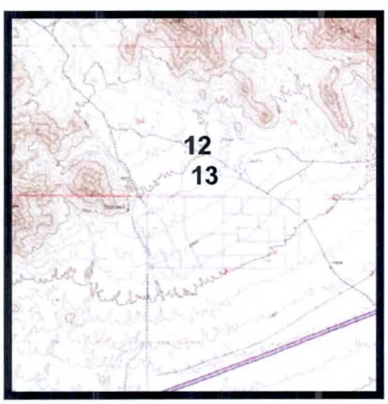
Skyline 9.
Scene: **Looking upslope and across to northeast for same location as photo 8.**
Landforms: **Active alluvial fan. Mountains in background.**

Skyline 10.
Scene: **Looking northeast from same location as photos Skyline 8 and 9.**
Landforms: **Active alluvial fan with mountains.**
Comment: **Note the dumps of angular cobbles with scattered boulders.**

Skyline 11.
Scene: **Looking south at alluvial fan on upslope side of large gravel pit.**
Landforms: **Active alluvial fan. Sierra Estrella Mountains in distance.**
Comment: **Mounds of sand and gravel from the gravel pit are on the left. The natural vegetation was removed when the pit was in use.**
Further Reference & Sources: **See photos Skyline 12 and 13 of the gravel pit area.**

Skyline 12.
Scene: Looking southeast and downslope at gravel pit area from incised channel of throughflow distributary channel.
Landforms: Active alluvial fan
Comment: Channel has headcut into the cemented material following development of the gravel pit.
Further Reference & Sources: See photos Skyline 11 and 13 of the gravel pit area.

Skyline 13.
Scene: Looking east across southern side of gravel pit.
Landforms: Active fan with mountains.
Comment: Approximately 10 ft. of material was removed for gravel pit before bedrock pediment was encountered. The survey rod next to the truck is on the pediment.
The gravel pit presently (2002) acts as a retention and detention basin of storm runoff on part of the alluvial fan.



Skyline 14.

Scene: **Looking upstream at the west distributary channel on the active alluvial fan.**

Landforms: **West side of active alluvial fan.**

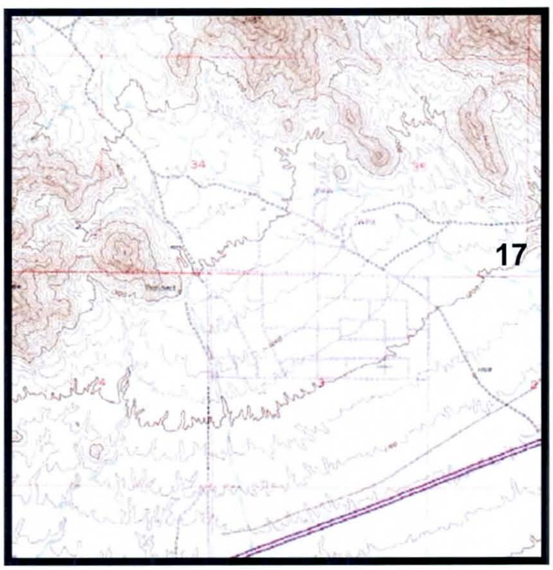
Comments: **Pediment bedrock forms the right bank and parts of the streambed. There is a thin veneer of alluvium in this area. There are dumps of angular boulders along the left bank.**

Further Reference & Sources: **The bedrock appears to be the same material as in the bottom of the gravel pit in photo Skyline 13.**

Skyline 15.
Scene: Looking north at inactive part of the alluvial fan.
Landforms: Inactive alluvial fan. Distant mountains of drainage basin.
Comment: These scenes show typical characteristics of the Sonoran Basin and Range physiographic province. There are scattered low mountains like those in the background with large adjacent piedmonts. There are large areas of palo verde-cactus shrub and giant saguaro cactus, with areas of creosote bush. There is also some desert pavement, desert varnish and calcium carbonate near the soil surface in this particular area.

Skyline 16.
Scene: Looking south from same location as photo Skyline 15.
Landforms: Inactive alluvial fan.
Comment: No evidence of flow path movement in this area. Some desert pavement with some desert varnish.

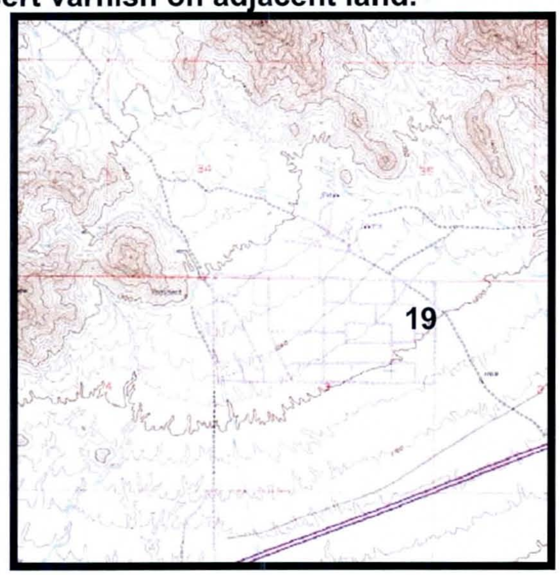
Skyline 17
Scene: . Looking upstream at distributary channel along east side of the alluvial fan.
Landforms: Throughflow channel. Mountains in background.
Comment: Adjacent land is covered with desert pavement.



Skyline 18

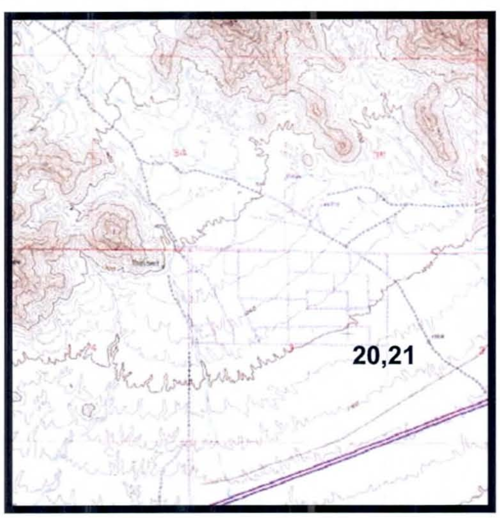
Scene: Looking downslope at developed soil on inactive part of the alluvial fan.
Landforms: Relict fan.
Comment: Desert pavement with some desert varnish. Calcium carbonate near surface.
Further Reference & Sources: Soil is similar to that in photo Skyline 19.

Skyline 19
Scene: Looking north and upslope at small channel that heads on the inactive part of the alluvial fan.
Landforms: Relict fan. Mountains of watershed in background.
Comment: Desert pavement with some desert varnish on adjacent land.
Further Reference & Sources:



Skyline 20
Scene: Looking north at headcut channel on upslope side of FCDMC Buckeye Flood Retenting Structure No.3.
Landforms: Active alluvial fan.
Comment: There is little calcium carbonate development in this area.

Skyline 21
Scene: View of cut bank just upslope of the survey rod in the scene above.
Landforms: Active alluvial fan.
Comment: The upper 1-1/2 ft does not have the gravel lenses of the lower material. The more recent sediments may be from secondary fan building processes where the fan material upslope was remobilized and deposited. Recent aeolian processes are likely.



Skyline 22
Scene: Looking north at soil in center of alluvial fan.
Landforms: Active alluvial fan. Mountains of watershed in background.
Comment: Very little calcium carbonate 0-1 ft. Minor desert pavement. Generally the uncemented fragmental sandy material is erodable but there is little evidence of erosion. There are no throughflow channels in this area. Much of this fragmental material originated from the weathering of the rock mountains in the background and was transported by, suspended in, or deposited by water or air.

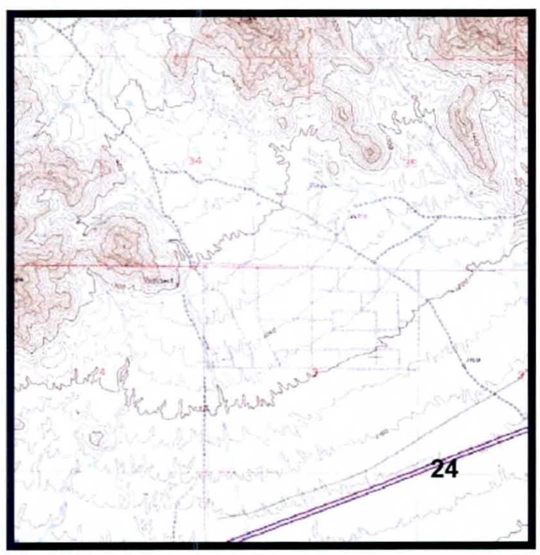
Skyline 23
Scene: Soil near center of alluvial fan.
Landforms: Active alluvial fan.
Comment: Similar appearance and conditions as in photographs Skyline 20-22. This soil is easily eroded by any man caused concentration of runoff.

Skyline 24

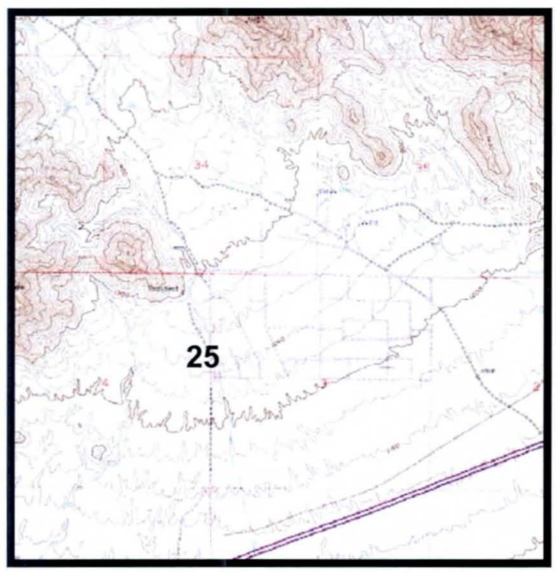
Scene: Looking upstream at throughflow channel of east side of the alluvial fan.

Landforms: Active alluvial fan.

Comment: Soft sand bed with dumps of angular rock. Note the light grayish colored rock along the streambed in this and photo 10 above that is indicative of recent abrasion during sediment transport. The rock along the banks is slightly browner because of oxidation and less abrasion. The bank is composed of cemented rock and is considered stable



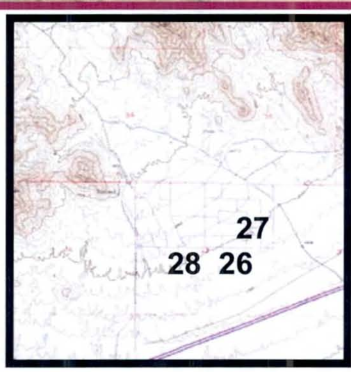
Skyline 25
Scene: Looking downstream at channel with bedrock pediment bed.
Landforms: Inactive alluvial fan with pediment bedrock.
Comment: Channel is cut several feet below the surface to bedrock. Torrifluvents are about 35 to 80 percent gravel, cobbles and boulders. Surface is undulating and dissected by many stream channels that have cut a few feet below the surface as shown by the contour crenulations on the photo location map to the right.
Further Reference & Sources: For further information on soil characteristics see NRCS soil type TB (Hartman, 1977).

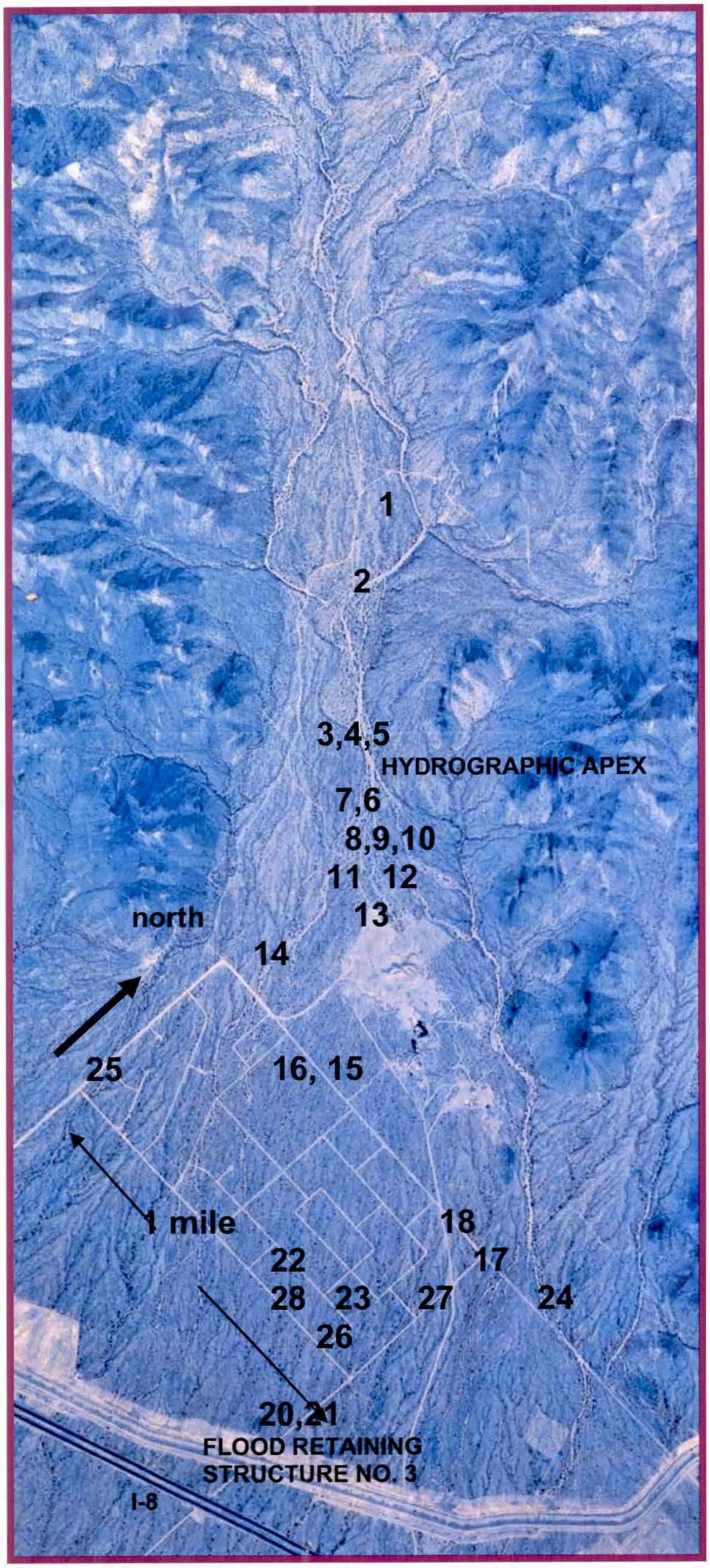


Skyline 26
Scene: Looking east at small channel that heads on gently undulating unconsolidated gravelly loam.
Landforms: Alluvial fan
Comment: Surface material is easily eroded by concentrated flows. Some scattered areas of desert pavement.
Further Reference & Sources: See NRCS soil type AGB (Hartman, 1977).

Skyline 27
Scene: Looking north at relatively level stable land surface.
Landforms: Relict fan.
Comment: Desert pavement with desert varnish. Note the smooth contour lines on the location map below.
Further Reference & Sources: See NRCS soil type GYD (Hartman, 1977).

Skyline 28
Scene: Looking upstream and north at join of two small channels that head on the alluvial fan.
Landforms: Alluvial fan. Mountains in background.
Comment: Typical channels that head on the fan.
Further Reference & Sources: See NRCS soil type AGB (Hartman, 1977).





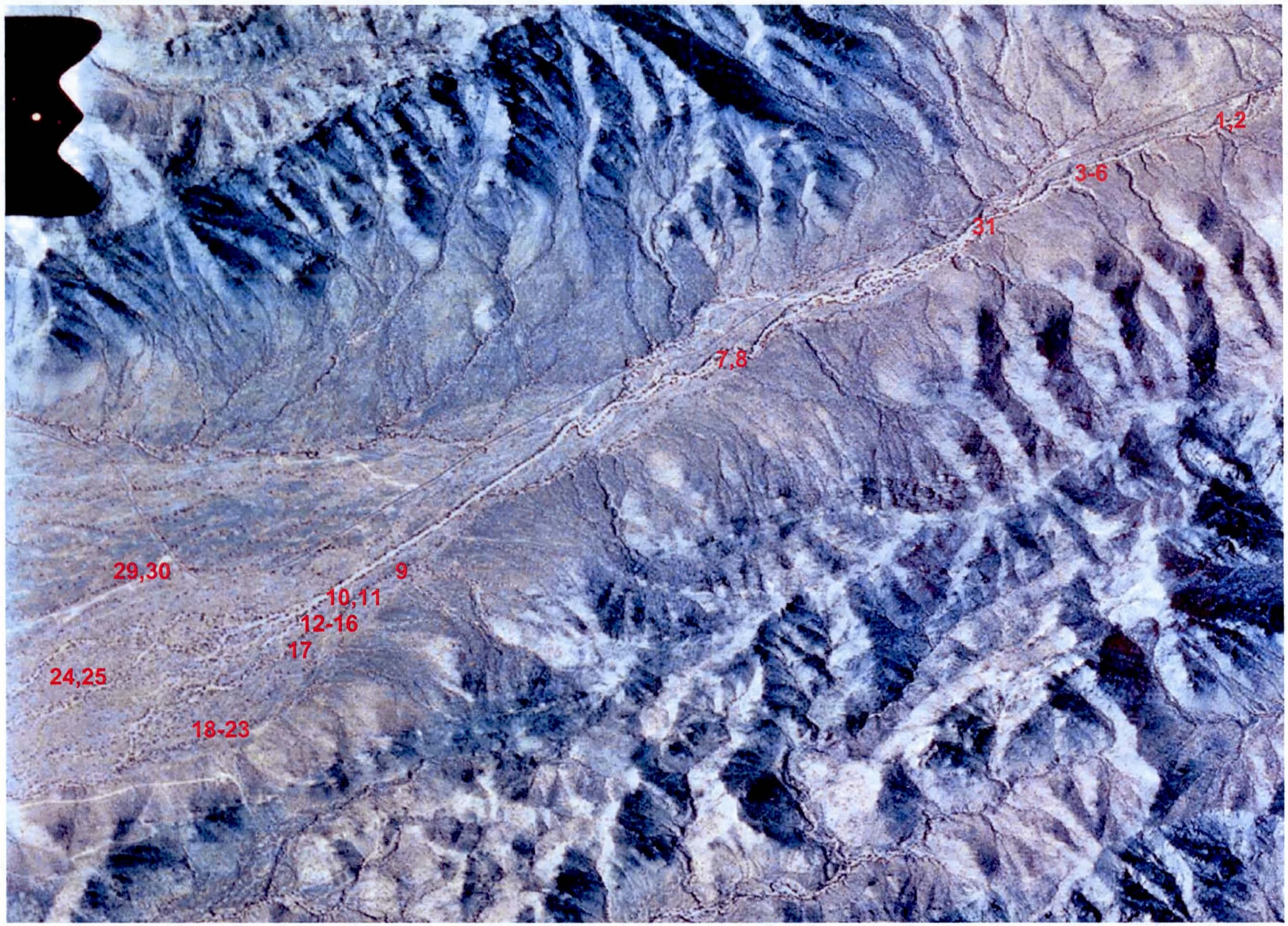
Skyline 29

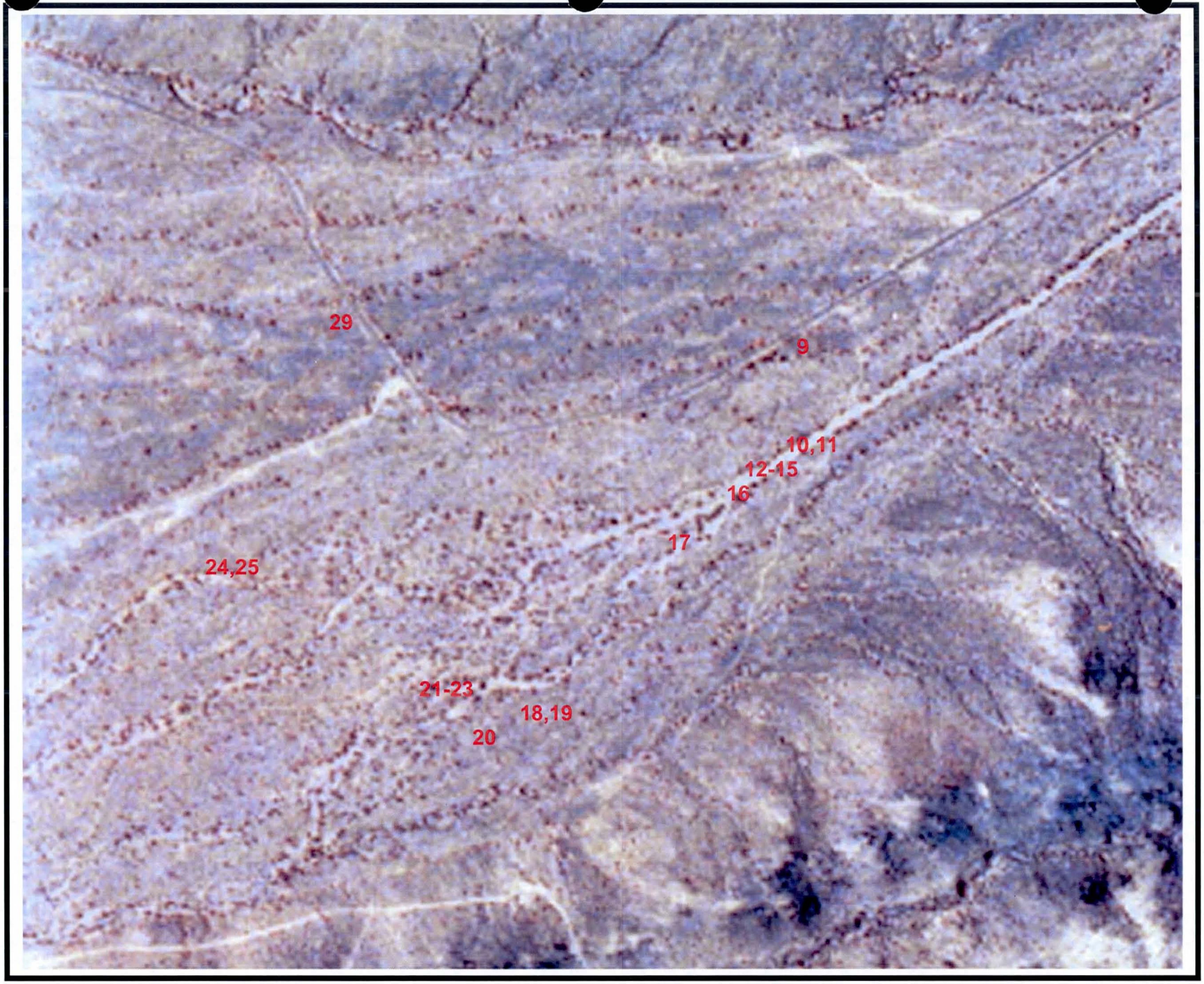
Scene: Color infrared aerial photograph of headwater streams and alluvial fan.

Comment: The numbers correspond to the photographs on the preceding pages of this appendix.

Note: The light shaded sand channels upstream (north) of the hydrographic apex. The large amount of stored sand in these channels suggests a large flood may carry the sand to the alluvial fan downstream. The storage may be approaching a threshold amount that could be released by a large flood.

Appendix I. South Mountain Park site

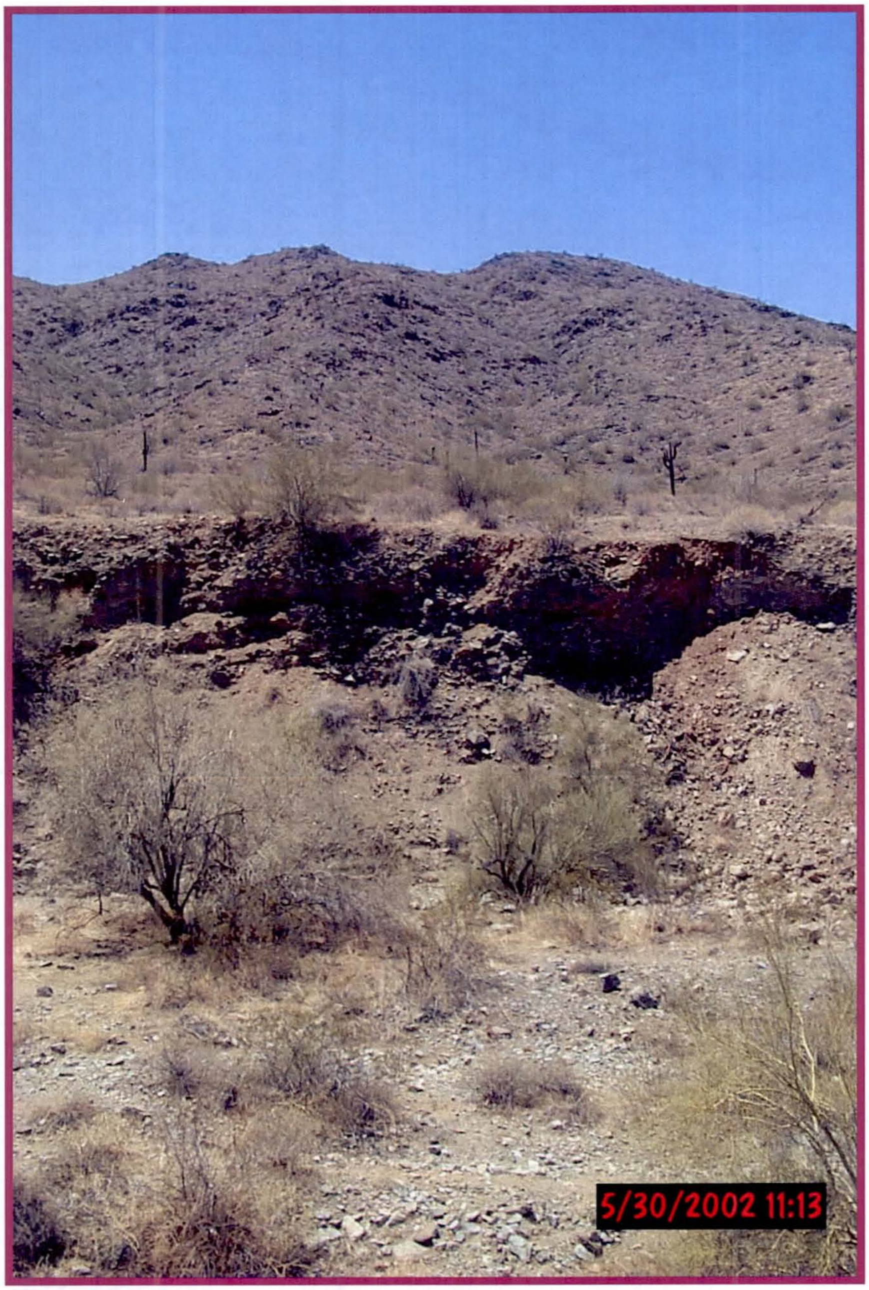



29
9
10,11
12-15
16
17
24,25
21-23
18,19
20

View looking west at road to the San Juan overlook at about mile 1.8. Drainage basin is beyond the drainage divide in background at about mile 2.1.

South Mountain Park 1

Scene: Looking downstream and west at throughflow channel from pullout-parking area at mile 2.5. Estrella mountains are in distant background. Topographic apex is upstream of this scene.



South Mountain Park 2
Scene: Looking south and across throughflow channel at left bank.
Landforms: Channel deeply incised in old cemented very gravelly cobbly material of relict fan. Mountain of drainage basin in background.
Comment: Scene is at mile 2.5. The old fan material is the source for much of the alluvium of the active alluvial fan downstream.
Further Reference & Sources: For further description of the soil see NRCS report by Hartman (1977).

South Mountain Park 3
Scene: **Looking upstream and east at main channel and tributary entering on south or left bank side of main channel.**
Landforms: **Upper slopes of old alluvial fan. Mountains in background.**
Comments: **Considerable desert pavement on old fan. Considerable dark desert varnish on most rock in scene except along incised channels and sloughed areas along steep banks.**

This channel is considered stable in realistic assessments of flood risk. The coarse bed material will be remobilized by large floods but the amount of change of geometry and roughness is set aside.

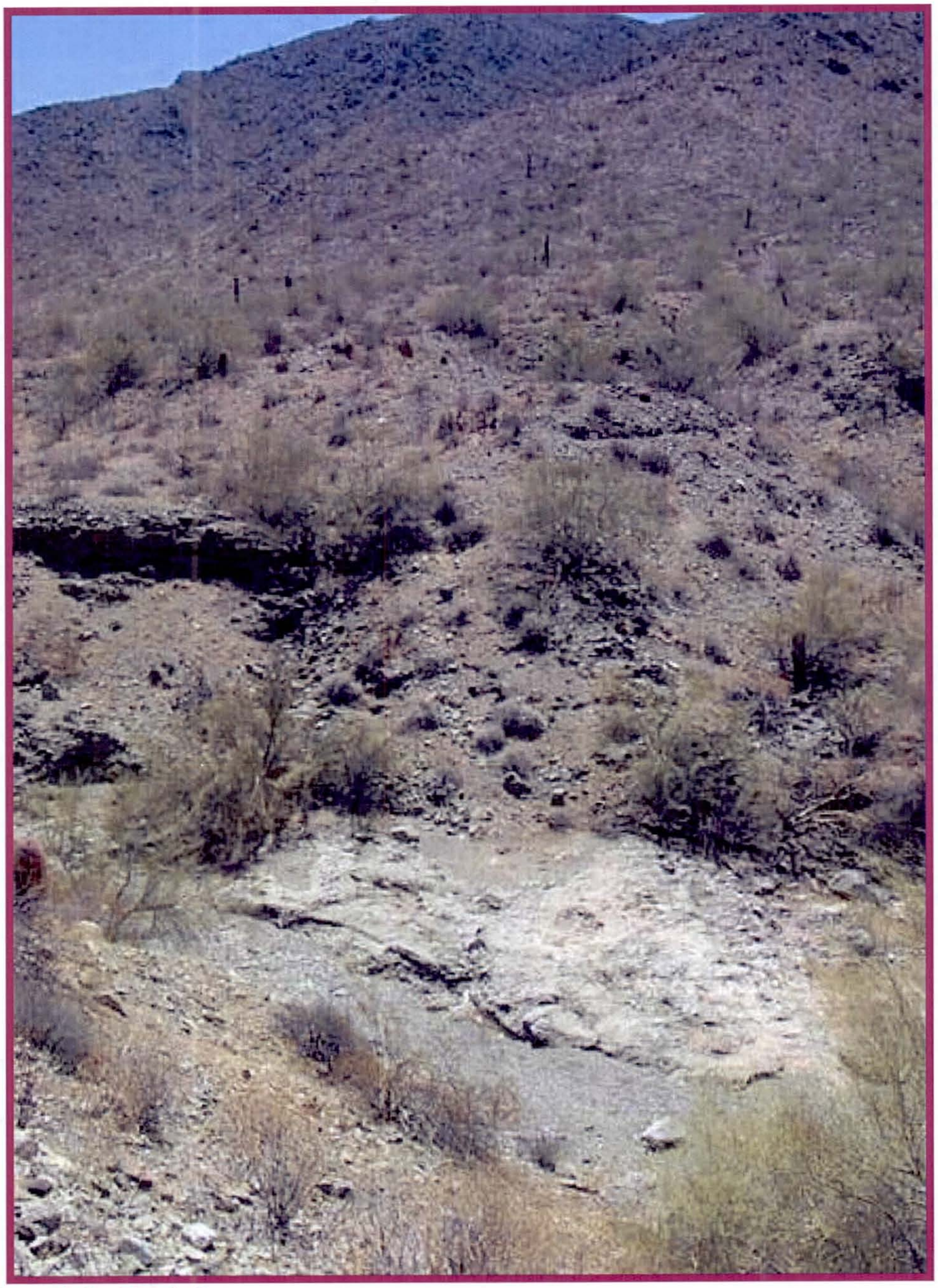
Note the light grayish colored rock along the streambed that is indicative of recent abrasion during sediment transport.

