SOME GEOMORPHIC MODELS OF FLOOD HAZARDS ON DISTUBUTARY FLOW AREAS ON SOUTHERN ARIZON

SOME GEOMORPHIC MODELS OF FLOOD HAZARDS ON DISTRIBUTARY FLOW AREAS IN SOUTHERN ARIZONA

by

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"I tell you the truth, unless a kernel of wheat falls to the ground and dies, it remains only a single seed. But if it dies, it produces many seeds." - Gospel of John 12:24

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ABSTRACT

The Federal Emergency Management Agency (FEMA) uses a method for evaluating flood hazards on alluvial fans that assumes an equal chance of flooding along a radial arc across the fan surface. In southern Arizona there are distributary flow areas (alluvial fans) that do not conform with FEMA's assumption.

Thirty-nine sample sites were chosen from the Basin and Range physiographic province in southern Arizona. These sites were classified into five categories of flood hazard; A, B, C, D, and E. The classification scheme is based on the potential randomness of flooding across each site.

A method is proposed for locating the primary diffluence (apex) of a distributary flow area. Texture curve analysis is used to locate distributary flow areas on the piedmont plain. Two alternative methods, topologic analysis and a multiple regression model, are presented for evaluating flood hazards on distributary flow areas in southern Arizona.

Only eight of the sample sites studied strictly conformed with FEMA's assumption of an equal probability of flooding along a radial arc across the fan surface. The topologic analysis may be used to determine if the FEMA method is appropriate for a given site. A multiple regression model

provides rough predictions of the degree of flood hazard based on morphometric and hydrologic variables.

INTRODUCTION

Statement of Problem

The Federal Emergency Management Agency (FEMA) uses a modification of Dawdy's method (FEMA, 1985, Appendix 5) to delineate flood hazard zones on alluvial fans. FEMA applies this method to southern Arizona. Yet, the method alone is not adequate because of the complex geomorphic history that has left landforms which violate the assumptions of FEMA's methodology. These same complexities lead investigators to misapply FEMA's method even where it is appropriate. A simple procedure is needed to locate the apex (primary diffluence) of alluvial fans (a type of distributary flow area). Also, a reconnaissance method is needed to determine the flood hazards of distributary flow areas and to determine where FEMA's method is applicable.

This thesis examines the assumptions of FEMA's method, determines where it is applicable, and proposes ways to avoid misapplying the method. This includes a procedure for locating the primary diffluence and a method for locating distributary flow on the piedmont plain. It also investigates two alternative methodologies for determining where the FEMA method may be applied and for classifying flood hazards on distributary flow areas (including alluvial fans) in southern Arizona.

Location of Study Area

Thirty-nine sites were chosen in the Basin and Range physiographic province in southern Arizona (Table 1, Fig.1). The sites were selected using 7.5 minute topographic maps, oblique 35 mm aerial photographs, AMS maps, orthophotos, and a geomorphic map of Arizona (Cooley, 1977).

The AMS maps and the map of geomorphic features helped locate general areas of distributary flow. The 7.5 minute topographic maps and the aerial photographs enabled the delineation of specific sites. James Marie and Hjalmar Hjalmarson, of the U.S. Geological Survey, surveyed the southern half of the state and selected a representative sample of distributary flow areas. Figure 1 displays the location of the 39 sites.

Terminology

A distributary flow area (DFA) is defined as an area on the piedmont plain where stream channels separate in a downstream direction (Appendix K - Glossary). These

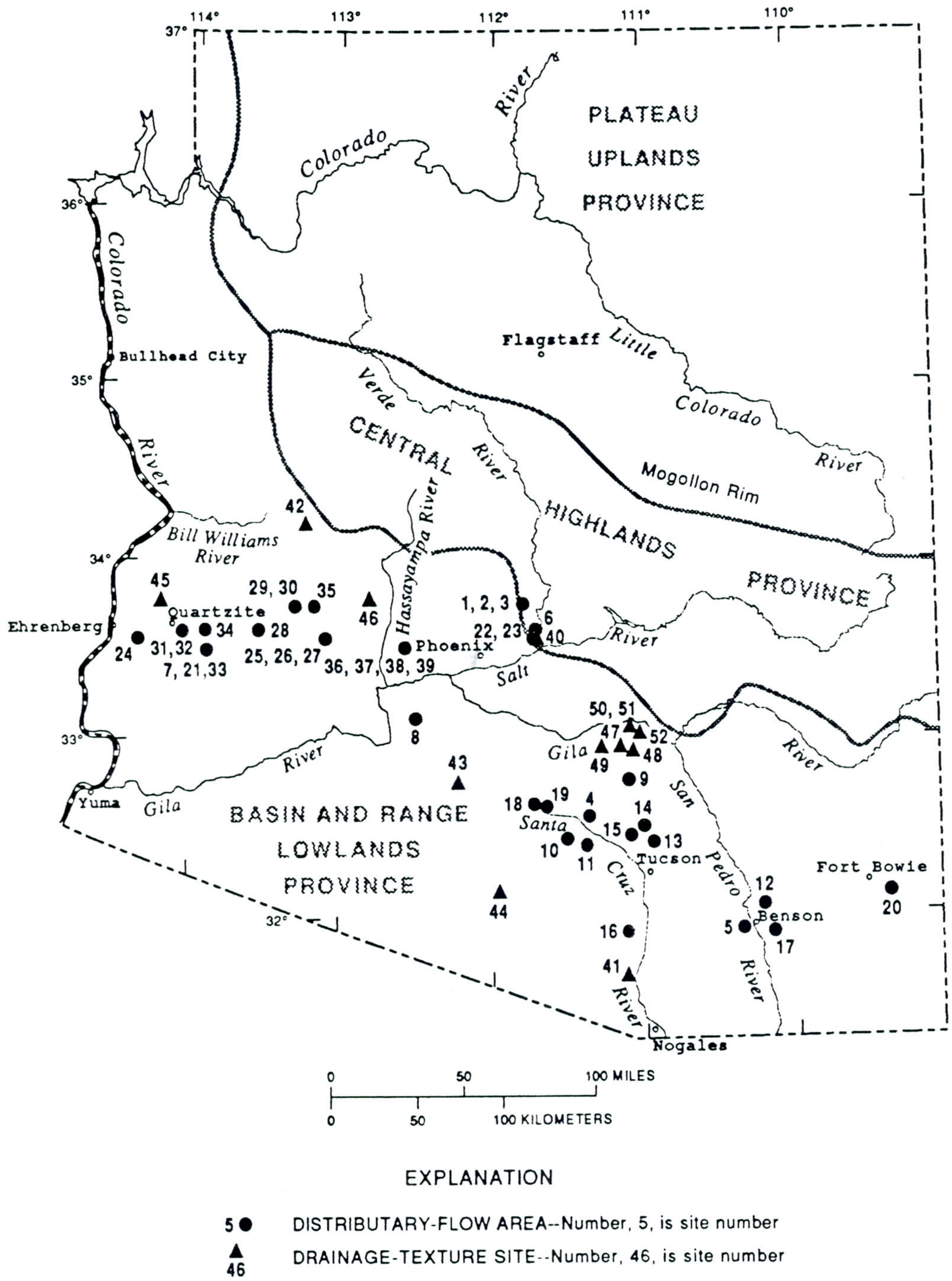


Figure 1.—Location of distributary flow and drainage texture measurement sites.

SITES

Table 1.-- Location of Thirty-nine Sample Sites and Thirteen (*) Miscellaneous Texture Measurement Sites

Site No.	Location	Landform
1	Lat 33 47'37'', long 111 54'53'', in sec.11, T.5 N., R.4 E., Maricopa County	DFA
2	Lat 33 46'43'', long 111 54'28'', in sec.13, T.5 N., R.4 E., Maricopa County	DFA
3	Lat 33 46'10'', long 111 54'08'', in sec.24, T.5 N., R.4 E., Maricopa County	DFA
4	Lat 32 38'35'', long 111 26'22'', in sec.17, T.9 S., R.9 E., Pinal County	DFA
5	Lat 31 56'28'', long 110 18'34'', in sec.21, T.17 S., R.20 E., Cochise County	DFA
6	Lat 33 41'48'', long 111 51'56'', in sec.17, T.4 N., R.5 E., Maricopa County	DFA
7	Lat 33 31'34'', long 114 07'10'', in sec.9, T.3 N., R.18 W., Yuma County	DFA
8	Lat 33 11'48'', long 112 36'49'', in sec.6, T.3 S., R.3 W., Maricopa County	DFA
9	Lat 32 46'42'', long 111 10'53'', in sec.35, T.7 S, R.11 E., Pinal County	DFA
10	Lat 32 30'45'', long 111 28'22'', in sec.36, T.10 S., R.9 E., Pinal County	DFA
11	Lat 32 30'57'', long 111 28'48'', in sec.34, T.10 S., R.9 E., Pinal County	DFA
12	Lat 32 05'00'', long 110 17'24'', in sec.34, T.15 S., R.20 E., Cochise County	DFA
13	Lat 32 25'37'', long 111 05'18'', in sec.35, T.11 S., R.12 E., Pima County	DFA
14	Lat 32 27'34'', long 111 04'47'', in sec.24, T.11 S., R.12 E., Pima County	DFA
15	Lat 32 29'19'', long 111 07'34'', in sec.9, T.11 S., R.12 E., Pima County	DFA
16	Lat 32 01'09'', long 111 12'40'', in sec.22, T.16 S., R.11 E., Pima County	DFA
17	Lat 31 54'08'', long 110 11'34'', in sec.3, T.18 S., R.21 E., Cochise County	DFA
18	Lat 32 38'45'', long 111 44'42'', in sec.16, T.9 S., R.6 E., Pinal County	DFA
19	Lat 32 36'52'', long 111 42'04'', in sec.25, R.9 S., R.6 E., Pinal County	DFA
20	Lat 32 08'58'', long 109 22'58'', in sec.3, T.15 S., R.29 E., Cochise County	DFA
21	Lat 33 30'48'', long 114 09'42'', in sec.18, T.2 N., R.18 W., Yuma County	DFA
22	Lat 33 34'51'', long 111 49'16'', in sec.26, T.3 N., R.5 E., Maricopa County	DFA
23	Lat 33 35'40'', long 111 48'55'', in sec.23, T.3 N., R.5 E., Maricopa County	DFA
24	Lat 33 34'47'', long 114 24'31'', in sec.27, T.3 N., R.21 W., Yuma County	DFA
25	Lat 33 39'56'', long 113 11'47'', in sec.29, T.4 N., R.9 W., Maricopa County	DFA
26	Lat 33 37'02'', long 113 10'02'', in sec.3, T.3 N., R.9 W., Maricopa County	DFA

Table 1.-- Continued

Site No.	Location	Landform
27	Lat 33 33'42'', long 113 05'15'', in sec.33, T.3 N., R.7 W., Maricopa County	DFA
28	Lat 33 38'23'', long 113 35'00'', in sec.34, T.4 N., R.13 W., Yuma County	DFA
29	Lat 33 43'57'', long 113 26'37'', in sec.31, T.5 N., R.11 W., Yuma County	DFA
30	Lat 33 44'08'', long 113 22'42'', in sec.35, T.5 N., R.11 W., Yuma County	DFA
31	Lat 33 38'33'', long 114 06'30'', in sec.34, T.4 N., R.18 W., Yuma County	DFA
32	Lat 33 37'42'', long 114 06'42'', in sec.4, T.3 N., R.18 W., Yuma County	DFA
33	Lat 33 33'58'', long 114 08'33'', in sec.32, T.3 N., R.18 W., Yuma County	DFA
34	Lat 33 30'57'', long 113 47'27'', in sec.15, T.2 N., R.15 W., Yuma County	DFA
35	Lat 33 43'48'', long 113 17'28'', in sec.34, T.5 N., R.10 W., Maricopa County	DFA
36	Lat 33 30'52'', long 112 37'07'', in sec.13, T.2 N., R.4 W., Maricopa County	DFA
37	Lat 33 31'23'', long 112 37'19'', in sec.12, T.2 N., R.4 W., Maricopa County	DFA
38	Lat 33 31'35'', long 112 39'13'', in sec.10, T.2 N., R.4 W., Maricopa County	DFA
39	Lat 33 32'38'', long 112 38'35'', in sec.3, T.2 N., R.4 W., Maricopa County	DFA
40*	Lat 33 33'37'', long 111 49'22'', in sec.34., T.3 N., R.5 E., Maricopa County	Old Fan
41*	Lat 31 40'27'', long 111 04'32'', in sec.24, T.20 S., R.12 E., Santa Cruz County	Old Fan
42*	Lat 34 12'36'', long 113 17'42'', in sec.16, T.10 N., R.10 W., Yavapai County	Old Fan
43*	Lat 32 43'13'', long 112 13'12'', in sec.24, T.8 S., R.1 E., Maricopa County	Old Fan
44*	Lat 32 06'30'', long 111 59'50'', in sec.19, T.15 S., R.4 E., Pima County	Old Fan
45*	Lat 33 45'23'', long 114 12'22'', in sec.23, T.5 N., R.19 W., Yuma County	Old Fan
46*	Lat 33 47'48'', long 112 51'30'', in sec.2, T.5 N., R.6 W., Maricopa County	Old Fan
47*	Lat 32 58'03'', long 111 11'53'', in sec.26, T.5 S., R.11 E., Pinal County	Pediment
48*	Lat 32 57'07'', long 111 10'43'', in sec.36, T.5 S., R.11 E., Pinal County	Pediment
49*	Lat 32 58'23'', long 111 20'45'', in sec.20, T.5 S., R.10 E., Pinal County	Pediment
50*	Lat 33 03'32'', long 111 06'33'', in sec.27, T.4 S., R.12 E., Pinal County	Pediment
51*	Lat 33 03'05'', long 111 06'52'', in sec.27, T.4 S., R.12 E., Pinal County	Old Fan
52*	Lat 33 03'08'', long 111 04'38'', in sec.25, T.4 S., R.12 E., Pinal County	Pediment

for DFAs - location of primary diffluence
* for miscellaneous texture measurement sites - location of toe of sampling strip

distributary channels first divide at a point called the primary diffluence. Down slope of the primary diffluence, distributary channels can continually divide and combine. The number of forks in the channels commonly exceeds the number of places where the channels join. Distributary flow areas possess many types of bifurcations. These range from two channels that separate and remain confined, to complex systems of channels that divide and combine many times on the piedmont plain.

In contrast to the "DFA", the term alluvial fan is well known to anyone who has taken an elementary course in geology. Of the many definitions for an alluvial fan, the definition given in the Federal Register is chosen for this study (Appendix K - Glossary). Bull offers another definition for an alluvial fan. He defines an alluvial fan as "a stream deposit whose surface forms a segment of a cone that radiates downslope from the point where the stream channel emerges from a mountainous area" (Bull, 1964, 352-E, p.iv).

It is true that "alluvial fan" is the more common term. Yet, this study uses "distributary flow area" as a more general name for areas subject to diffluent channels and their associated flood hazards. There are three reasons for this choice. To begin with, there are at least two locations in southern Arizona where stream channels bifurcate downstream but do not form alluvial fans (sites #12 and #24). Neither are situated on old alluvial fan deposits. Based on Cooley's geomorphic map (1977) these two sites are located on weakly cemented valley fill deposits and old alluvial deposits. The term, DFA, encompasses those few areas that possess flood hazards characteristic of distributary channels and yet do not form alluvial fans.

Secondly, the term DFA helps avoid the confusion over the age of alluvial fans. While the Federal Register defines alluvial fans in terms of processes acting in the present, yet geomorphologists recognize alluvial fans of various ages. In southern Arizona some alluvial fans formed during the Pleistocene Epoch (Melton, 1965, p.29) and are not aggrading anymore (old fans). In terms of engineering time they are ancient surfaces which no longer possess the unique processes or flood hazards associated with modern alluvial fans. Active and extinct volcanoes provide a helpful analogy. While both landforms are generally referred to as "volcanoes", their respective geologic hazards are radically different. The term DFA does not need a qualifier for age as all DFAs currently possess distributary channels.

The term DFA, not only includes landforms which are not alluvial fans and excludes old fans, but it also recognizes areas with distributary channels that may occupy only a small subarea on an alluvial fan. Areas which are actively aggrading today may occur as component landforms on top of old fan surfaces. Old fan remnants often protrude in the middle of an actively aggrading area (Fig.2). Often a complex relationship exists between old fans of different ages and "active" areas which are presently depositing sediment over broad areas. The term, DFA, simply focuses on areas that display the unique flood hazards associated with distributary channels.

While the term DFA is used throughout this paper most of the research on flood hazards associated with distributary channels has been done on alluvial fans. Since, active alluvial fans make up the vast majority of DFAs, the term alluvial fan will be used as a synonym, especially when referencing previous investigations.

Flood Hazards of Distributary Flow Areas

The term, DFA, includes the area on an alluvial fan subject to distributary flow and its associated flood hazards during an engineering time frame. Most research in distributary flood hazards has been conducted on alluvial fans.

In general, there are three likely types of channel

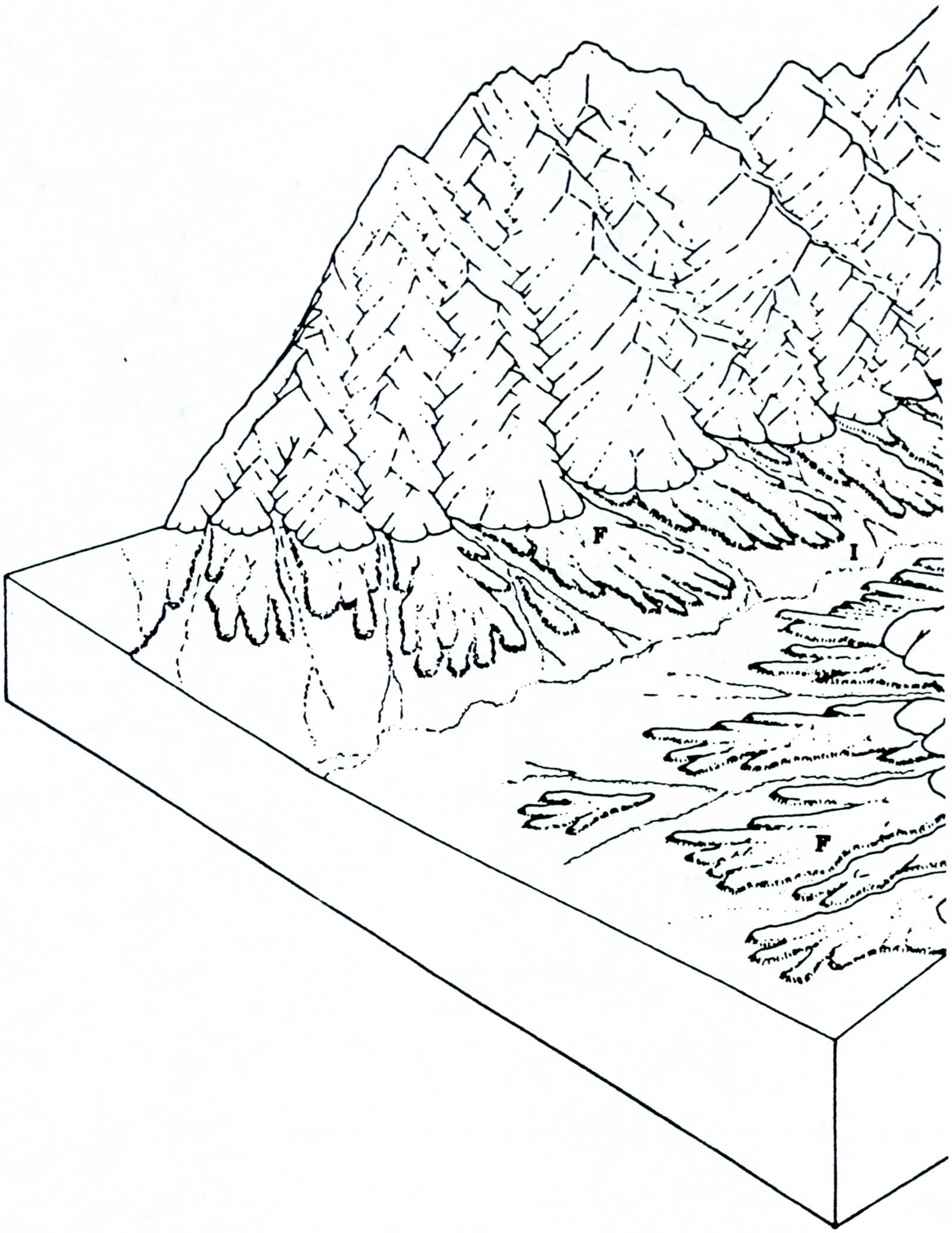


Figure 2. - Inset fans (I) located on and within old fan remnants (F) (after Peterson, F.F., 1981, Landforms of the Basin and Range Province, p.13).

patterns on alluvial fans. There is a single channel region, a split channel region, and a braided channel region (DMA, 1985, p.70). These three regions are often subject to stream floods which can last from only minutes to hours in duration. Some portions of a fan are also subject to sheet floods (Blissenbach, 1954, p.53-4). Flood hazards associated with stream floods and sheet floods include erosion of banks, high flow velocities, and the deposition of sediment which can result in the rapid relocation of channels across the fan surface (Magura and Wood, 1980, p.58).

Another type of flood hazard common to alluvial fans is the debris flow. The debris flow is a "rapid mass movement of a dense, viscous mixture of rock fragments, fine earth, water, and entrapped air" (Peterson, 1981, p.50). Bull (1977, p.236) lists the conditions conducive to the development of debris flows as, "abundant water (usually intense rainfall) over short periods of time at regular intervals, steep slopes having insufficient vegetative cover to prevent rapid erosion, and a source material that provides a readily available and abundant source of detritus and a matrix of mud". Melton considered debris flows as very rare events in southern Arizona (Melton, 1965, p.17). For this reason and due to their complexity they will not be analyzed in this investigation.

On many alluvial fans in the Basin and Range physiographic province, these various types of flood hazards operate over nearly the entire surface of the fan. Yet, in some locations these flood hazards may only affect a portion of the fan during engineering time.

For example, when the single channel region of an alluvial fan has been permanently entrenched (permanent relative to engineering time) it may carry flood flows downslope to a point where the channel is no longer confined and distributary flow begins. Hooke calls this the intersection point. It is where the entrenched channel meets the surface of the fan (Hooke, 1967, p.450). Figure 3 is a diagram of a typical intersection point.

Intersection points are common in southern Arizona and they often separate two distinct zones on the alluvial fan. An erosional surface with tributary drainage often lies upstream of the intersection point. Downstream of this point the fan is often aggrading and distributary flow exists. It should be noted that some single channel reaches may undergo avulsion, and yet they still possess an intersection point downstream.

The following description of a hypothetical flood event summarizes some of the flood hazards typical of DFAs in southern Arizona. Wells (1976, p.177-80) describes a

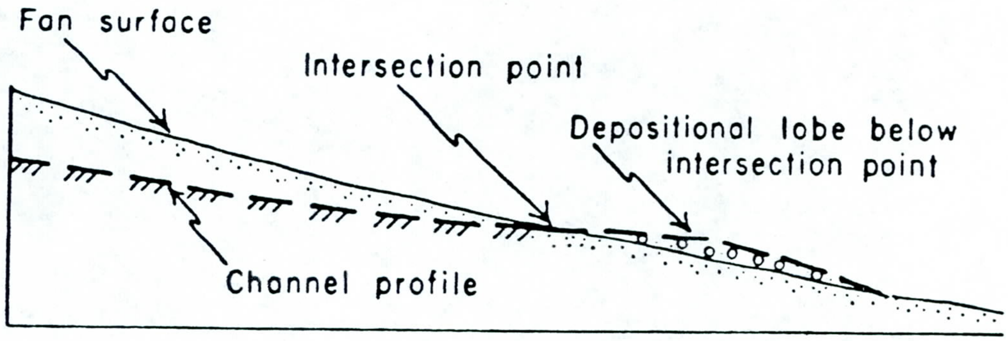


Figure 3. - The intersection point occurs where the channel intersects the fan surface. A flattening and steepening of slope occurs at the intersection point. Distributary flow begins at the intersection point (after Hooke, R.L., Processes on Arid-Region Alluvial Fans: Jour. Geol. v.75, p.450).

hypothetical flood below the intersection point on the piedmont plain of the Harquahala Valley, Az. as follows: "Runoff resulting from intense, short, and rather infrequent summer precipitation is transmitted down a wash." As the peak discharge recedes coarse sediment is deposited in the entrenched single channel upstream of the intersection point. "After the maximum discharge passes, runoff is reduced, resulting in an increase of the suspended load-discharge ratio...the flood becomes overloaded with fine sediment.

"On slopes less than one degree and areas of low dissection, the flood, which is overcharged with fine sediment, spreads laterally over the shallow interfluves." "Sheet flow dominates during this portion of the flood event and is depositional, not erosional." Sheet flooding and the deposition of fine sediment occurs downstream of the intersection point.

The Effect of Old Fans on Flood Hazard

While many alluvial fans in California and Nevada are formed as a result of tectonic activity (mountain uplift) the vast majority of alluvial fans in southern Arizona formed in response to ancient climatic conditions and changes that occurred during the Pleistocene Epoch (Melton, 1965, p.10).

These relict fan surfaces often produce unique flood hazards.

Bull (1977, p.250) describes how tectonic fans form. He claims that when the rate of tectonic uplift exceeds the rate of fan deposition and channel down cutting then sediment deposits along a mountain front. In some tectonically active areas, climatic change (such as change in precipitation intensity) can result in the entrenchment of channels on the fan. Such entrenchment may produce areas on the fan which no longer receive sediment. Extensive desert varnish is an indicator of a surface which has not received deposition in an engineering time frame.

Yet, many alluvial fans produced in tectonically active areas experience only temporary entrenchment. During flow events incised channels and the loci of deposition change location along both the radial axis of the fan and across the width of the fan surface.

In contrast, the majority of coarse grained fans in southern Arizona formed during the Pleistocene Epoch under a colder climate which included mechanical weathering due to frost and increased rainfall (Melton, 1965, p.29). Today, southern Arizona is tectonically stable and possesses an arid climate. Small fans are forming from material derived from mountains and from the erosion of Pleistocene fan deposits (Melton, 1965, p.10).

Wells (1976) conducted a detailed geomorphic analysis of the Harquahala Valley in south central Arizona. His study area exemplifies the effect that old fans from past climates have on the flood hazards of today's piedmont plains. He describes two types of drainage patterns in his study area (Fig.4). There are tributary systems (with channels from 1 to 25 meters deep) on the eroding coarse grained Pleistocene fan deposits.

In contrast, there are "broad, shallow anastomosing - distributary drainage systems" (with channels 1 to 5 meters deep) on the lower piedmont plain (Wells, 1976, p.37). The coarse grained fans with the tributary drainage system covered 62% of the Harquahala Valley Bolson Plain. The recent (probably Holocene Epoch) fine grained alluvial fans that exhibit distributary flow cover 16% of the Harquahala Valley Bolson Plain (Wells, 1976, p.51-54, 95-96).

The fine grained fans have apices which occur along the gradational boundary between the tributary drainage of the old Pleistocene fans and the distributary flow of the fine grained fans. Wells refers to this boundary as the "lateral zero edge of alluviation on the bolson plain" (Wells, 1976, p.67,187).

Wells attributes the coarse Pleistocene fans as the products of a past climate not occurring today. The fine grained "active" fans or DFAs are operating under present

Figure 4. - Map of Harquahala Valley, Arizona showing the relative position of tributary and distributary drainage networks on the piedmont plain (after Wells, S.G., 1976, A Study of Surficial Processes and Geomorphic History of a Basin in the Sonoran Desert, Southwestern Arizona, p.109).

climatic conditions (Wells, 1976, p.198-199). Wells' study area clearly shows how old fans formed under past climatic conditions can completely isolate large areas of the piedmont plain from alluvial fan flood hazards (the upper piedmont plain possesses tributary drainage).

While the upper slopes of tectonic fans can become isolated within engineering time, many of these tectonic fans show evidence of channel avulsion and recent deposition close to the mountain front (DMA, 1985, p.51). On tectonic fans, intersection points often indicate a temporary point of deposition.

In southern Arizona, however, an intersection point often indicates a zone between surfaces undergoing erosion (in engineering time) and surfaces downslope subject to alluvial fan flood hazards. Also, the surfaces of modern fans can be influenced by the surrounding and underlying morphology of pediments and old fans (Nilsen, 1985, p.5).

Some may argue about the exact climatic causes that produced an abundance of old fans in southern Arizona which are undergoing erosion today. Yet, the important point is that fans of different ages exist extensively in southern Arizona and the relicts of old fans influence the type and location of alluvial fan flood hazards on the piedmont plain.

Types of Flood Hazards on DFAs in Southern Arizona

Burkham classified methods for delineating flood hazards in the Great Basin physiographic province (including parts of California, Nevada, Utah, Oregon, Idaho, and Wyoming). He grouped these methods into the following five categories: detailed, historical, analytical, physiographic, and reconnaissance. The first four methods rely on the determination of a T-year discharge, the T-year water surface profile, and the construction of a flood-boundary map. Examples of the analytical methods used on alluvial fans includes Dawdy (1979) and Magura and Wood method (1980), as described in the next section of this report (Burkham, 1988, p.7-16).

The detailed method, historical method, and the physiographic methods have only limited value on alluvial fans because they assume that channel boundaries are rigid. As described in the previous section, the flood hazards associated with DFAs (alluvial fans) include rapid scour and fill. Due to channel instability, Burkham concludes that the reconnaissance method may "be the most rational one (method) for delineating flood hazard areas on some alluvial fans" (Burkham, 1988, p. 18).

Burkham describes the reconnaissance method as an approximate delineation of areas subject to flooding based on the use of maps, photographs, and experience. When performing the reconnaissance method he suggests that the investigator, "include the collection and use of general information about (1) topographic features such as old and new channel banks, old and new sand and gravel bars, terraces, and stepped topography; (2) vegetation features such as distinctive vegetation, vegetation form related to high water, and microvegetation related to high water; and (3) pedologic conditions, such as soil development, stratification, and drainage." (Burkham, 1988, p. 18). The following paragraphs are an attempt to classify the flood hazards found on DFAs in southern Arizona using a reconnaissance methodology.

Based on a sample of 39 DFAs in southern Arizona a general classification of distributary flood hazards was developed based on the potential randomness of flooding across the DFA near the primary diffluence. The potential randomness of flooding is based on the number of possible flow paths and the stability of these channels.

Small local relief and recent deposition (as shown by light colored soils on orthophotos and oblique aerial photos) indicates potentially random movement of channels. Entrenched channels, dark colored soils (potentially oxidized), and desert varnish within the DFA indicate stable surfaces which have not been subject to extensive deposition (and extreme depths of flooding) within an engineering time frame.

Cross sections of the channel at the primary diffluence were determined from 7.5 minute topographic maps. Conveyance-slope estimates were used to evaluate the capacities of the channels. This procedure was repeated for distributary channels downstream of the primary diffluence.

