CONTRACT FCD 93-12

REVIEW OF CURRENT FEMA METHODOLOGY AND APPEAL DATA FOR FANS 5 AND 6 OF THE SCOTTSDALE FLOOD INSURANCE STUDY

Final Report

by
Hjalmar W. Hjalmarson, P.E.
Consulting Hydrologist

Submitted to

Flood Control District
of
Maricopa County

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PREFACE

This report deals with the problem of defining flood hazards of areas with distributary systems of channels and stable paths of flow. Several local hydrologists, engineers, and geologists have expressed concern that the method used by the Federal Emergency Management Agency (FEMA) to define the flood hazard on alluvial fans should not be used on landforms in Arizona with stable paths of flow. These concerns have been mostly ignored and the Flood Control District of Maricopa County(FCD) is considering their next recourse in the FEMA appeal process--to take the issue to U. S. District Court.

The author was hired to assess the issue and advise the FCD on whether they should take the issue to court. The author researched the development of the alluvial fan method and performed an exhaustive critical analysis of the method. "No punches are pulled" because there is a significant and unjustified potential loss of property value resulting from the misuse of the method. Also, the information provided herein could be used in court by the FCD. The author gives little or no benefit of doubt to the developers of the FEMA alluvial fan method. It is the professional opinion of the author that the numerous critical comments made in this report are justified.

Aug. 18, 1993 H. W. Hjalmarson

CONTENTS

Page

Summary 6
Introduction 8
  Alluvial fans and distributary-flow areas 8
  Movement of flow paths 9
  List of acronyms 9
FEMA alluvial fan method 10
  Telephone conversation 10
  Critical examination of Dawdy's(1979) report 12
  Critical examination of the DMA(1985) report 14
  Critical examination of appendix 5 of FEMA 37(FEMA, 1985) 20
  Critical examination of appendix 5 of FEMA 37(FEMA, 1993) 22
Consultation with Corps of Engineers 24
FEMA flood maps for fans 5 and 6 30
  Floodflow and sediment movement of sites 5 and 6 31
  Channel movement 33
  Channel entrenchment 36
  Hydraulic geometry 38
General comments 43
Selected references 46
Appendices
  A.--David Dawdy's comments on visit to fan 6A, June 29, 1993.
  B.--Corps of Engineers information including unpublished report by Boyd Lare and Gary Eyster.
  C.--Excerpts from Corps of Engineers report of the stability of flood control channels.
  D.--Report on flood hazard identification and flood plain management on alluvial fans by L. M. Magura and D. E. Wood.
  E.--FEMA flood map for fans 5 and 6 and report.
  F.--Letter to FCD from John Matticks of FEMA.
  G.--Original report by David Dawdy entitled Flood-frequency estimates on alluvial fans.
  H.--Report entitled Alluvial fan flooding methodology, An analysis by DMA consulting engineers.
  I.--FEMA 37 sections on alluvial fans.
  J.--Sample computation of hydraulic geometry exponents.
  K.--Letter from FEMA to FCD.

ILLUSTRATIONS

Page

Figure 1.--Plot of slope of alluvial fans and basin area for DMA sites and fans 5 and 6 19

2.--Plot of slope of alluvial fan and expansion angle for DMA sites and fans 5 and 6 19

3.--Approximate cross section at 2074 ft. elevation of fan 6A 34

4.--Schematic cross section of alluvial fan from Boyd Lare 34

5.--Location of hydraulic geometry sections 41

TABLES

Page

Table 1.--Basin characteristics of DMA sites with USGS gaging stations located in the Great Basin and the Colorado River Basin 15

2.--Flow pattern and channels movement characteristics of DMA sites 17

3.--Hydraulic characteristics of overland flow condition by Lare and Eyster 28

4.--Theoretical, average, assumed and computed hydraulic geometry exponents for channel cross sections 39

5.--Computed hydraulic-geometry exponents and soil type for channel cross sections in fan 6A 42

SUMMARY

The present status of the disagreement between the Flood Control District of Maricopa County(FCD) and the Federal Emergency Management Agency(FEMA) over the depiction of flood hazards for fans 5 and 6 near Carefree, Arizona is evaluated by: (1) critical examination of the development and application of the FEMA alluvial fan method, (2) consultation with present and retired personnel of the Corps of Engineers, and (3) critical examination of the FEMA flood maps for fans 5 and 6. Suggestions about "where do we go from here?" are offered including (A) we should pursue all means possible of resolving the issue between FEMA and the local communities before going to court, (B) we need dialogue between FEMA and the FCD on as much of a factual basis as possible, (C) consider publishing facts and decisions based on facts in technical journals if the letter of map revision process proves unsatisfactory, and (D) the FCD should produce a better method rather than criticize the FEMA alluvial fan method.

Alluvial fans are complex landforms that commonly form by deposited debris when floodwater leaves the confines of mountain canyons and narrow channels. Alluvial fans are in various stages of progressive aging. Young fans are actively aggrading and flow paths move over wide areas depositing debris and spreading floodwater. As fans age they become large relative to the drainage basin upstream. There is less floodwater and debris per unit area of the alluvial fan and large areas become isolated from debris deposition and floodflow. Some alluvial slopes have networks of incised distributary channels that appear to be very old alluvial fans that are stable or slightly eroding. The paths of flow on old fans are stable while flow paths on young fans are unpredictable and can change during flooding

The basis for FEMA alluvial fan method incorrectly assumes that paths of flow on all fans are unpredictable. Recent FEMA guidelines have recognized this error and caution the study contractor of the problem. The development of the FEMA alluvial fan method is based on several unsupported assumptions. A reference to a particular channel geometry formed during floodflow as based on "field evidence" is misleading. The original development of the method is seriously flawed by the unsupported assumption that the paths of flow are random on all alluvial fans. A subsequent study sponsored by FEMA makes the claim that the location of any stream channel on a fan is random but this conclusion appears unfounded. In fact, an overall channel stability is indicated for the 15 fans used for the study. There are no data available which substantiate the basic assumptions or the methodology.

The guidelines and specifications for study contractors of FEMA alluvial fan studies lack technical instruction for detailed studies The guidelines ignore the identification of an alluvial fan and the discrimination between active fans and systems of distributary channels on pediments. There are no instructions on how to define the apex and boundaries of alluvial fans. Terms such as "alluvial fan processes" should be defined because several processes are described in technical literature by geologists. The undefined methods and techniques cause confusion among technical specialists.

The Corps of Engineers has no published standards and guidelines for the definition of flood hazards of alluvial fans. The Corps does recognize there are active and inactive alluvial fans but the flood hazards are defined by individual offices. Apparently there are methods published in design memos for flood control projects that include alluvial fans. The work of two Corps engineers in Albuquerque, New Mexico was referenced in the development of the alluvial fan method. A lengthy discussion of the method with one of the engineers revealed there was little data on which the alluvial fan method was developed.

The method used by the study contractor to define the flood maps for fans 5 and 6 is not clearly in accordance with the published FEMA alluvial fan method. The published guidelines are unclear and the study contractor gave little technical detail on how the flood hazard was defined. For fan 6, four small alluvial fans seem to be defined at the ends of defined stream channels and the location of a single apex in accordance with the FEMA definition of "apex". is unclear. In fact, there may not be an apex for the system of channels. The fact that alluvial fan processes are absent because there is no mountain in the drainage basin is ignored. The apparent assumption that the site is subject to alluvial fan flooding in accordance with FEMA's definition of "alluvial fan flooding" is unsubstantiated. Several hydrologic and geologic characteristics of fan 6A, ignored in the report by the study contractor, that show the flow paths are stable are presented in this report.

Suggested steps to solving the problem are: (1) Show where the Alluvial Fan Method is inapplicable and why; (2) Examine the development of the FEMA methodology and request documentation of every assumption made. Also, ask for any unpublished data used to develop the method; (3) Present the documented evidence to FEMA and ask that we get together to resolve the issues and solve the problem. Journal articles should be considered to present the technical issues. Technical journal articles can carry significant weight among hydraulic engineers, hydrologists and flood plain managers throughout the U.S.. If FEMA won't work with us, then colleagues can serve as the referee; (4) Don't ever throw FEMA's method out. Rather, define where it applies and where it may not apply. Keep as much of FEMA on the table as possible; (5) Develop a better method of defining flood hazards.

FEMA has left the burden on state and local agencies to develop methods of identifying the kinds of flood hazards on alluvial fans. FEMA has greatly oversimplified the hazard with the alluvial fan methodology and has skirted it's responsibility as the national leader of the flood insurance program. FEMA has ignored the expressed concerns of many engineers, hydrologists and geologists familiar with alluvial fans in the arid southwestern United States. I feel FEMA's application of the alluvial fan methodology has departed from the spirit of federal, state and local agencies working together to reduce flood losses. FEMA's attitude toward sponsoring applied research and incorporating research results into it's operational efforts ought to be reviewed(National Academy of Public Administration, 1993).

INTRODUCTION

On February 26, 1992 the Flood Control District of Maricopa County submitted an appeal to preliminary FIRMS for FEMA designated fans 1-6 of the North Scottsdale Flood Insurance Study. The appeal for fans 5 and 6 was not resolved to the satisfaction of the FCD. The intent of this report is to (1)quantify whether the FCD should take the issue to U.S. District Court, (2) assess deficiencies in the FEMA methodology and the appeal by the FCD, (3) further define hydraulic conditions of fans 5 and 6, (4) present new information related to the stability of flow paths of fans 5 and 6, and (5) make recommendations for resolution of technical issues. The applicability of the FEMA alluvial fan methodology to fans 5 and 6 was examined based on topographic and geomorphic conditions. Published assumptions made in the development of the alluvial fan method were examined in detail and discussed with Mr. Dave Dawdy, the original author of the method(Dawdy, 1979), and Mr. Boyd Lare, the Corps of Engineers engineer referenced by Dawdy(1979, p. 1409). Several federal agencies including the U. S. Army Corps of Engineers were consulted to obtain published standards and guidelines for the definition of flood hazards on alluvial fans. A small scale copy of the revised Flood Insurance Rate Maps(FIRMs) was reviewed and the methods used by the study contractor were examined. Fan 6A was examined in detail using (1) detailed topographic maps and aerial photographs, (2) a detailed examination of soil characteristics with the assistance of U. S. Soil Conservation Service soil scientists, (3) a detailed field examination of hydraulic conditions, (4) a review of field notes from previous studies of the area (Hjalmarson, 1978), and (5) field reconnaissances with technical specialists including Mr. Dave Dawdy(See a summary of Dawdy's comments in appendix A).

The reader is reminded that this critical examination focuses on weaknesses rather than strengths of the alluvial fan method and related publications. Even with it's weaknesses, the alluvial fan method developed by Dawdy is considered a useful engineering approach to the definition of flood hazards of active-aggrading alluvial fans. Some of the assumptions made by Dawdy in the development of the method are unsupported by data. The FEMA alluvial fan method is considered inapplicable for fans 5 and 6 where the paths of flow and the area of the fan are considered stable.

Alluvial fans and distributary flow areas

Alluvial fans are landforms characterized by an apex where floodflow becomes unconfined and a land delta below the apex is formed where stream channels have a radiating pattern. Distributary flow is flow that divides into two or more distributary channels. A **distributary channel** flows away from the main(other) channel, is separate from the main channel, and commonly does not return to the main channel. **Distributary flow** is diffuse flow where there is at least one distinct diffluence at the outflowing branch of a stream. There generally are channel forks, joins, and outlets for a system of distributary channels and the number of outlets is more than the number of forks. These flow systems, which have

little to do with topographic relief, are called distributary flow areas(DFAs) **Sheet flow** also is diffuse, generally occurs where there is little topographic relief, commonly is unconfined and spreads freely, and is not considered to be distributary flow. Floodflow that leaves distributary flow areas onto base-level plains such as playas commonly is sheet flow. Areas with distributary flow(DFAs) have at least one channel fork or diffluence where at least two channel links are formed. Thus, **DFAs** are not landforms but rather areas of land where the drainage pattern is distributary as opposed to areas with the more common tributary drainage pattern. Because floodflow on alluvial fans commonly is distributary, alluvial fans are considered to be DFAs. Floodflow on some pediments is distributary and these erosional areas are also considered to be DFAs. Both aggrading landforms(alluvial fans) and degrading landforms (pleistocene sediments and pediments for example) have systems of distributary channels.

Movement of flow paths

The stability of flow paths on alluvial fans is an integral part of the nature of alluvial fan flooding. According to FEMA(1990A), alluvial fan flooding means flooding occurring on the surface of an alluvial fan or similar landform which originates at the apex and is characterized by high-velocity flows; active processes of erosion, sediment transport, and deposition; and unpredictable flow paths. Apex means a point on an alluvial fan or similar landform below which the flow path of the major stream that formed the fan becomes unpredictable and alluvial fan flooding can occur. Clearly, the method of defining flood hazards of alluvial fans or similar landforms by FEMA(1990B) is for surfaces with unpredictable flow paths.

List of acronyms

CofE	U.S. Army Corps of Engineers
DFA	Distributary-flow area
FCD	Flood Control District of Maricopa County
FEMA	Federal Emergency Management Agency
PD	Primary diffluence
SC	Study contractor
SCS	U.S. Soil Conservation Service
TEC	Technical evaluation contractor
USGS	U.S. Geological Survey

FEMA ALLUVIAL FAN METHOD

The initial author of the FEMA methodology, Mr. Dave Dawdy, was consulted on several occasions and also was hired to examine fan 6A(Dawdy's comments are in Appendix A). Dawdy's original paper(1979) and the subsequent study by DMA consulting engineers(DMA, 1985) were critically examined. Finally, the alluvial fan methodology given in the1985 and 1993 publications of FEMA 37 were critically examined.

Consulted with Dave Dawdy as follows:

Date	Commun -ication	Remarks
Dec. 1992	Telephone &written	Review of "Potential flood hazards and hydraulic characteristics of distributary flow areas in Maricopa County, AZ". This report was written while I was with the U.S. Geological Survey. I reviewed my notes and Dave's written comments about the report. Sites 2 and 3 of the report are FEMA fan sites 5 and 6.
May 1993	Telephone	Asked Dave to comment on final draft of the above report and discussed Dave's ASCE paper(1979).
June 1993	Telephone	Discussed Dave's progress with his re-review of the above report. Also discussed characteristics of FEMA fan 6A and invited Dave to visit the site at my expense.
June 29, 1993	Field visit	Visited fan 6A with Win Hjalmarson and Joe Tram. & written. Discussed stability of flow paths of fan 6A and how fan 6A compared with sites in the DMA study.

Telephone conversation

The following is an excerpt from our phone conversation during May, 1993. The actual conversation is presented because Dawdy's thoughts and insights given in his own words are considered important.

WIN.--The purpose of my paper "Potential flood hazards and hydraulic characteristics of distributary-flow areas in Maricopa County, Arizona" was to show there are differences among alluvial fans.

DAVE.-- "That was stated in (my) the original procedures. Say if you've got

Pearson Type III distribution. To prove otherwise is complex and probably inconclusive partly because of the limited long-term records of annual peaks for streams draining small-arid basins. Dawdy's development of the method is clever but is based on a flawed model of random flow paths. Suggest the FCD not take issue with the mathematical development because the problem lies in the underlying assumptions discussed previously and later in this report.

At issue is the random movement, or more basically, whether there is movement at all of flow paths on all alluvial fans. The results of my comparison of flow paths depicted on two sets of aerial photographs for fan 6A are given later. In regard to the statement by Dawdy concerning the random position of flow paths, surely interested hydrologists, engineers and earth scientists are deserving of factual support of such a profound statement.

Critical examination of the DMA(1985) report.

This report "Alluvial fan flooding methodology an analysis" was prepared by DMA consulting engineers for FEMA in October 1985. This report and the journal article by Dawdy(1979) are the only references which pertain to alluvial fan flooding given in FEMA(1990). The conclusions reached in this report are problematic and seem to contradict observations of channel movement(or lack of channel movement) following large floods at fans in California and Nevada(Appendix H).

The report is an admission by FEMA that the assumptions(Dawdy, 1979) are unsubstantiated. FEMA commissioned DMA to conduct the study to verify two key assumptions. The first, is that the location of any stream channel on a fan is random, that it has an equal probability of occurring anywhere across the fan. Second, is that the flow forms it's own channel and remains in one channel throughout the flow event except that the location of the channel can change through avulsion. Because Dawdy was employed by DMA, which was the TEC for FEMA at that time, an examination of Dawdy's assumptions by Dawdy himself is potentially biased and not an ideal scientific approach. The selection of the sample of alluvial fans for the study is a sound scientific approach except for (1) the sample was taken from a small geographic area of the arid southwestern U.S., and (2) the selection of sites within the small geographic area was not random. Some of the most active alluvial fans in the United States are in the area used by DMA and even then the conclusions reached may be unfounded. The sites were selected because the effects of recent flooding at the sites was more easily seen on aerial photograghs. The flow paths of recent flooding can be depicted more readily than flow paths of old floods. In other words, the sites were selected for hydraulic considerations and not necessarily for hydrologic considerations. It appears that the sample of DMA fans may include the more active alluvial fans, or fans which tend to flood more often or more noticably, in the area.

COMMENTS: A review of measurements of basin, channel, peak flow, and hydraulic characteristics made by DMA and the USGS is recommended. The author personally reviewed much of the peak flow data collected by the USGS in the Great and Colorado River Basins. About three years ago, I asked the Nevada district of the USGS to examine the records at Humbolt River Tributary near Rye Patch, NV. A revision to the drainage area has since been made. A brief examination of the data used by DMA revealed an error in the drainage area for Las Vegas Wash near Henderson, NV(09419697) as shown in Table 1 of this report.

Table 1.--Basin characteristics of DMA sites with USGS gaging stations located in the Great Basin and the Colorado River Basin.

SITE Name	USGS No.	AREA sq. ft.	ELEV ft.	EVAP in.	INTSI in hr	PRECIP in.
Las Vegas	09419697	1.17**	2370	79.1	3.00	6.0
Pinte	09423300	3.40	3670	74.7	4.00	6.0
Tahquitz	10258000	16.90	6800	61.3	5.11	24.0
Whitewater	10256000	57.50	5600	60.5	5.85	26.0

SITE (cont.)	LENGTH mi.	LAT	LONG
09419697	2.84	36.0314	115.0300
09423300	2.76	35.4667	114.9390
10258000	9.30	33.8050	116.5580
10256000	17.40	33.9467	116.6400

Source: USGS Streamflow and Basin Characteristics computer file.

** *On p.23 and Tables 2 and 3 of the DMA report the area is incorrectly listed as 0.06 square miles.*

On January 29-31, 1992 I was a member of a team of USGS surface water specialists who met in San Bernardino, CA to discuss problems with indirect measurements made on high-gradient streams and streams with unstable channels. One of the areas in the U.S. where past indirect measurements of peak discharge may be in error is the area used by DMA. Several USGS indirect measurements may be affected by debris flow or excessive scour that was not recognized when the measurements were made. Mr. Robert Meyer of the USGS CA district is reviewing these records and measurements. I visited several alluvial fans in the San Bernardino area which potentially were much more hazardous than most alluvial fans in AZ.

The conclusions reached by DMA appear unfounded. For several of the sites the flow was in more than one entrenched channel and DMA separated these sites as shown in the DMA report by Figures 18 and 19 and Table 3(DMA, 1985). DMA also did not show that channel relocations will occur during the FEMA regulatory flood. In fact, an overall channel stability may be indicated by the report based on observations of the absence of channel movement at most of the fans used for the study. There was apparent channel movement at only one site and possible movement at a few other sites(Table 2). At 11 of the 15 fans the floodflow apparently followed the pre-existing network of channels. The lack of observed channel movement following large floods on fans like Lytle and Cucamonga indicates such fans have stable flow paths.

A split-channel methodology resulted from the DMA study(Appendix H). Two methodologies are presently used - the single and multiple channel methods(FEMA, 1990). This practice is inconsistent with the original model where Dawdy(1979, p.1408) states "The degree of flood hazard is approximately equal for all points that are radially equidistant from the fan apex." If there is a uniformity of flood-hazard degree then how can two distinct methods be used? DMA appears to suggest that parts of alluvial fans are stable and other parts are not. Such logic is fuzzy.

The first paragraph of the Theoretical Aspects on p. 8 is separated in parts to show the hypothetical stages of fan development as follows:

Alluvial fans develop from the outwash of a canyon draining an erodible upstream watershed, which is subjected to high intensity and short duration rain storms. The sediments eroded from the watershed by the rain storms are transported downstream by the canyon flow and discharged onto the valley floor below the mouth of the canyon.

A.--Due to the spreading of water and the flat valley floor, the flow on the valley floor slows and becomes shallow. This results in low sediment transport capacity and causes the sediment to drop out, initially near the mouth of the canyon.

B.--As the deposits continue to accumulate, the slope of the alluvial deposits increases, and so does the sediment transport capacity of the flow.

Table 2.--Flow pattern and channel movement characteristics of DMA sites.

(Note: The characteristics below are based on information given in the published report.)

Site	Fan-like floodflow	Channel movement	Remarks
Northunderland	yes	no	Confined until became radial pattern.
Mason	yes	no	No developed channels depicted on photos.
Humbolt-Rye Patch	yes	unclear	Expanded to braided sheet flow. Unclear if flood channels were defined.
Rocky Canyon	yes	recent	Entrenched in multi-channels until became braided pattern. Recent movement indicated.
Humbolt-Oreana	yes	no	Entrenched in 2 channels until became braided. Tendency for future channel relocation.
Las Vegas	no	no	Single channel. Braided after combining with adjacent fan.
Piute	no	no	Single channel to confluence with channel from adjacent fan.
San Antonio	no	no	Flow in channels.
Lytle	yes	no	Single channel became braided.
Day	yes	yes	One new channel. Levees.
Deer	yes	no	Became braided.
Cucamonga	yes	no	Levees and structures.
Tahquitz	yes	unclear	Two channels with braided flow between. Levees.
Palm Canyon	yes	no	Most flow in one channel.
Whitewater	yes	no	Several channels.

C.--The sediments are therefore carried and deposited further downstream.

D.--When the alluvium reaches the canyon bed elevation, flood channels are developed by the momentum of the canyon flow.

E.--At this time, the deposition of sediment is extended further downstream along the channels. For unusual events, the sediment discharged onto the alluvial fan is so great in quantity that rapid deposition of sediment occurs at a point along a channel. Sediment deposition lessens the channel slope above the point of deposition, but also steepens the slope below the point. Lessening of channel slope further accelerates the deposition process already begun.

F.--The deposition process rapidly extends upstream along the channel reach to a point that channel overflow occurs and a new channel is developed to transport the flood water.

G.--This process of backfilling an existing channel and developing a new channel is called an avulsion.

COMMENTS: In Arizona not all fans are on the valley floor as stated in item A. Several fans are inset in old-fan remnants on piedmont slopes. In regard to item B, the slope of the upper part of the fan decreases as does the sediment transport capacity of the flow. Only on the lower part of the fan are the slopes steepened.

The above development of a fan, as depicted by DMA, is for the early stages when the fan is increasing in volume and area. In the later stages of fan development the fan is large and the sediment delivered per unit of fan size is less than in the early more active stage of development. Areas on the fan become isolated from floodflow and tributary channel systems develop on these areas.

The sample of fans used by DMA appears to include fans in various stages of development. Some fans appear more stable than others. On the more stable fans large areas may not be subject to the FEMA regulatory flood. The failure to investigate the apparent different flood hazards associated with fans of different ages and different geographic locations in the U.S. is considered a major weakness of the DMA report. For example, the slope of fans 5 and 6 is less than the slope of all but one of the DMA fans(Figures 1 and 2). Also, as shown in figure 2, a rough estimate of the expansion angle(Figure 1, Appendix H) for fans 5 and 6, defined to include the flooded areas(Appendix E), is less than the expansion angles for most DMA fans. The computed expansion angle for fans 5 and 6, however, has limited meaning because there are small fans nestled within the area encompassed by the angle. The estimated expansion angles for fans 5 and 6 are not comperable to the expansion angle depicted by DMA(Figure 1, Appendix H) mostly because the incised channels of fans 5 and 6 are stable. In fact, the upper end of "FEMA fan 6" is on a pediment.

```
      -  *
0.105+     *
      -                    Note: Plot is approximate.
s-af  -
      -
      -
0.070+ **
      -  *
      -  **                          *
      - *   *     *     *
      -
0.035+ **    *
      -              *    *
      -   * fan 6
      -  **fan 5
      -
      +-------+-------+-------+-------+-------+
      0      20      40      60      80     100  Area, in mi2
```

Figure 1.--Plot of slope of alluvial fan(s-af) and basin area(area) for DMA sites and fans 5 and 6.

```
      -
      -                          *
0.105+                       *
      -
s-af  -                                Note: Plot is approximate.
      -
      -
0.070+                          **
      -          *
      -        *    *     *              *
      -              * *          **
      -
0.035+         *         *    *
      -                    *       *
      -        * fan 6
      -     * fan 5
      -
      +------+------+------+-----+------+-------+
      0    20     40     60     80    100    120  ex-a, in degrees
```

Figure 2.--Plot of slope of alluvial fan(s-af) and expansion angle(ex-a) for DMA sites and fans 5 and 6.

Critical examination of Appendix 5. of FEMA 37(FEMA, 1985).

An important test of the alluvial fan methodology is how well the flood prone area maps depict the flood hazard for sites such as fans 5 and 6. Another important test is the reproducibility of the method by other hydrologists and engineers. This implies that standards and guidelines are available that can be followed by engineers and hydrologists and the bounds for scientific judgment are not too soft. Lastly, the methodology should accurately model the active geologic and hydrologic processes of fans 5 and 6. For example, a methodology based on aggrading processes when applied to a system of distributary channels incised in Pleistocene sediments can arbitrarily emphasize the random movement of flow paths and lead to systematic bias of the model.

This "Guidelines and specifications for study contractors" of FEMA flood insurance studies dated September 1985 included alluvial fans with split flow conditions. The method outlined in the guidelines is based on procedures developed by Dawdy(1979) and later modified by DMA(1985) to account for split flow conditions generally found in the lower reaches of active alluvial fans. There are at least two typographic errors. For the last equation on page A5-4, lambda is the exponent for previous term(Appendix I). For the first equation on page A5-5, the exponent of e is both of the terms which should be within a single parenthesis. A critical examination of the latest guidelines dated March 1993 follows this critical examination. The following comments are intended to identify deficiencies and sources of confusion in the guidelines of September 1985. In general, the guidelines lack specific technical procedures for defining the boundaries of alluvial fans.

There are a few terms such as "alluvial fan processes" and "active alluvial fans" that need definition. Alluvial fans are in various stages of development and some fans are aggrading today while other fans are stable or even eroding today. These different fans may be subject to debris flows, aggradation, degradation, or hydraulic processes. Some fans are more active that other fans. Some areas are subject to frequent inundation and debris deposition while other areas are stable or eroding with developed tributary drainage systems. Some of the more stable fans have large trees along the distributary channels and brush, grasses and trees scattered over much of the areas between the channels. Other alluvial fans have little vegetation. Thus, what are alluvial fan processes and what are active alluvial fans?

Unsupported statements such as "the channel will occur at random locations at any place on the fan surface" are considered inappropriate. There is no proof of the statement. The "geologic" reasoning that there is equal accumulation of sediment on the same contour also is unsupported. Therefore, the assumption that the frequency of flooding is the same along the contour is flawed. For example, no explanation for the fact that points of a particular contour of an alluvial fan are at different distances from the apex is given. The contours of some alluvial fans are not symmetrical about the apex(See for example figure 6.2.5 of

Appendix C). If sediment accumulation is equal on the same contour, there would be more symmetry of the contours about the apexes of fans than is observed on topographic maps. Also, fan processes are progressive and old-mature fans may, in fact, have a network of channels eroded in cemented Pleistocene or Holocene sediments.

The guidelines are unclear about how the topographic, geologic, and soils maps are to be used to define the apex and boundaries of a particular alluvial fan. FEMA has stated in writing(letter of 4/12/93 to Jim Bruner in Appendix F) that they are not charged with the geologic description of landforms but the more informed hydrologist may realize that the nature and extent of flood hazard is, in fact, related to the geology. The soil maps may show younger soils on parts of the fan and older cemented soils on other parts of the fan. Is the hydrologist to ignore this data and if not, how is the hydrologist to use this information? FEMA suggests that geologic and soils maps should be used in a reconnaissance but how these maps are to be used is unclear. These undefined methods and techniques cause confusion amoung hydrologists and engineers.

The following are comments about specific statements within the subject guidelines:

Sec. A5-2a.,1st sentence(p.A5-1). I agree that flow does not spread evenly over the fan surface.

Sec. A5-2a.,2nd sentence. I guess there is a single channel at the apex of most alluvial fans but not at site 6 near Carefree, AZ where there are at least 2 distinct channels in the pediment area at the apex. These channels are at, upstream of, and downstream of the apex. In fact, there really is no apex at fans 5 and 6(See comments in Appendix A). I also cannot agree that the single channel is formed by erosion of the loose material that makes up the fan. At inset fans, for example, the channel is eroded in the old fan material on which the present (active) fan is depositing material.

Sec. A5-2a.,3rd sentence. What are the slopes relative to? I'm confused because not all fans are steeper at the top than at the middle and bottom. Also, where is the flow critical; in the main channel(s) and/or on the adjacent land? The overflow areas of any alluvial fan in Arizona is covered with boulders, bushes, and scattered trees. Critical velocities for shallow floodflow seems unlikely. Any direct measurements of flow velocities and depths in the upper regions of alluvial fans should be given or referenced. Do we really know this statement is a fact for all alluvial fans or is it a judgment based on indirect measurements on some fans?

Sec. A5-2a.,4th sentence. I've never seen an analysis of data that supports this statement of apparent fact. Hjalmarson and Kemna(1991) found this to be true for fans with a high degree of hazard but not for all fans(DFAs). Appears this statement is an unsupported judgment perhaps based on experienced observation but not based on rigorous mathematical methods.

Sec. A5-2a.,5th sentence. Dawdy uses this assumption based on the unpublished work of Lare and Eyster. For a rectangular channel the slope of stage-discharge relations is 2.5 or the exponent of the hydraulic geometry relation is 1/2.5 or 0.4. I examined this exponent for 12 sites in Maricopa County and could not find support for an average exponent of 0.4 for mean channel depth. Apparently, this statement is unsupported and perhaps influenced by the hypothetical width-depth model used by Dawdy to estimate the depth of floodflow on AFs.

Sec. A5-2a., 2nd paragraph. Dawdy uses this concept of a single equivalent channel without supporting it with physical documentation. This assumption of a single equivalent channel appears to be a judgment call only. This assumption may be considered a useful engineering approach to solving the problem of managing development on some fans but there is no physical documentation that the single equivalent channel applies to all alluvial fans.

Sec. A5-2b. and Sec. A5-2c. Depends on the previous assumed conditions.

Sec. A5-2d. This statement appears to be based on an assumption that avulsions occur during an average 100-year period. It is assumed that on the average, there are enough avulsions to cause an equal probability of flooding at any point on the AF. There are no data to support the assumption except for the geologic reasoning discussed previously.

Sec. A5-4, I. The use of D = pressure + velocity head is not supported. The addition of velocity head appears arbitrary and may depict an unrealistically high degree of hazard. The use of total head for flood depth appears to be all judgment and is in disagreement with Boyd Lare(retired engineer, CofE), one of the first engineers to define flood hazards of alluvial fans in New Mexico. Boyd's comments are given in discussion item B of this report.

COMMENTS: Where are the data that support the several factual appearing statements in the guidelines? Also, can FEMA explain why several of the apparently unsupported statements do not to apply for fans in AZ(Hjalmarson and Kemna, 1991)? For example, why did the study contractor for site 6 not use a single channel at the upstream end of the fan?

Critical examination of Appendix 5. of FEMA 37(FEMA, 1993).

These revised guidelines and specifications for studies of alluvial fan flooding may be an improvement over previous guidelines but remain based on unsupported assumptions, many of which are discussed previously in this report. The added comment in the introduction concerning the lack of active deposition on some portion of a fan is unsupported by facts or reason. Does it mean that some areas of inactive deposition,

perhaps with significant erosion of stream channels traversing the alluvial fan, may not be subject to FEMA's methodology? Or, instead, does it mean that eroding areas of Pleistocene sediments are subject to FEMA's methodology because there is remote chance that because of a climate change the channels may now aggrade?

A major source of irritation with the methodology continues to be the assumption that the flood follows a random path down the fan surface. There is considerable evidence that some alluvial fans(DFAs) have distributary channels eroded in Pleistocene sediments that are resistant to erosion and lateral bank movement. FEMA continues to ignore this fact that some sediment surfaces of alluvial fans are degrading and are incised by a network of distributary channels not subject to relocation under natural conditions. It is unclear why FEMA continues to ignore the concerns expressed by numerous technical experts familiar with floodflow conditions of the arid southwestern United States.

The author attempted to obtain data which support the relation discussed in item 3 on page A5-2. No data were available from Boyd Lare or the CofE office at Albuquerque. FEMA backs up Dawdy's claim that data are available from the CofE(Appendix K) but the CofE says there are no data.

CONSULTATION WITH CORPS OF ENGINEERS

The purpose of this discussion item was to consult with the Cof E and substantiate whether or not fans 5 and 6 are represented by fans studied by FEMA and thereby determine if the FEMA methodology is appropriate. Little information was available from the Cof E and the greatest source was Mr. Boyd Lare, retired engineer, U.S. Army Corps of Engineers. Both Boyd Lare and Gary Eyster are referenced by Dawdy(1979) on page 1409 of his paper as the source of the dd/dw =-.005 relation. Gary Eyster was unavailable for comment because he is on a year leave without pay from the Cof E. During May 1993 I discussed the Dawdy(1979) method with Boyd Lare. The following is an account of my contact with the Albuquerque office of the Cof E and my conversation with Mr. Boyd Lare.

Dawdy says the relation is based on field evidence and there is an implication(Dawdy,1979, p. 1408) that the field evidence was for flow on alluvial fans. Boyd Lare and the U. S. Army Corps of Engineer's office at Albuquerque, New Mexico have no field data to support this relation. Boyd Lare and Gary Eyster coauthored an unpublished paper which they presented at a FEMA meeting. Mr. Frank Jaramillo, U. S. Army Corps of Engineer's, Albuquerque, New Mexico, mailed a copy of a draft of this paper to me during May 1993. Frank said there were no data available that support the relations in the paper. I attempted to contact Mr. Gary Eyster but Frank said he was on a year leave without pay from the CofE. The following analysis includes comments by Mr.Boyd Lare during a telephone conversation between Boyd Lare and myself on this subject.

According to Dawdy(1979, p. 1408) there is field evidence that supports his estimate that a channel stabilizes approximately at the point where dd/dw = - 0.005. Dawdy attributes the use of this relation to geomorphologic reasoning and principles but there are no data that support his reasoning. According to Lare:

1. The relation of dd/dw = -.005 is not really based on a whole lot of field data.
2. It was developed by taking a look at the hydraulics of the situation. You obtain a plot of depth and width for a channel cross section. You get a point where the depth doesn't decrease very much as width increases.
3. For that type of channel there is the potential to create a channel anywhere across the fan when the channel avulses. You can **assume** it will establish a channel that looks pretty much the same and the depth would be pretty close.
4. You are determining the maximum the flow will spread out because it can't get any shallower. Boyd seems to mean that at dd/dw = -0.005 the flow is at a maximum attainable width and a minimum attainable depth.
5. You are trying to bottle up the flow into an area of the alluvial fan and see what the maximum width might have been.

There appears to be no data to support the relation dd/dw = -0.005. The relation was developed by Boyd Lare and Gary Eyster using assumed hydraulic conditions. Boyd admits he used judgment and not facts to represent what happens on an alluvial fan. Apparently, Boyd developed the method based on his field observations of flow in sand channels and simply used his judgment to transfer his hypothetical relation to the channel that potentially could form on an alluvial fan. The width of floodflow simply occurs where the depth doesn't get much smaller as indicated on the relation of width and depth.

The following is an examination of the relation dd/dw = -.005(dw/dd= -200) as used by Dawdy(1979, p. 1408).

The overland flow condition in Fig. 7 of Magura and Wood(1980) is first examined(See Appendix D). The relations in Figure 7 are from unpublished work of Boyd Lare that is referenced by Dawdy(1979, p. 1409).

At critical velocity, $V = (gd)^{1/2}$ ..... (1)

and for the cross section of the assumed overland flow condition

$$Q = vdw \qquad (2)$$

where

d = critical depth(average depth because bed of channel is flat and at same elevation),
v = avg. velocity,
w = width of flow path.

Combining equations (1) and (2)

$$Q = w\, d^{3/2}\, g^{1/2} \qquad (3)$$

and rearranging equation (3)

$$w = CQ\, d^{3/2} \qquad \text{where } C = 1/g^{1/2}$$

differentiating the function of w with respect to critical depth(d),

$$dw/dd = -3/2\, CQ\, d^{-5/2} \qquad (4)$$

at g = 32.2, -3/2 C = -.264 and the equation becomes

$$dw/dd = -.264\ Q\ d^{-5/2} \qquad (5)$$

for the hypothetical value of dw/dd = -(1/.005) = -200 (from p. 60 of Magura and Wood(Appendix D), with the correction for the missing negative sign)

$$d = 0.0705\ Q^{.4}$$

and for the values of discharge, Q, shown in figure 7 of Magura and Wood,

Q	d	w
1000	1.12	149
4000	1.95	260
12000	3.02	403
18000	3.55	474

Thus, the method used by Magura and Wood is unnecessary because, as shown above, there is a direct solution of width and depth for a given value of dw/dd. The use of Manning's equation is unnecessary to define the width versus depth relations shown in Figure 7 of Magura and Wood(1980).

The Manning equation can be used to examine the hydraulic conditions for the imagined overland flow conditions used by Dawdy(1979).

Manning's equation is

$$Q = (1.486/n)\ A\ R^{2/3}\ S^{1/2} \qquad (6)$$

where

A = area of cross section(A = wd),
R = hydraulic radius(R = d for the overland flow conditions),
S = friction slope(S = slope of alluvial fan surface for the overland flow conditions),
n = roughness coefficient.

Rearranging and substituting

$$n/S^{1/2} = 1.486\ w\ d^{5/3} \qquad (7)$$

Equations 5 and 7 are used to examine the Manning roughness coefficients needed to satisfy the hydraulic conditions for the assumed overland flow.

For a given surface slope of an alluvial fan the roughness coefficient must be less than the roughness coefficient needed to maintain the critical velocity for the assumed conditions. If the surface of the alluvial fan is rough and the flow is turbulent, critical velocities cannot be attained because of high energy losses. For the range of surface slope conditions of most of the fans studied in Arizona by Hjalmarson and Kemna(1991, p. 48), the computed roughness coefficients are shown in table 1. The depths(d) and widths(w) are computed for the four discharges in Figure 7 of Magura and Wood(1980) and the roughness coefficients(n) are also computed for slopes of 0.007, 0.01, 0.02 and 0.03. Three values of dw/dd are used to show the effect of larger and smaller values of dw/dd on the assumption that dw/dd=-200(Table 3). Critical velocity is maintained for all values of dw/dd.

For the assumed overland flow condition, the roughness coefficient(n) for critical velocities increases as the slope of the fan surface increases from 0.007 to 0.03. The computed roughness coefficient also increases as the computed critical depth(d) increases. Thus, to accomplish the condition dd/dw = -.005 assumed by Dawdy(1979), the roughness coefficient of the surface of the alluvial fan must change with depth of flow and slope of the fan.

The alluvial slopes of fans in Arizona typically are composed of sand, gravel and scattered cobbles and boulders. The slopes typically are covered with scattered grass, brush, cacti, and small trees. The surfaces also are typically irregular and dissected by numerous rills and small channels.

Values of Manning's n for alluvial fan surfaces can range from 0.020 to more than 0.080. Typical base values of roughness coefficient range from 0.025 for soil and sand(Thomsen and Hjalmarson, 1991) to about 0.060 for cobbles and boulders. Adjustment factors to the base value typically are from 0.005 to 0.010 for irregularity of the fan surface, 0.002 to 0.005 for obstructions such as fallen trees and cacti, and 0.010 to 0.050 for vegetation such as weeds and dense brush and bushes. For flow depths less than 2 feet, roughness coefficients less than about 0.035 are considered uncommon.

Table 3.--Hydraulic characteristics of overland flow condition by Lare and Eyster (unpublished report, 1978) and referenced by Magura and Wood (Figure 7, 1980) and Dawdy(1979, p 1408).

[Q, discharge, in cubic feet/sec.; dw/dd, first derivative of w = function of d with respect to d; d, critical depth, in feet; w, flow path width, in feet. Based on FEMA methodology dw/dd only occurs at -200]

Q	dw/dd	d	w	Computed value of Manning's n at indicated amount of slope			
				0.007	0.01	0.02	0.03
1,000	-10	3.70	25	0.027	0.033	0.046	0.057
	-200	1.12	149	.022	.027	.038	.046
	-1,000	.59	392	.020	.024	.034	.041
4,000	-10	6.45	43	.030	.036	.051	.062
	-200	1.95	260	.025	.029	.041	.051
	-1,000	1.02	682	.022	.026	.037	.046
12,000	-10	10.0	67	.032	.039	.055	.067
	-200	3.02	403	.026	.032	.045	.055
	-1,000	1.59	1,059	.024	.028	.040	.049
18,000	-10	11.8	79	.033	.040	.056	.069
	-100	6.18	206	.030	.036	.050	.062
	-1,000	1.87	1,245	.024	.029	.041	.050

For each of the four discharges the computed maximum allowable roughness coefficient appears smaller than is typically found on alluvial on alluvial fans in Arizona for shallow depths and small slopes. Thus, one of the most important elements(critical velocity) of the assumed flow condition is not satisfied for most alluvial fans in Arizona with slopes less than about 0.01 or depths of flow less than about one foot. The surface of these fans is relatively rough and critical velocities of floodflow are considered unlikely. Roughness coefficients for overland flow on many other active alluvial fans with greater slopes and potential flow depths also exceed the computed values(Table 3). Except along the defined channels of typical fans with slopes less than about 0.02, the attainment of critical and supercritical velocities over much of the fan surface is considered unlikely for the three values of dw/dd and four values of discharge(Table 3). At dw/dd = -200, larger roughness coefficients than the maximum roughness coefficients shown in Table 3 are common over much of the surface of alluvial fans in Arizona. The adjustment factor to base values of Manning's n for vegetation commonly is large because the surfaces of alluvial fans(distributary-flow areas)

in Arizona are relatively stable and the vegetation is undisturbed by floodwater.