South Mountain Park 4

Scene: **Looking across at headwater mountains from roadway at mile 2.6.**
Landforms: **Upper slopes of old fan. Mountains of drainage basin in back.**
Comment: **Desert pavement and desert varnish on interfluves. Lower slopes are considered rather stable and channels stable or eroding.**

South Mountain Park 5

Scene: **Looking upstream from right bank (at mile 2.6) at main channel with bedrock bed in the foreground. Channel incision from headcutting is restricted at this location.**



South Mountain Park 6
Scene: Looking down at bedrock bed of throughflow channel at mile 2.7.
Landforms: Old alluvial fan on pediment.
Comment: Upstream channel erosion from general channel headcutting restricted by this bedrock.

South Mountain Park 7
Scene: Looking down and west at desert pavement with desert varnish at mile 3.
Landforms: Inactive alluvial fan.
Comment: This is a good example of dense desert pavement with desert varnish. This surface is old, has not experienced fluvial sedimentation for a long time and is considered stable for reasonable assessments of flood hazard. The tightly packed gravel armors the underlying soil. The dark desert varnish suggests that abrasion and burial of the rock surface has not occurred for several thousand years.
Desert varnish that forms on stable stones of large alluvial surfaces can be a reliable indication of the absence of significant floodflow during the past few thousand years. A dark-brown desert varnish on the surface of stones exposed to the atmosphere may indicate that the stones have been undisturbed for perhaps 3,000 to 5,000 years (Dorn and Oberlander 1982) A black surface stain indicates the absence of significant flood depths and velocities for perhaps 10 000 years or more. According to Dorn and Oberlander (1982), a blackish manganese-rich varnish takes many thousands of years to coat completely the tops of stones. Desert varnish is seldom found on the surface of stones such as granite fragments that weather easily in the desert environment of the southwestern United States. A typical varnished stone in central and southwestern Arizona has a dark-brown "varnished" top and a reddish-brown "rusted" bottom like the overturned stones above the rod in the scene above.
Further Reference & Sources: For additional information on desert varnish see Dorn and Oberlander (1982) and Dorn, Donahue, Linick, and Toolin (1989).

South Mountain Park 8

Scene: Looking down and west at desert varnish with microbiotic soil crust.
Landforms: Inactive alluvial fan.
Comment: Microbiotic soil crusts suggest a stable surface for tens of years. However, for this site the lightly packed desert pavement with the varnished pebbles suggests a stable surface for a much longer period.

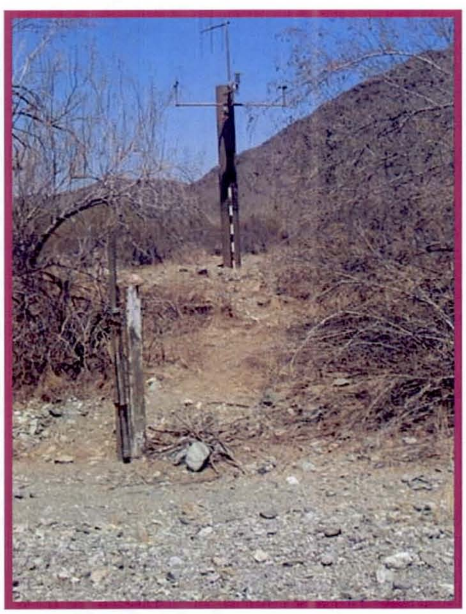
South Mountain Park 9

Scene: Looking down at well developed desert varnish on desert pavement.
Landforms: Inactive alluvial fan.
Comment: Very tightly packed desert pavement with very dark rock varnish. Surface appears stable for few thousand years.

South Mountain Park 10

Scene: **Looking downstream at right bank of throughflow channel near gage just above the hydrographic apex.**

Landforms: **Incised channel in stable alluvial fan. Sierra Estrella Mountains in background.**



South Mountain Park 11

Scene: **Looking north at gages.**

Comment: **Note the light grayish colored rock along the streambed in this and photo 10 above that is indicative of recent abrasion during sediment transport. The rock along the banks is slightly browner because of oxidation and less abrasion. The bank is composed of cemented rock and is considered stable.**

South Mountain Park 12
Scene: **Looking downstream from near gage at hydrographic apex.**

South Mountain Park 13
Scene: **Looking downstream at fork where distributary channel on the right is steepened.**
Comment: **Note the mound of angular rock in center of scene with braided channel to the right. This scene is about 100 ft downstream of photo 12.**
Further Reference & Sources: **A more detailed description of flooding processes of streamflow fans is given on page 33 of National Research Council (1996).**

South Mountain Park 14
Scene: Looking upstream from near gage at throughflow channel with upper crest stage gage on the left side of the scene.

South Mountain Park 15
Scene: . Looking downstream at fork and mound of fresh debris in center of channel at upper end of active alluvial fan.
Landform: Apex of active alluvial fan.
Comment: Note the mounding of debris in the main channel. There is general mounding on the alluvial fan from here to about 1,200 ft downslope.

South Mountain Park 16
Scene: Looking downstream at right channel at fork shown in photo 15.
Landforms: Active alluvial fan.
Comment: Cobble and boulder deposit with subsequent scour in foreground and along right side.

South Mountain Park 17
Scene: Looking downstream at fork of braid with debris mound along the south site of the active alluvial fan.
Landform: Active alluvial fan.
Comment: Same site as in photo 16 above. Note mounded appearance.

South Mountain Park 18
Scene: Looking northeast and across the lower part of the active alluvial fan.
Landforms: Southern edge of active alluvial fan.

South Mountain Park 19
Scene: Looking upstream and east along south side of active alluvial fan.
Landforms: Inactive fan in right foreground. Active fan with mountains in back.
Comment: Note rock varnish on boulders of inactive fan.

South Mountain Park 20
Scene: Looking northeast and across upper end of inactive alluvial fan and lower end of active alluvial fan.
Landforms: Transition between active and Inactive alluvial fans

South Mountain Park 21
Scene: Looking south from upper end of inactive alluvial fan at left side of fan.
Comment: Channel geometry unstable in this area.

South Mountain Park 22
Scene: Looking north across inactive alluvial fan from same location as photo 21.
Comment: Distribution of flow uncertain because site is below the active alluvial fan.

South Mountain Park 23
Scene: Looking north across inactive alluvial fan at undulating topography and angular rock.
Landforms: Inactive alluvial fan

South Mountain Park 24.
Scene: Looking upstream along the north side of the lower part of the active alluvial fan at deposit of angular boulders.
Comment: Distribution of floodflow is uncertain.

South Mountain Park 25
Scene: Channel material along north side of inactive alluvial fan.
Comment: The lack of oxidation on the rock surfaces clearly indicates recent abrasion from floodwater. The angular rock is typical of a nearby source and the calciul carbonate on many of the rocks indicates the rock if from relict fan deposits like those in photos 1 and 2 of this appendix.

South Mountain Park 26
Scene: Looking downsteam and west at incised stable channel of inactive fan.

South Mountain Park 27
Scene: Looking east.
Landforms: Mountain
Comment: Heavy varnish

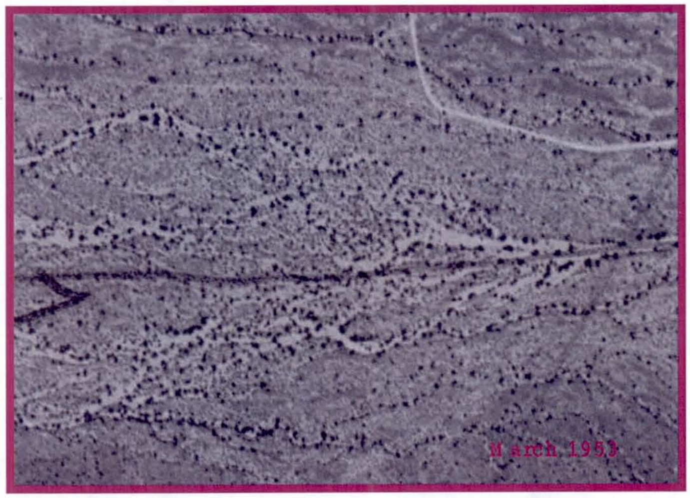
South Mountain Park 28
Scene: Looking down at desert pavement with desert varnish.
Landforms: Inactive alluvial fan
Comment: This surface represents the desert pavement in this area.

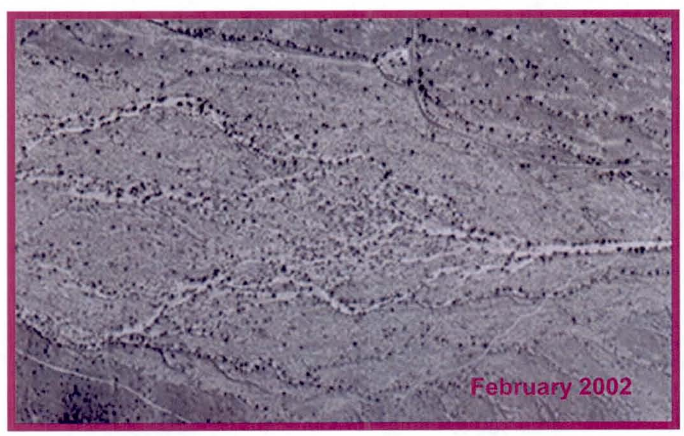
South Mountain Park 29
Scene: Desert varnish typical of the dark varnish to the north of the active and inactive alluvial fan areas.
Comment: This is an old-stable surface. Note the overturned stone with reddish-brown "rusted" bottom. See photo 30 on next page for scene of this location.

South Mountain Park 30
Scene: Looking west at desert pavement and some desert varnish.
Landforms: Inactive alluvial fan
Comment: See photo 29 on previous page for surface detail at rod.
The surface has areas of tightly packed gravel that armor a thin layer of sand and silt. The smooth surface probably is caused by obliteration of the original relief by downwasting into depressions.

South Mountain Park 31
Scene: Looking north at tributary incised in bedrock pediment.
Landforms: Mountain and pediment

The deposits of angular rock below the hydrographic apex of the South Mountain Park alluvial fan are mounded in the area of distributary and braided channels shown in the photographs to the right. The angular alluvium that forms the mound is light colored indicating recent abrasion during transport from the nearby headwater mountains. Little, if any, flowpath movement since March 1953 is evident based on examination of the aerial photos. Some sediment movement at a few places along the flowpaths is suggested but no major changes in the flowpaths or width of sediment is apparent. Also, little scour is indicated because few trees have been removed since March 1953.



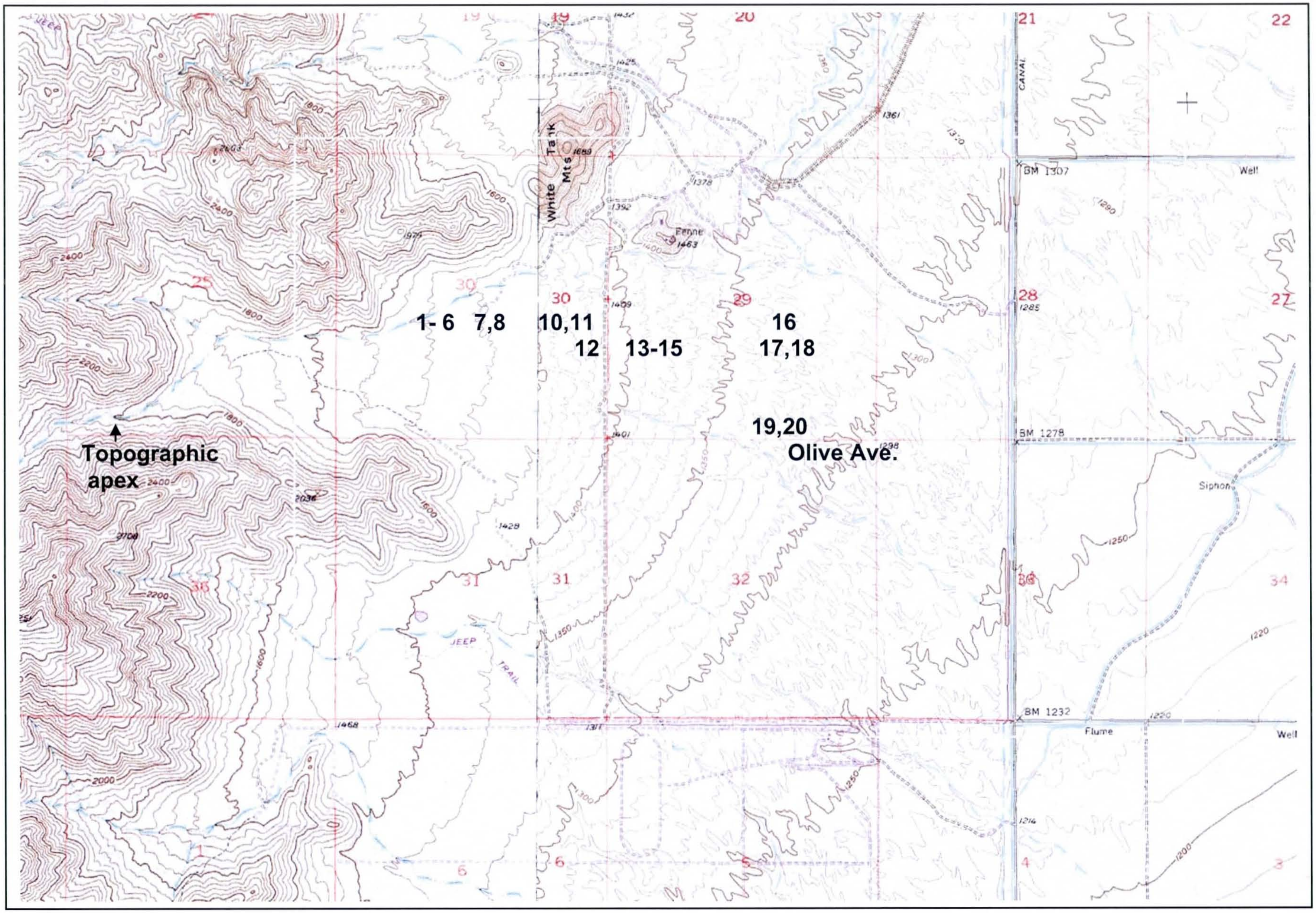


The lines on the photo of March 1953 are from a pencil.

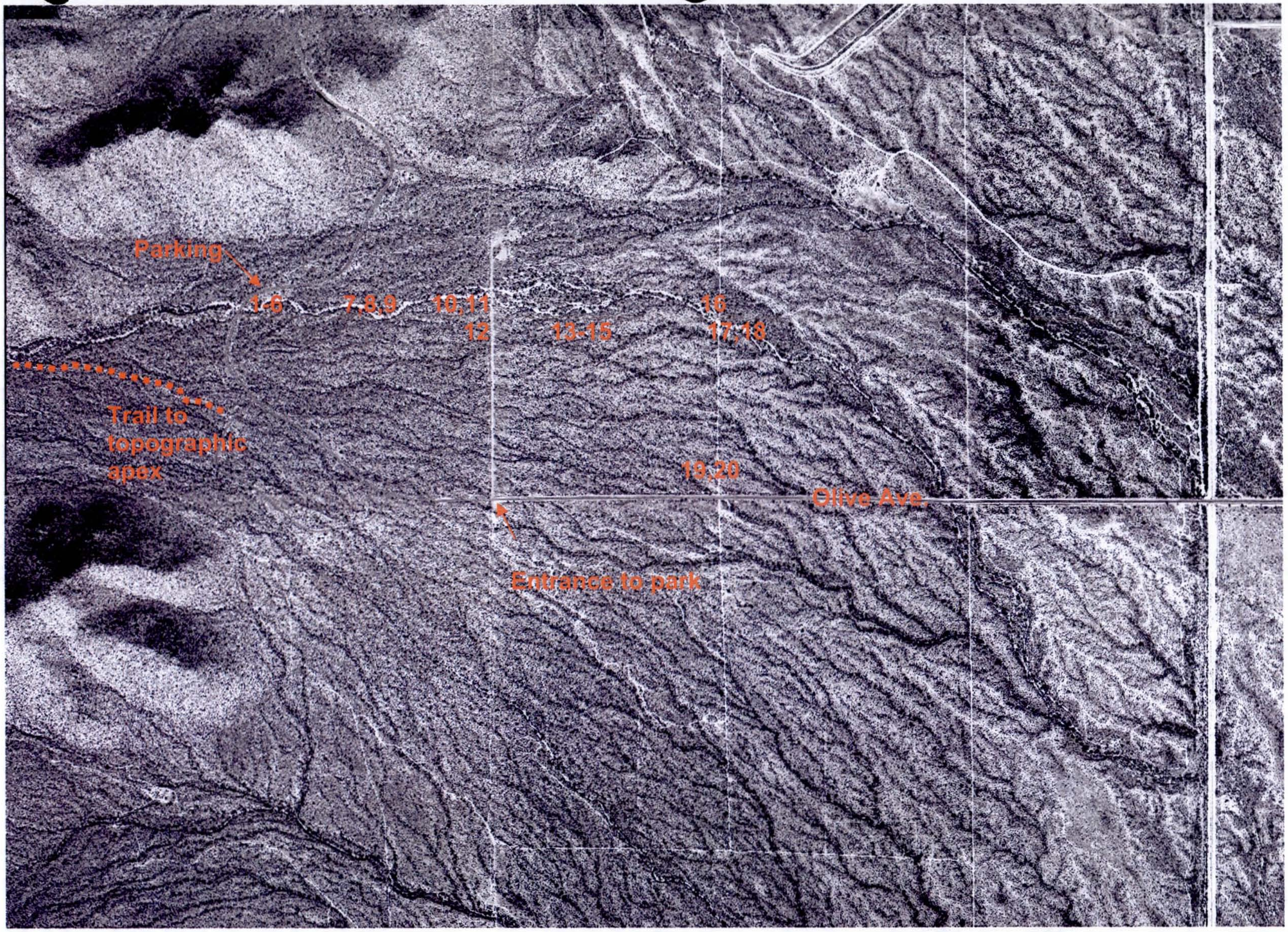
The differences in brightness and contrast among the three photos is related to the age of the photos and the lighting conditions when the photos were taken. The differences in brightness, contrast and surface texture within each of the photos is mostly related to the type of landform, age of the surface and vegetation as discussed in this manual.

South Mountain Park 32
Scene: Aerial photographs of active alluvial fan

Appendix J. White Tank alluvial fan—Location of photographs

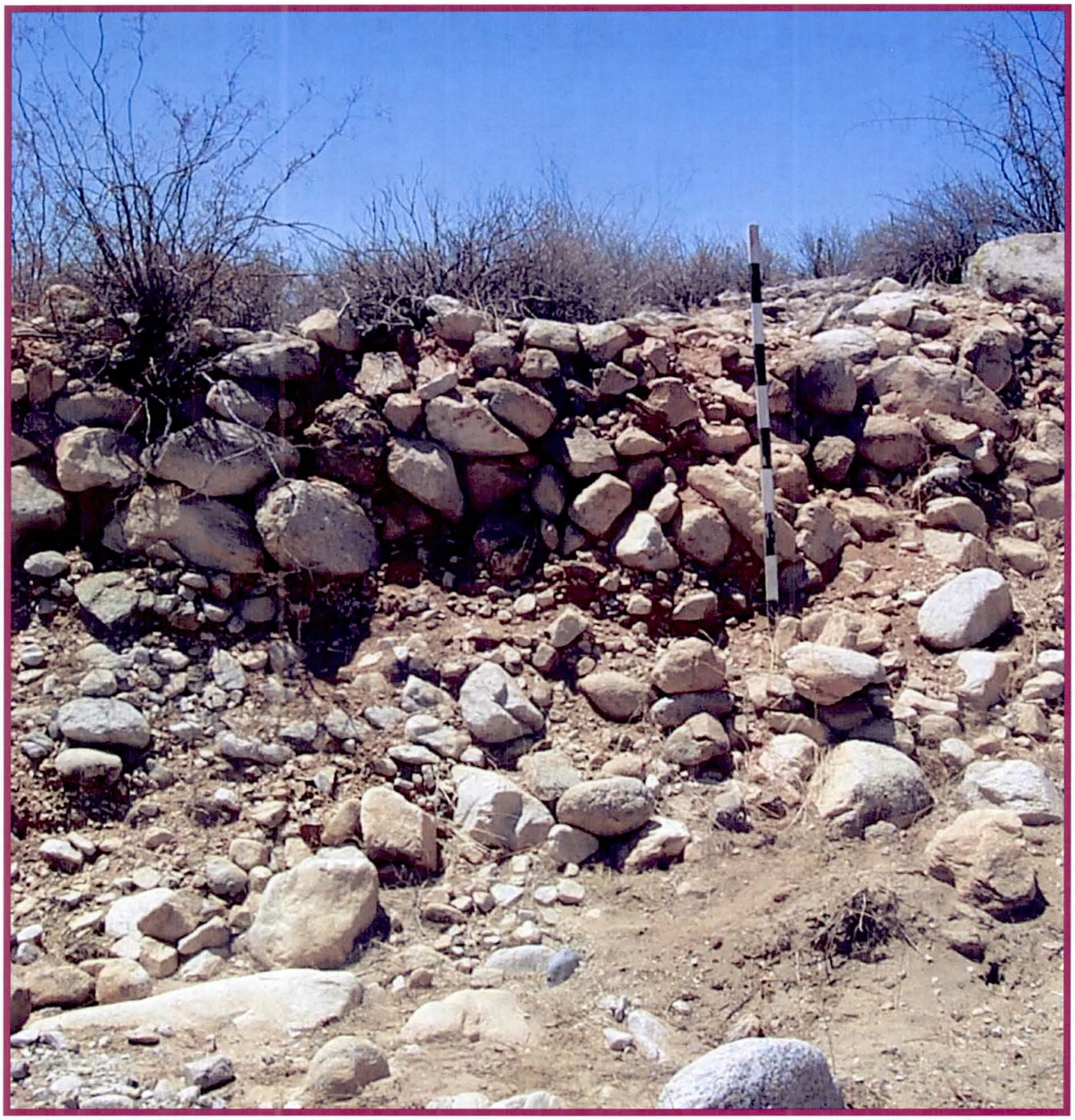


White Tank alluvial fan—Location of photographs on aerial photograph.



White Tank 1
Scene: Looking downstream from paved road crossing at main channel.
Landform: Inactive alluvial fan.
Comment: Note survey rod with ½ ft intervals next to orange flag.

White Tank 2
Scene: Looking upstream and across at main channel and overflow area on right bank at upper end of bend.
Landforms: Inactive alluvial fan. Mountains in background.
Comment: See photograph 4 for view of overflow area with orange flag.



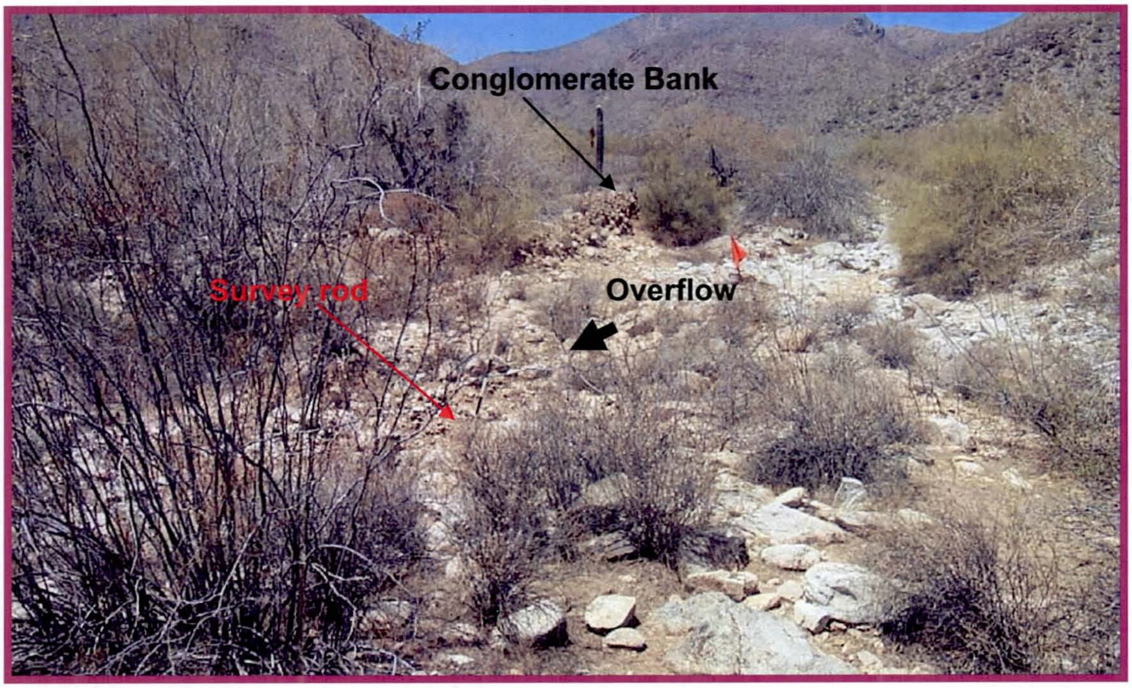
White Tank 3.

Scene: **Conglomerate along right(south) bank of incised throughflow channel.**

Landforms: **Inactive alluvial fan.**

Comment: **Site is 150 ft. downstream of paved road and upstream of the parking area at the restrooms. Note the boulder position that suggests imbrication and boulder angularity that suggests a nearby source of rock. Intervals of survey rod are ½ ft. Photo taken June 12, 2002.**

Further Reference & Sources: **For additional information on calcic soil development see Christenson and Purcell (1985) and Camp (1986). For additional information on incised channels on fans see page 38 of National Research Council (1996).**



White Tank 4
Scene: Looking upstream and west at throughflow channel where high flows have spilled over the right bank.
Landforms: Inactive alluvial fan. Headwater mountains in background.
Comment: Spill first occurs near the orange flag.

White Tank 5
Scene: : Looking upstream and west at downstream side of overflow area where headcut has progressed to within several feet of the right bank of the throughflow channel (orange flag).
Landform: Inactive alluvial fan.
Comment: Headcut is nearly 3 ft at the survey rod. Rod and flag are at same locations in photos 4 and 5.

White Tanks 6

Scene: Looking downstream and east at throughflow channel that is incised in the boulder conglomerate.

Landforms: Old inactive alluvial fan.

Comment: The channel geometry appears stable but there are several boulder dumps, possibly from debris flows, along the throughflow channel. The boulder mounds can significantly decrease the conveyance capacity of the channel.

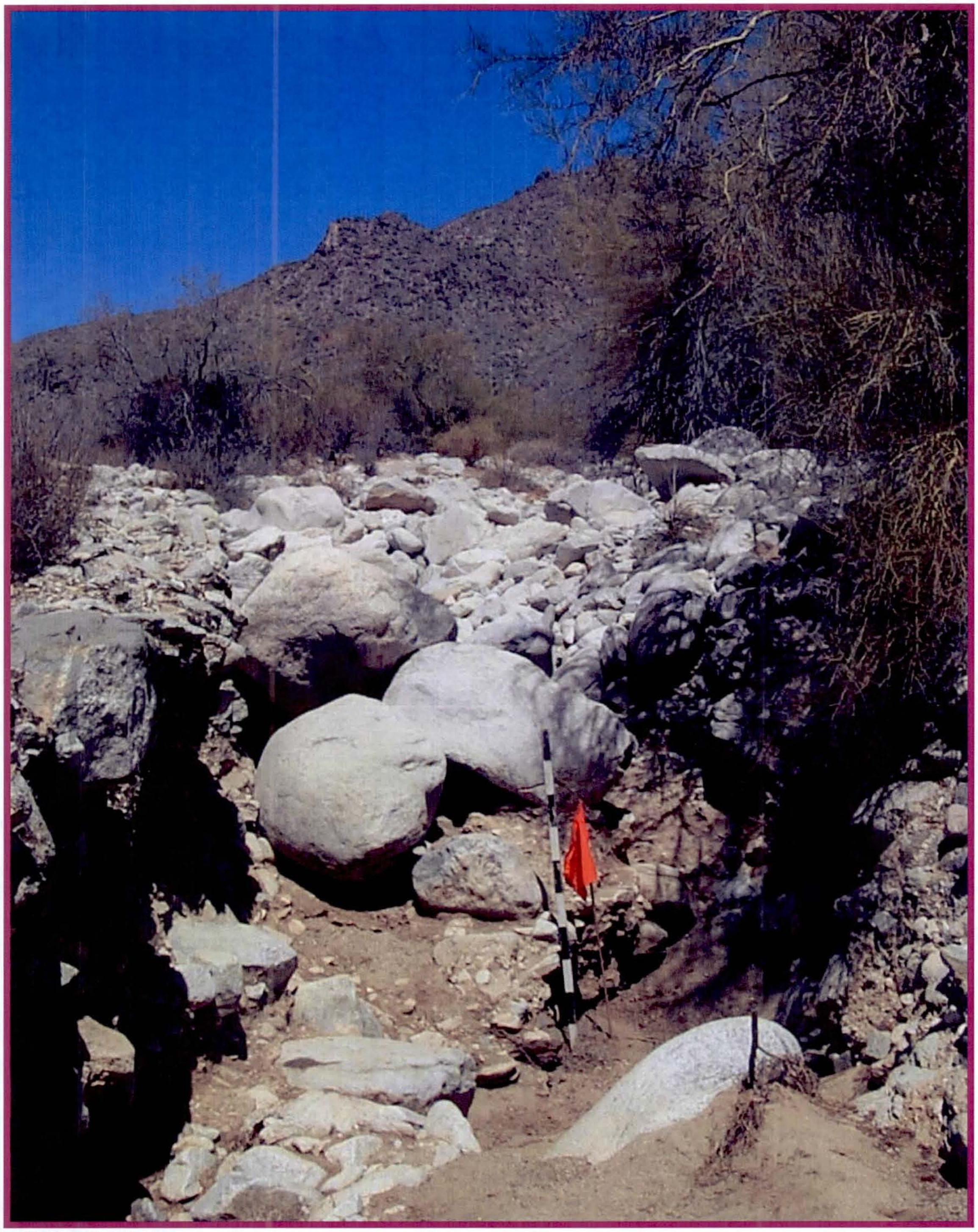
The restrooms at the parking area are to the left.