The flood hazards found on DFAs were divided into five categories; A, B, C, D, and E. At one end of the spectrum is the simplest type of flood hazard called category "A". Type "A" includes two or three distributary channels that are separated by high ridges. The channels can convey large flood events. If the channels are stable then the DFA is assigned a degree 1. If the channels are unstable then the DFA is assigned a degree of 2.

The next category "B" represents a situation with a slightly more random distribution of channels. Frequent small floods can be contained within two or three defined channels as in category A, but rare floods can overtop the interfluves. A degree of 3 is used where the ridges are high relative to the 100-year discharge. A degree of 4 is used where ridges are low compared to the 100-year discharge.

Type "C" describes a more random channel behavior than the previous categories. In category C, many channels (more channels than in categories A or B) divide and combine and are separated by stable ridges commonly above the level of the 100-year flood. A degree 5, 6, or 7 is assigned depending on the amount of the DFA potentially inundated by the 100-year flood. A degree of 5 is assigned when two-thirds of the DFA is above the level of the 100-year flood. When more of the DFA will likely be inundated by the 100-year flood then a degree of 6 or 7 is appropriate.

When low ridges separate numerous distributary channels which are relatively stable during small flow events but are unstable during large floods then the DFA should be assigned to the category "D". The degree of flood hazard is 8 where ridges are not easily eroded. A degree of 9 is used where the channels can more easily change position. Small floods will use only a few distributary channels while large floods will occupy many channels. Many of the DFAs that fall in category D possess old fan remnants or inselbergs.

A hazard of type "E" is assigned when flood water can cover the entire DFA and channels can relocate randomly across the DFA. For a hazard of E the degree of flood hazard is 10.

The reconnaissance method was used to construct the categories A through E (and their respective degrees of flood hazard, 1 through 10). This method is based on the potential randomness of flow across the DFA. Representative channel patterns and slope profiles for the five categories are displayed in Figure 5.

Although Burkham recommends using the reconnaissance approach for evaluating the flood hazards on alluvial fans (DFAs) he also recognizes that there are several drawbacks to the approach. First of all, the method requires experience in many scientific fields. Also, the method lacks an objective relation between the 100-year discharge and the flood boundaries (Burkham, 1988, p. 18).

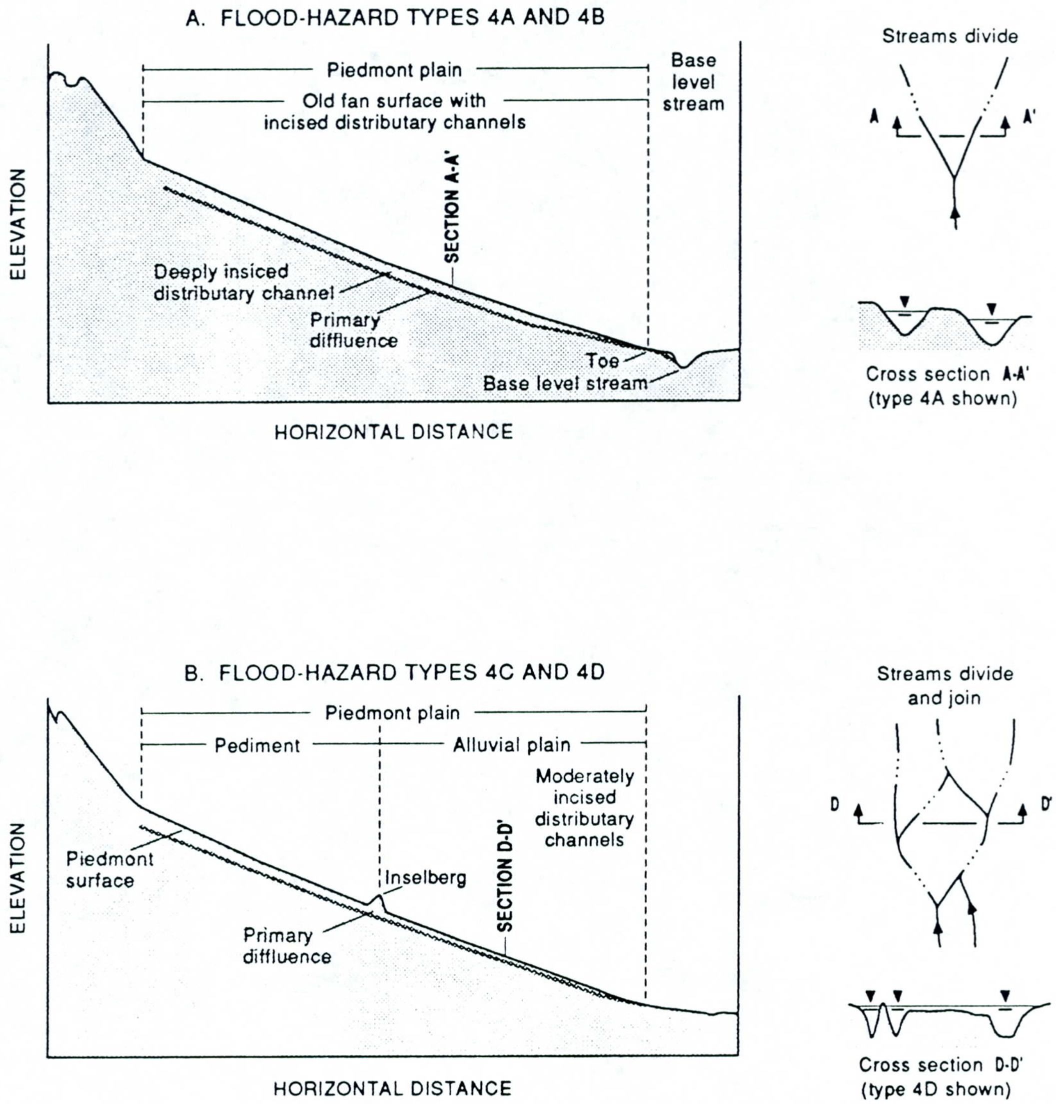
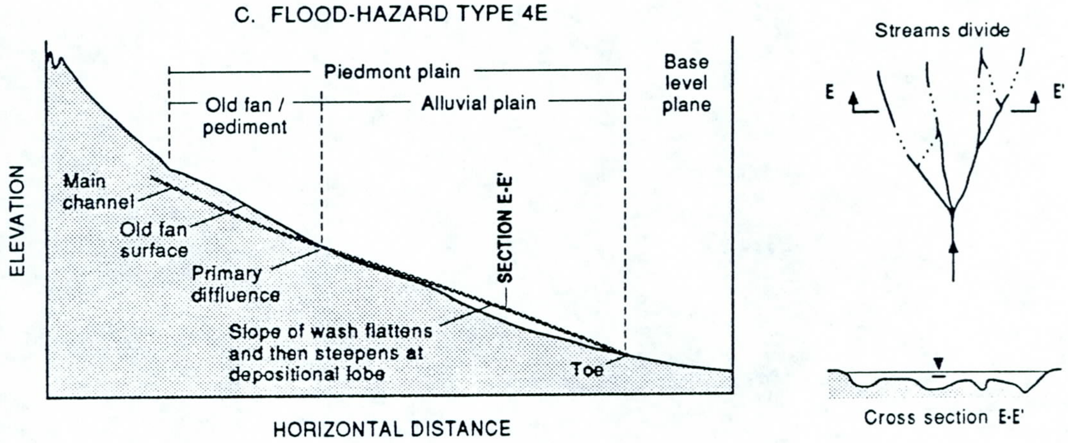


Figure 5. - Characteristic profiles, stream patterns, cross sections, and flood hazard types for distributary flow areas in southern Arizona.



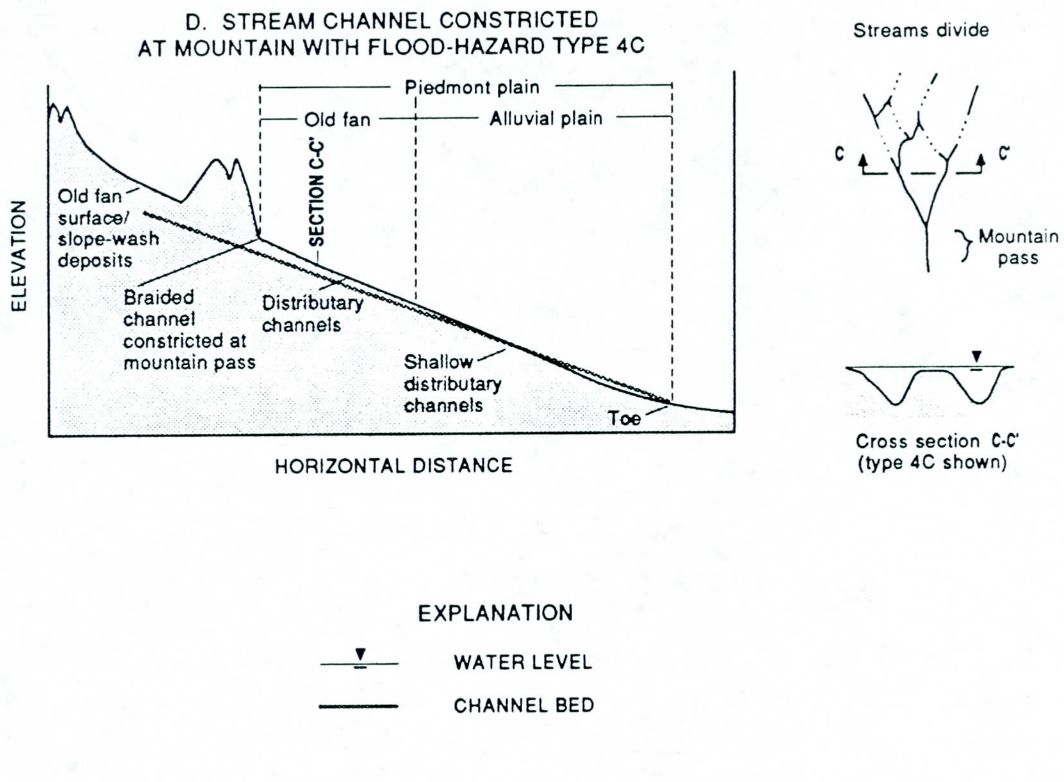


Figure 5. - Continued.

EVALUATING FLOOD HAZARDS ON DFAS - A LITERATURE REVIEW

The analysis of flood hazards on aggrading portions of alluvial fans is synonymous with the evaluation of flood hazards on DFAs. French summarizes the state of modeling flood hazards on alluvial fans in his book, "Hydraulic Processes on Alluvial Fans", with the following statement: "At the time of writing, there is not a single method which is clearly superior for performing comprehensive flood hazard assessment on alluvial fans." (French, 1987, p.183).

The following paragraphs describe two current methods for determining the flood hazards on alluvial fans. These include a method developed by Magura and Wood and also the methodology adopted by FEMA (a procedure developed by Dawdy and modified following the suggestions of DMA consulting engineers).

The Magura and Wood method uses hydraulic relationships to delineate the zones on an alluvial fan which are inundated by the 100-year flood. They assume that a channel will carry flood flow and can move randomly across the fan. All points at a given radial distance from the apex have an equal probability of being crossed by the channel. They also assume that the closer a point is to the apex the larger the flood hazard. Lastly, Magura and Wood assume that generally the flow is critical with some supercritical flow occurring in small areas (Magura, 1980, p.57-8). Their procedure is summarized in the paragraph below.

First one must determine the 100-year discharge at the apex using either rainfall-runoff modeling or regional regression equations. Then the reaches of channels on the fans must be classified into groups based on similar hydraulics (for example, the change in channel pattern and the occurrence of structures are instances where a new reach should be designated). Third, families of curves are generated with a water surface profile program such as HEC-2.

One family of curves shows flow path width versus critical depth for various discharges. One family shows the relationship between the velocity in the overbank areas versus flow path width for given discharges. Another shows the relationship between the percent of flow in overbanks versus flow path width for given discharges. Also a family of curves shows the relationship between critical depth and the width of the "flow path" for sheetflow conditions at given discharges (Magura and Wood, 1980, p.59-60). Graphs can be generated based on local channel geometry.

To use the graphs one must enter a discharge. At the point on the graph where dD/dW = -.005, one can determine the corresponding depth and velocity of flow (D is channel depth and W is channel width where a decrease in one unit of depth results in an increase in 200 units of width. The value, -.005, is an average based on observations of flooding on alluvial fans). These values are applied over the entire fan surface within the hydraulically uniform reach (Magura and Wood, 1980, p.60-61).

A second method for evaluating flood hazards on alluvial fans was developed by Dawdy. He combined the hydraulic geometry of stream channels with the parameters for the Log Pearson Type III distribution in order to delineate depth and velocity zones on a fan. His assumptions are listed below.

Dawdy first assumed that the discharge at the apex follows a Log Pearson Type III distribution. Second, he assumes that for various predetermined depth and velocity values (each value represents the boundary of a zone) the corresponding discharge can be calculated based on the principles of hydraulic geometry (flows form their own channels). Third, he assumes that a flood event can be modeled with single channel which has an equal probability of crossing any point on the fan surface at a given radial distance from the apex. Lastly, he claims that field evidence shows that channels carrying flood flow will stabilize when $dD/dW = -.005$ (Dawdy, 1979, p.1408-9).

Dawdy's procedure entails first computing the transformation constant from the statistical parameters of a complete Log Pearson III distribution for peak discharges at the apex. Next, Dawdy computes the discharge for the predetermined depth zone boundaries. The discharge is also calculated for the predetermined velocity zone boundaries. His boundaries are based on the relationships developed from the hydraulic geometry of channels in arid regions.

Next Dawdy utilizes an equation for the width of the fan at the given zone boundary. This equation includes the avulsion coefficient, the probability of the discharge computed for the appropriate zone boundary, and the transformation constant. The computed width of the fan is matched to the topographic map of the actual fan to determine the position of the various zone boundaries (FEMA, 1985, p.A5-1-A5-7).

Edwards and Thielmann proposed a modification of Dawdy's procedure. They use Manning's equation rather than the hydraulic geometry of stream channels to relate the discharge with the depth and velocity of flow (DMA, 1985, p.63).

DMA consultants also modified Dawdy's method for areas with multiple distributary channels. Based on data from four alluvial fans in Nevada and California they measured the channel widths of the multi-channel regions. They found that the ratio of the sum of the widths of the many distributary channels is 3.8 times the width of the single channel located upstream (DMA, 1985, p.72, A-1 - A-4).

They then derived a modification of Dawdy's equation to be applied in the multiple channel region of a fan. DMA used Manning's equation and derived a new relationship for the discharge, given the depth and velocity zones (FEMA, 1985, p.A5-7). Some of the equations used in the FEMA methodology are in Appendix A. FEMA adopted Dawdy's method (with the modifications proposed by DMA consulting engineers) in their, "Flood insurance guidelines and specifications for study contractors" (1985).

Analyzing the FEMA Method

Many DFAs in southern Arizona violate an important assumption inherent in FEMA's methodology. For many DFAs in southern Arizona the probability of flow across the DFA is not equal along a given radial distance from the primary diffluence.

Dawdy assumed that the probability of flow across the fan surface followed a uniform distribution, ie. each point on the fan (at the same radial distance from the apex) has an equal likelihood of being flooded (Dawdy, 1979, p.1408). Many DFAs (and also old fans) in southern Arizona violate this assumption. All of the sites with a degree of flood hazard of 1 through 8 (and some sites with a degree of 9) do not possess an equal probability of flow across the fan surface. Some sites have distributary channels separated by old fan remnants with surfaces covered by desert varnish.

The presence of extensive desert varnish indicates a surface at least older than the few hundred years in an engineering time frame. Dorn and Oberlander estimate that thousands of years are required to form a complete layer of varnish given an arid climate (Dorn and Oberlander, 1982, p.321). Some distributary channels are separated by ridges with a relief of tens of feet. Such ridges within the DFA negate the equal likelihood of flow across the DFA.

In his geomorphic study of the Harquahala Valley, Wells makes the following claim: "Relicts from previous climates are preserved in the Harquahala Valley, and in some cases, influence the present day processes." He describes how caliche cemented alluvium can influence the geometry of stream channels (Wells, 1976, p.210). Likewise, in the 15 sites with a degree of flood hazard of 1 through 8 (and some sites with a degree of 9) there are old fan remnants or large ridges that produce areas within the DFA that are not subject to a uniform chance of flooding.

Even for a degree of flood hazard of 10, there is no consensus that there exists an equal likelihood of flooding across the fan. Dawdy proposes that the probability that a given flood event (f), will inundate a point, x, on the radial contour can be expressed with the following equation: $P(x/f) = T/W$, where T is the channel width and W is the width of the alluvial fan at point x.

French maintains that this assumption is conservative for an engineering time frame. He proposes the following equation to describe the probability that a point, x, on the fan will be inundated by flood flow: $P(x/f) = (T/W)(1-e/g)$, where T is the channel width, W is the width of the fan at point x, e is the angle from point x to the axis of the alluvial fan, and g is the angle from the axis of the alluvial fan to the outer edge of the fan. French's equation describes a distribution where flow is more likely to inundate areas close to the axis of the fan (French, 1984, p.8-10).

French summarizes his view on the nature of the probability of channel movement across the alluvial fan surface in terms of engineering time (French considers engineering time as years to decades) when he states, "On a geologic time scale, flow paths across a fan surface are erratic and unstable. On an engineering time scale flow paths across a fan surface may be stable if they are not changed by development" (French, 1987, p.18).

LOCATING THE PRIMARY DIFFLUENCE

A Misapplication of the FEMA Method

FEMA's methodology states: "portions of alluvial fans in which natural alluvial fan processes may not occur, such as in areas of entrenched channels... the Study Contractor should exercise good engineering judgement in determining the most appropriate methodology or combinations of methodologies" (FEMA, 1985, p.A5-1). Yet, the FEMA method does not adequately describe how to locate the primary diffluence (apex) for areas located in southern Arizona. Consequently, large areas on the piedmont plain that are subject to conventional flood hazards in eroding tributary drainage systems, are classified as if they experienced flood hazards typical of alluvial fans.

An example of misapplying FEMA's methodology occurred on the Tortolita Mountains in Pima County, Arizona. Along the western slopes of the Tortolita Mountains the study contractor was required to evaluate the flood hazards on the piedmont plain. He first had to determine the apices for any alluvial fans in the area. In his original analysis the study contractor chose an apex far upslope on the piedmont plain. In fact, his apex was located 3.5 miles upstream of the proper apex which marked the beginning of flood hazards characteristic of alluvial fans (Pima County, 1987, Figure 6). Other apices were also located by the contractor at points adjacent to the mountain front. Yet much of the upper piedmont plain is made up of a Pleistocene surface that presently possesses a tributary drainage system. Many of the stream channels that appeared to radiate from canyons were actually incised channels which originated on the Pleistocene deposits (Pima County, 1987, p.14-15).

Part of the contractor's confusion may be due to the fact that primary diffluences in southern Arizona do not always occur at the mountain front or at the mouth of a canyon. FEMA says that the alluvial fan will have a single channel zone located "from the mouth of the canyon to the point where the flood channel splits" (FEMA, 1985, p.A5-5). FEMA also states that this single channel zone is subject to random relocation. This reference to a random single channel near the canyon mouth may have led the study contractor for the Tortolita study to assume that the apex would be at a canyon mouth at the mountain front.

Also, adding to the confusion, the Federal Register defines the apex as "the point of highest elevation on an alluvial fan, which on undisturbed fans is generally the point where the major stream that formed the fan emerges from the mountain front" (Federal Register, 1989, p.9528).

Eighteen of the sites studied had the primary diffluence located upslope or at the general mountain front while eleven had the primary diffluence located downslope of the general mountain front. Ten sites had no discernable mountain front. Eleven sites had the primary diffluence located in the lower half of the piedmont plain, and 28 of the sites had the primary diffluence located in the upper half of the piedmont plain.

In regard to the presence of a canyon mouth, fifteen sites possessed a discernible canyon mouth. Twenty-four sites had no canyon mouth (based on 7.5 minute topographic maps and orthophotos). Thus the location of a canyon mouth or mountain front does not automatically pinpoint the location of the primary diffluence.

Some of the ambiguity in choosing the proper location of the primary diffluence comes from the fact that on DFAs the single channel reach can become permanently entrenched. A permanently entrenched channel will probably not relocate in engineering time. In many of the DFAs in southern Arizona the channels located on the upper slopes of the piedmont plain are permanently entrenched. The surrounding surfaces have tributary drainage systems and are eroding.

Bull attributes the entrenchment of channels in the upper part of alluvial fans to climatic changes, a complex response to a perturbation of the geomorphic system, and/or when flood flows cut channels at a faster rate than the rate of mountain uplift (Bull, 1977, p.252). For tectonically stable areas Bull says that permanent trenching can occur as the upper slopes of the fan are eroded. As a result, Bull says, "the fans become alluviated slopes that are characterized by large areas of erosion as well as areas of deposition" (Bull, 1964, p.112).

Often as the upper slopes of the fan become entrenched the point of deposition moves downslope on the piedmont plain. This point of deposition is called the intersection point and is the primary diffluence of many DFAs. Dawdy, under criticism, clarified the application of his method for evaluating flood hazards on alluvial fans by saying that in the case of permanently entrenched fans his method should be applied below the intersection point (Dawdy, 1981, p.379).

Bull claims that many fan head trenches are temporary and may only exist from 10 to 10000 years before radically changing form and/or position on the piedmont plain (Bull, 1977, p.252). He describes how the balance of stream power versus the resisting power of the channels determines whether a given reach of a channel will aggrade or degrade. This determines if and how much the intersection point will move upslope or downslope on the piedmont plain. Both man's impact on the geomorphic system and climatic change can result in the relocation of an intersection point (Bull, 1988, p.160-161). Therefore, the location of the primary diffluence depends on whether the single channel reach may relocate or if it is entrenched permanently.

In order to delineate areas subject to distributary flow one needs to locate a stable primary diffluence. In order to determine the permanency of an intersection point or other type of primary diffluence, one can look at the surrounding surface adjacent to the channel upstream of the primary diffluence. The development of a soil profile provides evidence that there has not been deposition due to distributary flow hazards in an engineering time frame. Other indicators of a surface not subject to distributary flow hazards include prolific desert varnish, and the filling of soil pore space with fine sediment (Hooke, 1967, p.439-440).

For the 39 sites used in this study,a major test for the permanency of a primary diffluence included the ability of the channel to contain the 100-year flood as well as the color of the soil surrounding the banks of the channel upstream of the primary diffluence. It is assumed that where light colored soils exist there is a strong chance that deposition occurred in engineering time. Where only darker colored surfaces exist there has not been major deposition in engineering time. Where light colored soil indicated overflow channels or recently abandoned channels the primary diffluence was relocated upstream to a more stable reach.

Another factor in the location of the primary diffluence is the presence of a base level stream. Twenty-two of the thirty-nine sites had a base level stream near the toe of the DFA and seventeen of the sites had no base level stream. A contingency table was developed utilizing a chi-square test to test the dependence between the presence of a base level stream and the position of the primary diffluence on the piedmont plain.

It was found that there is a strong dependence between the location of the primary diffluence on the piedmont plain and whether a base level stream is present or not. The null hypothesis, that there is no relationship between the location of the primary diffluence (on the piedmont plain) and the presence of a base level stream, is rejected at the 95% level of significance ($p<.05$, Appendix B). Therefore, a primary diffluence located in the lower half of the piedmont plain is often accompanied by a base level stream. It is evident that locating the primary diffluence is no easy task.

One cannot rely solely on the location of a canyon mouth or mountain front to locate the primary diffluence. It is important to determine if a single channel reach will relocate in an engineering time frame. The permanency of the primary diffluence can be evaluated from soil characteristics. Lastly, the presence of a base level stream may provide some clues as to the position of the primary diffluence on the piedmont plain.

A Method for Locating the Primary Diffluence

Once it has been established that alluvial fan flooding exists (Appendix C), FEMA recommends the following approach: "a thorough reconnaissance of the alluvial fan should be made in order to determine the source of flooding, the apex of the fan, the boundaries of the fan, the areas of coalescence of contiguous fans, the limits of entrenched channels, single and multiple channel regions where evident, and the areas of active alluvial fan processes."

FEMA recommends using, "topographic, geologic, and soil maps; aerial photographs; historic records; and site inspection" (FEMA, 1985, p.A5-1). Based on these suggestions, the next section will describe how to better locate the primary diffluence and define the limits of flood flow (using a reconnaissance method as recommended by Burkham, 1988).

1. Given a wash which is suspected of having

distributary flow one must choose a point of origin on which to begin the procedure. If one is interested in the evaluation of an area covering the length of the piedmont plain then he must begin along a wash at the downstream edge of the piedmont plain at the local base level. On the other hand, if one is interested in evaluating the distributary flow above a point of interest (for example, above a road culvert) then he must begin the procedure along a wash at that point.

One way that base level can be recognized is by the presence of a large wash that is approximately perpendicular to the slope of the piedmont. Often the base level wash has the lowest elevations in the valley. Dense vegetation accompanies the floodplains of these washes. For the purposes of this study the boundaries of the floodplain are considered at base level.

In some areas the base level wash is not well defined or does not exist. In such areas base level can be recognized by its relatively small slopes (less than 0.5%). Often these gradual slopes are coupled with contours that form parabolas (pointing perpendicular to the slope of the piedmont) and provide drainage for the piedmont. After locating the point of origin on the topographic map proceed to step 2 (Fig.6).

2. Delineate the drainage area for that location. Locate the point of interest on the orthophoto. Determine if

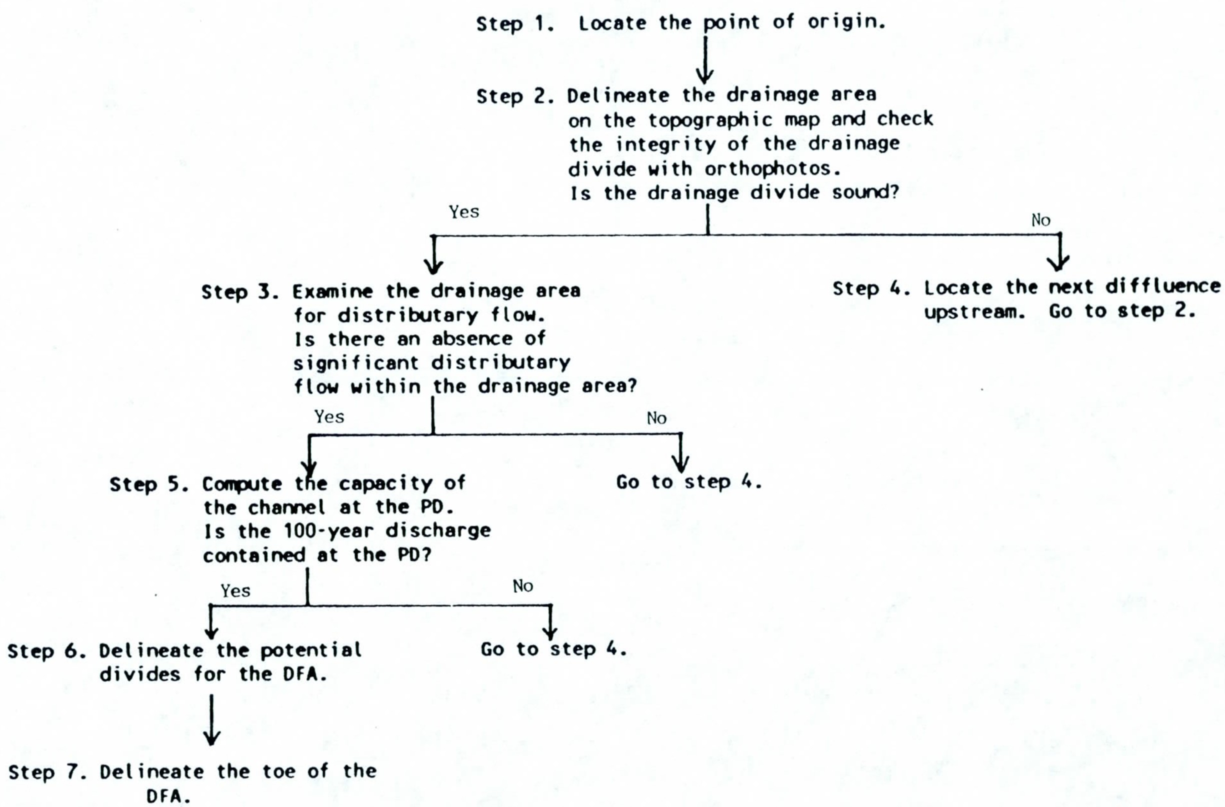


Figure 6. - Flow chart for locating the primary diffluence and delineating the potential divides and toe of the DFA.

there are any channels that show up on the orthophoto which cross the drainage divide of the drainage area. If the drainage area can be delineated on the topographic map, and the orthophoto confirms the integrity of the drainage area then go to step 3. If the drainage area cannot be delineated at the point of interest based on the topographic map and the supplementary information gleaned from the orthophoto then go to step 4.

3. In some cases there are distributary channels in the drainage basin that converge into tributary channels above the point of origin. If this is the case and one wants to analyze this distributary flow then the point of origin must be relocated upstream as in step 4. Otherwise proceed to step 5.

It is important to note that some diffluences are relatively small compared to others. In some instances relatively insignificant distributary flow areas may be nested within larger ones. It is up to the investigator to decide whether to focus on the larger distributary flow areas or the smaller ones. This decision will help the investigator decide which diffluence is the primary diffluence.

Also, some areas possess a primary diffluence at the constriction of flow near an inselberg or mountain pass. Often the constriction is composed of many small channels which may act as one larger channel during a large flood such as the 100-year discharge. Finally, there are distributary flow areas which are composed of a "network" of channels which begin dividing at the edges of the drainage area and defy delineation. For these areas a primary diffluence zone may be more appropriate. The zone may be a line parallel to the contours of the piedmont separating areas which are primarily tributary to areas which are more distributary. Site #8 is an example of such an area.

4. Use the topographic map in conjunction with the orthophotos to locate the first diffluence upstream of the present point of origin. This diffluence is the new point of origin. Repeat step 2. This process of attempting to delineate the drainage area from the point of origin, is continued until the diffluence located the farthest upstream of the original point of origin is found. This diffluence is the primary diffluence.

5. Determine the 100-year discharge for the drainage area above the primary diffluence (Roeske, 1978). Using the conveyance-slope method and the cross section of the channel (determined from the topographic map) determine if the 100-year discharge is confined within the channel at the primary diffluence. If the channel can contain the 100-year discharge then proceed to step 6. Otherwise go to step 4 and search for

a more obscure diffluence.

To determine the cross-section of the channel at the primary diffluence, one must draw a datum (a line intersecting the ridges on either side of the contour crenulation that represents the channel) and use linear interpolation to estimate the elevations of the ridges and the channel bottom. Use this cross section with the 100-year discharge in a conveyance-slope estimate. Manning's n values may be roughly estimated from aerial photographs. Compute a rough estimate of the water surface elevation of the 100-year discharge and determine if the channel at the primary diffluence can contain the 100-year discharge.