The presence of large desert trees, smaller desert vegetation, and incised channels on many alluvial fans in Arizona is evidence that floodflow does not erode a new channel to the parameters defined by Dawdy(1979) and FEMA. The 'n' value thus obtained is not substantiated by field data.

Although there are no known direct measurements of floodflow depth and velocity on alluvial fans in the arid southwestern United States, it is a well known fact that Manning's n is inversely related to depth of flow for relatively shallow depths(Barnes, 1967). Emmett(1970, figure 14) found for depths of less than 0.1 ft., values of Manning's n from about 0.2 to more than 1.0 on hillsides in west-central Wyoming. Jarrett(1984, figure 2) presented several relations of Manning's n and hydraulic radius for defined channels which depicted significant inverse relations. The effects of roughness elements on or near the land surface tend to diminish as the depth of flow increases. The effect of vegetation depends greatly on depth(Thomsen and Hjalmarson, 1991). Because the vegetation tends to be more dense on alluvial fans than on adjacent land, the Manning roughness coefficient can be large and depth dependent. Reconnaissance photographs of five alluvial fans considered representative of alluvial fans in Maricopa County depict hydraulically rough fan surfaces covered with bushes and scattered trees(Hjalmarson, 1993, in press).

A letter from Vern Bonner, Chief of the Training Division, Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA. during late May, 1993(Appendix B) indicates the CofE does not have published guidelines for defining flood hazards on alluvial fans.

A review of a draft of a Cof E engineer manual(EM) "Stability of flood control channels" dated January 1990 which was scheduled to be incorporated in EM 1110-2-1601, Hydraulic Design of Flood Control Channels indicates the general characteristics of alluvial fans are described in section 2.1.2 and design characteristics for stability are given in section 6.2.3.. These two sections are in Appendix C. The report discusses fans that are actively aggrading and fans in a stable or degrading state. It recognizes that fans with a perched principle channel in relation to ground equal distances from the apex and that are unvegetated are likely to be actively aggrading. Fans with perched principle channels are dipicted by Boyd Lare(Appendix B) The report also recognizes that fans that are vegetated with an entrenched primary channel may be stable or degrading.

COMMENT: Mr. Boyd Lare should be credited with the ideas which led to the Dawdy(1979) method. Clearly, Boyd hypothesized the wide-flat channel that stabilizes at dd dw = -.005. He also had observed critical and supercritical velocities on alluvial fan in New Mexico. However, when Dawdy offered Boyd co authorship of his paper, Boyd refused. Boyd told me during our conversation in May 1993 that he felt Dawdy's method had gone beyond reality.

FEMA FLOOD MAPS FOR FANS 5 AND 6.

As previously stated, an important test of the alluvial fan methodology is how well the flood prone area maps depict the flood hazard for sites such as fans 5 and 6.. Another important test is the reproducibility of the method by other hydrologists and engineers. This implies that standards and guidelines are available that can be followed by engineers and hydrologists and the bounds for scientific judgment are not too soft. Lastly, the methodology should accurately model the active geologic and hydrologic processes of the particular DFA. For example, a methodology based on aggrading processes when applied to a system of distributary channels incised in Pleistocene sediments can arbitrarily emphasize the random movement of flow paths and lead to systematic bias of the model.

It seems there are no published standards that clearly define the method used by the study contractor to delineate the apexes and flood boundaries of fans 5 and 6 . According to Ed Mifflin of Michael Baker, Jr., Inc., the technical evaluation contractor(TEC) for FEMA, the apexes and boundaries of the "alluvial fans" were defined using topographic maps and aerial photographs. The study contractor(SC) (for fans 5 and 6 the SC also appears to have served as the TEC) next assumed that floodflow could inundate the entire area(See Appendix E) within the boundaries defined and gave the areas a zone designation of AO. Because the FCD wanted the depths and velocities defined, the study contractor used the FEMA alluvial fan methodology to define the depths and velocities(Ed Mifflin, oral communication). The FEMA alluvial fan method was used to define the downstream limit of zone AO.

Before discussing the depiction of flood hazards(Appendix E) it is important to note that the original flood boundaries that were reviewed by the TEC were for much larger areas for fans 5 and 6. The apexes were further upstream and large areas adjacent to large incised channels which effectively conveyed the 100-year peak discharge were included in zone AO. Thus, the author feels the latest flood maps represent an improvement in the depiction of the potential flood hazard of fans 5 and 6. The areas prone to flooding in the upper reaches are approaching those described in general terms by Hjalmarson and Kemna(1991).

The flood maps(Appendix E) appear odd and unlike common fan like areas (FEMA, 1990B). The apex of fan 6 is undefined and there is no mountain in the drainage basin. On June 29, 1993 David Dawdy, Joe Tram and I visited fan 6A from the "apex" to a few miles downstream(Appendix A). Flow is constricted by granite outcroppings at the edge of the bedrock pediment. These lateral constrictions form the "apex" of the eroding surface. The stream profile is fairly uniform for about 15,000 ft. above and 30,000 ft. below the "apex"(Hjalmarson, fig.7, in press). Four separate "alluvial fans" are depicted by the SC at the ends of defined channels which convey the computed 100-year discharge. It is unclear if four apexes are modeled and if so, the SC has not explained how the floodflow can divide into four stable channels. Does the fan start at the uppermost diffluence? If so, the SC did not explain the presence of a fan on the pediment. Hjalmarson

and Kemna(1991) applied methods by Doehring(1970) to discriminate between the pediment and alluvial plain for fans 5 and 6 and found that the two uppermost diffluences are on the pediment. The SC also has neglected to explain how the channel forks above fan 6A are not unlike those below the "apex" of fan 6A(not shown in Appendix E).

What happens to the flood hazard in the defined channels below the northern three "fans"? The SC has spread the floodwater in semiconfined fan like areas while not defining the hazard in the entrenched channels downstream. A significant flood hazard remains undefined below the three small fans as stated in the FEMA report for the site(Appendix E).

The channels in fan 6A are incised in Pleistocene sediments separated by Pleistocene and older Holocene interfluves. The soils of these sediments are well developed with distinct B horizons of carbonates. The channels and surface are stable or slightly eroding. The SC has depicted widespread inundation where several large-stable interfluves are above the level of flooding. The SC has not explained how this dipiction was made or the basis for such widespread inundation.

The SC to some extent may have followed the latest guidelines for study contractors (FEMA, 1993). Unfortunately these published guidelines do not explain how to use available topographic, geologic, and soils maps(FEMA, 1993, p.A5-3) to define the apexes and boundaries of alluvial fans. In fact, the guidelines do not explain precisely how to identify if a particular landform is an alluvial fan or how to distinguish an alluvial fan from a pediment.

Some hydraulic, soil and geomorphologic characteristics pertinent to the definition of flood hazards of fans 5 and 6(fan 6A in particular) follow.

Floodflow and sediment movement of fans 5 and 6.

The soils adjacent to the major streams are on fan terraces that have been eroding slightly during the past few hundred or perhaps thousand years. The soils of these terraces are well developed and commonly are oxidized to depths of 1 1/2 to 2 feet. There is a distinct B horizon with a build up of limy clay from leaching of clay minerals from the surface part of the soil to the lower part of the soil. There are systems of tributary channels developed in these eroding areas that are commonly located between the several distributary channels that emanate from the primary diffluences(PDs). In the lower parts of the DFAs the soils contain more gravel and are not as well developed. The calcareous gravely sandy loam is resistant to erosion along the washes and the hazard to runoff erosion is slight(Camp, 1986, p.71). The infiltration of rainfall is moderately rapid and the residual amount of runoff is small.

The channels and adjacent floodplains of streams emanating from the PDs are composed of sandy loam and gravely-sandy loam. The stream channels are composed of more granitic type gravel than the floodplains. The channel beds can easily erode and the channel banks are susceptible to erosion especially where unprotected by vegetation. The banks generally are

calcareous sandy loam starting from a few inches below the surface. The amount of cementation by the calcium carbonate varies along the channel banks and commonly affords slight to moderate resistance to erosion. Some channeling, deposition and streambank erosion is common during infrequent flooding. Most of the erosion and deposition occurs along the unstable streambeds which scour and fill as sandy-gravely material is moved and deposited by ephemeral runoff and infrequent floodflow. Soils along the major streams are not developed and are stratified by deposits of sediment and organic material. The deposits occasionally are washed away by large floodflows. The beds of the major streams have cut into the underlying old fan remnants or fan terraces as described by Camp(1986).

Although there are no continuous records of streamflow for streams draining nearby similar basins, the runoff characteristics can be estimated from records of streamflow in the region. The coefficient of variation for ephemeral streams at similar latitude in the southwestern U. S. probably is more than one(Hjalmarson, 1991) and there are many years with no flow. Runoff typically is only a few hours each year. Most of the runoff over periods of several years probably is from one, two, or possibly three storms.

Floodflows are competent to move most of the bed material of the channels that emanate from the primary diffluences of sites 5 and 6. Hjalmarson(1993, in press) showed the channel competence of the 2-year flood was several times more than the grain size of the bed material at the primary diffluences. The channel competence along the channels in the DFAs appears considerably larger than the grain size of the channel beds(SCS, 1986, table 13). Most floods are not of sufficient duration and magnitude to move sediment past the PDs and through the DFAs. Typical floods that originate above the PDs or within the DFAs are short lived and floodwater is completely lost to infiltration into the sandy channel beds. The complete loss of floodwater to infiltration and evaporation within a few hours is common in central and southern Arizona(Hjalmarson, 1984). Sediment is moved during these short periods of floodflow and deposited downstream until it is again remobilized by another infrequent floodflow perhaps a year or two later. Sediment passes into and through the DFAs in pulses and seldom does much sediment pass through the DFA during a single floodflow.

The amount of sediment transported into the DFA and from within the DFA can appear to be more than actually occurs. Sediment is deposited in the many roadway dip crossings during runoff mostly because the dip crossings act as sediment traps. The banks of the stream channels are steeper and the channels are narrower above and below the dip crossings. The flow expands as it enters the dip crossings, looses kinetic energy, and deposits some of it's sediment load. The streambeds are composed of gravelly sandy loam of granitic origin that is moved short distances by small flows. The beds of the channels that emanate from the PDs are soft and in places difficult to walk in and can give the false appearance that large amounts of sediment move into the area.

Because of the distributary nature of the channels, high energy floodflow at the PD is split into several channels with permeable sand beds. Large amounts of floodwater are lost to infiltration and flashy peaks are attenuated as flow divides. As found on

other DFAs in the arid southwestern U.S.(Thomas and others, 1993, in press), most of the peak discharge of large floods on the DFAS of sites 5 and 6 can be lost to attenuation and infiltration. The DFAs of sites 5 and 6 are unusually large relative to the area drained above the PDs because the areas are old and relatively inactive. The area presently drained above the PDs is a mild sloping pediment where mountains once stood. Nearly all active alluvial fans are formed below, but not necessarily at the toe of steep mountains. Lesser active fans, like those for sites 5 and 6 are found below milder slopes such as pediments.

The channels of sites 5 and 6 are formed by erosion of the Pleistocene sediments and the channel banks typically are lower than the adjacent land(figure 3). The channels are lined with trees and bushes and there are scattered bushes and trees on the interfluves. There are a few channel banks that are higher than the shoreward land but these typically are erosional features. The channels depicted by Boyd Lare(written communication) for alluvial fans that Dawdy(1979) based his model on are formed by aggradational processes. The channel banks are depositional mounds and are higher than the shoreward land(figure 4). When these channels fill with debris or the banks are overtopped, avulsions occur and floodwater spreads over adjacent areas. Because of the unstable nature of "Lare's" fans, there are few trees and older vegetation along the channels.

According to Hjalmarson and Kemna(1991, p. 29) there is a general relation between DFAs with small drainage basins and discharge intensity--flood peak discharge at the PD divided by the DFA. Sites like fans 5 and 6 with a low discharge intensity (Hjalmarson and Kemna, 1991,Table 4, sites 3 and 2, respectively) have a lower relative degree of flood hazard than sites with large discharge intensities. The low degree of hazard is common to DFAs with relatively stable flow paths(less active alluvial fans).

Channel movement

On June 8, 1993 I examined two sets of aerial photographs of FEMA fan 6A in the sections 5 and 6 of T. 4 N., R. 4 E., and sections 19-23, 26-32 of T. 5 N., R. 4 E.. The areal photographs were furnished by Mr. Joe Tram of the Flood Control District of Maricopa County. Both sets of photographs were of good to excellent quality. There was no cloud cover and the resolution was satisfactory for the identification of small trees and low-order stream channels. The scale of both sets of photographs was 1 inch = 1,200 feet or approximately 1:14,500. The photographs were black and white. Horizontal registration of the mylar overlays was made using road intersections and prominent trees as control points.

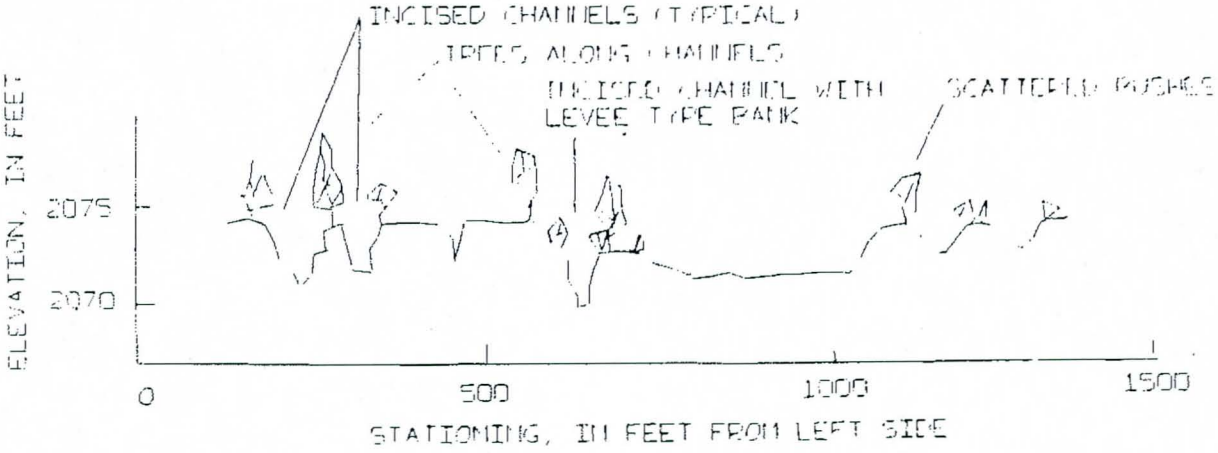

FIGURE 3.--APPROXIMATE CROSS SECTION AT 2074 FT ELEVATION OF SITE 6A

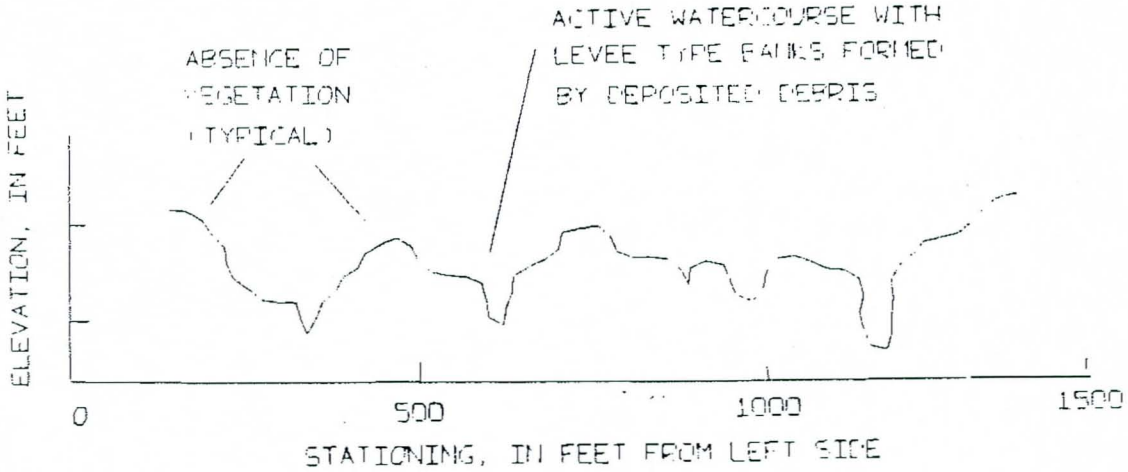

FIGURE 4 --SCHEMATIC CROSS SECTION OF ALLUVIAL FAN FROM BOYD LAKE

Additional characteristics of the photographs are:

Set	Date taken	Identification
1	March 8, 1953	Nos. 66,68 and 69. I.D. on no. 68 is: VV BE MI AMS * MAR. 53 1145 52.22 31,000 33 degrees 48 min. N 115 deg. 55 min. W. Physical size of the glossy prints was about 3.1 ft. x 3.1 ft.
2	March 30, 1991	Nos. I-17 and I-18. Taken by Landiscor Aerial Photo, Inc., 3816 North 7th St. Phoenix, Arizona 85014. Physical size of the prints was about 1.7 ft. x 1.7 ft. Physical size of the negatives was 8-1/2 x 11 inches.

The network of stream channels depicted on the two sets of aerial photographs were examined and no differences in the locations of the stream channels were found. There also were no discernible changes in channel width for streams located in the areas listed above. The display of the negatives over the glossy prints when placed on a light table revealed no movement of the stream channels or the formation of new stream channels.

While employed as a hydrologist with the U. S. Geological Survey(USGS) I studied the potential flood hazards of the Cave Creek quadrangle which include much of the area in the sections above. Stream channels were examined from a helicopter on several occasions in the mid 1970s as part of this study. Also as part of this study and subsequent studies in the late 1980s and early 1990s, there were many on-site investigations of the stream channels and associated potential flood hazards. A major objective of these studies was to assess the potential movement of the channels. The following publications are the result of these studies:

Hjalmarson, H.W., 1993, Flood characteristics of alluvial fans in Arizona: Association of State Floodplain Managers, Arid West Conference Proceedings, 1992, in press.

Hjalmarson, H.W.,1993, Potential flood hazards and hydraulic characteristics of distributary-flow areas in Maricopa County, Arizona: U.S. Geological Survey Water-Resources Investigations Report, in press.

Hjalmarson, H.W., 1978, Delineation of flood hazards in the Cave Creek quadrangle, Maricopa County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-843-B, I sheet.

Hjalmarson, H.W., and Kemna, S.P., 1991, Flood hazards of distributary-flow areas in southwestern Arizona: U.S. Geological Survey Water

Resources Investigations Report 91-4171, 68 p.

The potential flood hazards, stream channels, topography, physiography, soils and geology that I have observed, studied and reviewed as part of these studies are sufficient in my professional opinion to enable me to make the comments and draw the following conclusions:

1.--To a degree of reasonable engineering certainty, I do not believe that the stream channels emanating from the south channel of site 2(Hjalmarson and Kemna, 1991) otherwise known as FEMA fan 6A will change location significantly under natural processes during engineering time or approximately 100 years.

2.--The systems of both tributary and distributary channels are considered relatively stable unless manmade obstructions to floodflow are constructed in the channels and adjacent floodplains. The distributary channels are incised in old-fan remnants and the old-fan remnants are slowly eroding.

3.--The relative amounts of floodflow in distributary channels downstream of forks will change some from one flood to the next. Precise estimates of the distribution of floodflow in the system of distributary channels cannot be made because the channel beds scour and fill. However, for major floods any scour and fill in the relatively small entrenched channels will have little affect on total channel conveyance of the channel forks.

4.--The construction of homes, buildings, roadways and other obstructions in the distributary channels and adjacent floodplains can cause lateral migration of the channels. If such disturbances of the natural system of channels are large, new channels may form and existing channels may be abandoned. There presently(June 9,1993) are a few homes and roadways that form obstructions to runoff and floodflow.

5.--Small amounts of lateral movement of channels caused both naturally and by man occurs throughout the area. Observed scour and fill is local and commonly on the order of a few feet laterally and less then about 1 ft. vertically.

Channel entrenchment

The report "Flood hazard identification and floodplain management on alluvial fans" by two FEMA employees, Magura and Wood(1980), was critically examined. Additional remarks are in the Consultation with Corps of Engineers section of this report. The following comments address references to and implications of channel stability.

The following paragraph is from the Federal Emergency Management Agency, 1985, Flood insurance study guidelines and specifications for study contractors:

Federal Emergency Management Agency Report 37, Appendix 5, p. 1-14. Of interest is the term "entrenched channels".

When it is determined that an area in a community is subject to alluvial fan flooding, 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. The reconnaissance should make use available topographic, geologic, and soil maps; aerial photographs; historic records; and site inspection.

According to Magura and Wood(1980, p60), most alluvial fans analyses of alluvial fan flooding will be performed on areas where natural fan processes such as trenching, lateral migration of channels, and sediment deposition are free to take place. There are two general categories of these fans: 1) where the fan is untrenched and 2) where the fan is entrenched. Magura and Wood define entrenched fans as those where an unbroken flow path exists which conveys up-canyon flow down-fan to a point where sediment deposition takes place.

COMMENTS: Are continuous channels with defined banks considered to be unbroken flow paths? Are two or more defined distributary channels considered unbroken flow paths? Are flow paths considered broken at the intersection point of the distributary channel?

Magura and Wood continue with "Such entrenched channels may be straight or meandering single channels, or a network of interwoven channels. In either case, an average channel cross section is determined for each reach from either field inspection, large-scale topographic mapping, or actual field survey."

COMMENT: This is an interesting description of an entrenched channel where it seems to include braided channels. To me, braided channels are networks of interwoven channels which appear to be part of a single large channel that has defined banks. On page 59, however, they refer to differences in flow characteristics that occur where reaches change from entrenched channel to braided channel. Thus, it is unclear what an entrenched channel really is.

For site 6 there may be several entrenched channels which form a network of interwoven "braided" channels. In many places these entrenched channels are separated by areas of tributary channels. These interfluvial areas appear free from flooding that originates from the apex(PD).

Magura and Wood, like Dawdy(1979), also make the assumption that the main channel may shift just below the fan apex during a flood, forming a new channel elsewhere on the surface of the fan. Magura and Wood(1980) do not substantiate that this assumption applies to all alluvial fans. No data are presented to support this assumption.

Hydraulic geometry

Dawdy(1979,p.1408) models the assumed overland flow on alluvial fans(condition he attributes to Lare and Eyster) by defining hydraulic geometry relations for the rectangular channel. The method by Dawdy is based on geomorphologic principles that were first presented for river channels by Leopold and Maddock (1953). Dawdy's method is based on the assumed flow condition with a rectangular channel and is based on the premise that the hydraulic geometry relations apply to the 100-year flood. While plots of channel width and depth for wide-flat alluvial channels commonly have a depth where dd/dw = -.005, the discharge corresponding to this depth commonly is much less than the100-year flood. Thus, the assumption that the channel is rectangular and defined by dd/dw = -.005 is problematic. Dawdy (1979, p. 1412) also assumes " that each flood event forms a single channel and flow remains in that channel throughout the event." Data do not support this last assumption.

The hydraulic geometry relations at a given cross section or at various cross sections along a stream for channel width, depth, and velocity are:

$$W = CwQ^b \qquad (8)$$

where

W = width of the channel in feet,
Cw = constant related to the size of the channel,
Q = peak discharge, in cubic feet per second, that formed the channel, and
b = constant exponent.

$$D = CbQ^f \qquad (9)$$

where

D = mean depth of the channel,
Cb = constant related to the size of the channel, and
f = constant exponent.

$$V = CvQ^m \qquad (10)$$

where

V = mean velocity of the discharge that formed the channel,
Cv = constant, and
m = constant exponent.

The exponents of b = 0.4, f = 0.4, and m = 0.2 given by Dawdy (1979, table 1) are difficult to evaluate using indirect methods because the discharge of the floodflow that formed the channels is unknown. The exponents at a particular location, however, can be computed and compared to the theoretical and average values for the "at a station" relations by Leopold and Maddock (1953, p. 26) and Leopold and others(1964).

To test if the above hydraulic geometry equations apply to streams in Maricopa County cross sections of the stream channel were surveyed at the apexes (primary diffluences) of 13 alluvial fans where the floodflow is in a single channel (Hjalmarson, 1993). The control for the reach at the PD's was the channel and the cross sections commonly were in fairly uniform reaches. Using conveyance-slope methods, the exponents for the cross sections at each site were computed for the values of peak discharge of the 2-, 10-, and 100-year floods(Hjalmarson, 1993). The mean values for the exponents of the sites were then computed for the 2-, 10-, and 100-year floods (table 4).

Table 4.--Theoretical, average, assumed and computed hydraulic-geometry exponents for channel cross sections.

	Theoretical values(1)		Average values(2)		Assumed values(3)	Computed values(4)		
Component	Cohesive bank material	Non-cohesive bank material	Ephemeral streams in south-western United States	Mid-western United States	Used for FEMA method	Average value for peak discharge at indicated recurrence interval		
						2-yr	10-yr	100-yr
Width	0.25	0.50	0.29	0.26	0.40	0.32	0.27	0.11
Depth	.43	.27	.36	.40	.40	.41	.44	.53
Velocity	.32	.23	.34	.34	.20	.27	.29	.36

(1) Leopold and others (1964, table 7-8).
(2) Leopold and others (1964, table 7-5).
(3) Dawdy(1979)
(4) Hjalmarson(1993, in press). Average exponents for 13 sites in Maricopa County, Arizona.

The method is limited because the channel geometry for the 2-, 10-, and 100-year floods is estimated by the surveyed cross sections when there was no flow. The differences between the geometry of the channels at the peak discharge of interest and at the time that the cross sections were surveyed is unknown. Small differences because of scour and fill during subsequent flow are considered likely.

The average of the exponents of the thirteen sites in Maricopa County for the 10-year flood (table 4) are similar to the exponents for the streams in the midwestern United States. The exponents of the 10-year flood for the sites in Maricopa County also are similar the theoretical exponents for cohesive bank material. The small differences are well within the potential error of the data because of the scatter of the width, depth, and velocity exponents for the sites. The computed average exponents for the 2-year flood also are similar to the exponents computed by Leopold and Maddock (1953).

The level of the 2-year flood was below the banks of the active channel as defined by several authors including Hedman and Ostercamp (1982). Because the active channel was difficult to define at the PD for several sites, it is uncertain if the level of the 10-year flood was below the top of the banks of the active channel. At most of the sites, however, much of the flow of the 10-year flood may be within the active channel.

The average exponents for the channel width, depth, and velocity for the 100-year flood are different than the exponents for the smaller floods (table 4). At all sites, the level of the 100-year flood was above what appeared to be the active channel but was below the top of the confining banks. At several of the sites, the level of the 100-year flood was above the small flood plains adjacent to the active channel. Hydraulic geometry equations for 100-year flood are different than the hydraulic geometry equations for the 2- and 10-year floods.

There appears to be no basis for assuming that hydraulic geometry relations with average exponents can be applied over a wide range of discharge. At many channels, the floodflow of the 100-year flood spreads over low terraces and other gently sloping land. For these channels, the width increases rapidly, and as reported by Leopold and Maddock (1953), the hydraulic relations are expected to be different.

The average exponents for fifteen sections in fan 6A(Table 5 and figure 5) closely agree with the exponents for sections with cohesive bank material(Table 5). This further indicates the channels are stable and do not move about freely.

The assumed condition used by Dawdy(1979) and defined by hydraulic geometry exponents(Tables 4 and 5) is not supported by data. The average hydraulic geometry exponents for alluvial fans in Maricopa County are different than those for a rectangular channel but are similar to the theoretical exponents for a channel with cohesive bank material. The flow condition use by Dawdy and the assumption that channels are formed freely(non-cohesive bank material) are not supported by reason or facts.

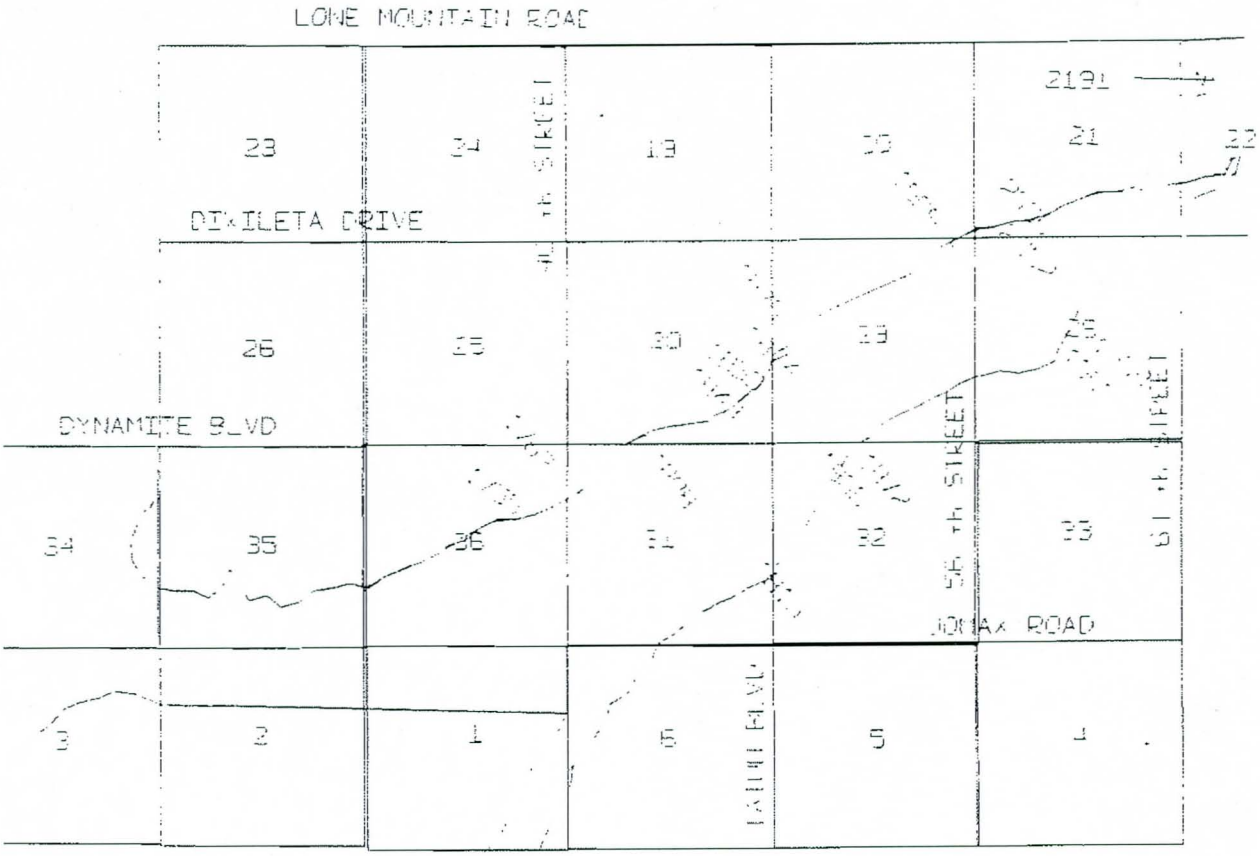

FIGURE 5.--LOCATION OF HYDRAULIC GEOMETRY SECTIONS.

The assumption that the channel is rectangular does not have a significant affect on the "Dawdy Method". The shape could also be triangular or parabolic and the computed depths and velocities from the FEMA Fan Method would be about the same for the wide-shallow condition.

Table 5.--Computed hydraulic-geometry exponents and soil type for channels cross sections in fan 6A

Site (elevation, in ft.)	Exponents			Soil* type
	Width	Depth	Velocity	
1843	.20	.48	.32	3
1850	.25	.45	.30	3
1866	.31	.44	.25	3
1872	.40	.49	.11	3
1874	.16	.51	.33	3
1960	.39	.35	.26	3
1998	.38	.37	.25	3
2191	.22	.47	.31	6
1755	.20	.47	.33	90
1808	.44	.37	.19	90
1876	.30	.47	.23	90
1969	.29	.44	.27	90
2002	.30	.42	.28	96
2006	.41	.34	.25	96
1763	.21	.50	.29	98
Mean	.30	.44	.26	
Standard deviation	.084	.053	.055	

*--From maps of soil types in Camp(1986).

GENERAL COMMENTS

The following comments are respectfully submitted as a summary of suggestions made during several conversations with Joe Tram.

Suggest we pursue all means of resolving the issue between FEMA and the local communities before taking the issue to U.S. District Court. The judge may assume the Alluvial Fan Method that FEMA recommends for study contractors is correct and based on facts and reason. The "playing field" will slope toward FEMA and they will "own the goal". We will be following FEMA's rules. The burden of proof will be up to the local communities and it will be a difficult task to show that the FEMA method is inapplicable for fans 5 & 6 and other similar landforms. A tie probably will go to FEMA.

Do we really know how the FEMA method was applied to fans 5 and 6? Are published standards available to study contractors and if so, were the published standards followed? As I understand the process, an early step in the process is to define the boundaries or lateral extent of potential flooding. I've never seen published standards for the definition of the apex and boundaries of alluvial fans. Is the best available topography used? If so, how is it used? Is the 100-year peak discharge used for the definition of the boundaries? If so, how? If not, why not? For sites 5 and 6, did the study contractor follow established guidelines and did the technical evaluation contractor(TEC) follow established guidelines. Because there is no clear documentation of how the TEC revised the study contractor's work, how do we really know the method used to define the potential flood hazard of fans 5 and 6? In other words, if the FCD takes FEMA to court, what is the issue to be resolved?

If the issue is that the FEMA alluvial fan method is inapplicable for fans 5 and 6, there is a good chance that FEMA will agree. It seems to me there may be no standards for the method used for fans 5 and 6 by the study contractor. The study contractor(SC) defined the apexes and boundaries. The SC next assumed that floodflow could inundate the entire area within the boundaries. Based on a recent conversation with Ed Mifflin, because the FCD wanted the depths and velocities defined, the study contractor used the FEMA methodology to define the depths and velocities. The SC may argue that approximate methods were used and that the FEMA method was used only to estimate the depths and velocities as requested by the FCD. If the designation of fans 5 and 6 was FEMA's doing, is this designation their present position? These issues are raised as an attempt to anticipate FEMA's and the SC's positions in a court of law. Thus, caution is advised if the FCD is to take issue with FEMA in a court of law.

We need to get the dialogue on as much of a factual basis as possible. Throughout the discussions there have been issues based on judgment. The original paper by Dawdy(1979) had several assumptions and judgements in the development of the alluvial fan method that became FEMA's model. To me, judgment is a catchall phrase for people who didn't do their homework, with a certain amount of respect. We should examine all of the unsupported judgments and assumptions on which the Alluvial Fan Method is based and try and put these judgments on a factual basis.

Suggested steps to solving the problem are:

1. Show where the Alluvial Fan Method is inapplicable and why.
2. Examine the development of the FEMA methodology and request documentation of every assumption made. Also, ask for any unpublished data used to develop the method.
3. Present the documented evidence to FEMA and ask that we get together to resolve the issues and solve the problem. Journal articles should be considered to present the technical issues. Technical journal articles can carry significant weight among hydraulic engineers, hydrologists and flood plain managers throughout the U.S.. If FEMA won't work with us, then colleagues can serve as the referee.
4. Don't ever throw FEMA's method out. Rather, define where it applies and where it may not apply. Keep as much of FEMA on the table as possible.
5. Develop a better method of defining flood hazards.

I realize the FCD has made considerable effort to resolve the issue but throughout the resolution process the above steps should be followed.

Suggest we obtain all guidelines and techniques used by Federal Agencies for defining flood hazards of alluvial fans. Joe Tram and I contacted several agencies including the U.S. Army Corps of Engineers(CofE), U.S. Soil Conservation Service(SCS), FEMA, and the Federal Highway Administration. According to the CofE(1988,p.13) each district and division within the CofE uses methods appropriate for their specific problems. A careful examination of the 1993 publications catalog of the Transportation Research Board of the National Research Council revealed nothing pertaining to alluvial fans. Apparently, there are no published guidelines and techniques endorsed by Federal Agencies except those used by FEMA. I consider this the first and most important level of factual documentation and unfortunately there are no known guidelines and techniques published by agencies other than FEMA.

The second level of factual documentation are published papers in technical journals and government papers. Many of these publications are given in the attached references. Little data are available that define the hydraulic conditions of alluvial-fan flooding. I know of no direct measurements of flood depths and velocities on alluvial fans and distributary-flow areas. Journal articles are just one person's opinion that hasn't yet made it's way into the regulatory domain.

The potentially best method of obtaining facts on the type and degree of potential flood hazard on fans like 5 and 6 is to collect and analyze floodflow data and define the topology, topography, physiology, geology, soils, vegetation, etc. of the areas. This method obviously is expensive and time consuming but is proving to be necessary to resolve the issue with FEMA. Perhaps others can share in the cost of data collection and analysis.

Consider publishing facts and decisions based on facts in technical journals. When you are not satisfied with FEMA's appeal and CLOMR processes, valid issues with the FEMA alluvial fan method and the proper application of the method are better presented in technical journals than in a court of law. Suggest high-level journals with colleague reviews and opportunities for comments to be published. I feel rather strongly that FEMA does not want this issue discussed in technical journals because their assumption that flow paths are free to form in a random fashion on alluvial fans is incorrect. Also, the FCD needs to show a method of defining the flood hazards on the more stable alluvial fans. The FCD method does not necessarily need to be compared with the FEMA method but instead, simply described in a technical journal for a particular alluvial fan.

A judge may feel that because the FCD has not produced a better method, there is no issue to be resolved. How can the FCD justify criticism of the FEMA method when they haven't produced a better method of defining flood hazards on alluvial fans? A judge may not look favorably on this. It is one issue to show that FEMA's assumptions are incorrect but it is another issue to produce a better method. I suggest that a judge may feel that all state and local agencies in the arid southwestern U. S. have neglected to produce a better method. If a better method had been presented to FEMA, I feel they will argue in a court of law that the method would have been given serious consideration. Again, these issues are raised for consideration as an attempt to anticipate FEMA's and the SC's positions in a court of law.

FEMA has left the burden on state and local agencies to develop methods of identifying the kinds of flood hazards on alluvial fans. FEMA has greatly oversimplified the hazard with the alluvial fan methodology and has skirted it's responsibility as the national leader of the flood insurance program. FEMA has ignored the expressed concerns of many engineers, hydrologists and geologists familiar with alluvial fans in the arid southwestern United States. I feel FEMAs application of the alluvial fan methodology has departed from the spirit of federal, state and local agencies working together to reduce flood losses. FEMA's attitude toward sponsoring applied research and incorporating research results into it's operational efforts ought to be reviewed (National Academy of Public Administration, 1993).

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APPENDIX A.--David Dawdy's comments on visit to fan 6A, June 29, 1993

SITE VISIT. MARICOPA COUNTY, JUNE 29, 1993

On June 29 I was taken on a site visit by Wen Hjalmarson to the southern and eastern most channel for Site 2 in Hjarlmarson's report. We were accompanied by a Maricopa County flood engineer.

We followed the channel from the upper end, or 'apex', well down the fan. There is no true apex, because the deposits are from a general outwash, with concentration to an 'apex' because of outcroppings of granite bedrock. At the upper end there were large granite boulders, and at one point the right bank of the channel is actually against a granite outcrop. The channel in this reach is either a stable or an eroding channel. Evidence for this is the fact that the bedrock outcrops and room sized boulders indicate that there has been no extensive deposition. Evidence for erosion is an outcrop of caliche somewhat further downstream where there is a fall of about 3-4 feet in some 25-30 feet. The caliche forms a local grade, with slopes above and below seemingly similar, with the drop caused by erosion.

On a short time scale the system is in quasi-equilibrium. The material being transported at the uppermost reach of the channel is composed of pea-gravel sized decomposed granite. There is no source for debris flows, and the sediment transport seems to be hydraulically controlled almost all of the time. I say 'almost', because in the long term it appears to be degrading, but in the short term what comes in goes out.

Where the channel has downcut, there are deposits of caliche in the banks. This also indicates an erosional environment. Caliche forms at the depth of maximum water penetration, where it deposits dissolved constituents. On an active alluvial fan there are caliche deposits in the soil column, but they seldom outcrop, and they are usually at depth, with several caliche layers at different depths resulting from the different cycles of deposition. The several layers of caliche in the stream cut banks indicate a previous depositional environment, with the present channel downcutting through those earlier deposits.

The channels in the upper two miles below the apex have caliche exposed at the surface or at shallow road cuts. There is little evidence of a fining of the channel bed materials in a downstream direction. What fining there is can be explained by infiltration reducing the competence in a downstream direction.