White Tank 7.

Scene: Looking upstream at headcut in boulder conglomerate.

Landforms: Inactive alluvial fan.

Comment: A good example of headcutting in conglomerate.



White Tank 8

Scene: Looking upstream at headcut and scour hole in boulder channel bed.

Landforms: Inactive alluvial fan.

Comment: Rod and orange flag are in a local 1 ft deep scour hole. This is a closeup of headcut in photo White Tank 7.

Further Reference & Sources: Schumm, Harvey and Watson (1988) is suggested for further discussion of incised channel morphology.

White Tanks 9

Scene: **Looking upstream at right(south) bank of throughflow channel.**

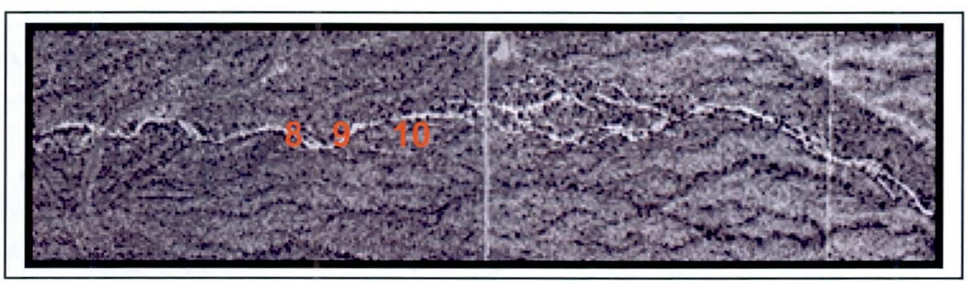
Landforms: **Inactive alluvial fan.**

Comments: **The channel is incised in old boulder conglomerate. Two distinct ages of the bank material are indicated by the change in color and composition at the orange flag. Of importance for the assessment of flood hazard is both alluvial deposits that form the banks and bed are old cemented material.**

The conglomerate banks are generally stable but the steep upper side slope with the sharp crest suggests recent flooding with bank erosion in addition to the cementation by calcium carbonate. Some lateral bank movement during large floods is considered likely.

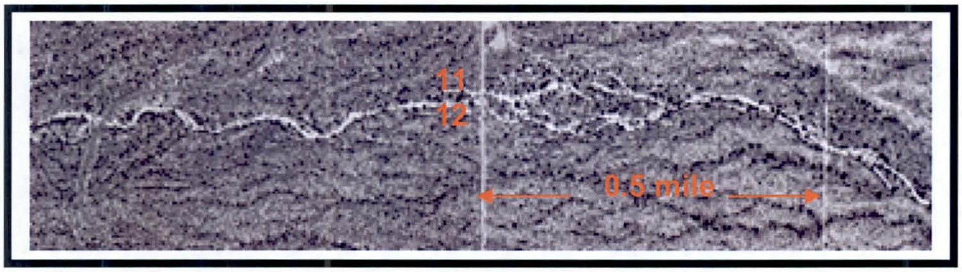
The frontal lobe of a boulder dump in the channel is shown in the right-center of the scene.

Further Reference & Sources: **For additional information on calcic soil development see Christenson and Purcell (1985) and Camp (1986).**

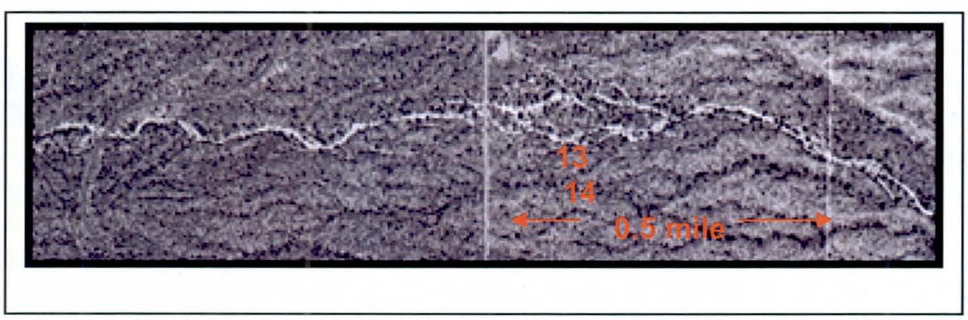


White Tanks 10
Scene: **Looking upstream at boulder deposit in main channel.**
Landforms: **Inactive alluvial fan**
Comment: **There are several of these localized boulder dumps that locally significantly reduce channel conveyance along the incised channel.**

White Tank 11
Scene: **Looking downstream at upper end of braided channel area where a small channel splits to the left (to the left of the orange flag) or north of the main channel**



White Tank 12
Scene: Looking downstream at main channel to right of photo 11.
Landforms: Braided channels along throughflow channel incised in inactive alluvial fan.
Comment: This rather narrow incised drainage way widens below this location and is filled to a width of about 600 ft. with coarse alluvium. There are braided channels for about 0.3 mile along the filled reach.



White Tank 13

Scene: **Looking north and across at braided channel area from right bank.**

Landforms: **Braided channels inset in inactive alluvial fan. Mountains in back.**

Comment: **Note the old boulder dump in the left foreground on the inactive fan.**

White Tank 14

Scene: **Looking upstream at inactive alluvial fan with watershed in the background.**

Landforms: **Inactive alluvial fan.**

Comment: **The many old boulder dumps on the alluvial fan suggest debris flows have influenced the fan morphology.**

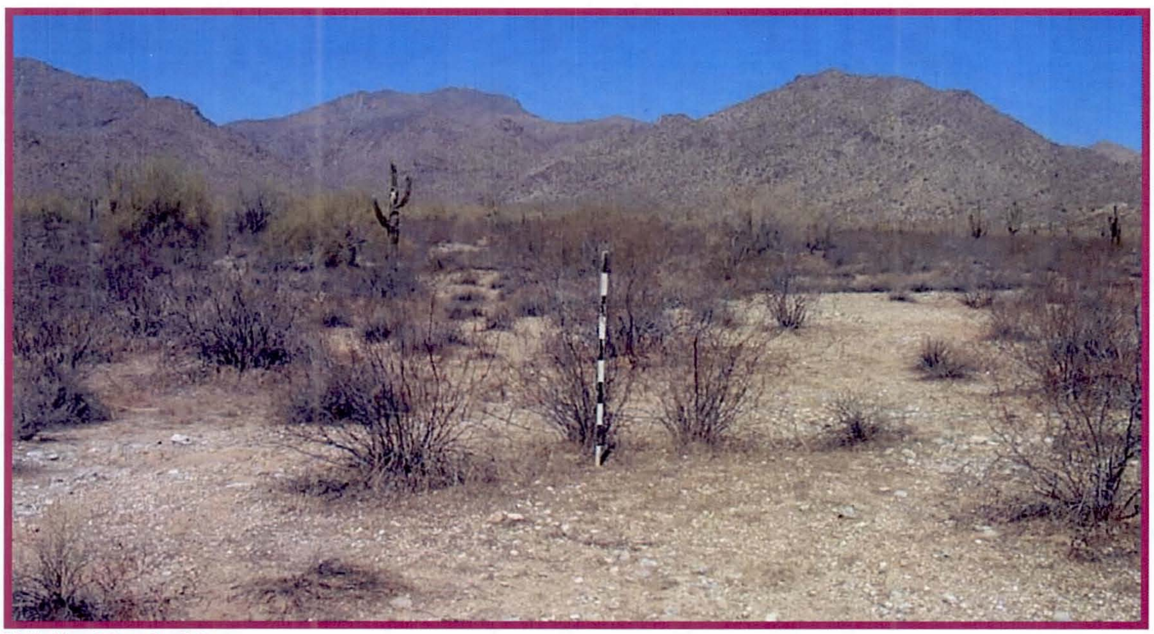
Further Reference & Sources: **For discussion of debris flow processes at a site in California see Whipple and Dunne (1992).**

White Tank 15

Scene: **Looking down and east at inactive alluvial fan.**

Landforms: **Inactive alluvial fan.**

Comment: **Palo Verde trees along the throughflow channel are on the left of the scene. Considerable desert pavement with dark desert varnish on undisturbed boulders indicate the surface is stable. The surface has areas of tightly packed gravel that armor a thin layer of sand and silt. The surface has not experienced fluvial sedimentation for a long time, as shown by the thick varnish coating on the larger stones. The smooth surface probably is caused by obliteration of the original relief by downwasting into depressions.**



White Tank 16

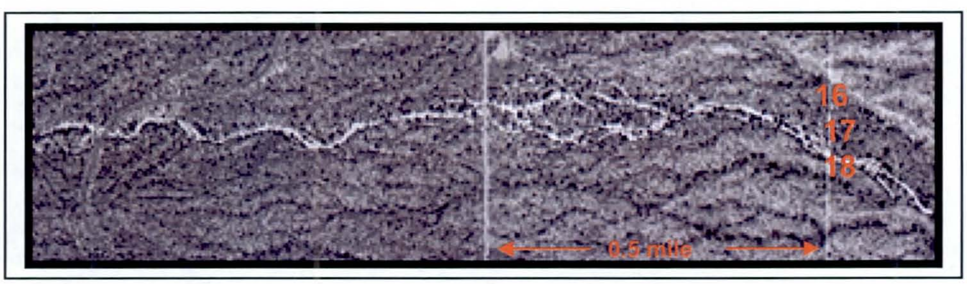
Scene: **Looking upslope and west along north side of throughflow channel.**

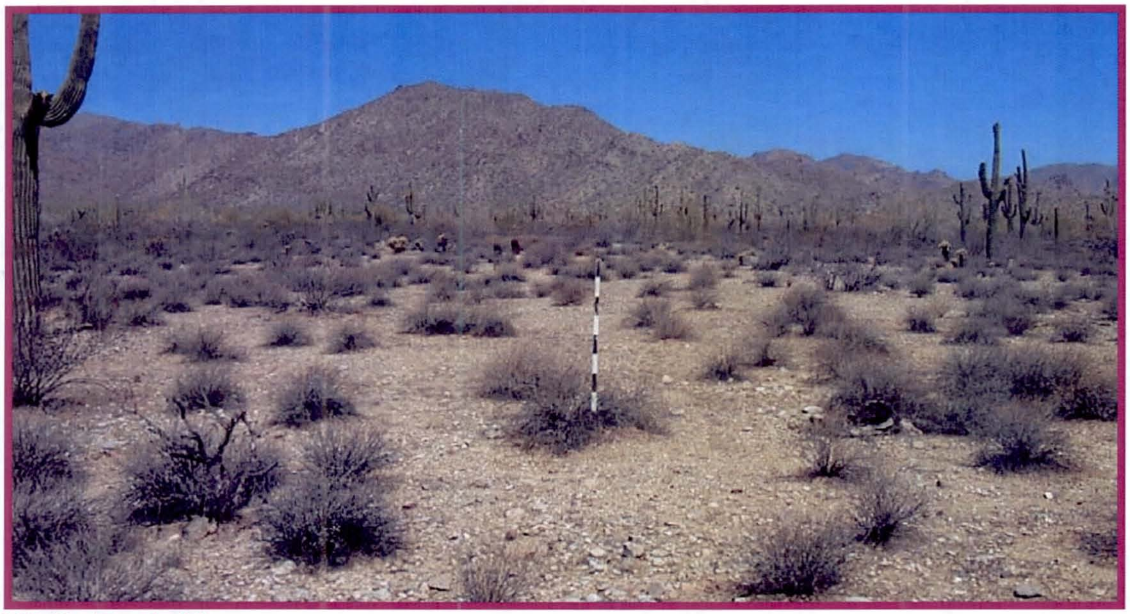
Landforms: **Inactive alluvial fan.**

Comment: **Desert pavement with light varnish on some stones.**

White Tank 17
Scene: : **Looking upstream and west at small north braid of throughflow channel.**
Further Reference & Sources: **See photo 18 for adjacent scene to the south.**

White Tank 18.
Scene: **Looking upstream and west at main channel of braided throughflow channel.**
Landforms: **Incised channel on inactive alluvial fan.**
Comment: **Note the cobble and boulder debris dumps in this and photo 17 above.**





White Tank 19
Scene: **Looking upslope and west at inactive alluvial fan.**
Landforms: **Inactive alluvial fan. Mountains of drainage basin in background.**
Comment: **Classic desert pavement with light desert varnish on many pebbles.**

White Tank 20
Scene: **Looking down at inactive alluvial fan at site in photo 19.**
Further Reference & Sources: **For description of biological soil crusts and the effects of "gluing" loose soil particles together see BLM training manual (Course No. 1730-41) Role of Microbiotic Soil Crusts in Rangeland Health and/or Belnap (1995).**

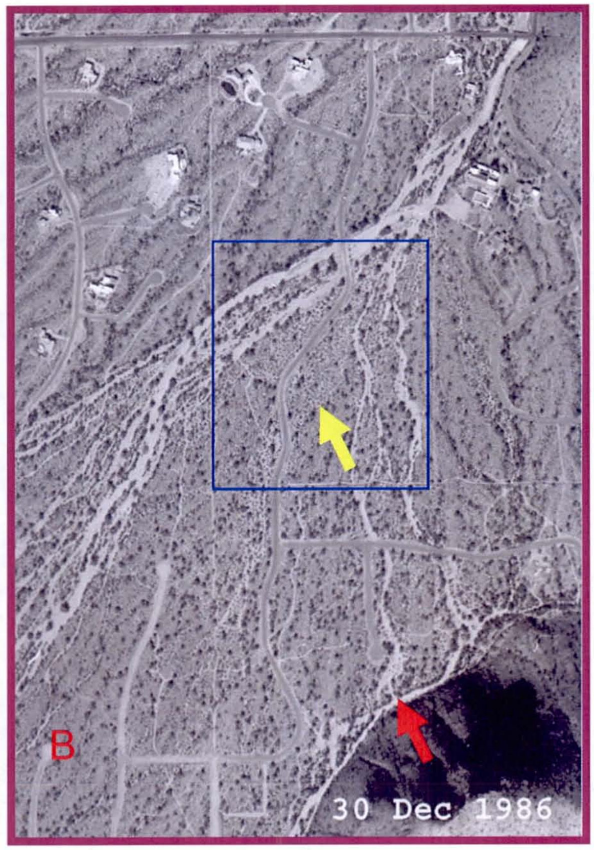
Appendix K. Reata Pass Alluvial Fan

A variety of surface texture is gleaned in the upper part of the Reata Pass alluvial fan (Figure K1). This site also contains additional information on changes in surface texture over time shown in aerial photographs taken from 1964 to 1997 (Figures K2 to K4). Figure K2-A shows the surface texture of the active fan on January 2, 1964. Figures K2-B & C were taken a few years following a large flood on June 22, 1972 and show a salt and pepper (coarse stippled) surface texture where there was sheet flow.

Channel movement along the west side of the channel, indicated by the red arrow (Figures K2 A & B and K3), resulted during floods of June 22, 1972 and August 29, 1996. The fresh cut channel bank is shown in Figure K4.

This site is described in USGS WRI 93-4169 (Site 6, Hjalmarson, 1994), in Alluvial Fan Flooding (pages 33-34, National Research Council, 1996) and also Rhoads (1986).

Figure K1. Oblique aerial photograph of the Reata Pass alluvial fan on the western slopes of the McDowell Mountains showing distributary and braided channels with a variety of surface texture. The grainy salt and pepper pattern (for example the area indicated by the yellow arrow) is where there has been recent sheetflow. The darker relict fan areas that bound the active alluvial fan are covered with weeds, grasses, bushed and trees. The parallel ridgeline remnants of the relict fan have rounded tops bounded by erosional sholders the decend to concave drainageways. The darker-smoother areas on the active alluvial fan have not been flooded recently.



Figures K2 A-C. Aerial photos of upper part of Reata Pass alluvial fan showing changes of surface texture from flood of June 22, 1972. Erosion and sediment deposition from sheetflow produced a salt and pepper texture (for example at area indicated by yellow arrow). Other changes, some rather subtle microchanges, in surface texture are gleaned by comparison of the photos. Photo C is a blowup of the area in photo B.

The salt and pepper texture is produced as small ground cover such as grass and weeds are removed or buried leaving a light colored surface of fresh sediment or soil under the bushes and trees.

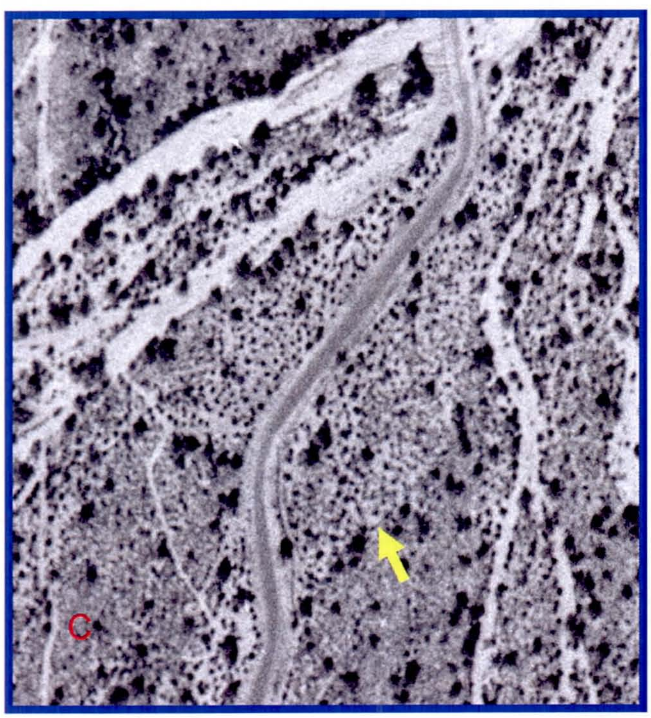


Figure K3. Aerial photo of upper Reata Pass alluvial fan taken on January 19, 1997 showing recent channel movement and recent changes of surface texture. Comparison with Figure K2-B shows an increase in the salt and pepper texture resulting from sheetflow during August 29, 1996 flood. Note the stippled texture along the wash in the relict fan along the right or east side of the photo.

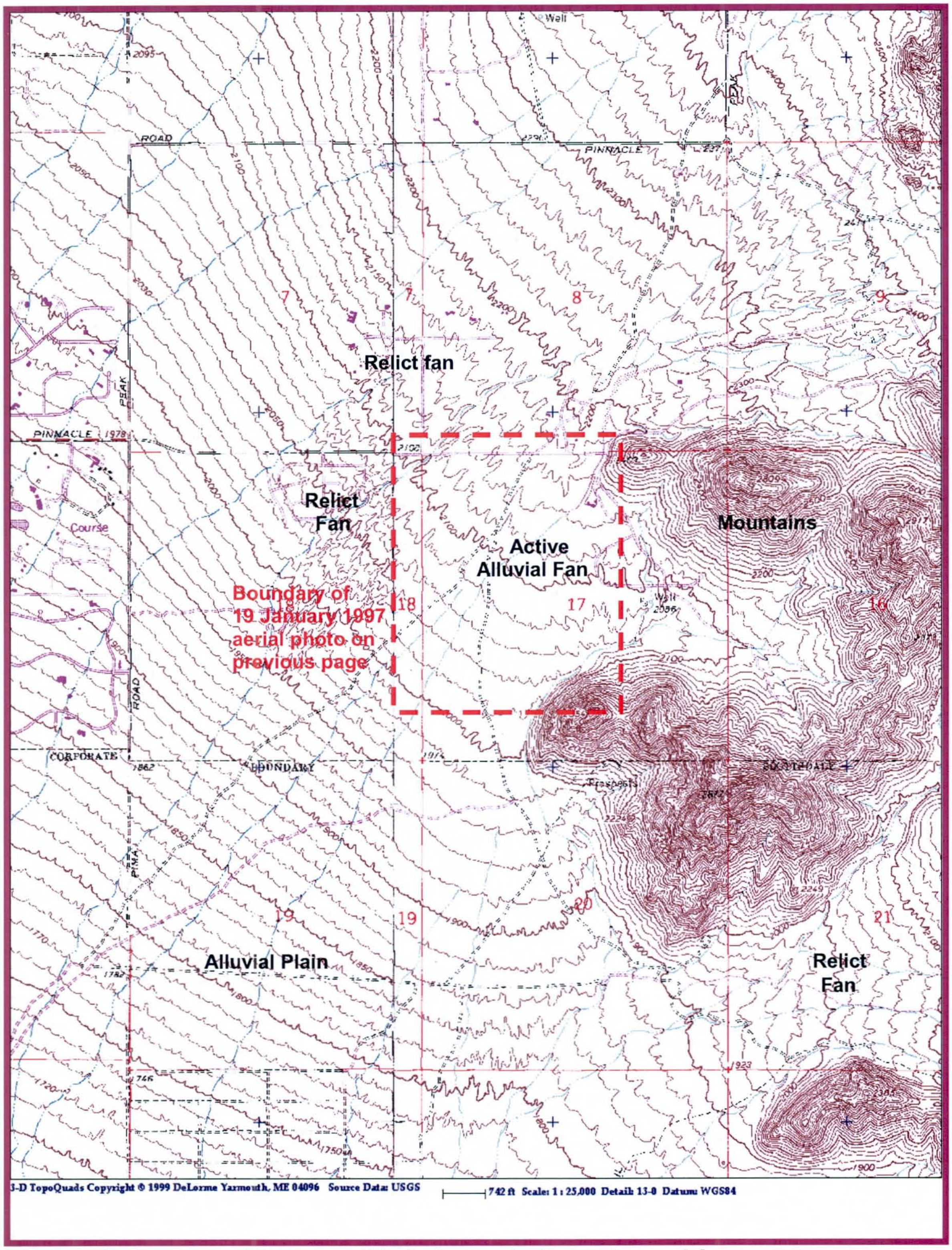
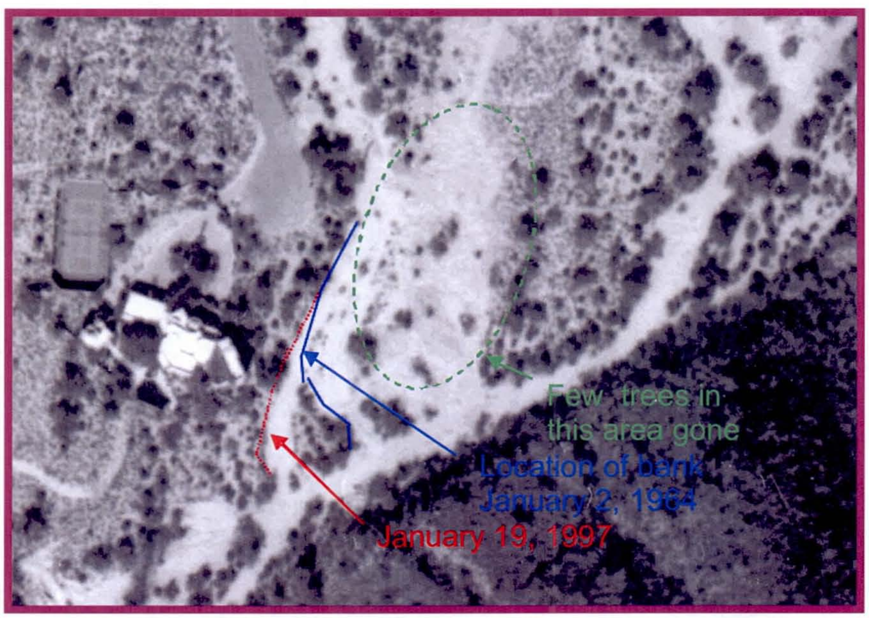


Figure K4. Topographic map with drainage texture gleaned from contour crenulations.

Figure K5. View looking upstream and north at west side of channel where bank has moved a few tens of feet to the west as a result of erosion mostly during floods on June 22, 1972 and August 29, 1996. This general area is indicated by the red arrow in photos K2 A & B and K3. Red arrow in Figure K5 is pointing at this location. Intervals on rod are 6 inches.

Figure K6. Aerial photo of January 19, 1997 showing bank move-ment (see area indicated by red arrow in Figure K3). Compare with photos K2A and K2B.
Red arrow is pointing at location of photo in Figure K4. Holocene alluvium of active fan has little calcium carbonate and is easily eroded.



Appendix L. Surficial geologic mapping and piedmont flood hazards in Maricopa County

by Philip A. Pearthree
Arizona Geological Survey

L1. Introduction

Surficial geologic maps provide information about the age and character of alluvial deposits on piedmonts that can be extremely useful in assessing the character of piedmont landforms and the nature and extent of piedmont flood hazards. All piedmonts in Maricopa County are covered by complex mosaics of surficial deposits with different physical characteristics related primarily to the ages of the deposits. The long history of stream behavior and flooding recorded in the geology and geomorphology of piedmonts provides a valuable perspective on floodplain-management issues. For example, on some piedmonts geologically young deposits are very extensive, suggesting that areas of active deposition have moved around or sheetflooding is an important process on the piedmont. On other piedmonts, young deposits are quite limited in extent, suggesting that the current channel and flow patterns are stable and have been for a long time.

Modern surficial geologic maps differentiate alluvial deposits based on physical characteristics of the deposits (sediment size and character) and geomorphic characteristics of the upper surfaces of the deposits. Differences in the primary physical characteristics of surficial deposits result from differences in rock types in drainage basins and differences in the size and character of the stream system that transported the sediment. Surficial deposits are subsequently altered by processes including weathering, soil development, and local erosion, so the character of the surface and near-surface portion of the deposits is related to the length of time that the deposits have been exposed at the surface. Information about the character and distribution of surficial deposits of different ages and sources may be used to help understand the recent geologic history of fluvial systems, explore possible linkages between fluvial deposition and climate changes and tectonic activity, evaluate potential for aggregate resources, and assess a variety of geologic hazards. Surficial geologic maps are extremely useful in defining the physical framework of active fluvial systems on piedmonts because these systems leave behind evidence of their activity in the form of young deposits.

Objectives. The primary purposes of this appendix are to explain the methods used in modern surficial geologic mapping, describe what criteria are used to map piedmont alluvial deposits, explore relationships between the geomorphology of the alluvial surfaces and their ages, and consider how surficial geologic mapping can be used to help understand the character and extent of piedmont flood hazards. This appendix concludes with an example of surficial geologic mapping that was done to help assess flood hazards associated with Tiger Wash alluvial fan in westernmost Maricopa County. The Arizona Geological Survey (AZGS) has completed many maps detailing the surficial geology of much of Maricopa County. Users of the Piedmont Flood Hazard Assessment Manual are encouraged to contact the AZGS or visit its website at (http:\www.azgs.az.gov) for a current list of map products.

Development of surficial geologic mapping in Arizona. Through much of the 20th century, geologic mapping focused primarily on bedrock geology and little attention was paid to the details of the age and distribution of surficial deposits. Pioneering work in the geomorphology and surficial geology of Arizona was done by Bryan (1925), Melton (1965), Cooley (1967), Morrison (1985), and Pewe (for example, Christenson et al, 1979). Unfortunately, the mapping done by these individuals was limited to relatively small areas or was quite general in nature. Most geologists of that time were not concerned about surficial deposits, which were commonly seen as overburden that obscured bedrock, and mappers lacked the training in geomorphology and pedology (soil science) necessary to differentiate surficial deposits by age. If geologic mappers were sufficiently interested in alluvium to differentiate it at all, they generally focused on differences in particle size, rock type, and the most obvious geomorphic characteristics such as dissection and height above modern channels. Thus, nearly all of the geologic maps that were completed in Arizona by the U.S. Geological Survey or the Arizona Geological Survey prior to the past 20 years show little differentiation of Quaternary surficial deposits by age (see Table L1 for geologic time intervals used in this appendix). Maps of this vintage, therefore, provide only a little information that is useful in assessing piedmont flood hazards.

Table L1. Time intervals as used in this report. "Thousands of years before present" is abbreviated as ka; "millions of years before present" is abbreviated as Ma. The first two columns list formal subdivisions of geologic time with established ages, although there is some dispute regarding the age of the inception of the Quaternary. Subdivisions are listed only if there are lithologic units of that age in the study area. The last column consists of informal time subdivisions defined for this report.

Period	Epoch	Informal subdivisions
Quaternary (0 to ~2 Ma)	Holocene (0 to 10 ka)	late Holocene (~0 to 4 ka) middle Holocene (~4 to 8 ka) early Holocene (~8-10 ka)
	Pleistocene (10 ka to ~2 Ma)	late Pleistocene (~10 to 150 ka) middle Pleistocene (~150 to 750 ka) early Pleistocene (~750 ka to 2 Ma)
Tertiary (~2 to 65 Ma)	Pliocene (~2 to 5.5 Ma) Miocene (5.5 to 22 Ma)	

The geologic community gradually came to understand the societal value of surficial geologic mapping when environmental applications of geologic mapping began to gain prominence in the 1970's. The increased emphasis on surficial geology developed for several reasons. During this period, there was modest interest in exploration for new metallic mineral resources because of low metal prices and the abundance of known deposits, so the impetus for mapping bedrock geology lessened somewhat. More importantly, nearly all of the rapid urban development that has been occurring in the past 50 years in the western U.S. has been on surficial deposits, so links between the character and age of surficial deposits and geologic hazards such as problem soils, flooding and earthquake hazards have become quite important. Evaluation of seismic hazards posed to critical facilities such as nuclear power plants and large dams led to innovations in the mapping and dating of surficial geologic units, because these deposits record the recent part of the geologic record that is critical to evaluating recent fault activity (Bull, 1984). Beginning in the 1960's, the Soil Conservation Service (now the NRCS) made a major effort to integrate soils mapping and geomorphology in the western U.S. through detailed investigations in the Desert Project area near Las Cruces, New Mexico (Gile et al, 1966; Gile and Grossman, 1979; Gile et al, 1981). More recently, several workers have argued that the surficial geology of a piedmont records the long-term history of flooding, and that this information can be used to help delineate active alluvial fans and other potentially flood-prone areas (Pearthree and Pearthree, 1988; Pearthree, 1989; Baker et al, 1990; Pearthree, 1991; Field and Pearthree, 1992; Pearthree et al, 2000).