The 100-year discharge is representative of the larger floods that an area may experience in an engineering time frame. If the channel just upstream of the primary diffluence cannot contain the 100-year discharge then it is likely that a more obscure diffluence exists upstream. The orthophotos and any aerial photographs may show overflow channels or light colored sediment along banks upstream of the primary diffluence. Field inspection may be necessary in order to locate obscure diffluences. The primary diffluence should be located so that it contains at least the 100-year discharge.

Another check for the location of the primary diffluence is found in the profile of the longest water course. Use the

7.5 minute topographic maps to produce a profile of the longest wash in the drainage basin as it continues into the distributary flow area. Most primary diffluences are accompanied by a flattening of slope where the channels distribute and then a steepening of slope at the downstream edge of a depositional lobe of sediment. The choice for the location of the primary diffluence can be checked against the slope profile to compare it against any flattening/steepening sequences. Once this is accomplished then go to step 6.

Locating the Approximate Boundaries of Distributary Flow

6. Starting at the primary diffluence, draw the potential divides of the probable distributary flow area. The potential divides are based on the relief and soil color. Follow the drainage divides (located on the outer edges of the diffluent channels) downstream to the base level of the piedmont.

While following the drainage divides one must follow the outer edge of the outer most wash of subsequent diffluences. Tributaries to the distributary flow area should be severed. Many potential divides correspond to the boundaries of texture domains. Blue lines often provide an initial basis for drawing potential divides but orthophotos and aerial photographs should be consulted also. Photographs help adjust the potential divides to encompass areas of recent deposition as indicated by light colored soils.

Complications in drawing potential divides occur in areas where several distributary flow areas coalesce. In some instances the distributary channels of one area cross the distributary channels of a neighboring area so that their source area is indistinguishable. In such cases, one must choose potential divides which run perpendicular to the contours, follow the drainage divides as close as possible, and split any "X" shaped diffluences (where two channels join and then immediately split). Once the potential divides are delineated then go to step 7.

7. Delineate the toe of the distributary flow area. The location of the toe of the probable distributary flow area is based on the weighing of several factors which indicate the downstream limits of distributary flow. Washes and plains that form base level represent the downstream limit for the toe. Another indicator of the location of the toe is the point where stream patterns change from distributary flow back to tributary flow over the entire width of the probable distributary flow area.

Also, aerial photographs and orthophotos may help locate the toe by revealing the lower limits of recent sediment deposition as indicated by changes in soil color. Lastly, slope profiles of the piedmont plain may show a rapid decrease in slope that corresponds to the location of the toe. The toe is located based on the above considerations, and a line is drawn parallel to the contours connecting the potential divides. Appendix C shows an example of a DFA delineated on a topographic map.

ALTERNATIVE METHODS

Previous discussion points out that FEMA's method cannot be applied, per se to many DFAs in southern Arizona (namely, categories A, B, C, and some areas in category D). This is due to the fact that there is not an equal probability of flow across the surface of many DFAs. As a result, a method is proposed for locating distributary flow on the piedmont plain. Also, two attempts were made to develop a methodology for evaluating flood hazards on DFAs based on simple geomorphic measurements. FEMA's method continues to be the most appropriate for the DFAs in category E.

Thirty-nine sites were selected and a flood hazard classification scheme developed (utilizing a reconnaissance method as mentioned in "Types of Flood Hazards on DFAs in Southern Arizona"). Categories A through E (with associated degrees of flood hazard of 1 through 10) provide a starting point to develop less subjective approaches to delineating flood hazards on DFAs. Texture curve analysis helps define the boundaries of distributary flow. Topologic analysis and a multiple regression analysis are attempts at determining where the FEMA method applies and at evaluating the type of flood hazard.

These three methods were chosen for several reasons.

First of all, the three methods proved useful in other geomorphic research. Secondly, the requirements of each method can be obtained from topographic maps, orthophotos, and oblique aerial photographs. Lastly, they all attempt to measure geomorphic characteristics related to channels.

Texture Curve Analysis

Background

The texture curve analysis provides a general method for distinguishing between pediments, active fans (DFAs), and old fans no longer subject to distributary flow. The method attempts to quantify the change in the drainage pattern along the piedmont plain.

Doehring developed texture curve analysis to provide a simple technique to distinguish between alluvial fans and pediments. He analyzed 37 alluvial fans and pediments in California, Nevada, and Arizona (Doehring, 1970, p.3110). Doehring recognized that the drainage texture exhibited by the crenulations (a sharp kink in a contour that points upstream) on topographic maps provided clues to the type of land form. A crenulation usually represents an active channel.

Pediments often possess a drainage texture which becomes finer in the upslope direction. In contrast, alluvial fans do not possess a significant change in texture.

Doehring drew a sampling strip up the piedmont plain and counted the number of crenulations versus the contour number (Fig.7). He found that for every pediment he sampled the linear regression of the number of crenulations versus the contour number produced a significant positive slope (at a level of significance of alpha = 0.025). Yet, everyone of the alluvial fans lacked a significant slope.

Doehring's method requires that the sampling strip avoid the margins of the landform, run roughly perpendicular to the contours, and avoid mountains or areas where contours "have a short radius of curvature". The strip must cover at least ten contours. Also, one should avoid crossing different texture domains (Doehring, 1970, p.3111-3113).

Application and Results

Approximately seventy sampling strips (one inch wide) were drawn and the accompanying texture curve analysis made on pediments, distributary flow areas, and old fans throughout southern Arizona (Table 2). Texture measurements were made using Doehring's method on 7.5 minute topographic maps. A regression was performed for the number of crenulations versus

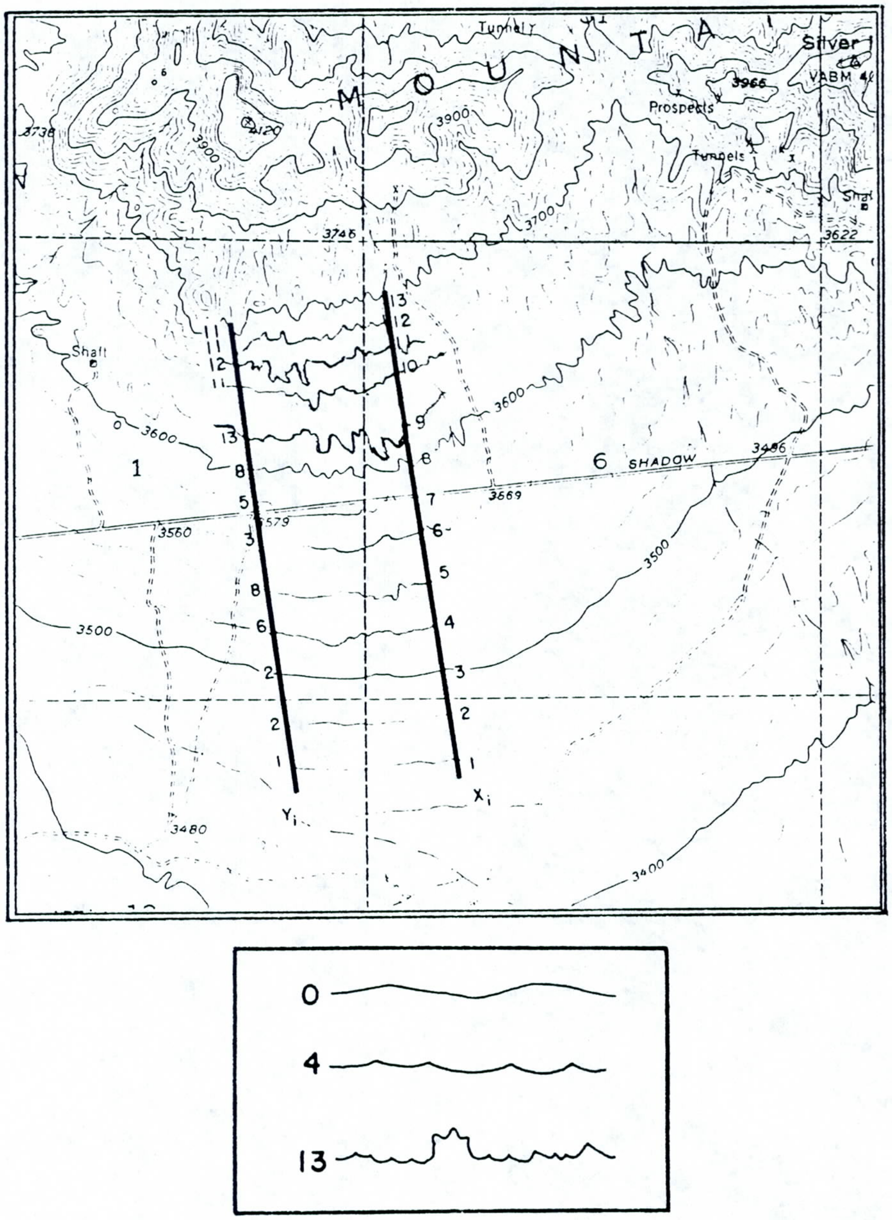


Figure 7. - Top: Sampling strip used in texture curve analysis (Xi = the contour number, Yi = the number of crenulations per contour). Bottom: Examples of contours with crenulation count (after Doehring, D.O., 1970, Discrimination of Pediments and Alluvial Fans from Topographic Maps, p.3111-3113).

Table 2.-- Summary of Texture Curve Analysis

Site No.	Landform	Slope of Regression Line	P Value	Rejected (R) or Failed to Reject (F) Null Hypothesis	
2B	Pediment	1.21	0.001	R	Ho: B1 <= 0
3	Pediment	.26	.000	R	Ha: B1 > 0
6C	Pediment	1.59	.011	R	alpha = .05
6D	Pediment	.04	.406	F	
9	Pediment	.41	.027	R	
9D	Pediment	.03	.419	F	
13	Pediment	.52	.002	R	
13B	Pediment	.22	.014	R	
47	Pediment	.74	.000	R	
48	Pediment	.52	.020	R	
50	Pediment	.49	.003	R	
52	Pediment	.81	.002	R	
2B	DFA	.03	.752	F	Ho: B1 = 0
3	DFA	.03	.301	F	Ha: B1 <> 0
6	DFA	.22	.000	R	alpha = .05
6B	DFA	-.01	.712	F	
6C	DFA	.05	.682	F	
7	DFA	.02	.797	F	
8	DFA	-.34	.236	F	
9	DFA	-.11	.405	F	
9B	DFA	-.68	.007	R	
9C	DFA	.05	.727	F	
9D	DFA	.13	.132	F	
13	DFA	-.04	.601	F	
13B	DFA	-.12	.005	R	
13C	DFA	-.14	.263	F	
14	DFA	-.03	.124	F	
15	DFA	-.42	.072	F	
15B	DFA	-.11	.437	F	
16	DFA	.01	.621	F	
20B	DFA	-.11	.483	F	
21	DFA	.12	.489	F	
22	DFA	.38	.027	R	
23	DFA	-.44	.073	F	
24	DFA	-.74	.086	F	
25	DFA	-.15	.058	F	
25B	DFA	-.10	.067	F	
26	DFA	.22	.064	F	
27	DFA	-.05	.840	F	
28	DFA	.26	.049	R	
29	DFA	.20	.194	F	
30	DFA	.33	.007	R	
31	DFA	.36	.059	F	
32	DFA	.23	.165	F	
33	DFA	.07	.805	F	
33B	DFA	-.04	.845	F	
34	DFA	-.13	.011	R	
34E	DFA	-.06	.592	F	
35	DFA	.09	.538	F	
35B	DFA	-.08	.300	F	
36	DFA	-.10	.281	F	
37	DFA	.13	.222	F	
39	DFA	-.60	.020	R	
7B	Old Fan	-.32	.001	R	Ho: B1 >= 0
20C	Old Fan	-.37	.000	R	Ha: B1 < 0
30C	Old Fan	.46	>.450	F	alpha = .05
34B	Old Fan	-.23	.005	R	
35C	Old Fan	-.20	.031	R	
40	Old Fan	-.41	.018	R	
41	Old Fan	-.03	.463	F	
42	Old Fan	-2.19	.005	R	
43	Old Fan	-.15	.164	F	
44	Old Fan	-.62	.021	R	
45	Old Fan	-1.09	.009	R	
46	Old Fan	-.60	.041	R	
49	Old Fan	-.27	.001	R	
51	Old Fan	-.45	.003	R	

the contour number for each sampling strip. The sign of the regression coefficient and its significance provide information about the type of landform being analyzed.

All pediments were located with the aid of Cooley's geomorphology map (1977), while orthophotos helped identify old fans. A ninety-five percent ($p < .05$) level of significance was used for the t-test for each regression coefficient. All texture measurements cross at least ten contours. In many instances the texture was influenced by the cartographer and therefore one should not cross map boundaries along a single sampling strip.

Sampling sites included 29 of the 39 DFAs and thirteen miscellaneous sites (Fig.1, Table 1). Some sites (including 6B, 6C, 6D, 9B, 9C, 9D) were made at locations near the respective sample sites. Some sites did not possess enough contours to perform the analysis. Multiple sampling strips were constructed at some DFA sites and sampling strips could not be constructed at ten of the DFA sites.

Ten of twelve sampling strips on five pediments showed a significant positive regression coefficient ($p < .05$, Fig.8C). The two measurements that were exceptions may be influenced by the crossing of texture domain boundaries.

Once a pediment is recognized, the texture analysis often reveals the location of the primary diffluence when the

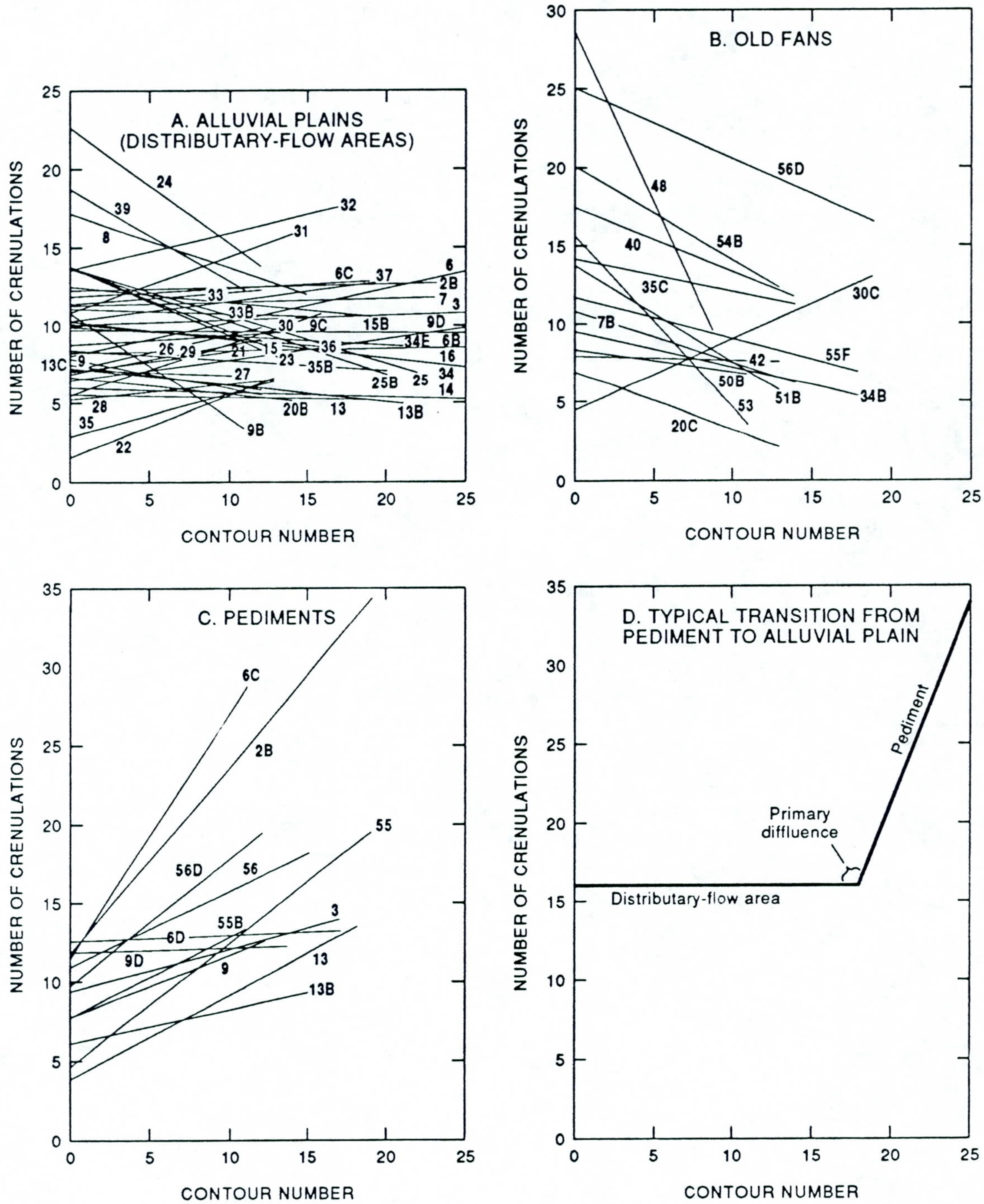


Figure 8.—Drainage-texture relations for distributary-flow areas, pediments and old fans.

primary diffluence is located at the juncture of the downslope edge of the pediment and the upslope edge of the DFA. Figure 8D shows an example of a texture plot that displays the location of the primary diffluence. Fourteen of the eighteen transects (on seven pediments) revealed the general location (within a few thousand feet) of the primary diffluence with a sharp break in the texture plot.

Thirty-three of forty-one sampling strips (on twenty-nine DFAs) yielded a regression coefficient that is statistically insignificant ($p > .05$). Of the eight exceptions four possessed significant positive regression coefficients. Four of the sampling strips had a significant decreasing texture. Two of these possessed old fan remnants within their boundaries which may have influenced the texture analysis (Fig.8A).

There are several reasons why the texture method may not properly identify a DFA. For example, the DFAs for sites 6 and 9B both yielded significant changes in texture. They epitomize the problems that can occur when encountering heterogeneous texture domains at the transitional zone between an alluvial plain and a pediment. Doehring suggests that the transects avoid texture domain boundaries. Also, the sampling strip on the DFA of site 30 crossed texture domains and showed a significantly positive increase in texture. Also, if a sampling strip crosses large incised channels the test may not identify the DFA. As a result the DFA of site 39 showed a decrease in texture moving up the piedmont plain.

Texture measurements were made on fourteen old fans that had no distributary flow (Fig.8B). Eleven of the fourteen yielded a significantly negative regression coefficient ($p < .05$). Two of the exceptions had a small decrease of texture that was not statistically significant at the level of significance. Exceptions may arise due to the close proximity of fans of different ages. Neighboring old fans (some superimposed on others) may retain different relict drainage patterns that result in regression coefficients which are statistically insignificant.

In general the texture method yields a statistically positive regression coefficient in the presence of a pediment. The texture method may be used to locate the primary diffluence of DFAs near the pediment/DFA boundary. In such cases there is a sharp break in the texture plot near the location of the primary diffluence.

A regression coefficient which is statistically insignificant at the ninety-five percent level of significance may reveal the presence of distributary flow or the presence of a complex mixture of landforms. Often this complex situation will be recognized due to a variety of texture domains and the texture analysis may not be performed.

Old fans will generally yield a significantly negative regression coefficient if there are at least ten contours used in the analysis. The texture curve analysis can, in many cases, distinguish between an area on the piedmont plain subject to distributary flow and an old fan that has a gross appearance of radiating contours, but in reality possesses only a tributary drainage network. Multiple strips may help determine the margins of distributary flow areas. Yet, as mentioned above when several texture domains are crossed the method proves less reliable.

Topologic Analysis

Background

Topologic analysis is a possible quantitative method for measuring the potential for random channel formation and relocation on a DFA. Topologic analysis measures the behavior of the links in the channel network which provides information about the behavior of the channels. The randomness of channel location is related to the potential randomness of flooding. These properties help determine the degree of flood hazard on the DFA. Topologic analysis also determines if the FEMA method is applicable for a given site.

Smart and Moruzzi studied the topology of distributary networks of deltas. They divided the distributary network into vertices and links. They define vertices as "points at which channels intersect or terminate". A link is "a channel segment connecting two successive vertices". Vertices are subdivided into joins (where two links combine in a downstream direction), and forks (where two links divide in a downstream direction), and outlets (where a link exits the toe of the DFA, Smart and Moruzzi, 1972, p.271).

Smart and Moruzzi developed the recombination factor (R) to relate the following five classes of variables: number of vertices (Nv), the number of links (Nl), the number of forks (Nf), the number of joins (Nj), and the number of outlets (No). The recombination factor is the ratio of the number of joins divided by the number of forks. The recombination factor ranges from zero for a network which possesses no joins to a value of one for a network in which the number of joins equals the number of forks (e.g. a braided stream).

Smart and Moruzzi relate these five topologic properties with equations (Appendix E) using "simple heuristic methods" rather than conventional mathematical theory (Smart and Moruzzi, 1972, p.272-273).

Smart and Moruzzi classified links into six categories.

The type of link is based on the vertices that both begin the link upstream and terminate the same link downstream (Fig.9A). The six categories are: FF (the link emanates from a fork and terminates in a fork), FJ (the link begins at a fork and ends at a join), JF (the link begins at a join and ends at a fork), JJ (join to join), FO (fork to outlet), JO (join to outlet)(Smart and Moruzzi, 1972, p.273).

Using these concepts, Smart and Moruzzi developed a random link model to describe the distribution of links within a distributary network (Smart and Moruzzi, 1972, p.281-2). By utilizing the recombination factor, they derived six equations relating the expected frequencies of the various types of links as a function of the recombination factor (Appendix E).

Smart and Moruzzi claim that although their random link model is not based on rigorous statistical theory, it is still "useful in exhibiting the broad features of link distribution" (Smart and Moruzzi, 1972, p.274).

Morisawa utilized Smart and Moruzzi's scheme to analyze the channel patterns of deltas. Based on various maps (including topographic and political maps) she calculated the number of links and the recombination factor of twenty deltas. Her sample ranged in size from less than 1 square mile to greater than 10,000 square miles.

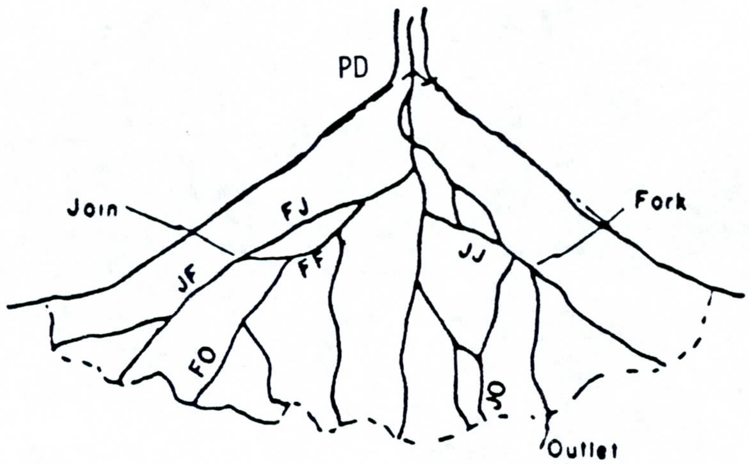


Figure 9a. - Distributary drainage network depicting the six types of links: FF, FJ, JF, JJ, JO, FO (after Morisawa, 1985, p.240).

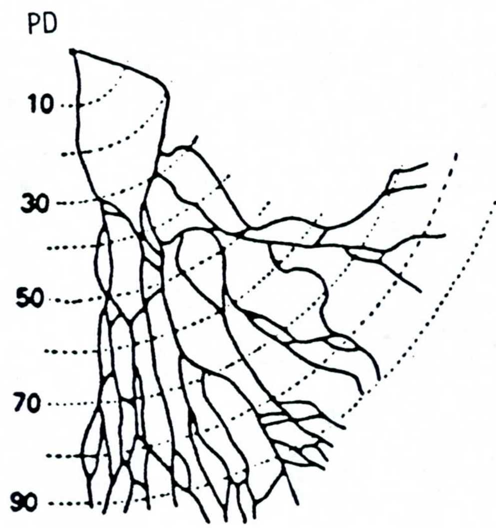


Figure 9b. - Distributary drainage network with arcs used to calculate the recombination factor at different distances from the primary diffluence (after Morisawa, 1985, p.252).

Morisawa analyzed the recombination factor for each delta network. She also examined the change in the recombination factor with increasing distance from the apex of the delta. She measured a cumulative recombination factor at 10% intervals (delineated by arcs) along the length of the delta (Fig.9B). Her plots of the recombination factor versus distance from the apex revealed that the recombination factor generally increases with distance from the apex and reaches a relatively steady value near the distal portions of the delta network (Morisawa, 1985, p.246).

Morisawa suggested using the recombination factor as a quantitative measurement of Coleman's classification scheme for distributary channel patterns. Coleman separated distributary networks into two categories, bifurcating and rejoining. The bifurcating network has channels that fork without rejoining. The rejoining network possesses channels that often rejoin after forking. (He also mentions a single channel distributary pattern that has very few forks and only one main channel conveys the flow.) Morisawa proposed that a recombination factor less than 0.5 generally indicates a bifurcating pattern while a recombination factor greater than 0.5 suggests a rejoining pattern (Morisawa, 1985, p.265). As the recombination factor approaches a value of one, the channel pattern resembles a braided stream in the relationship between the number of joins and forks.

Morisawa not only used the recombination factor to analyze the topology of her twenty deltas, but she also examined the frequency of the six types of links. She compared the observed number of each type of link with the expected number predicted by Smart and Moruzzi's random link model. The observed number of links were counted from maps while the predicted values were calculated from Smart and Moruzzi's equations (Appendix E). A chi-square test (goodness of fit) was conducted on the twenty networks and it was concluded that five deltas differed significantly ($p<.05$) from Smart and Moruzzi's random connection model. The join links made the most contribution to the chi-square statistic (Morisawa, 1985, p.249).

Application and Results - Analysis of Recombination Factor

Morisawa concluded that the recombination factor could be used as an indicator of the type of channel pattern of a delta's distributary network. A major factor in the degree of flood hazard on a DFA is the potential for the random formation and relocation of channels across the DFA. The number of joins and the number of forks (the recombination factor) may reflect the random behavior of the channels.

The DFA was delineated for 39 sites based on the procedure in "A Method for Locating the Primary Diffluence". Distributary channel patterns were traced from 7.5 minute orthophoto quads (Appendix F). Arcs were drawn to separate the length of the DFA into ten equal segments following Morisawa's procedure. The cumulative number of forks and joins was tabulated for 10% intervals from the primary diffluence to the toe. Only 21 of the sites had both a sufficient number of vertices (Nv > 50) to provide a representative recombination factor and a large enough DFA to facilitate the recognition of distributary channels.

The distributary channels were traced from the orthophotos based on the light colored soils and increased density of vegetation along channels. It is assumed that these channels have experienced recent flow. Although not all channels are flooded during each event and not all channels receive the same number of flood events, it is assumed that soil color and vegetation provide a representative channel pattern for an engineering time frame.

The cumulative recombination factor values (from 10% to 100% of the distance from the primary diffluence to the toe) were analyzed to see if they were related to the degree of flood hazard. The degree of flood hazard was determined using the reconnaissance method outlined in "Types of Flood Hazards on DFAs in Southern Arizona". The correlation coefficients between the degree of flood hazard and the various recombination factors (R10 to R100) were very small. Therefore, the linear relationship between the various recombination factor values and the degree of flood hazard is poor.

A direct correlation of the degree of flood hazard versus the recombination factor did not prove helpful. Fortunately, the plots of the recombination factor versus percent distance along the DFA did yield some insight into the degree of flood hazard on the DFAs.

In general, the cumulative recombination factor increases with distance along the DFA. Morisawa recognized a similar trend among delta distributary networks. She noted that generally the R value increases toward the toe of the network where it "resonates" about a relatively constant value or trend.

Morisawa attributes the rapid increase in the number of joins to the number of forks toward the toe of the deltas as a result of energy and space constraints. In the upper reaches of the delta there are few channels and thus little opportunity for channels to join. Down slope there are more channels and joins predominate due to a dense channel pattern. Also, as the slope of the delta decreases away from the apex, the channels merge to conserve energy (Morisawa, 1985, p.265).

Among the 21 DFAs analyzed, the R plots displayed a variety of shapes, but Morisawa's observations applied in most cases. The plot of the mean R values versus percent distance down the DFA shows that the R values increased toward the toe of the DFA (Fig.10). The plot of the standard deviation of the various R values shows that the R values varied less among the DFAs as the measurements approached the toe. For the 21 sites the R100 values only ranged from 0.69 to 0.98 which revealed little information about the degree of flood hazard. Yet, some clues as to the flood hazard can be gleaned from the great variance displayed in the R values closer to the primary diffluence.

Plots of R can reveal differences in flood hazard between adjacent sites (Fig.11). For example, sites 36, 37, 38, and 39 are all located on the west slopes of the White Tank Mountains. The plot of R versus percent distance for site 36 (degree of flood hazard is 10) rises more quickly and achieves a larger R100 value than the other three adjacent DFAs with smaller degrees of flood hazard (9, 9, and 8, respectively). This suggests that the old fan remnants in site 39 (which contribute to its relatively small degree of flood hazard) are preventing channels from rejoining and therefore the R values remain smaller farther down slope on the DFA.