July 1. 1993

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APPENDIX B.--Corps of Engineers information including unpublished report by Boyd Lare and Gary Eyster

Evaluation of Flood Hazard on Alluvial Fans

By Boyd D. Lare and Gary L. Eyster

Introduction

As urban development radiates away from population centers the alluvial fan often becomes a prime area for new expansion. In the western United States where fans occur frequently, factors such as topography and public land boundaries may necessarily restrict urban growth to alluvial fans. Because untold economic resources will be expended in such development, it is imperative that a uniform technique for evaluating flood hazard of such areas be available which is based on sound scientific knowledge and reasoning. The approach presented herein has been developed from considerations of fan formation and evolution, and application of known hydraulic principles. It is intended to produce accurate analyses of depth and velocity of flow at various locations on a fan resulting from specific flows for use in planning optimal development and determining flood insurance hazard factors.

Fan Morphology

Steep mountain canyons provide the slope necessary to transport the tremendous quantities of sediment produced by heavy storms in their watersheds. The size of such sediment ranges from colloidal clay to massive boulders. As the mountain streams suddenly emerge onto comparatively mild slopes at the foot of the mountains, velocity of flow decreases dramatically with subsequent loss of entrainment capacity. As a result, much of the transported sediment is deposited in a very

short distance. In the geological time frame deposits several thousand feet in thickness and extending on the order of 20 miles have accrued. The building of such fans has been accomplished by innumerable episodes of sediment deposition or debris flow during which the fan has assumed different forms in response to changes in streamflow, supply of sediment, and mountain building processes. Often a number of canyons flow out of the mountains next to each other resulting in coalescence of neighboring fans. The result of this situation is a composite alluvial apron, known as a bajada (bah-hah'-da) in the southwestern states.

Modern fans have been classified into two types (Bull, 1964). The first is when deposition takes place near the fan apex and the downfan area is largely undissected. In the second case a fanhead trench has developed which conveys sediment-laden water to the toe of the fan where it is deposited. The local relief on fans is generally small (on the order of 5 feet) except at fanhead trenches which may be incised as much as 50 feet. Channels may occur at any location on the fan and are characterized by rapid lateral migration and change in flows delivered to each channel. Such channels are especially susceptible to changes in form and alignment due to the highly erosive nature of materials making up the fan.

Another factor contributing to lateral migration of watercourses is the variation in shape of the fan surface in a radial direction. The overall radial profiles of most alluvial fans are concave upward. Krumbein (1937), in studies of the San Antonio Canyon fan in southern

California, concluded that slope could be expressed as a negative exponential function of distance downslope from the fan apex. In contrast, fans in western Fresno County, California have been found to have slopes which decrease in discreet segments (Bull, 1964). In any case, a change in slope often produces a change in the cross section of a channel. Karaki et. al. (1974) indicate that changes in slope, along with discharge and sediment size, can induce changes in the form of a channel, with decrease in slope generally inducing braiding of the channel. Schumm (1975) has induced that geomorphic thresholds exist at which, upon reaching certain values of discharge, bed material size or quantity, or slope, a channel may abruptly change from a single main channel to a braided, shallow channel. This may be the reason for the intersection point on a trenched fan where an entrenched channel suddenly spreads or braids downslope.

Flood Hazard

High velocities and sediment deposition are the chief hazards to which economic development on an alluvial fan are subjected. Flood control may be established by construction of up-canyon dams, channel deepening and stabilization measures, and fanhead diversions. Where such structures are in place, evaluation of flood hazard may be accomplished by established hydraulic analysis. However, development more often takes place gradually in such a way that costly structural measures are not immediately justified. In such cases, flows on the fan are essentially unmodified and processes such as fanhead trenching, braiding, and lateral migration are free to occur. The layman's conception

often is that channels are immobile and that distributaries are fully competent to convey the split flows delivered to them. In reality, braided channels in the highly erodible alluvium are highly mobile and threshold changes at the intersection point or fanhead can radically change the quantity of water and sediment delivered to a particular distributary. The relief in the vicinity of a braided channel or distributary is often as little as a few feet, giving the false impression that flows in the watercourse are inconsequential and infrequent. Therefore, structures are built adjacent to or encroaching upon distributaries. Distributaries, in fact, have been filled in and structures built on the sites.

Historical studies of the Kosi River fan in eastern India reveal the migratory character of river channels on alluvial fans (Gole and Chitale, 1966). The braided main channel and distributaries of the Kosi have shifted 70 miles from east to west in the last 200 years with episodes of spectacular avulsion. Over 3500 sq. miles have been laid waste with sand deposits giving the Kosi the name river of sorrow. The migration of the Kosi River is illustrative of processes on dry fans in the western United States. As the main channel or distributaries gradually fill with sediment, alternate routes become more efficient for conveying flow. The channel then breaks into adjacent flow areas some of which may have been inactive recently or may have formed as drainage courses of fan areas. This erratic, unpredictable behavior subjects all areas of the fan to danger regardless of their location relative to active watercourses.

The behavior of flood flows and, thus, flood hazard varies radially downslope from the apex. Conversely, in emphasis of the above paragraph, flood hazard is comparable at any site along the locus of points equidistant from the apex. If adequate structural measures exist to positively control lateral migration of the main channel for a given discharge then areas on each side of the controlled channel may be designated safe for that discharge. In general, however, where significant change in the conveyance characteristics occurs (i.e. intersection point, meander to braiding) the nature and severity of flood hazard changes.

Quantitive Analysis

The technique for quantitatively evaluating flood hazard presented herein is based on the premise that when channel gradient approaches or exceeds critical slope, the critical state of flow may be assumed to accurately represent potential depth and velocity of flow. While slopes in excess of critical slope may produce depths less than critical depth, minor changes in energy due to variations in channel roughness, cross section, slope, or deposits of sediment or debris may cause depth to approach critical depth (Chow, 1959). As long as bed slope exceeds critical slope, however, the flow will not revert to the subcritical alternate depth.

The first step in a quantitative determination of flood hazard is to compute magnitude of flood flows. This is a matter of hydrology which is beyond the scope of this paper. Techniques for frequency analysis

in mountainous areas are widely available (Water Res. Council, 1976). Knowing the magnitude of flow to be analyzed, the investigator must compute the depth, velocity, and areal extent of flooding.

Because of the variation in flow characteristics radially on the fan, several reaches may have to be designated. Possible reach boundaries are: fan apex, intersection point, substantial change in entrenched channel cross section, change in overbank encroachments (structures). Each reach will have unique properties of cross sectional area, shape factor, slope, and width to which overbank flow may practically spread.

In many cases fan development is sparse and topography does not limit the extent to which flow may spread. Yet, practically, some limit must be defined for purposes of analysis. For a channel of constant cross section the critical depth, overbank velocity, and percent of discharge conveyed by overbanks were computed for varying overbank width. The computations were made for a range of discharges and channel configurations. Representative results are presented in figures 1, 2, and 3. For flows well in excess of channel capacity at critical depth, the computed depth decreases as top widths increase with the rate of change gradually approaching zero. Apparently, the rate of change never actually reaches zero so that for an infinitely wide top width depth of flow becomes infinitesmal. In the practical situation neither the fully-contained flows or the infinitesmal depth occur. Rather, some intermediate characteristic depth is established at a cross section wherein a balance of forces and momentum exists. The important aspect

in formulating flood hazard policy is to accurately estimate the depth and velocity of flow which may reasonably be expected at particular locations when the fan is subjected to a given flow.

While a simplified technique may be employed in general, no analysis can be expected to be accurate unless each individual fan is analyzed on a reach by reach basis. Analysis for each reach may then take one of the following forms:

I. Areas within the canyon. Such areas should be approached with established techniques of hydraulic computations. In cases where structural flood control measures are in place, design computations may be used if they are available and are deemed accurate. Otherwise, standard procedures of gradually varied flow computations and valley or reservoir routing may be used.

II. Areas on fan protected by structural works. Hydraulic analysis of diversions and stablized channels should be carried out with particular attention to structural integrity and sediment transport capability.

III. Majority of areas, in which natural fan processes such as trenching, migration, and avulsion are free to take place. By far, most analyses fall into this category. Two general sub-categories exist here: The untrenched fan and the fan which is entrenched at the upper end.

The untrenched fan will be discussed first. Such a feature often issues from a relatively small canyon and immediately upon leaving the mountains flow spreads evenly. Critical depth analysis has been carried out for this case and is presented in fig. 4. After the expected discharge is computed it can be applied to the figure and the depth may be established at the point on the curve at which $\Delta d/\Delta W$ becomes sufficiently small. Based upon field experience and floods of record this $\Delta d/\Delta W$ has been established as .005 ft/ft. At this rate of change an increase in width of flow of 100 feet results in a change in depth of flow of 0.5 ft. Additional increases in W result in rapidly decreasing changes in d. The critical concept to ponder at this point is that this method establishes the potential for flooding at a point. The depth and velocity so obtained are applied to the locus of points equidistant from the apex regardless of the position relative to an apparent flowcourse. On such fans minor drainage patterns often develop in response to runoff generated on the fan itself. However, it cannot be expected that flows originating up-canyon will follow such courses to the exclusion of lesser-developed flowpaths.

The second sub-category is for cases where an unbroken flowpath exists which conveys canyon flows downfan for deposition elsewhere. Such channels may be straight or meandering single channels or a network of interwoven, braided channels. In either case, for each reach an average channel cross-section is determined and, for the discharge of interest, a curve of d vs. W is developed. Potential flood depth

may be determined using the .005 ft/ft criterion. The depth is applied across the entire fan under the assumption that the main channel may shift at the fan apex during a flood, forming a new channel elsewhere on the fan. Wherever flow charateristics change sufficiently as discussed above a different reach is established and analyzed independently. Using this technique a typical floodplain delineation on a sparsely developed fan would take the form shown in fig. 5. In a given zone bounded by reach limits and the boundary of coalescence, the potential for flooding may be defined by the velocities and depths of flow computed as outlined above.

Conclusions

Flows rarely spread evenly on an alluvial fan. Rather, flow is concentrated in an identifiable temporary channel or is spread on an isolated portion of the fan. Such flowpaths are prone to lateral migration and to sudden relocation to any area of the fan during a given runoff event such that the degree of flood hazard is similar at all points a given distance downslope from the apex. Therefore, a site distant from an identifiable channel has approximately the same potential for flooding as a site near an identifiable flowpath at a similar elevation on the fan.

A technique is presented for determining the depth and velocity of flow which may reasonably be expected on a sparsely developed fan. In evaluating a particular segment of a fan it is recognized that the slope of almost all fans is in the supercritical range. Further, a natural cross

section rarely sustains a supercritical normal depth due to variations in channel roughness, shape, slope, and deposits of debris. Therefore, flood hazard is defined using critical depth computed with an overbank width beyond which further increases in width result in insignificant changes in computed depth. For sparsely developed fans on which natural processes are free to act, this technique provides an accurate means for estimating potential depth and velocity of flooding at any point.

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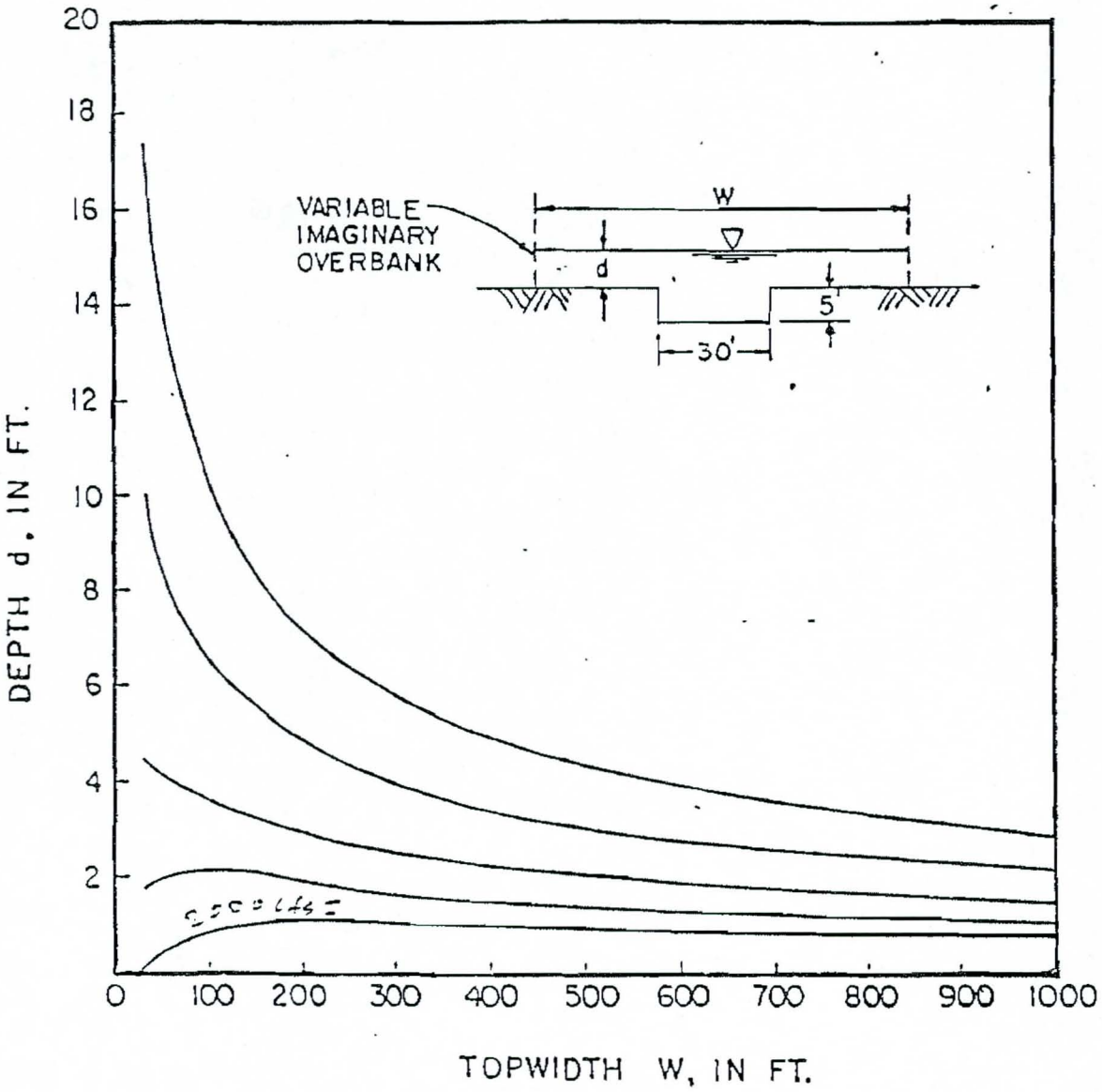


FIG. 1 - RELATIONSHIP OF COMPUTED CRITICAL DEPTH TO TOPWIDTH FOR A CHANNEL AND OVERBANK. DISCHARGES OF 2000, 3000, 5000, 10000, 18000 CFS

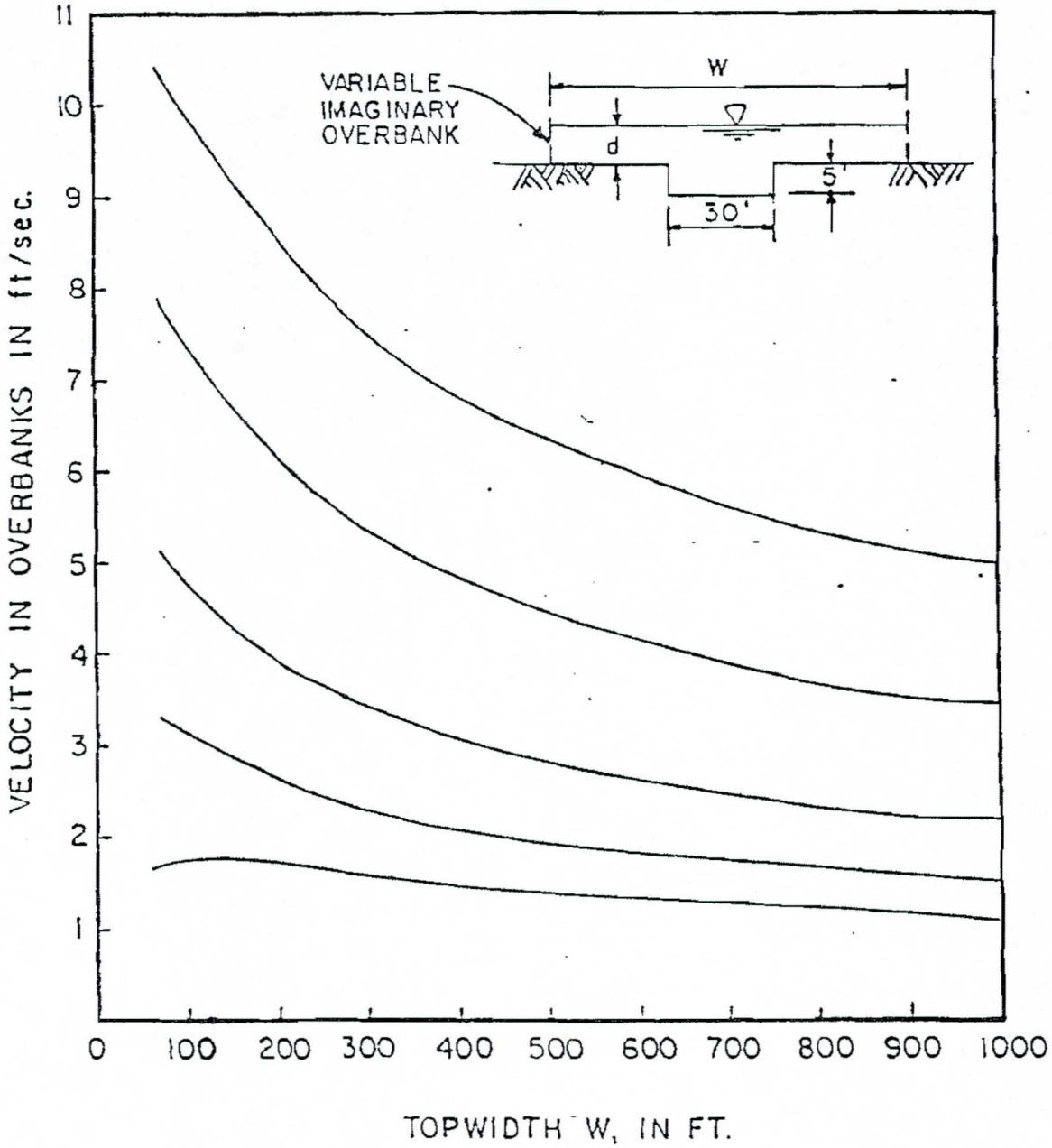


FIG. 2 - VELOCITY IN OVERBANKS VS. TOPWIDTH FOR A CHANNEL AND OVERBANK. DISCHARGES OF 2000, 3000, 5000, 10000, 18000 CFS

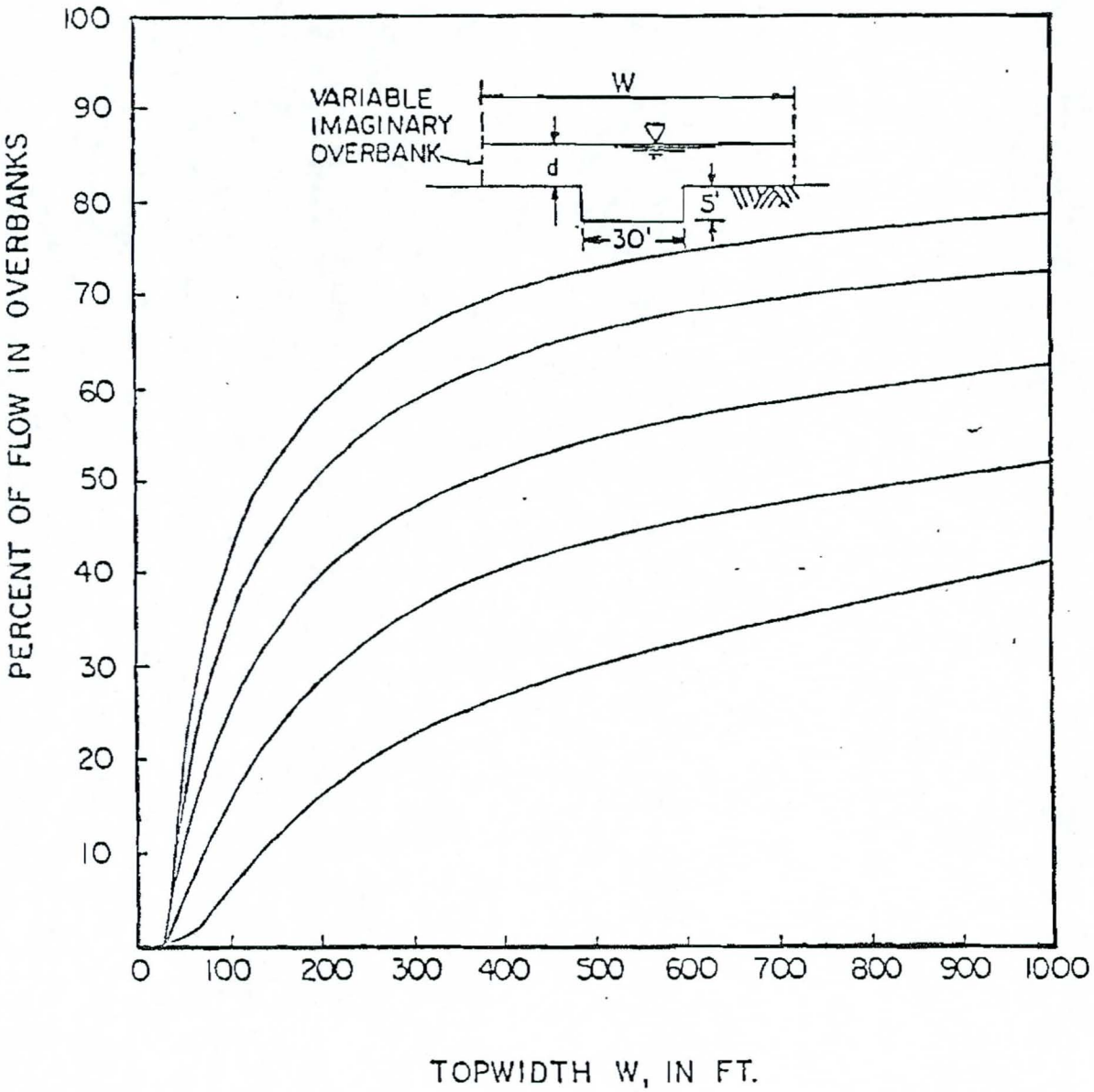


FIG. 3 - PERCENT OF FLOW IN OVERBANKS VS. TOPWIDTH FOR A CHANNEL AND OVERBANK. DISCHARGES OF 2000, 3000, 5000, 10000, 18000 CFS

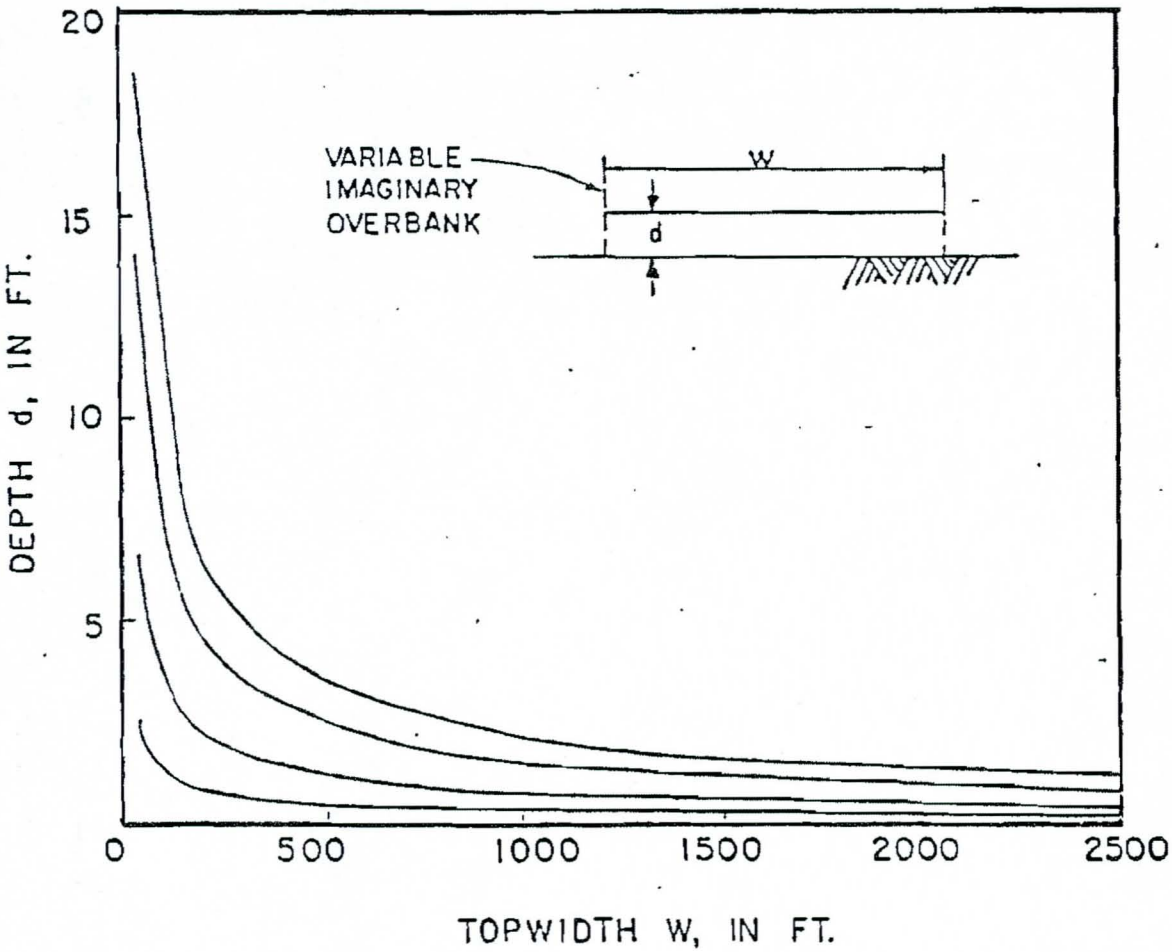


FIG. 4 - RELATIONSHIP OF COMPUTED CRITICAL DEPTH TO TOPWIDTH FOR OVERLAND FLOW (NO CHANNEL) FOR DISCHARGES OF 1000, 4000, 12000, 18000 CFS

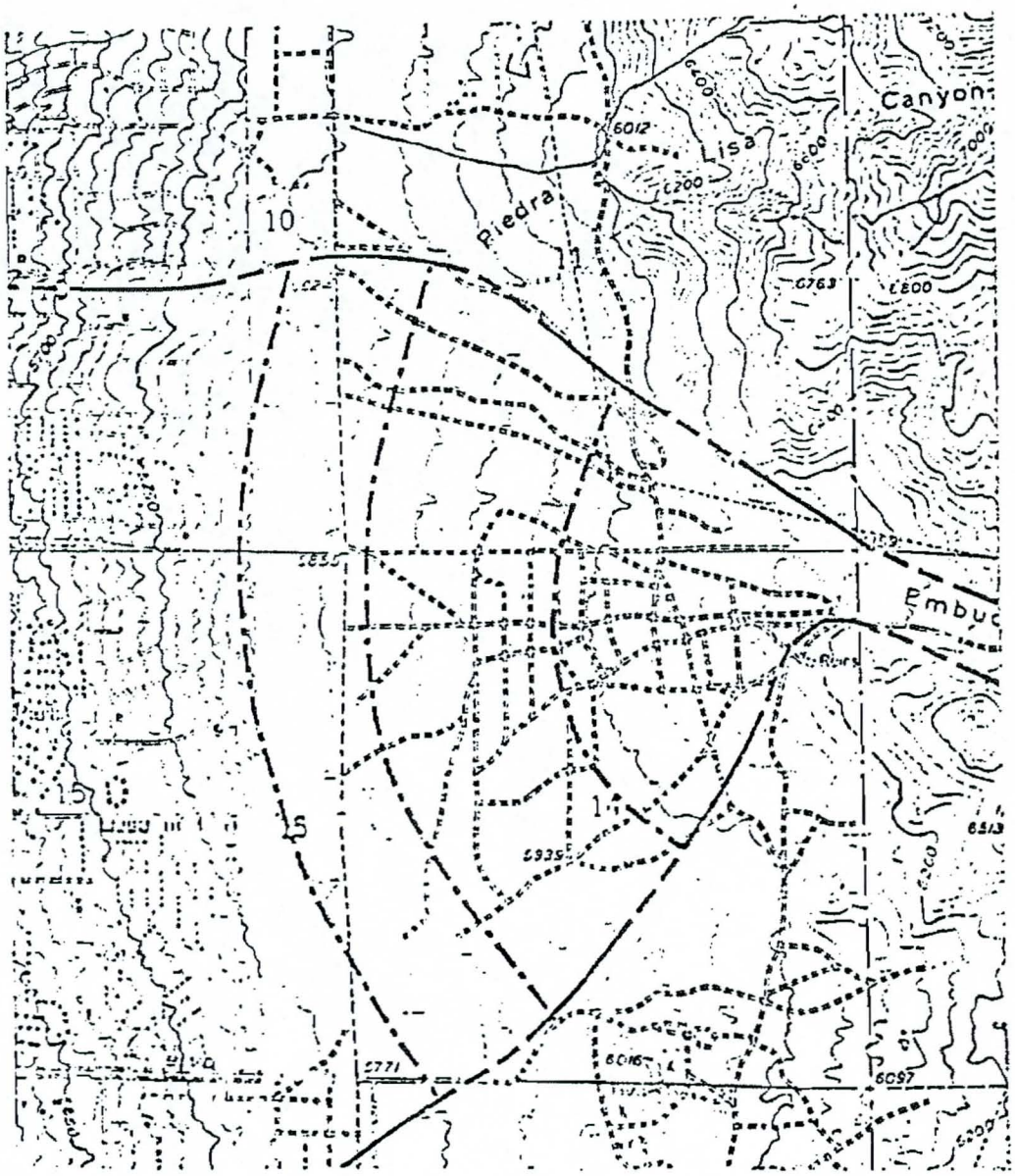


FIG. 5 - TYPICAL FLOODPLAIN DELINEATION ON A DEVELOPING FAN.
LEGEND:

——— — — ——— — — ——— BOUNDARY OF COALESCENCE

—·—·—·—·—·—·—·— REACH LIMITS

at the apex of a given fan — — with very little data and lots of problems - and refine this exacting science to point where we decrease the probability in proportion to the distance down the fan from the Apex. (Daudy A-6-2 P a.)
Theoretically and mathematically, within the assumptions made the procedure ~~may be~~ right.
The basic assumptions used by Daudy are the same, essentially as presented in our original alluvial fan paper — prior to the expansion for reduced probabilities.

Following is a letter with at least some acknowledgement of this!

3

SUITE 700, 7101 WISCONSIN AVENUE • WASHINGTON, D. C. 20014 • (301) 652-2215
TWX: 710-824-9613

October 18, 1978

Mr. Boyd Lare
U.S. Army Corps of Engineers
New Mexico District
Albuquerque, NM 87103

Dear Boyd,

After considerable delay, a study finally was approved and completed on alluvial fan flooding. A copy of my administrative report to FIA is enclosed. I realize that your name is taken in vain in it, because what FIA calls the "Lare Method" really was not endorsed by you. It was based on your ideas (was it in January), but much extrapolated. At any rate, I intend to publish the results in ASCE someday soon, and want to give you credit for your ideas. Certainly the dD/dW = - .002 is yours. Did you ever publish your paper? If not, I will credit personal communication. I will send you a copy of the paper if I ever finish it, so you can have a first crack at a discussion in ASCE, anyway.

I hope to see you in Albuquerque again some day.

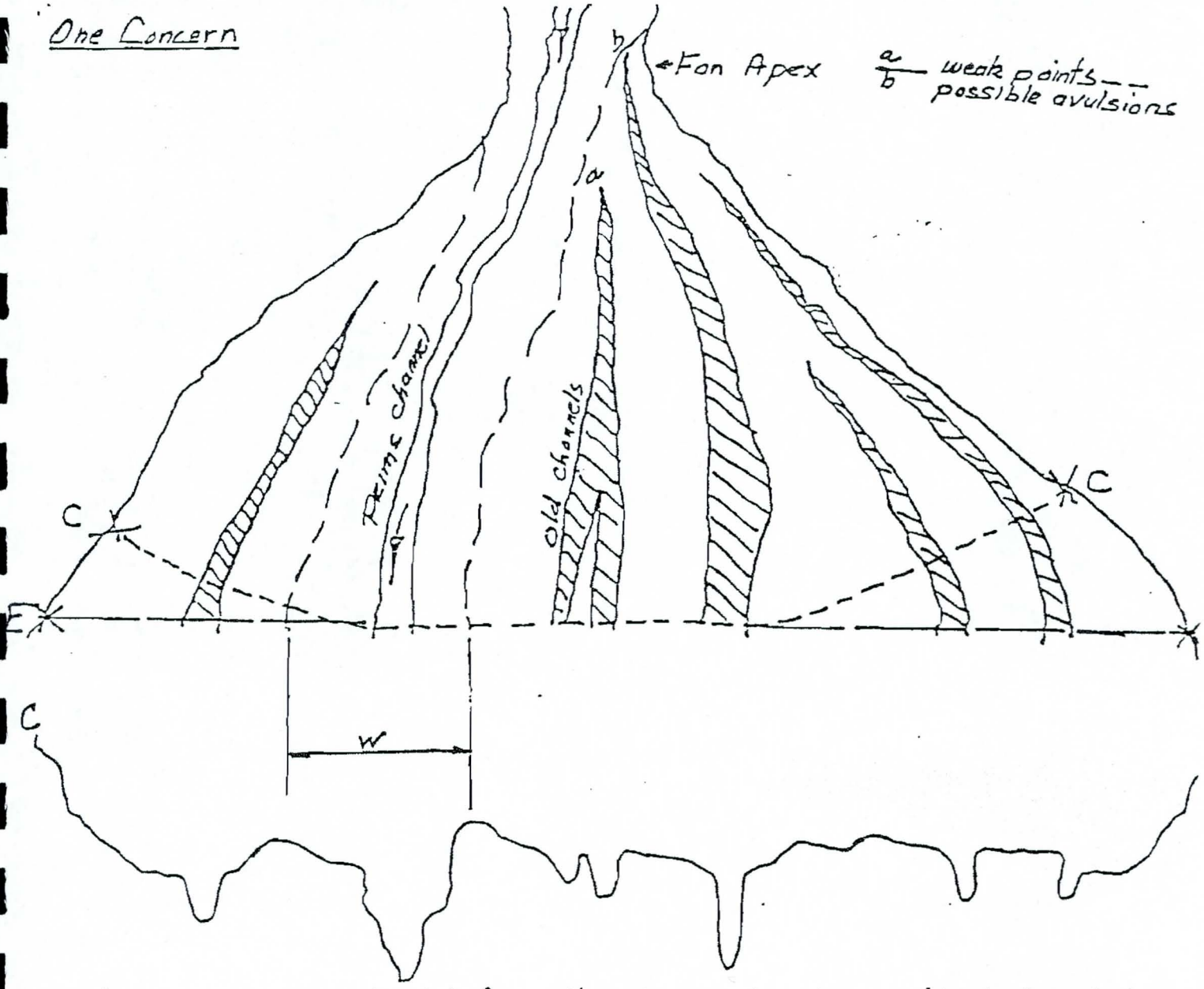
Sincerely,

Dames & Moore

David

David R. Dawdy

One Concern



Often on numerous alluvial fans the channel has been established and has been effective in that location for years. Large floods may experience little flow loss, if any, historically to other fan areas. However the potential may exist as noted at weak points a & b. If I understand the FEMA procedure, the probability is reduced at Section C-C over width W, simply because other identifiable avulsions are possible. They may say "well this is a special case which would have to be approved for different treatment by the CO". But what if the CO is not an hydraulics expert? -- and insists on the "book procedure".

In my opinion the reduced probability means a lesser flood hazard thus an encouragement to development. The author of the paper must have had some inkling as to this problem -- because after all the reduced probability comps. he adds back in the velocity head to make sure they gain back some depth. -- Ridiculous!!

In areas of treacherous velocities and high debris loads we add in the velocity head anyhow but without contending with reduced probability. In the case described above we might well evaluate the hazard using standard hydraulic procedures -- but show

MORE SPECIFIC They diverge from our normal procedures by assumming a rectangular channel. Although in ~~our~~ our paper on alluvial fans we simplified sections for ease of illustration -- we in fact use actual measured channel and fan sections at representative locations for the various fan segments. We analyze by hydraulics each particular channel ~~Conveyance~~ Conveyance potential and quite often this is based on critical depth -- This is used because a natural tortuous channel on a super-critical slope cannot sustain super critical flow hydraulic characteristics.

NOTE: The paragraph numbering system is identical to the page numbers and most difficult to reference. Referencing by paragraphs:

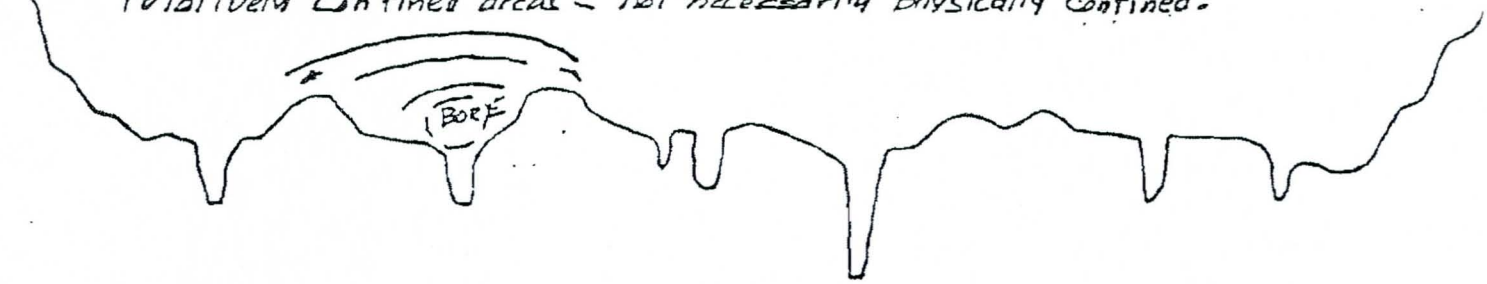
PARA. A6-4. In effect the flows are distributed across the entire fan. There is a hesitance to identify too many avulsions i.e. 1 to 1.5 -- probably because of the realization that there would result in too much reduction in probability and result in even more obvious unreasonable answers: Even 1.5 is not typical of our area, where we easily experience 3 to 4 avulsions. whether you reduce probabilities using their methods or evaluate the 100 YR across the entire fan -- regardless of procedure -- if not tempered with judgement and experience, you can result in depths of flow that are inconsequential and not indicative of the flooding potential. Hence they've corrected this by adding back in the velocity head (as related to a rectangular channel) to obtain a more realistic depth). I feel this procedure will not define a flood potential across the fan....

Avulsions Inadequate discussion in ADD. 6. Extremely vague generalization of "1.5 in absense of other data.".

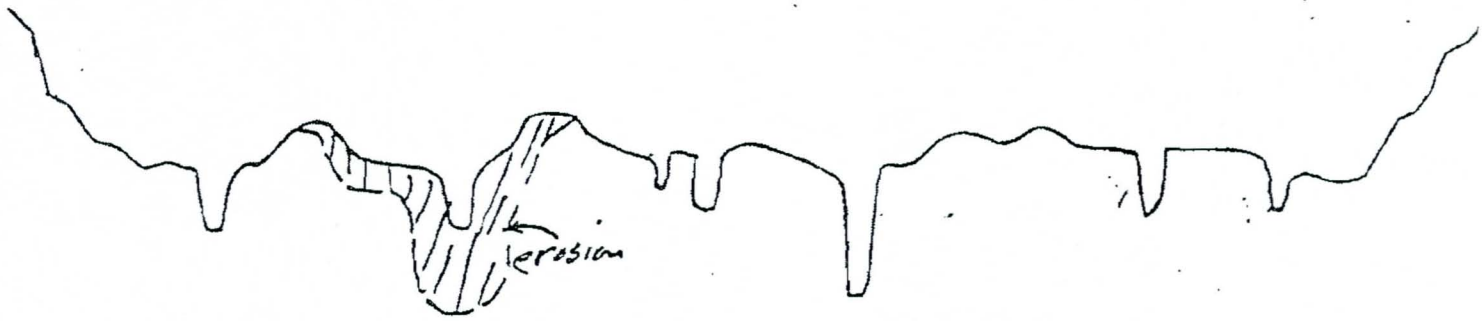
Some basic facts about alluvial fans

(a) Flood flows often carry very large amounts of debris and sediment (rocks-boulders-trees etc) which have a pronounced effect on hydraulics.

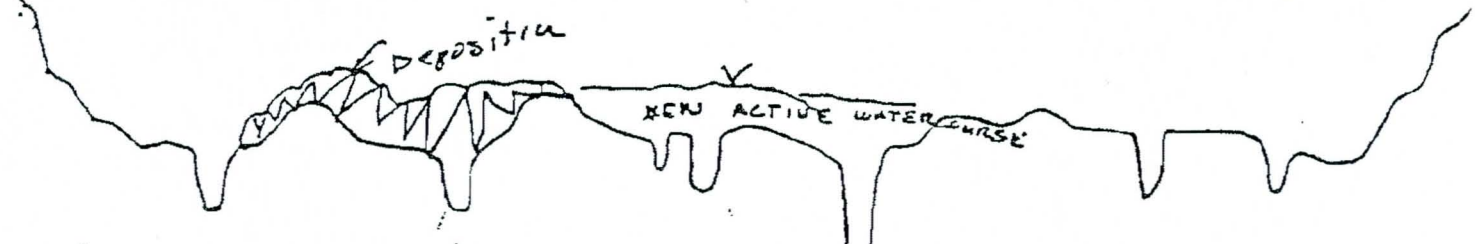
(b) Because of high flow momentum-floods tend to concentrate in relatively confined areas - not necessarily physically confined.