L2. Criteria used to differentiate and map piedmont alluvial surfaces

In order to make a surficial geologic map of a piedmont, the physical characteristics of Quaternary alluvial surfaces are used to differentiate their associated deposits by age. Alluvial surfaces of similar age have a distinctive appearance and soil characteristics because they have undergone similar post-depositional modifications. Alluvial fans, floodplains, and low terraces that are less than a few thousand years old still retain clear evidence of the original depositional topography, such as bars of coarse deposits, swales (trough-like depressions) where low flows passed between bars, and braided or distributary channel networks. Young alluvial surfaces have little rock varnish on surface clasts, weak or no desert pavement development, minimal soil development, and channels typically are incised a few feet or less below adjacent terrace or fan surfaces. Young alluvial surfaces tend to be found in proximity to modern channel systems, although in some areas channels may be small and discontinuous. Very old alluvial surfaces, in contrast, have been isolated from substantial fluvial deposition or reworking for hundreds of thousands of years. These surfaces have been srongly modified by processes of erosion and soil formation since they were deposited, and thus look substantially different from young deposits both in the field, on aerial photographs, and on topographic maps. Old alluvial surfaces are characterized by strongly developed soils with clay-rich argillic horizons or cemented calcium-carbonate horizons or both, well-developed tributary stream networks that are entrenched 3 or more feet below the fan surface, and strongly developed varnish on surface rocks. The ages of alluvial surfaces in the southwestern United States may be roughly estimated based on these surface characteristics, especially soil development (Gile et al, 1981; Bull, 1991). Specific geomorphic and soils characteristics and how they evolve with time are discussed in this section. An example of how these characteristics vary with surface age is summarized in Tables L2 and L3.

Topographic relationships between adjacent surfaces. Topographic relief between adjacent alluvial surfaces is the most basic criterion used to map surfaces of different ages. In areas undergoing active aggradation, such as active alluvial fans and alluvial plains, the land surface is composed of young deposits and any older deposits are buried beneath the surface deposits. In these situations, deposits at the surface must be younger than the deposits that they bury (the classic geologic concept of superposition). On active alluvial fans, the middle of the fan typically is higher than surrounding areas, which is consistent with the convex-downslope topographic contours that are a primary characteristic of alluvial fans. It is common for the lateral margins of active fans to be formed in older surficial deposits, in which case the surface of the older deposits is generally, but not always, higher than the adjacent active fan surface (Figure L1A). Topographic - age relationships are somewhat more complicated in many piedmont areas in Maricopa County that have undergone net long-term downcutting and erosion. In these areas, active channels occupy the lowest position in the local landscape and increasingly older alluvial surfaces are found at progressively higher levels. Where younger deposits are confined to valleys eroded into older alluvial fans, one or more terraces record periods of lateral stream erosion or aggradation, and a relative surface age sequence from youngest (lowest) to oldest (highest) can be readily established (Figure L1B). It is even more common on piedmonts of Maricopa County to find nested or adjacent sets of alluvial fans. In these areas, the younger fans were deposited after erosion removed part of the older fan, creating space for younger fan deposition. Where the fan surfaces are reasonably well preserved, the younger fan surface is lower than immediately adjacent older fan surfaces, but in some situations the differences in elevation are subtle. In some areas, younger fans are inset below older fans in the upper piedmont but bury the same older fans lower in the piedmont.

Drainage characteristics. Drainage network character is also a fundamental criterion that may be recognized on aerial photographs and on topographic maps. Channel patterns associated with active and recently active alluvial surfaces typically are braided or distributary (Figure L2). In detail, most channel systems alternate between relatively narrow channels and expansion reaches in a downstream direction. On active alluvial fans, the expansion reaches are commonly associated with complex, downstream-branching distributary channel networks (Vincent, 2000). In areas of active sheetflooding, channels typically are small and discontinuous and broad areas may have no recognizable channels at all. Drainage networks on abandoned alluvial fans and terraces typically are tributary. On older fans, the tributary drainage networks typically extend throughout the landform and are entrenched well below the old fan surface. Incised distributary channel networks extend through some old fans, but tributary channels drain the portions of the fan away from the distributary channels. The pervasiveness of tributary drainage development and the amount that drainages are incised below the original depositional surface generally reflect the time since the surface was abandoned.

Local topography on surfaces. Local topography on an alluvial surface reflects the relative dominance of primary depositional processes associated with throughflow streams versus secondary deposition and erosion that modifies the surface of the alluvium after it is emplaced. The amount of local topography that exists on actively aggrading alluvial surfaces is very much a product of sediment size, with larger gravel bars found on drainages that carry a coarser bed load. Where gravel bars consist of cobbles or boulders, there may be 3 feet or more of local relief. Local relief is much less in areas with little or no gravel, but typically there is some

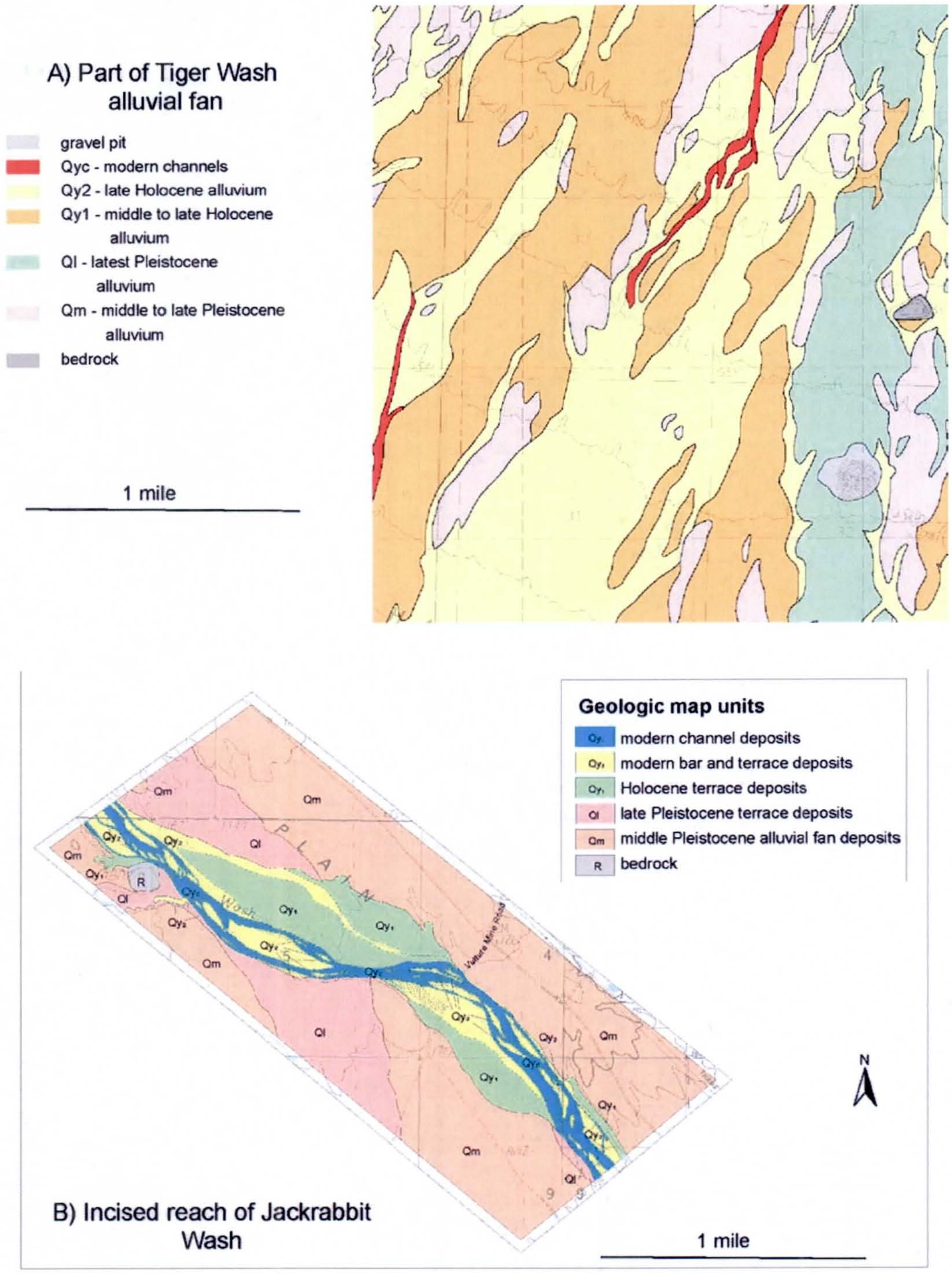


Figure L1. Surficial geologic maps showing topographic relationships between surfaces of different ages. On Tiger Wash alluvial fan, young fan surfaces are at about the same elevation as Pleistocene surfaces and are quite extensive. Along Jackrabbit Wash, the modern fluvial system is incised and Holocene and late Pleistocene deposits are confined to valleys and paleovalleys inset below the middle Pleistocene surface.

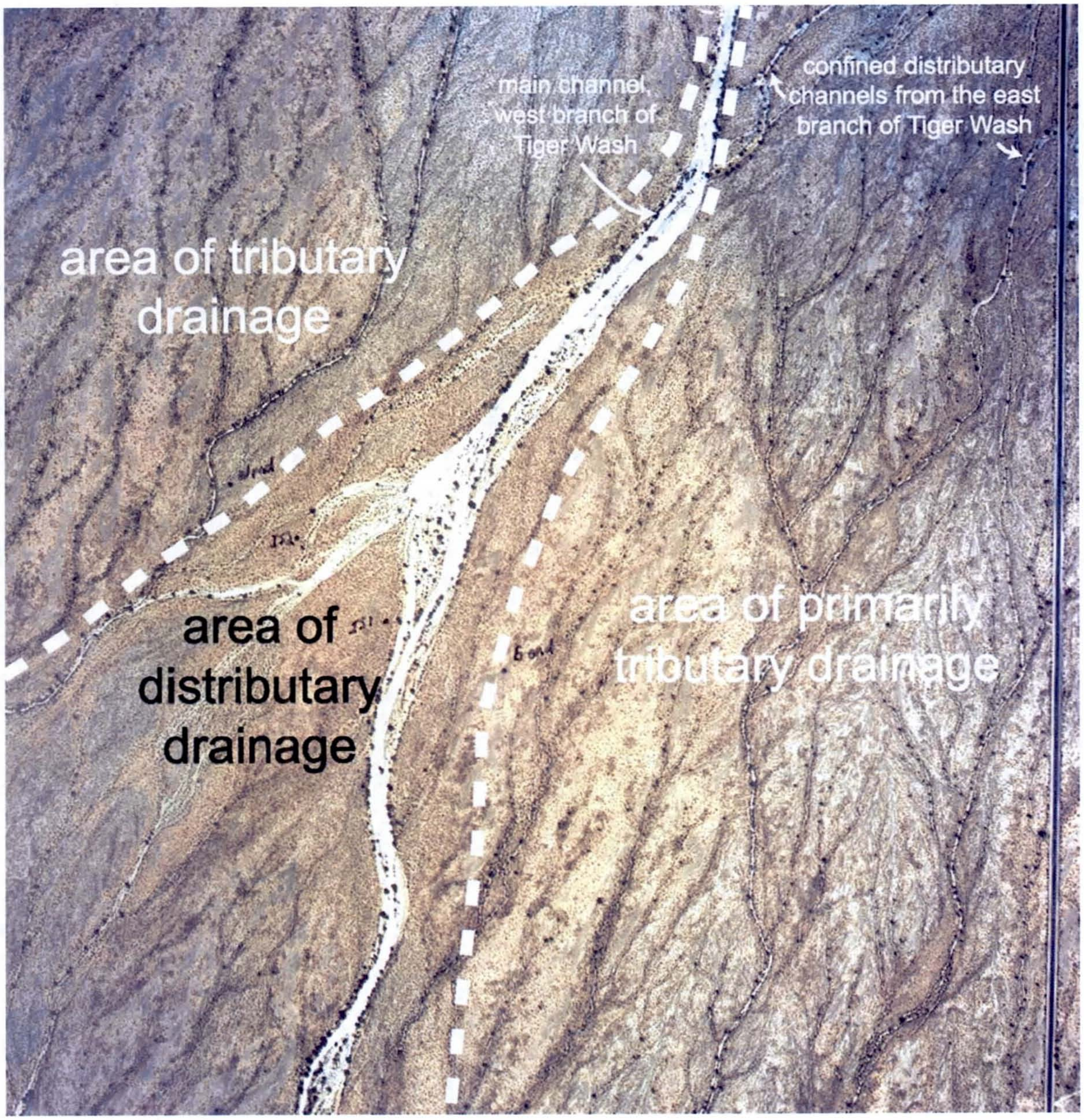


Figure L2. Areas of tributary drainage associated primarily with dissected Pleistocene alluvial fans and distributary drainage associated with the active fluvial system of Tiger Wash, westernmost Maricopa County.

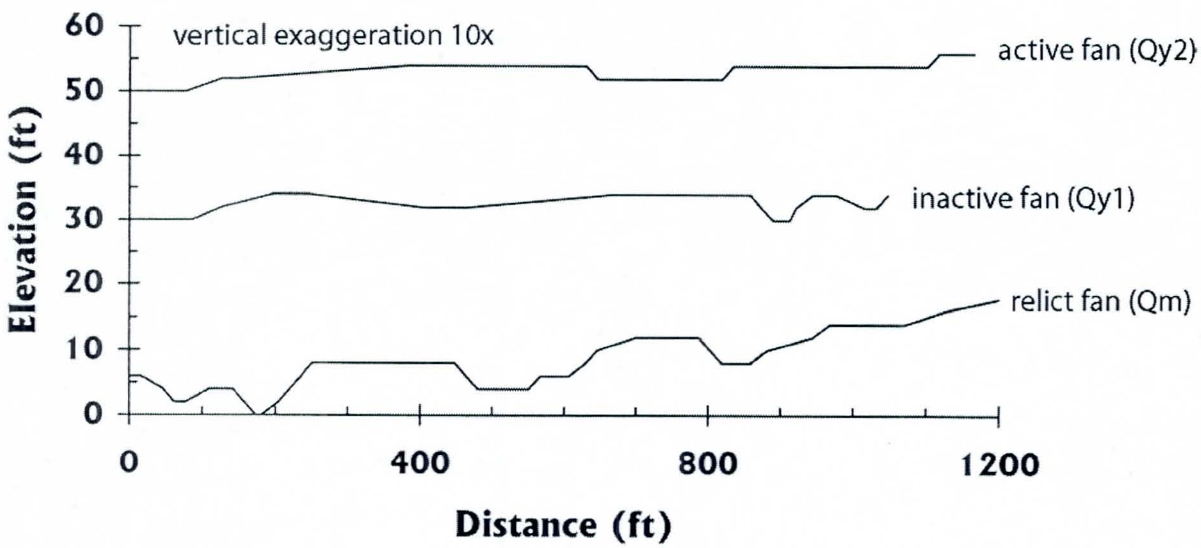


Figure L3. Local topography across an active alluvial fan (Qy2), a recently abandoned alluvial fan (Qy1), and a much older Pleistocene alluvial fan (Qm). This example is from the Tortolita piedmont in Pima County.

topographic relief between channels and adjacent bars (Figure L3). When alluvial surfaces are no longer subject to large-scale fluvial depositional processes, local processes of erosion and deposition gradually diminish topographic relief on surfaces. Local erosion tends to move material from higher areas into swales. In addition, any surface flows tend to be in the swales, potentially depositing fine-grained material there. Inputs of fine-grained sediment as atmospheric dust also contribute to filling low areas. These processes tend to smooth local topography over time. With coarse gravel deposits, it might take tens of thousands of years to smooth a surface. With sandy deposits, typically surfaces are quite smooth when they are deposited, or relief is leveled out quite quickly.

Desert pavement and rock varnish. Desert pavement and rock varnish are good measures of relative surface age and surface stability when used together. A concentration of interlocking gravel clasts on the land surface is known as desert pavement (Figure L4). Tightly packed desert pavements have formed by the addition of wind blown silt and clay to soil profiles beneath surface gravel clasts (Wells et al, 1995). The gravel mantle protects the fine-grained material beneath it from surface runoff and wind erosion, eventually leading to the development of a thin gravel layer over a relatively thick horizon of silt and clay (McFadden et al, 1987). Desert pavement development is inhibited by the presence of sizable plants and extensive animal burrowing (Quade, 2001), and is favored in the more arid, lower altitude portions of Maricopa County.

Rock varnish refers to the dark brown to black and orange to red layers of clays, manganese and iron oxides that form on the surface of rocks exposed at the surface over thousands of years. Red varnish accumulates in the subsurface beneath gravel clasts, and brown varnish accumulates on the exposed rock surface (Liu and Dorn, 1996; Dorn and Oberlander, 1982; Dorn et al, 1989). Varnish development requires stable rock surfaces, so varnish does not develop readily of rocks that disaggregate (granite) or dissolve (limestone) fairly rapidly at the surface. In addition, animal burrowing, root throw associated with the demise of sizable plants, and anthropogenic activities may result in the overturning of surface gravel clasts.

Desert pavement and rock varnish can be used together to evaluate surface stability and presence or absence of significant flooding over thousands of years. Gravel lag deposits that exist locally on active alluvial fans, in stream channels, and on young terraces may form weak desert pavements fairly rapidly (Christenson and Purcell, 1985). Tightly packed desert pavements with brown to black rock varnish coatings on the gravel, however, form over a much longer period. It is common to find moderate rock varnish on some surface clasts when gravel bars are still readily apparent, well before the development of a strong desert pavement. This indicates that these surfaces have been stable for a reasonable length of time and are probably not part of the active fluvial system. Well-developed desert pavements are quite effective at minimizing wind erosion but are vulnerable to disruption by fluvial erosion if they are inundated by even a few inches of sheetflow. In addition, desert pavement will be degraded as older surfaces are rounded by local erosion associated with on-fan tributary drainages. Therefore, very old alluvial surfaces may have little or no desert pavement, but large cobbles or boulders on these surfaces may have extremely dark varnish.

Vegetation assemblages. Vegetation assemblages on desert piedmonts depend strongly on soil characteristics and moisture availability (McAuliffe, 1995). Since soil characteristics and soil moisture correlate with surface age and sediment character, different vegetation assemblages are found on surfaces of different ages. Plants such as desert trees that require more moisture or tap deeper moisture sources typically are found on young deposits near active channels (Figure L4). These desert riparian areas tend to support a reasonable variety of desert shrubs and trees such as ironwood, mesquite, acacia, and palo verde. Vegetation such as creosote that is adaptable to a variety of environmental conditions may be larger and in better condition in areas that receive more moisture. Some vegetation such as saguaro and bursage draw upon shallow moisture and favor situations where moisture is held close to the surface. Such environments include older alluvial surfaces with clay-rich soils or shallow bedrock. Vegetation such as creosote and saltbush can tolerate soils with relatively high pH values, and thus tends to dominate in areas where soils are rich in calcium carbonate.

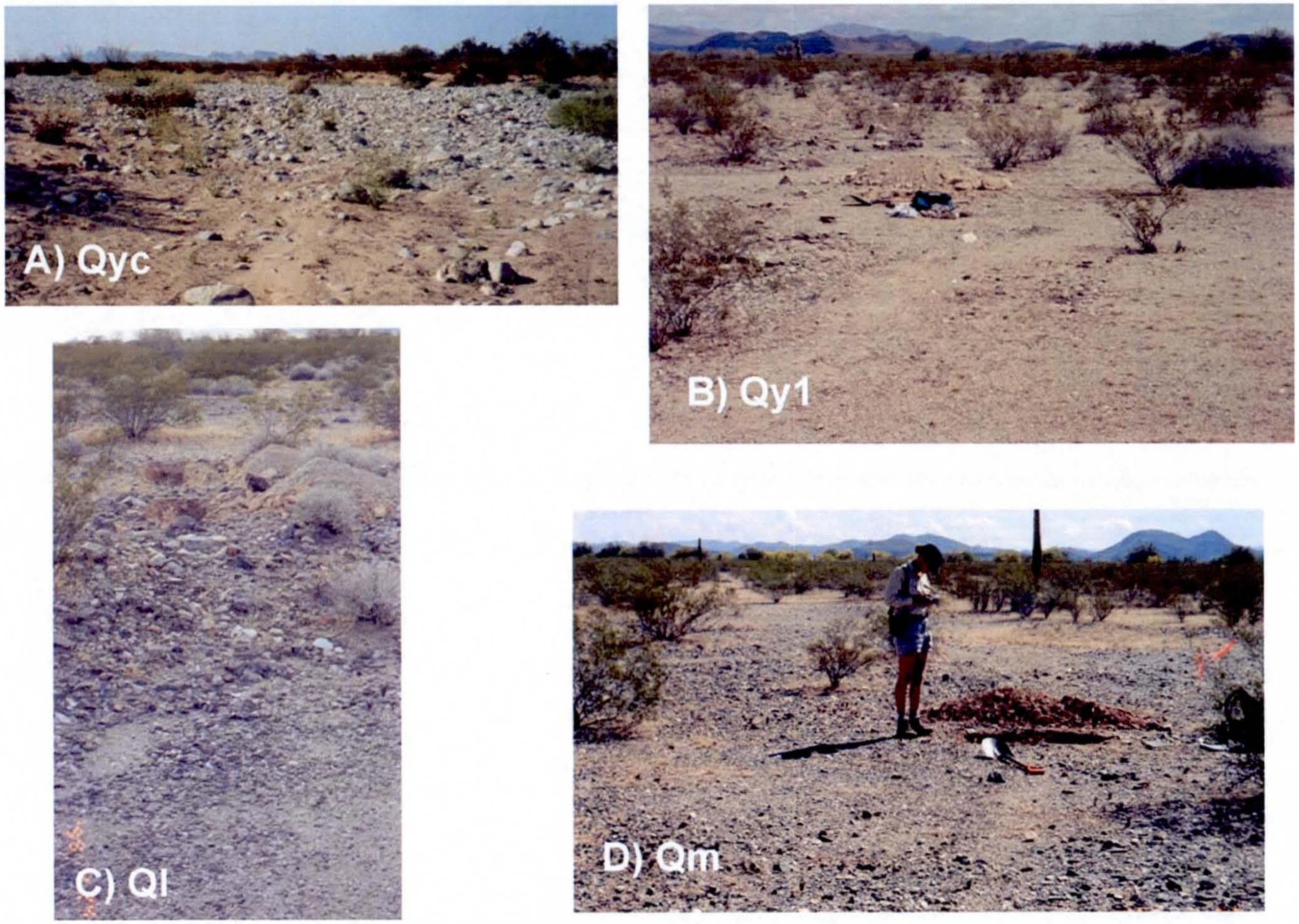


Figure L4. Progression of desert pavement and rock varnish development on surfaces in the Tiger Wash area. Holocene surfaces (Qyc, Qy1) retain bar-and-swale topography. They may have weakly developed pavements, but surface gravel has little or no rock varnish. The latest Pleistocene Ql surface has obvious rock varnish and moderate pavement development, but gravel bars are still obvious. The older Pleistocene Qm surface has a smooth pavement with darkly varnished gravel clasts and patchy vegetation.

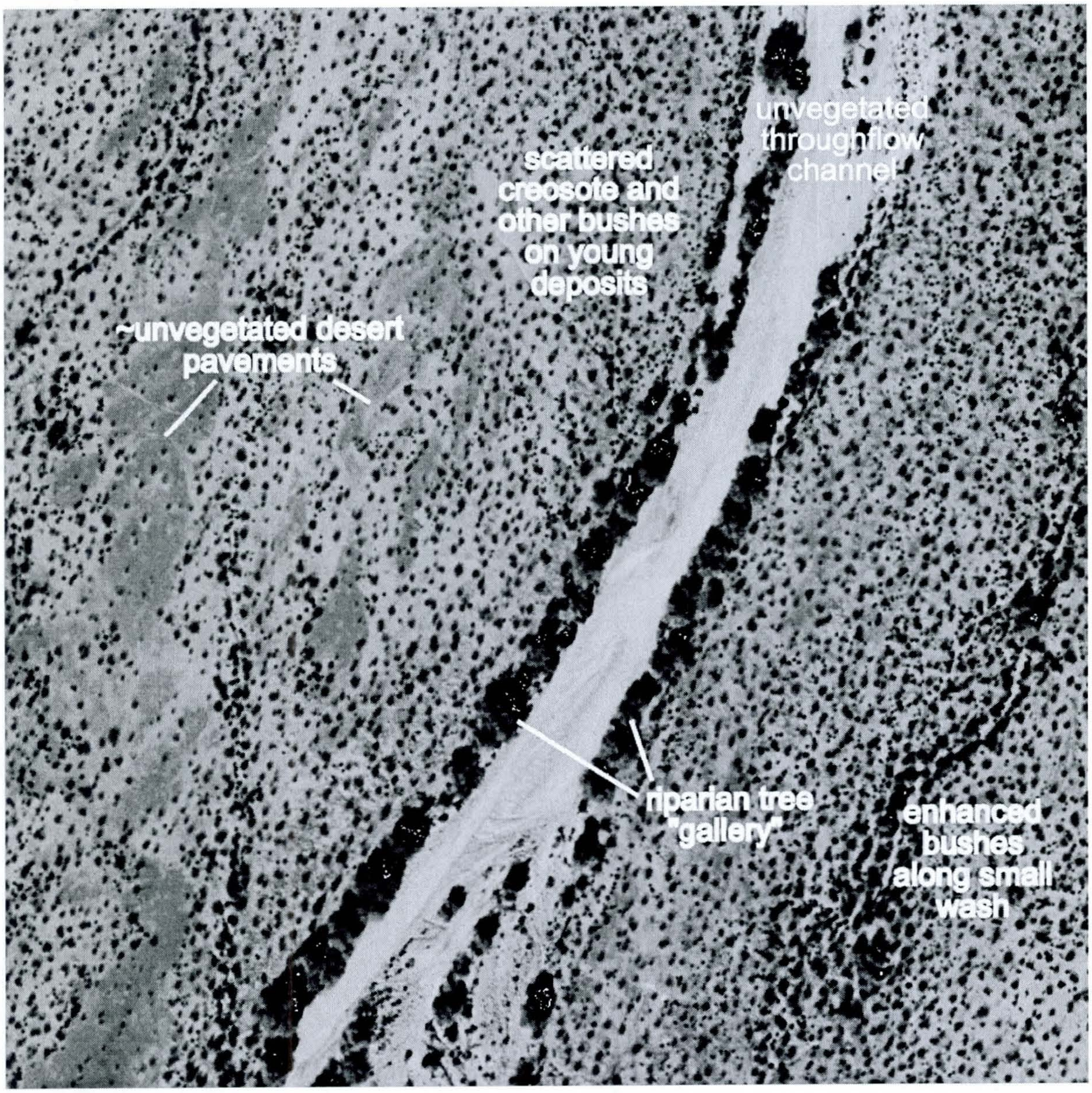


Figure L5. Example of vegetation assemblages found on alluvial surfaces of different ages in western Maricopa County. In this dry environment, desert trees line channels but are rare away from channels. Active channels and old surfaces with desert pavements have little vegetation. Young to moderately old surfaces are dotted with creosote bushes, which are larger and denser along small washes.

Soil development. Soil development is an excellent measure of relative age of piedmont alluvial surfaces in Maricopa County, and with some caveats, can be a reasonable numerical measure of surface age. In the arid environments of Maricopa County, processes of soil formation primarily involve the incremental input of material into the soil from atmospheric sources and slow weathering of mineral constituents of the soil (Figure L6). Processes of soil formation proceed slowly and require surface stability or at least a slowly changing surface in order to be recognizable. Recently deposited piedmont sediment typically retains abundant evidence of the fluvial processes of erosion and deposition (sediment sorting and layering, for example) and little evidence of soil development. In contrast, the upper few feet of deposits that have been at the surface for tens to hundreds of thousands of years commonly are strongly altered by accumulation of clay and calcium carbonate and there may be clear evidence of weathering of rock fragments in the soil. Thus, we can use those soil factors that change with time as a crude measure of surface ages.

Several soil properties that are readily identifiable in the field increase with surface age. The principal soil factors that geomorphologists focus on in this environment are increases in clay and silt content and redness (development of cambic and argillic horizons) and calcium carbonate accumulation (development of calcic horizons). Surficial deposits on piedmonts typically consist mainly of sand and gravel with minor silt and clay when they are deposited, although finer deposits are common on lower piedmont areas (alluvial plains). When these deposits are no longer subject to fluvial deposition, silt and clay from atmospheric dust is translocated in suspension by infiltrating water into the relatively open framework of the deposit. As soil water is extracted by evaporation, fine particles remain behind in the deposit. Initially, this fine material may accumulate just beneath the surface, forming a silt-rich horizon with numerous tiny voids or vesicles. Eventually, enough silt and clay may accumulate at a shallow depth in the soil profile to retain water longer, facilitating weathering of mineral constituents in the soil (McFadden and Weldon, 1987). In this zone of clay accumulation and weathering, oxidation of mineral constituents results in reddening of the soil.

Calcium carbonate from dust and rainwater is similarly translocated into the soil by the downward movement of infiltrating water, but unlike fine particles, the calcium carbonate is dissolved in the soil water. Therefore, calcium carbonate typically is carried deeper into the soil profile. As most soil moisture is extracted by evaporation, remaining water becomes saturated and calcium carbonate is precipitated and a calcic horizon begins to form. Typically, carbonate begins to accumulate as thin, discontinuous coatings on gravel or filaments in finer sediment. Eventually, gravel coatings become more continuous and thicker, and filaments become carbonate concretions and nodules. As carbonate continues to accumulate over a long period of time, eventually fairly continuous, cemented petrocalcic horizons ("caliche") develop. Cemented petrocalcic horizons may persist on old alluvial surfaces long after any overlying clay-rich horizons have been removed by erosion. Various morphologic stages of carbonate accumulation in soils are described by Gile et al (1966) and Machette (1985) (see Table L2).