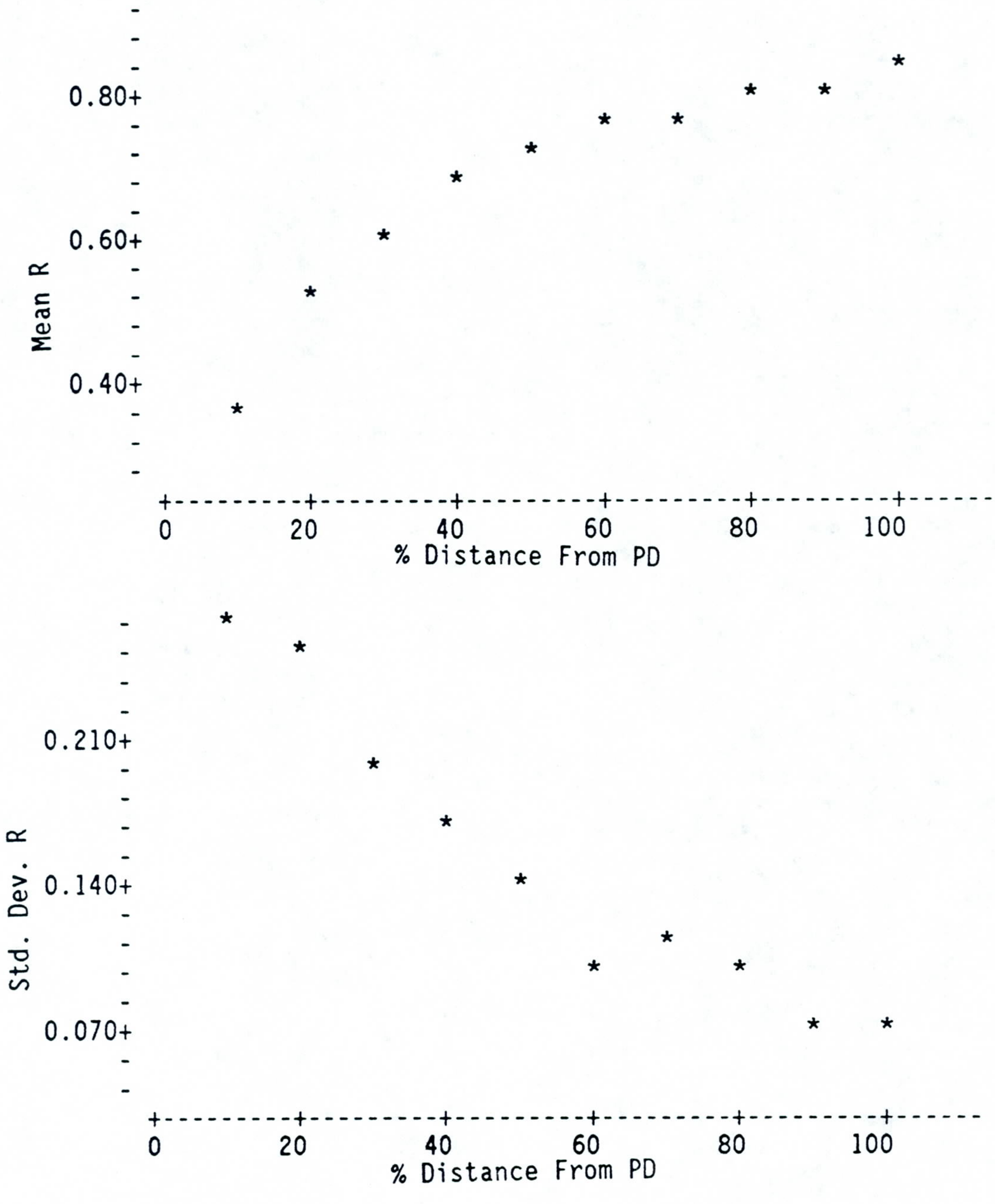


Figure 10. - Plot of the mean and standard deviation of the recombination factor (R) for the 21 sites versus the percent distance from the primary diffluence.

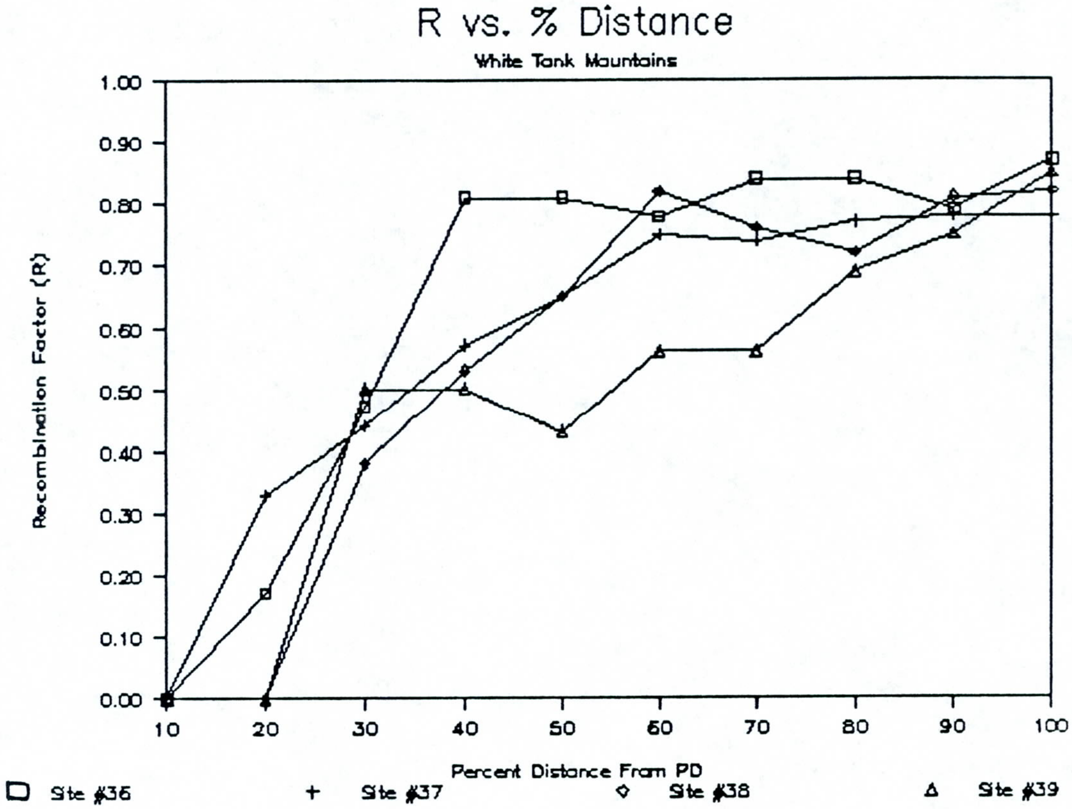


Figure 11. - Plots of the recombination factor (R) versus the percent distance from the primary diffluence to the toe. The plot includes sites # 36, 37, 38, and 39.

Also, the plot of R versus the percent distance can reveal a change in flood hazard within a DFA. Near the primary diffluence, site 10 contains two distinct distributary channels which warrant a degree of flood hazard of 2. Yet, half way down the DFA the two confined distributary channels form small random alluvial fans which deserve a ranking of 10 (fully random). The plot of R versus percent distance displays a low R (indicating some forks with few joins) until about 40% of the distance downslope of the primary diffluence. Then the plot shows R increasing as the channels on the small random fans merge and join (Site #10 in Appendix G).

Morisawa suggested that the recombination factor could be used to classify channel patterns of distributary networks. This investigation found that R could provide very little information about the degree of flood hazard on DFAs as expressed in the distributary channel patterns.

The R could not provide consistent information about the degree of flood hazard for a number of reasons. First, the old fan remnants and the high ridges which provide flood free surfaces may influence channel patterns in two ways. They may keep channels separated resulting in a low R value (ridges can prevent joining). They may also funnel channels into swales where random flow occurs between flood free areas. Site 7 exemplifies how old fan remnants can separate channels with flood free ridges and yet induce random distributary flow in small pockets on the DFA.

Application and Results - Random Link Analysis

The analysis of the frequency of the six types of links proved to enable one to distinguish between DFAs with a large potential for the random formation and relocation of channels (degree of 9 or 10) and those that have channels which do not behave in a purely random fashion (degree less than 9).

Eighteen of the thirty-nine sites yielded a sufficient number of each type of link to allow the application of a goodness of fit test (utilizing the chi-square) between the observed frequency of links and the expected frequency based on Smart and Moruzzi's random connection model.

Each of the channel patterns for the 18 DFAs was color coded and the number of each type of link was tabulated (Table 3). Generally, the links were in order of decreasing frequency: FJ, FF, JF, JJ, FO, JO. This result roughly agrees with Morisawa's findings for the distributary networks of twenty deltas.

Morisawa plotted R100 versus the number of each type of link. She found that as R increased the number of FF and FO links decreased while FJ, JJ, and JF links increased. These

Table 3.-- Summary of topological data

[A, site no.; B, degree of flood hazard; RF, recombination factor; NL, observed number of links; FF, number of FF links; FJ, number of FJ links; JF, number of JF links; JJ, number of JJ links; JO, number of JO links; FO, number of FO links; XF, contribution to chisqure from the FF, FJ, and FO links; XJ, contribution to the chisquare from the JF, JJ, and JO links; X, total chisquare; N/R, N = does not follow random link model, R = follows random link model; DV, Yes = desert varnish is present within the DFA, No = there is not any apparent desert varnish in the DFA; OF, Yes = there are old fan remnants and/or inselbergs within the DFA, No = there are not any apparent old fan remnants and/or inselbergs within the DFA; X critical = 5.99 for 2 d.f]

			[-------Observed-----]						[--------Expected---------]											
A	B	RF	NL	FF	FJ	JF	JJ	JO	FO	FF	FJ	JF	JJ	JO	FO	XF	XJ	X	N/R	DV	OF
1	5	0.767	83	15	38	14	8	1	7	21.7	33.3	8.3	12.7	1.9	5.1	3.48	6.11	9.60	N	No	No
3	7	.868	195	41	88	26	30	6	4	47.4	82.3	20.6	35.7	2.7	6.3	2.09	6.29	8.38	N	No	No
6	9	.831	166	39	68	19	30	3	7	41.4	68.8	17.2	28.6	2.9	7.0	.15	.26	.41	R	No	No
7	8	.926	238	33	130	47	20	3	5	55.6	103.0	25.7	47.7	1.9	4.1	16.47	34.24	50.72	N	Yes	Yes
8	5	.800	155	30	70	24	18	7	6	39.5	63.3	15.8	25.3	3.2	7.9	3.48	11.00	14.48	N	No	Yes
9	9	.935	449	84	201	68	85	5	6	104.3	194.9	48.7	91.1	3.2	6.8	4.23	9.06	13.29	N	No	No
10	2	.760	68	17	27	7	11	1	5	17.9	27.1	6.8	10.3	1.6	4.3	.16	.30	.46	R	No	No
14	9	.910	226	39	105	38	37	1	6	53.4	97.2	24.3	44.2	2.2	4.8	4.81	9.56	14.36	N	No	No
18	9	.848	132	28	58	17	20	5	4	32.6	55.2	13.8	23.4	2.1	5.0	.96	5.24	6.20	N	Yes	Yes
25	9	.780	331	64	136	53	48	6	24	85.7	133.6	33.4	52.1	7.4	18.9	6.92	12.07	18.99	N	Yes	Yes
29	9	.694	97	22	39	13	11	3	9	26.7	37.1	9.3	12.9	2.8	8.2	1.02	1.78	2.79	R	No	No
30	2	.829	214	38	105	37	21	4	9	53.5	88.7	22.2	36.7	3.8	9.1	7.49	16.69	24.18	N	No	Yes
32	8	.859	180	29	93	34	17	3	4	44.0	75.7	18.9	32.5	2.7	6.2	9.87	19.47	29.34	N	Yes	Yes
33	7	.848	130	22	58	23	20	2	5	32.1	54.4	13.6	23.0	2.1	4.9	3.40	6.92	10.32	N	Yes	Yes
35	10	.837	247	55	100	30	44	4	14	61.4	102.8	25.7	43.0	4.2	10.0	2.34	.75	3.10	R	No	Yes
36	10	.870	156	37	64	16	30	4	5	37.9	65.9	16.5	28.7	2.1	4.9	.08	1.70	1.78	R	No	No
37	9	.778	75	15	33	11	9	2	5	19.4	30.2	7.6	11.8	1.7	4.3	1.37	2.27	3.65	R	No	No
38	9	.818	95	17	41	15	13	2	7	23.9	39.1	9.8	16.0	1.8	4.3	3.71	3.37	7.08	N	No	No

relationships were predictable since the joins increase as R increases and therefore the number of links with joins increases. Yet, she found no relation between JO and R (Morisawa, 1985, p.246). For the sample of 18 DFAs, as R increased the number of FF and FO links decreased and the number of FJ links increased. The correlation coefficients for R and the links JF, JJ, and JO were less than 0.5. Yet, the number of all three types of links generally increased with an increasing R.

All six types of links were tabulated for each site. The expected number for a type of link is the product of the total number of links for the site and the expected frequency of that type of link found from Smart and Moruzzi's random connection model (Appendix E). A chi-square test compared the expected number of each type of link with the observed number. The chi-square provides a method for checking whether the difference between the observations and the expected numbers is due to chance alone. A large chi-square means that the observed frequency of links differs significantly from the expected frequency of links.

The results of the chi-square test showed that 12 of the 18 distributary networks differed significantly ($p<.05$) from the random connection model of Smart and Moruzzi and the channels did not display random behavior. Five of the six sites that obeyed Smart and Moruzzi's random connection model possessed a degree of flood hazard of nine or ten.

The exception was a site which has a degree of flood hazard of 2 near the primary diffluence, yet the flood hazard changes significantly downstream to an 8 or 9 in the lower distributary flow area. Of the 12 sites that do not follow Smart and Moruzzi's random connection model the degree of flood hazard ranges from 2 to 9. The greatest contribution to the chi-square came from the links with joins (JJ, JF, JO).

Eight of the sites had more than two cells with observed or expected values less than 5. JO and FO links yielded the deficiencies. In only one of these cases did the deficient cell contribute significantly to the chi-square value. The FO links for site #38 may influence its classification as random or non-random due to its borderline chi-square value.

The 18 sites were also analyzed to see if any qualitative relationship could be found between the degree of flood hazard and whether the frequency of links fit a random connection model. The difference between the DFAs with a random distribution of links and the DFAs with a non-random distribution of links lies in the presence of old fan remnants and/or inselbergs in the DFA. Seven of twelve DFAs with non random links have significant old fan remnants and/or inselbergs within the DFA. Of these seven there are five with significant desert varnish on surfaces within the DFA.

Old fan remnants represent stable surfaces within engineering time and are areas where rapid channel relocations do not occur. The presence of desert varnish provides evidence for a lack of sediment deposition well beyond engineering time. Stable surfaces constrain the random formation of channel links. They also reduce the potential random relocation of flood flows. As a result, the degree of flood hazard is low where Smart and Moruzzi's random connection model does not apply. Stable surfaces also prevent the equal chance of flooding across the DFA. Therefore, the FEMA method should probably not be applied at sites that possess a non-random distribution of channel links.

Only one (from a total of six) of the DFAs with random links has significant old fan remnants. None of these six DFAs has significant desert varnish within the DFA.

This evidence shows that the procedure outlined above can approximately distinguish between DFAs with extremely random flow paths (degree = 9 or 10) and DFAs where the channels do not behave as randomly (degree < 9). The stable surfaces (old fan remnants, inselbergs) within many DFAs prevent an equal probability of flooding from occurring across a radial arc along the fan surface. Smart and Moruzzi's random connection model adequately describes the frequency of links for DFAs without significant stable surfaces. FEMA's method may be applicable in such cases. A non-random frequency of links develops due to the effect that stable surfaces have on channel patterns. FEMA's method should not be applied where Smart and Moruzzi's model does not hold.

Multiple Regression Analysis

The texture curve analysis is a method that can be used to define the boundaries of distributary flow. The topologic analysis attempted to determine where FEMA's method is applicable and to evaluate the flood hazards of DFAs. The final attempt at developing a quantitative method for determining the degree of flood hazard on DFAs is a statistical model based on a multiple regression equation.

The independent variable is the degree of flood hazard as determined in the section "Types of Flood Hazards on DFAs in Southern Arizona". The dependent variables are various morphometric and hydrologic characteristics which are easily obtained from 7.5 minute topographic maps, orthophotos, and standard references (Table 4).

Independent variables with an intercorrelation of more than 0.7 were excluded from the analysis. The variables that proved to be significant in the final regression equations

Table 4.-- Physiographic and hydrologic characteristics of sample sites

[A, site number; B, degree of flood hazard; RN, ruggedness number of drainage basin; MRDA, mean relief ratio of drainage basin; MRDFA, mean relief ratio of distributary flow area; H, average contour sinuosity of distributary flow area; K, average contour band width of drainage basin, in inches; L, average contour band width of distributary flow area, in inches; DA, drainage basin area, in square miles; FA, area of distributary flow area, in square miles; MBE, mean basin elevation, in feet; P, 10-year 24-hour precipitation, in tenths of inches; MAF, mountain-area factor; V, location factor of primary diffluence; W, 100-year flood at primary diffluence, in cubic feet per second; CC, contour band width just downstream from the primary diffluence, in inches; AA, aspect angle of the drainage basin, in degrees]

A	B	RN	MRDA	MRDFA	H	K	L	DA	FA	MBE	P	MAF	V	W	CC	AA
1	5	0.085	0.0292	0.0198	1.49	0.47	0.31	3.89	6.46	2590	30	1	5	4380	0.20	50
2	6	.0721	.0273	.0183	1.45	.49	.30	6.10	10.0	2710	30	1	5	5440	.24	41
3	7	.0997	.0256	.0173	1.46	.49	.24	2.79	9.11	2660	30	1	6	3450	.24	41
4	10	.247	.138	.0193	1.18	.33	.55	.479	.429	2030	28	4	8	885	.08	88
5	10	.189	.0812	.0247	1.34	.92	.13	10.8	1.68	4660	26	1	2	3560	.04	224
6	9	.119	.110	.0312	1.18	.38	.09	8.04	1.71	2670	30	4	8	6150	.05	45
7	8	.0546	.0359	.0108	2.26	1.5	.65	56.0	20.7	2060	27	4	5	8200	1.0	132
8	5	.0905	.0685	.0121	1.54	.18	.20	9.24	8.17	1240	25	1	5	3340	.32	110
9	9	.0775	.0434	.0115	1.36	1.2	.56	58.4	35.9	3310	29	2	5	7580	.22	88
10	2	.0996	.0779	.0126	1.71	.40	.26	1.37	1.38	2240	34	7	7	1420	.25	180
11	9	.0543	.0348	.0107	1.99	.76	.27	7.65	.549	2140	30	3	2	3050	.26	227
12	2	.0968	.0526	.0261	1.85	.80	.15	3.17	.682	3960	28	6	3	2060	1.1	70
13	8	.164	.0636	.0289	1.11	.78	.11	5.46	1.52	3150	27	6	6	2630	.10	39
14	9	.169	.0767	.0322	1.14	.98	.08	3.77	2.26	3440	30	7	8	2230	.08	45
15	9	.217	.0930	.0318	1.30	.31	.15	.989	.916	3100	30	6	7	1220	.06	42
16	5	.221	.0556	.0312	1.38	.33	.18	1.65	3.72	3950	32	3	7	1540	.14	165
17	10	.0609	.0251	.0192	1.63	1.1	.20	3.60	.631	4090	26	1	3	2180	.14	82
18	9	.121	.0707	.00980	1.29	1.0	.15	2.40	3.32	1870	29	6	10	1700	.22	154
19	9	.199	.141	.0161	1.29	.36	.15	.922	.320	1820	29	5	4	1060	.08	330
20	9	.155	.0924	.0202	1.39	1.2	.31	12.7	5.89	5670	30	9	10	3830	.12	164
21	9	.115	.0967	.00912	1.94	.46	.46	3.41	5.18	1470	27	2	9	2030	.46	106
22	10	.151	.0898	.00577	1.26	.33	.26	2.33	5.46	1740	28	3	7	4400	.18	40
23	10	.245	.143	.0270	1.32	.44	.12	2.81	.600	2260	28	7	8	3500	.04	29
24	3	.235	.105	.0165	3.75	1.4	.80	4.05	4.98	1600	22	8	9	2210	.25	81
25	9	.0551	.0394	.0127	1.32	1.2	.30	21.6	26.4	2160	26	1	6	5100	.12	28
26	9	.173	.128	.0214	1.37	1.2	.16	1.99	1.99	2170	26	9	9	1550	.46	119
27	9	.101	.0562	.0130	1.30	1.1	.22	7.54	2.77	1790	26	5	8	3010	.21	323
28	10	.103	.0548	.00972	1.09	1.3	.18	5.25	2.65	1870	25	4	5	2520	.18	339
29	9	.253	.130	.0165	1.78	1.2	.26	2.07	1.44	2420	26	3	9	1580	.17	344
30	2	.208	.124	.0197	2.52	1.2	.44	11.1	2.62	3110	28	9	9	3660	.47	20
31	8	.243	.174	.0260	2.05	.48	.35	.847	2.84	1770	26	8	10	1010	.52	130
32	8	.184	.154	.0287	2.21	.90	.43	1.28	2.62	1990	26	9	10	1240	.20	130
33	7	.126	.0694	.0114	3.09	1.1	.44	9.73	3.45	1720	27	4	6	3420	.14	108
34	9	.0482	.0341	.00706	2.03	.94	.58	88.8	25.2	2070	27	4	6	10300	.77	294
35	10	.0747	.0708	.0073	1.75	2.5	.51	95.9	38.8	2600	26	4	9	10700	.56	94
36	10	.131	.0837	.0192	1.36	.94	.14	5.63	2.15	2130	26	6	7	2610	.12	72
37	9	.188	.0946	.0175	1.47	.73	.15	4.30	1.03	2150	26	4	8	2280	.18	74
38	9	.271	.0948	.0152	1.75	.71	.19	3.47	.700	2160	26	4	6	2050	.24	52
39	8	.191	.110	.0137	2.37	.81	.41	3.26	2.25	1860	26	3	8	1980	.42	57

were also significant when the flood hazard index was transformed using the logarithm and also when the degree of flood hazard was reversed.

The drainage basin characteristics that proved significant in the regression analysis were the ratio of the area of DFA divided by the area of the drainage basin, the mean relief ratio of the drainage basin, and the mountainous area factor. The 10-year 24-hour intensity of precipitation was the only significant climatic characteristic. The variables are described below.

The ratio of the area of the DFA divided by the drainage basin area is inversely related to the degree of flood hazard. Areas with small DFAs relative to the drainage basin area are subject to large peak flows per unit area of DFA and as a result the degree of flood hazard will likely be great.

The 10-year 24-hour precipitation intensity values were obtained from the NOAA Precipitation Frequency Atlas of the Western United States (Miller, 1973). Interestingly, in developing the regression equation for the degree of flood hazard there was an inverse relationship with the intensity of precipitation. This is difficult to explain.

The mean relief ratio of the drainage basin is a measure of the average slope of the drainage basin. There is a direct relationship between the mean relief ratio of the drainage basin and the degree of flood hazard. The greater the mean relief ratio of the drainage basin the greater the potential energy of the flood flow. This increase in the potential energy of flow may result in a larger degree of flood hazard. Also, some studies have found that the mean relief ratio of the drainage basin is directly related to the sediment yield (Chow, 1964, p.17-13). Increased sediment yields may contribute to avulsions and a greater degree of flood hazard.

The contour band width is the measured distance, in inches, between the tangent of the largest upslope crenulation and a parallel tangent line to the largest downslope crenulation (on the same contour). The crenulations used are representative of canyons and stream channels and not mountain ridges. The average of 4 to 6 equally spaced contours over the drainage basin was used.

There is a direct relationship between the average contour band width of the drainage basin and the degree of flood hazard. The average contour band width of the drainage basin is a measure of the relief resulting from the depths of canyons and stream channels (Appendix H).

The mountainous area factor is the ratio of the drainage basin area (typically composed of bedrock mountains) which is not on the piedmont plain and the total drainage basin area. The ratio is multiplied by ten and rounded to one significant figure so that the final index ranges from 1 to 10. There is an inverse relationship between the mountainous area factor and the degree of flood hazard. The mountainous area factor may be a surrogate for the effects of geology on the degree of flood hazard (including lithology and geologic structure).

The characteristics of the DFA that proved significant in the regression analysis were the average contour sinuosity of the DFA and the contour band width just downstream of the primary diffluence.

The average contour sinuosity of the distributary flow area is the average of the contour sinuosities of four to six contours evenly spaced within the DFA. The sinuosity of a contour is the ratio of the length of a contour (as measured on a map) and a straight line that splits the longitudinal trend of the contour (Appendix H).

There is an inverse relationship between the average contour sinuosity of the DFA and the degree of flood hazard. The contour sinuosity is a proxy for the depth of channels, the number of defined channels, and the relative relief on the surface of the DFA. DFAs with a large degree of flood hazard may have small channels subject to crenulations with low contour sinuosities. In contrast, old fan surfaces (fan remnants) often have many deeply incised channels from local tributary drainage systems. The greater the number of large channels and the greater the depth of each channel the greater the average contour sinuosity of the DFA.

The contour band width just downstream of the primary diffluence is the contour band width of one contour within the region where distributary flow is established (usually three to four contour intervals downstream of the primary diffluence). There is an inverse relationship between the contour band width just downstream of the primary diffluence and the degree of flood hazard.

The contour band width just downstream of the primary diffluence is a proxy for the relative relief of the DFA close to the primary diffluence (height of ridges and depth of channels). DFAs with large ridges and well incised channels near the primary diffluence exhibit a large contour band width and usually possess a small degree of flood hazard.

Three regression equations were developed in which the dependent variable is the degree of flood hazard and the independent variables include the morphometric and climatic variables listed above. The first equation was developed from all 39 sample sites:

$$B = 26.1 - 2.75H - 0.491P$$

where B is the degree of flood hazard, H is the average contour sinuosity of the DFA, and P is the 10-year 24-hour precipitation for the drainage basin. The standard error of estimate is 1.9 and the correlation coefficient is 0.64 (Appendix I).

The range of values for the average contour sinuosity of the DFA is 1.09 to 3.75. The range of values for the 10-year 24-hour precipitation is 2.2 to 3.4 inches. As discussed previously, the negative relationship between the degree of flood hazard and the precipitation intensity is difficult to explain.

For the 35 sites with drainage areas less than about 22 square miles the equation with the largest correlation coefficient is:

$$B = 9.11 + 35.4MRDA - 2.33H + 3.01K - 0.424MAF - 3.89CC$$

where MRDA is the mean relief ratio of the drainage basin, K is the average contour band width of the drainage basin, MAF is the mountainous area factor, and CC is the contour band width just downstream of the primary diffluence. The standard error of estimate is 1.6 and the correlation coefficient is 0.79.

The range of values for the mean relief ratio of the drainage basin is .0251 to .174. The range of values for the average contour sinuosity of the DFA is 1.09 to 3.75. The range of values for the average contour band width of the drainage basin is .18 to 1.40 inches. The range of values for the mountainous area factor is 1 to 9. Lastly, the range of values for the contour band width just downstream of the primary diffluence is .04 to 1.1 inches.

For the 35 sites with flood hazard types C, D, and E (with degree of flood hazard between 5 and 10) the equation with the smallest standard error of estimate (1.1) is:

$$B = 8.44 - 0.537DD + 14.9MRDA - 1.06H + 1.28K$$

where DD is the ratio of the area of the DFA divided by the area of the drainage basin. The correlation coefficient is 0.69. The range of values for the ratio of the area of the DFA divided by the drainage basin area is 0.0718 to 3.35.

The range of values for the mean relief ratio of the drainage basin is 0.0251 to .174. The range of values for the average contour sinuosity of the DFA is 1.09 to 3.09. Lastly, the range of values for the average contour band width of the drainage basin is .18 to 2.5 inches.

Approximately 25 morphometric and hydrologic variables were used as independent variables in the regression analysis. The seven listed above proved to be the most significant in predicting the degree of flood hazard. These variables also proved to be significant when the data were logged and when the index of the degree of flood hazard was reversed.

Both the sinuosity of the contours and the contour band width just downstream of the primary diffluence proxy properties of the channels within the DFA. The depth and number of channels described by these variables may reflect the potential randomness of flooding across the DFA.

These equations do not serve any other purpose than the prediction of the degree of flood hazard. The relationships between the degree of flood hazard and the morphometric and hydrologic variables is complex and the regression equations only provide rough predictions of flood hazard.

SUMMARY AND CONCLUSIONS

The Federal Emergency Management Agency (FEMA) has prescribed a method for analyzing flood hazards on alluvial fans. The FEMA method assumes an equal probability of flooding across a radial arc on the alluvial fan. The term, distributary flow area (DFA), better describes the areas in southern Arizona subject to bifurcating channels and their associated hazards.

A reconnaissance methodology was used to classify 39 sample sites into five categories (A, B, C, D, and E) based on the potential randomness of flooding across the DFA. The potential randomness of flooding is based on the number of possible flow paths and the stability of the channels.

Category A represents sites with the least potential for random flooding across the DFA. At the other end of the spectrum is category E. It represents sites that likely obey FEMA's assumption of an equal chance of flooding across the DFA. The five categories were further broken down into a quantitative index called the degree of flood hazard. This index ranges from 1 (corresponding to category A) to 10 (for category E).

It was found that 31 of the 39 sample sites belong in categories A, B, C, and D. Sixteen of the thirty-one sites have a degree of flood hazard of 9. Some of these 16 sites may approximately satisfy FEMA's assumption; however the other 15 sites violate FEMA's assumption. FEMA's method may be appropriate for the eight sites in flood hazard type E (degree of flood hazard of 10) and for some borderline cases in category D (degree of flood hazard of 9).

A procedure is presented for properly locating the primary diffluence (apex) of the DFA. Although some contractors assume that the primary diffluence is located at the mountain front, in 21 of the 39 sample sites studied the primary diffluence was located downstream of the general mountain front (or the sites had no mountain front).

No easy rule of thumb can accurately locate the beginning of flood hazards associated with distributary flow. Therefore, a method is proposed for locating the primary diffluence on the piedmont plain. This method uses topographic maps and orthophotos to examine the relationships between topography, soils, and vegetation.

A method called texture curve analysis, was developed to help locate distributary flow on the piedmont plain. The technique accurately recognized DFAs in 80% of the cases investigated (33 of 41 sampling strips). The technique recognized old fans with tributary drainage in about 78% of the cases examined (11 of 14 sampling strips). Lastly, the technique located the primary diffluence in 78% of the cases where the DFA was located on an alluvial plain downstream of a pediment. Error occurs when the sampling strip crosses texture domains and large incised channels.

Multiple sampling strips may help determine the margins of distributary flow. Texture curve analysis should be used in conjunction with other tools such as topographic maps and aerial photographs to determine areas of distributary flow. The texture curve analysis requires little time to perform and clear instructions are presented by Doehring (1970).

Also, two attempts were made to develop more objective and quantitative methods for evaluating the flood hazards on DFAs in southern Arizona. These methods build from the reconnaissance method which classified 39 sample sites into five categories. The two methods include the topologic analysis, and a multiple regression model.

The topologic analysis proved useful in quantifying the randomness of flooding across the DFA. The recombination factor was not directly related to the degree of flood hazard. The analysis of the link types, however, was able to distinguish between categories of flood hazard A through D and category E (with some borderline cases in category D).

FEMA's method may apply in cases where the links follow Smart and Moruzzi's random connection model. Of the six sites that follow the random link model, two had a degree of flood hazard of 10. A degree of 10 means that the sites likely conform with FEMA's assumption of purely random flow across the DFA. Three sites had a degree of flood hazard of 9 and are borderline cases in regards to the suitability of the FEMA method. Site #10 proved to be an exception as the degree of flood hazard was small, but the distributary network followed the random connection model.

Nine of the twelve sites that did not follow the random connection model violated FEMA's assumption. The other 3 sites are borderline cases. Therefore, the topologic analysis roughly distinguishes between areas where FEMA's method is appropriate and those areas that do not conform with the assumption of an equal chance of flooding across the DFA. The topologic analysis requires a moderate amount of effort in the tracing of the distributary network from orthophotos and in the counting of the various link types.