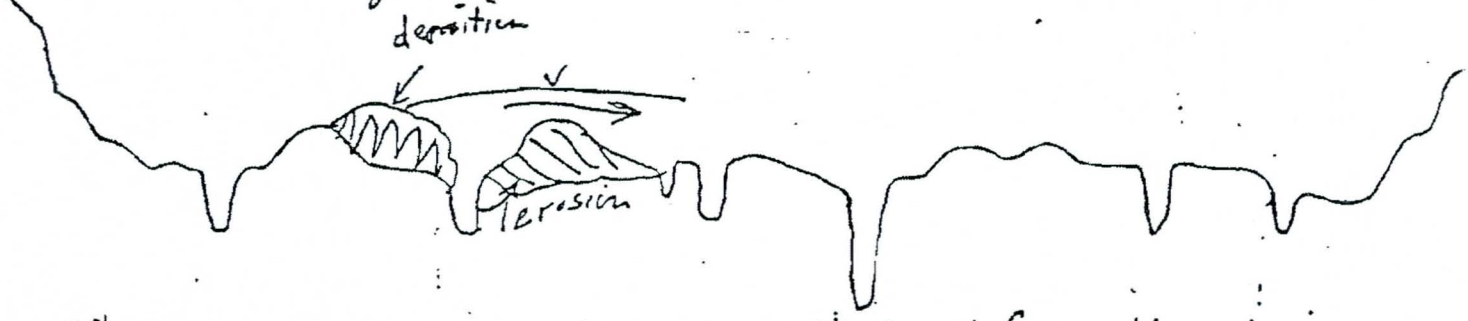
(c) Erosion occurs during the rising limb of the hydrograph - through the peak and partly down the falling limb.



(d) Deposition - possibly severe enough to block later flood flows occurs on the lower part of the falling limb of the hydrograph. If the deposits consolidate over a period of time the channel may



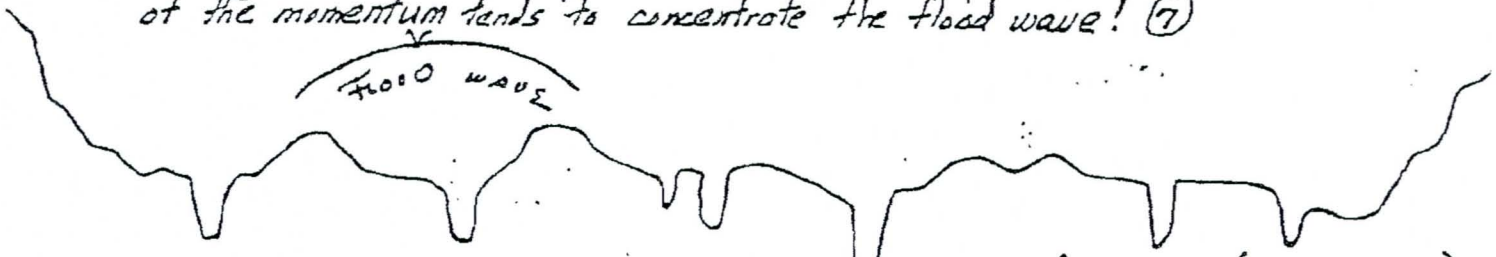
(e) no longer be an effective flow carrier -- Thus new flood paths (avulsions) may be activated across the fan.



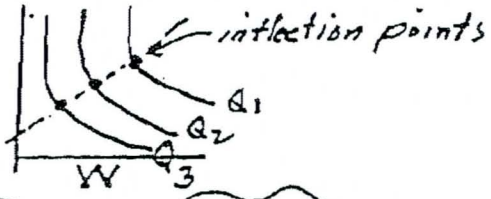
(f) Severe erosion or deposition may activate old fan portions during a single event. The actions along a given reach are not necessarily the same throughout all reaches.

(8) a "Standing wave" or "wall of water" are experienced on alluvial fans because of two reasons: Sudden break through of debris loads - old or new - And the peak of the hydrograph velocities catching up and overriding the rising limb velocities. The intensity of the momentum tends to concentrate the flood wave! (7)

7)



The approach presented in the original alluvial fan paper (LANE, EYSTER) is somewhat as follows: A flow width is determined based on the apparent flow path - often with topographic limits. If no flow path exists or no positive topographic limits a simple relationship may be established. The depth-width relationship near the inflection points may be obtained.

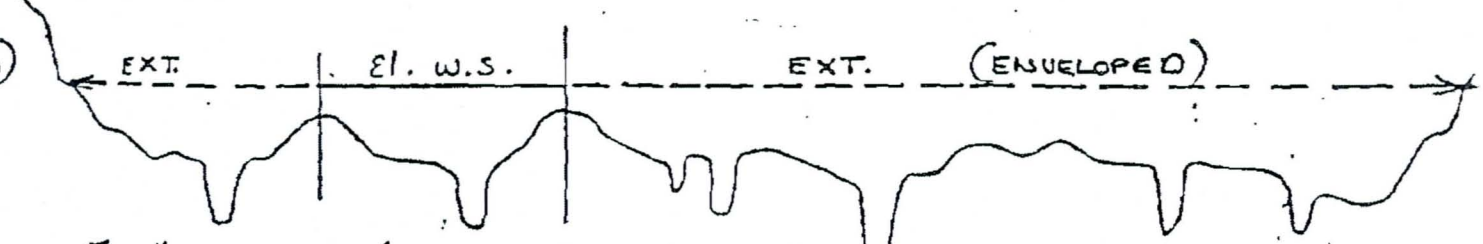


The use of this relationship follows a very simple assumption —
The depth can't become too great without widening!
The width can't become too great without deepening!
In the area of the inflection points a line may be drawn designating the widths and depths associated with a range of flows.

9

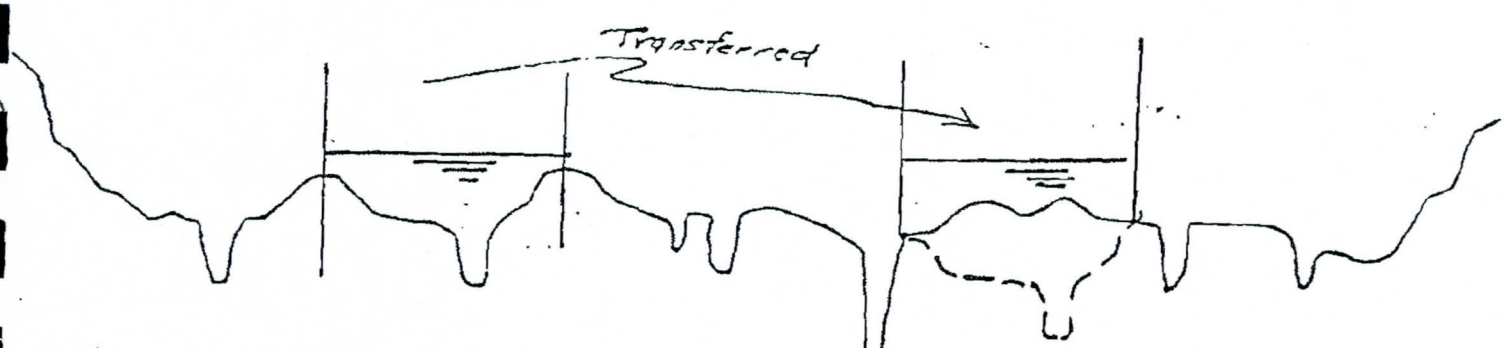
The water surface thus determined (9) for a given Q. is an approximation of what happens in (3) and (7) above.

10

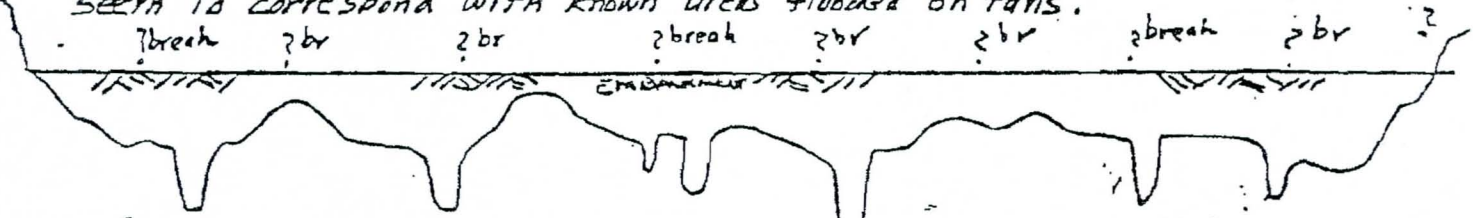


Furthermore: because of the known high hazard potential of shifting floods on a fan (reasons explained in (4) (5) (6) above) the water surface elevation may be extended to envelope the entire fan. The reasoning being that it is simply potentially a flood hazard - unpredictable, dangerous and quite capable of happening with no reduction of

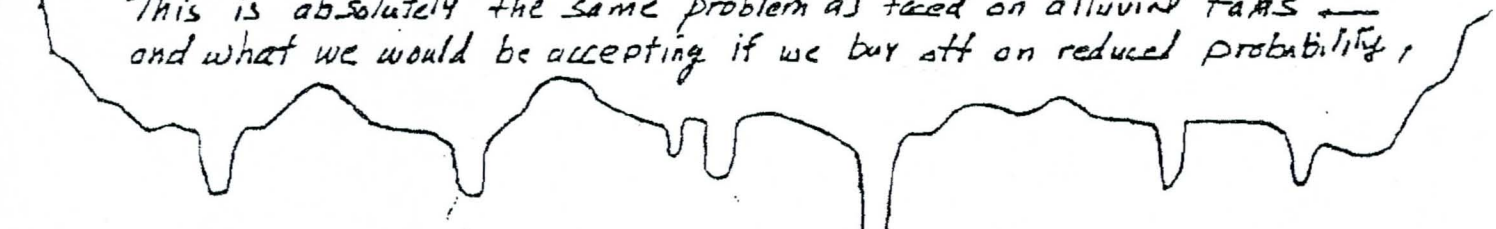
Hydraulic Assumption



Also, as shown in (11), the channel may be assumed to maintain the same type of regime and conveyance characteristics if transferred and activated at any point on the fan.
This procedure has been used for many years in the Alb. Dist and the results seem to correspond with known areas flooded on fans.

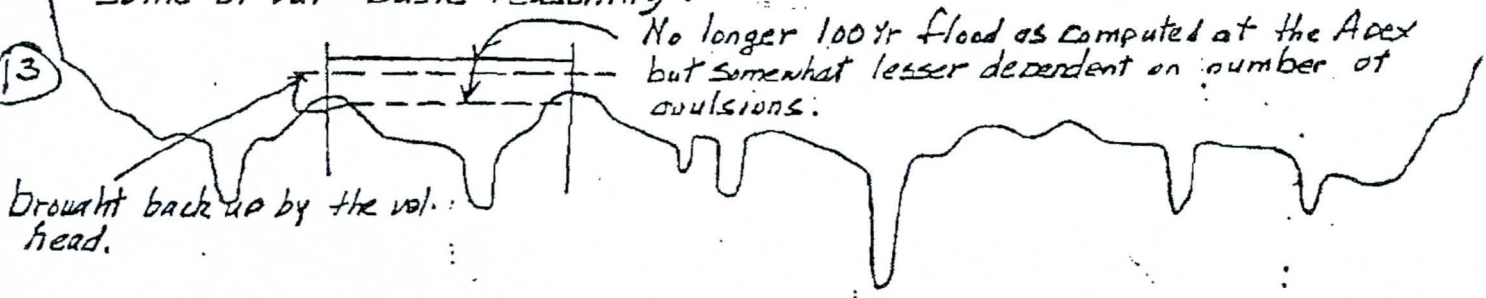


The approach is also analagous to determining flood potential and flood depths below canal or levee breaks — where the location of the next possible break is anybodys' guess. We certainly do not reduce the probability based on length of embankment. Any development at all below the embankment must be made aware of the full flood potential. This is absolutely the same problem as faced on alluvial fans — and what we would be accepting if we buy off on reduced probability.



Dowdy — wants to change the probability, using the prestigerus reference of WATER RESOURCE COUNCIL BULLETIN 17B — and applying some of our basic reasoning.

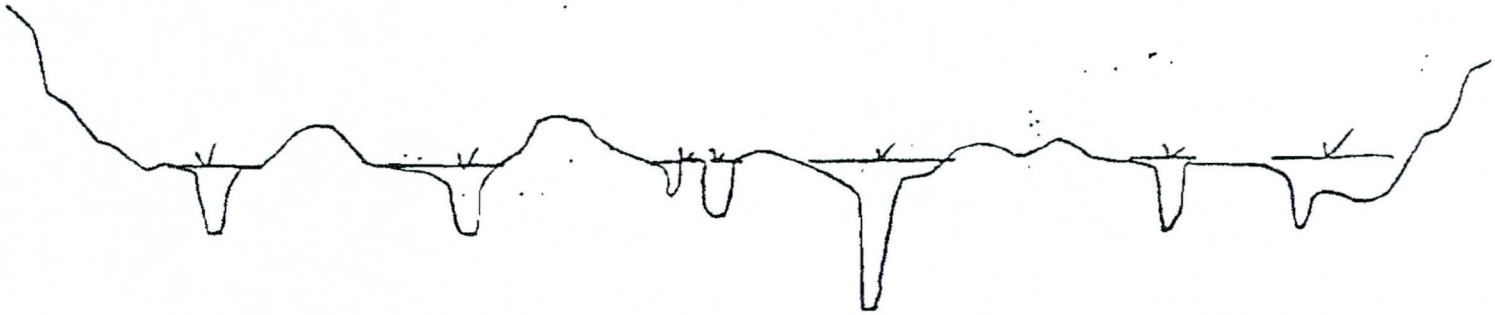
(13)



Reasoning: Smaller flood = smaller depth

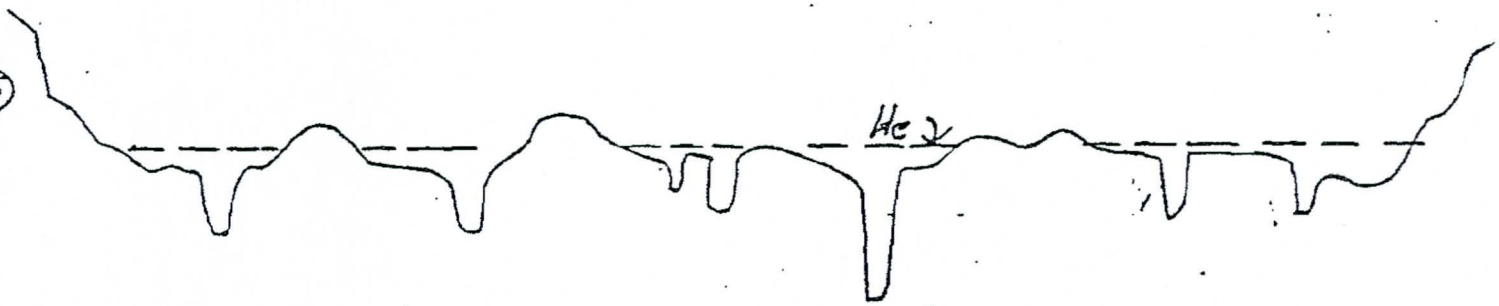
When translated and compared we could be back to square 1 with results somewhat as shown in (1) & (4).

(4)



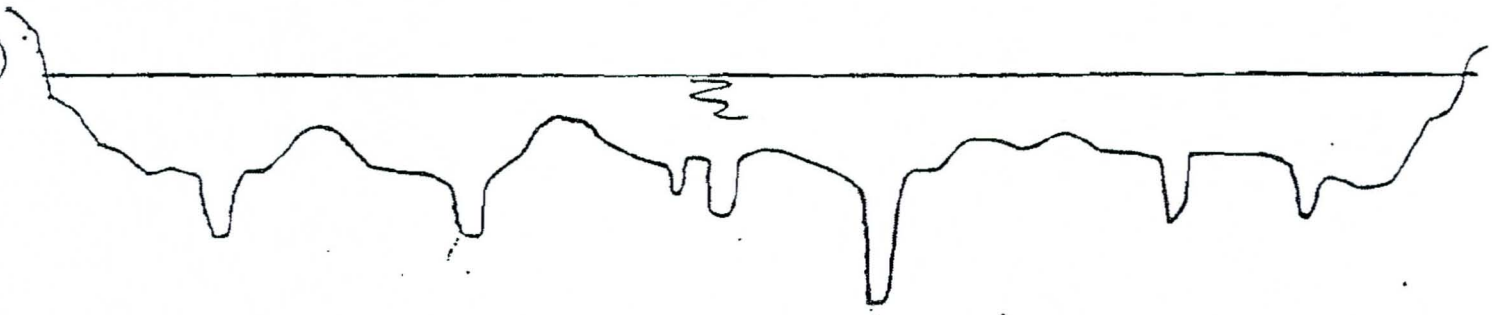
But they're back some by adding in the Vel. head.

(5)

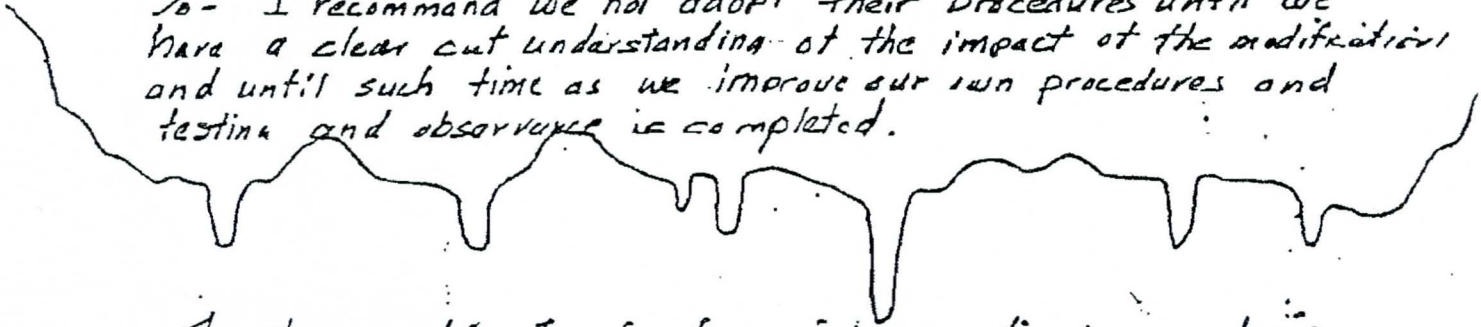


Our approach in comparison may seem too severe -- but so can our floods be -- and unpredictable -

(6)



So - I recommend we not adopt their procedures until we have a clear cut understanding of the impact of the modifications and until such time as we improve our own procedures and testing and observance is completed.



In the meantime I prefer to remain conservative in my analysis

Boyd D. Lare

Boyd D. Lare PE

Hjalmar W. Hjalmarson,P.E.
HC75 Box 3558
Camp Verde, AZ 86322
602 567-6755

May 25, 1993

Mr. Vernon Bonner
Department of Army
Corps of Engineers
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616-4687

Dear Vernon,

I've recently retired and I'm working part time with the U.S. Geological Survey to complete my studies of flood hazards on alluvial fans. As I'm sure you're aware, I take exception with the FEMA alluvial fan method. Many fans in southern Arizona are geologically older and less active than fans depicted by the FEMA method.

I'm writing you for two reasons. First, in my efforts to examine Dawdy's method(ASCE, 1979) which of course is the basis of the FEMA method, I contacted the C of E office in Albuquerque. I hoped to contact Boyd Lare or Gary Eyster because Dawdy gives credit to them for the relation of width and depth of overland flow on fans. Boyd has retired and Gary is on a years leave from the Corps without pay. Mr. Frank Jaramillo sent me a rough draft of their unpublished paper on alluvial fans and said there were no data available at your Albuquerque office that support the relation dd/dw =-0.005 which Dawdy attributes to Boyd and Gary. Frank suggsted I contact you. Second, I was curious why you were at the Arid West Conference at Las Vegas last year. I hope you found the report by Hjalmarson and Kemna useful. I have another report on fans in Maricopa County that uses many photographs to describe flood characteristics of typical fans. The report will be published soon.

I assume you are neck deep in the assessment of structural approaches to flood control on alluvial fans. I recall that the program started in late 1990 to determine how well typical flood control measure perform on alluvial fans.

As you probably guessed, I want something. First, are there data for alluvial fans that support the work of Lare and Eyster? If so, how can I obtain copies of the data or where can I examine the data. I'm prepared to travel almost anywhere to examine floodflow and hydraulic data for alluvial fans. Second, does the Corps have manuals or published methodology for making hydrologic, hydraulic or geomorphologic determinations on fans?

If so, how can I obtain the manuals? If not, why not?
Third, do you know of any such manuals by other federal agencies such as the SCS of FHA?

With respect,

Hjalmar W. Hjalmarson,P.E.

DEPARTMENT OF THE ARMY
WATER RESOURCES SUPPORT CENTER, CORPS OF ENGINEERS
HYDROLOGIC ENGINEERING CENTER
609 SECOND STREET
DAVIS, CALIFORNIA 95616-4687

REPLY TO
ATTENTION OF

June 2, 1993

Training Division

Hjalmar W. Hjalmarson
HC75 Box 3558
Camp Verde, Arizona 86322

Dear Hjalmar:

Congratulations on your retirement. It sounds like you are continuing your work just on your own schedule?

I have completed the final draft of the study report "Assessment of Structural Flood Control Measures on Alluvial Fans" for FEMA. FEMA still has the report under review. I attended the Arid West Conference in Las Vegas to coordinate with the FEMA Project Officer on the report and to present our tentative findings at the conference. Unfortunately, the conference proceeding still has not been distributed.

Our contract with FEMA specifically excluded two topics from consideration: FEMA Alluvial Fan Methodology and Non-structural measures to reduce flood damage. I believe Non-structural measures are being reviewed by another contractor. Our report references to the Dawdy method are limited to acknowledging its use for hazard mapping and suggesting that more site-specific analysis would usually be required for planning and designing flood reduction measures.

Frank Jaramillo knew we were reviewing existing projects on alluvial fans because we contacted him for examples. However, we did not look into the Dawdy Method or review its background. Dr. Richard H. French, Desert Research Institute, University of Nevada, 2505 Chandler Ave., Las Vegas, NV, 89102, has written several reviews of the FEMA Alluvial Fan Model. Perhaps he can provide you some information on the history of the method.

It was good to hear from you. I did use your report as an example of the type of regional information that may be available for local studies. Good luck on your research.

Sincerely,

Vern Bonner

Vern Bonner
Chief, Training Division

(916) 756-1104 - Office (916) 756-8250 - FAX

July 22, 1993

Dear Win:

Personal communication unrelated to this report.

I am glad to hear that Maricopa County has taken advantage of your expertise. I called around to some CofE offices and this is what I found:

- The latest edition of the CofE report, "Stability of Flood Control Channels", will be incorporated into an existing Engineering Manual entitled, "Hydraulic of Flood Control Channels, EM 1110-2-1601". I called the Waterways Experiment Station (601-634-2608) and they said that the new EM should be ready for publication in the near future.
- I called the Los Angeles District office of the CofE to find out what they know about CofE policy regarding alluvial fan flood hazards. I talked with Grigor Grigorian (not Icelandic name), Chief of Flood plain Management (213-894-5375). He said that the CorE had no written policy endorsing any method for delineating flooding on alluvial fans. He said that the Cof E does not endorse any particular method. He also said that he didn't know of any CofE publications that dealt with a suggested method for attacking the problem. The LA District uses different methods for different purposes. He said that the FEMA method would be the method of choice if their office was working with FIS contracts for FEMA. Yet, on another project where he was trying to justify a Cof E project (not directly related to FEMA) he felt comfortable using an ad hoc method based on hydraulic principles and logical assumptions.
- Another engineer that I talked with at the LA District was a woman named Janice Lera-Chan (213-894-6239). She works for one of their alluvial fan experts, Glenn Mashburn, who was out of the office. She is working on a project that defines the area flooded by a Probable Maximum Flood occurring downstream of a dam. Since the FEMA method cannot handle the PMF event they are using HEC-2 with some engineering judgement to draw some conclusions. She confirmed Mr. Grigorian's statement that there are no CofE guidelines or publications concerning alluvial fan flooding.

Well, I hope you keep me posted on your progress. I trust that your orchards are fruitful. Please give my regards to your better half.

Sincerely,

Steve Kemna

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US Army Corps of Engineers
The Hydrologic Engineering Center

AD-A202 119

Review of the U.S. Army Corps of Engineers Involvement with Alluvial Fan Flooding Problems

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TECHNICAL PAPER NO. 124

December 1988

Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution within the Corps of Engineers.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

REVIEW OF THE U.S. ARMY CORPS OF ENGINEERS INVOLVEMENT WITH ALLUVIAL FAN FLOODING PROBLEMS[1]

The Hydrologic Engineering Center[2]

INTRODUCTION

The U.S. Army Corps of Engineers has shared responsibility for resolving flood problems in the United States. Alluvial fans are areas of special interest that present some of the most complex analytical and managerial challenges to engineers and floodplain managers. Successful analysis and management of alluvial fan flooding problems are often elusive and quite costly. There are many different analytical approaches used to assess flood hazards on alluvial fans. The present consensus among experienced engineers and geologists, however, is that there is no single, clearly superior method for accurate assessment of flood hazards on alluvial fans. The choice of methods should be based on the goals and objectives of the particular study, the complexity of the hazard situation, the applicable regulatory policies, and the availability of field data. Experience and good engineering judgement are the most important factors in the successful selection and application of any technique.

This paper presents a general overview of the Corps of Engineers past involvements, present practices, and the future roles in dealing with alluvial fan flooding problems.

Mission and Historical Perspective

The U.S. Army Corps of Engineers is the largest water resources development and management agency in the federal government. The Corps began its Civil Works program in 1824 when Congress first appropriated money for improving river navigation. Since then, the Corps' mission has been expanded to include activities for reducing flooding, controlling beach erosion, continuing to improve river navigation, developing hydropower, providing urban and industrial water supply, regulating development in navigable waterways and on floodplains, managing a nationwide recreation program and conserving fish and wildlife resources.

June 1988, marked the 52nd anniversary of the Flood Control Act of 1936 that officially established flood control as a Federal

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[1]Presented at the Association of State Floodplain Managers Conference on "Arid West Issues," 19-21 October, 1988, in Las Vegas, NV. Authors: Robert C. MacArthur and Douglas L. Hamilton.

[2]Department of the Army, Water Resources Support Center, Corps of Engineers, The Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616-4687.

responsibility. The purpose of flood control is to regulate flood flows and thereby reduce flooding damage. This is accomplished primarily through structural methods that are planned, designed and constructed by the Corps in conjunction with state, county and local agencies. The Corps also addresses the Nation's flood problems by providing (upon request) flood hazard information, technical assistance and planning guidance to other Federal agencies, states, local governments and private individuals. The data and assistance are designed to reduce unwise use of floodplains, correct present flood problems, and to avoid future flood hazards. In fiscal year 1988 alone, the Corps provided some 87,000 responses to inquiries relating to potential floodplain development valued at over $14 billion.

The Corps is intent upon using up-to-date methods and technical procedures for solving complex flooding problems in the areas of planning, design, construction and management. Close ties with the private engineering community and universities ensure the availability and use of sophisticated state-of-the-art technology wherever and whenever possible. This is particularly true when dealing with complex flooding problems such as those often found on alluvial fans in the arid West.

THE CORPS OF ENGINEERS' APPROACH TO ALLUVIAL FAN FLOODING

The degree of flood hazard at different locations on an alluvial fan is difficult to predict except in a simplified probabilistic or general way. Behavior of individual flood events on alluvial fans depends on the history of past events as well as the geological, topographic and hydrologic characteristics of the drainage basin and fan area during the present event. Non-uniform distribution of flow and of sediment and debris loads over the fan surface during an event may result in scour, deposition, blockage, avulsion and redistribution of flow over the fan. The size, direction and location of the main channels and distributaries can change rapidly during a severe event. The net result is that a flood moving across the upper portion of an alluvial fan may not follow the same flow path, have the same velocity, depth, and distribution of flow, have the same sediment load, or cause the same channel blockages as previous floods with the same peak flow characteristics. Cultivation, grading and urbanization activities often contribute to the erratic nature of the movement of water and debris during a flood. These inherent characteristics of alluvial fans make quantitative analysis of fan processes extremely difficult.

Analytical Methods

Although many flood assessment procedures for alluvial fans have been developed during the past 10 to 15 years, no single procedure is clearly superior or completely appropriate for general application. Consequently, the Corps of Engineers may use several different procedures depending on the nature of the flooding problem and purpose of the particular study. Those procedures

include methods reported by Tatum (1963), Dawdy (1979), Magura and Wood (1980), Anderson-Nichols and Company, Inc. (1981), FEMA (1983, 1985), Edwards and Thielmann (1984), Squires and Young (1984), DMA Consulting Engineers (1985), the Hydrologic Engineering Center (1985), the L.A. County Flood Control District (Kumar and Pederson, 1986), MacArthur and Hamilton (1986), French (1987a), Hamilton, et al. (1987), MacArthur, et al. (1987), Los Angeles District Corps of Engineers (1987a, 1987b) Omaha District Corps of Engineers (1988), and the Hydrologic Engineering Center (1988). An excellent synopsis of the presently available management and technical practices for alluvial fan areas has just been completed by Ward (1988). This document should be available from the Arizona Department of Transportation or the Federal Highway Administration in a few months.

At the present time the Corps does not have any specific Nationwide guidelines or engineering manuals for conducting alluvial fan analyses. This is because of the simple fact that was mentioned previously - there is no method yet available that is valid for generalized applications on alluvial fans. Consequently, each Corps district office uses methods and procedures they feel are the most appropriate for the specific problems they are addressing, according to the project's purpose and the specific characteristics of the fan area. As more project investigations are completed by the various district offices, more and more experience will develop. Eventually, if there is enough demand within the Corps to conduct these kinds of flooding studies regularly, official engineering procedures manuals will be developed. However, a few special projects reports and draft guidelines for conducting specific kinds of analyses on alluvial fans have been recently completed. The Los Angeles District recently prepared two draft documents entitled "Engineering Standards For Flood Protection of Single Lot Developments On Alluvial Fans" (L.A. COE, 1987a) and "Los Angeles District Method For Prediction of Debris Yield From Coastal Southern California Watersheds" (L.A. COE, 1987b). The Omaha District just completed a draft project report entitled "Mudflow Modelling, One- and Two-Dimensional, Davis County, Utah" (Omaha COE, 1988a). The Hydrologic Engineering Center (HEC) has also completed a draft Special Projects Report entitled "Incorporating The Effects of Mudflows Into Flood Studies On Alluvial Fans," (HEC, 1988). The Corps will continue to work closely with Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), Association of State Floodplain Managers (ASFPM), state and local agencies and the universities to develop better and more standard procedures for alluvial fan flooding problems.

French (1987a) provides a thorough and up-to-date evaluation of the most commonly used methods and procedures in his book entitled Hydraulic Processes On Alluvial Fans. He concludes that further basic and applied research is necessary in order to incorporate geomorphologic fan processes into present analytical procedures. Numerical models capable of estimating the location and size of channels formed by unsteady, high Froude number flows

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on alluvial fans should also be developed. The Hydrologic Engineering Center (1985 and 1987) developed a pair of "first generation" models for simulating the dynamics of mudflow events in confining channels and on alluvial fans. These tools show good promise but need further refinement for general applications. Case study results from the application of these methods are presented later in this paper.

Model verification is an essential, yet often difficult part of model development. Coordinated physical and numerical model studies with field verification of the results must be designed and conducted. An example of this type of study was the laboratory and numerical verification of the one-dimensional mudflow model conducted by the Portland District Corps of Engineers (MacArthur, et al., 1987). Computed results from their numerical mudflow model were compared to experimental data for laminar and turbulent dam break problems using various concentrations of bentonite slurries in an adjustable slope flume.

Finally, in those areas where adequate stream gaging records are not available, new methods for estimating accurate hydrologic characteristics of single event storms must be developed. Present regional methods and envelope curve methods are often inappropriate for some situations and drainage basins in the arid west. At the present time, the Corps has not developed any new approaches for synthesizing the hydrology on alluvial fans because there hasn't been the project support to do so. However, recent work by the Los Angeles District Corps, with assistance from HEC (Brunner, 1988), evaluated the applicability and accuracy of the HEC-1 Kinematic Wave method for estimating "feasibility level" hydrology for the Las Vegas Drainage Basin for Clark County, Nevada (HEC, 1986 and Brunner, 1988). As further urbanization and development occurs on alluvial fans and population centers in and around these kinds of geological features grow, more need for improved methods will develop.

CASE STUDIES

Selected case studies conducted by the Corps of Engineers are presented here. They provide examples of the types of projects conducted by the Corps and the variety of analytical methods used by the Corps to evaluate different kinds of flooding problems.

Alluvial Fan Flood Protection Studies In Coachella Valley, CA.

The City of Rancho Mirage is located in the Coachella Valley, about 10 miles southeast of Palm Springs, California. Figure 1 presents an aerial view of Rancho Mirage after the July, 1979 flood. Situated on the alluvial fan of Magnesia Spring Creek, the community of Rancho Mirage is subject to high velocity flood flows and associated sediment and debris deposition. Flooding events in 1976 and 1979 caused widespread destruction that led to the design and construction of a flood control project by the Corps' Los Angeles District. The project consists of a debris retention basin

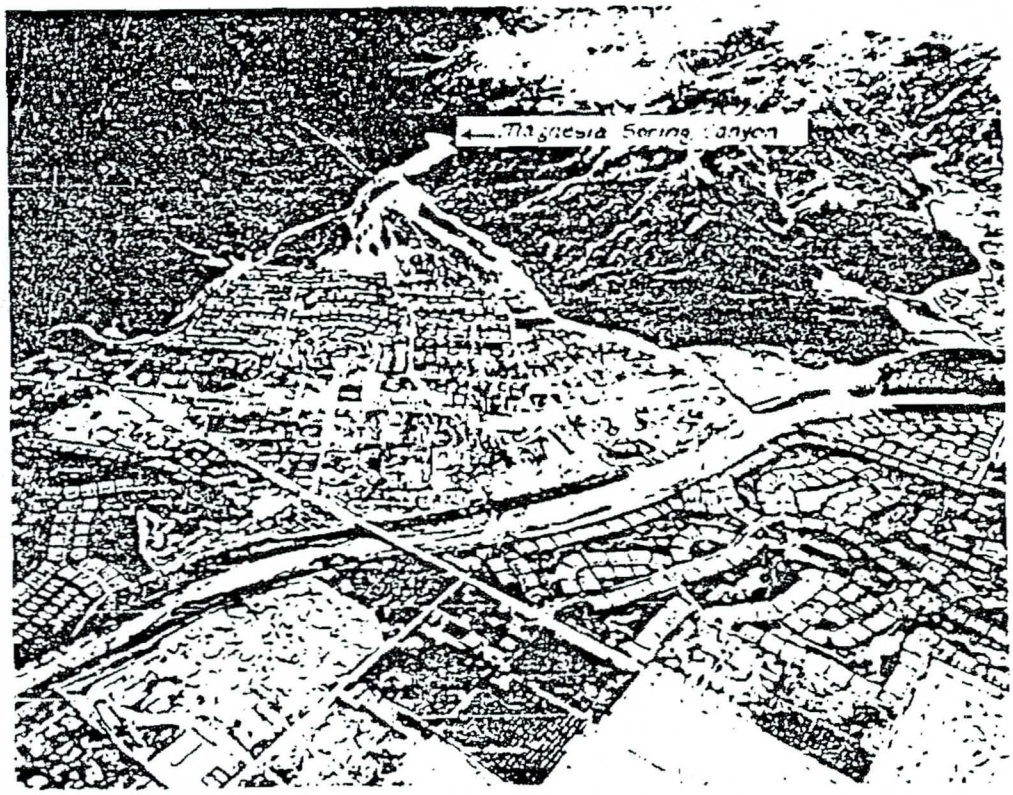


Figure 1

Aerial View of City of Rancho Mirage in Coachella Valley, CA, After the July, 1979 Flood (from L.A. COE, 1982).

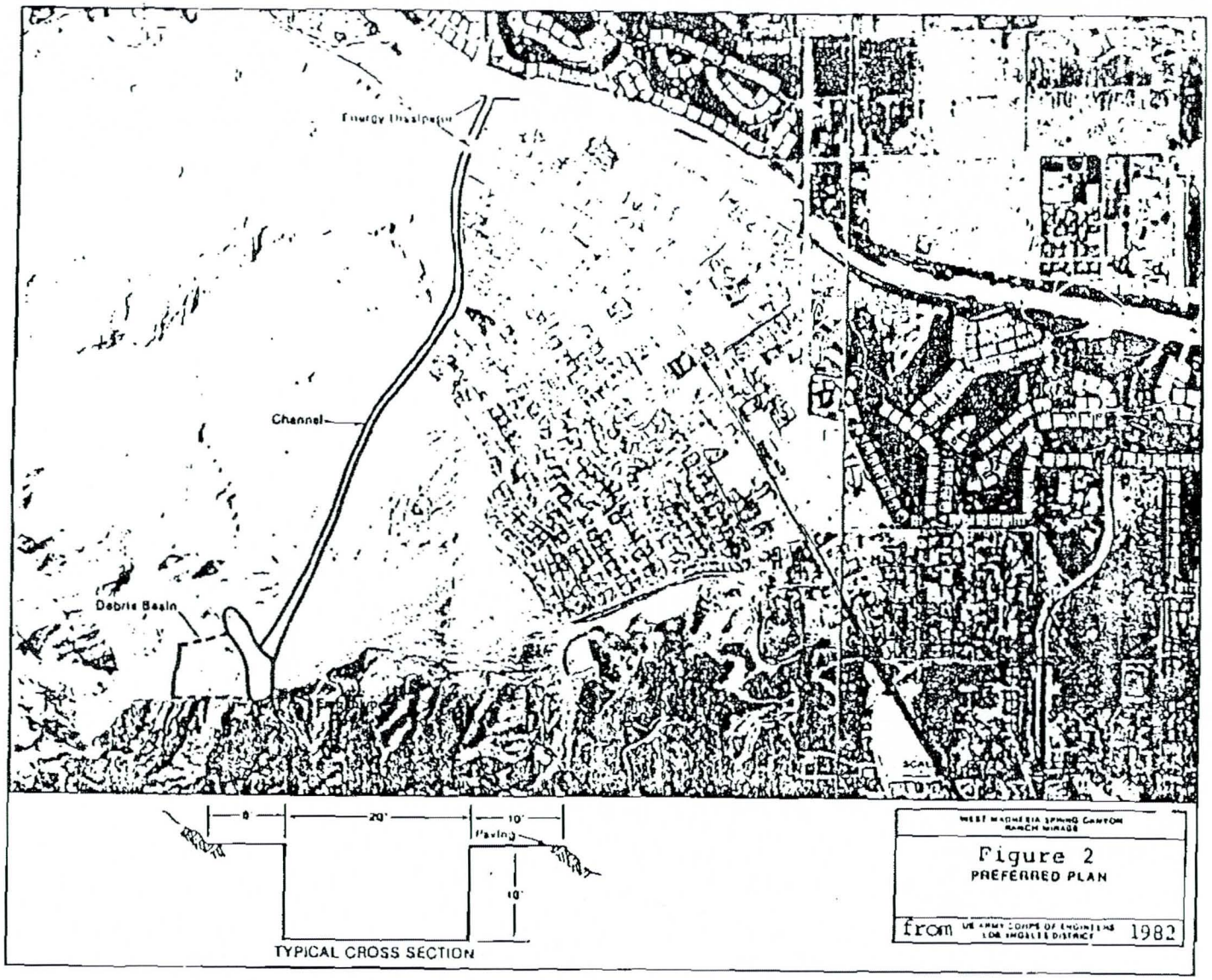
with a spillway and a concrete-lined flood channel with an energy dissipator at the downstream end where it enters the Whitewater River. Figure 2 shows the components of the preferred plan developed by the Los Angeles District. The project is designed to provide standard project flood (SPF) protection for the community.

The Corps used traditional procedures to develop the SPF hydrology. However, in order to size and design the sediment retention basin, the L.A. District engineers worked closely with geologists, soil scientists and Coachella Valley Water District personnel to evaluate soil erodibility and the basin sediment production volume for the SPF. Working together, the multi-disciplinary team modified the Tatum Method (1963) so it could be applied to the Magnesia Spring Canyon drainage basin. Based on the soil type, vegetative cover, slope angle and soil erodibility, the team estimated that a 10-year Tatum burn recurrence condition would best represent the drainage basin sediment production characteristics. Computed sediment yield values compared favorably to observed yield values from a similar debris basin located in Coachella Valley near Rancho Mirage. After verifying the sediment and debris production volume as accurately as possible with measured field data, the sediment basin was sized to capture the SPF sediment load. The spillway and concrete channel sections were designed according to standard Corps of Engineers flood control structures design procedures found in EM-1110-2-1601 (USACE, 1970).