Factors such as the amount of calcium present in deposits and the amount of precipitation that an area receives affect the development of clay-rich and carbonate-rich horizons. Particularly

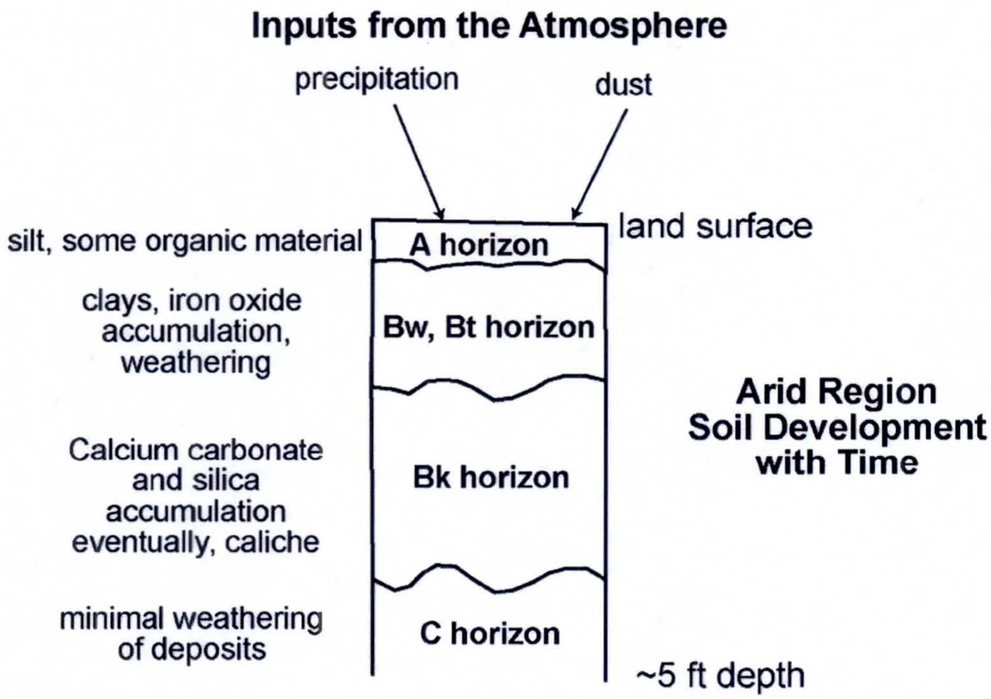


Figure L6. Schematic diagram illustrating soil profile development and typical soil horizons found in arid and semiarid regions.

Table L2. Morphologic stages of calcic horizon development in the southwestern U.S. (from Machette, 1985).

Stage	Diagnostic carbonate morphology
I	Thin filaments in fine-grained sediment; thin, discontinuous coatings on gravel clasts.
II	Few to common soft to firm carbonate nodules; continuous, thin coatings on gravel clasts.
III	Hard, coalesced nodules in whitened matrix; continuous, moderately thick coatings on gravel clasts.
IV	Platy, massive indurated matrix, with some relict nodules embedded; may have weak, discontinuous laminae on top of plugged horizon.
V	Platy to tabular, dense and firmly cemented matrix; well-developed laminar layer or layers on top of plugged horizon; incipient recrystallization of carbonate in fractures.
VI	Massive, multi-laminar, brecciated and recrystallized, dense and firmly cemented.

important is the presence or absence of calcium-rich material in the deposit itself. If there is substantial limestone in the drainage basin or if deposits are eroded from older surficial deposits that are rich in calcium carbonate, then typically the limiting factor in the development of calcic horizons is the amount of soil moisture, as there obviously is abundant calcium carbonate. In the portions of the soil where there is abundant calcium carbonate, typically there will be little or no clay accumulation, as the presence of calcium tends to inhibit the movement of clay particles. Therefore, in order for an argillic horizon to form, most carbonate must be leached from the upper part of a soil profile. It is likely that the modern moisture regime in much of Maricopa County is too dry to completely leach carbonate from the upper part of the soil profile. Thus, development of soils in young (Holocene) deposits is expressed primarily as a thin, slightly darkened silty surface horizon and limited calcium carbonate accumulation within 1 to 2 feet of the surface. Although most of Maricopa County is quite arid, there nonetheless are variations in available moisture that affect the depth and character of soil development (see Huckleberry, 1997). Reddened, clay-rich argillic horizons typically are found above calcic or petrocalcic horizons in older soils, suggesting that calcium carbonate was leached to greater depths during glacial periods during the Quaternary (see Figure L7). Thus, the presence of obviously reddened, clay-rich soils indicates that the associated surface has been stable for at least 10,000 years (Table L3).

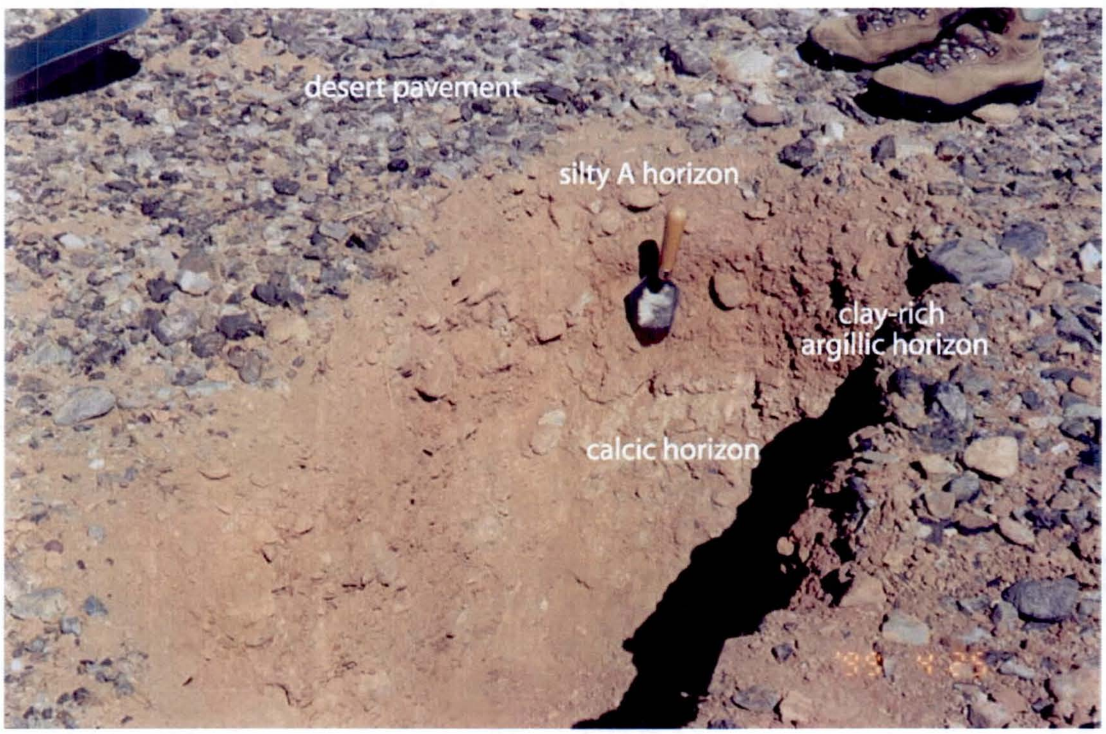


Figure L7. Example of a moderately well-developed soil profile on a Pleistocene alluvial fan, Tiger Wash.

Table L3. Soil properties associated with surficial deposits of different ages in southern New Mexico (from Gile and Grossman, 1979) and the lower Colorado River area near Parker, Arizona (from Bull, 1991).

Geomorphic surface estimated age (ka)	Max redness	Max % clay	Max texture	Calcic Horizon Stage
Desert Project, southern New Mexico				
Organ 1 to 5	5YR to 10YR	12 to 18	Loam	I to II
Isaac's Ranch 8 to 15	5 YR	16 to 28	Loam, sandy clay loam	I to III
Jornada II 25 to 75	2.5YR to 5YR	28 to 32	Clay loam	III to IV
Jornada I 200 to 400	2.5YR to 5YR	33 to 47	Clay loam to clay	III to V
Dona Ana > 500	5YR to 10YR	15 to 74	Loam to clay	IV to V
Lower Colorado River Valley				
Q3b 4 to 8	7.5YR	<10	Sand	I
Q2c 12 to 70	5YR	20 to 30	Silty loam to silty clay loam	II to III
Q2b 70 to 200	5YR	<20	Sandy loam	III
Q2a 400 to 730	5 YR	30 to 40	Clay loam	II to III

L3. Dating

Estimates for alluvial surface ages in geologic mapping projects are mostly obtained by regional correlations to other surfaces and to soils and surface chronosequences that have been established in the Desert Southwest. In addition, geologists utilize radiocarbon dating of organic material found in deposits, dated or datable archaeological features and artifacts, and surface exposure dating in some cases to obtain direct numerical age estimates for surficial deposits. Surficial deposits are almost never dated to the precision that might be desired for an engineering timescale. For example, it is unusual to be able to date deposits to an accuracy of ±100 years, and dating accuracies as small as decades would always apply to deposits with modern cultural remains or living trees. Much more commonly, age estimates for piedmont surfaces are on the order of ±50 percent, which in some cases involves uncertainties of tens or even hundreds of thousands of years. Even with these uncertainties, however, the rough age estimates that are typically made for piedmont alluvial surfaces provide an excellent framework with which to evaluate the behavior of piedmont fluvial systems.

The two primary chronosequences of alluvial surfaces and soils that have been developed in the Desert Southwest are located in the Las Cruces area of southern New Mexico (Gile and Grossman, 1979; Gile et al, 1981) and on either side of the lower Colorado River in western Arizona and eastern California (Bull, 1991). In both of these areas, substantial efforts have been made to document soils and surface characteristics and to develop numerical estimates for surface ages (see Table L4). It is convenient for workers in Arizona that these areas bracket our area of interest both geographically and climatically. The climate of the lower Colorado River Valley is warm and as or more arid than any place in Maricopa County (Bull, 1991), whereas the climate in southern New Mexico is arid to semiarid, but annual average temperatures are similar to the higher portions of Maricopa County (Gile and Grossman, 1979). Soil development for surfaces of similar age is generally greater for southern New Mexico than in the lower Colorado River area, but surface characteristics such as desert pavements are much more strongly developed along the lower Colorado River. There is evidence for greater depths of calcium carbonate accumulation and substantially more clay accumulation and reddening in soils that are more than 10,000 years old in both areas. In addition, there are more subtle age-related differences in development of soil structure and calcium carbonate accumulation in younger soils.

Ages of some alluvial surfaces in Maricopa County and adjacent areas have been estimated based on radiocarbon dating of organic material found in the deposits, archaeological features found on or in the deposits, and surface exposure dating based on the accumulation of cosmogenic nuclides in surface rocks. Radiocarbon dating or organic material is a well-proven method that generally provides useful estimates for surface ages. However, understanding the physical character and context of the organic material is critical. For example, charcoal is much more stable and long-lasting in our desert environment that unburned organic material. It can, therefore, be hundreds of years older than the age of emplacement of the deposits it is found in (Blong and Gillespie, 1978). In addition, there is substantial inherent uncertainty in radiocarbon dates that are less than a few hundred years old because of variation in atmospheric flux of ^{14}C, so dates from less than about 400 years are not very precise (for example, House et al, 2002). Tree-rings and direct dating of living and dead trees generally have not been utilized to estimate the ages of deposits in Maricopa County. Radiocarbon dates obtained from a dead ironwood tree along Tiger Wash, however, provide good age estimates for young deposits that are not part of the active system (Pearthree et al, 2000). This suggests that under some circumstances direct dating of trees may help document changes in sedimentation patterns in distributary flow systems over the past few centuries.

Archaeological features and datable organic material found in association with them can provide valuable constraints on deposit and surface ages. There is much less ambiguity associated with charcoal that is found in association with archaeological features such as fire pits. If the features are intact, then the charcoal almost certainly dates the feature quite closely. If the feature is on an alluvial surface, then it provides a minimum age estimate for the surface (the feature must be younger than the surface by some unknown amount). If the feature is found within a deposit it provides a maximum age estimate for the alluvial surface above it. Similar reasoning applies to other archaeological material that may provide numerical age information. Painted potsherds may be diagnostic of a particular cultural interval. In Maricopa County, painted ceramics primarily date to the Hohokam period of occupation (A.D. 800-1400), and experts may be able to date a painted sherd much more closely based on its style. Painted potsherds found in association with cultural features such as fire pits or pit houses typically provide excellent numerical control on the age of the feature and associated deposits. Isolated sherds found on an alluvial surface are of dubious value, however, because they may have been made prior to deposition of the surficial deposits and dropped on the surface at some later date.

Numerical surface and soil age estimates have been developed for a few young surfaces and some very old surfaces in and adjacent to Maricopa County. Huckleberry (1997) summarized characteristics of dated Holocene soils in the Phoenix area and into the higher valleys to the east. He found that there are observable differences in soil color (reddening), soil structure and texture (silt and clay accumulation), and carbonate accumulation that are related to surface age in soils that are less than 10,000 years old. He found that local climate is also very important, especially for soil reddening and soil texture and structure, with soils developing more rapidly in higher, wetter localities. Very recently, surface age estimates have been developed for several Pleistocene alluvial fans on the west side of the White Tank Mountains (Robinson, 2002). An alluvial surface with a strongly developed desert pavement a well developed soil profile including an argillic horizon and a weak petrocalcic horizon was estimated to be about 700,000 years old. Older, highly dissected relict fan deposits were estimated to be 1.2 to 2 million years old (Robinson, 2002).

Table L4. Geomorphic surfaces with estimated ages from the lower Colorado River area (Bull, 1991) and the Las Cruces area in southern New Mexico (Gile et al, 1981).

Epoch	Lower Colorado River area, Arizona and California		Las Cruces area, southern New Mexico	
	Estimated Age (ka)	**Geomorphic surface**	**Estimated Age (ka)**	**Geomorphic surface**
Holocene	0 to 2	Q4	0.1 to 7	Fillmore
	2 to 4	Q3c		
	4 to 8	Q3b		
	8 to 15	Q3a	8 to 15	Leasburg, Isaak's Ranch
Pleistocene	15 to 70	Q2c	25 to 100	Picacho, Jornada II
	70 to 200	Q2b	150 to 250	Tortugas
			250 to 400	Jornada I
	400 to 750	Q2a	400 to 2000	La Mesa, Dona Ana
	>1200	Q1		

L4. Mapping procedures

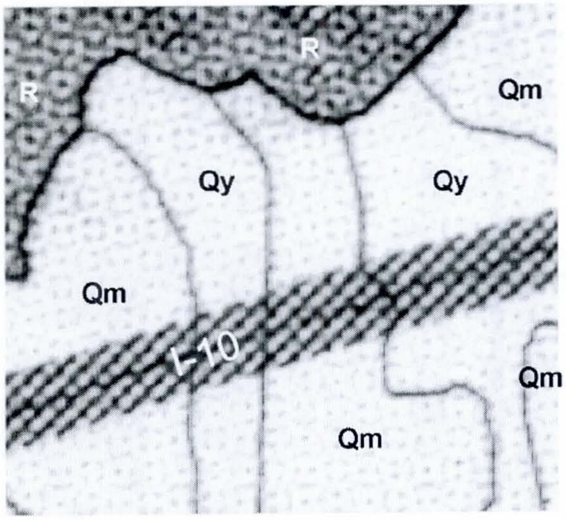
Surficial geologic mapping is accomplished with a combination of remote sensing and field investigations. Interpretation of stereo pairs of aerial photographs is critical to the process of mapping, because many of the characteristics that distinguish alluvial surfaces of different ages are evident on aerial photographs. Color aerial photographs at a scale comparable to the final map product are ideal, but high-quality black-and-white photographs may also be very valuable and in some cases are the only available photographs. Topographic maps also provide information about surface character and drainage development, provided that the contour intervals are closely spaced enough. For example, maps with 2-ft or 5-ft contour intervals provide a tremendous amount of information about surface topography, whereas maps with 40-ft or greater contour intervals provide little useful information with which to differentiate surficial geologic units. Interpretation of aerial photographs typically is interspersed with visits to key sites in the field. Boundaries between units (geologic contacts) are spot-checked in the field, and field observations and descriptions are made of soils and stratigraphic exposures. In the past, field sites were marked on topographic maps or on aerial photographs. While this still may be done, geologists are also using hand-held GPS units to document the locations of key field sites. Geomorphologists also draw upon any available soils mapping and analyses that have been conducted by soil scientists of the NRCS.

Original mapping generally is done on overlays over aerial photos, which are then transferred to a georeferenced base map. In the past, original mapping was mechanically fit as carefully as possible to 1:24,000-scale topographic or orthophoto base maps. Currently, aerial photographs and overlays are scanned and orthorectified to a digital orthophotoquad base. Mapping is then compiled in a GIS format and the final linework is generated from the digital data. Mapping that has been prepared digitally should be more accurate than mapping that was compiled mechanically. The geographic uncertainty of surficial geologic contacts has not been rigorously assessed, but we estimate an uncertainty of less than about 30 feet in horizontal position for most contacts on a 1:24,000-scale geologic map. As a final step, surficial deposits of the map area are correlated with similar deposits in the region in order to roughly estimate their ages. As was noted above, numerical age constraints on the ages of surficial deposits in central Arizona are few, so we generally rely on correlation with other deposits that have been mapped in the area and refer to soils and surface chronosequences developed in southern New Mexico (Gile et al, 1981) and along the lower Colorado River (Bull, 1991).

L5. Mapping scale and map detail

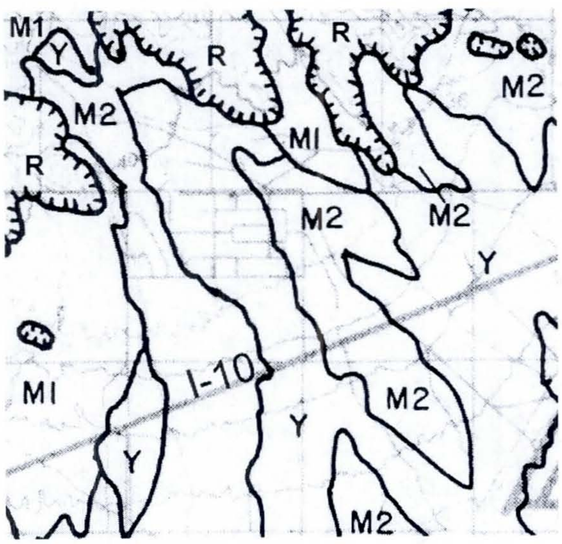
Useful information regarding flood hazards that can be obtained from surficial geologic maps depends to a large degree on the scale and detail of the mapping. One can obtain general information on the extent of young deposits on a piedmont from surficial maps at a scale of 1:100,000 (Figure L8), but smaller scale maps generally will not provide information that is useful for a particular location on a piedmont. Larger-scale (1:24,000) geologic mapping that has been completed for much of central and eastern Maricopa County has a much greater level of detail and accuracy, and is more useful for defining flood hazards on piedmonts (Figure L8).

Figure L8. Example of detail shown on small- (1:1,000,000; Richard et al, 2000),intermediate- (1:100,000; Demsey, 1989), and large-scale (1: 24,000; Field and Pearthree, 1991) geologic maps of the south side of the White Tank Mountains that include the Skyline Wash alluvial fan (Section 5.3 and Appendix H of Manual).



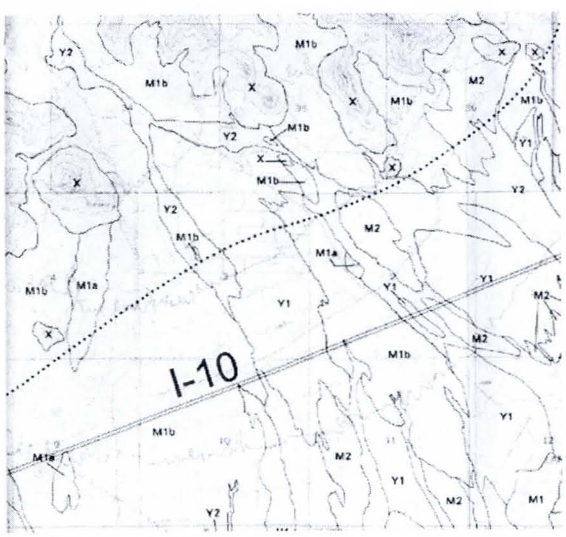
A) 1:1,000,000 scale

Qy - Holocene alluvium
Qm - middle and late Pleistocene alluvium
R - bedrock



B) 1:100,000 scale

Y - Holocene alluvium
M2 - late Pleistocene alluvium
M1 - middle Pleistocene alluvium
R - bedrock



C) 1:24,000 scale

Y2 - late Holocene alluvium
Y1 - older Holocene alluvium
M2 - late Pleistocene alluvium
M1b - middle to late Pleistocene alluvium
M1a - middle Pleistocene alluvium
X - bedrock

Nonetheless, the linework accuracy and level of detail of 1:24,000-scale geologic mapping varies between maps and may not be sufficient for detailed flood hazard assessments.

L6. Application of Surficial Geologic Mapping to Flood Hazard Assessment – Tiger Wash Alluvial Fan, Western Maricopa County

Introduction. Recent geologic mapping and field investigations of the Tiger Wash alluvial fan on the Harquahala Plain in westernmost Maricopa County demonstrate some of the basic principles of surficial geologic mapping and its usefulness for assessing piedmont flood hazards. Tiger Wash is a moderately large drainage in the Gila River system located in west-central Arizona approximately 70 miles west of Phoenix. The surficial geology of Tiger Wash and the Harquahala Plain is representative of much of western Maricopa County, where vegetation is rather sparse and desert pavements with rock varnish have developed on older alluvial surfaces. Tiger Wash is especially interesting because it has experienced several floods in the past decade, including a large alluvial fan flood in 1997 that resulted in widespread inundation and development of some new channels. This section summarizes a study that was conducted in 1999 (Klawon and Pearthree, 2000), wherein inundation that occurred in that flood was mapped in detail and compared to the distribution of surficial geologic map units that existed on the piedmont prior to the flood.

Tiger Wash is a valuable case study because it experienced a large flood in 1997, which allows us to compare the distribution of surficial deposits prior to the flood with the inundation that occurred during flood. On September 25 and 26, 1997, heavy precipitation associated with dissipating tropical storm Nora generated a flood on Tiger Wash that inundated much of the piedmont and caused several significant changes in the distributary channel system (Klawon and Pearthree, 2000; Mayer and Pearthree, 2002). The peak flood discharge at the USGS stream gage upstream of the distributary system was about 8,000 cfs (Waters, 1997), and peak flow at the head of the distributary system was about 9,000 cfs (T.W. Lehman, written communication, cited in Klawon and Pearthree, 2000). Based on the gage record prior to the 1997 flood, the 100-year flood at the gage was estimated at 7,340 cfs (Pope et al, 1998). The abundant evidence of inundation left by the 1997 flood provided an opportunity to analyze the extent of inundation. The existence of color, 1:24,000-scale aerial photographs that were taken in 1979 allows us to map the surficial geology on the piedmont as it existed prior to the 1997 flood. Thus, the primary purposes of the study summarized here were to: (1) map the surficial geology of the piedmont as it existed prior to the flood; (2) document the extent and character of flood inundation; and (3) compare the extent of potentially flood-prone areas predicted by analysis of the surficial geology with the actual extent of inundation in 1997.

The upper reaches of Tiger Wash are a ~100 mi^2 tributary system that drains parts of the Harquahala and Big Horn mountains and a moderately dissected basin between them (Figure L9). Topographic relief in the roughly circular upper basin is modest, with maximum elevation difference of 3900 ft between the base of the tributary system on Tiger Wash and the top of

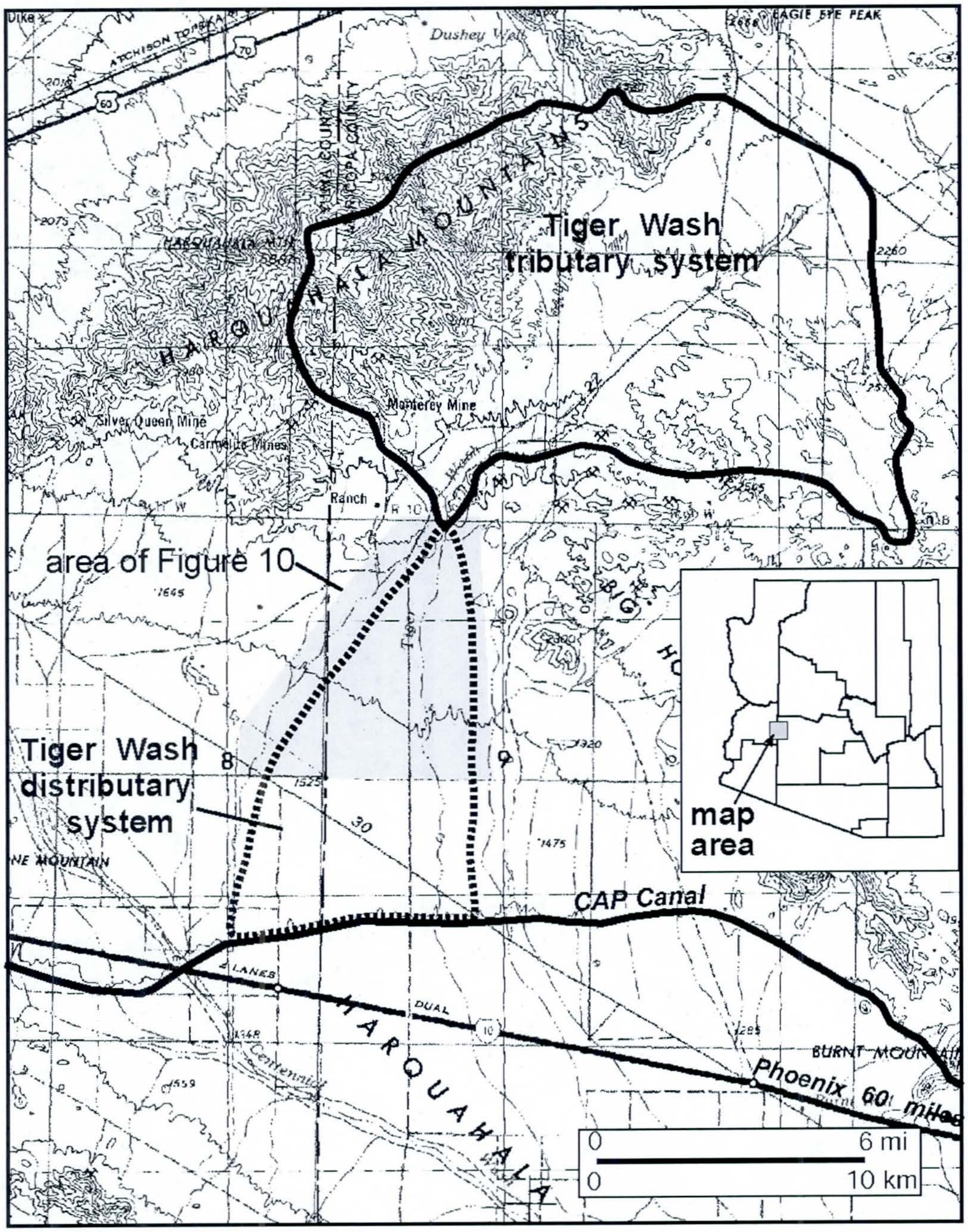


Figure L9. Location of Tiger Wash drainage system in westernmost Maricopa County.

Harquahala Peak. As Tiger Wash enters the low-relief piedmont of the Harquahala Plain to the south, it changes from a tributary system to a ~40 mi^2, complex, downstream-branching distributary drainage system.

Broad portions of the piedmont associated with Tiger Wash are covered with young deposits indicative of geologically recent fluvial activity, but other areas are covered with deposits that are likely more than 10,000 years old. The relatively detailed surficial geologic mapping that is described here served to differentiate areas of the piedmont that are part of the modern fluvial system, areas that have not been subject to substantial flooding from Tiger Wash for 10,000 years or more, and areas that are covered with geologically young deposits but evidently are not part of the modern distributary system.

Surficial Geologic Map Units. The surficial geology of the Tiger Wash distributary system provides insights into the character of fluvial behavior and flood hazards throughout the system. Several Holocene and Pleistocene surficial map units were differentiated based on surface and soil characteristics. These characteristics are summarized in Tables L5 and L6, but they are explored in more detail below. The following text summarizes the characteristics of the surficial geologic map units in the Tiger Wash system.

Qyc Late Holocene active channel deposits

General description. This unit consists of active channels of Tiger Wash that are large enough to be depicted at the 1:24,000 map scale. These channels convey the majority of bedload sediment from the upper Tiger Wash watershed into the Tiger Wash distributary system.
Distribution and drainage characteristics. In the northern map area, channels are topographically confined by middle Holocene to middle Pleistocene alluvial fan deposits (see below for descriptions of these units). In this area, channel character ranges from large, single channels to smaller, multiple braided channels, and cohesive Pleistocene alluvial fan deposits are exposed in channel bed and banks in many places. Farther to the south, topographic confinement of channels is minimal and the drainage pattern is distributary, with channels branching downstream. Channels also exhibit braided patterns, where an intricate network of channels diverge and converge within the active fan. As channels increase in number downslope, they decrease in size and become discontinuous; when channels become too small to represent on the map, they are included in unit Qy2.
Sedimentology. Channel sediment is very poorly sorted sand, cobbles, and boulders, with sand and silt deposited on banks and adjacent overbank locations.
Geomorphology/surface topography. Relatively flat-bottomed sandy channels are most common, but sand bars, coarser gravel bars, and finer channel fringe deposits are also common.
Soils. Primary depositional layering typically is well preserved, and there is essentially no soil development.
Vegetation. Vegetation consists of moderate to large ironwood, palo verde, and acacia trees and relatively dense cover of smaller bushes along channel banks, but vegetation is small and sparse within channels.
Appearance on aerial photos. Channels are light-colored on the ground and on aerial photographs due to minimal vegetation cover and weathering of surface deposits.

Qy2 Late Holocene sheetflood and overbank deposits

General description. This unit includes young deposits associated with broad sheetflood areas, terraces and limited overbank areas that are part of the modern drainage system and are at least occasionally inundated. Qy2 deposits comprise most of the active alluvial fan areas within the Tiger Wash distributary drainage system.