The multiple regression model attempts to predict the degree of flood hazard based on morphometric and hydrologic variables. A few dependent variables proved to be significant including the mean relief ratio of the drainage basin, the ratio of the size of the DFA and the drainage area, the 10-year 24-hour precipitation, and some unusual variables such as the average contour sinuosity of the DFA, the average contour band width of the drainage basin, the contour band width just downstream of the primary diffluence, and the mountainous area factor of the drainage basin. These equations provide rough predictions of the degree of flood hazard. The standard error of estimate and the residuals (Appendix I) reveal that the predicted values fall within plus or minus two degrees of flood hazard. The independent variables are easy to obtain from references and topographic maps.

The texture curve analysis, the topologic analysis, and the multiple regression model attempt to measure geomorphic properties related to the location and type of flood hazard found on distributary flow areas. Where the FEMA method is not adequate (categories A, B, C, and some cases in category D) these methods are an improvement over the reconnaissance method alone.

The topologic analysis and the multiple regression model are rapid and inexpensive methods for attempting to quantify the degree of flood hazard on DFAs that do not possess an equal chance of flooding across the DFA. These methods provide rough approximations and must be used together along with supplementary information from orthophotos, and aerial photographs.

This author recognizes that geomorphic mapping and dating techniques provide the best method for defining areas subject to distributary flood hazards. They may also provide estimates of the age of deposition and inundation associated with large flood events. Examples include the use of rock varnish for dating surfaces (Dorn and Oberlander, 1982) and the use of pedologic and stratigraphic information for evaluating the dominant processes at work on distributary flow areas (Demsey and Pearthree, 1990). These methods require specially trained experts, and significant amounts of time and money.

Further research is needed in the area of geomorphic processes associated with DFAs in southern Arizona. Also, there is little data on the spatial distribution of flood water across a DFA during a flood event. Similarly, there is a need to better understand the amount of attenuation of flood peaks that occurs due to the infiltration of flood flows into alluvial channels and the spreading of flow in distributary channels. Finally, Bull (1977) presents some estimates for the permanency of intersection points. Further research needs to be done to better understand the effects of man's activities on the drainage basin and on the relocation of the intersection point.

APPENDIX A

FEMA METHODOLOGY

For the single channel region:

$$Q = 280\ D^{2.5}$$

Discharge corresponding to the depth zone boundaries

Q	49.5	772	2,770	6,420	12,000	cfs
D	0.5	1.5	2.5	3.5	4.5	ft

$$Q = 0.13\ V^{5}$$

Discharge corresponding to the velocity zone boundaries

Q	68	240	654	1,510	3,080	5,770	cfs
V	3.5	4.5	5.5	6.5	7.5	8.5	ft/s

Fan Width = 950 ACP

For the multiple channel region:

$$D = 0.0917\ n^{.6} S^{-.3} Q^{.36} + 0.001426\ n^{-1.2} S^{.6} Q^{.48}$$

$$Q = 99314\ n^{4.17} S^{-1.25} V^{4.17}$$

(the above equations are solved for the discharge that corresponds to the same depth and velocity zone boundaries of the single channel region)

Fan Width = 3610 ACP

Q = discharge in cubic feet per second, D = total depth in feet due to pressure head and velocity head, V = velocity of flow in feet per second, n = Manning's roughness coefficient for the alluvial fan flood channel, S = fan slope, A = the avulsion coefficient (default value is 1.5), C = the transformation constant for the log-Pearson III distribution, P = the probability of the discharge for the respective depth or velocity zone boundary

APPENDIX B

CHI-SQUARE TEST RESULTS FOR PRIMARY DIFFLUENCE

Ho: There is no relationship between the location of the PD on the piedmont plain and the presence of a base level stream.

Ha: There is a relationship between the location of the PD and the presence of a base level stream.

V	BLS	NO BLS	Total
1-6	13	4	17
	9.59	7.41	
7-10	9	13	22
	12.41	9.59	
Total	22	17	39

ChiSq = 1.213 + 1.569 +
0.937 + 1.213 = 4.932

df = 1

The ChiSq critical value ($p<.05$) = 3.84

Where the Location factor of the PD (V) is the ratio of the distance from the primary diffluence to the base of the piedmont plain (in miles) divided by the total length of the piedmont plain (in miles). All lengths are map distances and measured appoximately perpendicular to the contours. The fraction is rounded to one significant figure and multiplied by ten. If V is from 1 to 6 then the PD is approximately located in the lower half of the piedmont plain. If V is from 7 to 10 then the PD is in the upper half of the piedmont plain.

Therefore, the null hypothesis is rejected and the location of the primary diffluence on the piedmont plain is dependent on the presence of a base level stream.

APPENDIX C

CHARACTERISTICS OF DFAS

The first step in analyzing the flood hazards of a DFA is a general survey to confirm the existence of distributary flow and its approximate limits on the piedmont plain. The following list provides some indicators of distributary flow which can be gleaned from topographic maps, aerial photographs, and orthophotos.

1. Distributary flow areas are found on the piedmont plain and within intermontane valleys.

2. Many fan skirts are situated near the junction of the piedmont and the basin floor. This is especially true where the floodplain of a large wash covers the basin floor.

3. Other distributary flow areas are formed where large washes are constricted and confined by inselbergs, a mountain pass, the edge of a mountain range, or the remnant of an old fan.

4. Pediments and the area below the pediment/alluvial plain boundaries may possess a network of distributary flow channels or coalescing fans.

5. Texture domains provide excellent clues to potential distributary flow areas. Smooth contours with straight or convex profiles (bend down slope in plan view) indicate mild relief which may indicate distributary flow. Doehring presents an excellent diagram depicting texture domains. He described alluvial fans which "contain several distinctly

different texture domains which may represent areas of presently active and non-active deposition" (Doehring, 1970, p. 3111-3112).

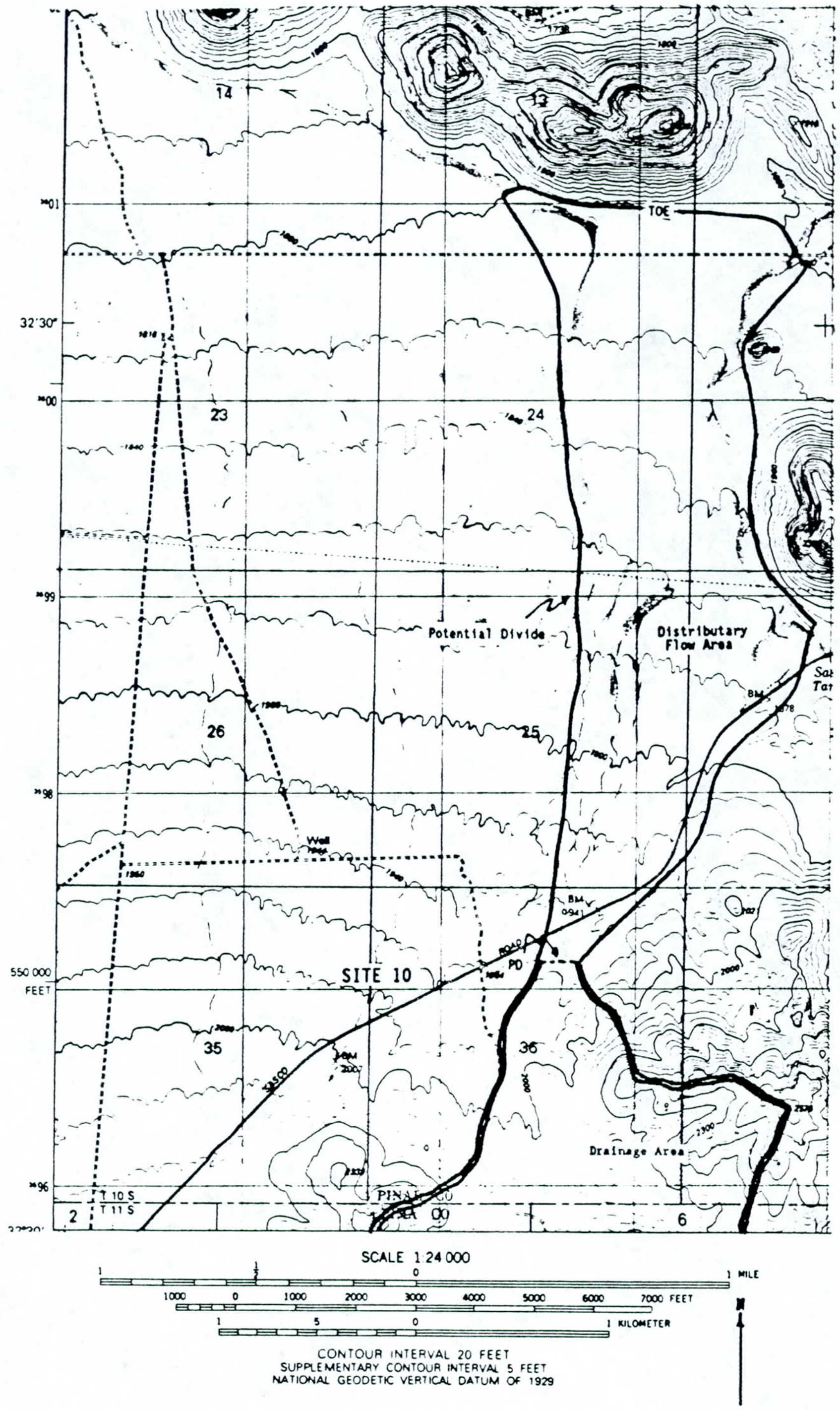
6. The profiles of washes on the piedmont plain may show a patten of flattening/steepening which is characteristic of intersection points and other types of distributary flow. The entire pattern may only cover a mile of the wash. Some washes show a distinct hump, or depositional lobe, where the gradual slopes occur near the intersection point and the steep slopes occur on the downstream edge of the depositional lobe. Other misleading flattening/steepening sequences show up in narrow canyons which may result from the influence of the underlying bedrock. Many DFAs are inset fans. The intersection point often marks the location of the primary diffluence for the fan. Inspection of the topographic maps may reveal points where an incised wash with large crenulations "disappears" downstream into smooth contours. This may also indicate an intersection point.

7. Orthophoto quads and aerial photographs can show differences in the soil color on the piedmont (Appendix D). Often varnished surfaces form the boundaries of distributary flow areas and indicate the limits of riverine flooding and recent deposition.

8. Vegetation anomalies may indicate the presence of

distributary flow. Distributary flow allows for increased infiltration over larger areas which supports dense thickets of trees. Often diffluences can be recognized by the junction of a narrow line of vegetation along a wash and the irregularly shaped zone of trees and shrubs at a diffluence.

Packard studied a 1.2 kilometer segment of a discontinuous ephemeral wash (a DFA) just south of Tucson, Arizona. He found that the type of channel pattern influenced the type and density of vegetation in the area. As the straight channel changes to a braided reach and then to a sheetflow area, the vegetation density increased. Packard attributed the increase in the density of vegetation in the sheetflow area to longer durations of flow during runoff events. While runoff might only flow five to ten minutes in low order streams, the sheetflow area might experience flow for as long as five hours (Packard, 1974, p.83).



APPENDIX C (cont.) - An example of a distributary flow area depicting the potential divides, primary diffluence (PD), toe, and the drainage area.

APPENDIX D

USE OF SOIL SURVEYS

The Soil Conservation Service has produced general soils maps (1:500,000 and 1:600,000) for the entire state of Arizona. Soils are grouped in mapping units consisting of a few dominant soils and several minor soils which form a recognizable pattern over broad areas (Torrance, 1969, p.1). Due to their relatively small scale these maps are useful in locating large geomorphic features (such as the piedmont plain and base level floodplains). They are not as useful in locating specific areas subject to distributary flow. Such broad mapping units often contain soils characteristic of both active and inactive alluvial fans.

Soils maps of a larger scale (1:20,000 and 1:24,000) cover more than one-half of the state. These maps delineate soils characteristic of flooding and active deposition. Some examples of soils characteristic of active fans include the Anthony and the Arizo units (Pima County, 1987, p.13).

The following are general characteristics of soils that are subject to flooding and are commonly found on active fans. The color of soils on DFAs is often more yellow (7.5 YR to 10 YR on the Munsell Color Chart) than the redder soils of inactive areas. The soils of active fans usually lack lime masses and concretions. If lime is present on active fans it is usually disseminated, but the soil may still effervesce slightly, Lastly, the texture of soils on active fans is generally loam and loamy sand to sandy loam and sand. These soils usually lack silty clay loam (Cochran, Personal communication, October 24, 1989).

Soils maps are not the only means for distinguishing between areas subject to distributary flow and old alluvial fans. Wells used satellite imagery to distinguish between coarse grained fans which possessed tributary drainage systems and fine grained fans where distributary flow prevailed (density analysis of MSS Band 7 and color composites of Bands 4, 5, and 7)(Wells, 1976, p.106-108).

APPENDIX E

SMART AND MORUZZI'S MODEL

$R = Nj/Nf$

$Nff + Nfj + Nfo = 2Nf$
$Njf + Njj + Njo = Nj$
$Nff + Njf = Nf - 1$
$Nfj + Njj = 2Nj$
$Nfo + Njo = No$

$Fff = \frac{2}{(2+R)^2}$

$Ffj = \frac{4R}{(2+R)^2}$

$Ffo = \frac{2(1-R)}{(2+R)^2}$

$Fjf = \frac{R}{(2+R)^2}$

$Fjj = \frac{2R^2}{(2+R)^2}$

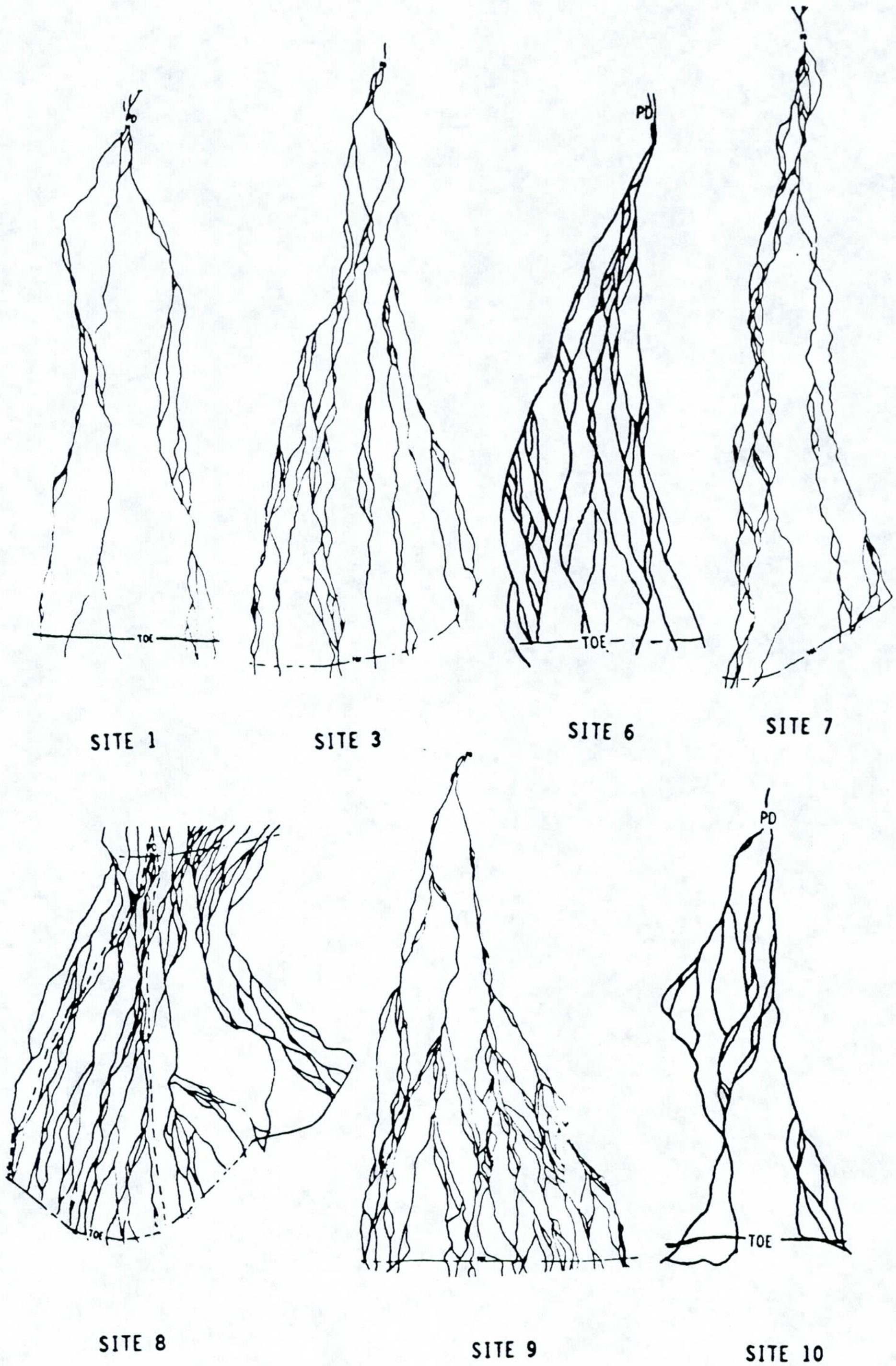
$Fjo = \frac{R(1-R)}{(2+R)^2}$

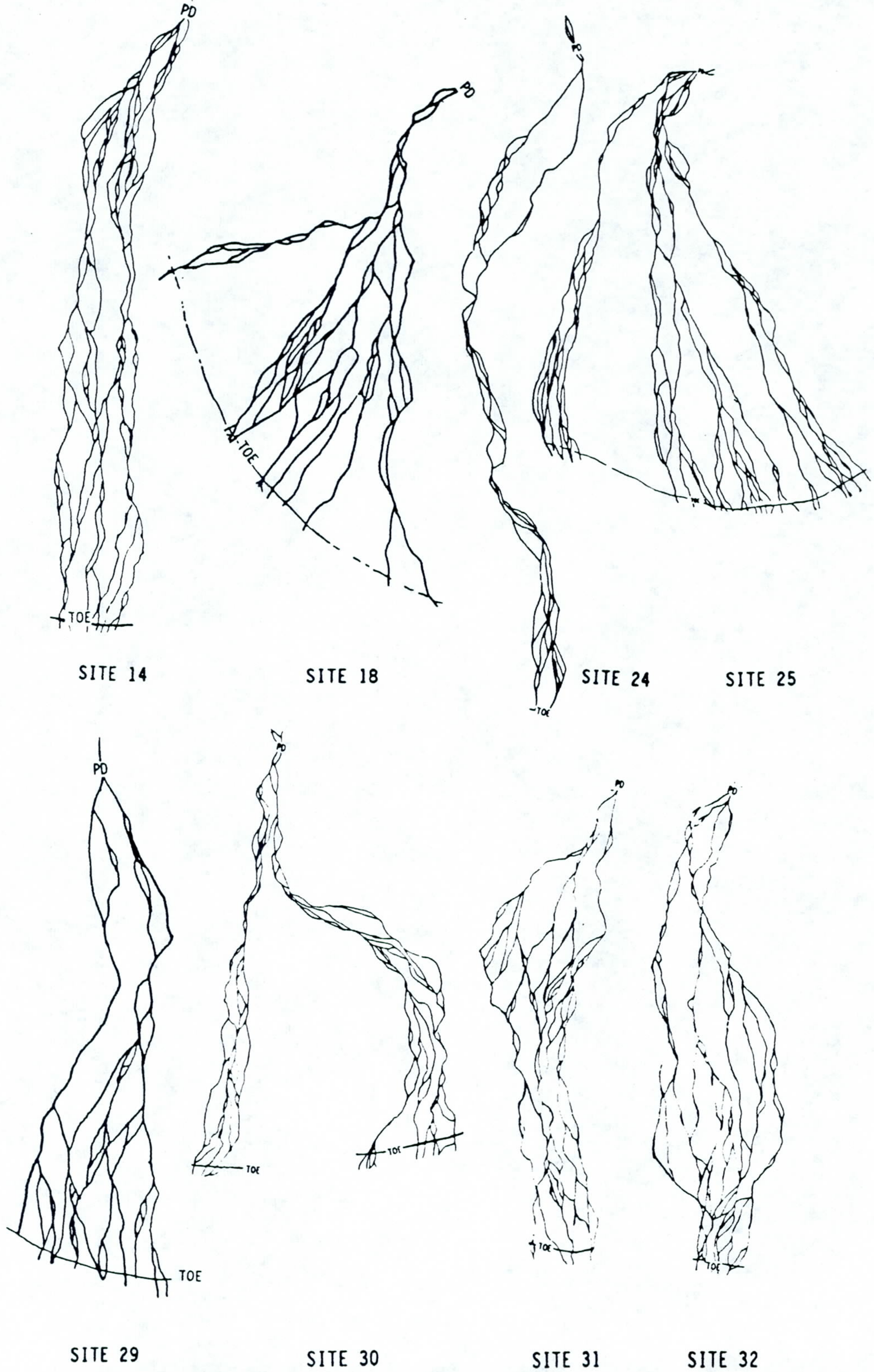
Expected $Nff = Nl * Fff$

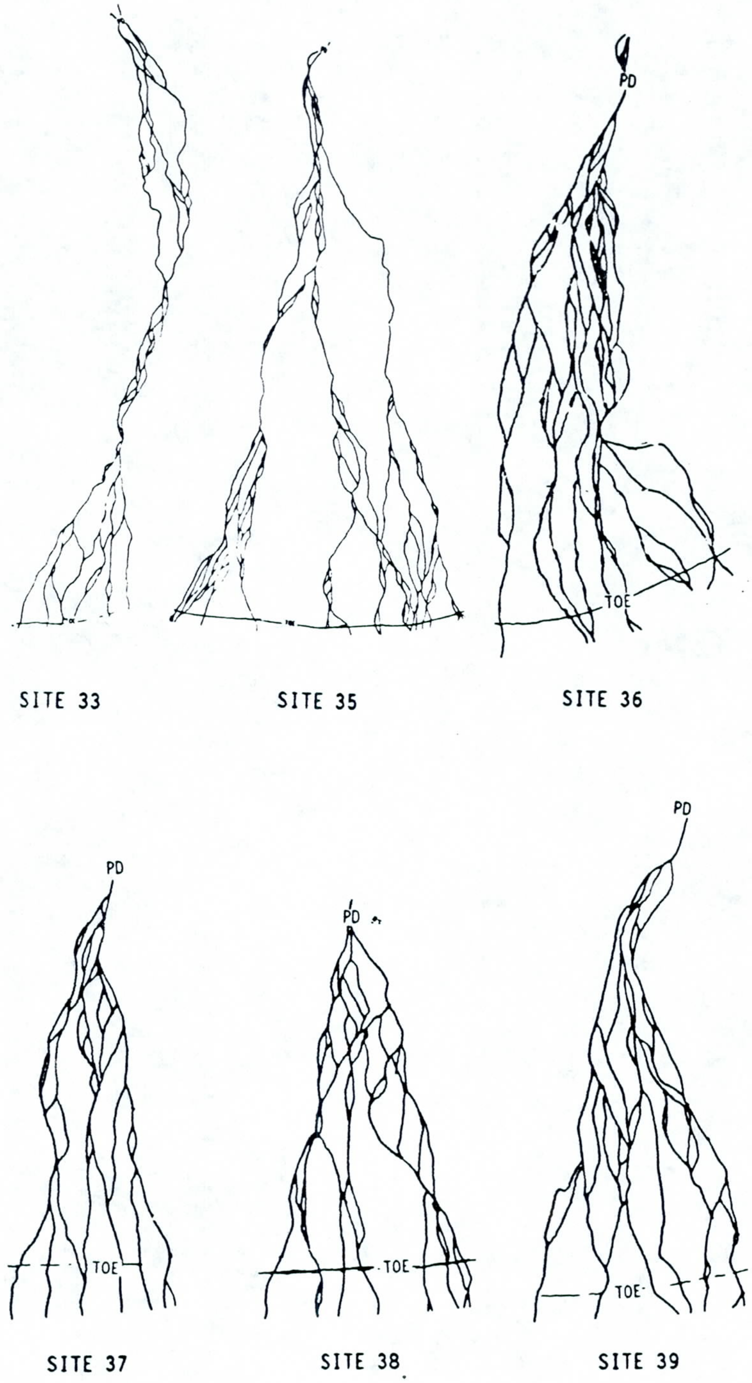
R = recombination factor, Nl = total number of links, Nj = the number of joins, Nf = the number of forks, No = the number of outlets, Nff = the number of FF links, Njf = the number of JF links, Njj = the number of JJ links, Nfj = the number of FJ links, Nfo = the number of FO links, Njo = the number of JO links, Fff = the expected frequency of FF links, Ffj = the expected frequency of FJ links, Ffo = the expected frequency of FO links, Fjf = the expected frequency of JF links, Fjj = the expected frequency of JJ links, Fjo = the expected frequency of JO links