Two similar projects were investigated by the L.A. District in Coachella Valley at the request of the Coachella Valley Water District. The communities of Palm Desert and La Quinta both had similar alluvial fan flooding problems. The Coachella Valley Water District constructed the Corps-designed flood control project for the community of Palm Desert. However, following reconnaissance and feasibility level studies conducted by the Corps, the costs associated with the La Quinta project were too high to justify construction of the proposed project.

Mudflow Studies On The Alluvial Fans of Davis County, UT.

In the spring of 1983, widespread flooding and mudflows caused an estimated $250 million in damages to communities located on the numerous alluvial fans along the base of the Wasatch Mountains in Utah. The destruction was so extensive that 22 of Utah's 28 counties were declared national disaster areas. Flash flooding and mudflows resulted from a rapidly melting snow pack that triggered over 1000 landslides in the steep canyons above the communities. Detailed flood insurance studies had been completed for the communities in Davis County just prior to the events. Traditional steady state, clear water flood insurance study methods were used to delineate potential flood hazard zones for the communities of Farmington, Centerville and Bountiful. However, these studies did not account for mud and debris flows or the magnitude of the damage they cause. As a result, the predicted hazard regions within Davis County were considerably smaller than the actual damage areas that occurred. Therefore, the Corps' primary objectives for this case


Energy Dissipator
Channel
Debris Basin
8'
20'
10'
Paving
10'
TYPICAL CROSS SECTION
WEST MADONNA SPRING CANYON
RANCH MIRAGE
Figure 2
PREFERRED PLAN
from U.S. ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT
1982

study were to develop new flood hazard maps for FEMA considering the potential for the combined effects of mudflows as well as clear water flooding. The Hydrologic Engineering Center (HEC) was asked to develop practical methods for use in these studies, capable of simulating the dynamic behavior of the mudflow events that occurred in Davis County, Utah, in 1983.

Many of the mudflows that occurred in the region can be described with reference to Figure 3. A mudflow is initiated by a landslide occurring in region A. The flow then proceeds down a steep confining canyon along path A-B. At point B, the apex of the fan, the channel opens onto an unbounded plain (alluvial fan) that no longer confines the fluid. The mudflow then spreads out over the fan-shaped area depicted by region B-C-D. After determining that there were no methods available for handling these types of non-Newtonian flow problems, the Corps, with the help of the University of Utah, developed two first generation mudflow routing models for use in these studies. The one-dimensional mudflow simulation model (Schamber and MacArthur, 1985) is used to describe the mudflow behavior between points A and B. Results from the one-dimensional model provide the mudflow hydrograph characteristics needed at the apex of the fan. The Corps' two-dimensional mudflow model (MacArthur and Schamber, 1986 and MacArthur, et al., 1986) uses results from the one-dimensional model to describe the mudflow movement in the region B-C-D. At the end of a simulated mudflow event, the maximum depth and velocity at each computational grid point in the hazard region is determined and displayed as contour maps of depth and velocity. Figure 4 shows computed results for a simulated mudflow event in Rudd Creek, Utah. Figure 5 shows a map outlining the actual damage area for the 1983 event and the simulated damage area from the modeling results. The agreement is quite good.

A similar approach was used to evaluate the other canyons in Davis County, Utah (Omaha District, Corps of Engineers, 1988b). Using these methods, flood insurance study mappings for 15 different streams along the Wasatch Range were prepared. The new modeling procedures provide a practical method for simulating mudflow behavior on alluvial fans that can be used to address some special kinds of flood insurance study needs. The HEC, the Omaha District, and FEMA do not profess that these new methods have been finalized or are now the recommended methods to use. Additional refinement of the codes and generalization of the procedures are necessary.

SIX IMPORTANT ISSUES FOR THE FUTURE

The amount of scientific research necessary to develop a closed form approach to alluvial fan management is almost intimidating. The development of solutions and even the formulation of the problem statement cannot be conducted without regard to a wide range of issues. While conducting projects dealing with alluvial fan flooding, the Corps has identified six important issues that need to be a part of an effective management approach.

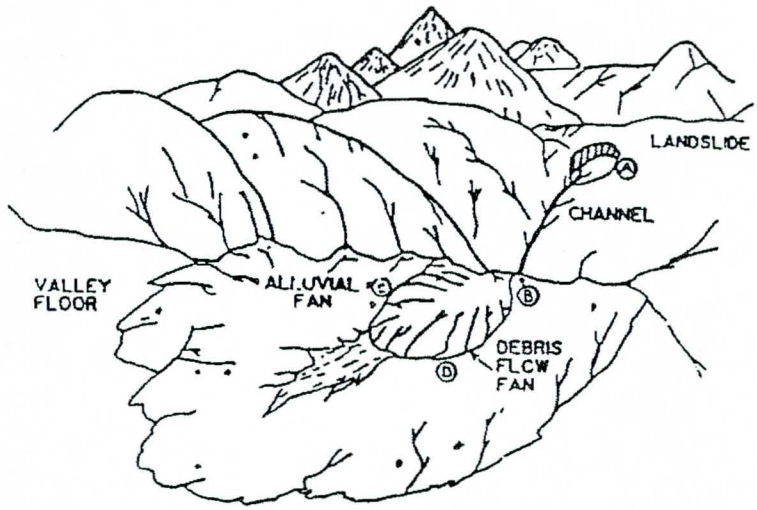


Figure 3

Mudflow Path On An Alluvial Fan.

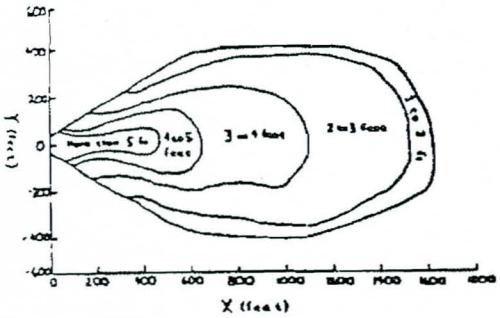


Figure 4-a

Depth Contours For Simulated Mudflow.

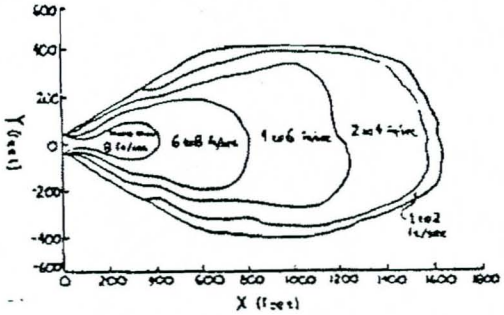


Figure 4-b

Velocity Contours for Simulated Mudflow.

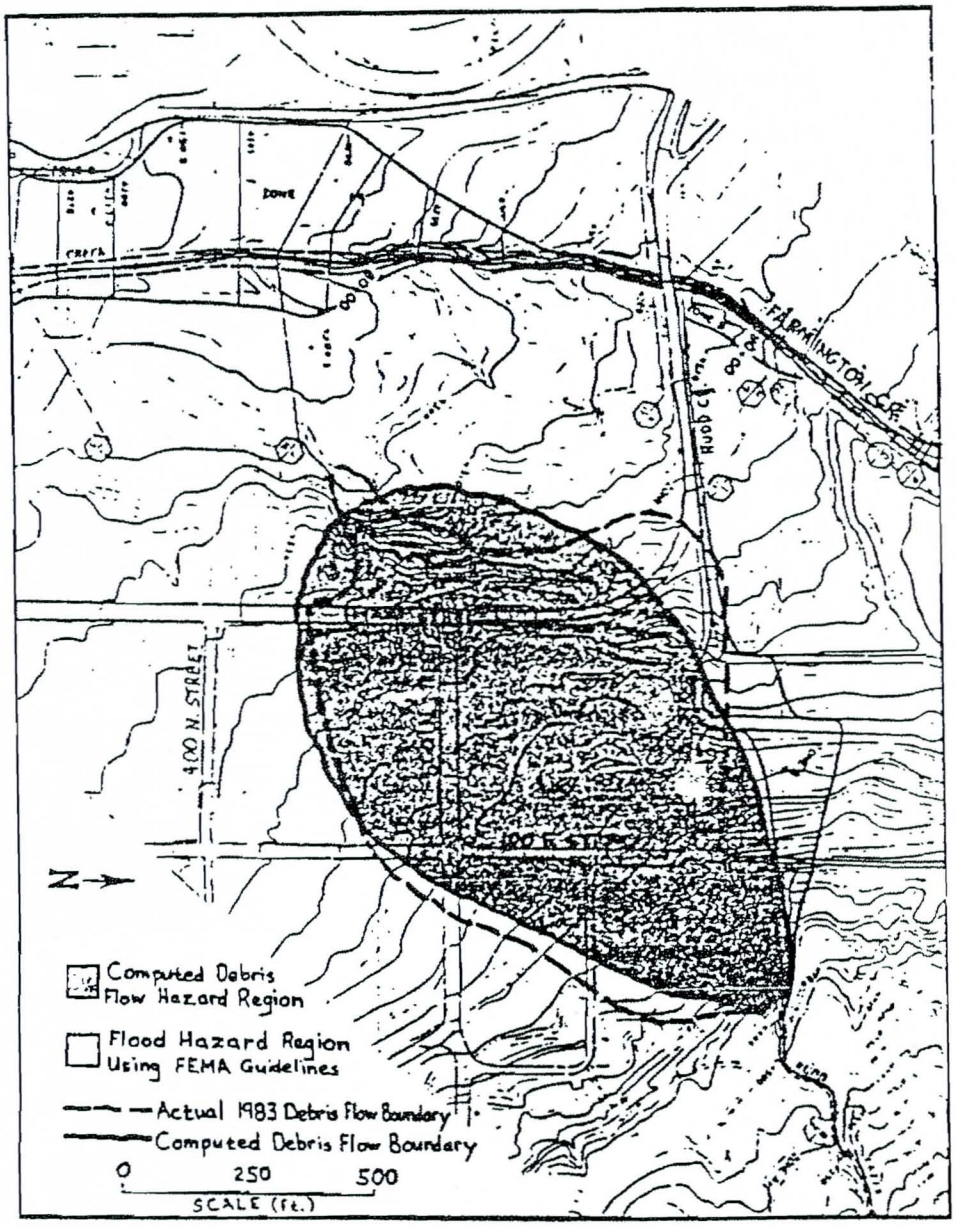


Figure 5

Computed Outline of 1983 Rudd Creek Mudflow

Compared to Observed Event

And Estimated FEMA Hazard Region, Farmington, Utah.

Issues of Historical Perspective

It is well established that the degree of public reverence for natural hazards decays with time after an event. Immediate post-event concern, however, has initiated some of the most significant contributions to our understanding of arid west processes. Consider the 1983 debris flows in Davis County, Utah, for example. The Hydrologic Engineering Center (1988), Keaton and Mathewson (1988), MacArthur, et al. (1986), Wieczorek, et al. (1983), Jeppson and Rodriguez (1983), along with several other significant works came as a response to these events. Our challenge for the future on this issue takes place along two different time scales. The first is to incorporate the knowledge gained by geologic and paleohydrologic investigation. The second is to document the relevant data contained in our relatively short written and oral history. This can take place as hydrologists and hydraulic engineers have more contact with their colleagues from the geological sciences.

Issues of Technical Knowledge

Issues dealing with technical knowledge focus on the collection of data, the conceptual and mathematical description of physical processes, and the formulation of structural and non-structural approaches to flood problems. Unlike humid region flooding, there are two major fields of technical knowledge involved in understanding arid region processes. Alluvial fan management requires the confrontation of not only a hydrologic process but also a complex geologic process. Hydrologists tend to focus on developing short-term solutions to allow safe development. Geologists tend to look at the classification of long-term erosional and depositional trends (French, 1987a). The challenge for the future on this issue is again to combine the experience and knowledge in the fields of hydrology, geology and geomorphology in order to develop an "integrated approach" to alluvial fan flooding problems.

Issues of Analytical Ability

Issues dealing with analytical ability are similar to those of technical knowledge but revolve around the actual solution and implementation of techniques, guidelines, procedures and computations. One common test for the usefulness of a technique is its reproducibility. If two people perform independent studies using the same methods they should arrive at generally the same conclusions. This does not always occur for alluvial fan flooding studies because many of the methods employed by analysts are based on judgement and personal experience. Imposing humid region procedures on arid region studies can be as much of a barrier as it is a guide. There may be site specific factors for each alluvial fan that cannot be generalized into a standard procedure without sacrificing the realism of the solution. As technical knowledge increases, the level of standardization and reproducibility for alluvial fan flooding procedures may increase. The present lack of

a generalized approach should not be viewed as a weakness but as an opportunity to set the direction for future work.

Issues of Institutional Leadership

Public institutions, such as the Corps of Engineers, have historically been the leaders in the construction of flood control projects and the development of related practical knowledge. There is currently no organization clearly recognized as a source of information, guidance, and authority for arid region flood management. However, the Arid West Committee of the Association of State Floodplain Managers has done significant work within the last 3 to 4 years in providing institutional leadership. The great needs for fundamental research, continuous technology transfer and a centralized data base will probably remain unfulfilled for some time until the roles of public agencies and their ability to fund such endeavors change.

Issues of Public Behavior

Recent increases in research efforts in arid region hydrology partially result from the tremendous acceleration in residential development occurring on alluvial fans and the increasing flood damage potential associated with that development. As more people move to these high hazard areas, increasing flood damage inspires greater understanding and more mitigation measures. Part of the reason for the damage is the transfer of flatland housing concepts to steep, high hazard areas. The most common types of developments are large, high density housing tracts with designs that attempt to divert water around their perimeter. Floodplain management often takes the form of a response to such development. Although it is doubtful that residential growth in alluvial fan areas will stop, guidelines for creative approaches to drainage can be set forth in advance in order to shape public behavior. "Complete basin master planning" for flood control and drainage along with tougher zoning and drainage ordinances are becoming essential in many rapidly growing desert communities.

Issues of Legal Implication

Public agencies, developers, consultants, and private landowners have become aware in the past few years of the increase in litigation relating to "natural" hazards. Without comment on the litigation process, the response to this issue should be more care in planning and more awareness and application of state-of-the-art methods. As professional skill, knowledge and specialized expertise continue to improve and be applied to arid region floodplain management, there will be a decrease in the number of issues that need to enter the legal arena.

THE CORPS' FUTURE ACTIVITIES AND INVOLVEMENT

At the present time there are no active research activities within the Corps for the development of improved methods for

analyzing alluvial fan flooding problems. Each district and division within the Corps is presently using methods and procedures their planning and engineering offices feel are the most appropriate for their specific problems. Wherever and whenever possible, the Corps utilizes the most up-to-date methods available from other state or federal agencies, or from universities or private individuals. Through the project reporting and review process, all project reports prepared by Corps district offices are thoroughly reviewed by experienced staff in each division office and eventually by technical staff in the Headquarters offices in Washington, D.C. Often criticized for taking too long, this required review process ensures consistent, accurate and defensible results from the Corps' planning and design activities.

As more projects are completed by the district offices, more and more experience will develop. Eventually, if there is enough demand within the Corps or if there are special assistance requests from FEMA or other agencies to conduct these kinds of flooding studies regularly, official engineering procedures manuals may be developed.

The Corps will continue to work closely with FEMA, the USGS and the Association of Floodplain Managers to eventually develop and document the best possible procedures for evaluating alluvial fan flooding problems.

ACKNOWLEDGMENTS

Robert C. MacArthur and Douglas L. Hamilton wrote this paper and presented it at the October 19-21, 1988 Conference in Las Vegas, NV. Arlen Feldman and Vern Bonner supervised the preparation of the manuscript. Bill S. Eichert is the Director of the Hydrologic Engineering Center. The opinions expressed are those of the authors and not necessarily those of the U.S. Army Corps of Engineers or the Association of State Floodplain Managers.

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APPENDIX C.--Exerpts from Corps of Engineers report of the stability of flood control channels

STABILITY OF FLOOD CONTROL CHANNELS

Draft document prepared for the Waterways Experiment Station and the Committee on Channel Stabilization of the U.S. Army Corps of Engineers.

Prepared by Northwest Hydraulic Consultants Inc., Kent, Washington, in collaboration with an Editorial Board from the Committee on Channel Stabilization.

January 1990

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Selected references on the geomorphology and hydraulics of stream systems are listed in the Bibliography at the end of this chapter.

2.1.2 **Common channel types.** A number of common channel types and their characteristic stability problems are described below and summarized in Table 2.1.1.

Mountain torrents. These are high-velocity streams on steep slopes, often exhibiting a sequence of drops and chutes controlled by large boulders, deadfalls etc. (Figure 2.1.3). Erosion and deposition is sometimes confined to severe flood events. Some mountain torrents on very steep slopes are subject to the phenomenon of "debris flows or "debris torrents" whereby under severe flood conditions the bed becomes fluidized and a virtual avalanche of boulders and gravel runs down the mountainside. In some regions, debris flows are caused by deforestation which increases flood runoff and destabilizes streambanks.

Alluvial fans. Fans generally occur where a stream emerges from a mountain valley on to relatively flat land (Figure 2.1.4). Fans are usually depositional features characterized by coarse alluvial materials, unstable multiple channels subject to frequent shifts or "avulsions". The main channel is often "perched" on the highest ground. Sometimes the fan is inactive depositionally and the stream is eroding into earlier deposits. Fans are usually easily recognizable on airphotos and sometimes on topographic maps. In wooded country they are not always easily recognized on the ground.

Potential stability problems on alluvial fans include avulsion of the stream at a point upstream of training works or channelization, thereby by-passing the works, and infilling of the designed conveyance channel by coarse sediment deposits. Flood control works should be carried sufficiently far upstream and consideration should be given to trapping or removal of coarse sediment upstream of the flood control zone. Location of the flood control channel requires consideration of local features and processes.

Braided rivers. Braided rivers consist of a network of interlacing channels with unstable bars and islands (Figure 2.1.5). They generally occur in the upper and upper-middle zones of a basin. Bed materials are usually gravels or cobbles, but braided sand rivers are found occasionally. Bed-material transport tends to be high, at least in flood periods. For flood-control purposes the wide braided flats are sometimes confined by training works to a single channel or floodway. Stability problems include how to maintain through transport of the bed-material load, and how to avoid serious disturbances of the longitudinal profile. Points that require consideration are the planned cross-section, the alignment in plan, and provision for future shifting and erosional attack.

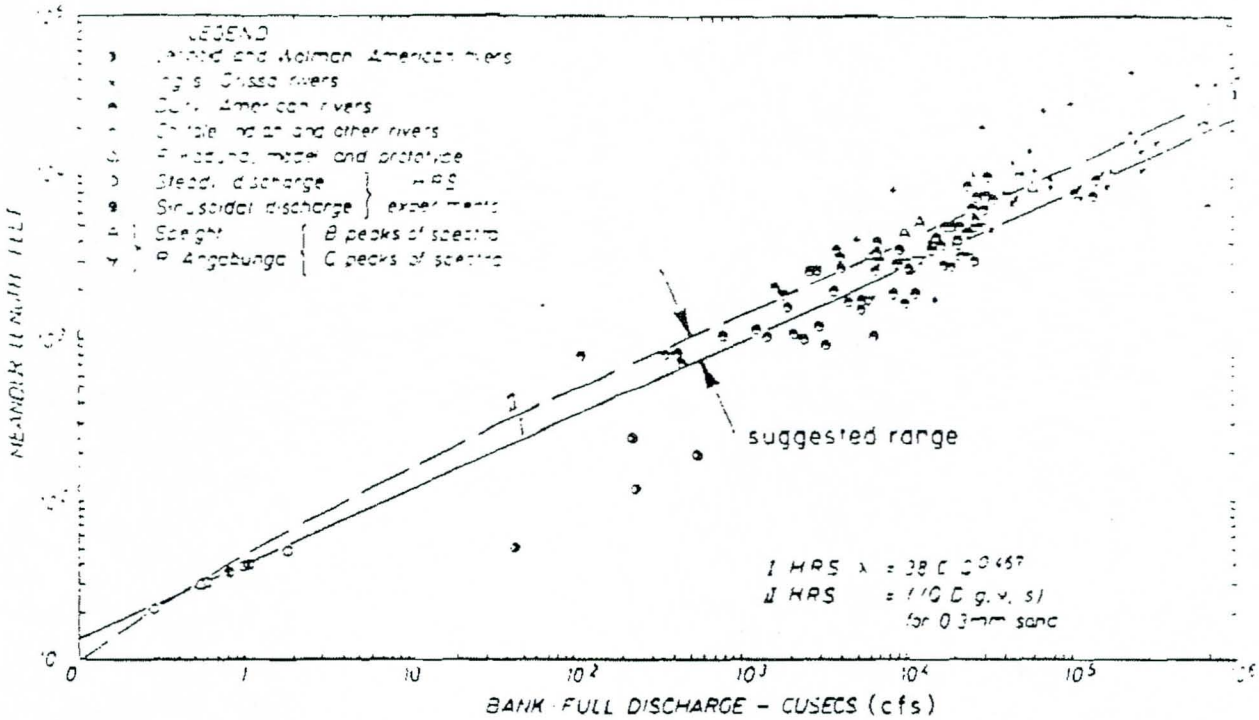

Figure 6.2.4 Suggested relationship between bankfull (channel-forming) discharge and meander wavelength for layout of new channel. (After Ackers and Charlton 1970).

6.2.2 Multi-channel streams. Some streams consist of two or more sub-channels over substantial parts of their length. Examples include the Snake River near Jackson Hole, Wyoming as described in Section 3.2.4 and the Tanana River at Fairbanks, Alaska as described in Section 3.2.9. Braided rivers (Figure 2.1.5) constitute a limiting case.

In utilizing a multi-channel stream for flood control conveyance, it is usually more economical to avoid interference with the stream itself. Levees set back clear of the active channel shift zone are preferred. Alternative locations for levees in such a situation are illustrated in Figure 3.2.6 in the context of a discussion of bank protection in the Snake River.

6.2.3 Alluvial fans. The general characteristics of alluvial fans are described in Section 2.1.2. A typical development on an alluvial fan in California is illustrated in Figure 2.1.3. It is important to determine whether the fan is actively aggrading or in a stable or degrading state. If the fan is

generally unvegetated and the principal channel is "perched" in relation to ground at equal distances from the apex (Figure 6.2.5), the fan is likely to be actively aggrading. On the other hand, if the fan is generally vegetated and the main channel is somewhat entrenched, it may be stable or degrading

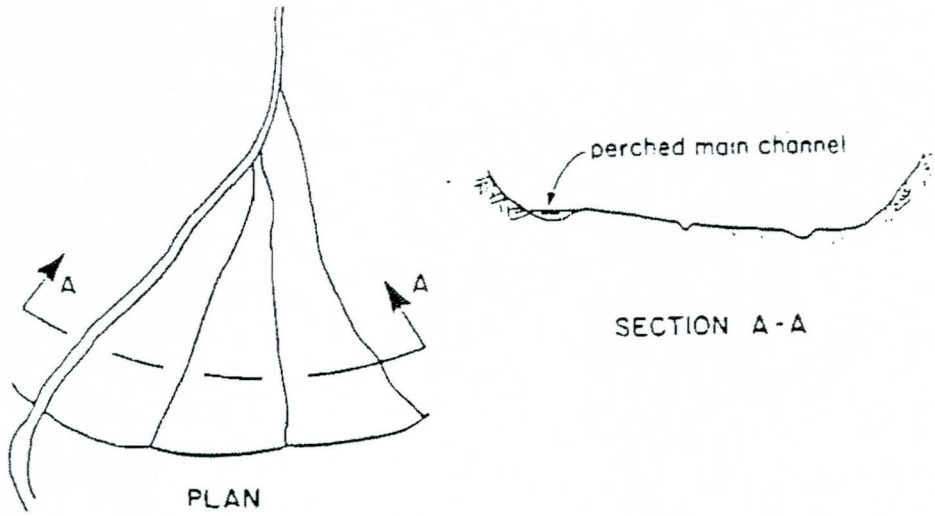

Figure 6.2.5 Perched channel on aggrading alluvial fan.

Developments requiring flood protection on aggrading alluvial fans should in many cases be discouraged. It is difficult to keep the main flow in its existing channel without expensive special measures. The channel may plug with the bedload during a flood and the main flow may divert to a lower route.

One workable although expensive method of flood control is to build a debris basin at the head or apex of the fan with provision for period cleanout (Figure 6.2.6). Deprived of bed load, the channel then tends to entrench and degrade to a flatter slope. To avoid excessive erosion it is generally necessary to line the flood control channel with concrete or riprap (Figure 6.2.7) or to provide grade control structures. Before committing to a debris basin at the apex, however, it is advisable to confirm that the main supply of coarse sediment is derived from the upstream channel or gorge and not from terrace erosion farther downstream, as is sometimes the case (Figure 6.2.8).

In some places where development has occurred on closely adjacent alluvial fans all issuing from the same mountain range, cross-slope interceptor channels have been used to pick up flows from a series of fans (Figure 6.2.9). Debris basins are located at the head of each fan.

Figure 6.2.6 Debris basin and dam at head of alluvial fan

Figure 6.2.7 Concrete-lined channel on alluvial fan below debris dam.

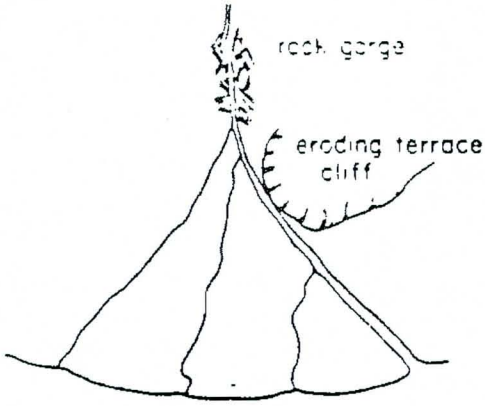

Figure 6.2.8 Principal active source of fan bed load may be downstream of apex.

Figure 6.2.9 Cross-slope interceptor channels collecting flood flows from adjacent alluvial fans.

APPENDIX D.--Report on flood hazard identification and flood plain management on alluvial fans by L. M. Magura and D. E. Wood

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FLOOD HAZARD IDENTIFICATION AND FLOOD PLAIN MANAGEMENT ON ALLUVIAL FANS[1]

Lawrence M. Magura and Darrel E. Wood[2]

ABSTRACT: Recognition of the flood hazard that exists on alluvial fans has seriously lagged behind the recognition of other more conventional flood hazards such as those associated with most rivers. This delay in recognition was due, until recently, to a general lack of economic investment and development in these areas and a concomitant lack of historical alluvial fan flood damage. Dramatic recent events, such as Tropical Storm Kathleen, emphasized to the Federal Insurance Administration (FIA) the need for developing an appropriate methodology to identify flood hazard areas on alluvial fans. This paper presents the methodology now employed by FIA as well as flood plain management considerations that could reduce future flood related damage to communities developing in these areas.
(KEY TERMS: alluvial fans; flood insurance; flood plain management; western United States.)

INTRODUCTION

As part of the National Flood Insurance Program, the Federal Insurance Administration (FIA) is responsible for identifying flood hazard areas and developing flood plain management regulations for the nearly 20,000 flood prone communities in the United States. Most of these communities can have their flood-prone areas delineated by conventional means using such techniques as analysis of stream gaging station records, and step-backwater hydraulic computer programs. However, when the flood-prone community is situated on the surface of an alluvial fan, as a large number of rapidly growing southwestern communities are, flood hazard identification becomes a major problem.

Alluvial fans are found throughout the arid western United States. The nature and characteristics of flooding on alluvial fans are such that conventional riverine flood insurance study procedures cannot be employed. Identifiable stream channels are frequently discontinuous and often appear to be scattered at random across the fan's surface, with each channel capable of conveying only a fraction of a flood peak discharge. In response to the special flooding problems that exist on alluvial fans, and the concomitant special flood plain management regulations necessary to reduce future flood-related damage, FIA is experimenting with a special flood insurance zone designation. This special zone is identified by the letters AF (for

Figure 1. Aerial View of the City of Palm Desert, California. Taken Shortly After the Flood of September 9-10, 1976 (Tropical Storm Kathleen). Flood waters of approximately 100-year frequency roared down Dead Indian Canyon (in background), breaching a flood control dike near the top of the alluvial fan on which the town is built and raced through the community below. Note the clearly visable path of the water. Photo Credit: Fred Bouman.

[1] Paper No. 79031 of the *Water Resources Bulletin*. Discussions are open until October 1, 1980.

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alluvial fan) and is now being applied by FIA study contractors to identify those portions of an alluvial fan surface that are subject to flooding from a 100-year flood event. This paper will focus on the special study procedure that FIA has developed and is requiring its flood insurance study contractors to utilize for identifying AF zones.

TROPICAL STORM KATHLEEN SPURS DEVELOPMENT OF AN APPROPRIATE STUDY PROCEDURE

The need for the development of an appropriate alluvial fan hazard identification procedure was dramatically emphasized by the passage of Tropical Storm Kathleen over the desert areas of Southern California on September 9 and 10, 1976. Kathleen was the most severe storm to pass over this normally very arid region since at least September 1939. Many locations received as much rainfall on September 10, 1976, as would normally fall over an entire year. The precipitation gage at Palm Springs recorded 2.76 inches of rainfall for this date, and nearby Indio recorded 2.67 inches. These amounts compare with normal annual precipitation totals for the communities of 5.33 and 3.00 inches, respectively. These one-day rainfall totals nearly equal the published NOAA 100-year 6-hour rainfall of 2.80 inches for this area. The California Department of Water Resources estimated that portions of the drainage basins located in the high, rugged mountains near these communities may have received as much as 10 or 11 inches of rainfall on this single day. Many newspaper accounts referred to this event as the "storm of the century" for this region, and no substantive analysis has yet been published that would dispute this contention.

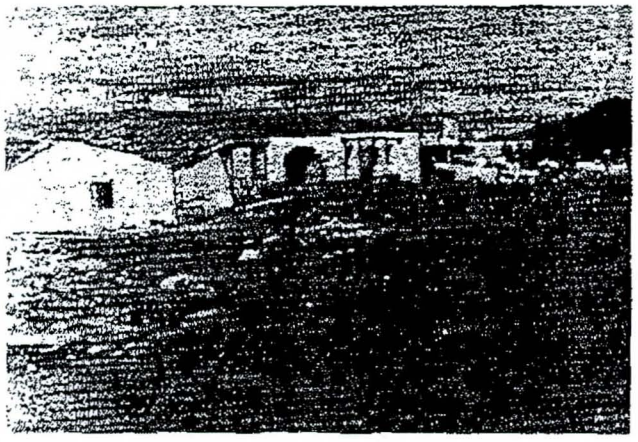

Figure 2. Palm Desert, California, Immediately After the Flood of September 9-10, 1976 (Tropical Storm Kathleen). This home was severely damaged by the rapidly moving flood water which undermined its foundation, resulting in a partial collapse of the structure. Clearly visible high water marks on the front of the home indicates a depth of flow being less than 3 feet. Photo Credit: PRC/Toups Corporation and Riverside County Sheriffs Department, California.

Figure 3. Example of Damage Caused by Debris Deposition by Flood of September 9-10, 1976 (Tropical Storm Kathleen) in Palm Desert, California. This one-story home is partially buried by approximately four feet of accumulated silty sand, gravel, and large boulders. Photo Credit: PRC/Toups Corporation and Riverside County Sheriffs Department, California.

The pattern of flood damage left by Kathleen was more typical of midwestern tornado damage; certain localities were extremely hard hit, while areas immediately adjacent experienced little or no structural damage. As an example, in eastern Riverside County, the City of Palm Springs was essentially undamaged, while Palm Desert, located only a few miles away, suffered over six million dollars worth of property damage. (Figures 1, 2, and 3 dramatically show the impact of Kathleen on the City of Palm Desert.) Flood-related damage included the near total destruction of seven expensive homes, such as the one shown in Figure 2 (one home was valued at over $125,000) and lesser damage to several hundred others. This less severe damage ranged from the deposition of sediment and debris in homes and swimming pools, to the scouring away of expensive landscaping. Throughout Riverside County alone, total damage from Kathleen was estimated at $38.5 million by the California Department of Water Resources. Total damages caused by Kathleen in the desert areas of Southern California are estimated to have exceeded $50 million.

The basic cause of this substantial flood damage was a failure on the part of local planning and building officials and developers to recognize the true degree of flood hazard that exists on alluvial fans. In part, the responsibility for not recognizing this flood hazard belongs to FIA, which, prior to the experience gained from Kathleen, had failed to develop an engineering procedure that could reasonably define this type of flood hazard. But to a larger degree, the responsibility is due to the lack of sufficient historical precedents. Prior to Kathleen, the last damaging flood in Southern California desert areas occurred in 1939, when the area had a very low population density and a concurrent low level of economic

development. In the absence of any historical record of flood damage, it is easy to understand how the severity of the alluvial fan flooding problem has gone unrecognized for so long.

CHARACTERISTICS OF ALLUVIAL FAN FLOODING

Flow rarely spreads evenly over the surface of an alluvial fan or occurs to depths of more than a few feet (as Figure 2 indicates). Typically flow is concentrated in an identifiable temporary channel, or it is confined to only portions of the fan surface. Such flow paths are prone to lateral migration and a sudden relocation to any other portion of the fan during a runoff event. This erratic, unpredictable behavior subjects almost all portions of the fan to potential flood hazard, regardless of location. Therefore, a site that is distant from an identifiable channel has approximately the same potential for flooding as a site at the same elevation near an identifiable channel. The zone at risk from 100-year flooding is therefore much larger than any single 100-year flood plain computed by conventional means.

Alluvial fans can generally be grouped into two classes (Bull, 1974): *Type 1* fans are those where sediment deposition takes place near the fan apex, and the lower portions of the fan are largely undissected. *Type 2* fans possess a characteristic fanhead trench which conveys sediment-laden water to the lower portion of the fan, where it spreads out and the sediment is deposited. Local relief on alluvial fans is usually small (on the order of 5 to 10 feet) except at fanhead trenches, which may be incised up to 50 feet or more. Identifiable channels may occur at any location on an alluvial fan, but they are usually very small in relation to the magnitude of expected flood discharges and are subject to rapid alteration and change in geometry due to the highly erosive nature of the materials of which an alluvial fan is composed.

High velocities, rapid bank erosion, and sediment deposition are the major flood-related hazards to which economic development on an alluvial fan is subjected. Conventional structural flood control may be imposed by construction of upcanyon dams and diversion structures, channel deepening or realignment, and bank stabilization measures (Bishop, 1978). Where such structural solutions are in place, remaining flood hazards can usually be evaluated through the use of established hydraulic analysis techniques. However, development on alluvial fans usually takes place gradually, so that costly structural solutions to flooding problems can seldom be economically justified. Also, the pervasive poor recognition of alluvial fan flood hazards generally means that structural flood control measures are all too often not considered to be necessary. In most cases, therefore, flood flows on fans are essentially unmodified and processes such as fanhead trenching, braiding of distributary channels, and channel abandonment take place unconstrained by the works of man.

The behavior of flood flows, and the associated flood hazard, is largely a function of location below the apex of the fan. The degree of flood hazard can be considered to be equal for all points that are radially equidistant from the fan apex. If adequate structural measures exist, so that lateral migration of the main channel is controlled up to a certain design discharge, then areas on each side of the controlled channel can be designated as not-at-risk from discharges of that magnitude or less. In general, however, where significant change in the conveyance characteristics occur (i.e., at breakpoints in local gradient, or transitions from a meandering to a braided channel) the nature and severity of the flood hazard changes.

The basic premise of the technique that FIA is now experimenting with for quantitatively evaluating the degree of flood hazard on alluvial fans is that when channel gradient approaches or exceeds a certain critical slope, then the critical state of flow may be assumed to accurately represent the potential depth and velocity of flow at that point. Critical slope is simply defined as the slope or S term from Manning's Equation:

$$Q = A \frac{1.486}{n} R^{2/3} S^{1/2}$$

where:

- Q = discharge, c.f.s.;
- A = channel cross-sectional area, ft^2;
- R = hydraulic radius, ft;
- S = slope, ft/ft; and
- n = a dimensionless roughness coefficient.

Critical slope is thus the slope required to impart the minimum specific energy to a constant unit of flowing water, that will cause it to flow at critical depth. This is usually expressed in terms of the Froude Number, N_F, which for critical depth, is defined as being equal to 1. While slopes in excess of critical slope would theoretically produce higher velocities and shallower depths (super-critical flow), the combined effects of minor variations in channel roughness, geometry, slope, and sediment scour and deposition will usually cause flow depth to approach but not exceed critical depth. In reality, super-critical flow in natural alluvial channels is a transitory phenomenon and not a representative steady-state condition. As long as channel gradient exceeds critical slope, the flow will not revert to the subcritical alternate depth. For the majority of alluvial fans, critical slope or greater appears to be the natural condition across the entire surface of the fan.

FLOOD HAZARD DETERMINATION

The mechanics of the procedure adopted by the FIA for alluvial fan flood hazard identification is based on unpublished work by B. C. Lare and G. L. Esyter of the Albuquerque District, Corps of Engineers. Before the procedure can be employed, however, it is first necessary to develop 100-year flood discharge values at the apex of the fan. Recent experience by FIA has shown that hydrologic analyses in desert and arid regions frequently become very complicated because of the

general lack of sufficient hydrologic data to perform a conventional discharge frequency analysis. Not only are stream gaging station records usually of short length, when they exist at all, but the record itself is usually composed of many low outliers and only a few meaningful values. Rainfall-runoff modeling and regional regression equations frequently have to be developed, although the solutions generated by these means have many uncertainties associated with them. Once the magnitude of flood discharge at the top of the fan has been determined, the alluvial fan flood hazard identification procedure can be applied to determine the depth, average velocity, and aerial extent of flooding on the fan surface.

Due to the variation in flow characteristics on alluvial fans, separate reaches, where flow characteristics are more or less the same normally have to be designated. Possible reach boundaries are: the fan apex, intersection points with main valley and canyon sides, points of substantial change from entrenched channel to braided channel, change in overbank encroachments (structures), or points of substantial change in gradient. Each reach will have unique but relatively constant properties of channel cross-sectional area, shape, slope, and width to which overbank flow can spread.

In many cases, development on alluvial fans is very sparse or confined to a relatively small portion of the fan surface, and topography does not limit the extent to which flow may spread. From a practical point of view, some limit must be defined for purposes of analysis, since overland flooding cannot extend infinitely. For a channel of constant cross section, the critical depth overbank velocity and percent of discharge conveyed in the overbank area has been computed for different overbank widths. Computations utilizing the Corps of Engineers HEC-2 step backwater computer program have been made for a range of discharges and channel configurations and tabulated by Lare and Eyster. Representative results are presented as the curves in Figures 4 through 7. The 30-foot channel width and 5-foot depth shown on Figures 4 through 6 represent the average channel geometry for an area investigated by Lare and Eyster in New Mexico. The investigator may interpolate or extend these results to meet his specific needs as required, or compute a new family of curves if the gross conveyance characteristics modeled by these curves do not appear to fit a particular area under study. The flow regime presented in Figure 7 is perhaps the most typical situation, wherein identifiable channels are so insignificant that they are not effective in conveying substantial flows, and a true sheetflow condition exists. For flows well in excess of channel capacity at critical depth, the computed depth decreases as flowpath width increases, with the rate of change gradually approaching zero. Theoretically, this rate of change can never actually reach zero, because for an infinitely wide flowpath width, the corresponding depth of flow would become infinitesimally small. In reality, neither fully contained flows nor infinitesimally small depths occur. Rather, some intermediate *characteristic* depth can be generalized at some cross sectional point wherein a balance of forces and momentum can be considered to exist. No analysis of flooding on an alluvial fan can be considered to be realistic unless it is composed of individual separate analyses for each identified reach of the fan surface. It is suggested that the analysis of each of the reaches that together comprise the fan surface conform to the appropriate guidelines listed below for the various types of reaches:

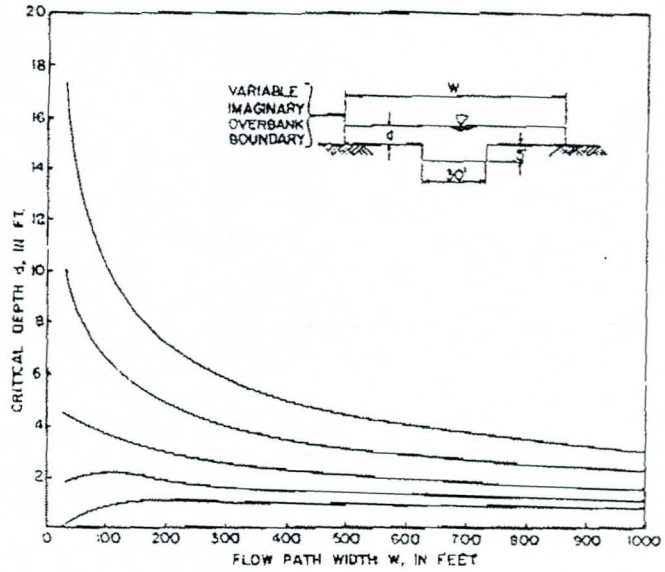

Figure 4. Relationship of Critical Depth to Flow Path Width, W, Compiled From Multiple-HEC-2 Runs by Lare and Eyster for a Channel and Overbank Configuration as Shown Schematically Above. Individual curves are for discharges of 2,000, 3,000, 5,000, 10,000, and 18,000 cfs, respectively.