Distribution and drainage characteristics. These deposits flank channels and are found downstream from them. In the former setting, Qy2 deposits reflect overbank deposition on fairly narrow terraces and on broader sheetflood areas, where channel capacity is exceeded during large floods. In the latter setting, Qy2 deposits reflect the downstream decrease in channel capacity and the increasing importance of unconfined sheetflooding; Qy2 deposits are increasingly extensive downstream in the system. They also occupy strips of variable width along smaller piedmont drainages.

Sedimentology. Qy2 sediments typically are fine-grained sand and silt, but they also contain narrow ribbons and broader sheets of coarse sand and fine gravel.

Geomorphology/surface topography. Active channels typically are incised less than 0.5 m below these surfaces, but locally Qy2 surfaces are up to 1.5 m above large, confined active channels and scoured gullies. Where flow in large floods is moderately deep, drainage networks on these surfaces typically consist of intricate, discontinuous, small to very small channels that form complex distributary or braided patterns. In these areas, streamlined vegetation mounds and sand bars are ubiquitous between channels, giving the surface a corrogated texture. Where flow is shallower, channels are very small and the surface between vegetation mounds is relatively smooth.

Soils and surface characteristics. Soil development associated with Qy2 surfaces is minimal, and thin, well-preserved bedding is preserved in many places. There is no desert pavement development or rock varnish on surface clasts unless they have been reworked from older deposits.

Vegetation. Creosote bushes are the predominant vegetation on Qy2 surfaces, but ironwood, palo verde, and acacia trees exist in proximity to some channels and grass and other small bushes are common locally.

Appearance on aerial photos. Qy2 surfaces appear smooth with colors that are various shades of brown on color aerial photos. These characteristics reflect the general absence of dissection of these active depositional surfaces and the color of the deposits and variations in vegetative cover on the surfaces.

Qy1 Early to late Holocene inactive alluvial fan and terrace deposits

General description. This unit includes young alluvial fan and terrace deposits that have been isolated from active deposition from the Tiger Wash distributary drainage system for hundreds of years to a few thousand years. Qy1 surfaces are extensive within the modern distributary network of both the east and west branches of Tiger Wash. Their presence indicates that loci of fan deposition within the distributary system have shifted during the past few thousand years.

Distribution and drainage characteristics. Qy1 surfaces are drained by a combination of fairly large, entrenched distributary channels associated with Tiger Wash and small tributary drainage networks that head on Qy1 surfaces. Distributary channels are entrenched as much as 2 m below adjacent Qy1 surfaces. The smaller local drainages have formed extensive, unentrenched

tributary networks on Qy1 surfaces. These local drainages commonly follow what appear to be abandoned distributary drainage channels ("ghost" channels). On the ground, these abandoned channels are wide and shallow, presumably having been filled in somewhat since they were part of the active distributary system.
Sedimentology. Qy1 sediments consist primarily of very poorly sorted sand, pebbles, and cobbles, with lesser amounts of small boulders and silt.
Geomorphology/surface topography. Surface topography typically is undulating, with local relief of about 0.5 m between coarse gravel bars and finer-grained swales. In areas where Qy1 deposits contain less coarse material, surfaces may be quite smooth. Mounds of eolian sand and silt around creosote bushes are very common on Qy1 surfaces; these mounds typically are 10 to 30 cm higher than the surrounding surface.
Soils and surface characteristics. Surfaces are commonly partially covered by loose pebbles and cobbles forming weak desert pavements. These surface clasts have minimal rock varnish unless they have been reworked from older deposits, in which case they may have considerable varnish or relict carbonate coatings. Coarse bedding may be preserved, but finer sedimentary structures have been obscured by bioturbation and soil development. Soil development associated with Qy1 surfaces is weak, with slight development of soil structure and thin, discontinuous carbonate coatings on gravel clasts. Qy1 surfaces typically are slightly higher than surrounding younger and older surfaces.
Vegetation. Vegetation on Qy1 surfaces is sparse; creosote is the dominant shrub, with lesser amounts of small cactus and ocotillo. Scattered trees survive along some drainages.
Appearance on aerial photos. Qy1 surfaces have a mottled, light to dark gray appearance on color aerial photos.

Ql Late to latest Pleistocene inactive fan and terrace deposits

General description. This unit consists of moderately old relict alluvial fan and terrace deposits that have been isolated from active deposition from the Tiger Wash distributary system for at least 10,000 years. Ql deposits record locations of major fan deposition during the late Pleistocene that were significantly different from the modern system.
Distribution and drainage characteristics. Ql deposits are found on the fringes of the Tiger Wash system in the northern part of the map area; farther south, they are found primarily between the main east and west branches of Tiger Wash within the distributary drainage network. Ql surfaces are drained primarily by local tributary channel networks, although they are traversed by a few distributary channels of the Tiger Wash system. These distributary channels are incised 0.5 to 2 m below adjacent Ql surfaces. As with Qy1 surfaces, local drainages appear to follow former distributary channels that are now partially filled with young sediment.
Sedimentology. Ql sediments consist of very poorly sorted cobbles, pebbles, sand, small boulders, and silt. Ql deposits are probably the coarsest of any of the surficial units associated with Tiger Wash.
Deposit character/surface topography. Ql surfaces are broadly rounded and minimally dissected, with obvious erosion limited to areas adjacent to larger channels. Ql surfaces have moderate local topographic relief because the primary bars and swales are well preserved, although excavations reveal that substantial infilling of swales by younger sediment has occurred. Ql surfaces are distinguished from older Qm surfaces by more local relief and

commonly, larger clast size. Ql surfaces may actually be higher in elevation than adjacent Qm surfaces.
Soils and surface characteristics. Ql surfaces typically are covered with moderately packed desert pavements composed of varnished pebbles, cobbles and boulders. Exposed surfaces of gravel clasts on relict bars typically are moderately to darkly varnished, with bright orange varnish on their undersides. Pavements are also developed in most swales, but are finer and less varnished. Coarse bedding associated with gravel deposits is preserved, but finer sedimentary structures are not evident. Soil development is weak to moderate, with slight reddening, weak soil structure, and thin, discontinuous carbonate coatings on subsurface gravel clasts.
Vegetation. Vegetation on Ql surfaces is sparse; creosote is the dominant shrub, with lesser amounts of small cactus and ocotillo.
Appearance on aerial photos. The Ql surface can be distinguished on aerial photos by its medium gray color and "plumose" (feathery) texture where varnished bars appear to fan out in the downslope direction.

Qm Middle to late Pleistocene inactive fan deposits

General description. This unit consists of old relict alluvial fan deposits that have been isolated from active deposition from the Tiger Wash distributary system for 100,000 years or more.
Distribution and drainage characteristics. Extensive Qm relict alluvial fans form both the east and west margins of the Tiger Wash distributary system in the central and northern parts of the map area. Many less extensive Qm surface remnants are preserved within the distributary system. Based on numerous exposures of Qm deposits in channel bottoms and banks, they also underlie relatively thin younger deposits in many areas. Qm surfaces are drained by well-developed tributary drainage networks that head on the piedmont. Tributary channels are entrenched from up to 3 m below adjacent Qm surfaces.
Sedimentology. Qm sediments consist of very poorly sorted cobbles, pebbles, sand, small boulders, and silt. Qm deposits are quite similar in composition to Ql deposits.
Deposit character/surface topography. Qm surfaces are remarkably planar between the channels and swales of the tributary drainage network. Concentrations of coarser gravel on Qm surfaces are evidence for relict gravel bars, but topographic relief between bars and swales is commonly less than 10 cm.
Soils and surface characteristics. Qm surfaces are covered by strongly developed, closely packed desert pavements. Surface clasts have dark brown to black varnish, with red coatings on their undersides. Pavement development and varnish are similar on bars and swales. Coarse sedimentary structure in gravel deposits is preserved. Soil development is moderate, with reddened zones of clay accumulation, continuous carbonate coatings and bottom pendants on gravel clasts, and locally weak carbonate cementation. Where Qm surfaces have been eroded, exposure of soil horizons results in slightly red or white surface color.
Vegetation. Vegetation on Qm surfaces is sparse. It consists primarily of clusters of creosote bushes, sparse grasses, and occasional saguaro cactus. Vegetation is concentrated along drainages.
Appearance on aerial photos. Qm surfaces appear mottled medium to dark gray and orange on aerial photographs. The gray colors reflect well-preserved desert pavements; the orange color reflects more eroded portions of Qm. Tributary drainages stand out as distinctly darker than adjacent Qm surfaces because of the vegetation concentrated along them.

Table L5. Soil and surface characteristics associated with various surficial geologic units on the Tiger Wash piedmont in westernmost Maricopa County. Pleistocene units Qm and Ql have not been subject to substantial fluvial deposition for at least 10,000 years. Younger Holocene units Qy2 and Qyc outline the active fluvial system on Tiger Wash alluvial fan. Areas mapped as Qy1 are fairly young geologically, but are not currently part of the active fluvial system.

Geologic Unit Landform(s)	***Estimated Age***	***Soils***	***Surface Characteristics***
Qyc modern channels	modern	depositional layering, no soil development	light-colored sand and gravel
Qy2 sheetflood areas and terraces	modern to late Holocene	depositional layering, carbonate filaments, weak structure	brown fine sand and silt, local fine gravel
Qy1 young inactive alluvial fans and terraces	middle to late Holocene	weak soil structure and thin, discontinuous carbonate coatings on gravel clasts	gravel lag but no interlocking pavement, minimal rock varnish
Ql intermediate inactive alluvial fans	latest Pleistocene	slight reddening, weak soil structure, and thin, discontinuous carbonate coatings	weakly to moderately packed desert pavements; rock varnish fairly dark
Qm old inactive alluvial fans	middle to late Pleistocene	reddened zones of clay accumulation, variable carbonate cementation and bottom pendants on gravel clasts	strongly developed, smooth desert pavements with interlocking clasts; dark rock varnish

Table L6. Drainage patterns, topographic, and sedimentologic characteristics associated with various surficial geologic units on the Tiger Wash piedmont in westernmost Maricopa County. Pleistocene units Qm and Ql have not been subject to substantial fluvial deposition for at least 10,000 years. Younger Holocene units Qy2 and Qyc outline the active fluvial system on Tiger Wash alluvial fan.

Unit	*Drainage characteristics*	*Sedimentology*	*Surface topography*
Qyc modern channels	single, braided, distributary	very poorly sorted sand and gravel	flat-bottomed sandy channels, sand and gravel bars
Qy2 sheetflood areas and terraces	discontinuous small channels and gullies	sand and silt, with some gravel sheet and channel deposits	fairly planar with small gullies and mounds around vegetation
Qy1 young relict alluvial fans and terraces	entrenched distributary channels and tributary swales and channels	poorly sorted sand, pebbles, and cobbles, with small boulders and silt	undulating, with coarse gravel bars and finer-grained swales; smooth where fine-grained
Ql moderately old relict alluvial fan deposits	local tributary channels, with a few distributary channels	very poorly sorted cobbles, pebbles, sand, small boulders, and silt	broadly rounded but minimally dissected, bars and swales well preserved
Qm old relict alluvial fan deposits	well-developed, entrenched tributary drainage networks	poorly sorted cobbles, pebbles, sand, small boulders, and silt	broadly rounded near channels; minimal relief on relict gravel bars

Qmo Older middle Pleistocene relict fan deposits

General description. This unit consists of very old relict alluvial fan deposits derived from tributary stream systems that drain the southeast flank of the Harquahala Mountains. They are found only in the northernmost part of the map area and are not part of the Tiger Wash distributary system, so they are only described briefly here. Qmo surfaces are as high or slightly higher than adjacent Qm surfaces, but Qmo surfaces are much more deeply dissected; they consist of rounded ridges and moderately deep valleys; soil development may be fairly strong on ridgecrests, but is generally weak to moderate on side-slopes and in valley bottoms. Qmo surfaces have been isolated from active deposition for several hundred thousand years.

Summary of Distinguishing Characteristics of Surficial Geologic Units. Holocene units include Qyc, Qy2 and Qy1. The active fluvial system is outlined by the extent of modern channels (Qyc) and overbank and sheetflood areas (Qy2). In the terminology of this Manual, these areas are throughflow channels and adjacent overbank areas, active alluvial fans, and alluvial plains. Qyc deposits are light-colored, freshly deposited channel sediment ranging in size from sand to small to medium boulders. Sediment is typically is deposited on flat, generally sandy channel bottoms with some sheets of gravel, gravel bars, and lower-relief sand bars. Channel banks generally are a few feet high or less, and typically are formed in Qy2 terrace deposits. Note that only moderately large channels are represented on the 1:24,000-scale geologic map, and many small channels are not depicted. Qy2 deposits are generally much finer grained sandy to silty overbank and sheetflood deposits, but they also include sheet gravel deposits at the downslope margins of channels and fine gravel deposits on the beds of small channels. Soils developed on Qy2 deposits are very weak and sedimentary bedding is obvious, reflecting the periodic deposition of fresh sediment in these areas during floods.

Older Holocene deposits (Qy1) cover areas that have been part of the active depositional system quite recently but which appeared to have been isolated from flood inundation during the past few decades to millennia. Although these areas are quite young geologically, they would likely be classified as inactive alluvial fans in the terminology of this Manual. Qy1 surfaces have minimal rock varnish and desert pavement development and are weakly dissected. Qy1 surface relief is quite variable, depending on particle size and post-depositional entrenchment by local drainages. Commonly, however, local relief on Qy1 surfaces is greater than on adjacent Pleistocene surfaces because of well-preserved bar and swale depositional topography and burrowed areas. Relict distributary channels ("ghost channels") can commonly be observed on Qy1 surfaces. Many of these relict channels are now part of local tributary drainage networks developed on Qy1 surfaces. Broad areas covered by Qy1 deposits within and along the margins of the distributary drainage system imply that substantial changes in the loci of flooding and deposition have occurred during the past few thousand years.

Pleistocene surficial geologic units record the longer-term evolution of the Tiger Wash distributary system. Areas covered by units Ql and Qm would likely be classified as inactive fan areas in the terminology of this manual, as they are fairly old but their surfaces are quite well preserved and their fan shapes are apparent. Qmo surfaces, which are found only in the northernmost part of Figure L10, and are not part of the Tiger Wash distributary system, would likely be classified as relict fans. Pleistocene Ql and Qm surfaces are the inactive alluvial fans of Tiger Wash that have been isolated from active fluvial deposition or reworking for at least 10,000 years. In upper piedmont areas, these surfaces are substantially higher than adjacent Holocene channels and terraces. In middle and lower piedmont areas, however, topographic relief between Holocene and Pleistocene surfaces in minimal. In these areas, some Pleistocene surfaces have been partially buried by Holocene deposits within and along the margins of active deposition. Pleistocene surficial geologic units typically have moderately to strongly developed rock varnish; smooth desert pavements are well developed on the Qm surfaces. Surface clasts are mostly pebbles and cobbles, which are poorly sorted on Ql surfaces and moderately sorted on Qm surfaces. Local topographic relief is greater on Ql surfaces than Qm surfaces due to much better preservation of bar and swale topography. Former bars and swales may be recognized on Qm surfaces by variations in particle size, but original depositional topography has been almost

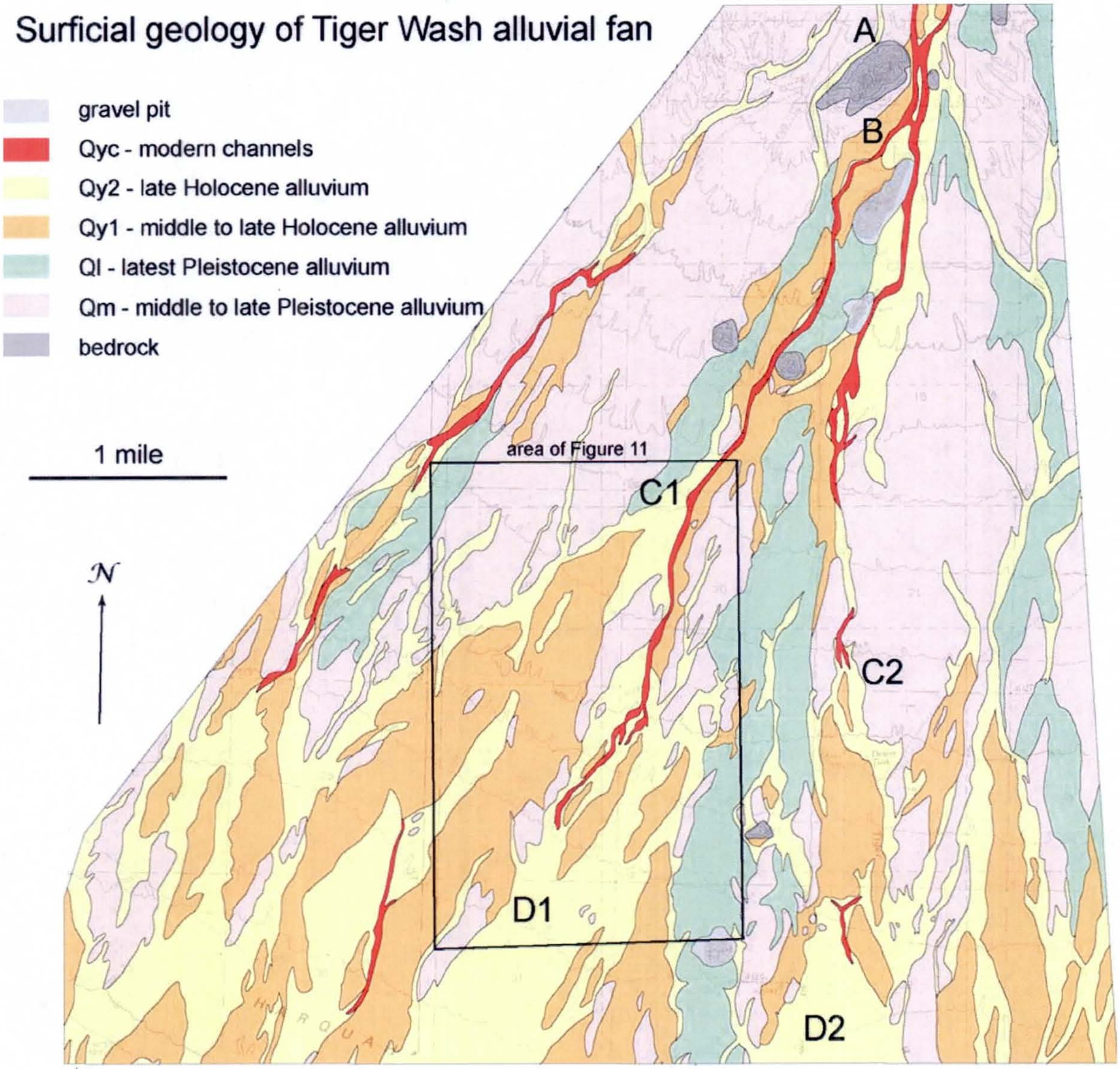


Figure L10. Surficial geologic map of part of the Tiger Wash distributary system. Geologic units are described in the text. Mappable channel areas (Qyc) and very young overbank and sheetflood deposits (Qy2) are the youngest deposits associated with the active distributary system. Much of the distributary system downstream of the mapped channels consists is likely an alluvial plain. Letters identify locations discussed in the text.smoothed by local deposition and erosion.

completely smoothed. Pleistocene soils show an increase in soil development with increase in age of the map unit. For example, Ql soils have slight clay accumulation, weak structure, and thin discontinuous carbonate coatings on clasts. Qm soils have moderately developed structure, reddened zones of clay accumulation, and continuous carbonate coatings on clasts and local cementation in the calcic horizon.

Implications for the Extent of Active Flooding in the Tiger Wash Distributary System. Tiger Wash is typical of many drainage systems in southern and central Arizona in that the channel network changes from tributary to distributary (branching and diverging downstream) on the piedmont downslope from the mountains. Distributary systems spread water and sediment over wide portions of the piedmont, but the existence of distributary channel networks alone does not imply that the entire system is an active alluvial fan. All or parts of distributary drainage systems may be considered active alluvial fans if: (1) topographic relief between channels and surfaces between channels is low enough that channel banks along most reaches are overtopped during large floods; and (2) the surfaces between channels are primarily composed of Holocene deposits. The predominance of Holocene deposits in parts of a distributary system implies that these areas have been inundated in the past few thousand years either by sheetflooding, changes in channel positions, or both. On active alluvial fans, channels typically are discontinuous and decrease in size downfan. Channels typically are a minor element in the lower parts of these fans, which are covered with young, fine-grained deposits indicative of extensive unconfined sheetflooding between channels. In this Manual, these areas are classified as alluvial plains.

The mapped distribution of surficial deposits of different ages points to areas that are likely to be subject to alluvial fan flooding. Young deposits are quite limited at the northern edge of the map area, where Tiger Wash is a tributary drainage system that is topographically confined by bedrock hills and Pleistocene alluvial fan deposits (Figure L10, site A). Along this reach of Tiger Wash, the channel pattern is braided and young terraces (units Qy2 and Qy1) are extensive, but the limits of the flood-prone area are well defined by topography and geology.

Extensive Holocene deposits exist along both branches of Tiger Wash in the area of the first major distributary channel split, but very young deposits (units Qy2 and Qyc) are restricted to narrow areas along the main channel systems (Figure L10, site B). Qy2 deposits are actually more extensive along the east branch of Tiger Wash, which suggests that this branch may have been relatively more important in the recent past. During the 1997 flood, however, most of the flow went down the west branch and much of the area covered by Qy2 deposits on the east branch was not inundated. This is also the area where sizable gravel pits have been excavated on the east branch, but it is not clear if this gravel mining contributed to the diversion of flow to the west branch. The distribution of young surficial deposits in the area of the first distributary split implies that substantial changes in depositional patterns have occurred recently; these deposits may record a shift in flow and deposition from the east branch to the west branch over the past century or so. The moderate topographic relief between active channels and adjacent fan surfaces (up to 10 ft) and the existence of relict Pleistocene alluvial fan surfaces within and bounding the distributary system implies that the general configuration of the distributary channel system in this area is reasonably stable.

Well downstream of the first distributary split, the lateral extent of Qy2 deposits increases dramatically along both the east and west branches of Tiger Wash (Figure L10, sites C1 and C2). In these same areas, channel systems branch and become smaller downstream and local topographic relief generally is less than about 3 ft. We consider these areas with extensive Qy2 deposits and downstream-branching channel networks to be active alluvial fans within the larger distributary drainage system. Most of these areas would be inundated in large floods, and the potential exists for significant changes in channel patterns.

Farther downslope, Qy2 deposits are very extensive and channels are narrow and discontinuous. These areas are subject to very broad, relatively shallow sheetflooding during large flow events, with localized deeper, higher velocity flow in channels and gullies (Figure L10, site D1 and D2). Topographic relief across the piedmont decreases gradually downslope in conjunction with the increase in extent of very young deposits, so that the topography associated with the lateral boundaries of young deposition in the middle and lower piedmont is minimal. Relief between Pleistocene remnants and Holocene deposits is also very small, and in some situations Pleistocene surfaces are actually lower than adjacent Qy2 and Qy1 surfaces. The margins of the active alluvial fan areas are evolving over time, and the contacts between young and older surficial deposits along the fan margins are modified during large floods.

1997 Flood Inundation

We can evaluate the usefulness of surficial geologic mapping as a predictive tool in piedmont flood hazard assessment by comparing the extent of inundated areas of the 1997 flood with the pre-flood surficial geology (Figure L11). Based on the ages of surfaces, we expect that older surfaces such as Qm, Ql, and Qy1 would be unlikely to experience significant flooding, and that the younger surfaces, Qyc and Qy2, would likely be inundated in a large flood. Our inundation mapping for the 1997 flood shows that this generally was the case. Flow remained confined in the upper part of west branch Tiger Wash where older deposits exist along the banks, and it broke out and spread widely where Qy2 deposits are adjacent to the main channel. Although the vast majority of the inundation during the 1997 flood occurred in areas covered by young deposits, some inundation occurred on surfaces of all ages. Older surfaces (Qy1, Ql, and Qm) were inundated in some areas where they are adjacent to younger surfaces. In these situations, there is minimal topographic relief between younger and older surfaces. We also found field evidence for local burial and erosion of Pleistocene alluvial fan surfaces during the 1997 flood. Approximately 10 percent of the area mapped as Ql and Qm was inundated in the 1997 flood, whereas almost all Qyc areas, most Qy2 areas, and about 1/3 of Qy1 areas were inundated (Table L7). Nearly all of the inundation of older surfaces was quite shallow.

Table L7. Inundation in the 1997 flood on Tiger Wash subdivided by underlying surface age. All values are percentages of the total area of each surficial geologic map unit. The category "deep flow" includes channel flow and deep unconfined flow, generally more than 1 foot deep.

Inundation type	All	Qyc	Qy2	Qy1	Ql	Qm
deep flow	8.0	70.5	11.9	5.4	1.5	1.9
all flow	41.3	95.0	65.9	32.9	11.1	10.7
no flow	58.7	5.0	34.1	67.1	88.9	89.3

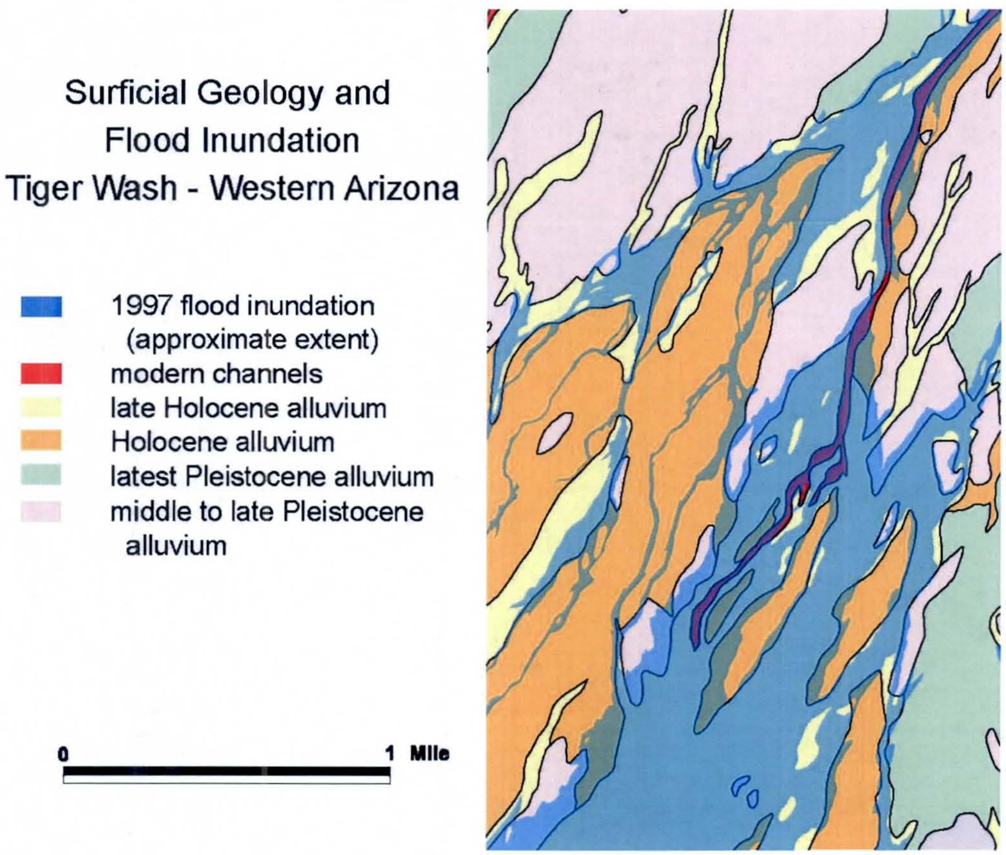


Figure L11. Comparison of surficial geologic mapping based on 1979 aerial photographs and inundation in the 1997 flood on Tiger Wash. Most of the flood inundation occurred on late Holocene deposits, but some inundation occurred on older units, especially where there was little topographic relief between young and old surfaces.

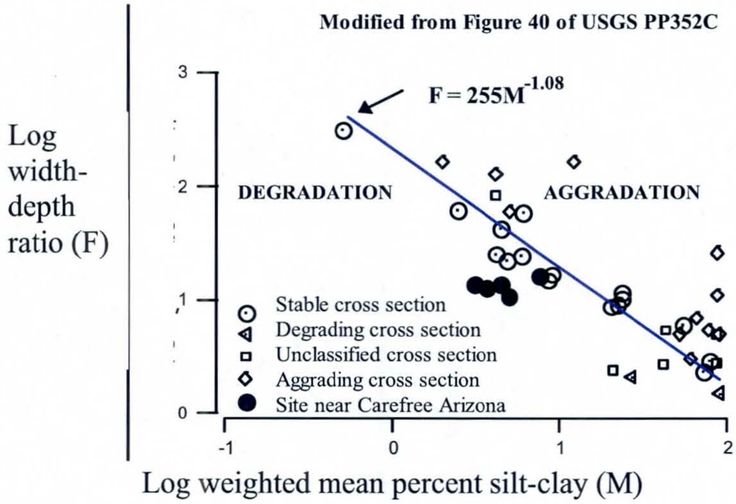


Figure M1. Relation between width-depth ratio (F) and weighted mean percent silt-clay (M) at sites with straight reaches of distributary channels.

The weighted mean percent silt-clay (M) is based on a mix of geologic processes. The bed material is actively being transported through the channels while the bank material is not mobile and was deposited a long time ago. Thus, the relation defined by equation M.1 is empirical and might not be supported by process theory.

The silt and clay (Sb of equation M.1) in ephemeral channel banks on piedmonts of Maricopa County is mostly from plastering. Relatively stable alluvial channel banks become plastered with suspended sediments left by infiltrating floodwater. The bank material grades from more silts and clays at and near the bank surface to coarser texture at depth perpendicular to the bank surface. For additional information on the effect of fine cohesive sediment at shallow depths along the wetted perimeter of the banks see Osterkamp and Harrold (1982). Clearly, the particle size distribution of fluvial deposits along the banks of alluvial channels may be used to assess flow path and channel stability.

Unstable channels of aggrading areas exhibit little plastering of suspended material along the wetted perimeter of channels. The texture of bank material of unstable channels grades little, if any, with depth perpendicular to the bank surface. The texture of the shallow bank material is the same as the texture of the deep bank material. An application of this method is given in Hjalmarson and Tram (1995).