APPENDIX F

DISTRIBUTARY NETWORKS

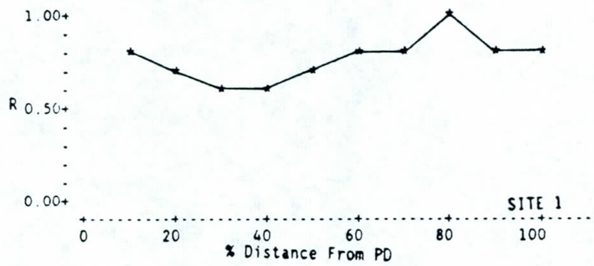

PD
PD
TOE
TOE
TOE
TOE
SITE 1
SITE 3
SITE 6
SITE 7
SITE 8
SITE 9
SITE 10

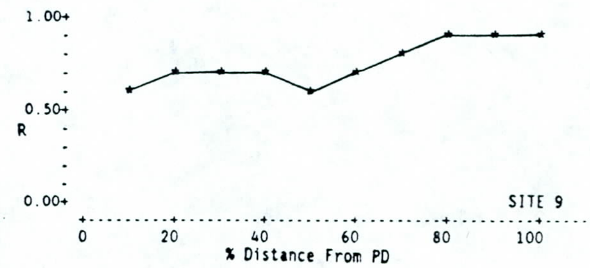

PD
TOE
SITE 14
PD
TOE
SITE 18
PD
TOE
SITE 24
SITE 25
PD
TOE
SITE 29
PD
TOE
SITE 30
PD
TOE
SITE 31
PD
TOE
SITE 32


PD
TOE
SITE 33
SITE 35
SITE 36
PD
PD
PD
TOE
TOE
TOE
SITE 37
SITE 38
SITE 39

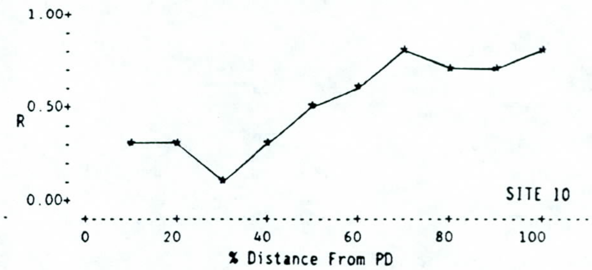
APPENDIX G

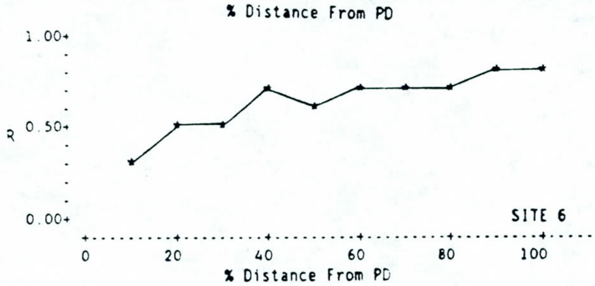
PLOTS OF RECOMBINATION FACTOR

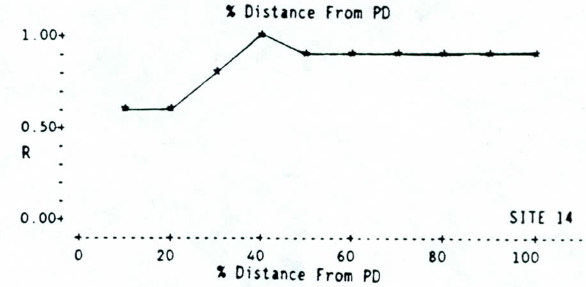

1.00+
R 0.50+
0.00+
SITE 1
0 20 40 60 80 100
% Distance From PD

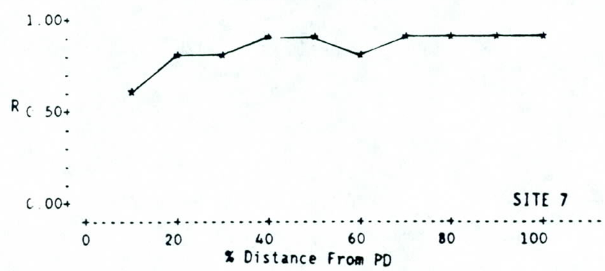

1.00+
0.50+
R
0.00+
SITE 9
0 20 40 60 80 100
% Distance From PD

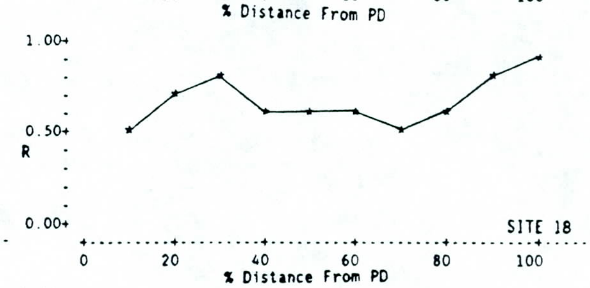

1.00+
R 0.50+
0.00+
SITE 3
0 20 40 60 80 100
% Distance From PD

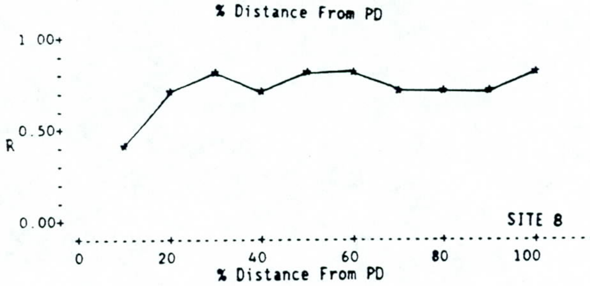

1.00+
0.50+
R
0.00+
SITE 10
0 20 40 60 80 100
% Distance From PD

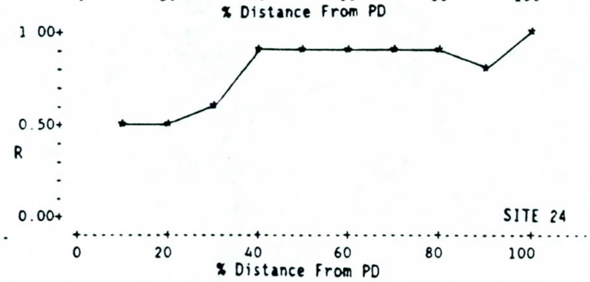

1.00+
R 0.50+
0.00+
SITE 6
0 20 40 60 80 100
% Distance From PD

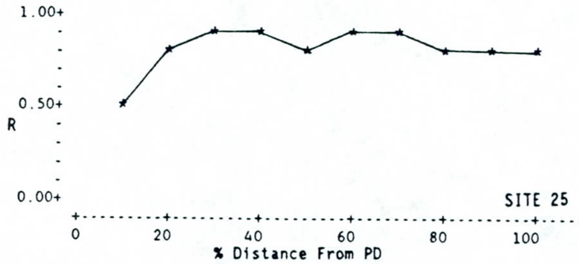

1.00+
0.50+
R
0.00+
SITE 14
0 20 40 60 80 100
% Distance From PD

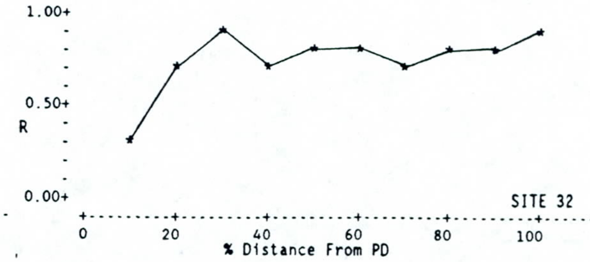

1.00+
R
SITE 7
0 20 40 60 80 100
% Distance From PD

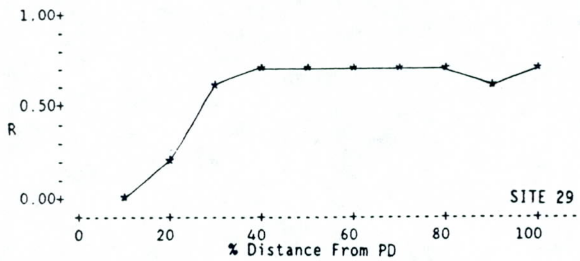

1.00+
0.50+
R
0.00+
SITE 18
0 20 40 60 80 100
% Distance From PD

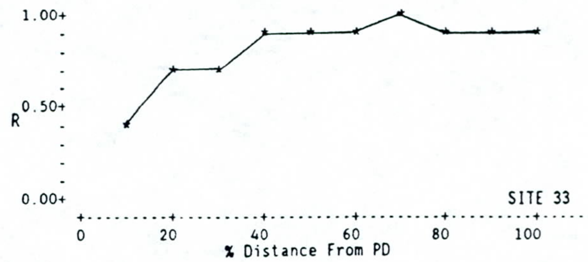

1.00+
0.50+
R
0.00+
SITE 8
0 20 40 60 80 100
% Distance From PD

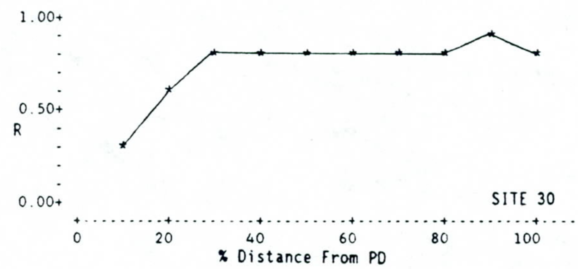

0.50+
R
0.00+
SITE 24
0 20 40 60 80 100
% Distance From PD

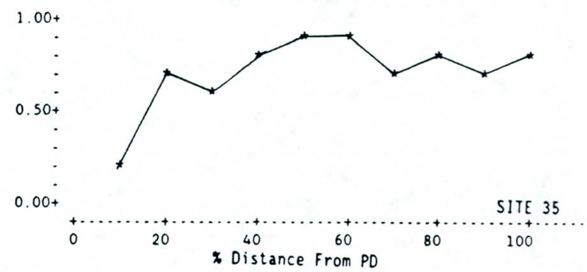

1.00+
0.50+
R
0.00+
SITE 25
0 20 40 60 80 100
% Distance From PD

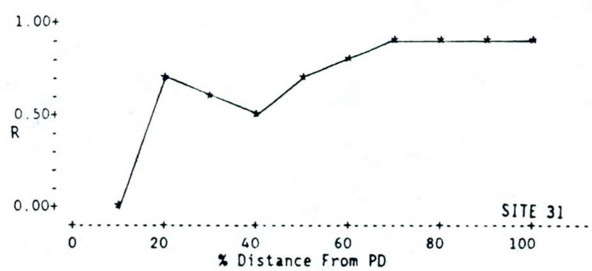

1.00+
0.50+
R
0.00+
SITE 32
0 20 40 60 80 100
% Distance From PD


1.00+
0.50+
R
0.00+
SITE 29
0 20 40 60 80 100
% Distance From PD


1.00+
0.50+
R
0.00+
SITE 33
0 20 40 60 80 100
% Distance From PD


1.00+
0.50+
R
0.00+
SITE 30
0 20 40 60 80 100
% Distance From PD

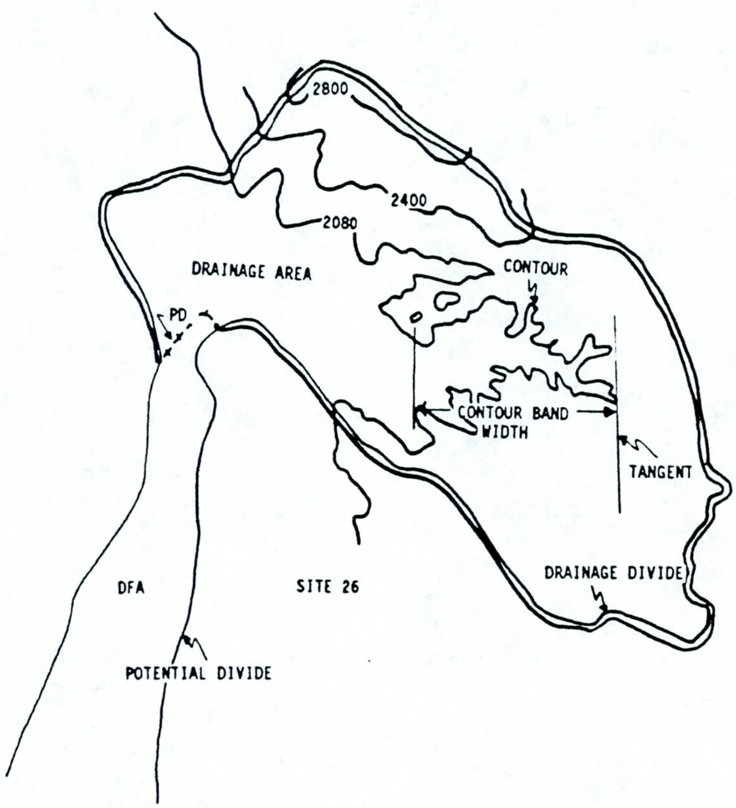

1.00+
0.50+
0.00+
SITE 35
0 20 40 60 80 100
% Distance From PD


1.00+
0.50+
R
0.00+
SITE 31
0 20 40 60 80 100
% Distance From PD

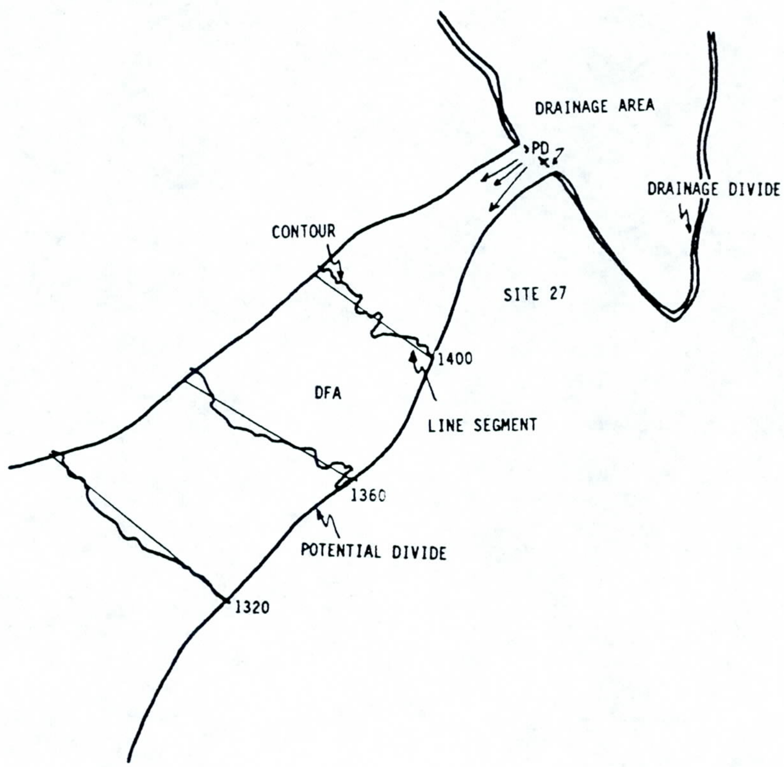
APPENDIX H

INDEPENDENT VARIABLES IN MULTIPLE REGRESSION MODEL

Average Contour Band Width of the Drainage Basin (K) - Choose four to six contours within the drainage area which are approximately uniformly spaced over the length of the basin. Choose the largest crenulations on each contour that are indicative of canyons. Ignore smaller crenulations within any canyon as well as the crenulations resulting from mountain ridges. Draw tangents to the peaks of the crenulations. The tangents should be parallel to each other. Measure the distance between the tangent of the crenulation that points the farthest upstream and the tangent of the crenulation that points the farthest downstream. The tangent is measured in inches. Compute the average of the measurements made on the four to six contours.



Average Contour Sinuosity of the DFA (H) - Choose four to six contours within the DFA which are approximately uniformly spaced over its length. Measure the length of a contour between the boundaries of the DFA. Measure the length of the line segment that parallels the contour and approximately splits the height of the crenulations. If the contour is sharply convex in plan view then choose a segment of the contour which is relatively straight. Compute the ratio of the length of the contour divided by the length of the line segment. Compute the average of the measurements made on the four to six contours.



APPENDIX I

DETAILS OF MULTIPLE REGRESSION

The regression equation is
C1 = 26.1 - 2.75 C9 - 0.491 C24

Predictor	Coef	Stdev	t-ratio	p
Constant	26.062	4.534	5.75	0.000
C9	-2.7470	0.5921	-4.64	0.000
C24	-0.4914	0.1466	-3.35	0.002

s = 1.880 R-sq = 40.4% R-sq(adj) = 37.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	86.323	43.161	12.21	0.000
Error	36	127.267	3.535		
Total	38	213.590			

SOURCE	DF	SEQ SS
C9	1	46.600
C24	1	39.723

Obs.	C9	C1	Fit	Stdev.Fit	Residual	St.Resid
1	1.49	5.000	7.229	0.440	-2.229	-1.22
2	1.45	6.000	7.338	0.439	-1.338	-0.73
3	1.46	7.000	7.311	0.439	-0.311	-0.17
4	1.18	10.000	9.063	0.407	0.937	0.51
5	1.34	10.000	9.606	0.471	0.394	0.22
6	1.18	9.000	8.080	0.466	0.920	0.50
7	2.26	8.000	6.587	0.444	1.413	0.77
8	1.54	5.000	9.548	0.519	-4.548	-2.52R
9	1.36	9.000	8.077	0.368	0.923	0.50
10	1.71	2.000	4.659	0.989	-2.659	-1.66 X
11	1.99	9.000	5.855	0.545	3.145	1.75
12	1.85	2.000	7.222	0.331	-5.222	-2.82R
13	1.11	8.000	9.747	0.482	-1.747	-0.96
14	1.14	9.000	8.190	0.474	0.810	0.45
15	1.30	9.000	7.750	0.447	1.250	0.68
16	1.38	5.000	6.548	0.667	-1.548	-0.88
17	1.63	10.000	8.809	0.391	1.191	0.65
18	1.29	9.000	8.269	0.382	0.731	0.40
19	1.29	9.000	8.269	0.382	0.731	0.40
20	1.39	9.000	7.503	0.440	1.497	0.82
21	1.94	9.000	7.466	0.337	1.534	0.83
22	1.26	10.000	8.843	0.377	1.157	0.63
23	1.32	10.000	8.678	0.357	1.322	0.72
24	3.75	3.000	4.951	1.229	-1.951	-1.37 X
25	1.32	9.000	9.661	0.479	-0.661	-0.36
26	1.37	9.000	9.524	0.461	-0.524	-0.29
27	1.30	9.000	9.716	0.486	-0.716	-0.39
28	1.09	10.000	10.784	0.678	-0.784	-0.45
29	1.78	9.000	8.397	0.375	0.603	0.33
30	2.52	2.000	5.382	0.607	-3.382	-1.90
31	2.05	8.000	7.656	0.397	0.344	0.19
32	2.21	8.000	7.216	0.438	0.784	0.43
33	3.09	7.000	4.307	0.864	2.693	1.61
34	2.03	9.000	7.219	0.360	1.781	0.96
35	1.75	10.000	8.480	0.377	1.520	0.83
36	1.36	10.000	9.551	0.464	0.449	0.25
37	1.47	9.000	9.249	0.429	-0.249	-0.14
38	1.75	9.000	8.480	0.377	0.520	0.28
39	2.37	8.000	6.777	0.494	1.223	0.67

R denotes an obs. with a large st. resid.
X denotes an obs. whose X value gives it large influence.

The regression equation is
C1 = 9.11 + 35.4 C6 - 2.33 C9 + 3.01 C14 - 0.424 C26 - 3.89 C34

Predictor	Coef	Stdev	t-ratio	p
Constant	9.110	1.081	8.43	0.000
C6	35.394	9.686	3.65	0.001
C9	-2.3288	0.5647	-4.12	0.000
C14	3.0109	0.9442	3.19	0.003
C26	-0.4244	0.1484	-2.86	0.008
C34	-3.889	1.530	-2.54	0.017

s = 1.634   R-sq = 62.5%   R-sq(adj) = 56.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	5	128.781	25.756	9.65	0.000
Error	29	77.391	2.669		
Total	34	206.171			

SOURCE	DF	SEQ SS
C6	1	5.065
C9	1	58.863
C14	1	15.334
C26	1	32.277
C34	1	17.242

Obs.	C6	C1	Fit	Stdev.Fit	Residual	St.Resid
1	0.029	5.000	6.887	0.570	-1.887	-1.23
2	0.027	6.000	6.817	0.568	-0.817	-0.53
3	0.026	7.000	6.734	0.577	0.266	0.17
4	0.138	10.000	10.232	0.651	-0.232	-0.15
5	0.081	10.000	11.054	0.672	-1.054	-0.71
6	0.110	9.000	9.508	0.512	-0.508	-0.33
7	0.068	5.000	6.822	0.634	-1.822	-1.21
8	0.078	2.000	5.147	0.704	-3.147	-2.13R
9	0.035	9.000	5.712	0.541	3.288	2.13R
10	0.053	2.000	2.249	1.318	-0.249	-0.26 X
11	0.064	8.000	8.190	0.554	-0.190	-0.12
12	0.077	9.000	8.839	0.593	0.161	0.11
13	0.093	9.000	7.528	0.637	1.472	0.98
14	0.056	5.000	7.040	0.540	-2.040	-1.32
15	0.025	10.000	8.546	0.636	1.454	0.97
16	0.071	9.000	8.218	0.468	0.782	0.50
17	0.141	9.000	9.748	0.613	-0.748	-0.49
18	0.092	9.000	8.471	0.708	0.529	0.36
19	0.097	9.000	6.763	0.649	2.237	1.49
20	0.090	10.000	8.375	0.459	1.625	1.04
21	0.143	10.000	9.296	0.633	0.704	0.47
22	0.105	3.000	3.941	1.142	-0.941	-0.81
23	0.039	9.000	10.153	0.714	-1.153	-0.78
24	0.128	9.000	8.455	0.792	0.545	0.38
25	0.056	9.000	8.445	0.504	0.555	0.36
26	0.055	10.000	10.028	0.691	-0.028	-0.02
27	0.130	9.000	11.245	0.880	-2.245	-1.63
28	0.124	2.000	5.596	0.672	-3.596	-2.42R
29	0.174	8.000	6.523	0.819	1.477	1.05
30	0.154	8.000	7.527	0.638	0.473	0.31
31	0.069	7.000	5.441	0.887	1.559	1.14
32	0.084	10.000	8.723	0.422	1.277	0.81
33	0.095	9.000	8.836	0.326	0.164	0.10
34	0.095	9.000	7.897	0.315	1.103	0.69
35	0.110	8.000	7.017	0.658	0.983	0.66

R denotes an obs. with a large st. resid.
X denotes an obs. whose X value gives it large influence.

The regression equation is
C1 = 8.44 - 0.537 C3 + 14.9 C6 - 1.06 C9 + 1.28 C14

Predictor	Coef	Stdev	t-ratio	p
Constant	8.4361	0.8927	9.45	0.000
C3	-0.5372	0.2356	-2.28	0.030
C6	14.881	4.824	3.09	0.004
C9	-1.0628	0.4497	-2.36	0.025
C14	1.2833	0.4670	2.75	0.010

s = 1.107 R-sq = 48.0% R-sq(adj) = 41.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	33.902	8.475	6.91	0.000
Error	30	36.784	1.226		
Total	34	70.686			

SOURCE	DF	SEQ SS
C3	1	13.338
C6	1	7.535
C9	1	3.769
C14	1	9.260

Obs.	C3	C1	Fit	Stdev.Fit	Residual	St.Resid
1	1.66	5.000	6.999	0.392	-1.999	-1.93
2	1.64	6.000	7.049	0.394	-1.049	-1.01
3	3.26	7.000	6.143	0.633	0.857	0.94
4	0.90	10.000	9.178	0.398	0.822	0.80
5	0.16	10.000	9.317	0.270	0.683	0.64
6	0.21	9.000	9.193	0.388	-0.193	-0.19
7	0.37	8.000	8.295	0.453	-0.295	-0.29
8	0.88	5.000	7.575	0.372	-2.575	-2.47R
9	0.61	9.000	8.846	0.305	0.154	0.14
10	0.07	9.000	7.776	0.429	1.224	1.20
11	0.28	8.000	9.054	0.316	-1.054	-0.99
12	0.60	9.000	9.300	0.288	-0.300	-0.28
13	0.93	9.000	8.339	0.306	0.661	0.62
14	2.26	5.000	7.006	0.411	-2.006	-1.95
15	0.17	10.000	8.395	0.351	1.605	1.53
16	1.39	9.000	8.654	0.291	0.346	0.32
17	0.19	9.000	9.522	0.448	-0.522	-0.52
18	0.46	9.000	9.626	0.288	-0.626	-0.59
19	1.52	9.000	7.587	0.317	1.413	1.33
20	2.34	10.000	7.600	0.400	2.400	2.32R
21	0.21	10.000	9.611	0.435	0.389	0.38
22	1.22	9.000	8.504	0.354	0.496	0.47
23	1.00	9.000	9.888	0.396	-0.888	-0.86
24	0.37	9.000	9.105	0.283	-0.105	-0.10
25	0.50	10.000	9.490	0.377	0.510	0.49
26	0.69	9.000	9.646	0.364	-0.646	-0.62
27	3.35	8.000	7.663	0.712	0.337	0.40
28	2.05	8.000	8.433	0.532	-0.433	-0.45
29	0.35	7.000	7.406	0.709	-0.406	-0.48
30	0.28	9.000	7.840	0.388	1.160	1.12
31	0.40	10.000	10.621	0.745	-0.621	-0.76 X
32	0.38	10.000	9.237	0.242	0.763	0.71
33	0.24	9.000	9.090	0.267	-0.090	-0.08
34	0.20	9.000	8.790	0.293	0.210	0.20
35	0.69	8.000	8.224	0.425	-0.224	-0.22

R denotes an obs. with a large st. resid.
X denotes an obs. whose X value gives it large influence.

C1 - (B) the degree of flood hazard
C3 - (DD) the ratio of the area of the DFA divided by the area of the drainage basin
C6 - (MRDA) the mean relief ratio of the drainage basin
C9 - (H) the average contour sinuosity of the DFA
C14 - (K) the average contour band width of the drainage basin
C24 - (P) the 10-year 24-hour precipitation
C26 - (MAF) the mountainous area factor
C34 - (CC) the contour band width just downstream of the PD

APPENDIX J

CHARACTERISTICS OF 39 DFAS

SITE NO: 1 Type and Rank of Flood Hazard: C/5

Drainage Basin

Area (sq.mi.): 3.89 Mean Basin Elevation (ft.): 2590
Basin Shape: 8.47 Total Relief (ft.): 885
Mean Relief Ratio: .0292 Ruggedness Number: .0850

Description: The drainage basin is on a pediment. There are several deeply incised tributary channels. There are scattered trees with bushes and grass. The pediment is sparsely covered with a thin veneer of soil.

Primary Diffluence (PD)

100 Year Discharge (cfs): 4380
Estimated Average Channel Velocity of Q100 (ft./sec.): 8+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0210

Description: The flow is confined to several channels between two inselbergs that are approximately 4000 ft. apart. The PD is located in a transitional area between a pediment and an alluvial plain.

Distributary Flow Area (DFA)

Area (sq.mi.): 6.46 Average Slope of Main Channel: .0190
Total Relief (ft.): 420 Mean Relief Ratio: .0198

Topography: The contours are slightly convex (in plan view). The topo. map shows divergent stream channels as depicted by map stream symbols. The texture is uniform for at least 2 mi. downstream of the PD. At the upper end of the DFA the slope of the wash flattens and then steepens. In places the channels are separated by high ridges and channels divide and combine at many locations over the entire surface.
Geology: A piedmont plain composed of a pediment and an alluvial plain with mountains on the right (north) side and a DFA on the left side.
Soil Color: The soils in the active channels are slightly lighter than the soils on ridges. Approximately one half of the DFA is light colored soil. Areas with light soils are wider where channels divide and combine.
Desert Varnish: Not apparent.
Vegetation: There is an increase in the density of vegetation along active channels where soils are lighter in color.

General Characteristics

Overall profile: The slope profile of the wash is generally uniform with a slight flattening at the lower end. On the alluvial plain there are minor irregularities in slope at local diffluences where there is flattening and steepening of slope.

Lower Distributary Flow Area: At the lower end of the DFA the channels become entrenched and tributary before entering Cave Creek which acts as a base level stream.

SITE NO: 2 Type and Rank of Flood Hazard: C/6

Drainage Basin

Area (sq.mi.): 6.10 Mean Basin Elevation (ft.): 2710
Basin Shape: 6.99 Total Relief (ft.): 940
Mean Relief Ratio: .0273 Ruggedness Number: .0721

Description: The drainage basin is on a pediment. There are several deeply incised tributary channels. There are scattered trees with bushes and grass. The pediment is sparsely covered with a thin veneer of soil.

Primary Diffluence (PD)

100 Year Discharge (cfs): 5440
Estimated Average Channel Velocity of Q100 (ft./sec.): 7
Estimated Froude Number for Q100: less than 1
Slope of Main Channel: .0222

Description: The flow is confined between an inselberg and a ridge which are approximately 2200 ft. apart. The PD is located in a transitional area between the pediment and an alluvial plain.

Distributary Flow Area (DFA)

Area (sq.mi.): 10.0 Average Slope of Main Channel: .0181
Total Relief (ft.): 640 Mean Relief Ratio: .0183

Topography: The contours are slightly convex (plan view). The topo. map shows divergent stream channels as depicted by map stream symbols. The texture is uniform for at least 2 mi. downstream of the PD. At the upper end of the DFA the slope of the wash is constant for about 0.2 mi. where there is then a slight flattening and steepening of slope. Channels are separated by low ridges and scattered high ridges. Channels divide and combine at many locations over the entire surface.
Geology: A piedmont plain composed of a pediment and an alluvial plain and bounded by DFAs on both sides.
Soil Color: The soils in the active channels are slightly lighter than the soils on ridges. Approximately one half of the DFA is light colored soil. Areas with light soils are wider where channels divide and combine.
Desert Varnish: Not apparent.
Vegetation: There is an increase in the density of the vegetation along active channels where soils are lighter colored.

General Characteristics

Overall profile: The slope profile of the wash is rather uniform with irregularities in slope to about the middle of the DFA. Below this point the slope is concave.
Lower Distributary Flow Area: At the lower end of the DFA the channels become entrenched and tributary near Cave Creek and Union Hills. Cave Creek acts as a base level stream but to a lesser degree than at site no. 1.

SITE NO: 3 Type and Rank of Flood Hazard: C/7

Drainage Basin

Area (sq.mi.): 2.79
Basin Shape: 15.1
Mean Relief Ratio: .0256
Mean Basin Elevation (ft.): 2660
Total Relief (ft.): 880
Ruggedness Number: .0997

Description: The drainage basin is on a pediment. There are several deeply incised tributary channels. There are scattered trees with bushes and grass. The pediment is sparsely covered with a thin veneer of soil.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3450
Estimated Average Channel Velocity of Q100 (ft./sec.): 5
Estimated Froude Number for Q100: less than 1
Slope of Main Channel: .0166

Description: The flow is confined between two ridges which are about 2000 ft. apart. The ridges lie between two inselbergs that are about 1 mi. apart. The PD is located in a transitional area between the pediment and an alluvial plain.

Distributary Flow Area (DFA)

Area (sq.mi.): 9.11
Total Relief (ft.): 750
Average Slope of Main Channel: .0173
Mean Relief Ratio: .0173

Topography: The contours are slightly convex (plan view). The topo. map shows divergent stream channels as depicted by map stream symbols. The texture is uniform for at least 2 mi. downstream of the PD. At the upper end of the DFA the slope of the wash steepens. Channels are separated by low ridges and scattered high ridges. Channels divide and combine at many locations over the entire surface.
Geology: A piedmont plain composed of a pediment and an alluvial plain bounded by DFAs on both sides.
Soil Color: The soils in the active channels are slightly lighter than the soils on the ridges. Approximately one half of the DFA is light colored soil. Areas with light soils are wider where channels divide and combine.
Desert Varnish: Not apparent.
Vegetation: There is an increase in the density of vegetation along active channels where soils are lighter colored.

General Characteristics

Overall profile: The slope profile of the wash is rather uniform with irregularities in slope to about the middle of the DFA. Below this point the slope is concave.

Lower Distributary Flow Area: The channels become entrenched at the lower end of the DFA in the vicinity of Union Hills. At this location they flow around the edges of several bedrock hills.

SITE NO: 4 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): .479
Mean Basin Elevation (ft.): 2030
Basin Shape: 3.20
Total Relief (ft.): 902
Mean Relief Ratio: .138
Ruggedness Number: .247

Description: The drainage area consists of mountains and well cemented old fan deposits. The basin has scattered trees along the washes with some bushes and grass. There is very little soil on the steep mountain slopes. There is a single, deeply entrenched channel upstream of the PD.

Primary Diffluence (PD)

100 Year Discharge (cfs): 885
Estimated Average Channel Velocity of Q100 (ft./sec.): 8+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0243

Description: The PD is located at an intersection point 4000 ft. downstream of the mountain front.

Distributary Flow Area (DFA)

Area (sq.mi.): .429
Average Slope of Main Channel: .0187
Total Relief (ft.): 100
Mean Relief Ratio: .0193

Topography: The contours are convex (plan view). Map stream symbols diverge at the PD. The slope profile of the wash flattens and steepens just below the PD. There are two small distinct channels on each side of the DFA. A general ridge is located on the right center of the DFA and there is a relatively steep slope to the left of the ridge. Flood flow is unconfined across the DFA.

Geology: Inset fan on old fan.

Soil Color: There is a distinct color change from the dark red surface of the old fan to the light colored soil of the DFA.

Desert Varnish: Rocks on the old fan surface, that are above and on either side of the DFA, are covered with desert varnish.

Vegetation: There is a distinct increase in the size and density of vegetation on the DFA. The vegetation on the right side of the DFA is larger and more dense than the vegetation on the left side.

General Characteristics

Overall profile: The slope profile of the wash in the DFA is slightly concave.

Lower Distributary Flow Area: About 1.5 mi. below the PD the flow becomes tributary.

SITE NO: 5 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): 10.8	Mean Basin Elevation (ft.): 4660
Basin Shape: 5.39	Total Relief (ft.): 3265
Mean Relief Ratio: .0812	Ruggedness Number: .189

Description: The basin consists of mountains and weakly cemented valley fill deposits. There are trees and brush in the mountain area and along a few large stream channels. The drainage basin has a few wide-flat tributary channels that are braided. Near the mouth of the basin there is a single large braided channel about 1000 ft. wide.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3560
Estimated Average Channel Velocity of Q100 (ft./sec.): 8
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .0287

Description: The Whetstone Mountains are about 10 mi. upstream of the PD. The PD is located at a narrows about 0.5 mi. upstream of where the ridges of the valley fill deposits abruptly end. The channel at the PD is deeply incised in the valley fill deposits.

Distributary Flow Area (DFA)

Area (sq.mi.): 1.68	Average Slope of Main Channel: .0250
Total Relief (ft.): 305	Mean Relief Ratio: .0247

Topography: Downstream of the PD the contours become convex and the channel changes from a braided appearance to a distributary flow appearance in a reach about 0.5 mi. long. There is a general divergence of map stream symbols below the PD. The slope profile of the wash is constant below the PD with a few irregularities. Channels in the upper part of the DFA are small and can erode easily. Flood flow is unconfined and can spread over the entire DFA.
Geology: A major source of material for the DFA is the valley fill deposits.
Soil Color: The color of the more active channels is lighter than the surrounding valley fill deposits. The color change is not distinct.
Desert Varnish: Not apparent.
Vegetation: There is a very distinct increase in the size and density of the vegetation on the DFA.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave with a few irregularities.
Lower Distributary Flow Area: The San Pedro River acts as a base level stream and forms the boundary at the toe of the DFA. Channels near the river are filled with eroded material from the valley fill deposits. In contrast, the channel to the right of the DFA is deeply entrenched in response to deep entrenchment of the channel of the San Pedro River.

SITE NO: 6 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 8.04
Basin Shape: 1.17
Mean Relief Ratio: .110
Mean Basin Elevation (ft.): 2670
Total Relief (ft.): 1784
Ruggedness Number: .119

Description: The drainage basin consists of mountains, pediment, and old fan. Several confined tributary streams join about 0.2 mi. upstream of the PD. The channel of one of the tributaries is wide and braided. The mountains are sparsely covered with bushes and trees. Channels in the piedmont area are lined with scattered trees. The ridges between the washes are covered with small bushes.

Primary Diffluence (PD)

100 Year Discharge (cfs): 6150
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0329

Description: Flow is constricted by a high ridge of an old fan remnant on the right side and by a mountain on the left side. The PD is at a point on the mountain front about 1 mi. downstream from the pediment. Flood flow is confined to the deeply entrenched channel.