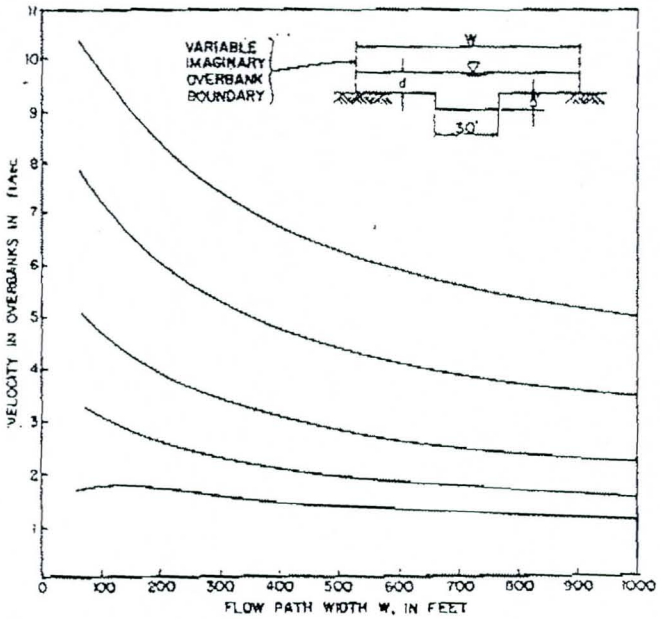

Figure 5. Relationship of Velocity in Overbanks vs. Flow Path Width, W, Compiled From Multiple-HEC-2 Runs by Lare and Eyster for a Channel and Overbank Configuration as Shown Schematically Above. Individual curves are for discharges of 2,000, 3,000, 5,000, 10,000, and 18,000 cfs, respectively.

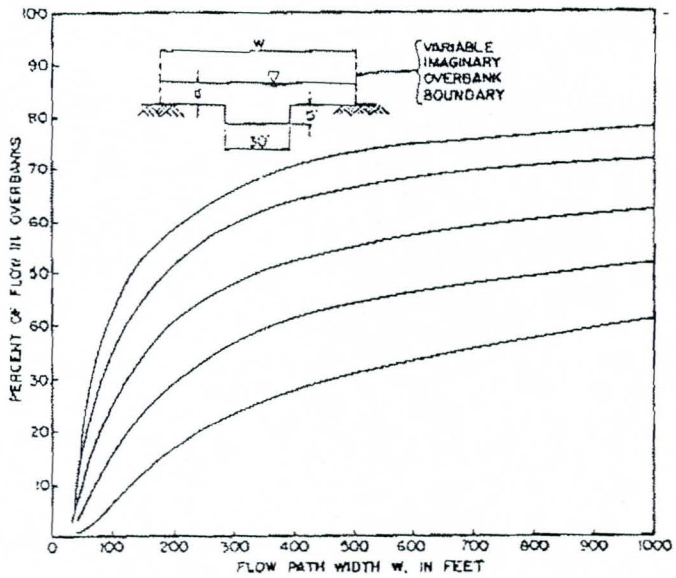

Figure 6. Relationship Between Percent of Flow in Overbank to Flow Path Width, W, for a Channel and Overbank Areas With a Configuration as Shown Schematically Above. Original data compiled from multiple HEC-2 runs by Lare and Eyster. Individual curves are for discharges of 2,000, 3,000, 5,000, 10,000, and 18,000 cfs, respectively.

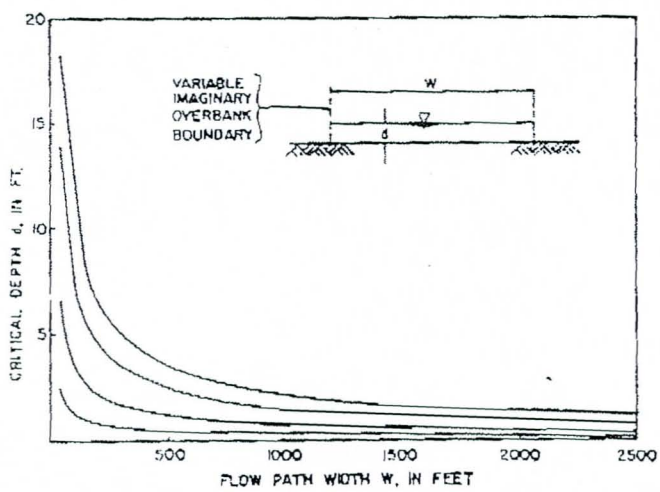

Figure 7. Relationship of Critical Depth to Flow Path Width, W, for Overland Flow Conditions (no channel). Original data compiled from multiple HEC-2 runs by Lare and Eyster. Individual curves are for discharges of 1,000, 4,000, 12,000, and 18,000 cfs, respectively.

1. *Areas within the canyon, or areas on the fan surface where a deeply entrenched channel exists* – Such areas should be approached with established techniques of hydraulic computations, bearing in mind that super-critical flow cannot be sustained in natural channels. In cases where structural flood control measures are in place, design computations may be used if they are available and deemed to still reflect the hydrologic regime of the watershed. Otherwise standard hydraulic procedures utilizing variable flow computations in valleys and reservoir routing may be used.

2. *Areas on an alluvial fan protected by structural works* – Hydraulic analysis of diversions and stabilized channels should be carried out with particular attention to the structural integrity and design adequacy of the structures. The long-term ability of the structure to retain adequate capacity for passing 100-year flows in a region of heavy sediment transport and deposition must be assessed.

3. *Majority of areas where natural fan processes such as trenching, lateral migration of channels, and sediment deposition are free to take place* – Most analyses will probably fall into this category. Two general subcategories can be defined: the untrenched fan and the fan which is entrenched at the upper end.

a. **Untrenched Fans.** The lack of entrenchment often occurs on fans with relatively small upstream canyons where, immediately upon leaving the canyon mouth, flow spreads out. Critical depth analysis alone is employed in these cases and is represented in Figure 7. If the range of discharges presented on this figure is not appropriate for a particular area under study, the investigator can easily compute one that meets his specific requirements by using any hydraulic computer model. After the 100-year discharge has been computed, it can be applied to Figure 7 and a resultant depth may be established at the point on the curve to which the ratio $\Delta d/\Delta W$, where Δd is the difference in depth of flow and ΔW is the difference in width of the flowpath, becomes sufficiently small. Based upon field experience accrued from observations of historical flood events on alluvial fans, an average value for the ratio of $\Delta d/\Delta W$ has been established as 0.005 feet per foot. This value should be used for all cases unless a different ratio appears to be more representative for a particular situation based on observational or other mitigating evidence. Utilizing the established ratio, an increase in the width of flow of 100 feet results in a change in depth of flow of 0.5 feet. Additional increases in W result in a rapid decrease in d. Since the AF zones are rounded to the nearest one foot depth increment for flood insurance study purposes, this characteristic depth and associated velocity are applied to the locus of points equidistant from the apex of the fan, regardless of location on the fan relative to an apparent flow path. On larger alluvial fans in this category, minor drainage patterns often develop in response to runoff generated on the fan surface itself. However, it cannot be expected that flows originating up-canyon will follow such courses to the exclusion of lesser-developed flow paths.

b. **Entrenched Fans.** This second category should be applied to those cases where an unbroken flow path exists which conveys up-canyon flow down-fan to a point where sediment deposition takes place. Such entrenched channels may be straight or meandering single channels, or a network of interwoven channels. In either case, an average channel cross section is determined for each reach from either field inspection,

large-scale topographic mapping, or actual field survey. For the discharge of interest, a curve of d vs. W is developed. Potential flood depth may be determined using the 0.005 feet per foot criterion, unless this ratio seems inappropriate. The resultant depth is applied across the entire fan under the assumption that the main channel may shift at the fan apex during a flood, forming a new channel elsewhere on the surface of the fan. Wherever flow characteristics change sufficiently, as discussed above, a different reach is established and analyzed separately. Using this technique, a typical flood plain delineation on a sparsely developed fan may take the form shown in Figure 8. In a given zone bounded by reach limits, the potential for flood damage may be defined by the velocities and depths of flow computed by the method outlined above.

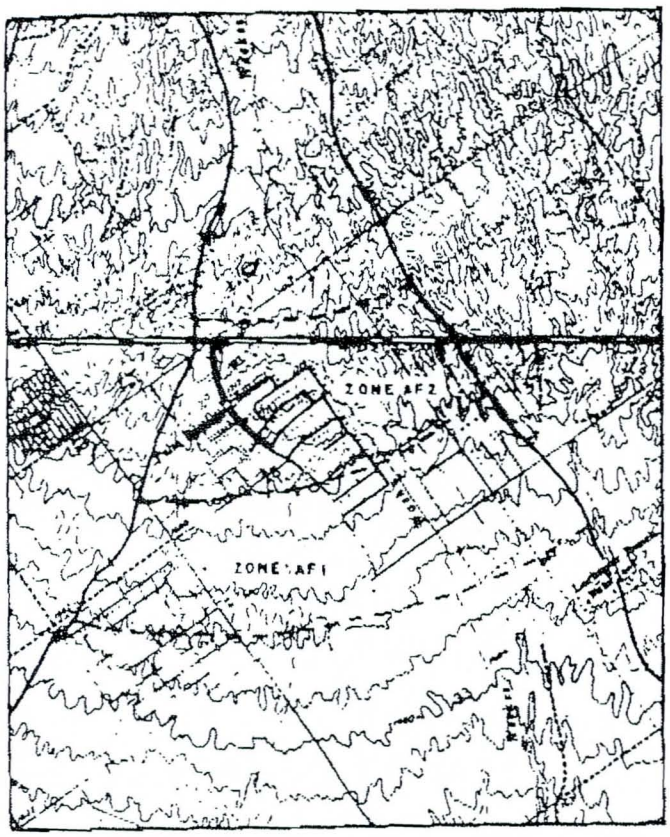

Figure 8. Example of Application of Alluvial Fan Flood Hazard Analysis Procedure to a Portion of an Alluvial Fan Near Apache Junction, Arizona.

FLOOD PLAIN MANAGEMENT ON ALLUVIAL FANS

Conventional flood plain management techniques such as the regulatory floodway concept wherein a portion of a stream channel is reserved for the conveyance of the 100-year flood event with a surcharge of one foot, are not appropriate on alluvial fans. Obviously, as recent flood damage experience in communities such as Palm Desert has shown, construction of structures with the first finished floor at essentially the ground level (slab-on-grade) is not appropriate. Also, the raising of a structure to above the calculated 100-year flood elevation using fill material is not appropriate due to the extremely high erosion potential that exists from fairly shallow water flowing at high velocity. Finally, the application of structural flood control on alluvial fans through the development of dikes or levees is not generally appropriate. Typically, what happens is that in an effort to safeguard a particular structure or development, a builder will construct a diversion structure which has the effect of deflecting and concentrating flows into the immediate adjacent area. The effect of implementing unintegrated structural controls in these areas then is to provide localized protection at the expense of greatly increasing flood risks to adjacent unprotected areas.

At present, FIA has over 40 communities under study for flood insurance purposes in the southwest where the alluvial fan study procedure described in this paper is being applied. Flood plain management regulations for areas now being identified utilizing the alluvial fan study procedure are still being developed by FIA. While the specific focus of these regulations is not known at the present time, it may be reasonably assumed that they will include recognition that some portions of an alluvial fan are simply too hazardous to allow any structural development. These areas may include the entire upper portions of fans where flood flows are still concentrated by the orifice of the canyon mouth. Farther down the surface of the fan, where flows have had an opportunity to spread out and dissipate some of their damage-causing energy, flood plain management regulations may include the elevation of all new construction on some form of bridge system (i.e., piers, piles, or columns) that would allow for the free passage of flood waters underneath the structure. Only on the lowest portions of a fan can engineered fill safety be used for raising structures. Other regulations may address the requirement that all arterial streets be depressed below surrounding ground elevation so that during flood periods, the streets themselves would provide the principal conveyance for flood flow thereby reducing the risk of flood damage in the adjacent areas.

CONCLUSION

Reduction of future flood-related damage through a program of flood hazard identification and flood plain management regulation is the ultimate goal of the National Flood Insurance Program. The alluvial fan flood hazard identification procedure presented in this paper represents the first attempt to apply the goals of this program to areas where in the past, the degree of flood hazard has gone unrecognized. In comparison to other flood hazard identification techniques currently being applied to more conventional flood problems, this technique is fairly crude. Undeniably, the procedure presented in this paper will be superseded by subsequent improvements and modifications. If this paper has succeeded in stimulating the creative efforts of other water resources professionals, then it has accomplished its intended purpose.

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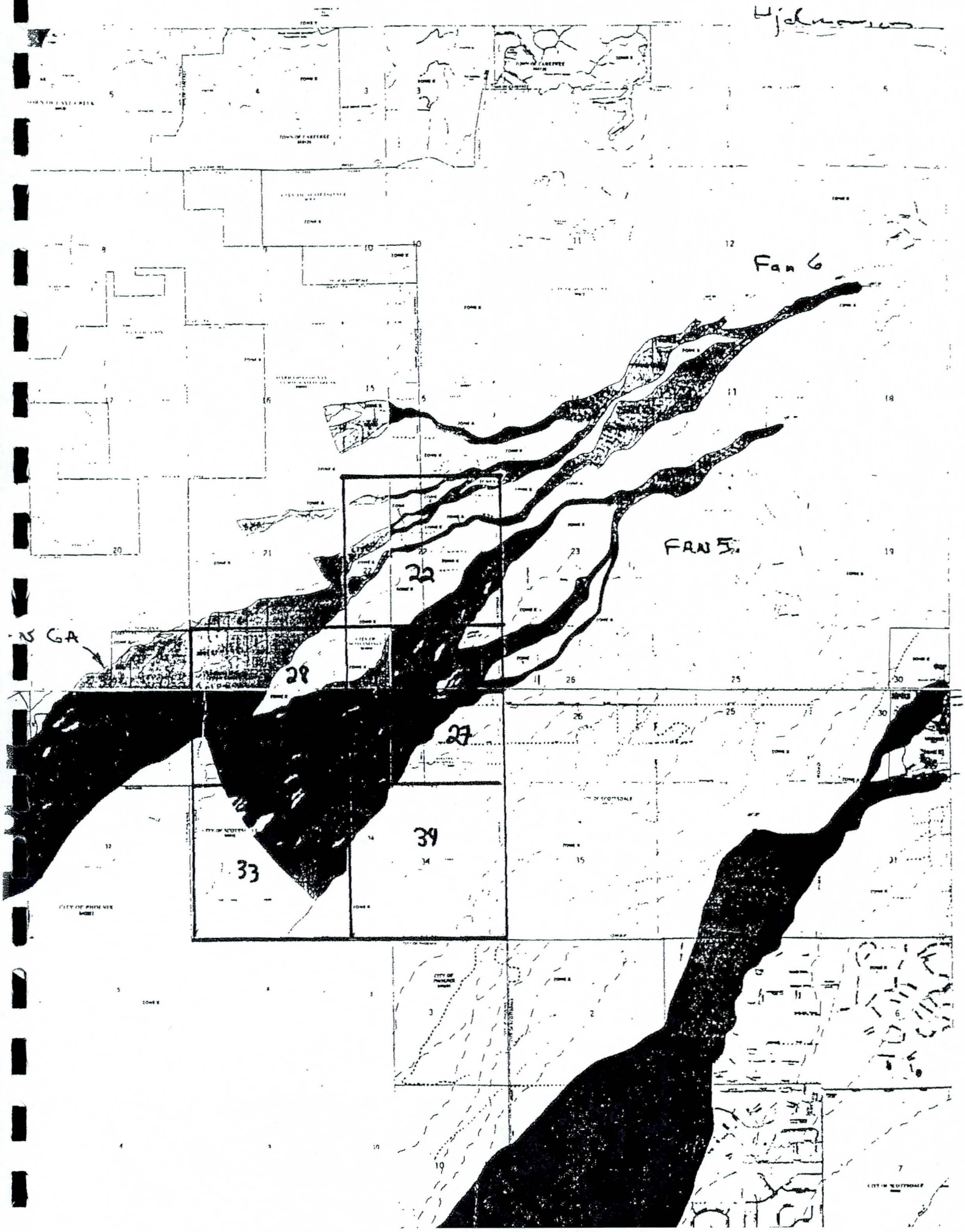
APPENDIX E.--FEMA flood map for fans 5 and 6


Fan 6
FAN 5
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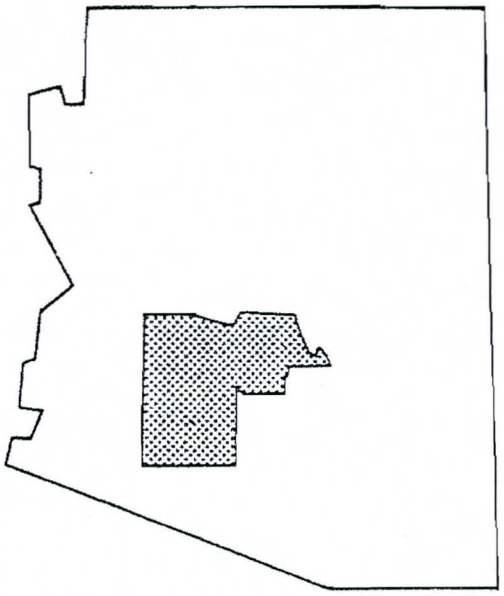
FLOOD INSURANCE STUDY

MARICOPA COUNTY, ARIZONA
AND INCORPORATED AREAS

JAN 4 1993



COMMUNITY NAME	COMMUNITY NUMBER
AVONDALE, CITY OF	040038
BUCKEYE, TOWN OF	040039
CAREFREE, TOWN OF	040126
CAVE CREEK, TOWN OF	040129
CHANDLER, CITY OF	040040
EL MIRAGE, TOWN OF	040041
GILA BEND, TOWN OF	040043
GILBERT, TOWN OF	040044
GLENDALE, CITY OF	040045
GOODYEAR, TOWN OF	040046
GUADALUPE, TOWN OF	040111
LITCHFIELD PARK, CITY OF	040128
MARICOPA COUNTY UNINCORPORATED AREAS	040037
MESA, CITY OF	040048
PARADISE VALLEY, TOWN OF	040049
PEORIA, CITY OF	040050
PHOENIX, CITY OF	040051
QUEEN CREEK, TOWN OF	040132
SCOTTSDALE, CITY OF	045012
SURPRISE, TOWN OF	045053
TEMPE, CITY OF	040054
TOLLESON, CITY OF	040055
WICKENBURG, TOWN OF	040056
YOUNGSTOWN, TOWN OF	040057

Federal Emergency Management Agency

NOTICE TO
FLOOD INSURANCE STUDY USERS

Communities participating in the National Flood Insurance Program have established repositories of flood hazard data for floodplain management and flood insurance purposes. The Flood Insurance Study may not contain all data available within the repository. It is advisable to contact the community repository for any additional data.

This publication incorporates revisions to the original Flood Insurance Study. These revisions are presented in Section 10.0

TABLE OF CONTENTS-VOLUME 1

		Page
1.0	INTRODUCTION	1
1.1	Purpose of Study	1
1.2	Authority and Acknowledgments	1
1.3	Coordination	3
2.0	AREA STUDIED	3
2.1	Scope of Study	3
2.2	Community Description	15
2.3	Principal Flood Problems	18
2.4	Flood Protection Measures	20
3.0	ENGINEERING METHODS	26
3.1	Hydrologic Analyses	26
3.2	Hydraulic Analyses	28
4.0	FLOODPLAIN MANAGEMENT APPLICATIONS	52
4.1	Flood Boundaries	53
4.2	Floodways	53

TABLE OF CONTENTS-VOLUME 3

5.0	INSURANCE APPLICATION	148
6.0	FLOOD INSURANCE RATE MAP	149
7.0	OTHER STUDIES	149
8.0	LOCATION OF DATA	151
9.0	BIBLIOGRAPHY AND REFERENCES	151
10.0	REVISION DESCRIPTIONS	167
10.1	First Revision	167
10.2	Second Revision	174
10.3	Third Revision	192
10.4	Fourth Revision	194

TABLE OF CONTENTS-VOLUME 1 (Cont'd)

Page

FIGURES

Figure 1 - Vicinity Map 4
Figure 2 - Historic Flooding 21
Figure 3 - Historic Flooding 21
Figure 4 - Historic Flooding 22
Figure 5 - Historic Flooding 23
Figure 6 - Historic Flooding 24
Figure 7 - Floodway Schematic 54

TABLES

Table 1 - Detailed-Study Sources 5
Table 2 - Approximate-Study Streams 11
Table 3 - Summary of Discharges 29
Table 4 - Range of Hydraulic Roughness Coefficients (Manning's "n") 48

TABLE OF CONTENTS-VOLUME 2

Table 5 - Floodway Data 55

TABLE OF CONTENTS-VOLUME 3 (Cont'd)

Table 6 - Community Map History 150

EXHIBITS

Exhibit 1 - Flood Profiles

Andora Hills Wash	Panels 01P-05P
Agua Fria River	Panels 06P-32P
Aguila Farm Channel	Panel 33P
Atchison, Topeka, and Santa Fe Railway Channel (At El Mirage)	Panel 34P
Buchanan Wash	Panels 35P-36P
Casandro Wash	Panels 37P-41P
Casandro Wash, South Branch	Panels 42P-43P

TABLE OF CONTENTS-VOLUME 4

Cave Creek Wash	Panels 44P-72P
Cemetery Wash	Panels 73P-75P
Centennial Wash	Panels 76P-105P
Centennial Wash, Left Overbank	Panels 106P-113P

TABLE OF CONTENTS-VOLUME 4 (Cont'd)

Circle City Area - Wash 1	Panels 114P-116P
Circle City Area - Wash 2	Panels 117P-118P
Circle City Area - Wash 2 Along Atchison, Topeka, and Santa Fe Railway	Panel 119P
Circle City Area - Wash 3	Panels 120P-122P
Circle City Area - Wash 4	Panels 123P
Circle City Area - Wash 4 Along Atchison, Topeka, and Santa Fe Railway	Panel 124P
Circle City Area - Wash 5	Panel 125P
Circle City Area - Wash 6	Panels 126P-127P
Circle City Area - Wash 7	Panels 128P-129P
Dreamy Draw Wash East	Panels 130P-131P
Panels Not Printed	Panels 132P-133P
Echo Canyon Wash	Panels 134P-137P
Flying "E" Wash	Panel 138P
Flynn Lane Wash	Panels 139P-141P

TABLE OF CONTENTS-VOLUME 5

Galloway Wash	Panels 142P-146P
Galloway Wash, Lower Branch	Panels 147P-150P
Galloway Wash, Middle Branch	Panels 151P-156P
Gila River	Panels 157P-170P
Unnamed Tributary to Galloway Wash	Panels 171P-172P
Granite Reef Wash	Panels 173P-174P
Panel Not Printed	Panel 175P
Hassayampa River	Panels 176P-209P
Hospital Wash	Panel 210P
Indian Bend Wash	Panels 211P-219P
Indian Bend Wash - Low Flow Channel	Panels 220P-222P
Little San Domingo Wash	Panels 223P-224P
Lower El Mirage Wash	Panel 225P
Martinez Wash	Panel 226P
McMicken Dam Outlet Wash	Panels 227P-230P
Mockingbird Wash	Panels 231P-232P
Moon Valley Wash	Panels 233P-234P
Myrtle Avenue Wash	Panels 235P-236P

TABLE OF CONTENTS-VOLUME 6

New River	Panels 237P-260P
New River East Split	Panel 261P
New River Middle Split	Panel 262P
New River West Split	Panels 263P-264P
Ocotillo Wash	Panels 265P-268P
Powder House Wash	Panels 269P-271P
Rowe Wash	Panels 272P-275P

TABLE OF CONTENTS-VOLUME 6 (Cont'd)

Salt River	Panels 276P-291P
Scatter Wash	Panels 292P-296P
Scatter Wash, North Branch	Panels 297P-300P
Scatter Wash, South Branch	Panels 301P-304P
Skunk Creek	Panels 305P-326P
Sols Wash	Panels 327P-333P
Sweat Canyon Wash	Panels 334P-335P
Tenth Street Wash	Panels 336P-337P

TABLE OF CONTENTS-VOLUME 7

Trilby Wash	Panels 338P-344P
Panels Not Printed	Panels 345P-347P
Wash "B"	Panels 348P-349P
Waterman Wash	Panels 350P-361P
Weekes Wash	Panels 362P-363P
West Split Flow Through El Mirage	Panel 364P
Willow Springs Wash	Panels 365P-367P
Wittmann Wash, Along Atchison, Topeka, and Santa Fe Railway	Panel 368P
Wittmann Wash, North Split	Panel 369P
Wittmann Wash, South Split	Panel 370P
Wittmann Wash, Upper Reach	Panel 371P
Wittmann Wash, West Split	Panel 372P-373P
Wittmann Wash, Grand Avenue to CAP 1 West Overchute	Panels 374P-377P
Aguila Farm Channel	Panels 378P-380P
North Branch Centennial Wash	Panels 381P-382P
Caterpillar Tank Wash	Panels 383P-386P
Cave Creek Wash	Panels 387P-389P
East Fork Cave Creek	Panels 390P-392P
Centennial Wash	Panels 393P-395P
Cline Creek	Panels 396P-400P
Tributary X5	Panels 401P-403P
Tributary C6	Panels 404P-406P
Tributary C8	Panels 407P-411P
Tributary X1	Panels 412P-413P
Tributary X2	Panels 414P-415P
Tributary X3	Panels 416P-417P
Tributary X4A	Panels 418P-419P
Tributary X4B	Panel 420P
Cottonwood Creek	Panels 421P-428P
Cottonwood Creek-Tributary 1	Panels 429P-430P
Cottonwood Creek-Tributary 2	Panels 431P-432P
East Garambullo Wash	Panels 433P-434P
Flemming Springs Wash	Panels 435P-437P
Grapevine Wash	Panels 438P-440P
Galloway Wash-North Tributary	Panels 441P-446P
Gila River	Panels 447P-459P

Gila Bend Canal	Panel 460P
Grass Wash	Panels 461P-463P
Jackrabbit Wash	Panels 464P-479P
Unnamed Tributary of Jackrabbit Wash	Panels 480P-490P
Morgan City Wash	Panels 491P-500P
Ocotillo Wash-Tributary 1	Panels 501P-502P
Ocotillo Wash-Tributary 1A	Panels 503P-504P
Ocotillo Wash-Tributary 2	Panels 505P-506P
Ocotillo Wash-Tributary 3	Panels 507P-509P
Ocotillo Wash-Tributary 4	Panels 510P-512P
Rodger Creek	Panels 513P-518P
Rowe Wash	Panels 519P-523P
Star Wash	Panels 524P-527P
Trilby Wash	Panels 528P-535P
Trilby Wash-Middle Channel	Panel 536P
Trilby Wash-West Channel	Panel 537P
Twin Buttes Wash	Panels 538P-542P
Wagner Wash	Panels 543P-548P
West Garambullo Wash	Panels 549P-550P
White Peak Wash	Panels 551P-553P
West Fork White Peak Wash	Panel 554P
Willow Springs Wash	Panels 555P-559P
Willow Springs Wash-Tributary 1	Panels 560P-565P
Willow Springs Wash-Tributary 1A	Panels 566P-567P
Willow Springs Wash-Tributary 2	Panels 568P-570P
Willow Springs Wash-Tributary 2A	Panels 571P-572P
Willow Springs Wash-Tributary 4	Panels 573P-574P
Willow Springs Wash-Tributary 5	Panels 575P-578P
Willow Springs Wash-Tributary 5A	Panel 579P

Exhibit 2 - Flood Boundary and Floodway Map Index
Flood Boundary and Floodway Map

PUBLISHED SEPARATELY:

Flood Insurance Rate Map Index
Flood Insurance Rate Map

Table 3. Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Year	50-Year	100-Year	500-Year
Basin 1A At Apex	1.46	348	2,148	4,083	14,981
Basin 1B At Apex	1.79	234	1,787	3,661	15,663
Basin 2A At Apex	0.80	169	1,063	2,036	7,572
Basin 2B At Apex	7.87	1,243	5,782	9,949	29,836
Basin 3 At Apex	0.46	86	482	887	3,021
Basin 4A At Apex	0.63	222	848	1,360	3,544
Basin 4B At Apex	0.78	153	706	1,210	3,620
Basin 4C At Apex	1.78	452	2,108	3,629	10,918
Basin 4D At Apex	9.70	901	4,062	6,912	20,276
Basin 5 At Apex	3.09[1]	358	1,659	2,849	8,535

[1]Includes portion of Basin 4D from which runoff can be diverted into Basin 5

Table 3. Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Year	50-Year	100-Year	500-Year
Basin 6A					
At Apex	3.32	322	1,831	3,382	11,709
Basin 6B					
At Apex	0.43	100	358	562	1,400
Basin 6C					
At Apex	1.49	182	854	1,475	4,451

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84. Topographic Map, Unnamed, area near McDowell Mountain, Scale 1" = 400', Contour Interval 5 feet

85. Pinnacle Peak Heights, spliced sheets, Scale 1" = 200', Contour Interval 2 feet, January 1974 and March 1979

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87. Kenney Aerial Surveys, Topographic Map, Unnamed, between Scottsdale and Pima Roads, and Deer Valley and Union Hills Roads, Scale 1" = 400', Contour Interval 2 feet, Undated

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10.3 Third Revision

This study was revised on _____, to provide detailed flood hazard information for the alluvial fans located in the area north of the Central Arizona Project Canal and between the McDowell Mountains and Cave Creek. Six major drainage areas were identified as the sources of flooding for the study area. The hydrologic analysis revealed that those six areas contained 13 distinct apexes (concentration points). The streams that drain the basins associated with each of those apexes are identified on the Flood Insurance Rate Map. Each stream is labeled with a number corresponding to one of the six major drainage areas, followed by a letter for streams draining areas having more than one distinct apex. A label identifying the source of flooding is provided on Flood Insurance Rate Map panels where the apex corresponding to the major drainage basin is shown on another panel.

The flood-frequency curves in this revision were taken to be log-normal. The means and standard deviations of the curves were computed from the 2- and 100-year discharge values determined at each apex using the U.S. Army Corps of Engineers HEC-1 computer program (Reference 78). Discharge values for selected recurrence intervals are presented in the Summary of Discharges (Table 3).

Floods from Basins 6B and 6C flow within a well-defined network of channel reaches until they are approximately 0.5 to 1.0 mile downslope of Scottsdale Road. There are three points in that network where one reach splits into two. The flood-frequency curves at the three outlets of the network were estimated by simulating 10,000 floods from each of the two basins. The probability density function describing the percentage of flow that takes either the right or left path below each split was taken to be uniform. Floods from each basin were treated as independent. At each outlet, the resulting flow values and their frequency of occurrence from the simulations were fit to a log-Pearson Type III distribution by the method of least squares.

This revision reflects flood hazards associated with runoff from the watersheds above the apexes only. Therefore, it should be noted that runoff resulting from rain falling directly on the Special Flood Hazard Areas (SFHAs) has not been considered. Runoff generated on the SFHAs is usually conveyed downslope as shallow overland sheetflow that eventually flows into and down the many channels on the alluvial fan surface. The flood hazards associated with that kind of runoff are usually considered minimal (because of the relatively small drainage area contributing to any one channel). However, care should be taken that those local drainageways be preserved. If shallow flows, which under natural conditions are distributed over a very large area, are somehow concentrated in a few small channels, the increase in flow depths and velocities and, consequently, the associated flood hazards, may be great.

The SFHAs presented in this revision were delineated using topographic maps, aerial photographs, and soil survey maps (References 66 and 79 through 88). The downslope limits of the SFHAs were determined using the FEMA methodology for analyzing areas subject to alluvial fan flooding. That limit denotes the boundary, downslope of which the probability of a given point being inundated by more than 0.5 foot of floodwater is less than 0.01 in any given year. That probability will be exceeded within well-defined washes below the limits shown on the Flood Insurance Rate Map. Because the flood hazards within a well-defined wash are self-evident and because of map scale restrictions, the SFHAs within those individual washes are not delineated on the Flood Insurance Rate Map. Obviously, sound floodplain management requires that those washes remain unobstructed.

Also note that downslope of the SFHA limits, the hazards associated with alluvial fan flooding are just as severe as those upslope of the limits. The distinction between the zone designations downslope and upslope of the limits should be regarded as a distinction between flooding potentials and not a distinction between the severity of damages to be expected in the event of a flood.

APPENDIX F.--Letter to FCD from John Matticks of FEMA

Federal Emergency Management Agency

Washington, D.C. 20472

APR 12 1993

FLOOD CONTROL DISTRICT
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CH ENG		P & PM	
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ADMIN		LMGT	
FINANCE		FILE	
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ENGR			
REMARKS			

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RETURN RECEIPT REQUESTED

The Honorable Jim Bruner
Chairperson, Maricopa County
Board of Supervisors
Office of the Board of Supervisors
County Administration Building
301 West Jefferson
Phoenix, Arizona 85003

Dear Chairperson Bruner:

With a letter dated July 9, 1991, we transmitted to then Chairperson Bayless the preliminary Flood Insurance Rate Map (FIRM) and Flood Insurance Study (FIS) report for Maricopa County, Arizona and Incorporated Areas. That map showed the results of our analyses of the alluvial fan flooding between the McDowell Mountains and Cave Creek, and north of the Central Arizona Project Canal. In a letter dated February 26, 1992, Maricopa County appealed our determination in that area. That appeal was resolved in our letter dated January 4, 1993, to Chairperson Bayless.

In the appeal resolution letter we noted that we would delay processing for 30 days to permit review of the revised FIRM. In a letter dated January 25, 1993, Mr. Joe Tram of the Flood Control District of Maricopa County (FCDMC) requested that we extend the 30-day review period.

In a letter dated February 8, 1993, we informed Chairperson Bayless that we had received Mr. Tram's letter and would address all comments received through February 19.

In a letter dated February 4, 1993, Mr. David R. Johnson, Chief Hydrologist of the FCDMC, commented on the appeal resolution letter. Mr. Johnson also attached a letter that was sent to him on February 3, 1993, by the Arizona Geological Survey (AGS). The AGS letter contained comments pertaining to the appeal resolution letter.

Mr. Johnson sent an additional letter to us, dated February 19, 1993. Enclosed with that letter was a letter dated February 8, 1993, from the Arizona State Land Department (ASLD) to Chairperson Bayless.

This is in response to Mr. Johnson's letters and their attachments.

The FCDMC requested clarification of the following statement in the FIS report in terms of the definition of alluvial fan flooding given in Section 59.1 of the National Flood Insurance Program (NFIP) regulations:

> Floods from Basins 6B and 6C flow within a well-defined network of channel reaches until they are approximately 0.5 to 1.0 mile downslope of Scottsdale Road

The statement is in the FIS report to explain how flood frequency was defined downslope of Scottsdale Road. Because the amount of flow taking any of the various paths available within the network of channel reaches is unpredictable, we describe in the FIS report how we account for that unpredictability. More precisely, the FIS report describes how the probability density functions which quantify the probability that a given flow would follow a given path within the network, were defined. As you can see, contrary to the FCDMC's inference that the report contradicts the definition, it is precisely because the areas so identified are subject to alluvial fan flooding that flood frequency had to be defined as described in the FIS report.

The FCDMC also suggested that the Federal Emergency Management Agency (FEMA) "references that the system is stable" by including the following statement in the FIS report:

> Because the flood hazards within a well defined wash are self-evident . . . the SFHAs within those individual washes are not delineated . . .

The paragraph in the FIS report which contains that statement describes how the downslope limits of the Special Flood Hazard Areas (SFHAs) were determined. The paragraph cautions that, even below these limits, washes that exist convey floodwaters from storms more frequent than those considered to determine the extent of the SFHAs and, therefore, should remain unobstructed.

It should be recognized that a drainage system does exist in the area and, regardless of the stability of that system, simply grading over an existing wash and constructing a building on the new grade is unwise. Because those washes are not shown on the FIRM, we point out in the FIS report that they can be easily identified in the field (well-defined) and they obviously present a flood hazard (self-evident). Please note that the flood hazards are not restricted to the existing washes. However, downslope of the SFHA limit and outside of the existing washes, the probability of flooding is less than 0.01 in any given year. In other words, the downslope SFHA boundaries demarcate a change in flood frequency, not flood hazards.

Please note that the fact that a wash exists does not imply that it is "stable."

Before considering the comments from the AGS, it should be noted that the fundamental purpose of the FIRM is related to flood insurance. We are charged with identifying areas subject to inundation at least once in 100 years, on the long-term average. We refer to those areas as SFHAs. We are not charged with determining the geologic description of a landform, and we

do not make such determinations. We do, however, make determinations of the nature of the flooding within the SFHAs and, to the extent possible, quantify the associated hazards in terms of elevation or depth and, in some cases, velocity of flood waters.

Three determinations were made in developing the preliminary FIRM dated July 9, 1991. Those determinations were:

- Which areas are subject to flooding at least once in 100 years, on the long-term average -- the SFHAs

- The areas within those SFHAs where the average of the 100-year depths and the 100-year velocities at each point is within 0.5 foot and 0.5 foot per second of the nearest integer depth and velocity, respectively -- the depths and velocities shown on the FIRM

- That the area is subject to alluvial fan flooding

The first determination, the extent of the SFHAs, was accomplished by developing flood frequency curves for each flooding source, consulting aerial photographs and topographic maps, and inspecting the results in the field. Please note that the determination was revised using the flood frequency information submitted with the appeal for all flooding sources studied and using detailed topographic information that was submitted with the appeal for Washes 5 and 6.

The second determination was accomplished using our methodology for determining depths and velocities in areas subject to alluvial fan flooding. Please note that although that methodology applies to areas subject to frequent debris flow (areas sometimes referred to as classic active alluvial fans), its use is by no means restricted to such areas. The methodology applies anywhere that given a flow value, the exact paths of that flow or portions of it are unpredictable. The methodology is, simply, applying the definition of the 100-year flood (which is probabilistic under any circumstances) under those conditions.

The methodology was first documented in a paper by Mr. David R. Dawdy published in 1979 in the American Society of Civil Engineers' *Journal of the Hydraulics Division*. In that paper, Mr. Dawdy demonstrated the method of applying the definition of 100-year flood under simple boundary conditions -- such as a flood is just as likely to follow a new path as an existing channel. Under those simple conditions, the mathematical treatment can be followed without much difficulty. Under more complicated boundary conditions, the mathematics may become more cumbersome, but the methodology applies just as well. For example, if a flood is more likely to follow an existing channel than a new path, and if under the less likely condition that a new path is followed, some new paths are more likely than others, one simply replaces the uniform distribution used by Mr. Dawdy in his paper with a function that describes the likelihood of the various paths possible.

The AGS seems to be inferring that because Washes 5 and 6 do not strictly adhere to the situation described in Mr. Dawdy's paper they are not alluvial fans and, therefore, are not subject to alluvial fan flooding. We trust that we have made it clear that that inference does not follow from adhering or

not adhering to the simple conditions in Mr. Dawdy's paper. The important point is not whether the simple function Mr. Dawdy used in his paper should be used but rather is to determine the function that should be used.

The third determination was that the SFHA was subject to alluvial fan flooding. Please note that the methodology is not used in making that determination. The determination is made by characterizing the nature of the flooding: are the floodpaths predictable; is the area susceptible to erosion; what is the potential for relatively large amounts of localized deposition?

We define alluvial fan flooding as:

> flooding occurring on the surface of an alluvial fan or similar landform which originates at the apex and is characterized by high-velocity flows; active processes of erosion, sediment transport, and deposition; and unpredictable flow paths.

Our determination was based on field inspections, inspection of aerial photographs and topographic maps of the area, and review of the U.S. Soil Conservation Service (SCS) soil survey of the area. For Washes 5 and 6, we also used the maps from the report entitled *Geology and Soils Study for a Nine Square Mile Area in the Northwestern Portion of the City of Scottsdale, Arizona*, dated August 1988, and prepared by Cella Barr Associates, Inc. (CBA).

Field reconnaissance revealed that the surface material in that area is sand and gravel. Thus, the area is very susceptible to erosion. The washes in the area contain the same material, making them an abundant source of sediment available for transport and deposition. The aerial photographs and topographic maps indicate that the susceptibility to erosion and the sediment supply available in the area have resulted in the drainage pattern that exists. That pattern is characterized by numerous splits in the existing washes. The number of splits (and consequently the number of existing washes) increases, and the flood-carrying capacity decreases, with a decrease in elevation (downslope).

As a resident of the area, you may find it helpful to understand our determination from a personal perspective. For example, alluvial fan flooding might affect local residents by depositing 1 or 2 feet of sediment at a road crossing, thus causing the road to be closed until it is cleared. Other evidence of alluvial fan flooding (on a much smaller scale than something approaching a 100-year flood) may be underground utilities that are exposed after a downpour, or scouring occurring downslope of a new road shortly after it is paved.

The AGS letter listed three comments regarding the discussion of alluvial fan flooding given in the appeal resolution letter.

(1) The appeal resolution letter pointed out that the question is not only how old the surfaces are between the channels, but also how long those channels have existed. The AGS noted that the real issue is how long channels have occupied the same positions on the piedmont. We are pleased that the AGS agrees.

(2) The AGS noted that, obviously, the issue is what exactly constitutes alluvial fan flooding. We trust that our previous discussion has clarified what we mean by alluvial fan flooding. We believe that the issue is not whether alluvial fan flooding occurs in the SFHAs; instead, we believe that the issue is how frequently such flooding occurs within the SFHAs. Specifically, the issue is how frequently that type of flooding takes paths other than the channels present -- closer to the real issue of Item (1) above.

The AGS asked, "Do relatively minor changes in channel patterns that might have occurred during the past 10,000 years constitute alluvial-fan flooding?"