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Appendix M. U. S. Geological Survey Professional Paper 352C

A technique for distinguishing between stable and unstable ephemeral stream-channel cross sections and the corresponding instability of flow paths associated with aggrading channels are given by Schumm (1960 and 1961). The technique requires measurements of channel width, depth and gradient and samples of channel bed and bank material with the computed weighted mean percent silt-clay at cross sections along the stream channel. The percent silt-clay is taken as that part of the sample smaller than the 200-mesh sieve of 0.074 mm. Cross sections should be located in uniform reaches that represent the channel gradient, width and depth along the stream. The method provides a suggestion that either aggradation of degradation is or has occurred (S. A. Schumm, written communication, Jan. 4, 1998).

Channel depth can be difficult to measure precisely because there may be recent scour or fill of the channel bed. Where there is recent scour along the banks the depth is the height above the channel profile to the top of the scour or deposited floodmarks, whichever is higher. Where there is recent fill along the channel the depth is the height above the channel profile (thalweg) to the first permanent surface or bank. Thus, the depth generally represents the distance from the thalweg to the height of the active channel within which the bed material is mobile. The stage of the channel-forming discharge (dominant discharge) is assumed to be at the top of the lowest bank. Channel width is the distance between the top of the banks. The width-depth ratio (F) is for the bank-full stage.

The percent silt-clay along the channel perimeter is determined as follows (Schumm, 1960, p. 18):

$$M = \frac{Sc(W) + Sb(2D)}{W + 2D} \qquad \text{(M.1)}$$

where M = weighted mean percent silt-clay,
Sc = percentage silt-clay in channel bed (Schumm, 1960),
Sb = percentage silt-clay in banks,
W= channel width , and
D = channel depth.

The width-depth ratio (F) is related to the weighted mean percent silt-clay (M) as follows:

$$F = 255M^{-1.08} \qquad \text{(M.2)}$$

The orderly plotting of the points well on the left or "degradation" side of the relation (Equation M.2) indicates that channel degradation could be occurring (Figure M1). Points that plot well above the relation are characteristic of aggrading channels. For further information see page 63 of Schumm (1961).

Appendix N. U. S. Soil Conservation Service TR-25

The U. S. Natural Resources Conservation Service developed a procedure to evaluate the stability of channels in cohesive soils in the western United States (USDA, 1977). This procedure, known as the tractive power approach, is specifically for channels in cohesive or partially cohesive lithified soils. In the tractive power approach the aggregate stability of soils related to erosion by floodwater is assessed by use of the unconfined compression test. The compressive strength of a soil sample is determined along with a computation of the tractive power of the floodflow and plotted on figure N1 (USDA, 1977, figure 6-15). Soils with a large compression strength relative to the tractive power of the streamflow can be expected to resist the erosive effects of the streamflow.

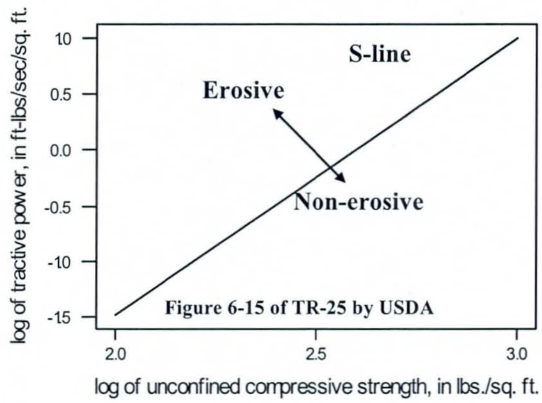

Figure N1. Unconfined compressive strength and tractive power as related to channel stability.

For this manual, vane shear measurements are suggested for *in place* shear strength of the bed and bank soils of the distributary channels. *In place* field tests are useful where it is difficult to obtain and transport undisturbed samples of the soils (USDA, 1977, p. 3-29). According to the USDA (1977, p.3-30) and Vanoni (1975, p. 109 and 112) the in situ shear strength can be determined using vane shear meters. A potential advantage of vane shear strength is that it is determined in the plane of the erosion forces as opposed to compression measurements that are made perpendicular to the shear forces exerted by floodflow. The shear strength is related to the unconfined compressive strength of the soil.

The tractive power approach is the result of limitations of tractive stress methods based on simple index properties determined for disturbed soils. Natural undisturbed soils have additional erosion resistance related to geological processes such as cementation in the B-horizon of developed soils and the presence of tree roots, grasses and microbiotic crusts. According the U. S. Soil Conservation Service, the tractive power approach overcomes some of the limitations of the tractive stress methods.

The tractive force on a stream channel is the force of the water on the wetted perimeter. The unit tractive force is the average tractive force per unit of wetted area. In a uniform flow the tractive force is equal to the component of gravity acting on the body of water in the direction parallel to the stream channel. Briefly, the total tractive force is as follows:

Tractive force = $wALS$ = $lb/ft^3(ft^2)(ft)(ft/ft) = lb$

where w = unit weight of water, in lb/ft^3,
A = wetted area, in ft^2,
L = length of channel reach, in ft, and
S = channel slope.

Unit tractive force = T_o = $wALS/PL = wRS = lb/ft^3(ft)(ft/ft) = lb/ft^2$

where R = hydraulic radius, in feet = A/P.

The unit tractive force is also the tractive stress. The product of the mean velocity and the tractive stress is the tractive power. It is important to note that the tractive power is for a unit area ($1ft^2$) of the wetted perimeter as shown by the following units.

$TP = T_o V = lb/ft^2(ft/sec) = ft\text{-}lb/sec/ft^2$

where V = mean velocity, in ft/sec.

The tractive power for cross sections was determined using methods in TR-25 (US Department of Agriculture, 1977, p.6-33). A kinematic viscosity of 1.42×10^{-5} (water temperature of 50^o F) may be used.

As stated previously, the compressive strength of the in situ bed and bank material may be estimated using measured shear strength by a vane meter. Several measurements of shear should be made on both banks and on the bed at the channel reach of interest. The average shear strength for bare soil at each site is suggested. According to two U.S. Soil Conservation Engineers (oral communication with Gary Conoway, Portland, Oregon and John Harrington, Phoenix, Arizona) the use of unconfined shear strength in place of unconfined compression strength for the relation given in Figure N1 (USDA, 1977, figure 6-15) adds a factor of safety of about 2 (based on the Mohr's circle diagram for vertical and lateral pressures) which is useful for design purposes. Because shear strength, which is half the value of the compression strength, was used for the analysis a conclusion that the banks are stable is considered very conservative. An application of this method is given in Hjalmarson and Tram (1995).

There is a marked difference in the shear stress of typical channel beds and banks of piedmont streams in Maricopa County. The shear strength of the channel bed can be about 1/5 the shear strength of the banks. Many beds of the distributary channels are erosive but scour is restricted at depth by underlying cemented sediments.

The shear stress of grassed banks or banks covered with microbiotic crusts may be 50-percent more than the shear stress of uncovered banks. The increased shear strength associated with the grass and crusts may be partially offset by the decrease of shear strength associated with soil wetting. Because floods are short lived, any grasses, trees and microbiotic crusts along the banks afford some protection against erosion.

Appendix O. USGS Water -Resources Investigations Report 91-4171

The intensity of flood hazard on active and inactive alluvial fans and weathered pediments with distributary channel networks is related to flow path stability using regression techniques. A wide variety of flood intensity is depicted in *Flood hazards of distributary-flow areas in southwestern Arizona* by Hjalmarson and S. P. Kemna (1991). The abstract of the report is followed by a sample calculation of the degree of flood hazard for the Skyline Wash alluvial fan site.

Abstract: Distinguishing features of flood hazards of distributary-flow areas in southwestern Arizona were studied using hydrologic and physiographic characteristics. These characteristics were defined for 39 sites that included both areas with a single diffluence (separation of a single channel) and two channels separated by a high ridge as well as more complex areas where active alluvial fans spread floodflow in an erratic manner. Areas drained above the apices of alluvial fans ranged from 0.48 to 95.9 square miles and the area of the alluvial fans (distributary-flow areas ranged) from 0.32 to 38.8 square miles.

Hydrographic apices can be identified by using 7.5-minute topographic maps, aerial photographs and reconnaissance, soils and geologic maps, and field reconnaissance. A procedure for consistently identifying the hydrographic apex is based on established physiographic and hydrologic principles. Major factors used to identify and categorize area of alluvial fans (distributary flow areas) below the apices include (1) differences in vegetation density across distributary-flow areas; (2) differences in soil color across alluvial fans; (3) drainage texture of some active alluvial fan areas, pediments, and inactive alluvial fans; and (4) the random nature of channel links.

The flood-hazard degree for five types of distributary flow is based on the potentially erratic paths of floodflow. A higher hazard degree (or intensity) was assigned to areas where the potential for lateral relocation of flow paths was large. The flood-hazard degree is related to physiographic characteristics such as the size and number of drainage channels of the distributary-flow area, the slope of the drainage basin, and the average contour-band width of the drainage area.

Degree of flood hazard: Equation 9 on page 54 of Hjalmarson and Kemna is appropriate for estimating the degree of flood hazard at alluvial fan sites in Maricopa County.

$$B = 6.21 - 0.62DD + 25.6MRDA - 1.19H + 2.70K$$

where

B = flood-hazard degree,
DD = ratio of the area of the alluvial fan (DFA) divided by the area of the drainage basin,
MRDA= mean relief ratio of the drainage basin,
H = average contour sinuosity of four to six contours evenly spaced within the DFA, and
K= average contour-band widths of four to six contours evenly spaced within the drainage basin.

The flood-hazard degree is computed for the Skyline Wash alluvial fan (Section 5.3 of the Manual) using the following values of the independent variables:

DD = 2.0/3.93=0.51,
MRDA = 0.124,
H = 1.64, and
K = 0.60.

The estimate flood-hazard degree is B = 8.7.

According to Hjalmarson (1994) (See Appendix P of this Manual), a degree of 8 corresponds to a network of distributary channels where most ridges can be overtopped by the 100-year flood but the location of the channels is stable. Hjalmarson classed this flow condition as unstable because the distribution of flow across the DFA may be uncertain. This area closely corresponds to the relatively small stable area and the east part of the "shadow" area down slope of the gravel pit (Figure 5.23 of the Manual). A flood-hazard degree of nine corresponds to unstable channels or flow paths where most of the ridges may be overtopped and the location of the channels can change. (Table 1 of Hjalmarson, 1994). This area closely corresponds to the more active parts of the unstable area of the Skyline Wash alluvial fan (Figure 5.23). The single rather simple numerical rating of 8.7 using methods by Hjalmarson and Kemna (1991) for sites in central and southern Arizona supports the flood hazard assessment using methods given in this Manual.

Appendix P. USGS Water -Resources Investigations Report 93-4169

An illustrative account of various landforms with distributary-flow channels on piedmonts of Maricopa County. Several photographs of sites are given in *Potential Flood Hazards and Hydraulic Characteristics of Distributary-Flow Areas in Maricopa County, Arizona* by Hjalmarson (1994).

Abstract: Flood hazards of distributary-flow areas in Maricopa County, Arizona, are related to the stability of flow paths, which can be defined using topographic maps, aerial photographs of distributary-flow areas, soil characteristics, and channel cross sections. Five distributary-flow areas that represent the range of flood-hazard degree associated with flow-path stability are discussed in this report. At sites where flow paths are unstable, channels are commonly perched above adjacent low-lying land, which is inundated by floodwaters that overtop the banks. Sites with stable paths of flow have abundant mature paloverde trees and other vegetation along distributary channels that are incised into the landform. Floodflow is apportioned through a network of distributary channels at one site using channel conveyance-slope methods.

The 2-year flood can transport the noncohesive bed material in the main channel at the primary diffluence of the sites selected for the study. The channel competence represented by the maximum grain size that could be moved at the peak discharge of the 2-year flood is typically at least twice that needed to move 90 percent of the bed material.

The average value of width, depth, and velocity exponents of the hydraulic-geometry relations at the primary diffluences of the sites are similar to theoretical exponents for streams with cohesive bank material and the average exponents of stream channels in other areas in the United States. Values of the exponent of channel width, however, show a high degree of unexplained scatter, thus the use of average hydraulic-geometry relations is considered inappropriate for characterizing flood hazards for specific distributary-flow areas in Maricopa County.

No evidence has been found that supports the use of stochastic modeling of flows or flood hazards of many distributary-flow areas. The surface of many distributary-flow areas is stable with many distributary channels eroded in the calcreted surface material. Many distributary-flow areas do not appear to be actively aggrading today, and the paths of flow are not changing.

Appendix Q. Sediment grain size along an idealized fan

Alluvial fan characteristics are related to the water and sediment that enters the active fan at the hydrographic apex. Fan characteristics are also related to the remobilization of fan sediment from rainfall and wind directly on the fan surface. Active fans tend to adjust or reach a state of equilibrium rate of aggrading over long periods. Over long periods the shear stress over the fan surface may reach this equilibrium state where there is no net change of aggradation rate. Thus, shear stress on the surface is a function of water and sediment entering and leaving the active fan. Because of the wide range of water and sediment discharge, typically from thunderstorms, the values of shear stress(represented by the value of D_{50}) and discharge (q) are the result of time integration over the wide range of storm values. These conditions, which form the basis of this idealized method, are similar to commonly used conditions for channel morphology studies (Osterkamp, Lane and Foster, 1983) and are similar to considerations for channel stability given by the COE (1990) as follows:

In considering channel stability, continuity of transport over a year or more is generally more important than in one event lasting a few days or hours. To compute transport over a period of time, a transport rate vs. discharge table is normally combined with a flow-duration table. It is important, however, not to overlook the low-frequency events. In some rivers a low-frequency flood event may transport as much sediment as several years of ordinary flows.

The distribution of sediment grain size along an active alluvial fan may be roughly estimated using an allowable mean velocity relation (COE, 1990) for the ideal fan shown in Figure Q1. The bounds of the fan are represented by a simple segment of a circle. The slope along the radius is uniform and the elevation along each arc is constant. Also, the surface roughness is uniform over the entire fan area and roughness does not change with flow depth. Water flood processes are assumed.

The water flood conditions for the fan are first estimated (Equations Q.3-Q.6). An expression for initial sediment movement is then incorporated in the analysis (Equation Q.7). The median grain size at initial sediment movement, that is a function of shear stress criteria and grain roughness (COE, 1990), represents the material along the fan.

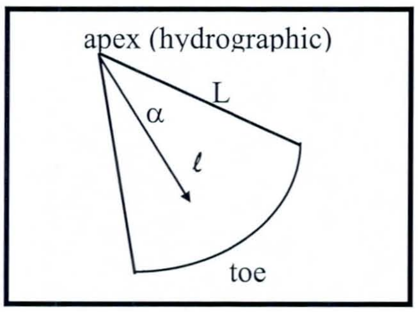

Figure Q1. Ideal active alluvial fan.

The area of the fan (A_f) shown in Figure Q1 is:

$$A_f = L^2\alpha/2 \qquad (Q.3)$$

where L = radius of fan in feet and
α = angle of fan in radians. Also,
ℓ = distance below apex.

The length of arc (wetted perimeter) across the fan at distance l from the apex is:

$$WP = \ell\,\alpha/4 \qquad (Q.4)$$

where WP =$L\alpha/4$ at the fan toe.

Manning's equation is assumed to define the hydraulic conditions with uniform flow depth(h) and velocity(V) across the fan arc. For this ideal fan, both V and h are a function of the distance from the apex. Using Manning's equation,

$$V = q/A = (1.486/n)\,R^{2/3}\,S^{1/2}$$

where n = Manning roughness coefficient,
q = representative discharge over a long period,
A = area of cross section along arc,
R = hydraulic radius = h for wide-shallow flow, and
S = slope.

For a uniform n and S and substituting h for R,

$$V = [(1.486/n)\,S^{1/2}]\,h^{2/3} \qquad (Q.5)$$

Combining equations Q.4 and Q.5 with q = AV = WP h V and rearranging

$$\ell = [4/\alpha]\,[q/[(1.486/n)\,S^{1/2}]]\;h^{-5/3}$$

and rearranging

$$h = [\alpha/4((1.486/n)\,S^{1/2})/q)]^{-3/5}\,\ell^{-3/5} \qquad (Q.6)$$

An relatively simple expression for allowable mean velocity (V) for initial sediment movement in terms of depth (h) and grain size is used. The following is equation 2.3.7 of Stability of Flood Control Channels (COE, 1990):

$$V_a = 10.66\, h^{1/6}\, D_{50}^{1/3} \qquad \text{(Q.7)}$$

where V_a = allowable mean velocity in ft per sec and
D_{50} = grain size in feet

The median grain size (D_{50}) is assumed to be representative of the of the sediment mixture. Combining equations Q.6 and Q.7

$$D_{50} = 0.0027\, n^{-3}\, S^{3/2} \left[\, [\alpha/4((1.486/n)\, S^{1/2})/q)]^{-3/5}\, \ell^{-3/5} \right]^{3/2} \qquad \text{(Q.8)}$$

If there is no loss of floodflow to infiltration then n, S, α, and q are constant. The discharge (q) is equal to the discharge at the apex (Q). The relation between D_{50} and ℓ is shown by the dashed line in Figure Q2.

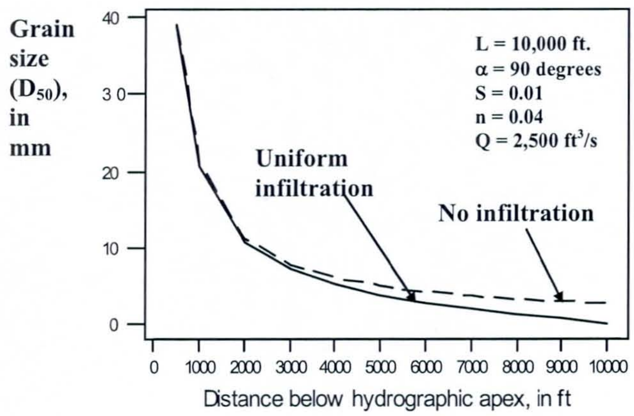

Figure Q2. Distribution of representative grain size (D_{50}) along an idealized active alluvial fan.

If floodflow is lost to infiltration along the fan surface and the loss is a function of fan area along the length of the ideal fan, then q = Q - constant $(\alpha/2)\, \ell^2$ and q = Q at ℓ = 0 and q = 0 at ℓ = L. This assumption of no flow past the fan toe represents an opposing extreme condition to that used in the previous example (dashed line of Figure Q2).

Thus, the constant = $2(Q/\alpha)\, L^{-2}$ and

$$q = Q(1 - (\ell / L)^2) \qquad \text{(Q.9)}$$

Substitution of equation Q.9 in equation Q.8 produces a relation like the solid line shown in Figure Q2.

The lessening of grain size along active alluvial fans and many alluvial plains has been recognized for many years. Thus, the idealized relations show nothing new in this regard. However, some insight may be gleaned into the effects of development on active fans. For example, if the infiltration along an active fan is reduced with all other factors kept constant, the grain size along the fan must increase in order to maintain the equilibrium rate of aggrading along the fan. This increase, that is greatest at the fan toe, means that coarser fan material is needed to offset the additional stream power in order to maintain a state of equilibrium. The effects of changing other factors such as fan roughness and active fan width (angle α) on the grain size of the fan may also be examined using this technique (See Figure Q3). The user is reminded that the grain size characteristics are for the long-term equilibrium rate of aggradation based on the family of floodflows represented by the discharge (q).

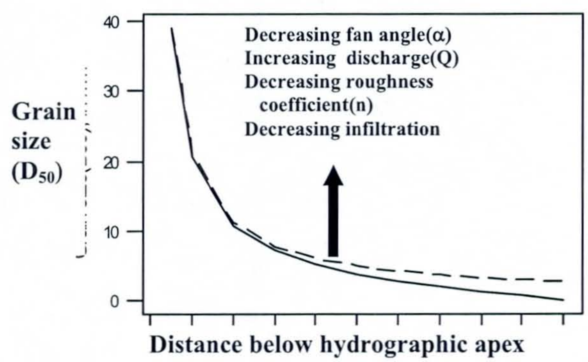

Figure Q3. Direction of shift in relation between grain size and distance below hydrographic apex to maintain equilibrium rate of aggrading for decreasing fan angle (α), decreasing Manning roughness coefficient (n), increasing discharge (Q) and decreasing infiltration for ideal active alluvial fan.

Appendix R – Flood Hazard Zones & Development Standards

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This appendix of the Manual describes the application of the FEMA flood insurance risk zones to the flood hazards found on piedmont landforms in Maricopa County. Much of the chapter is devoted to the alluvial fan flood hazard zones described in the FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix G: Guidance for Alluvial Fan Flooding Analyses and Mapping* (FEMA Guidelines) as they relate to the flood hazard zones described in the *Floodplain Regulations for Maricopa County*. In addition, this chapter presents guidelines for the placement of information within the Technical Document Notebooks for studies utilizing the Manual. The conventional riverine and shallow flooding hazard zones on relict fans, inactive alluvial fans, pediments, and alluvial plains are also discussed.

This appendix is structured as follows:

1) A discussion of the FEMA Flood Insurance Risk zones for piedmont landforms organized by landform type. Under the alluvial fan landform type, the Maricopa County flood hazard zones for alluvial fans are presented
2) Following the presentation the Maricopa County alluvial fan flood hazard zones, the relation between the County zones and the FEMA Zones is given
3) A section describing the Technical Documentation standards for flood hazard assessment studies utilizing the Manual is presented
4) The regulatory philosophy of piedmont landforms and flood hazard zones is given including some construction guidelines for each flood hazard zone
5) Finally, a brief description of the requirements for revision to piedmont flood hazard zones is presented.

R1. Application of FEMA Flood Insurance Risk Zones

The assignment of a flood hazard zone designation to a particular portion of a piedmont depends on the type of landform and the nature of the flooding that occurs in that area. In general, on stable areas where discharges can be reasonably estimated, flood hazard zones can be delineated using conventional methods. Riverine flood hazard zones such as Zone A or AE can be assigned based on the results of normal-depth or step-backwater hydraulic analyses. Landforms included would be relict alluvial fans, portions of some inactive alluvial fans, and pediments characterized by a system of entrenched channels. Active alluvial fans and unstable alluvial plains cannot be delineated with AE Zones. The flood zone designation and floodplain management strategies for alluvial plains will depend on the stability assessment of these areas. FEMA AO Zones may also be applied to areas of broad shallow flooding on inactive alluvial fans and stable alluvial plains.

Uncertainty and flood hazard zones for each of the piedmont landforms discussed in the Manual are addressed below.

Relict Fans

Relict alluvial fans are erosional remnants of old alluvial fans (See section 2.1.1 of the Manual). These landforms are usually characterized by riverine flooding along stable channels in a tributary drainage network (For example Figure 4.1 of the Manual). As such, flood hazards can be assessed using conventional engineering approaches to the rainfall-runoff process. Models such as HEC-1 and HEC-RAS can reasonably be applied to determine flood discharges and the limits of inundation for the 100-year flood on relict fans.

The resulting flood hazard zones would be delineated with FEMA Zones A or AE. FEMA method hydraulic floodways could also be evaluated and mapped on relict fans.

Pediments

Pediments, like relict fans, are erosional landforms (Section 2.1.2). Pediments are landforms underlain at relatively shallow depths by bedrock. In Maricopa County, pediment bedrock is often granitic. Pediment surfaces are usually mantled with a thin, discontinuous veneer of alluvium derived from weathering of bedrock. Appendix F provides additional details on pediments.

Two types of flood hazards are found on pediments (Section 4.1.1). The type of flood hazard zone to assign on pediments depends on the nature of the flood hazard.

First, stream channels on pediments may be entrenched into the bedrock surface such that the flow paths of the pediment drainage system may be considered stable in the terminology of the Manual. Regardless of whether the entrenched channel networks on a pediment are tributary or distributary, conventional hydrologic and hydraulic modeling approaches may be used to determine and delineate flood hazards along stable entrenched pediment channels. For distributary channel networks, the hydrologic accounting of discharges through the system could become rather complex, but conventional approaches would still be applicable due to the stable nature of the channels. Because traditional methods are used, the result would be Zone A or AE flood hazard zones. Application of conventional floodway encroachment techniques to delineation of the floodway however may not be desirable for complex distributary channel networks. Lateral relief on these distributary systems is often low. Therefore, floodplain encroachment threatens to alter the complex distribution of flow within the system and invalidate the floodplain delineation. Consequently, it may be more appropriate to delineate the entire floodplain system as the floodway.

The second type of pediment flood hazard occurs when the pediment is dominated by a thin veneer of alluvial materials with little to no entrenchment of the drainage network. Examples of this type of setting can be found on the Spook Pediment in eastern

Maricopa County and on the southwest slope of the Vulture Mountains west of Wickenburg, Arizona. In these cases, flooding may be better described as a shallow flooding hazard with significant channel position uncertainty. Due to the flow path and discharge uncertainty, delineation of AO zones or possibly the use of A zones with administrative floodways may be desired. Floodways should be assigned to those portions of pediments where flow path locations are highly uncertain. In such areas, consult with the FCDMC on a case by case basis prior to initiating a delineation.

The transition point from a pediment with a thin veneer and uncertain flow paths to an alluvial fan is sometimes a difficult line to draw. The determination of flood hazard zones in this case should consider the NRC/FEMA definition regarding "mitigation based on fill alone." If the investigator or floodplain manager thinks that fill is not an adequate mitigation measure of the flood hazard, designation of one of the alluvial fan flood hazard zones described later in this section may be preferred.

Alluvial Plains

Alluvial plains are found on the distal portions of the piedmont or along the margins of axial streams (See section 2.1.4 and Appendix G of the Manual). These landforms are characterized by broad shallow flooding with few to no defined through-flowing channels. The channels that do exist are usually small and provide collection for more frequent local runoff. Alluvial plains may contain stable or unstable areas. The flood hazard zones will differ depending on the stability assessment.

For stable portions of alluvial plains FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix G: Guidance for Alluvial Fan Flooding Analyses and Mapping* suggests application of *Appendix E, Guidance for Shallow Flooding Analyses and Mapping* to define flood hazards. Appendix E recommends that AO zones be used to designate of flood hazards for areas of shallow flooding. Appendix E states that:

> *For NFIP mapping purposes, areas of shallow flooding with average depths of 1.0 foot or less are designated as Zone X. Areas of shallow flooding with average depths between 1.0 and 1.5 feet are designated as Zone AO (DEPTH 1'); between 1.5 and 2.5 feet, Zone AO (DEPTH 2'); between 2.5 and 3.0 feet, Zone AO (DEPTH 3'). Only after the average depth for a selected reach is determined would that value, for NFIP mapping purposes, be rounded to the nearest whole foot.*

The following guidelines for application of AO Zones should be followed:

1) In Arizona there exists a State Standard, SS 4-95, *State Standard for Identification of and Development Within Sheet Flow Areas*. When the average depth of flow is difficult to determine engineering judgment should be applied based on the development standards outlined in SS 4-95 and the appropriate AO zone be designated.

2) Given District criteria for other flood hazard zones, areas with depths greater than two feet should be considered for designation as administrative floodways.

3) No areas with depths greater than three feet should be delineated as AO zones. Even AO (DEPTH 3') is probably not very realistic on most alluvial plains in Maricopa County. Experience indicates that if flow depths exceed 2.5 feet there are definable channels or broad axial drainages that should be evaluated using traditional riverine hydraulic methods like HECRAS.

Administrative floodways may also be considered for delineation of flood hazards in stable areas of alluvial plains to connect upstream flooding sources from the piedmont to larger axial streams downstream. Several examples of alluvial plain flooding are provided in Appendix G of the Manual. Some of those examples demonstrate how areas within the alluvial plain may be more likely to experience flow and hence worthy of designation as a floodway. Appendix G also points out the importance of small variations in topography or relatively small obstructions to the redistribution of flow on an alluvial plain. Therefore, the best use of an administrative floodway on alluvial plain is in conjunction with a drainage master plan.

Unstable portions of alluvial plains, those areas where flow path stability is uncertain, should be delineated with administrative floodways within an A or AO Zone.

Alluvial Fans

For FEMA FIRM panels, inactive alluvial fans should be delineated with Zones A, AE, or AO. Active alluvial fans should be delineated with Zone A administrative floodways. However, the work study maps should utilize the alluvial fan flood hazard zones for Maricopa County described in the following section.

Description of Alluvial Fan Flood Hazard Zones for Maricopa County

The Floodplain Regulations for Maricopa County as revised November 1, 2000 (Article III, Section 301) contain the following descriptions of the special flood hazard zones for alluvial fans in Maricopa County. The zones are in addition to the existing FEMA A, AE, and AO Zones that could also be found on inactive alluvial fans or other piedmont landforms as discussed elsewhere in this appendix.

- Alluvial Fan High Hazard Area (AFHH):
  An area of active alluvial fan flooding that is reserved to convey and receive sediment and floodwater without altering and thereby increasing the distribution of hazard across the fan to inactive areas and to areas downslope.

- Alluvial Fan Uncertain Flow Distribution Area (AFUFD):
  A transitional area for sheet flooding and channelized flow located below the AFHH area.

- Approximate Alluvial Fan Floodways (AAFF):
  Major conveyance corridors defined within AFUFD and AFZA areas for unimpeded through flow of floodwater and sediment.

- Alluvial Fan Zone A (AFZA):
  An area of an inactive alluvial fan characterized by flooding along stable flow paths and sheet flow or sheet flooding. These stable flow paths may still be subject to erosion hazards, channel bed and bank scour, and fill.

All of the above zones are inherently "approximate" methods from a FEMA perspective. That is, there is no Base Flood Elevation (BFE) associated with these zones. Moreover, the assignment of a BFE does not make sense for active areas. The NRC/FEMA definition of active alluvial fan flooding states that "...elevation on fill will not reliably mitigate the risk."

Stability and Other Criteria for Assignment/Delineation of Flood Hazard Zones on Alluvial Fans

The geomorphic characteristics described in other parts of the Manual facilitate the determination of the appropriate flood hazard zone designation. This section describes how to relate these geomorphic characteristics to the assignment of a flood hazard zone.

Unstable areas on alluvial fans should be delineated as zone AFHH. These are the highest hazard areas on the alluvial fan and as such should be reserved as floodway areas unless full structural engineered solutions for the entire active alluvial fan are provided.

A transitional area out of the unstable active alluvial fan area is provided in the AFUFD zone. The AFUFD zone is a transition zone between the active fan AFHH zone and the stable areas of the alluvial fan further downstream. The extent of this transition zone will depend on the size of the active area upstream and the watershed contributing to the active area. Professional judgment will be required to set the limits for this area. The downstream limit should be within an area that exhibits characteristics of landform and channel locational stability as outlined in Chapter 3 of the Manual.