Distributary Flow Area (DFA)

Area (sq.mi.): 1.71
Total Relief (ft.): 510
Average Slope of Main Channel: .0293
Mean Relief Ratio: .0312

Topography: Contours change from concave to convex at the PD. Map stream symbols diverge about 0.3 mi. downstream of the PD. The texture is uniform in the DFA. The slope profile of the wash shows a flattening and steepening just below the PD. There are several small channels separated by low ridges. The entire DFA is subject to inundation during major flooding.
Geology: The DFA is bounded on the left by mountains and on the right side by old fan remnants. It appears to be an inset fan.
Soil Color: The lightest soils are in the active channels.
Desert Varnish: Undefined.
Vegetation: Scattered trees are along the active channels.

General Characteristics

Overall profile: In the upper DFA there is a general steepening in the slope profile of the wash for about 4000 ft. downstream of the PD. The profile of the middle and lower DFA is concave.

Lower Distributary Flow Area: The contours change from concave to convex (plan view) at the toe and the channels become tributary. Downstream of the toe there is a large area of unconsolidated, slightly dissected alluvium.

SITE NO: 7 Type and Rank of Flood Hazard: D/8

Drainage Basin

Area (sq.mi.): 56.0 Mean Basin Elevation (ft.): 2060
Basin Shape: 2.32 Total Relief (ft.): 2159
Mean Relief Ratio: .0359 Ruggedness Number: .0546

Description: The drainage basin consists of mountains and old alluvial fans. A large braided channel (with two small tributaries) narrows at the mouth of the basin. There is sparse vegetation on the mountains. Trees grow along defined channels and bushes are on ridges of the old fans. The mountains have little soil.

Primary Diffluence (PD)

100 Year Discharge (cfs): 8200
Estimated Average Channel Velocity of Q100 (ft./sec.): 13+
Estimated Froude Number for Q100: greater than or equal to 1
Slope of Main Channel: .0108

Description: The PD is at the mountain front with a steep mountain slope forming the right bank and an alluvial slope on the left. There is some entrenchment, but with minor filling of the channel bed flood water of the 100 year flood can spread laterally into an adjacent DFA.

Distributary Flow Area (DFA)

Area (sq.mi.): 20.7 Average Slope of Main Channel: .0102
Total Relief (ft.): 480 Mean Relief Ratio: .0108

Topography: The upper DFA has both concave and convex contours (plan view). The main channel is generally well incised in the upper DFA. There are several small distributary channels to the left of the main channel that are separated by high-wide ridges that are above the level of the 100 year flood. Map stream symbols diverge about 0.5 mi. downstream of the PD. Just below the PD the slope profile of the wash flattens and then steepens.
Geology: The DFA is on dissected old alluvial fan deposits.
Soil Color: The soils of the active channels are light colored. The darker color of inactive areas is the result of desert varnish.
Desert Varnish: As seen from the air, there is a very dark desert varnish on the high ridges. In most places there is a distinct boundary between the dark ridges and the light colored active flow areas. In other areas there is a gradual transition of the color darkness indicating areas have experienced infrequent flooding.
Vegetation: Trees are dense along active channels. There are scattered bushes on the ridges. Overall, the area has very little vegetation.

General Characteristics

Overall profile: The slope profile of the wash is generally uniform with small irregularities.
Lower Distributary Flow Area: Tyson Wash acts as a base level stream about 9 mi. downstream of the PD.

SITE NO: 8 Type and Rank of Flood Hazard: C/5

Drainage Basin

Area (sq.mi.): 9.24 Mean Basin Elevation (ft.): 1240
Basin Shape: 1.75 Total Relief (ft.): 1453
Mean Relief Ratio: .0685 Ruggedness Number: .0905

Description: The drainage basin is surrounded by mountains, and it also contains a large bowl-like area of old fan deposits. There are many tributary channels (with a few distributary channels that commonly rejoin) that tend to converge at the basin mouth but remain separated. There is braiding along some of the channels. The mountains have very little vegetation, and the old fan deposits have sparse vegetation. There are scattered trees along active washes.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3340
Estimated Average Channel Velocity of Q100 (ft./sec.): 5
Estimated Froude Number for Q100: greater than or equal to 1
Slope of Main Channel: .0133

Description: The PD is at the mountain front where the contours change from concave to convex (plan view). The PD is 7000 ft. wide and consists of several channels and is bounded by mountains on the left and an inselberg on the right. During major flooding there will probably be large areas of dry land of dry land across the PD.

Distributary Flow Area (DFA)

Area (sq.mi.): 8.17 Average Slope of Main Channel: .0117
Total Relief (ft.): 200 Mean Relief Ratio: .0121

Topography: Contours are convex and become straight along parts of the toe. There are numerous separated streams that divide and combine. There are a few inselbergs in the DFA and most of the ridges are low. The slope profile of the wash shows a slight flattening and then steepening just below the PD.
Geology: The DFA is on old fan deposits.
Soil Color: The soils are lighter along the active channels.
Desert Varnish: Undefined.
Vegetation: There are trees along active channels with scattered bushes along the ridges.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave with small irregularities at local diffluences.

Lower Distributary Flow Area: Rainbow Wash and the Gila River act as the base level streams. Near the toe the numerous small channels enter a few larger channels.

SITE NO: 9 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 58.4 Mean Basin Elevation (ft.): 3310
Basin Shape: 3.19 Total Relief (ft.): 3127
Mean Relief Ratio: .0434 Ruggedness Number: .0775

Description: The upper end of the drainage basin is mountainous. The lower end is a pediment with two small inselbergs near the apex. Channels on the pediment are tributary and well entrenched and tend to flow parallel to each other. The mountains are sparsely covered with vegetation but the pediment is covered with trees and bushes. The texture increases upstream of the PD.

Primary Diffluence (PD)

100 Year Discharge (cfs): 7580
Estimated Average Channel Velocity of Q100 (ft./sec.): 12
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0108

Description: The PD is in a zone where the contours change from straight to convex (plan view). The PD is near the boundary of the pediment and the alluvial plain, and it is about 8 mi. downstream of the mountain front. Flood water is confined to one incised channel.

Distributary Flow Area (DFA)

Area (sq.mi.): 35.9 Average Slope of Main Channel: .0111
Total Relief (ft.): 530 Mean Relief Ratio: .0115

Topography: The contours change from convex on the upper DFA to straight (plan view) on the lower DFA. Several defined stream channels divide and combine over the entire area. There are several long wide ridges that are above the level of the 100 year flood. The texture is uniform in the DFA. The slope profile of the wash flattens and steepens just below the PD.
Geology: There may be some old fan deposits near the boundary of the pediment and the DFA.
Soil Color: In the lower DFA the soils are distinctly lighter than the surrounding soils. In the upper area the soils are lighter along the defined channels.
Desert Varnish: Undefined.
Vegetation: Trees are dense along active channels and on the upper DFA. There are scattered trees along active channels in the lower DFA with dense trees at the toe of the DFA along McClellan Wash.

General Characteristics

Overall profile: The slope profile of the wash has many irregularities and is generally uniform to slightly concave.
Lower Distributary Flow Area: McClellan Wash acts as a base level stream. During major flooding most of the water will enter McClellan Wash and will not remain in Brady Wash which exits the DFA to the north.

SITE NO: 10 Type and Rank of Flood Hazard: A/2

Drainage Basin

Area (sq.mi.): 1.37 Mean Basin Elevation (ft.): 2240
Basin Shape: 1.64 Total Relief (ft.): 616
Mean Relief Ratio: .0779 Ruggedness Number: .0996

Description: The drainage basin consists of mountains. There are trees along washes and scattered trees and bushes along mountain slopes. Two large incised tributaries join about 0.1 mi. upstream of the PD.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1420
Estimated Average Channel Velocity of Q100 (ft./sec.): 9+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0140

Description: The PD is about 0.5 mi. downstream of the mountain front. A single confined channel divides into two distinct confined channels. The channels are wide, flat, are composed of loose sand, and are subject to scour and fill.

Distributary Flow Area (DFA)

Area (sq.mi.): 1.38 Average Slope of Main Channel: .0119
Total Relief (ft.): 160 Mean Relief Ratio: .0126

Topography: The contours change from concave upstream of the PD to convex in the upper DFA and then back to concave in the middle DFA. There is no map stream symbol delineating the distributary channel to the right. The slope profile of the wash shows a flattening and steepening along the main channel just below the PD. In the upper end of the DFA the flood water is confined in two distributary channels. About 0.3 mi. downstream of the PD there is a small active fan.
Geology: The upper DFA is on weakly to firmly cemented valley fill. The lower DFA is on old fan deposits.
Soil Color: The soil color is distinctly lighter along the active channels.
Desert Varnish: There are boulders with desert varnish on surrounding areas but they are unrelated to this PD.
Vegetation: Trees are dense along active channels with scattered trees and bushes along ridges.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave. There is a distinct flattening and then steepening about 0.3 mi. below the PD at the diffluence of a small active fan.

Lower Distributary Flow Area: Mountains are located near the toe of the DFA about 2.5 mi. downstream of the PD.

SITE NO: 11   Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 7.65   Mean Basin Elevation (ft.): 2140
Basin Shape: 2.44   Total Relief (ft.): 793
Mean Relief Ratio: .0348   Ruggedness Number: .0543

Description: The drainage basin consists of mountains, slope wash and old fan deposits. There are scattered bushes and trees throughout the basin. Two large confined channels join at the PD to form a wide flat channel.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3050
Estimated Average Channel Velocity of Q100 (ft./sec.): 5
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .00800

Description: The PD is located at a mountain pass about 0.5 mi. upstream of the mountain front. The present channel is confined by a bedrock mountain on the right side and by old alluvium on the left. The channel is about 500 ft. wide and is slightly entrenched.

Distributary Flow Area (DFA)

Area (sq.mi.): .549   Average Slope of Main Channel: .0105
Total Relief (ft.): 80   Mean Relief Ratio: .0107

Topography: The PD is in a reach of the wash where the contours change from concave to convex. The map stream symbols diverge about 1500 ft. downstream of the PD. The slope profile of the wash shows a gentle flattening and then an abrupt steepening just below the PD. The floodwater spills over the left bank of the main channel. The channels are separated by low ridges except for one high ridge in the DFA. The channels are composed of coarse sand with scattered clusters of large angular boulders that may have been deposited by a debris flow.
Geology: The DFA is an inset fan.
Soil Color: The soils in the DFA are lighter than the soils of the surrounding old fan.
Desert Varnish: Undefined.
Vegetation: The relative density of the vegetation is much greater in the DFA than for the surrounding area.

General Characteristics

Overall profile: The slope profile of the wash shows a flattening and then a steepening with about 5000 ft. of fairly uniform slope to the Santa Cruz River.

Lower Distributary Flow Area: The Santa Cruz River acts a base level stream.

SITE NO: 12 Type and Rank of Flood Hazard: A/2

Drainage Basin

Area (sq.mi.): 3.17
Mean Basin Elevation (ft.): 3960
Basin Shape: 3.38
Total Relief (ft.): 910
Mean Relief Ratio: .0526
Ruggedness Number: .0968

Description: The drainage basin consists of mountains and weakly cemented valley fill deposits. There are sparse trees on mountain slopes and scattered trees on ridges. There are dense thickets of vegetation along the major channel which is braided.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2060
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0232

Description: The PD is about 2 mi. downstream of the mountain front. The capacity of the channel at the PD is many times the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): .682
Average Slope of Main Channel: .0197
Total Relief (ft.): 230
Mean Relief Ratio: .0261

Topography: The contours remain concave below the PD. The map stream symbols diverge at the PD. Below the PD there are two distinct, well entrenched distributary channels separated by a 30 ft. high interfluve which is a few hundred feet wide. The flow in the two distributary channels is confined until it reaches the floodplain of the San Pedro River where it spreads over two small alluvial fans. It appears that two independent tributary channels laterally migrated and joined to form the distributary system. The slope of the wash flattens and then steepens just below the PD.
Geology: The diffluence is located in weakly cemented valley fill deposits.
Soil Color: The active channels are distinctly lighter than the surrounding undisturbed soils.
Desert Varnish: Not apparent.
Vegetation: There is a marked increase in the density of the vegetation along active channels.

General Characteristics

Overall profile: The slope profile of the wash is uniform with several irregularities and a distinct flattening and then steepening at the small fans on the floodplain of the base level stream.

Lower Distributary Flow Area: The San Pedro River acts as a base level stream.

SITE NO: 13 Type and Rank of Flood Hazard: D/8

Drainage Basin

Area (sq.mi.): 5.46
Mean Basin Elevation (ft.): 3150
Basin Shape: 6.64
Total Relief (ft.): 2022
Mean Relief Ratio: .0636
Ruggedness Number: .164

Description: The drainage basin consists of mountains and old fan deposits. The old fan surface is densely covered with trees and brush. The mountains are covered with scattered trees and brush. There is a single channel entrenched in the old fan surface with numerous braids and two large anabranches.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2630
Estimated Average Channel Velocity of Q100 (ft./sec.): 7+
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .0231

Description: The PD is located on the old fan surface about 2.6 mi. downstream of the mountain front. The capacity of the channel is several times the amount of the 100 year flood. The channel is flat and about 400 ft. wide and covered with scattered trees and brush.

Distributary Flow Area (DFA)

Area (sq.mi.): 1.52
Average Slope of Main Channel: .0290
Total Relief (ft.): 400
Mean Relief Ratio: .0289

Topography: The contours change from concave upstream of the PD to straight and then to convex downstream of the PD. The map stream symbols diverge at the PD. The texture of the DFA is uniform and the texture of the old fan surface (to the southeast of the DFA) decreases in the upslope direction. At the PD the texture increases for about 1.5 mi. upstream. There are several channels separated by low ridges. It appears that the percentage of floodflow in the channels can easily change. The slope profile of the wash flattens and then steepens just below the PD.
Geology: The DFA is an inset fan and there are DFAreas on both sides.
Soil Color: The soils in the active channels are lighter than the surrounding old fan deposits and the interfluves.
Desert Varnish: None.
Vegetation: There is a marked increase in the density of the vegetation along the active channels and a gradual increase in the density of vegetation from the old fan surface to the DFA.

General Characteristics

Overall profile: The slope profile of the wash upstream of the PD is uniform. Just below the PD the slope of the wash steepens and remains uniform to the toe of the DFA.
Lower Distributary Flow Area: The Santa Cruz River acts as a base level stream.

SITE NO: 14 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 3.77
Basin Shape: 4.83
Mean Relief Ratio: .0767
Mean Basin Elevation (ft.): 3440
Total Relief (ft.): 1722
Ruggedness Number: .169

Description: The drainage basin consists of mountains. There is dense vegetation along the braided channel in the canyon. The mountains have sparse trees and bushes.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2230
Estimated Average Channel Velocity of Q100 (ft./sec.): 9
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .0356

Description: The PD is about 1000 ft. downstream of the canyon mouth. The channel is about 200 ft. wide and flat with a capacity at least twice the 100 year flood.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.26
Total Relief (ft.): 740
Average Slope of Main Channel: .0310
Mean Relief Ratio: .0322

Topography: The contours change from concave above the PD to convex and then straight below the PD. Map stream symbols diverge about 2000 ft. below the PD. The texture is uniform on the DFA. The slope of the wash flattens and then steepens just below the PD. There are several channels separated by low ridges. The percentage of flow in each channel can change greatly.

Geology: The DFA has DFAreas on both sides.

Soil Color: The soils in the active channels are lighter colored than those of the surrounding old fan deposits and interfluves.

Desert Varnish: None.

Vegetation: There is a marked increase in the density of the vegetation along the active channels and a gradual increase in the density of vegetation from the old fan surface to the DFA.

General Characteristics

Overall profile: The slope profile of the wash is concave with a mild steepening for about 1 mi. below the PD which is followed by a uniform slope to the toe.

Lower Distributary Flow Area: The Santa Cruz River acts as a base level stream.

SITE NO: 15 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): .989
Mean Basin Elevation (ft.): 3100
Basin Shape: 5.45
Total Relief (ft.): 1140
Mean Relief Ratio: .0930
Ruggedness Number: .217

Description: The drainage basin consists of mountains and old fan deposits. The mountains are sparsely covered with vegetation. The vegetation on the old fan deposits and active channels is dense with trees and brush. The main channel is about 80 ft. wide and 7 ft. deep. It is well incised and has stable banks and a sand bed.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1220
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .0296

Description: The PD is located at an intersection point on old fan deposits where the flow leaves the 80 ft. wide confined channel. The PD is about 0.6 mi. upstream of the mountain front.

Distributary Flow Area (DFA)

Area (sq.mi.): .916
Average Slope of Main Channel: .0317
Total Relief (ft.): 320
Mean Relief Ratio: .0318

Topography: The PD is located where the contours change from concave to convex. The map stream symbols diverge about 3000 ft. downstream of the PD. The slope profile of the wash flattens and then steepens just below the PD. There are two distinct distributary channels separated by a low ridge.
Geology: The DFA is an inset fan. It is bounded on the left side by a DFA. An old fan is located on the right side of the DFA near the toe. There is an old fan remnant on the left side of the DFA that starts about 1500 ft. downstream of the PD.
Soil Color: The active channels have a distinctly lighter color. The soils on the DFA are lighter colored than the soils on the old fan remnants.
Desert Varnish: Not apparent.
Vegetation: The density of the vegetation is greater on the DFA than on the old fan areas.

General Characteristics
Overall profile: There is a distinct flattening and then steepening of the slope of the wash at a secondary diffluence 2500 ft. downstream of the PD at the toe of the mountain. The slope is uniform and slightly decreases downstream of the secondary diffluence.
Lower Distributary Flow Area: There is no distinct base level stream near the toe of the DFA. The location of the toe is uncertain because it is in a gradual zone of transition where the channels become entrenched and tributary. This surface looks cone shaped.

SITE NO: 16 Type and Rank of Flood Hazard: C/5

Drainage Basin

Area (sq.mi.): 1.65 Mean Basin Elevation (ft.): 3950
Basin Shape: 15.8 Total Relief (ft.): 1500
Mean Relief Ratio: .0556 Ruggedness Number: .221

Description: The drainage basin consists of pediment and old fan deposits. There is scattered vegetation throughout the basin with scattered dense thickets along active channels. The basin is long and narrow with a minor distributary channel that is assumed to be insignificant. There is a major single channel which is generally confined.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1540
Estimated Average Channel Velocity of Q100 (ft./sec.): 7+
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .0270

Description: There is a single well incised channel at the PD with a capacity several times the amount of the 100 year flood. The PD is at the lower edge of the pediment.

Distributary Flow Area (DFA)

Area (sq.mi.): 3.72 Average Slope of Main Channel: .0306
Total Relief (ft.): 820 Mean Relief Ratio: .0312

Topography: The contours change from concave to convex at the PD. The map stream symbols diverge about 1 mi. downstream of the PD. The texture is uniform on the DFA and begins to increase in an upstream direction above the PD. The slope profile of the wash generally increases through the PD (to about 1 mi. downstream of the PD where it decreases to the toe with a slightly concave shape). The channels of the DFA are incised and separated by high ridges.
Geology: The DFA is on slightly dissected alluvial deposits.
Soil Color: The soils in the active channels are much lighter than on the surrounding interfluves. Soils near local diffluences are also lighter than the soils on the interfluves.
Desert Varnish: Not apparent.
Vegetation: The vegetation is more dense along active channels.

General Characteristics

Overall profile: The slope profile of the wash shows a distinct depositional mound at the PD to about 1 mi. downstream of the PD.

Lower Distributary Flow Area: The location of the toe is uncertain. Brawley Wash is a few miles downslope of the toe of the DFA, and it may act as a base level stream.

SITE NO: 17 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): 3.60 Mean Basin Elevation (ft.): 4090
Basin Shape: 5.90 Total Relief (ft.): 610
Mean Relief Ratio: .0251 Ruggedness Number: .0609

Description: The drainage basin consists of weakly cemented valley fill deposits. The vegetation is sparse on the ridges, but there are dense trees and bushes along the major wide flat sand channel. There is a single sinuous main channel with several large tributaries.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2180
Estimated Average Channel Velocity of Q100 (ft./sec.): 8
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .0156

Description: The PD is located at a narrows where the ridges of the valley fill deposits end. The channel is about 60 ft. wide and flat and it barely contains the 100 year discharge. During major flooding the floodwater can be a few hundred feet wide in a few secondary channels that are confined by steep banks of the valley fill deposits.

Distributary Flow Area (DFA)

Area (sq.mi.): .631 Average Slope of Main Channel: .0190
Total Relief (ft.): 110 Mean Relief Ratio: .0192

Topography: The contours change from concave to convex at the PD. The map stream symbols diverge at the PD. The slope profile of the wash has a slight flattening and steepening just below the PD. There are several small channels separated by low ridges.
Geology: The source of material for the DFA is the valley fill deposits.
Soil Color: The soils in the DFA are distinctly lighter than the soils on the surrounding valley fill deposits.
Desert Varnish: Not apparent.
Vegetation: There is a distinct increase in the density of the vegetation in the vicinity of the PD. In the upper DFA the vegetation changes from trees to brush to grass in a downstream direction. Grass and scattered bushes cover most of the DFA.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave in the upper DFA and slightly convex in the lower DFA.

Lower Distributary Flow Area: The San Pedro River acts as a base level stream. There are several headcuts in the lower DFA.

SITE NO: 18 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 2.40
Mean Basin Elevation (ft.): 1870
Basin Shape: 1.11
Total Relief (ft.): 990
Mean Relief Ratio: .0707
Ruggedness Number: .121

Description: The drainage basin consists of mountains with a small alluvial valley. There is a single confined channel with a major tributary about 0.25 mi. upstream of the PD. There is sparse vegetation on the mountains with a few scattered bushes and trees along the channels.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1700
Estimated Average Channel Velocity of Q100 (ft./sec.): 6
Estimated Froude Number for Q100: less than 1
Slope of Main Channel: .0126

Description: The PD is about 1000 ft. upstream of the mountain front in the mouth of a canyon. There are several overflow channels at the PD.

Distributary Flow Area (DFA)

Area (sq.mi.): 3.32
Average Slope of Main Channel: .00961
Total Relief (ft.): 120
Mean Relief Ratio: .00980

Topography: The contours remain concave to about 1000 ft. below the PD where they become convex. Map stream symbols diverge at the mountain front about 1000 ft. below the PD. The texture is uniform on the DFA. The slope profile of the wash flattens and then steepens just below the PD. The channels in the upper DFA are smaller and less incised then the channels in the lower DFA. In the upper DFA there are localized areas of recent deposition of unsorted boulders, gravel, and sand. Floodflow can spread over wide areas in the upper DFA and it becomes confined between ridges in the middle and lower DFA.
Geology: The upper DFA is an inset fan.
Soil Color: Along the boundaries of the DFA/old fan deposits there are soils which are darker red. Within the upper DFA there are light colored soils along the active channels and local depositional areas. In the lower DFA the soils become lighter colored with a distinct lightening along the toe.
Desert Varnish: Apparent on high ridges.
Vegetation: The vegetation is sparse over the DFA and dense along the active channels.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave. There appears to be two segments of uniform slope. The steeper upper segment appears to be associated with the upper DFA.
Lower Distributary Flow Area: Greene Wash is located about 1 mi. below the toe of the DFA. It tends to act as a base level stream.

SITE NO: 19 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): .922 Mean Basin Elevation (ft.): 1820
Basin Shape: .347 Total Relief (ft.): 1010
Mean Relief Ratio: .141 Ruggedness Number: .199

Description: The drainage basin consists of mountains and a small area of old fan deposits. The vegetation on the mountains is sparse. Trees and bushes grow along the larger channels. There is a single main channel that is braided in places.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1060
Estimated Average Channel Velocity of Q100 (ft./sec.): 6
Estimated Froude Number for Q100: less than 1
Slope of Main Channel: .0150

Description: The PD is about 3000 ft. downstream of the mountain front on an alluvial slope. The main channel at the PD is about 100 ft. wide and is generally V-shaped with a capacity slightly more than the 100 year flood.

Distributary Flow Area (DFA)

Area (sq.mi.): .320 Average Slope of Main Channel: .0130
Total Relief (ft.): 45 Mean Relief Ratio: .0161

Topography: The contours change from concave to convex at the PD. The texture appears to be uniform on the DFA. The distributary channels are not readily apparent on the 7 1/2 minute topo. map, but they are apparent on the oblique aerial photograph. The slope profile of the wash flattens and then steepens just below the PD. There is very little topographic relief about 1000 ft. below the PD but the main channel is very wide and flat.

Geology: The DFA is an inset fan.

Soil Color: There is no apparent change in the soil color based on a single aerial photo.

Desert Varnish: Not apparent.

Vegetation: There is an increase in the density of the vegetation along the larger channels. The ridges are sparsely covered with bushes.

General Characteristics

Overall profile: On the slope profile of the wash there appears to be two segments of uniform slope. The junction of the two segments occurs about 1000 ft. upstream of the PD.

Lower Distributary Flow Area: Greene Wash acts as a base level stream.

SITE NO: 20 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 12.7
Basin Shape: 2.81
Mean Relief Ratio: .0924
Mean Basin Elevation (ft.): 5670
Total Relief (ft.): 2922
Ruggedness Number: .155

Description: The drainage basin consists of mountains and a long narrow alluvial valley. The main channel is braided and lined with scattered trees. The higher mountains are densely covered with trees. The intermediate and low mountains are sparsely covered. The valley floor is covered with trees and bushes.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3830
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0275

Description: The PD is located about 0.5 mi. upstream of the mountain front. There is a single main channel that is about 300 ft. wide. It is bounded by the mountains.

Distributary Flow Area (DFA)

Area (sq.mi.): 5.89
Total Relief (ft.): 480
Average Slope of Main Channel: .0200
Mean Relief Ratio: .0202

Topography: The contours change from concave to straight and then to convex about 4000 ft. downstream of the PD. The map stream symbols diverge about 1000 ft. below the PD. The texture is uniform in the DFA. The texture in the adjoining old fan area decreases upslope. The slope profile of the wash shows a slight flattening and steepening just below the PD. There is a single large channel with a few small secondary channels.
Geology: The DFA is on an old fan surface. There is a DFA on the left side and an old fan on the right side.
Soil Color: There is light colored soil in the active channels.
Desert Varnish: None.
Vegetation: There is a distinct increase in the density of vegetation on the DFA and especially along active channels.

General Characteristics

Overall profile: The slope profile of the wash shows a general concave shape with two uniform segments. The change in slope that separates the segments occurs about 2 mi. downstream of the PD.

Lower Distributary Flow Area: The location of the toe is not certain but it is located where the fan profile tends to flatten.

SITE NO: 21 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 3.41 Mean Basin Elevation (ft.): 1470
Basin Shape: 1.41 Total Relief (ft.): 1120
Mean Relief Ratio: .0967 Ruggedness Number: .115

Description: The drainage basin consists of mountains and old fan deposits. The main channel is incised and has several tributaries. The vegetation on the old fan deposits is sparse and it consists of a few scattered bushes.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2030
Estimated Average Channel Velocity of Q100 (ft./sec.): 5
Estimated Froude Number for Q100: less than 1
Slope of Main Channel: .0112

Description: The PD is about 1 mi. downstream of the mountain front at the confluence of several tributaries. The main channel is about 600 ft. wide, and it is composed of several small channels. The main channel has a capacity many times the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 5.18 Average Slope of Main Channel: .00893
Total Relief (ft.): 240 Mean Relief Ratio: .00912

Topography: The contours change from concave to convex about 5000 ft. downstream of the PD. About 7000 ft. downstream of the PD the contours become straight. The map stream symbols diverge about 3000 ft. downstream of the PD. The slope profile of the wash flattens and then steepens just below the PD. There are several channels which are separated by low ridges in the upper DFA. The middle and lower DFA have incised channels separated by high flat ridges.
Geology: The DFA is an inset fan bounded by old fan deposits.
Soil Color: The DFA has distinctly lighter colored soils than the surrounding old fan surfaces.
Desert Varnish: There appears to be desert varnish on the ridges in the middle and lower DFA.
Vegetation: The density of the vegetation increases at the PD and along the active channels. The vegetation includes trees and bushes. The old fan deposits have only scattered bushes.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave with a large hump located from about 2000 ft. to 3500 ft. downstream of the PD. Another distinct flattening and then steepening of slope occurs at another diffluence about 9000 ft. downstream of the PD.

Lower Distributary Flow Area: Tyson Wash acts as a base level stream.

SITE NO: 22 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): 2.33 Mean Basin Elevation (ft.): 1740
Basin Shape: 2.84 Total Relief (ft.): 1220
Mean Relief Ratio: .0898 Ruggedness Number: .151

Description: The drainage basin consists of mountains and old fan deposits. The main channel is braided and has several tributaries.

Primary Diffluence (PD)

100 Year Discharge (cfs): 4400
Estimated Average Channel Velocity of Q100 (ft./sec.): 9
Estimated Froude Number for Q100: greater than 1
Slope of Main Channel: .0116

Description: The PD is located about 1.5 mi. downstream of the mountain front. The channel is about 350 ft. wide and its capacity is several times the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 5.46 Average Slope of Main Channel: .00776
Total Relief (ft.): 1440 Mean Relief Ratio: .0577

Topography: The contours change from concave above the PD to straight at about 2000 ft. downstream of the PD and then they become convex at about 4000 ft. downstream of the PD. The slope profile of the wash shows a minor flattening and then a steepening just below the PD. There are only small channels in the upper DFA. Several entrenched channels are found in the middle DFA and there are no channels in the lower DFA near the toe.

Geology: The DFA in on old fan deposits and is bounded by DFAreas on both sides.

Soil Color: The soil has a lighter color in the active washes. The soils in the lower DFA are lighter than the soils of the middle DFA.

Desert Varnish: Not evaluated.

Vegetation: There is an increase in the density of trees along the defined washes. There are sparse bushes on the ridges.

General Characteristics

Overall profile: The slope profile of the wash has a concave shape with a generally decreasing slope below the PD.

Lower Distributary Flow Area: In the lower DFA there are no channels and there is extensive potential for sheetflow.

SITE NO: 23 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): 2.81 Mean Basin Elevation (ft.): 2260
Basin Shape: 2.93 Total Relief (ft.): 2164
Mean Relief Ratio: .143 Ruggedness Number: .245

Description: The drainage basin consists of mountains with a small strip of old fan deposits. There is sparse vegetation in the mountains with scattered trees and bushes along the channel in the old fan deposits. There is a single deeply entrenched channel upstream of the DFA.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3500
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0288

Description: The PD is about 2000 ft. downslope of the mountain front and it is entrenched in old fan deposits. The capacity of the channel is about two times the 100 year discharge before spreading occurs.

Distributary Flow Area (DFA)

Area (sq.mi.): .600 Average Slope of Main Channel: .0270
Total Relief (ft.): 200 Mean Relief Ratio: .0270

Topography: The contours change from concave to slightly convex at the PD. The slope profile of the wash significantly flattens and then steepens just below the PD. There are a few large channels and numerous small channels separated by low ridges.
Geology: There are numerous large boulders in the DFA. The boulders appear to be old fan material. The DFA is bounded by old fan deposits on both sides.
Soil Color: The entire DFA has a generally lighter appearance then the surrounding old fan surfaces.
Desert Varnish: There is a significant decrease in the number of rocks covered with desert varnish in the DFA compared to the surrounding old fan surface. On ridges in the DFA there are scattered large rocks with desert varnish, but there are few small rocks coated with desert varnish.
Vegetation: There is a distinct increase in the density of vegetation in the DFA. There are many scattered trees and bushes in the DFA especially along the larger channels.