In areas such as the SFHAs associated with Washes 5 and 6, changes in the channel patterns indicate that alluvial fan flooding has occurred. We are not quite sure what the phrase "relatively minor changes in channel patterns" means, but if it means that new channels are being formed and old channels are being abandoned, then it would seem that relatively minor changes would mean relatively infrequent changes. Because one, two, or three events per 100 years or 100, 200, or 300 events per 10,000 years is infrequent, it would seem that the AGS would categorize the changes in the channel patterns as relatively minor. Nevertheless, those are the frequencies of occurrence on which our determinations are based. Please note that regardless of the frequency, when alluvial fan flooding occurs, the threat to life and property can hardly be characterized as relatively minor.

(3) In the appeal resolution letter, we noted that the geomorphic information submitted sheds some light on the frequency at which alluvial fan flooding occurs. The AGS commented that:

(i) Because of map scale limitations, all of the active channels in the area are not shown on the map submitted with the appeal.

(ii) The areas mapped Unit Y, Holocene terrace deposits, 0 to 10,000 years old, represent overbank or sheet-flood deposits and active channels too small to represent at a scale of 1:6,000. Although some areas mapped as Unit Y may represent channels that have been abandoned in the past 10,000 years, it does not follow that the total extent of Units Y_c and Y records the cumulative area occupied by channels in the past 10,000 years.

(iii) The drainage systems are not composed solely of channels (Unit Y_c). Significant portions of map Unit Y exist because they are inundated during floods. They do not represent areas of former channels that were abandoned.

(iv) Local topography is modest, but it influences where new channels may form. Evidently this modest amount of relief has

been enough to preclude development of channels during the past 10,000 years.

(v) Even if the questionable assumptions that are used in FEMA's reanalysis of our map data are accepted, it is still clear that broad areas that have not been subject to significant flooding in the past 10,000 years are included in the "100-year" floodplain.

Please note that the assumptions made in our resolution were that the information submitted was accurate. We understand that that accuracy is limited by map scale. However, recognizing that limit, we believe that our analysis of the geomorphic information described in the appeal resolution letter is correct. Regarding the distinction between modern channel deposits and Holocene terrace deposits (as it is referred to in the appeal documentation) or between channels and smaller channels, overbank flow areas, and sheetflow areas (as it is now referred to in the AGS letter), it may be helpful to think in terms of alluvial fan flooding. Specifically, the ages of the deposits left by past alluvial fan flooding are given by the geomorphic information. Whether one refers to a flood path 1 to 2 feet deep and up to hundreds of feet wide as a channel, overbank flow path, or sheetflow path, those flows left behind enough sediment to enable the AGS to identify their occurrence tens of thousands of years later. The discussion in the appeal resolution follows if one simply exchanges the phrase "path of an alluvial fan flood" for the word "channel."

In addition, the FCDMC mentions two publications in their February 4 letter. Those publications are Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona, issued by the SCS in April 1986; and Flood Hazards of Distributary Flow Areas in Southwestern Arizona, Open-File Report 91-4171, published by the U.S. Geological Survey (USGS) in December 1991.

Please note that both of those publications were considered in our determinations. We met with the SCS in their office in Phoenix in August 1990, to discuss how the information in the soil survey could be applied for flood insurance purposes. In addition, the USGS sent us a draft copy of their report in February 1991 and requested that we provide them with a technical review of the manuscript.

The FCDMC closed their February 4 letter by requesting documentation that supports our resolution. The technical data used to resolve the appeal were the data submitted with the appeal. We believe that the discussion in the resolution letter clearly documents that the data submitted do not support the conclusions of the appeal, and how those data were used to develop the appeal resolution.

In their letter to the County, the ASLD expressed support for objections to the appeal resolution that were raised in discussions between their staff and representatives of the Cities of Scottsdale and Phoenix, and the FCDMC. That letter has been added to our files.

In his February 19 letter, Mr. Johnson indicated a desire to meet with us to discuss the appeal resolution. If you believe that a meeting is still required, we can arrange to meet with you or your staff. If you desire such a meeting, please contact your National Flood Insurance Program State Coordinator, Ms. Terri Miller of the Arizona Department of Water Resources in Phoenix at (602) 542-1553 or Mr. Johnny Taylor of our Regional Office in San Francisco, California, at (415) 923-7192. Ms. Miller and Mr. Taylor are coordinating the arrangements for a meeting in Phoenix sometime in the middle of May. We have extended the same offer to meet with the Cities of Scottsdale and Phoenix, if they so desire.

Please note that the appeal is resolved. If the aforementioned meeting is arranged, we will come prepared to answer questions regarding our processing procedures, our regulations, and the resolution. The purpose of the meeting will not be to review new data or analyses. Requests for such a review must be submitted as provided for in Part 65 of the NFIP regulations.

As promised in our letter to Chairperson Bayless dated February 8, 1993, we have addressed all comments received up to February 19. The next step in the processing of the FIRM is the issuance of the final determination letter. We anticipate sending the final determination letters on June 3, 1993.

If you have any questions regarding this matter, please contact Mr. Karl Mohr of my staff in Washington, DC, either by telephone at (202) 646-2770 or by facsimile at (202) 646-3445.

Sincerely,

John L. Matticks
Assistant Administrator
Office of Risk Assessment
Federal Insurance Administration

cc: Mr. David R. Johnson
FCDMC

Mr. William Erickson
City of Scottsdale

APPENDIX G.--Original report by David Dawdy entitled Flood-frequency estimates on alluvial fans

l_p = length scale describing maximum rise for plume;
l_N = length scale describing transition from momentum to buoyant influence;
l_m = length scale describing maximum rise for jet;
M = source momentum flux;
m = local kinematic momentum flux per unit length;
Q = source volume flux;
q = local volume flux per unit length;
R_i = Richardson number defined by local fluxes;
S_a = average jet dilution $S_a = q/Q$;
w = vertical jet velocity;
w_m = local characteristic vertical velocity, function of z only;
w_0 = source vertical velocity;
x = transverse coordinate perpendicular to jet axis;
Z_m = maximum height of rise;
z = vertical coordinate parallel to jet axis;
α = entrainment coefficient;
α_p = plume entrainment coefficient;
α_j = jet entrainment coefficient;
β = local buoyancy flux;
ϵ = stratification parameter $\epsilon = (-g/\rho_0)(d\rho_a/dz)$;
λ = factor relating difference in widths of velocity and density profiles;
ρ_a = ambient density;
ρ_j = jet source density; and
ρ_0 = ambient density at level of source.

JOURNAL OF THE
HYDRAULICS DIVISION

Flood Frequency Estimates on Alluvial Fans

By David R. Dawdy,[1] M. ASCE

Introduction

The National Flood Insurance Act of 1968 was enacted to provide previously unavailable flood protection to property owners in flood-prone areas. In general, the Federal Insurance Administration (FIA) has chosen the 100-yr flood (that flood which has a 0.01 probability of occuring in any year) as the regulatory flood for the determination of flood hazards and for setting insurance rates.

The 100-yr flood and its resulting depth have well-defined meanings in the riverine environment. They are based on flood frequency analysis for the determination of discharge and the assumptions of a rigid boundary channel and of steady flow to determine flood depth. However, in the case of flooding on an alluvial fan, the 100-yr flooding event and its depth are more difficult to define. Still, FIA must determine the flood depth which has a 0.01 probability of occurrence at any point on an alluvial fan in order to set rates for flood insurance.

One of the major problems in the determination of shallow flooding probabilities on alluvial fans is that the probability with which a flood occurs at the apex of a fan does not alone determine the probability of flooding or of resulting flood depth at any point on the fan below the apex. As an alluvial fan widens, the probability of flooding of a given magnitude at a given point should, in general, decrease. A method is presented in this paper to assess that change in probability, and to develop a strategy for computing such a probability at any point on an alluvial fan.

Alluvial fans are found throughout the western United States. The nature and characteristics of flooding on alluvial fans are such that conventional riverine flood insurance study procedures cannot be employed. Flows rarely spread evenly over the surface of an alluvial fan. Typically, flow is concentrated in an identifiable temporary channel, or it is confined to only portions of the fan surface. Such flow paths are prone to lateral migration and to sudden relocation to any other portion of the fan during a single runoff event. This erratic,

Note.—Discussion open until April 1, 1980. To extend the closing date one month, a written request must be filed with the Editor of Technical Publications, ASCE. This paper is part of the copyrighted Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 105, No. HY11, November, 1979. Manuscript was submitted for review for possible publication on April 10, 1979.

[1]Sr. Hydro., Dames & Moore, Washington, D.C.

unpredictable behavior subjects all portions of the fan to potential flood hazard, regardless of location. Therefore, a site distant from an identifiable channel has approximately the same potential for flooding as a site at the same elevation near an identifiable flowpath.

The local relief across alluvial fans is usually small (on the order of 5 ft to 10 ft) except at fanhead trenches, which may be incised up to 50 ft or more. Identifiable channels may occur at any location on an alluvial fan, but they are usually very small in relation to the magnitude of expected flood discharges and are subject to rapid alteration and changes in geometry due to the highly erodible nature of the materials that make up an alluvial fan. The behavior of flood flows, and the associated flood hazard, is largely a function of location below the apex of the fan. The degree of flood hazard is approximately equal for all points that are radially equidistant from the fan apex. A basic premise for a technique that is to be used for quantitatively evaluating the degree of flood hazard on an alluvial fan is that when channel gradient approaches or exceeds critical slope, then critical flow will occur. The channels that are formed on the face of the alluvial fan are shaped by the flow itself. Any temporary state of supercritical flow will erode the channel banks so as to achieve a wider, shallower flow at critical depth. In reality, supercritical flow in natural alluvial channels is a transitory phenomenon, and not a representative steady-state condition. For the majority of alluvial fans, critical slope will be the natural condition.

Approach Taken

Alluvial fans are the result of a dynamic geomorphologic process. Mud flows deposit large amounts of ungraded material at the apex of the fan. Smaller flood events may rework those materials, but the major portion of this sediment load also is deposited upon the surface of the fan. Only the larger flood events will carry major amounts of sediment to the toe of the fan. The result of this process is the typical fan shape with a relatively uniform slope from apex to toe. The channels formed upon the surface of the fan by major flood events are modified and often filled by the more numerous smaller sediment depositing flood events. Therefore, when a major event occurs, it does not necessarily follow the path of a previous event. Rather, its position on the surface of the fan tends to be random.

Geomorphologic reasoning can be used to arrive at some hydraulic properties of alluvial fan flooding. One cannot assume that the probability of a flood of a given magnitude occuring at any point on the fan is the same as the probability of a flood of that magnitude at the apex. As an alluvial fan widens, the probability of flooding of a given magnitude at a point should, in general, decrease. Flood flows on alluvial fans tend to form their own channels during the flood event. In addition, they tend to form that channel so as to flow at critical depth and critical velocity, which is the most efficient movement of water and sediment down the fan. Field experience has shown that the flow widens a channel by bank erosion to meet those conditions. As the width increases, the depth of flow decreases. It has been estimated, based on field evidence, that the channel stabilizes approximately at that point where $dD/dW = -.005$, or where a decrease in depth creates a two hundred-fold increase in width

(Boyd Lare, U.S. Army Crops of Engineers, Personal Communication, 1978). Under those conditions, the channel formed by a flood flow on an alluvial fan should stabilize at a width of

$$W = 9.5\, Q^{0.5} \quad (1)$$

and a depth of

$$D = .07\, Q^{0.4} \quad (2)$$

in which W = the width of the channel in feet; D = the depth of the channel, in feet and Q = the flood flow, in cubic feet per second, forming the channel.

Leopold and Maddock (3) describe and evaluate from field data the hydraulic geometry of river channels by a set of relations as follows: $V \propto Q^m$; $D \propto Q^f$; and $W \propto Q^b$, in which V = the mean velocity; D = mean depth; W = surface width; Q = mean discharge; and m, f, and b = constant coefficients. Based on the field data, they developed values for m, f, and b. Later, Leopold

TABLE 1.—Comparison of Hydraulic Geometry Exponents from Field Data for Midwestern United States (3) and for Ephemeral Streams in Semi-arid United States (4), from Theoretical Development (2), and from This Paper

Variable (1)	VALUES OF EXPONENTS OF HYDRAULIC GEOMETRY			
	Field Data		Theoretical (4)	Dawdy (5)
	Midwest (2)	Semi-arid (3)		
Velocity m	0.10	0.2	0.09	0.2
Depth f	0.40	0.3	0.36	0.4
Width b	0.50	0.5	0.55	0.4

and Langbein (2) developed theoretical values. Those values in addition to values resulting from this study are shown in Table 1.

All sets of exponents are based on the assumption that the channels are formed by the flow. The first three sets are based on changes in a downstream direction, but they should be comparable to values for alluvial fan channels because similar processes are at work and the channels on alluvial fans develop much more rapidly in response to flow conditions than for the riverine case. A major difference is that the theoretical values of Leopold and Langbein assume Manning's equation applies, the field data of Leopold and Maddock include many sand-bed streams that more nearly approximate a Chezy law (1), and this study assumes critical depth. Therefore, one should expect velocity to be less for the theoretical, intermediate for the field case, and greatest for critical depth. Apparently the major channel adjustment to accomodate greater velocity is a narrowing to decrease area.

Development of Method

If we let $y = \log Q$, then Ref. 5 treats y as Pearson III:

$$f(y) = \frac{\alpha^{\lambda}}{\lambda}(y - m)^{\lambda - 1} \exp\left[-\alpha(y - m)\right] \quad (3)$$

(α, λ, y, m) = Log Pearson III parameters

with the relations: mean of logarithms $= m + \lambda/\alpha = \bar{y}$; variance of logarithms $= \lambda/\alpha^2 = S_y^2$; and skew of logarithms $= 2/\lambda^{1/2} = G_y$. Therefore:

$$\lambda = \frac{4}{G_y^2} \quad \text{(4a)}$$

$$\alpha = \frac{2}{GS}; \quad \alpha = \frac{2}{G_y S_y} \quad \text{(4b)}$$

$$m = \bar{y} - \frac{2S}{G}; \quad m = \bar{y} - \frac{2S_y}{G_y} \quad \text{(4c)}$$

The probability that a given flood will inundate a particular point on the fan may be less than the probability of that flood occurring at the apex, because at a particular contour on the face of the fan, the probability that a given flood flows past a particular point on that contour will depend, among other things, on the width, W_c, of the fan at that contour and on the number of possible flow paths down the fan. If it is assumed that a channel caused by a given flood has an equal probability to cross at any point on a contour, then that probability would be

$$p_c(Q) = \frac{W}{W_c} = \frac{9.5\,Q^{0.4}}{W_c} \quad \text{(5)}$$

The probability that a flood of size greater than Q, occurs at the apex of an alluvial fan may be broken into two parts

$$\int_Q^\infty P_A(Q)\,dQ = \int_Q^\infty \left([P_c(Q)\,p_A(Q)] + \{[1 - p_c(Q)]\,p_A(Q)\}\right) dQ \quad \text{(6)}$$

in which the term in the first set of brackets is the probability that flood will inundate a particular point on a contour; and the second term is the probability that it will not.

The proposed method for the three parameter log Pearson III leads to a solution as follows:

$$\log \int_Q^\infty \frac{9.5}{W_c} Q^{0.4}\,p(y)\,dy = \frac{9.5\,C}{W_c} \int_{\log Q}^\infty a^\lambda (z - m)^{\lambda - 1} \exp\left[-\alpha(z - m)\right] \frac{dz}{\lambda} \quad \text{(7)}$$

in which $a = \alpha - 0.92$ ($0.92 = 0.4 \log 10$); and

$$C = \left(\frac{\alpha}{a}\right)^\lambda \exp(0.92\,m) \quad \text{(8)}$$

Thus the integral on the right-hand side is a pseudo-distribution that has parameters a, λ, and m, which yields

$$G_z = \frac{2}{\lambda^{1/2}} \text{ is unchanged} \quad \text{(9a)}$$

$$S_z^2 = \frac{\lambda}{a^2} \text{ (variance increased to positive skew, decreased for negative)} \quad \text{(9b)}$$

$$\bar{z} = m + \frac{\lambda}{a} \text{ (mean increased)} \quad \text{(9c)}$$

for use in Ref. 5.

This method requires the use of a log Pearson III analysis, and can be implemented with the use of Ref. 5. Similar analyses could be performed for other distributions. The method will produce anomalous results if $\sigma = 0.92$. That will occur only for very large values of skew. The highest skew value shown as an isopleth on the regional skew map of Ref. 5 is 0.7. The largest areal value shown is 1.84 in Montana. The constant, 0.92, has no particular physical significance. It is a function of the assumptions concerning the power function relating width to discharge and the applicability of the log Pearson III distribution. Similarly, the transformed variable, Z, has no intrinsic meaning. It is merely an operational variable to transform the problem so that the solution can be derived solely through the use of the Pearson III tables.

For skew of zero, log Pearson III becomes a log normal with a density of

$$f(y) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(y - \bar{y})^2}{2\sigma^2}\right] \quad \text{(10)}$$

The transformed distribution, developed from equation 6, is similar to Eq. 7 and is

$$\int_Q^\infty p_c(Q)\,p_A(Q)\,dQ = \frac{9.5}{W_c} \int_Q^\infty \frac{Q^{0.4}}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(y - \bar{y})^2}{2\sigma^2}\right] \quad \text{(11)}$$

which leads to a constant similar to equation 6, of

$$C = \exp(0.92\,\bar{y} + 0.42\,\sigma^2) \quad \text{(12)}$$

The mean changes to

$$\bar{y} + 0.92\,\sigma^2 = \bar{z} \quad \text{(13)}$$

The variance stays constant. The 0.01 event for a given depth, D, of flooding is then computed as

$$\frac{9.5\,C}{W_c} \int_{\log Q}^\infty f(z)\,dz = 0.01 \quad \text{(14)}$$

Integral

$$\int_{\log Q}^\infty f(z)\,dz = P\{z \geq \log Q\} \quad \text{(15)}$$

can be computed from the tables in Ref. 5 for the mean, standard deviation, and skew of the transformed distribution developed in the foregoing. Thus, the width of contour across the fan at which a flow, Q, will be the 0.01 event is

$$W_c = \frac{9.5\,CP\{z \geq \log Q\}}{0.01} \quad \text{(16)}$$

Thus for a given depth of flow, D, the discharge, Q, can be computed from

Eq. 2 and then, the width of the channel formed can be computed from Eq. 1. The probability of the discharge Q for the transformed distribution can be computed from Ref. 5. Finally, by use of Eq. 16, the width of contour can be computed at which that flood will have a 0.01 probability of occurrence. The contours that are at the limits of flood zones of a particular depth may be computed, and the zone thus delineated.

Conclusion

A uniform method has been presented for the determination of flood flow frequencies on alluvial fans. The method is based on geomorphologic principles, and has general applicability. There are three basic assumptions underlying the proposed method. The first assumes that a log Pearson III distribution applies to the distribution of flood flows at the apex. The assumption is operational, and is based upon the fact that the Water Resources Council has chosen that distribution administratively for uniformity of analysis in the Federal government. Other distributions may be used if they are felt more applicable. However, a closed form solution may be more difficult for other distributions. The second basic assumption is that each event forms a single channel and flow remains in that channel throughout the event. Braided flow is not a problem with the slopes which occur on alluvial fans, but avulsions are. If an avulsion occurs at any flow greater than that for the 100-yr flood, then more than one channel may cross a given contour on the fan during different times during the event. Thus, the probability of an event crossing a contour at a point is probably greater than that derived above. Similarly, the estimated contour width for a given flow is probably less than that derived above, because width is inversely related to the probability. This could be handled by an "avulsion coefficient," K, which is a measure of the "average avulsions per event." The equation for width of contour then becomes

$$W_c = \frac{9.5\, CKP(z \geq \log Q)}{0.01} \qquad (17)$$

in which $1.0 \leq K$. The determination or estimation of K should be based on geomorphological principles.

Finally, the third basic assumption is that flood channels are distributed uniformly across any contour. The concept is basically reasonable, but it ignores the fact that equally valid assumptions concerning placing of channels and placing of centers of channels would result in different probabilities, particularly within one stream width of the edge of an alluvial fan. In particular, near the apex of the fan where the width of the contours is less than the width of the computed channel, other concepts must apply by physical reasoning.

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Appendix II.—Notation

The following symbols are used in this paper:

a = parameter of log Pearson III distribution for Z ($a = \alpha - 0.92$);
b = Leopold geomorphic exponent relating width to discharge;
C = constant resulting from transformation from y to z;
D = depth of flow in channel;
f = Leopold geomorphic exponent relating depth to discharge;
G = skew of logarithms of discharge;
K = "avulsion coefficient," average number of avulsions per flood event;
m = Leopold geomorphic exponent relating velocity to discharge;
m = parameter of Pearson III distribution;
P_a = probability of floods at apex of alluvial fan;
P_c = probability of floods at point on contour on alluvial fan;
Q = discharge in channel;
S = standard deviation of logarithms of discharge;
V = velocity of flow in a channel;
W = velocity of flow in a channel;
W_c = width of contour across alluvial fan;
y = log Pearson III variable;
z = transformed log Pearson III variable;
α = parameter of Pearson III distribution; and
λ = parameter of Pearson III distribution.

APPENDIX H.--Report entitled Alluvial fan flooding methodolgy, An analysis by DMA consulting engineers

CONSULTING
ENGINEERS

ALLUVIAL FAN FLOODING METHODOLOGY
AN ANALYSIS

PREPARED FOR

FEDERAL EMERGENCY MANAGEMENT AGENCY
CONTRACT EMW-84-C-1488

OCTOBER 1985

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TABLE OF CONTENTS

Acknowledgements i

Table of Contents ii

List of Tables iv

List of Figures v

List of Symbols viii

1.0 Introduction 1

2.0 Literature Review 3

2.1 Discussion of "Flood Plain Management Tools for Alluvial Fans" 7

3.0 Fan Formation and Process 8

3.1 Theoretical Aspects 8
3.2 Case Studies 10

3.2.1 Selection Criteria of Alluvial Fans 10
3.2.2 Observations of Alluvial Fans 13
3.2.3 Results of Case Studies 51

4.0 Fan Flood Analysis Methodology 62

4.1 Current Methods for Fan Flood Analysis 62

4.1.1 FEMA Method 62
4.1.2 Edwards and Thielmann's Modification 63
4.1.3 Discussion of the Current Methods 65

4.2 Major Factors Affecting Fan Floods 66
4.3 Classification of Fan Floods 68
4.4 Practical Considerations for the Analysis of Alluvial Fan Flooding 69
4.5 Proposed Modifications of Current FEMA Method 71

5.0 Study Findings and Recommendations 74

5.1 Study Findings 74
5.2 Recommendations 75

6.0 References 76

Appendix A Selected Observations of Channel Branching

Appendix B Comparison of Different Alluvial Fan Flood Analyis Methods

Appendix C Proposed Modification of FEMA "Guidelines and Specifications for Study Contractors: Appendix 6. Alluvial Fan Studies"

LIST OF TABLES

Table		Page
1.	Sources of Aerial Photographs for Alluvial Fans	12
2.	Summary of Alluvial Fan and Flood Channel Characteristics	54
3.	Summary of Single Channel Widths Calculated Using FEMA and Edwards & Thielmann's Methods	58

LIST OF FIGURES

Figure		Page
1.	Definition Sketch of Alluvial Fan Characteristics	14
2.	Topographic Map and Aerial Photograph of the Alluvial Fan below Northumberland Canyon near Austin, Nevada	16
3.	Topographic Map and Aerial Photograph of the Alluvial Fan below Masson Valley Tributary near Mason, Nevada	18
4.	Topographic Map and Aerial Photograph of the Alluvial Fans below Humbolt River Tributary Rye Patch and Oreana, and Rocky Canyon, Nevada	21
5.	Topographic Map and Aerial Photograph of the Alluvial Fan below Las Vegas Wash Tributary near Henderson, Nevada	25
6.	Topographic Map and Aerial Photograph of the Alluvial Fan below Piute Wash Tributary at Searchlight, Nevada	27
7.	Topographic Map and Aerial Photograph of the Alluvial Fan below San Antonio Wash Tributary near Tonopah, Nevada	29
8.	Topographic Map and Aerial Photograph of the Alluvial Fan below Eldorado Valley Tributary near Nelson, Nevada	31
9.	Topographic Map and Aerial Photograph of the Alluvial Fan below Lytle Creek near Fontana, California	33

10. Topographic Map and Aerial Photograph of the Alluvial Fan below Day and Deer Canyons near Etiwanda, California 36

11. Topographic Map and Aerial Photograph of the Alluvial Fan below Cucamonga Creek near Upland, California 39

12. Topographic Map and Aerial Photograph of the Alluvial Fan below San Antonio Creek near Claremont, California 42

13. Topographic Map and Aerial Photograph of the Alluvial Fan below Tahquitz Creek near Palm Springs, California 44

14. Topographic Map and Aerial Photograph of the Alluvial Fan below Palm Canyon near Palm Springs, California 46

15. Topographic Map and Aerial Photograph of the Alluvial Fan below Devil Canyon near San Bernardino, California 48

16. Topographic Map and Aerial Photograph of the Alluvial Fan below Whitewater River near Whitewater, California 50

17. Normalized Locations of Single Channels on Alluvial Fans 52

18. Relationship Between Observed Length of a Single Channel and the Ratio of Canyon Slope to Fan Slope 56

19. Relationship Between Fan Slope and the Ratio of Width Calculated Using the FEMA Method to Observed Width for a Single Channel 57

20. Relationship Between the Ratio of the Total Width for a Split Channel to the Width for a Single Channel and the Fan Slope 60

21. Comparison of Observed Widths Against Calculated Widths for Single Channels Using FEMA, and Edwards & Thielmann's Methods 64

LIST OF SYMBOLS

Symbol	
A	Avulsion Coefficient
A	Watershed drainage area
C	Transformation constant
D	Flow depth
G	Log Skewness
K	Log-Pearson Type 3 standard deviation
n	Manning's roughness coefficient
P	Probability of discharge for each depth and velocity
Q	Flow rate
S	Log standard deviation
S	Channel slope
S_{can}	Canyon slope
S_{fan}	Alluvial fan slope
S_z	Standard deviation of Z
V	Flow velocity
W	Fan arc width
W	Channel width
W_c	Calculated channel width
W_o	Observed channel width
X	Log mean
Z	Transformed Log-Pearson variable
$\bar{Z}$	Mean of Z

1.0 INTRODUCTION

Alluvial fans are estimated to cover approximately one third of the land area in the southwestern United States. Although mostly associated with arid and semiarid regions, alluvial fans also exist in humid regions and occur throughout the country. Because of their relatively gentle slopes and well draining characteristics, alluvial fans are subject to urbanization at an increasing pace as the supply of flat bottom land is exhausted. Development on fans is subject to damage from floods because of the unpredictable and violent nature of flood waters.

To minimize losses as a consequence of flooding and to protect those living in flood prone areas, the Federal Government passed the National Flood Insurance Act of 1968 which is administered through the Federal Emergency Management Agency (FEMA). Its purpose is to provide insurance against flood losses and to provide guidelines for regulating flood plain development. Implementation of the act has required that FEMA address the flooding issues particular to alluvial fans.

To determine the flood risk and flood prone areas of fans, FEMA adopted a methodology based on work by Dawdy (1979). The existing methodology is based on two key assumptions which have not been verified in the past. The first of these is that the location of any stream channel on a fan is random; that it has an equal probability of occurring anywhere across the fan. The second is that the flow forms its own channel and remains in one channel throughout the flow event, except that the location of the channel can change through avulsion. FEMA commissioned DMA Consulting Engineers to conduct a study to verify the

appropriateness of the assumptions and, should the need be shown, to modify the method. This study has focused on the development of a historical data base of floods on alluvial fans. Fans for which flow measurements are available were identified and aerial phctographs covering the flood events were sought. In developing the data base the goal was to bracket a flood event with before and after photographs so as to define the physical nature of the flood event on the alluvial fan proper. Personnel from Federal and local agencies in Arizona, California, Nevada, and New Mexico were contacted to obtain information of alluvial fan floods. A review of the literature was made, including a detailed analysis of a 1981 hydraulic investigation which was performed by the firm of Anderson - Nichols & Company.

2.0 LITERATURE REVIEW

A search of available literature was undertaken including a computer search through 12 data bases and the follow up of material referenced in the literature reviewed. Over 50 publications dealing with the subject of alluvial fans were reviewed. The overwhelming number of publications dealt with geologic and geomorphologic descriptions of fans. This included descriptions of fan material, fan make-up, fan deposits, fan age, and fan formation. Although it is universally agreed that water flow plays the key role in the fan formation process, very few of the publications addressed the hydrologic and hydraulic processes on fans.

The majority of investigations describe fans in the regions of the southwest. Bull (1960a, 1960b, 1961, 1963, 1964, 1966, 1968, 1973) studied fans on the east slopes of the Diablo Range in Western Fresno County, California. Denny (1965) gives a comprehensive description of fans in the Death Valley region. His study focused on three areas from the Panamint Range and the Funeral Mountains. He developed relationships between mean sediment size and fan slope, drainage area and width of wash, drainage area and fan slope, width of channel and slope of channel, and mean sediment size variation with distance from fan apex. Finally an expression was developed for the size of fans in terms of fan area as a function of drainage area.

Eckis (1928) gives a description of fans on the northern part of the San

Bernardino Basin in Southern California. Blissenbach (1954) discussed formation processes and alluvial fan deposits with emphasis on three fans in the Santa Catalina Mountains of Arizona.

An overview of alluvial fan characteristics is presented by Ansey (1965). This study discusses characteristics of both arid and humid region fans, classification of alluvial fans, and the incidence of alluvial fans, with particular emphasis on the Basin and Range Province. Such characteristics as fan gradient, width and radius are quantified on a gross basis.

Hooke (1967) describes two distinct types of alluvial fan deposits: water flow deposits and debris flow deposits. Water flow deposits are those laid down by running water while debris flow deposits are those flows having properties different than water with much greater specific densities and viscosities, resulting in non-newtonian flow. The sediment load of water flows may vary as a result of the processes of erosion and deposition. A debris flow on the other hand will not exhibit such a characteristic. It will flow as an entity, with the debris load coming to rest at a terminal point at which its momentum can no longer carry it further along the fan. Consequently debris flow deposits are characteristically sheetlike with lobate tongues that are well defined and terminate abruptly. Debris flows consist of muddy mixtures of gravel, sand and clay which can carry boulders in excess of 8 feet in diameter. Sharp and Nobles (1953), and Pierson (1981) have reported that these mud mixtures have water content between 20 and 40 percent by weight. Pierson (1981) has measured mud flows moving at velocities in excess of 15 feet per second on fans with slopes of 5 to 7 degrees.

Beaty (1974) argues that the primary agent in the formation of alluvial fans is the debris flow as opposed to what he terms the "so-called normal stream processes." In describing the formation of alluvial fans at the base of the White Mountains, along the California-Nevada border, Beaty contends that no more than 10 - 15 percent of the fan materials have been deposited by sediment- laden waters. In arguing the probability of occurrence of debris flows Beaty points out that during the 35 year period prior to 1970 there had been at least seven significant debris flows from canyons along the Western flanks of the White Mountain Range. He further cites, based on newspaper files and discussions with long time area residents, that two to three times as many debris flows occurred during the historical period dating back to the 1860's. The significant causative agent leading to debris flows according to Beaty are storms with precipitation intensities in excess of 50 - 70 mm/hr. Beaty believes that debris flows are highly unlikely without intensities equal to or exceeding those.

It is important to note that Beaty's work, although extensive, has been in the desert ranges of the Great Basin which have little or no vegetative cover. Such watersheds have ideal conditions for generating mud flows. However, it is arguable that for canyons with vegetation in the upland areas the frequency of debris flows would not show such a strong one to one relationship with precipitation intensity. If fan formation is dependent on catastrophic events then one is looking at events which may occur with relative infrequency to create the fans observed today. Beaty (1970) gives a rather simplistic but illustrative example of this. The Milner Creek fan on the western slopes of the

White Mountains is estimated to be 700,000 years old. The volume of the fan is 2.25 billion cubic yards. Assuming the fan was built at a constant rate, the average rate of deposition required would be 3,200 cubic yards per year. This translates to between 3 and 6 inches of deposit per 1000 years if the material were equally distributed over the growing fan. However, analysis of debris flow deposits indicates quite a different scenario. On July 26, 1952 a major debris flow occurred depositing 1,125,000 cubic yards of material on the fan. With debris flows of such a magnitude, only one event every 350 years, on the average, would be required to create the present fan.

Drainage basin lithology is an important factor in the determination of the size of the fan and on the make-up of fan materials. Bull (1964) points out that fans derived from source areas underlain by mudstones and shales are larger than fans orginating from equal sized drainage areas underlain by sandstone. The larger fans are due to the greater erodibility of the mudstones and shales in comparison to sandstone. The greater erodibility leads to a larger source of fan make-up material.

Two investigations included laboratory model studies of fans. In the first there was no attempt to develop a model fan and the basis of similitude criteria (Hooke; 1967, 1968, 1979). A gross scaling was used whereby small fans were created under laboratory conditions for the purpose of observing the overall fan building phenomenon. No prototype fans were used for comparison. Flow rates were selected arbitrarily over a range of value from low to high relative to the size of the fan. The second laboratory investigation was by Anderson-Nichols and Company (1981) and will be discussed in detail herein.

2.1 Discussion of "Flood Plain Management Tools For Alluvial Fans

FEMA commissioned Anderson-Nichols and Company (ANCO) of Palo Alto, California to conduct a study of flood processes on alluvial fans and to develop management guidelines for regulations on alluvial fans. In 1981 ANCO completed a report documenting the results of their study. The ANCO report consists of two volumes. The first presents their results and recommendations. The second gives detailed documentation for their study, including mathematical formulation and description of model testing. The emphasis of the study was on the development of physical models representative of idealized and actual fan conditions. The physical models were used to model specific flood events on actual fans as well as to study the overall flooding phenomenon particular to alluvial fans. In addition, the models were used to test the effectiveness of using various structural and non-structural measures to reduce flood damages to buildings and other structures on alluvial fans.

As a result of the modeling effort three hydraulic zones are identified as occurring along the length of the fan. The first zone is immediately downstream of the fan apex and is categorized by a single channel. This one is followed by one where the flow is in a split channel. The last zone is towards the toe of the fan where the flow becomes braided, relatively shallow and wide. The results of this study confirm the existence of the three zones as identified by ANCO.

3.0 FAN FORMATION AND PROCESS

Alluvial fans develop below the mouth of a canyon by the outwash from the canyon draining an upstream watershed. Flooding on an alluvial fan is part of the natural process for the formation of the fan. Urbanization on an alluvial fan imposes potential obstruction to the flood flows, therefore structures are subjected to flood hazard. In this chapter, the formation and processes of alluvial fans are described first. The characteristics of alluvial fan floods are then investigated using aerial photographs of alluvial fans taken before and after specific flood events. Finally, the results of case studies are presented. These will be used as a data base for the evaluation of the current FEMA method for the analysis of fan floods.

3.1 Theoretical Aspects

Alluvial fans develop from the outwash of a canyon draining an erodible upstream watershed, which is subjected to high intensity and short duration rain storms. The sediments eroded from the watershed by the rain storms are transported downstream by the canyon flow and discharged onto the valley floor below the mouth of the canyon. Due to the spreading of water and the flat valley floor, the flow on the valley floor slows and becomes shallow. This results in low sediment transport capacity and causes the sediment to drop out, initially near the mouth of the canyon. As the deposits continue to accumulate, the slope of the alluvial deposits increases, and so does the sediment transport capacity of the flow. The sediments are therefore carried and deposited further downstream. When the alluvium reaches the canyon bed elevation, flood channels

are developed by the momentum of the canyon flow. At this time, the deposition of sediment is extended further downstream along the channels.

For unusual events, the sediment discharged onto the alluvial fan is so great in quantity that rapid deposition of sediment occurs at a point along a channel. Sediment deposition lessens the channel slope above the point of deposition, but also steepens the slope below that point. Lessening of channel slope further accelerates the deposition process already begun. The deposition process rapidly extends upstream along the channel reach to a point that channel overflow occurs and a new channel is developed to transport the flood water. This process of backfilling an existing channel and developing a new channel is called an avulsion. The new channel developed by avulsion is likely to have a different direction along the fan slope. Water and sediments are now carried by this new channel to a new deposition area on the fan. Repeated occurrence of avulsions on an alluvial fan over a long period of geologic time results in a uniform fan slope in the radial direction from the apex. The steepening of the channel slope below the deposition point also enables the downstream channel to carry more sediment further downstream. Massive deposition of sediment at the downstream area may also result in a low cross-fan debris dam, which leads to steepening the fan slope below the dam. The flood waters passing the openings of the debris dam would develop new individual alluvial fans below each opening. This process also advances the formation of the fan.

Although the avulsion process for fan floods is the major mechanism for creating a uniform fan slope in the radial direction over geologic time, avulsions may not occur often over a planning horizon. Thus, the relocation of a flood channel by avulsion is only associated with the rare flood events, such as the debris flow

resulting from a severe high-intensity short-duration rainstorm on a highly erodible watershed, or massive landslides, etc. Frequently, flood channels are found to be deeply incised onto the fan due to repeating uses by consecutive floods. The flood channels are stable until relocated by channel avulsion in a severe debris flow.

The formation process of an alluvial fan may be affected or modified by human activities, such as the installation of levees or of a lined channel to guide the flood water, the construction of dams to reduce the peak discharge on the alluvial fan, and the construction of a debris dam to intercept the sediment and debris. The above activities will either lower the rate of fan formation or direct the further development of the alluvial fan in designated directions.

3.2 Case Studies

The selection and study of alluvial fans using aerial photographs are described in the following subsections.

3.2.1 Selection Criteria for Alluvial Fans

The characteristics of alluvial fan floods were studied using USGS topographic maps and aerial photographs of the alluvial fans. The topographic maps were used to determine the fan slope, expansion angle, upstream watershed drainage area, canyon slope, and the geographic relationship to adjacent alluvial fans. The aerial photographs were used to determine the fan flood characteristics including channel patterns (such as single channel, split channels, and braided channels),

and channel direction, length, and width. Aerial photographs within three years before and after major floods were compared and the changes recorded to determine the changes in channel patterns by floods, particularly large floods which usually shape the channel patterns.

The alluvial fans studied were selected from California and Nevada. Fans were selected based on the following criteria:

- The fan must be well-defined so that the fan characteristics can be abstracted from the USGS topographic map and the aerial photographs.
- There must be a USGS gaging station for the measurements of flood discharge or there must be estimates of major flood discharges made by USGS.
- There must be aerial photographs covering the fan area within three years before and after the major flood considered. (For some alluvial fans, this criterion could not be met.)

The alluvial fans studied ranged from nearly undeveloped fans in Nevada to fans subjected to highly developed fans in California. For nearly virgin alluvial fans, the process which actually forms the alluvial fan can be seen. For the densely populated fans, the modification of fan floods as a result of man-made structures such as levees, dams, roads, buildings, etc. can be observed. The sources of aerial photographs of alluvial fans used in the present study are summarized in Table 1.

TABLE 1 SOURCES OF AERIAL PHOTOGRAPHS FOR ALLUVIAL FANS

ALLUVIAL FAN	EXPOSURE DATE	SOURCE OF PHOTOS
Northumberland Canyon near Austin, NV	6/19/81	USGS EROS Data Center
Mason Valley Trib. near Mason, NV	10/7/68, 10/25/72	USGS EROS Data Center
Humboldt River Trib. near Rye Patch, NV	6/23/73	USGS EROS Data Center
Rocky Canyon near Oreana, NV	6/23/73	USGS EROS Data Center
Humboldt River Trib. near Oreana, NV	6/23/73	USGS EROS Data Center
Las Vegas Wash Trib. near Henderson, NV	10/21/71, 12/20/72 6/25/75, 7/4/80	USGS EROS Data Center
Piute Wash Trib. at Searchlight, NV	10/7/68	USGS EROS Data Center
San Antonio Wash Trib. near Tonopah, NV	8/29/73	USGS EROS Data Center
Eldorado Valley Trib. near Nelson, NV	7/24/73, 5/12/72	USGS EROS Data Center
Lytle Creek near Fontana, CA	4/13/33, 9/8/35 3/10/38, 4/17/67 10/12/67, 1/30/69, 3/4/69	Whittier College, LA; San Bernardino County, CA
Day Canyon near Etiwanda, CA	9/8/35, 3/10/38 3/30/66, 1/30/69, 2/27/69	Whittier College, LA; San Bernardino County, CA

TABLE 1 (continued)

SOURCES OF AERIAL PHOTOGRAPHS FOR ALLUVIAL FANS

ALLUVIAL FAN	EXPOSURE DATE	SOURCE OF PHOTOS
Deer Canyon near Guasti, CA	9/8/35, 1/30/69 2/27/69	Whittier College, LA; San Bernardino County, CA
Cucamonga Creek near Upland, CA	3/10/38, 1/30/69 2/27/69	San Bernardino County, CA
San Antonio Creek near Claremont, CA	3/10/38	San Bernardino County, CA
Tahquitz Creek near Palm Springs, CA	4/20/59	San Bernardino County, CA
Palm Canyon near Palm Springs, CA	11/5/40	Whittier College, LA
Devil Canyon near	2/17/37 3/10/38	Whittier College, San Bernardino, CA
		LA; San Bernardino
Whitewater River near Whitewater, CA	6/8/36	Whittier College, LA.

3.2.2 Observations of Alluvial Fans

The observed results for individual alluvial fans based on the use of aerial photographs are presented in the case studies. The characteristics of alluvial fan are defined in Figure 1.