For stable areas downstream of unstable areas, determination of the flood discharge is subject to significant uncertainty from event to event. Hydraulic calculations to determine a water surface elevation require a discharge. Determination of an appropriate discharge to perform those calculations is therefore subject to significant uncertainties. Nevertheless, engineering judgment can likely be applied to site-specific design studies to estimate discharges when uncertainty can reasonably be set aside or when the limits of uncertainty can be reasonably bounded in the determination of the flood risk at the site.

The three zones, AAFF, AFZA, and Shaded X are found on the stable portions of the alluvial fan landform. The AAFF and AFZA zones are typically located downstream of the active areas of the fan (if they are present). Shaded X zones will generally contain those areas that exhibit surficial, pedological, and topographical characteristics that place them within the Pleistocene epoch (more than 10,000 years old). These characteristics are described in detail Chapter 3 and Appendix L. However, note that it is possible for old geologic surfaces topographically low and proximately located to modern channels to be subject to flood hazards today. If the modern channels are considered stable the low-lying areas should be delineated as zone AFZA. If the modern channels are part of the unstable area, zone AFHH should be delineated.

AAFF zones are to be established as administrative floodways. The purpose of these floodways is to provide continuous corridors for continued transport of water and sediment discharges out of the active areas across the alluvial fan landform to the downstream axial stream or other "permanent" outlet (e.g. Buckeye FRS #2 for Skyline Wash (Section 5.3 and Appendix H)). Therefore, hydrologic and hydraulic continuity from the upstream active area to the downstream outlet is a key characteristic of the AAFF zone delineation. The major existing channels should form a primary starting point for delineation of the AAFF zones. Channels of significant size that are hydrologically connected to the active areas of the alluvial fan should be included as AAFF administrative floodways. Vegetation patterns, soil types, channel patterns, sediment distributions, and topography will be keys to establishing these zones. The AAFF corridors across the alluvial fan downstream of the active area(s) should cumulatively have more than sufficient hydraulic capacity to convey the potential upstream discharges.

AFZA zones are areas subject to inundation on stable areas of the alluvial fan (or alluvial plain) outside the AAFF corridors. The flood hazard is generally limited to inundation although local scour or deposition is possible in this zone, especially where flow is concentrated by obstructions or cuts. Flooding in AFZA zones is generally limited to relatively shallow, often broad areas of flow. Depths are generally less than 2 feet in depth, but often much shallower. Small channels may locally convey somewhat deeper floodwater. However, these channels will likely also be of limited depth and width. Otherwise, they should have been designated as AAFF zones.

AO Zones may be appropriate for some areas of inactive alluvial fans where flooding is characterized by areas broad shallow inundation with few identifiable channels. The important element for designation as Zone AO as opposed to zone AFZA is whether a bounded estimate of the possible peak discharge can be made. Another possibility is if a combination of geomorphic and hydraulic data can constrain uncertainty with respect to the depth of inundation. Examples of this situation may frequently occur on the distal portions of inactive alluvial fans and/or laterally adjacent to relatively entrenched throughflow channels delineated as approximate alluvial fan floodways (AAFF).

R2. Relation of County Flood Hazard Zones to FEMA FIRM Zones

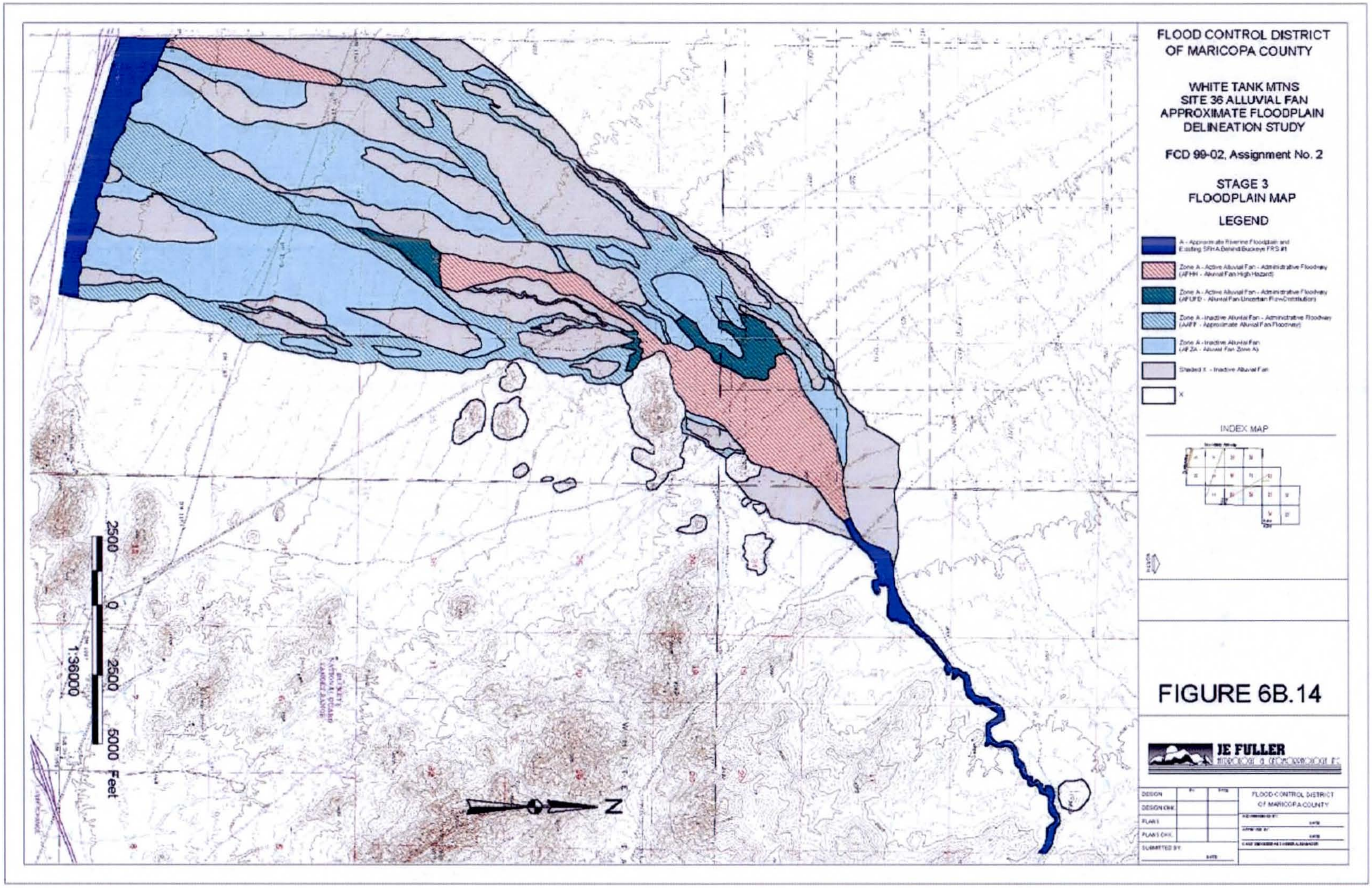
Table R1 shows the flood hazard zones for Maricopa County and their relationship to the FEMA zones that appear on the FIRM panels. Draft FIRM panels must show the FEMA zone designations.

FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix G: Guidance for Alluvial Fan Flooding Analyses and Mapping* presents examples of Flood Insurance Rate Map (FIRM) panels for alluvial fan flooding scenarios based on different hazard identification approaches deemed acceptable for various situations by FEMA. The Manual generally recommends the Geomorphic Method as described by FEMA in Table G-1 for alluvial fans with active areas. However, inactive portions of the piedmont may also utilize conventional step-backwater modeling techniques to delineate flood hazards. Similarly, two-dimensional hydraulic models may also be acceptable to the District for portions of some piedmonts. Consult the District for approval of application of 2-D models on a case by case basis. The ultimate "method" for most piedmont flood hazard assessment studies will fall under the Composite Methods category shown in Table G-1 of FEMA *Guidelines*.

The FIRM panel examples for Geomorphic and Composite Methods are presented in *Appendix G* in Figures G-8 through G-11 of the FEMA *Guidelines*. Figure G-12 of the FEMA *Guidelines* shows a composite method which includes the FEMA FAN program method. The FEMA FAN program is not recommended for use in Maricopa County. Figure G-13 of the FEMA *Guidelines* shows an example of a FIRM panel from 2-D model results.

An example of the District work study maps for the White Tank Fan, Site 36, Flood Hazard Assessment (JEF, 2002) is shown following Table R1.

Table R1. Possible Flood Hazard Zones for Piedmonts in Maricopa County			
Piedmont Landforms	FEMA Zone Name	Local Community Zone Designation	Description
Pediment Relict Fan Inactive Fan	Zone A	Zone A	Approximate 100-year riverine floodplains, no Base Flood Elevation (BFE) computed
Pediment Relict Fan Inactive Fan	Zone AE	Zone AE	Detailed 100-year riverine floodplain with BFE; If flood discharges can adequately be determined, BFE calculation may be possible in inactive areas of alluvial fans.
Pediment Inactive Fan Alluvial Plain	Zone AO	Zone AO	Areas of broad shallow flooding with depths less than 3 feet and where few or no defined channels exist
Active Alluvial Fan	Zone A – Administrative Floodway Active Alluvial Fan	AFHH – Administrative Floodway	Alluvial Fan High Hazard, community to treat as a floodway district
Transition from active to inactive alluvial fan	Zone A – Administrative Floodway Active Alluvial Fan	AFUFD – Administrative Floodway	Alluvial Fan Uncertain Flow Distribution Area; transitional area downstream of AFHH zone characterized by channelized and sheet flooding generally becoming more stable and less uncertain with increasing downstream distance from the AFHH zone; community to treat as a floodway district
Inactive alluvial fan	Zone A – Administrative Floodway Inactive Alluvial Fan	AAFF - Administrative Floodway	Approximate Alluvial Fan Floodway; corridors for conveyance of water and sediment on a stable alluvial fan surface downstream of the AFHH and AFUFD; community to treat as a floodway district
Inactive alluvial fan	Zone A – Inactive Alluvial Fan	AFZA	Alluvial Fan Zone A; areas within the 100-year floodplain on an inactive alluvial fan characterized by shallow channelized flow and sheet flooding in stable channels; zone is considered approximate because no base flood elevations are provided; flood hazards within this zone are not necessarily equal throughout, that is, the frequency and magnitude of flooding with respect to depth and velocity of flow may vary within the AFZA zone; floodplain managers should consult available aerial photographs and topographic maps for more detailed evaluation of site specific flood hazards within this zone; development will be allowed in this zone given demonstration of adequacy of site and/or design which addresses safety from inundation and sedimentation hazards
Inactive alluvial fan	X (shaded) – Inactive Alluvial Fan	X (shaded)	Areas flooded between 100-yr and 500-yr discharge; <u>or</u> areas of flooding with depth of 100-year flood less than 1 foot; <u>or</u> drainage area less than 1 square mile on an inactive alluvial fan
Pediment Relict Fan Alluvial Plain	X (shaded)	X (shaded)	Areas flooded between 100-yr and 500-yr discharge; <u>or</u> areas of flooding with depth of 100-year flood less than 1 foot; <u>or</u> drainage area less than 1 square mile
X (unshaded)	X (unshaded)	X (unshaded)	Areas outside the 500-year floodplain
D	D	D	Areas not studied



Example of Stage 3 Work Study Map with District and FEMA Flood Hazard Zones

R3. Technical Documentation Standards for Manual Studies and Revisions

Technical documentation of studies performed using the Manual should follow the Arizona State Standard SS1-97, *Instructions for Organizing and Submitting Technical Documentation for Flood Studies* (SS1-97). As such, the following slight modifications to SS1-97 are proposed for organization and delivery of technical documentation presented in support of a flood hazard assessment performed in Maricopa County using the Manual. The primary difference between the SS1-97 format and this modification is the addition of a new section, called Section 6B – Geomorphology and an accompanying Appendix G. Given that many studies may utilize compound methods in completion of a flood hazard assessment, this outline provides a framework for the documentation of all of the various methods that may be used in a particular study. Most importantly, the Introduction Section 1 of SS1-97 should be used to outline the specific nature of the approach(es) used and how they are presented within the Technical Data Notebook (TDN).

Revised SS1-97 Outline

Title

These studies should be referred to as Flood Hazard Assessments rather than Floodplain Delineation Studies for the following reasons. First, a flood plain is a type of landform normally associated with rivers. Use of this terminology for a flood hazard analysis on piedmont landforms is potentially misleading. Second, use of different terminology in the title can help distinguish the expectations of the organization of the technical data notebook on the part of the study contractor and the reviewer.

Section 1 - Introduction

Introduction outlining study area and approach. In particular, Section 1 should describe how the combination of approaches applied to the flood hazard assessment are organized within the TDN.

Section 2 - ADWR/FEMA Forms

The most current FEMA forms should be used. In particular if alluvial fan landforms are identified in Stage 1 of the piedmont flood hazard assessment, the forms for alluvial fans should be used.

Section 3 - (Topographic) Mapping

Section 3 typically contains the details of any topographic mapping used or developed for the flood hazard assessment. However, other mapping done for a flood hazard assessment, such as detailed soil surveys or surficial geologic mapping, should also be described in this section. If soils or geologic mapping are reported in Section 3, Section 3.2 should be subdivided into the following three subsections:

3.2.1 Topographic Mapping
3.2.2 Soils Mapping
3.2.3 Geologic Mapping.

The discussion within these subsections should be limited to the descriptions to the techniques used, accuracy standards, aerial photo sources, etc. Interpretations of these data as they relate to the landform, stability, and flood hazard assessment should be included in Section 6B.

Section 4 - Hydrologic Modeling and Assumptions
Section 4 should contain descriptions of the hydrologic modeling methods, assumptions, parameters, and results performed as part of the flood hazard assessment.

Section 5 - Detailed or Approximate Hydraulics
Section 5 should contain descriptions of the hydraulic modeling methods, assumptions, parameters, and results performed as part of the flood hazard assessment.

Section 6A - Sed. Transport / Special Erosion Analyses
Section 6A should address the riverine sediment transport and erosion analyses methods, assumptions, parameters, and results performed as part of the flood hazard assessment.

Section 6B – Geomorphology
Section 6B should address the geomorphic methods, assumptions, and results performed as part of the flood hazard assessment.

Section 6B should be organized according to the three stage approach described in the Manual, the FEMA *Guidelines* Appendix G, and the NRC report. Appendix G of the FEMA *Guidelines* also provides major subheadings for consideration in the organization of the Stage 1, 2, and 3 sections of the presentation of documentation within Section 6B of the TDN which may also facilitate smooth review and approval by FEMA.

Section 6B should be organized into the following major subheadings:

1. Introduction

2. Stage 1 – Recognizing and characterizing piedmont landforms
    a. Composition
    b. Morphology
    c. Location
    d. Boundaries

3. Stage 2 – Defining the nature of the alluvial fan environment and identifying active and inactive areas of the fan
    a. Identification of active areas

   b. Identification of inactive areas
   c. Types of flooding

4. Stage 3 – Defining and characterizing the 100-year flood within the defined areas

The following items should be considered for inclusion in the technical data presented in Section 6B and Appendix G of the TDN:

- Discussion of soils, descriptions of their characteristics and distributions
- Discussion of surficial geology or geologic mapping units, their characteristics and distributions
- Aerial photos and interpretations of them
- Longitudinal profile shape and slope
- Watershed map
- Tables of summary of soils units with landform and stability related characteristics
- Table for surficial geology units if available with landform and stability related characteristics
- Historical aerial photo comparison showing channel changes if any
- Sediment supply analysis emphasizing sediment delivery to the reaches near the hydrographic apex and channel avulsion potential in those reaches
- Map of Stage 1 results – include best available topography and recent aerial photo
- Map of Stage 2 results– include best available topography and recent aerial photo
- Map of Stage 3 results – include best available topography and recent aerial photo – use FEMA zones with FCD zones parenthetically shown in legend

Some of the bulleted items above could occur within different subsection of Section 6B because many of the types of information pertain to parts of each of the three stages of the flood hazard assessment. For example, interpretation of aerial photographs is important to all three stages. Similarly, the descriptions of soil and surficial geologic units and their characteristics have bearing on the landform, stability, and type and degree of flood hazards. Investigators should refer to the Stage 1, 2, and 3 discussions within the Manual and Appendix G of the FEMA *Guidelines* in addition to the organization guidance provided here.

Section 7 – DRAFT FIS
This section contains the Flood Insurance Study type data including summaries of discharges, drainage areas, and water surface profiles if applicable. It should also include a revised FIRM(s) with FEMA zones for the affected communities.

Appendix A
Appendix A contains the data collection summary and any referenced documents.

Appendix B
Appendix B contains general documentation and correspondence related to the project.

Appendix C
Appendix C contains backup documentation for Section 3. Details, survey notes, soil pit logs, and other backup documentation for the topographic, soils, and/or geologic mapping should be provided in Appendix C under separate subheadings C.4 for Soils Mapping, and C.5 for Geologic Mapping. The backup survey notes information for the topographic mapping are provided for in the existing State Standard 1-97 subheadings C.1-C.3.

Appendix D
Appendix D contains backup documentation for Section 4.

Appendix E
Appendix E contains backup documentation for Section 5.

Appendix F
Appendix F contains backup documentation for Section 6A.

Appendix G
Appendix G of the TDN contains backup documentation for information presented in Section 6B. Large scale versions of the at least the Stage 2 and Stage 3 maps should be included in Appendix G of the TDN at scale sufficient for interpretation of the aerial background and topography by the reviewer. In addition, a digital version of these maps, such as PDF, that can be viewed by the reviewer on the computer may also be helpful.

R4. Regulatory Philosophy for Piedmont Flood Hazard Zones

The delineation of flood hazard zones on piedmonts in Maricopa County exists within a regulatory arena. Some understanding of the context of the regulation of these zones can greatly facilitate their delineation. The remainder of this appendix presents information regarding regulation and administration of these zones that the investigator may find of use in the delineation of piedmont flood hazard zones.

The framework for the regulation of the piedmont flood hazard zones has been previously established in the *Floodplain Regulations for Maricopa County*. Regulation of riverine shallow flooding zones and alluvial fans are described in the *Regulations*. The regulations outline criteria for site grading, minimum lowest floor elevations, erosion setbacks, and other engineering requirements for development within flood hazard zones in Maricopa County.

Flood Zones in Stable Areas

The regulatory philosophy for flood hazard zones outlined in the *Regulations* consider riverine floodways as areas of limited use. Section 902. Floodway Development Standards reads "No structure, ..., or other uses shall be permitted which alone or in combination with existing or future uses, ... would cause an increase in the base flood elevation or flood damage potential." For riverine areas delineated by traditional methods (Zone A or AE), this means development within the floodway fringe are permitted provided certain criteria are met. Engineered plans and/or reports are generally required for development.

The identification of a flood fringe (or floodway) on AE Zones in some piedmont environments deserves thoughtful consideration. Complex distributary networks often found on inactive alluvial fans or entrenched pediments should be considered for zero-rise floodplains. That is, no encroachment should be allowed. The rationale for this designation is:

1) These areas are typically characterized by relatively low lateral relief. Consequently, a one foot rise in the base flood elevation could significantly redistribute the flood runoff and alter the nature and extent of the flood hazard at many locations downslope.
2) The complex hydrologic and hydraulic analyses conducted to delineate these AE Zones depends on the distribution of discharges at each of the channel splits modeled. Encroachment on the floodplain could change the distribution of the flood discharges at a split. This would alter the "true" flood hazard invalidating the flood hazard zone delineation(s) shown on the FIRM and the work study maps.

In zone AFZA, building will be allowed with elevation of the building pad and the surrounding area in a manner similar to Zone A riverine floodplains. The *Regulations* refer to elevation of the building pad two feet above the Base Flood Elevation (BFE).

While Zone A areas do not have a defined BFE or regulatory depth, a local BFE or depth on a specific site may be determined using a hybrid approach based on State Standards 4-95 and 2-96. SS 2-96 methods can be used to estimate a 100-year discharge for a site based on envelope curves or regional regression equations. This should be done based on a conservative evaluation of the potential drainage area to the site. A normal-depth determination of average flow depth can then be determined. The Flood Control District has 2001 vintage 10-foot topography for all of Maricopa County and more detailed topography for many other areas that could be used for this purpose if other more detailed topography is not available. Once a depth of flow has been determined, SS4-95 can be referenced for minimum floor elevations. A comparison of the average depth computed versus the minimum floor elevation criteria can be made to determine a reasonable minimum floor elevation for the proposed development. FEMA 265 (FEMA, 1995) also contains information on the determination of BFEs for Zone A areas.

The Floodplain Regulations for Maricopa County consider any riverine flooding area in a Zone A greater than two feet in depth to be the effective floodway. A similar criteria could be applied to AFZA. One additional criteria that the two foot rule might already accommodate is that existing "obvious washes" or channels be preserved. Typically in an AFZA area channels will be one to two feet in depth, so the two foot depth floodway would catch most of these channels. Preservation of these channels is important to maintain local drainage of water and sediment in more frequent floods as well as conveyance during larger, less frequent events. Fence treatments, ingress and egress, utilities, and out-buildings placement and design should also be designed to reduce impacts to the water and sediment balance within the AFZA areas. Additionally, scour protection of building foundations should be evaluated. Finally, buildings, fences, and other structures shall not block more than 50% of the width of the lot in the direction of flow. This is intended to allow flood water to pass around structures safely and reduce the cumulative disruption of the drainage system due to development.

Development within Shaded X areas should also have some minimum development criteria on piedmonts. A minimum lowest floor elevation of 12 inches as already required in the Drainage Regulation should be required. In addition the other drainage related criteria of maintaining ingress and egress of existing washes and similar concerns should be followed.

Flood Zones in Unstable Areas

Floodways on active areas of alluvial fans are considered off-limits to development without mitigation of those hazards by major engineering works. That is, the active alluvial fan flood zones AFHH and AFUFD, as well as the AAFF corridors, will be treated as zero rise floodways and no encroachment will be allowed. Moreover, proposed engineering works designed to modify or remove these zones from the Flood Management Maps for Maricopa County will require demonstration of the adequacy of the performance of those engineering works with respect to inundation and sedimentation. The performance of these engineered systems should be demonstrated for a range of frequencies of flood events. Maintenance and operations plans must also be provided and long-term responsibility arrangements be demonstrated to the satisfaction of the Floodplain Administrator.

Unstable areas on other landforms should also be treated as floodways. In particular, no encroachment of these areas should be allowed without adequate demonstration of the engineering works proposed to mitigate the hazards associated with the unstable areas. Additionally, all unstable areas should be evaluated in the wider landform context and the impacts to the sediment transport continuity and fluvial landform response to the proposed engineering measures requires demonstration to the satisfaction of the Floodplain Administrator.

Construction Guidelines

Additional requirements for development in the alluvial fan flood hazards zones are described below. These requirements apply equally to single-lot as to subdivision development.

AFZA

Generally the two feet elevation for the building and immediate area above adjacent natural grade and out of an identifiable wash (i.e. local drainage) is considered satisfactory remedy of the hazard in most cases as outlined in the *Regulations*. Therefore, an applicant will need detailed site topography and/or survey and a site plan showing the existing and proposed ground elevations, lot layout, grading, lowest floor elevations, and accurately located flood hazard boundaries. Deviations from this approach would require additional data and analysis. Arizona State Standards SS4-95 and SS2-96 may provide a suitable framework to design a suitable site plan.

AFHH

No development will be allowed without major engineering works (e.g. sediment basin, diversion levees, dam, etc.) to mitigate the flood and sedimentation hazards. All such proposed solutions will require sealed engineered plans. In addition, a maintenance plan will also be required which identifies responsible parties and demonstrates to the satisfaction of the Floodplain Administrator the long-term adequacy of the performance of the proposed facilities. In addition, an approved Conditional Letter of Map Revision will be required prior to approval of any proposed facilities.

AFUFD

Development will not be allowed within an AFUFD without major engineering works to mitigate the flood and sedimentation hazards associated with the AFHH zone upstream. A detailed two-dimensional hydraulic model or similar physical model to 'thoroughly document' the more detailed limits of the transition from stable to unstable areas (e.g. velocity distributions and comparisons to shear stress required for sediment transport for some worst case-type scenarios) could be considered for modifications of the downstream limits of the AFUFD zone. Development could then be proposed in the revised areas. However, the impacts of the proposed improvements on the downstream and adjacent areas will be required prior to approval of the development.

AAFF

The AAFF zone will generally be considered a zero rise floodway. The requirements to alter the AAFF delineation are as follows:

1) full engineering measures are provided upstream (i.e. elimination of active area hazards) or
2) Provide a demonstration that the proposed improvements will not significantly disturb the conveyance of water and sediment through the area, nor will they alter the sediment transport continuity in the upstream and downstream reaches. Adequate demonstrations would include, no change in channel slope in the impacted reach and preservation of (75%) of conveyance in the reach. The conveyance reduction would be evaluated based on the total conveyance of the reach at an elevation corresponding with the limits of the AAFF zone.

A number of Area Drainage Master Plan (ADMP) "Rules of Development" are also currently under development. These may provide additional criteria related to development of parcels on piedmonts in Maricopa County.

R5. Piedmont Flood Hazard Zone Revisions

Revision to a piedmont and alluvial fan flood hazard zone delineation can be accomplished when appropriate analyses have been conducted. Some of those analyses are discussed in the previous section. Other conditions for a revision would be to correct errors in the original analysis or if more detailed or better technical information can be presented.

A Conditional Letter of Map Revision (CLOMR) will be required for any structural measures proposed to remove a site from an AFHH or AFUFD zone prior to approval of the proposed development.

References

ADWR, 1997, Requirement for Flood Study Technical Documentation, State Standard 1-97

ADWR, 1996, Requirement for Riverine Floodplain and Floodway Delineation, State Standard 2-96

ADWR, 1995, State Standard for Identification of and Development Within Sheetflow Areas, State Standard 4-95

FEMA, 2002, Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix E. Guidance for Shallow Flooding Analyses and Mapping

FEMA, 2002, Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix G. Guidance for Alluvial Fan Flooding Analyses and Mapping

FEMA, 1995, Managing Floodplain Development in Approximate Zone A Areas, A Guide for Obtaining and Developing Base (100-Year) Flood Elevations, FEMA 265, July 1995

FCDMC, 2000, Floodplain Regulations for Maricopa County, as adopted Aug. 4, 1986 and subsequently amended

JEF, 2001, Approximate Floodplain Delineation Study for White Tank Fan, Site 36, performed under contract FCD 99-02, Assignment 2, by JE Fuller/Hydrology & Geomorphology, Inc. in association with Wood, Patel & Associates

Appendix S. Variables that affect fluvial hazards

Users of this manual should be aware that landform changes because of nonstationary runoff, sediment loads and base level could affect the assessment of stable and unstable areas using the indicator method. The indicator method is based largely on historical information that may not reflect future conditions if, for example, the climate is fluctuating or watershed conditions change. Changes of discharge, sediment load and base level of a piedmont landform can affect flood hazards described in Chapter 3. For example, the likelihood of channel avulsion on an alluvial fan increases with increasing time simply because more sediment laden floods from the watershed are experienced. Also, if discharge on a landform increases then dissection of the landform is expected because of excessive erosion. This issue was addressed by the Committee on Alluvial Fan Flooding (NRC, 1966) as follows:

> *Judging where flooding and deposition might occur is particularly important in cases where land use patterns are substantially altered by human activity (e.g., the Wasatch Range, Utah) or where recent decades have been marked by more intense storm patterns. As an example of the latter, storms in southern Arizona have changed in this century from moderate-sized summer events with sources in the south to much larger fall and winter events coming from the west-southwest (Pacific Ocean). Some of this change in storm conditions is attributed to the increasing frequency of El Nino climatic events over the past few decades. In such cases, it probably is prudent to define active as more than just those parts of the fan that have been the sites of flooding and deposition in the past 100 or 1,000 years.*

In regard to flooding on piedmonts of Maricopa County, the issue is whether the El Nino fluctuation affects the flood frequency of small mountainous basins. Because of the large variance of annual flood peaks this is a difficult issue to resolve. Clearly, any climate fluctuations make the assessment of stable and unstable areas less precise. Also, both engineering and geomorphic assessments of fluvial hazards and risk are affected by trends in factors such as the peak discharge of floods. The delineation of stable and unstable areas should be conservative to allow for any trends. If nonstationary site conditions are suspected, the following published studies of trends of climate, geomorphology, sediment yield and vegetation may be consulted.

1. The behavior of fluvial systems and in particular, the understanding of the cause of incised channels, is described by Schumm, Harvey and Watson(1988). Channel incision may be the result of changes imposed on the system such as climate fluctuations or changes within the system such as the accumulation of sediment to threshold levels where gulling occurs. Channel incision is a natural occurrence in semi-arid regions like Maricopa County that may be independent of climate fluctuations. For additional interesting discussion of "Geomorphic implication of climate change", see Schumm (1969).

2. Abrahams, Parsons and Wainwright (1995) found inter rill runoff and erosion increased as a result of replacement of grassland with shrubland at Walnut Gulch in southeastern Arizona during the past 100 years. There is some evidence of rill, interrill and channel erosion on piedmonts of Maricopa County that is similar to rill erosion at Walnut Gulch.
3. Nonstationarity or trends of annual peak discharge at USGS gages on streams draining areas less than 200 mi^2 were not detected for Arizona as part of an analysis of flood frequency of the western U. S.(Thomas, Hjalmarson and Waltemeyer, 1997). The highly variable nature of flood peak discharge in Maricopa County may mask the identification of recent changes, if any, of discharge.
4. A study of the variation of warm-season rainfall in the northern Arizona region shows a recent decrease of wet years and an increase of dry years has reduced runoff, sediment loads and erosion(Hereford and Webb, 1992).
5. Studies in southern Arizona have shown a slight decline in the frequency of heavy rains (Cooke, Warren and Goudie, 1993).

September 2005 - October 2005

September 2005						
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Monday	Tuesday	Wednesday	Thursday	Friday	Sat/Sun
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Ed Raleigh - FCDX

Subject:	Compensation Class Review; Please see below list
Location:	Pima conference room
Start:	Fri 09/09/2005 10:00 AM
End:	Fri 09/09/2005 11:00 AM
Recurrence:	(none)
Meeting Status:	Accepted
Required Attendees:	Mcdotx Conf Rm Pima; Lois Wahl - MCDOTX; Kenneth Proksa - PWX; Jeanine I. Linsenmeyer - FCDX; Ed Raleigh - FCDX
Optional Attendees:	Donna B. Brown - PWX

- Floodplain Rep
- Floodplain Rep. Sr.
- Floodplain Supervisor