General Characteristics

Overall profile: The slope profile of the wash shows a distinct depositional mound from the PD to about 4000 ft. downstream of the PD. The slope profile of the wash in the middle and lower DFA is concave.
Lower Distributary Flow Area: The channels become entrenched and tributary at the toe.

SITE NO: 24 Type and Rank of Flood Hazard: B/3

Drainage Basin

Area (sq.mi.): 4.05 Mean Basin Elevation (ft.): 1600
Basin Shape: 5.05 Total Relief (ft.): 2496
Mean Relief Ratio: .105 Ruggedness Number: .235

Description: The drainage basin consists of mountains. There is very little vegetation in the mountains. There is a large single braided channel lined with trees and brush.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2210
Estimated Average Channel Velocity of Q100 (ft./sec.): 6+
Estimated Froude Number for Q100: less than or equal to 1
Slope of Main Channel: .0170

Description: The PD is at the mountain front. The channel is about 300 ft. wide and is flat and braided. The capacity of the channel is several times the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 4.98 Average Slope of Main Channel: .0150
Total Relief (ft.): 540 Mean Relief Ratio: .0165

Topography: In the vicinity of the PD the contours change from concave to convex. About 3000 ft. downstream of the PD the shape of the contours is very irregular and there are numerous incised channels. The map stream symbols diverge at the PD. The slope profile of the wash shows a flattening and then a steepening just below the PD. There are two distinct channels below the PD and the left channel is an anabranch. The DFA has a general braided appearance with one major anabranch and a few potential anabranches.
Geology: The DFA is in a valley that is entrenched in old alluvial deposits. The surrounding area includes weakly cemented deposits of silty to coarse gravel.
Soil Color: The DFA has soils which are light colored with fewer brown and red colored soils than the adjacent areas.
Desert Varnish: There is desert varnish on the surrounding old alluvial deposits.
Vegetation: There is a marked increase in the density of vegetation in the DFA.

General Characteristics

Overall profile: The slope profile of the wash shows a distinct depositional lobe from just below the PD to about 1 mi. downstream of the PD. Downstream of the depositional lobe the slope of the wash becomes uniform.

Lower Distributary Flow Area: The Colorado River acts as a base level stream.

SITE NO: 25 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 21.6
Basin Shape: 1.95
Mean Relief Ratio: .0394
Mean Basin Elevation (ft.): 2160
Total Relief (ft.): 1351
Ruggedness Number: .0551

Description: The drainage basin consists of mountains and old fan deposits. The mountains have sparse vegetation. The main channel is wide and braided.

Primary Diffluence (PD)

100 Year Discharge (cfs): 5100
Estimated Average Channel Velocity of Q100 (ft./sec.): 5+
Estimated Froude Number for Q100: less than or equal to 1
Slope of Main Channel: .0110

Description: The PD is located at the mountain front in a mountain pass. The PD has a main channel which is generally flat and about 0.5 mi. wide, and the main channel consists of several small channels. The main channel is deeply entrenched and has a capacity many times the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 26.4
Total Relief (ft.): 540
Average Slope of Main Channel: .0119
Mean Relief Ratio:.0127

Topography: The contours change from concave to straight at the PD. About 0.5 mi. downstream of the PD the contours become convex. The map stream symbols diverge at the PD. The slope profile of the wash shows a general flattening and then a steepening just below the PD. There are numerous small channels with numerous diffluences. Between the small channels there are generally low ridges and a few scattered island-like high ridges (old fan remnants).
Geology: The DFA is on old fan deposits with several island-like old fan remnants in the DFA.
Soil Color: The soils in the DFA are distinctly lighter then the surrounding old fan surface and the old fan remnants.
Desert Varnish: There is significant desert varnish on the old fan surfaces and the old fan remnants.
Vegetation: There are scattered bushes and trees along the larger channels.

General Characteristics

Overall profile: The slope profile of the wash shows a uniform slope from the PD to about 5.5 mi. downstream of the PD where there is an abrupt decrease in slope. At this abrupt change in slope the contours change from straight to concave.

Lower Distributary Flow Area: The Harquahala Valley acts as a base level plain.

SITE NO: 26 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 1.99
Basin Shape: 1.83
Mean Relief Ratio: .128
Mean Basin Elevation (ft.): 2170
Total Relief (ft.): 1265
Ruggedness Number: .173

Description: The drainage basin consists of mountains covered with sparse vegetation. The main channel is a deeply incised with several tributaries.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1550
Estimated Average Channel Velocity of Q100 (ft./sec.): 8
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0208

Description: The PD is at the mountain front in a canyon. The channel is about 100 ft. wide with gradually sloping banks.

Distributary Flow Area (DFA)

Area (sq.mi.): 1.99
Total Relief (ft.): 380
Average Slope of Main Channel: .0194
Mean Relief Ratio: .0214

Topography: The contours change from concave to straight about 2000 ft. downstream of the PD. About another 1000 ft. downstream the contours become convex. The map stream symbols diverge about 1000 ft. below the PD. The slope profile of the wash shows a flattening and then a steepening just below the PD. There is a single large channel with several smaller channels separated by low ridges.

Geology: The DFA is on old fan deposits with four inselbergs in the middle to lower DFA.

Soil Color: The soil along the active channels is lighter than the surrounding old fan material.

Desert Varnish: Undefined.

Vegetation: The vegetation is dense in the vicinity of the PD, but it is sparse throughout the middle and lower DFA.

General Characteristics

Overall profile: The slope profile of the wash shows a generally concave shape with a decrease of slope at the upper end of the inselbergs.

Lower Distributary Flow Area: The toe is located where the contours are concave and the flow is tributary.

SITE NO: 27 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 7.54 Mean Basin Elevation (ft.): 1790
Basin Shape: 3.20 Total Relief (ft.): 1457
Mean Relief Ratio: .0562 Ruggedness Number: .101

Description: The drainage basin consists of mountains and old fan deposits. The main channel is wide and braided. The vegetation is sparse in the mountains and includes scattered trees and brush along the larger channels.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3010
Estimated Average Channel Velocity of Q100 (ft./sec.): 7
Estimated Froude Number for Q100: less than 1
Slope of Main Channel: .0134

Description: The PD is located at the mountain front at a mountain pass. The channel is about 200 ft. wide and is bounded by a mountain on the left and a gradual slope on the right.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.77 Average Slope of Main Channel: .0123
Total Relief (ft.): 260 Mean Relief Ratio: .0130

Topography: The contours change from concave to straight at the PD and then to convex downstream. The map stream symbols diverge at the PD. The slope profile of the wash shows a general flattening and then a steepening from the PD to about 5000 ft. downstream of the PD. There are two large channels separated by a low-wide ridge in the upper DFA. There are several small channels separated by low ridges in the middle and lower DFA.

Geology: The DFA is on old fan deposits.

Soil Color: The soils are lighter in the active channels.

Desert Varnish: It appears that there is desert varnish on the neighboring old fan surfaces with small areas of desert varnish on the high ridges in the DFA.

Vegetation: There is a greater number of small bushes on the DFA than on the surrounding old fan surfaces.

General Characteristics

Overall profile: The slope profile of the wash is generally concave with irregularities.

Lower Distributary Flow Area: The Harquahala Valley acts as a base level plain.

SITE NO: 28 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): 5.25 Mean Basin Elevation (ft.): 1870
Basin Shape: 3.50 Total Relief (ft.): 1240
Mean Relief Ratio: .0548 Ruggedness Number: .103

Description: The drainage basin consists of mountains and a narrow strip of old fan deposits. There is a single entrenched channel bounded by surfaces covered with desert varnish.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2520
Estimated Average Channel Velocity of Q100 (ft./sec.): 9
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0126

Description: The PD is located about 1 mi. downstream of the mountain front at an intersection point and about 2000 ft. to the left of an inselberg. The channel is about 180 ft. wide with gently sloping banks.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.65 Average Slope of Main Channel: .00925
Total Relief (ft.): 140 Mean Relief Ratio: .00972

Topography: The contours change from concave to convex at the PD. The map stream symbols diverge about 500 ft. downstream of the PD. The slope profile of the wash shows a slight flattening and then a steepening just below the PD. There is a small channel along each side of the upper DFA which is separated by almost no relief across the DFA.

Geology: The DFA is an inset fan on old fan deposits.

Soil Color: The entire DFA is distinctly lighter colored than the bordering old fan deposits.

Desert Varnish: There is a distinct change in the amount of desert varnish at the boundary of the DFA. There appears to be partial removal/burial of the desert varnish by major flood events on the fringe of the boundary of the DFA.

Vegetation: There is a distinct increase in the number of bushes in the DFA. There are scattered trees in the vicinity of the PD.

General Characteristics

Overall profile: The slope profile of the wash has a generally concave appearance with a small depositional lobe downstream of the PD.

Lower Distributary Flow Area: The Harquahala Valley acts as a base level plain. At the toe of the DFA the contours change from straight to concave. A stock tank is located in the middle DFA.

SITE NO: 29 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 2.07	Mean Basin Elevation (ft.): 2420
Basin Shape: 3.80	Total Relief (ft.): 1920
Mean Relief Ratio: .130	Ruggedness Number: .253

Description: The drainage basin consists of mountains and a small area of old fan deposits. There is a single confined channel. The mountains have sparse vegetation.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1580
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: greater than or equal to 1
Slope of Main Channel: .0241

Description: The PD is about 3000 ft. downstream of the general mountain front near two small inselbergs (possibly at the lower edge of a small pediment). The channel is about 100 ft. wide and easily contains the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 1.44	Average Slope of Main Channel: .0153
Total Relief (ft.): 240	Mean Relief Ratio: .0165

Topography: The contours change from concave to convex at the PD. The map stream symbols diverge at the PD. The slope profile of the wash flattens and then slightly steepens just below the PD. There are two channels separated by a wide flat ridge about 1000 ft. downstream of the PD. About 3000 ft. downsteam of the PD there are several defined channels separated by low ridges.

Geology: The DFA is on old fan deposits.

Soil Color: The soil color is slightly lighter in the DFA than on the surrounding old fan deposits.

Desert Varnish: Undefined.

Vegetation: There is a slight increase in the density of the vegetation on the DFA which includes scattered bushes and trees along the larger channels.

General Characteristics

Overall profile: The slope profile of the wash is generally concave with some irregularities.

Lower Distributary Flow Area: Centennial Wash acts as a base level stream and is about 1.5 mi. downslope of the toe of the DFA.

SITE NO: 30 Type and Rank of Flood Hazard: A/2

Drainage Basin

Area (sq.mi.): 11.1
Basin Shape: 2.82
Mean Relief Ratio: .124
Mean Basin Elevation (ft.): 3110
Total Relief (ft.): 3661
Ruggedness Number: .208

Description: The drainage basin consists of mountains. There are two confined channels that join about 1000 ft. upstream of the PD. The mountains have sparse vegetation, and there is more scattered vegetation along large channels.

Primary Diffluence (PD)

100 Year Discharge (cfs): 3660
Estimated Average Channel Velocity of Q100 (ft./sec.): 9+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0206

Description: The PD is at the general mountain front. The channel is about 150 ft. wide with gently sloping banks, and it easily contains the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.62
Total Relief (ft.): 440
Average Slope of Main Channel: .0199
Mean Relief Ratio: .0197

Topography: The contours change from concave to generally convex at the PD (with two large incised channels downstream of the PD). The map stream symbols diverge at the PD. The slope profile of the wash shows a distinct flattening and then a steepening just below the PD. Below the PD there are two distinct channels separated by an old fan remnant about 1 mi. wide (the old fan remnant attains this width in the middle and lower DFA). The old fan remnant is generally 10 ft. above the level of the 100 year discharge.
Geology: The DFA is on old fan deposits.
Soil Color: The soils along the active channels are distinctly light colored.
Desert Varnish: Undefined.
Vegetation: There are scattered trees and bushes along the two distributary channels.

General Characteristics

Overall profile: The slope profile of the wash is based on the largest distributary channel on the right. The slope profile of the wash is generally concave. The slope is fairly uniform from the PD to about 2 mi. downstream. At this point the slope decreases slightly to the toe of the DFA.

Lower Distributary Flow Area: In the lower DFA the two confined channels develop independent distributary systems. The Harquahala Valley acts as a base level plain.

SITE NO: 31 Type and Rank of Flood Hazard: D/8

Drainage Basin

Area (sq.mi.): .847
Basin Shape: 1.96
Mean Relief Ratio: .174
Mean Basin Elevation (ft.): 1770
Total Relief (ft.): 1179
Ruggedness Number: .243

Description: The drainage basin consists of mountains. There is a single confined channel. There is sparse vegetation on the mountains and scattered bushes and trees along the wash in the valley.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1010
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0406

Description: The PD is located about 0.5 mi. upstream of the mountain front in a canyon. The channel is deeply incised with a capacity several times the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.84
Total Relief (ft.): 480
Average Slope of Main Channel: .0253
Mean Relief Ratio: .0260

Topography: The contours change from concave to straight at the PD and then they become convex about 3000 ft. downstream of the PD. The map stream symbols diverge about 1000 ft. below the PD. The slope profile of the wash shows a slight flattening and then a steepening just below the PD. In the upper DFA there are two distinct channels separated by a high ridge. The middle and lower DFA have several distinct channels also separated by high ridges.
Geology: The DFA is composed of channels eroded into the old fan surface.
Soil Color: The active channels have a distinctly lighter color than the old fan remnants.
Desert Varnish: There is extensive desert varnish on the old fan remnants with a distinct boundary along the active channels.
Vegetation: There are scattered trees and bushes along the active channels. There is very little vegetation on the ridges.

General Characteristics

Overall profile: The slope profile of the wash is generally concave, but it is composed of three segments of uniform slope. The first segment ends near the mountain front (adjacent to an inselberg) where the general confinement of the floodwater ends. The second segment ends near the toe of the DFA.
Lower Distributary Flow Area: The toe is located where the flow is tributary and the contours are clearly concave. The location of the actual toe is uncertain. Tyson Wash is about 3 mi. downstream of the toe of the DFA.

SITE NO: 32 Type and Rank of Flood Hazard: D/8

Drainage Basin

Area (sq.mi.): 1.28
Basin Shape: 1.43
Mean Relief Ratio: .154
Mean Basin Elevation (ft.): 1990
Total Relief (ft.): 1099
Ruggedness Number: .184

Description: The drainage basin consists of mountains. There is a single confined channel. There is sparse vegetation on the mountains and scattered bushes and trees along the wash in the valley.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1240
Estimated Average Channel Velocity of Q100 (ft./sec.): 6+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0375

Description: The PD is located at the mountain front at the canyon mouth. The channel is about 150 ft. wide and flat with a gently sloping bank on the right side.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.62
Total Relief (ft.): 580
Average Slope of Main Channel: .0273
Mean Relief Ratio: .0287

Topography: The contours change from concave to convex at the PD. The map stream symbols diverge about 2000 ft. downstream of the PD. The slope profile of the wash flattens and then steepens just below the PD. There are two distinct channels separated by a high ridge in the upper DFA. The middle and lower DFA have several distinct channels separated by high irregular ridges.
Geology: The DFA is composed of channels eroded into an old fan surface.
Soil Color: The active channels are distinctly lighter than the old fan remnants.
Desert Varnish: There is extensive desert varnish on the old fan remnants with a distinct boundary along the active channels.
Vegetation: There are scattered trees and bushes along active channels. There is very little vegetation on the ridges.

General Characteristics

Overall profile: The slope profile of the wash is generally concave and composed of three segments that are less distinct than the segments for site 31. The first segment ends near an inselberg. The second segment occurs at the same elevation as the second segment of site 31, but distributary flow occurs below this point.

Lower Distributary Flow Area: The toe is where the contours are concave and the flow is tributary. Tyson Wash is about 3 mi. downstream of the toe of the DFA.

SITE NO: 33 Type and Rank of Flood Hazard: C/7

Drainage Basin

Area (sq.mi.): 9.73
Mean Basin Elevation (ft.): 1720
Basin Shape: 3.31
Total Relief (ft.): 2082
Mean Relief Ratio: .0694
Ruggedness Number: .126

Description: The drainage basin consists of mountains and old fan deposits. There is sparse vegetation on the mountains with some vegetation along stream channels on the valley floor. The main channel is a wide braided channel that narrows near the mouth of the basin (which is where the PD is located).

Primary Diffluence (PD)

100 Year Discharge (cfs): 3420
Estimated Average Channel Velocity of Q100 (ft./sec.): 4+
Estimated Froude Number for Q100: less than or equal to 1
Slope of Main Channel: .00989

Description: The PD is located at the general front of some small mountains. The main channel is about 700 ft. wide and relatively flat. The channel's capacity slightly exceeds the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 3.45
Average Slope of Main Channel: .0105
Total Relief (ft.): 400
Mean Relief Ratio: .0114

Topography: The contours change from concave to slightly concave at the PD and then change to convex about 4000 ft. downstream of the PD. The map stream symbols diverge at the PD. The slope profile of the wash shows a flattening and then a steepening just below the PD. There is a wide main channel downstream of the PD with a small secondary channel on the left. This secondary channel is separated by a low wide ridge. About 1 mi. downstream of the PD there are a few large channels and several small channels separated by generally low ridges and some high ridges. In the middle of the lower DFA there are large island-like old fan remnants.
Geology: The DFA is composed of channels eroded into old fan.
Soil Color: The edge of the DFA has distinctly lighter colored soils.
Desert Varnish: There is extensive desert varnish on the old fan remnants with a distinct boundary along the active channels. There appears to be an intermediate zone between the DFA and the dark desert varnish.
Vegetation: There are scattered trees and bushes along the active channels. There is very little vegetation on the ridges.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave with two segments of uniform slope. The end of the first segment occurs at a diffluence.
Lower Distributary Flow Area: Tyson Wash acts as a base level stream.

SITE NO: 34 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 88.8 Mean Basin Elevation (ft.): 2070
Basin Shape: 2.01 Total Relief (ft.): 2400
Mean Relief Ratio: .0341 Ruggedness Number: .0482

Description: The drainage basin consists of mountains and old fan deposits. There is a large channel that is braided and covered with scattered bushes and trees. The vegetation in the surrounding mountains and old fan deposits is sparse.

Primary Diffluence (PD)

100 Year Discharge (cfs): 10300
Estimated Average Channel Velocity of Q100 (ft./sec.): 7+
Estimated Froude Number for Q100: less than or equal to 1
Slope of Main Channel: .00800

Description: The PD is at the general mountain front in a mountain pass. The channel is entrenched in old alluvium and is bounded by a mountain on the left bank. The channel is flat and about 300 ft. wide.

Distributary Flow Area (DFA)

Area (sq.mi.): 25.2 Average Slope of Main Channel: .00733
Total Relief (ft.): 350 Mean Relief Ratio: .00706

Topography: The contours change form generally concave to generally convex at the PD. The map stream symbols diverge at the PD. The slope profile of the wash shows a flattening and then a steepening just below the PD. In the upper DFA there are two distinct channels that separate about 1000 ft. downstream of the PD. The channel on the right is deeply entrenched and appears to be the most active channel at this time. The channel on the left has a greater slope and is wider than the channel on the right. In the upper DFA the two distinct channels are separated by a high flat ridge. In the middle and lower DFA there are many channels separated by low ridges.
Geology: There are three inselbergs in the DFA and some scattered island-like old fan remnants.
Soil Color: There are large areas of light colored soil. There are scattered large areas of darker colored soil with various shades inbetween.
Desert Varnish: There is a large area of desert varnish along the entire length of the DFA that separates two active regions of the DFA.
Vegetation: The vegetation is sparse except along the larger channels where there are scattered trees and brush.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave with two segments of uniform slope.
Lower Distributary Flow Area: Ranegras Plain acts as a base level plain.

SITE NO: 35 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): 95.9
Basin Shape: 1.11
Mean Relief Ratio: .0708
Mean Basin Elevation (ft.): 2600
Total Relief (ft.): 3861
Ruggedness Number: .0747

Description: The drainage basin consists of mountains and weakly to firmly cemented valley fill deposits. The main channel is Tiger Wash and it is large and braided. The vegetation is sparse on the mountains and the valley fill deposits, but there are dense trees along Tiger Wash and its larger tributaries.

Primary Diffluence (PD)

100 Year Discharge (cfs): 10700
Estimated Average Channel Velocity of Q100 (ft./sec.): 6
Estimated Froude Number for Q100: less than 1
Slope of Main Channel: .00926

Description: The PD is located at a mountain pass. The right bank of the channel is composed of old fan deposits and the left bank is a mountain. The channel is about 1000 ft. wide, flat, and it easily contains the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 38.8
Total Relief (ft.): 520
Average Slope of Main Channel: .00724
Mean Relief Ratio: .00730

Topography: The contours change from concave to generally convex about 1 mi. downstream of the PD. The map stream symbols diverge at the PD. The slope profile of the wash is constant at the PD. The texture is uniform along the center of the DFA. There is some significant variation in the texture across the width of the DFA about 3 mi. downstream of the PD. About 3000 ft. downstream of the PD there are two distinct channels separated by a wide ridge. In the upper DFA there are numerous deeply incised channels separated by high ridges. In the middle and lower DFA there are many small channels separated by low ridges.
Geology: The upper and middle DFA is on old fan deposits. The lower DFA is on unconsolidated channel deposits.
Soil Color: There are light colored soils along the active channels.
Desert Varnish: Undefined.
Vegetation: The density of bushes increases in the DFA. There are scattered trees along the active channels.

General Characteristics

Overall profile: The slope profile of the wash is concave.

Lower Distributary Flow Area: In the middle and lower DFA there will be large areas of sheetflow during major flooding.

SITE NO: 36 Type and Rank of Flood Hazard: E/10

Drainage Basin

Area (sq.mi.): 5.63 Mean Basin Elevation (ft.): 2130
Basin Shape: 2.45 Total Relief (ft.): 1640
Mean Relief Ratio: .0837 Ruggedness Number: .131

Description: The drainage area consists of mountains and a small area of pediment. There is a single well defined main channel with several tributaries. There is sparse vegetation on the mountains with scattered trees and bushes along large channels.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2610
Estimated Average Channel Velocity of Q100 (ft./sec.): 7+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0178

Description: The PD is at the lower edge of the pediment. The channel is about 200 ft. wide and flat. The capacity of the channel is much greater than the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.15 Average Slope of Main Channel: .0192
Total Relief (ft.): 290 Mean Relief Ratio: .0192

Topography: The contours change from concave to convex at the PD. There is a very wide fan shaped stippled pattern depicting the stream channel below the PD. There are two distinct channels about 3000 ft. downstream of the PD which are separated by a low ridge. In the middle and lower DFA there are many small channels separated by low ridges. The slope profile of the wash shows a flattening and then a steepening just below the PD. (For texture see site 37).

Geology: The DFA is on an alluvial plain below a pediment.

Soil Color: The soils in the DFA are lighter colored than the surrounding areas.

Desert Varnish: Undefined.

Vegetation: There is a slight increase in the density of bushes in the DFA.

General Characteristics

Overall profile: The slope profile of the wash shows a hump at a depositional lobe below the PD. Downslope of the hump the profile is generally concave.

Lower Distributary Flow Area: The Hassayampa River acts as a base level stream and is located a few miles downstream of the toe of the DFA.

SITE NO: 37 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 4.30 Mean Basin Elevation (ft.): 2150
Basin Shape: 3.96 Total Relief (ft.): 2060
Mean Relief Ratio: .0946 Ruggedness Number: .188

Description: The drainage consists of mountains and pediment. There is a single well defined main channel with several tributaries. There is sparse vegetation on the mountains with scattered trees and bushes along the large channels.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2280
Estimated Average Channel Velocity of Q100 (ft./sec.): 10
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0159

Description: The PD is at the lower edge of the pediment. The channel is about 150 ft. wide with slightly sloping banks. The capacity of the channel greatly exceeds the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): 1.03 Average Slope of Main Channel: .0167
Total Relief (ft.): 180 Mean Relief Ratio: .0175

Topography: The contours change from concave to straight at the PD. The slope profile of the wash flattens and then steepens just below the PD. The texture is uniform in the DFA and increases in the pediment area upstream of the DFA. There are several small channels generally separated by low ridges with a couple of high ridges.

Geology: The DFA is on an alluvial plain below a pediment.

Soil Color: The soil is lighter in the active channels.

Desert Varnish: Undefined.

Vegetation: In the DFA there is a slight increase in the density of the bushes.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave with a constant slope downstream from the small depositional lobe.

Lower Distributary Flow Area: The Hassayampa River acts as a base level stream, and it is located a few miles downstream of the toe of the DFA.

SITE NO: 38 Type and Rank of Flood Hazard: D/9

Drainage Basin

Area (sq.mi.): 3.47
Basin Shape: 8.16
Mean Relief Ratio: .0948
Mean Basin Elevation (ft.): 2160
Total Relief (ft.): 2663
Ruggedness Number: .271

Description: The drainage basin consists of mountains and a large pediment area. There is a single well defined main channel with several tributaries. There is sparse vegetation on the mountains with scattered trees and bushes along large channels.

Primary Diffluence (PD)

100 Year Discharge (cfs): 2050
Estimated Average Channel Velocity of Q100 (ft./sec.): 9
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0148

Description: The PD is located on apparent old fan deposits about 1 mi. downstream of the lower edge of the pediment. The channel is about 150 ft. wide with gently sloping banks, and it appears to be entrenched in old fan material. The capacity of the main channel greatly exceeds the 100 year discharge.

Distributary Flow Area (DFA)

Area (sq.mi.): .700
Total Relief (ft.): 100
Average Slope of Main Channel: .0135
Mean Relief Ratio: .0152

Topography: The contours change from concave to straight at the PD. (For texture see site 37). The slope profile of the wash flattens and then slightly steepens just below the PD. There are several small channels which are generally separated by low ridges and a few high ridges.

Geology: The DFA is downstream of the pediment on an alluvial plain (or old fan deposits).

Soil Color: The soil is lighter in the active channels.

Desert Varnish: Undefined.

Vegetation: In the DFA there is a slight increase in the density of bushes.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave.

Lower Distributary Flow Area: The Hassayampa River acts as a base level stream a few miles downstream of the toe of the DFA.

SITE NO: 39 Type and Rank of Flood Hazard: D/8

Drainage Basin

Area (sq.mi.): 3.26
Basin Shape: 2.99
Mean Relief Ratio: .110
Mean Basin Elevation (ft.): 1860
Total Relief (ft.): 1820
Ruggedness Number: .191

Description: The drainage basin consists of mountains and pediment. There is a single well defined main channel with several tributaries. There is sparse vegetation on the mountains with scattered trees and bushes along large channels.

Primary Diffluence (PD)

100 Year Discharge (cfs): 1980
Estimated Average Channel Velocity of Q100 (ft./sec.): 10+
Estimated Froude Number for Q100: about 1
Slope of Main Channel: .0134

Description: The PD is located at the lower edge of the pediment. The channel is about 100 ft. wide with a wide flat overflow area on the right bank. The channel just contains the 100 year discharge before significant overflow occurs.

Distributary Flow Area (DFA)

Area (sq.mi.): 2.25
Total Relief (ft.): 180
Average Slope of Main Channel: .0119
Mean Relief Ratio: .0137

Topography: The contours change from concave to generally convex at the PD. The channels are deeply incised and are separated by high ridges. The slope profile of the wash generally flattens and then slightly steepens about 0.5 mi. downstream of the PD.

Geology: The DFA is on an alluvial plain below a pediment. Perhaps the DFA is also on some old fan deposits.

Soil Color: The soils in the DFA are lighter colored then the surrounding areas.

Desert Varnish: Undefined.

Vegetation: There is a slight increase in the density of bushes in the DFA.

General Characteristics

Overall profile: The slope profile of the wash is slightly concave with a fairly constant slope below the small depositional mound.

Lower Distributary Flow Area: The Hassayampa River acts as a base level stream a few miles downstream of the toe of the DFA.

APPENDIX K

GLOSSARY

Alluvial Fan - "a geomorphic feature characterized by a cone or fan-shaped deposit of boulders, gravel, and fine sediments that have been eroded from mountain slopes, transported by flood flows, and then deposited on the valley floors, and which is subject to flash flooding, high velocity flows, debris flows, erosion, sediment movement and deposition, and channel migration" (Federal Register, 1989, p. 9528).

Alluvial Plain - a broad area on the piedmont plain with little relief and covered with alluvium.

Apex - "the point of highest elevation on an alluvial fan, which on undisturbed fans is generally the point where the major stream that formed the fan emerges from the mountain front" (Federal Register, 1989, p. 9528).

Avulsion - the rapid change in the location of a channel.

Base Level Stream - a large wash or river at the lower edge of the piedmont plain. Streams on the piedmont plain cannot erode below the level of this stream.

Diffluence - the point where a stream channel separates into two or more channels in the downstream direction.

Distributary Channel - a separated channel downstream of a diffluence that commonly has a terrace independent of other channels.

Distributary Flow Area (DFA) - the area (in square miles) on the piedmont plain downstream from the primary diffluence and bounded by the potential limits of major floods. The stream channels are separated by a wide variety of interfluves that range from high ridges well above large floods to low indistinct ridges (as found on many actively aggrading alluvial fans).

Drainage Basin Area (DA) - the area (in square miles) drained by a stream which is upstream of the primary diffluence.

Engineering Time - the 100-year design period commonly used in engineering practice.

Fanhead Trench - "a stream channel entrenched into the upper, and possibly the middle, part of the fan" (Bull, 1964, p.iv).

Inset Fan - an alluvial fan which has formed on the surface of an old fan or in between old fans.

Old Fan - an alluvial fan or plain that no longer has distributary flow and possesses a predominantly tributary drainage pattern.

Old Fan Remnant (relict) - a part of an old fan surface that has been eroded or partially buried.

Piedmont Plain - the region extending from the mountain front to the basin floor.

Primary Diffluence (PD) - the diffluence or bifurcation below which flow is distributary and above which the 100-year discharge is contained in the channel and flow is tributary (with the possible exception of relatively minor diffluences in the drainage basin). For actively aggrading alluvial fans the primary diffluence is the same as the apex.

Rock Varnish (desert varnish) - a natural accretion of manganese and iron oxides, clay minerals, trace elements, and small quantities of organic matter that form dark coatings on stable surfaces in terrestrial weathering environments (Dorn and Deniro, 1985, p. 1472).

Texture Domain - a region consisting of a unique drainage texture (Doehring, 1970, p. 3111-3113). The region is distinguished by the size and orientation of the crenulations which may be characteristic of the depths of channels, the drainage pattern, and whether erosion or deposition is the dominant process at work.

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