Northumberland Canyon near Austin, Nevada

The Northumberland Canyon, located on the eastern slope of the Toquima Range in Nevada, drains an upstream watershed of 15.1 square miles. The relatively mild

slope of 0.033 extends upstream into the canyon beyond the mountain front. The outwash from the canyon has developed a downstream alluvial fan with a slope of 0.033 at the upfan area and an expansion angle of 60 degrees. The upstream watershed is sparsely vegetated below 7600 feet. However, the region from elevation 7600 feet to 8800 feet is well vegetated. Flooding is usually caused by summer thunderstorms in the upstream watershed. A peak discharge of 7680 cfs was estimated for the fan flood on August 7, 1979. Channel patterns due to fan flooding were identified from an aerial photograph taken on June 19, 1981 (see Figure 2).

Analysis of the aerial photograph indicates the flood water was apparently confined in a single channel for a distance of approximately 3300 feet below the mouth of the canyon. Beyond this point to a point about 14,500 feet below the mouth of the canyon the flow continued in a single channel, but the channel width increased. The floodwater then broke out into a radial flow pattern with a 35 degree expansion angle. Further downstream, the flood became a braided-sheet flow with isolated elevated dry patches. The variation of the width for the single channel, obtained from aerial photographs is as follows:

DISTANCE IN FEET	0	2000	3300	4500	10400	12500
WIDTH IN FEET	100	127	137	403	462	383

where the channel distance is measured from the mouth of the canyon.

Two neighboring alluvial fans, subjected to the same thunderstorm on August 7, 1979, were also studied using the same aerial photograph. It was found that these two fan floods, starting with noticeable single channels at the fanhead,

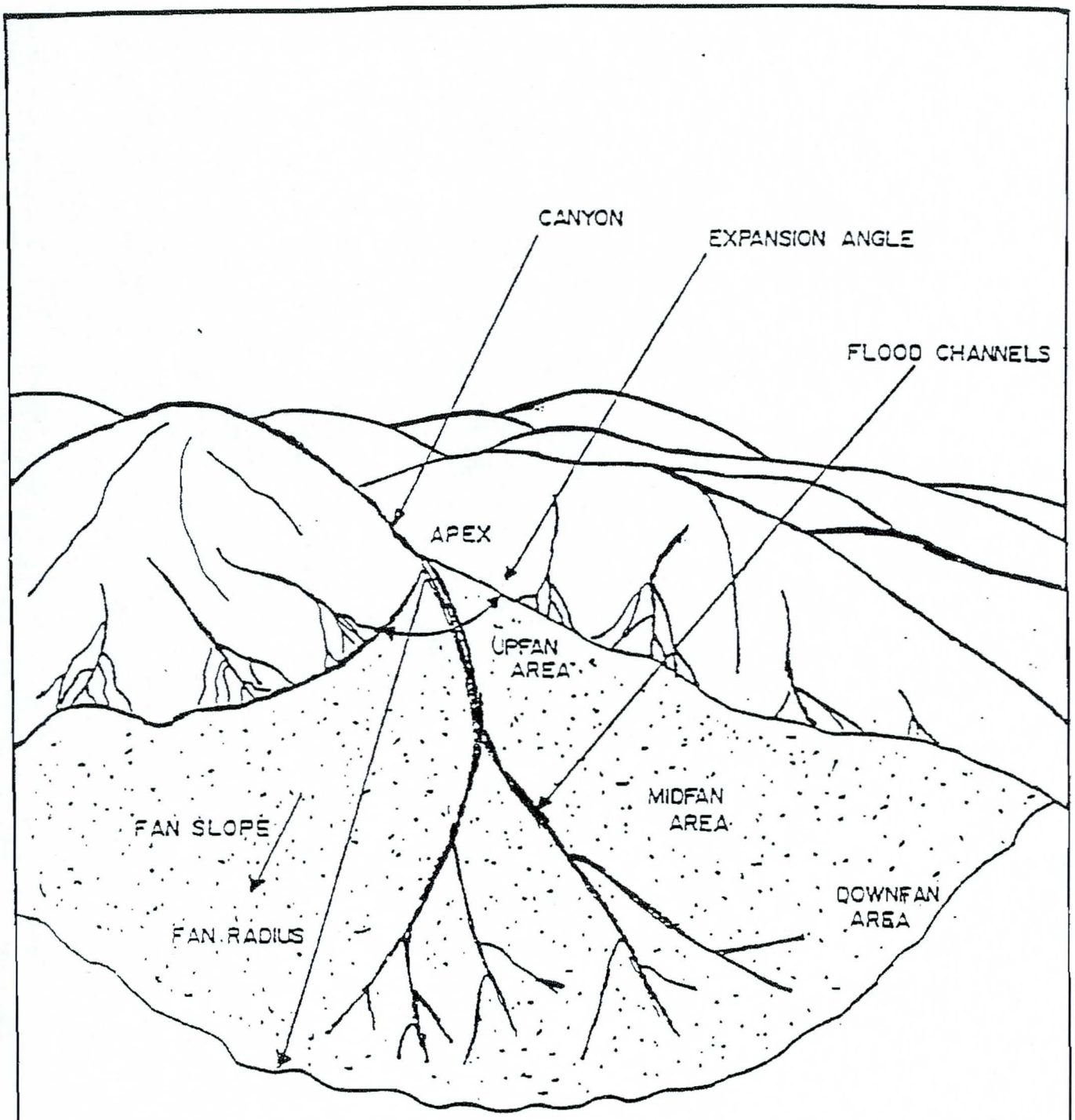
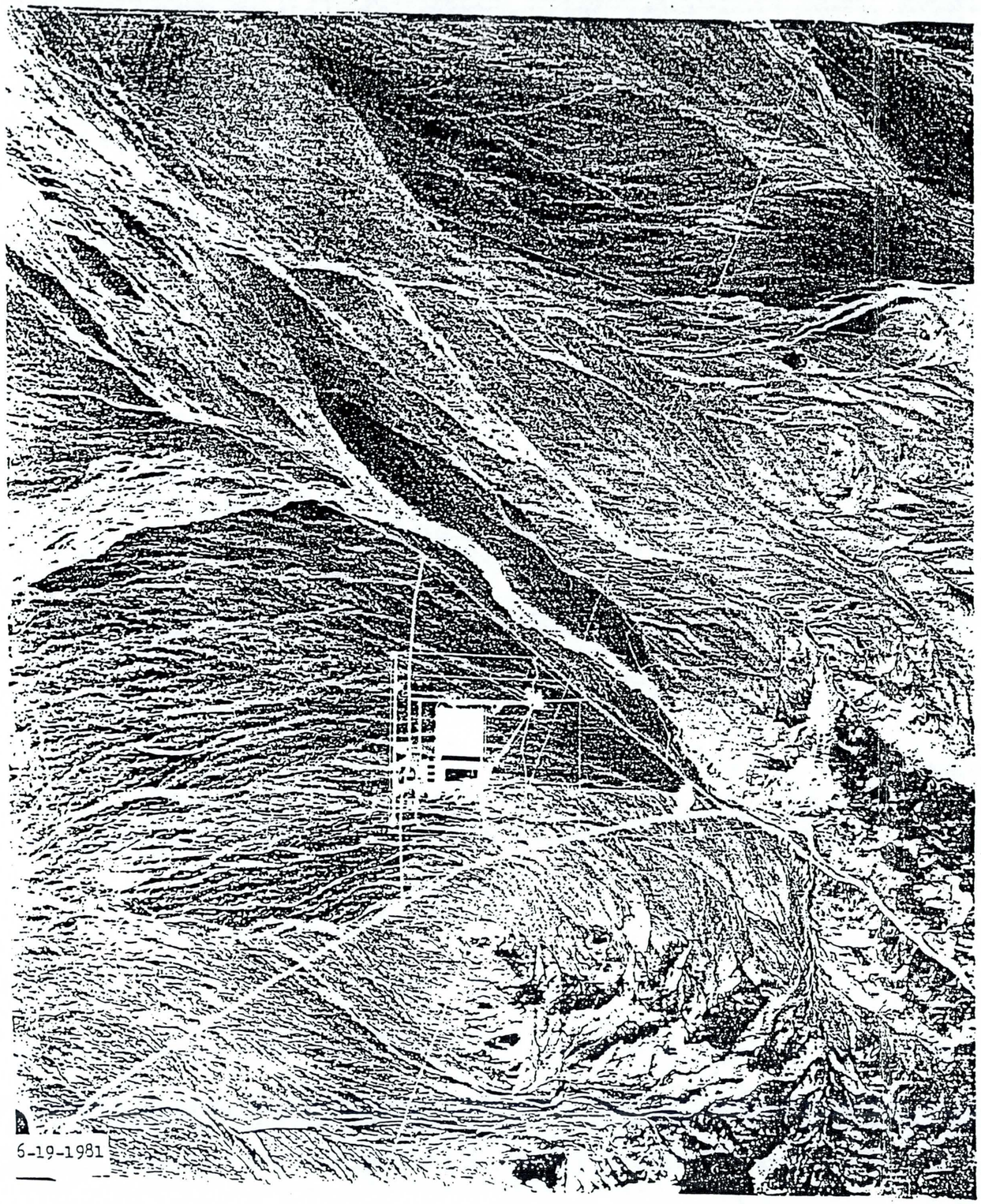


FIGURE 1
Definition Sketch of Alluvial Fan Characteristics



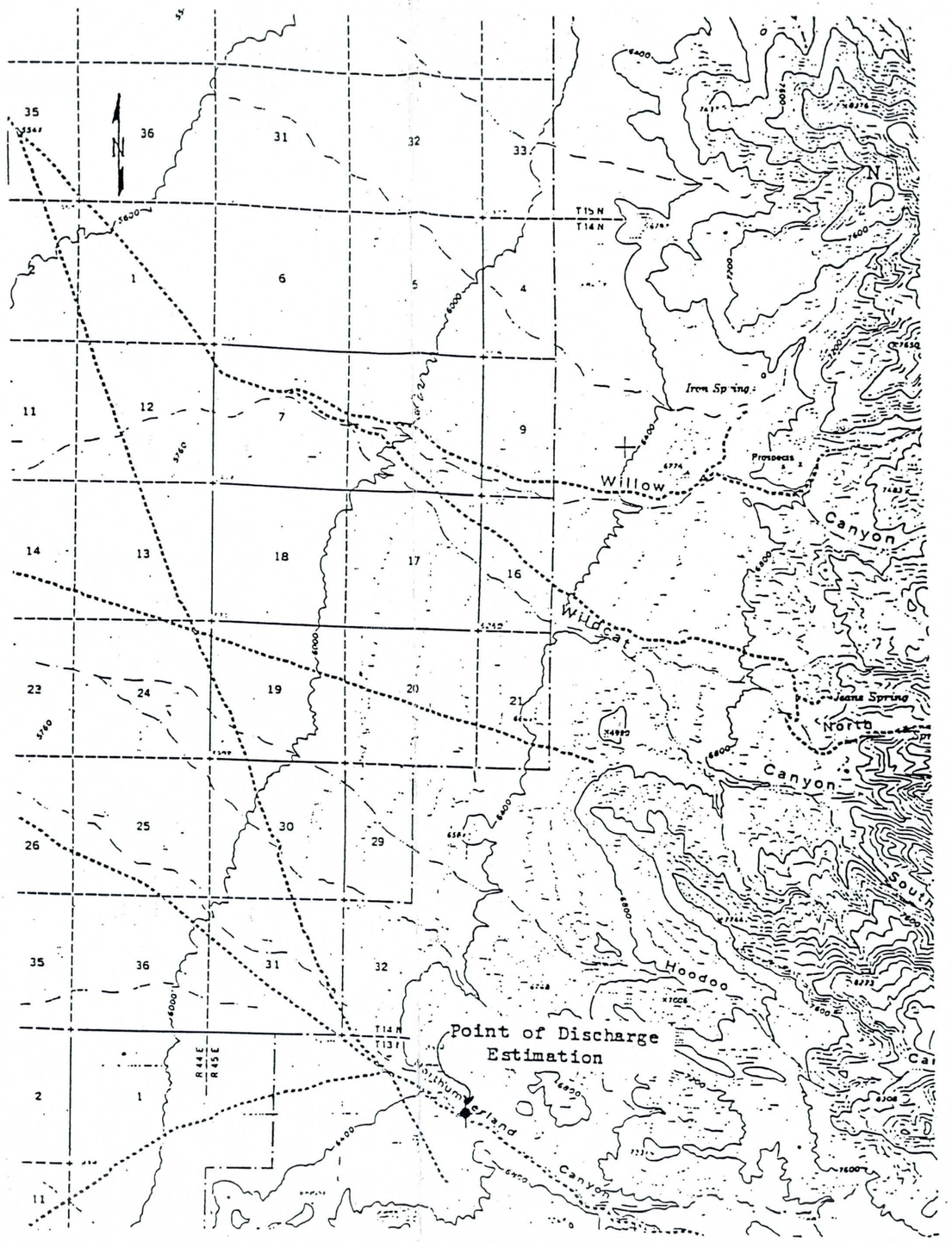


FIGURE 2
Topographic Map and Aerial Photograph of the Alluvial Fan below Northumberland Canyon near Austin Nevada

spread into a radial sheet flow with an expansion angle of 25 degrees and 40 degrees, respectively. The apex for each individual radial sheet flow appeared to be quite random, but probably depended upon the deposition and erosion patterns resulting from the previous flood, the present discharge, etc. There is evidence of extensive mining at the mountain front and the mine tailings seem to have altered the flow pattern extensively on these neighboring fans.

Mason Valley Tributary near Mason, Nevada

The alluvial fans in this region have been developed by the outwash from tributaries to Walker River in the Mason Valley and are located along the eastern slope of the Singatse Range. The village of Mason is situated on one of the fans and is about 1500 feet below the mouth of the canyon. The upland watersheds are all sparsely vegetated and drained by canyons of relatively mild slope. The alluvial fan on which Mason is located has a slope of 0.035 and an upstream canyon channel slope of 0.058. Although the upstream watershed has a drainage area of only 2.6 square miles, the USGS estimated a peak discharge of 4500 cfs for the flood of June 30, 1970. Two sets of aerial photographs, taken on October 7, 1968, and October 25, 1972, were used to identify the flow patterns of the 1970 flood. The aerial photograph of October 7, 1968, and the topographic map for this alluvial fan are shown in Figure 3. Examination of the aerial photographs showed no clear evidence of flood channels developed on the alluvial fan. There are, however, flood channels identifiable on the two other alluvial fans located south of the gauged alluvial fan. Those two alluvial fans have been developed by McConnell Canyon and Nevada Canyon, respectively (see Figure 3).

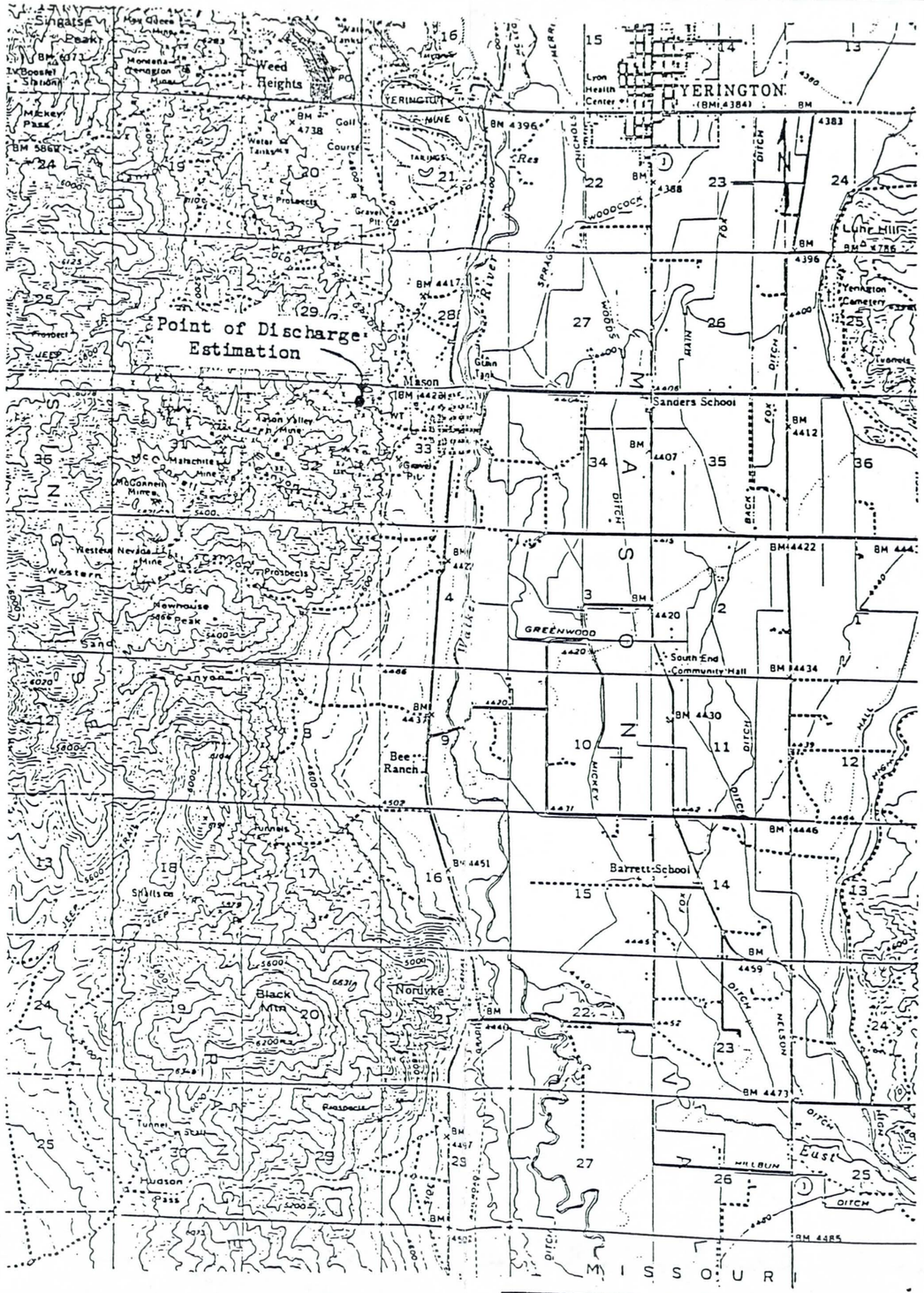


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FIGURE 3
Topographic Map and Aerial Photograph of the Alluvial Fan below Mason Valley Tributary near Mason, Nevada

McConnell Canyon The flood water branched into three channels immediately below the mouth of the canyon. The north channel spreads into a braided-sheet flow with an expansion angle of 20 degrees. The south channel, flowing along the southern boundary of the alluvial fan, bifurcated within a short distance below the mouth of the canyon. After passing the cross-fan West Side Canal, the southmost channel split into three branches but shortly rejoined into an apparently wide sheet flow. The middle channel maintained a single channel flow until it bifurcated shortly after passing the West Side Canal.

Nevada Canyon The flood water split into two branches immediately below the mouth of the canyon. The north branch further split into one large and three small channels. The large channel merged with one of the small channels at the cross-fan West Side Canal, then again separated into two channels of similar width below the West Side Canal. These two channels expanded radially into braided-sheet flows further downstream. One of the other small channels with relatively small flow apparently merged into the West Side Canal. The remaining channel bifurcated after passing the West Side Canal. The south branch consisted of a large and a small channel. The large channel expanded radially in a 30-degree angle while the small channel remained approximately the same width. Both of these channels slightly reduced their widths after passing the West Side Canal.

Comparison of those two sets of aerial photographs showed obvious shifting in major flood channels before and after the flood, even though the channel patterns were similar in appearance. This tends to show that the formation of those flood channels for those fans are random.

Humboldt River Tributary near Rye Patch, Nevada

This alluvial fan is located along the western slope of the Humboldt Range in Nevada. The upland watershed is barely vegetated and has a drainage area of 0.85 square miles. The canyon channel, with a slope of 0.11 near the mouth of the canyon, discharges flood water onto the alluvial fan with a slope of 0.071 and an expansion angle of 90 degrees. Flooding generally results from summer thunderstorm activity. The USGS has estimated a peak discharge of 8940 cfs for the flood of May 31, 1973, which is questionably high judging by the size of watershed. An aerial photograph taken on June 23, 1973 (see Figure 4) was used to determine the flood channel pattern.

The aerial photograph showed that a single channel had been developed near the center of the fan. The channel width of about 35 feet at the mouth of the canyon gradually increased to about 60 feet at a location 500 feet below the canyon mouth. The channel then shifted slightly toward the north and its width reduces to about 40 feet at a location 1,060 feet below the canyon mouth. Below that point, the channel expanded radially into a braided-sheet flow pattern with a 30-degree expansion angle and eventually discharged into the Humboldt River.

Rocky Canyon near Oreana, Nevada

The alluvial fan developed by Rocky Canyon is located along the western slope of the Humboldt Range near Oreana, Nevada. The canyon has a slope of 0.108 near the mouth and drains a sparsely vegetated watershed of 4.05 square miles. The alluvial fan expands in an angle of 110 degrees. The fan slope decreases gradual-

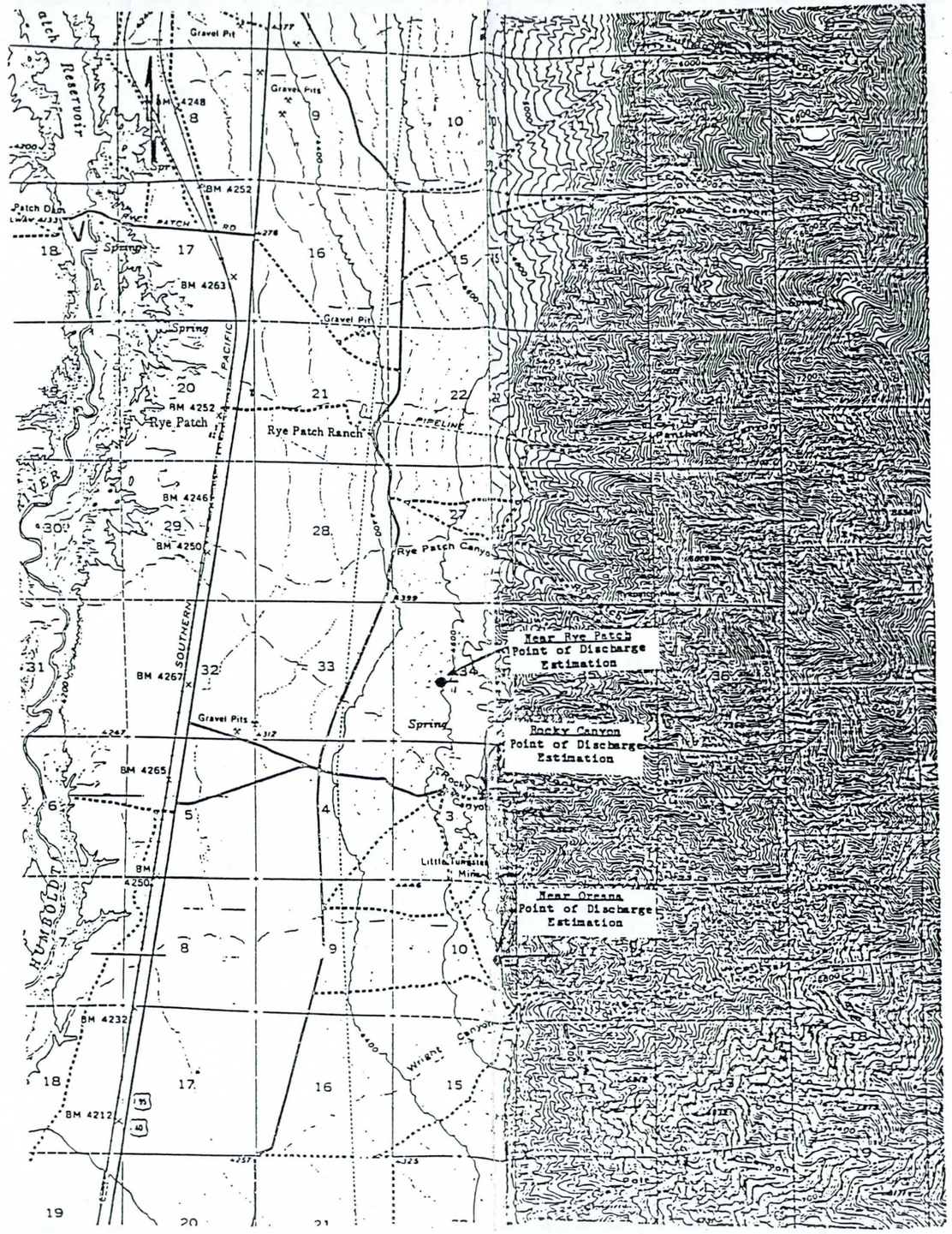

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FIGURE 4
Topographic Map and Aerial Photograph of the Alluvial Fans below Humboldt River Trib. Nr Rye Patch and Oreana, and Rocky Canyon, NV

ly from 0.058 near the canyon mouth to 0.013 near the east bank of the Humboldt River. Floods that discharge onto the alluvial fan are caused by summer thunderstorms. A peak discharge of 14,370 cfs has been estimated by the USGS for the flood on May 31, 1973. The fan flood pattern was identified for the flood of 1973 using an aerial photograph taken on June 23, 1973 (see Figure 4), less than one month after the flood. The flood flow split into two channels at about 1,500 feet above the canyon mouth with the north channel being wider than the south. The north channel, which probably carried the major portion of the floodwater, bifurcates at a point about 1,000 feet below the canyon mouth. The northmost channel further split into two branches at a point about 1,800 feet below the canyon mouth. One of the branches again bifurcates at a point about 2,200 feet below the mouth of the canyon. The south channel maintained a single channel pattern for about 5,000 feet below the canyon mouth and then became braided. Along the middle section of the fan, numerous braided channels apparently developed by previous floods could be seen. This indicated that shifting of flood channels has occurred in the recent past. The south channel maintained a width varying between 70 feet to 90 feet before the channel split at a point about 1000 feet below the canyon mouth.

Humboldt River Tributary near Oreana, Nevada

This alluvial fan, located along the western slope of the Humboldt Range, has been developed by an unnamed small tributary to the Humboldt River. The basin has a drainage area of 0.76 square miles, is sparsely vegetated, and is drained by a canyon with a channel slope of 0.124. The alluvial fan has an expansion angle of 90 degrees. The alluvial fan slope decreases from about 0.07 for the

upfan area to about 0.02 near the east bank of the Humboldt River. Similar to the other Humboldt River tributaries in this area, the fan floods are due to thunderstorm activity. The USGS has estimated a questionably high peak discharge of 6000 cfs for the flood of May 31, 1973. The fan flood pattern was identified using the aerial photograph of June 23, 1973 (see Figure 4). The flood channel bifurcated near the middle section of the fan immediately below the canyon mouth. The channel on the south apparently transported the major portion of the floodwater, and maintained a nearly constant width of 45 feet for some 1,500 feet and then became braided. The channel on the north traveled as a single channel for 1,300 feet, then bifurcated and rejoined after 4,200 more feet. Numerous highly braided old flood channels at the outfan area could be seen from the same aerial photograph. This indicates the likely tendency of channel relocation in future flood events on this fan.

Las Vegas Wash Tributary near Henderson, Nevada

The Las Vegas Wash is composed of many alluvial fans that have been developed by the canyons originating from the northern slope of the McCullough Range near Henderson, Nevada. These canyons flow mostly northward and eventually discharge into Duck Creek. The upstream watersheds of the canyons have little vegetation. The principal cause of floods is summer thunderstorms. The USGS maintains a gaging station, #09419697, on one of the alluvial fans, which measures stream discharge from an upstream watershed of 0.06 square miles. The alluvial fan slope extends into the canyon upstream of mountain front. The canyon draining this watershed has a slope of 0.058. The alluvium below the canyon is narrowly confined by the adjacent alluvial fans on both sides and has a slope of 0.050.

The major floods recorded by the USGS gaging station during the observation period had peak discharges of 655 cfs occurring on July 30, 1968, and 1290 cfs on July 1, 1980.

The flood channel pattern for Las Vegas Wash was studied using four sets of aerial photographs taken respectively on October 21, 1971, December 20, 1972, June 25, 1975, and July 4, 1980 (see Figure 5). Examination of the aerial photographs showed that the flood water flowed in a single channel 68 feet wide for 3,075 feet below the mouth of the canyon. The flood flow then merged with the flow from the adjacent fan and changed to a braided-sheet flow pattern further downstream. Comparison of aerial photographs taken on different dates further indicated that there was no apparent channel change during the period covered by the aerial photographs. One additional alluvial fan in the Las Vegas Wash area, designated as Fan A, with a canyon slope of 0.061 and fan slope of 0.056, was selected for the study using the same aerial photographs. The flood water in Fan A flowed in a single channel 183 feet wide for 3,250 feet below the canyon mouth, and then split and eventually changed into a braided-sheet flow. There were no apparent changes in channel pattern during the period 1971 - 1980.

Piute Wash Tributary at Searchlight, Nevada

The alluvial fan under consideration is only one of the many alluvial fans composing the Piute Wash near Searchlight, Nevada. This alluvial fan has been developed by the outwash from a canyon draining a watershed of 3.4 square miles. The alluvial deposit extends into the canyon upstream of the mountain front. The

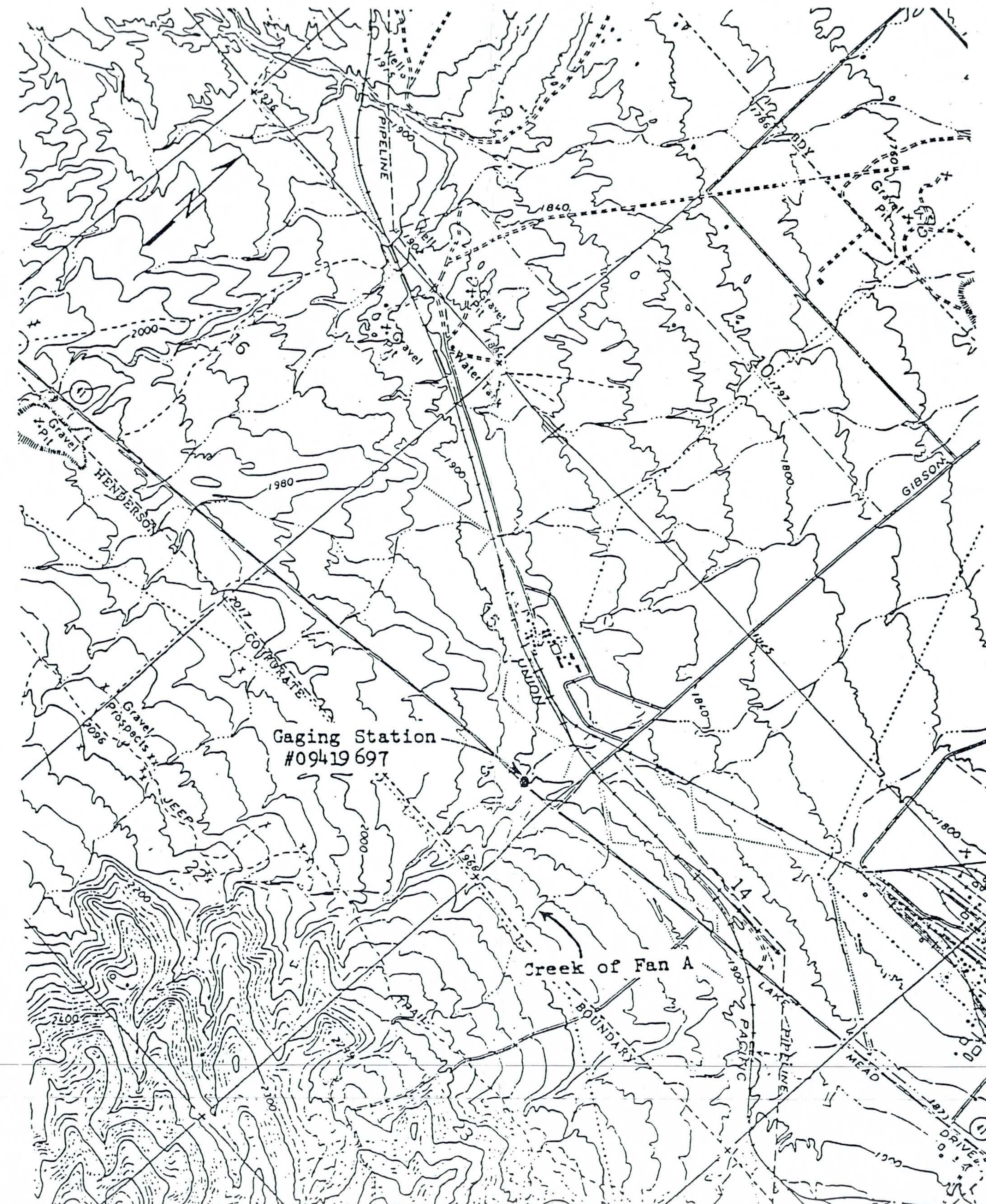

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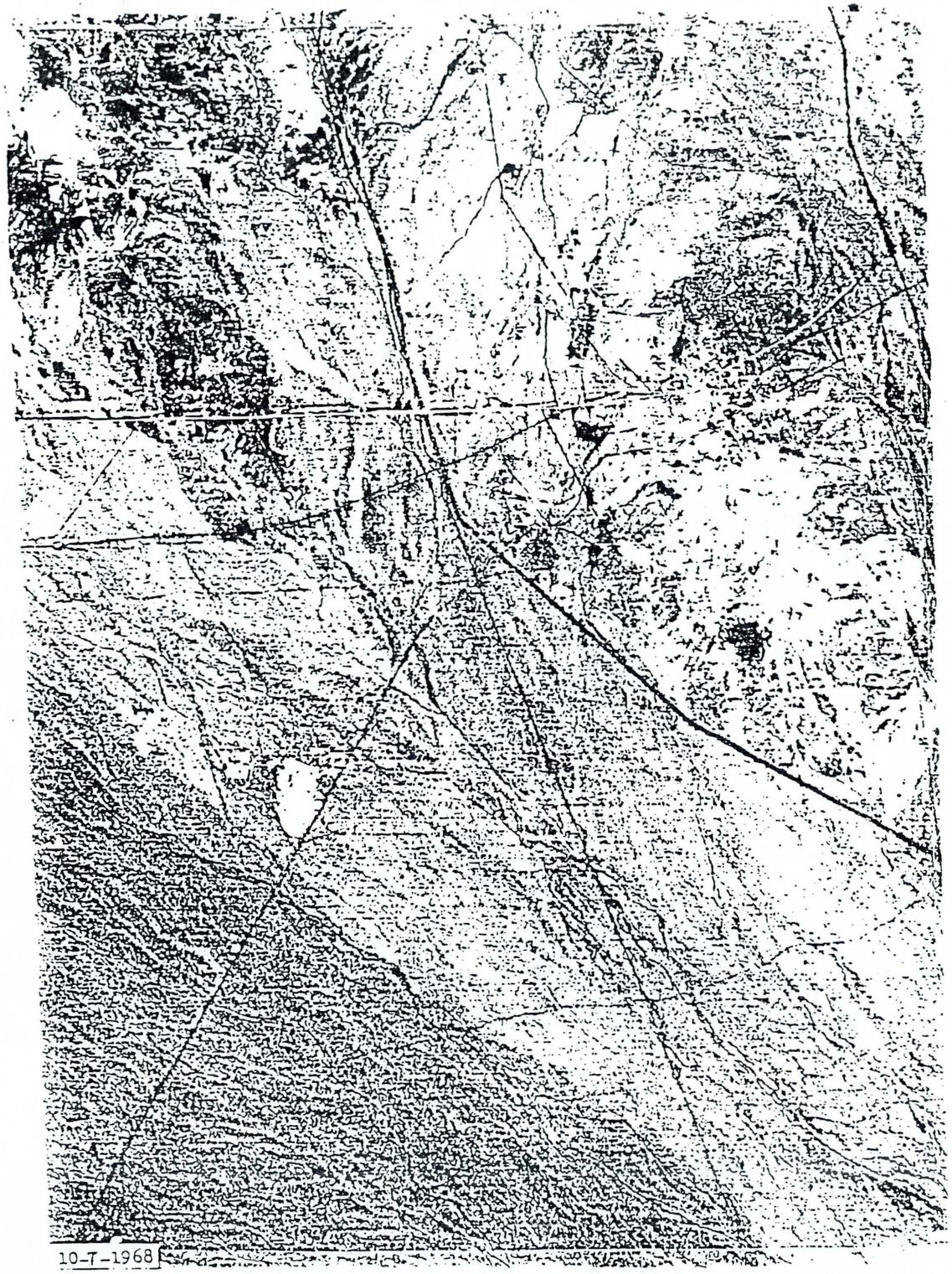
FIGURE 5
Topographic Map and Aerial Photc
graph of the Alluvial Fan belc
Las Vegas Wash Tributary ne
Henderson, Nevada

canyon therefore has a very mild slope of 0.016 near the canyon mouth. Similar to the other alluvial fans in the Piute Wash the studied alluvial fan has a mild slope of 0.016 and coalesces with the adjacent tributaries to form an apron characterized by straight, parallel contours. Summer thunderstorms, characteristic of this area, cause fan flood. USGS gaging station #09423300, located near the mouth of the canyon, recorded such floods with peak discharges of 207 cfs on August 4, 1970, 370 cfs on September 11, 1976, and 200 cfs on August 12, 1978.

The fan flood channel pattern was identified using an aerial photograph taken on October 7, 1968 (see Figure 6). The flood water flowed in a single channel down the fan to the confluence with the channel from an adjacent fan. This seemed to be the typical flood channel pattern in the wash, probably resulting from the lack of slope in the radial direction which generally characterizes other alluvial fans.

San Antonio Wash Tributary near Tonopah, Nevada

San Antonio Wash near Tonopah, Nevada, consists of many alluvial fans developed



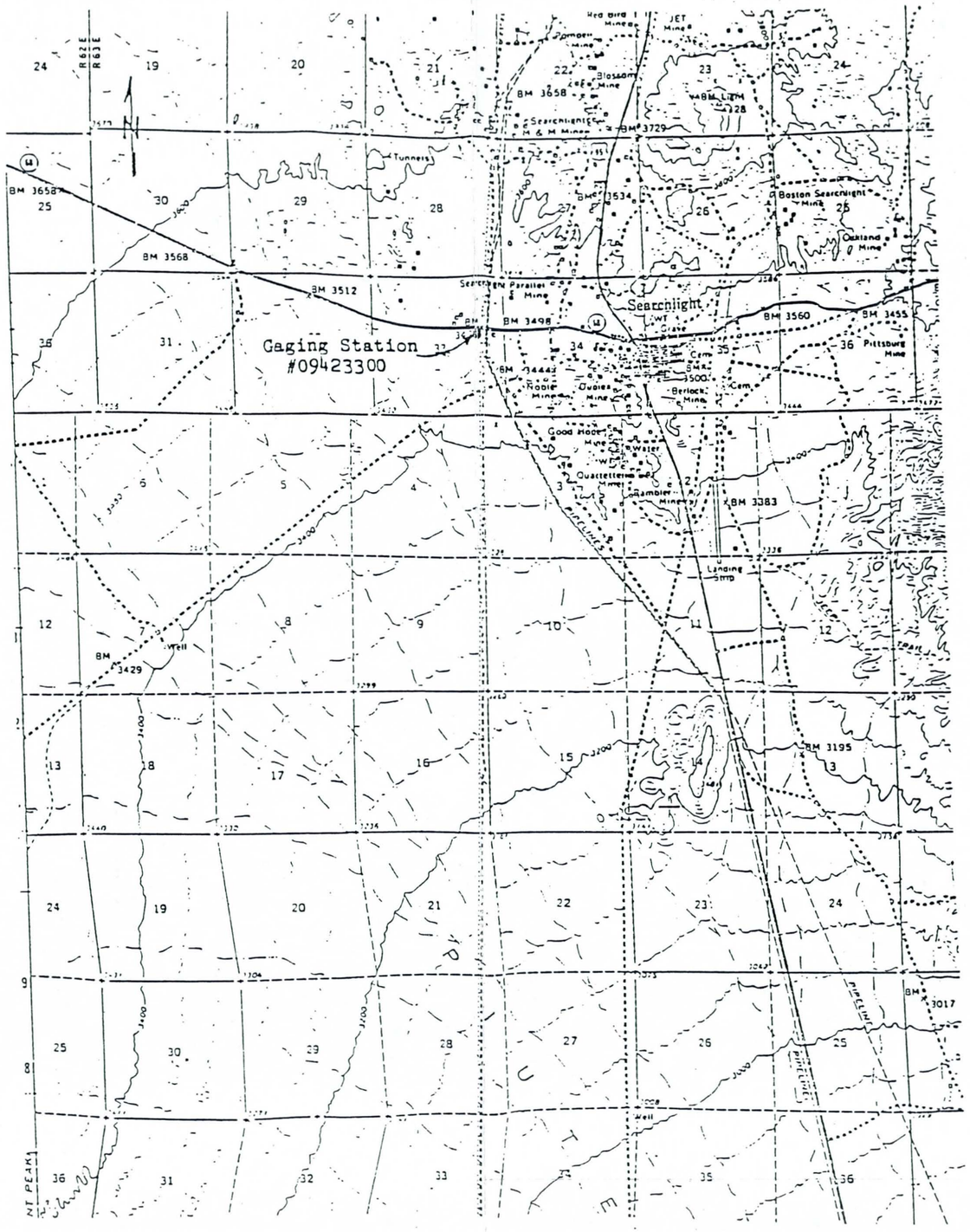


FIGURE 6
Topographic Map and Aerial Photograph of the Alluvial Fan below Piute Wash Tributary at Searchlight, Nevada

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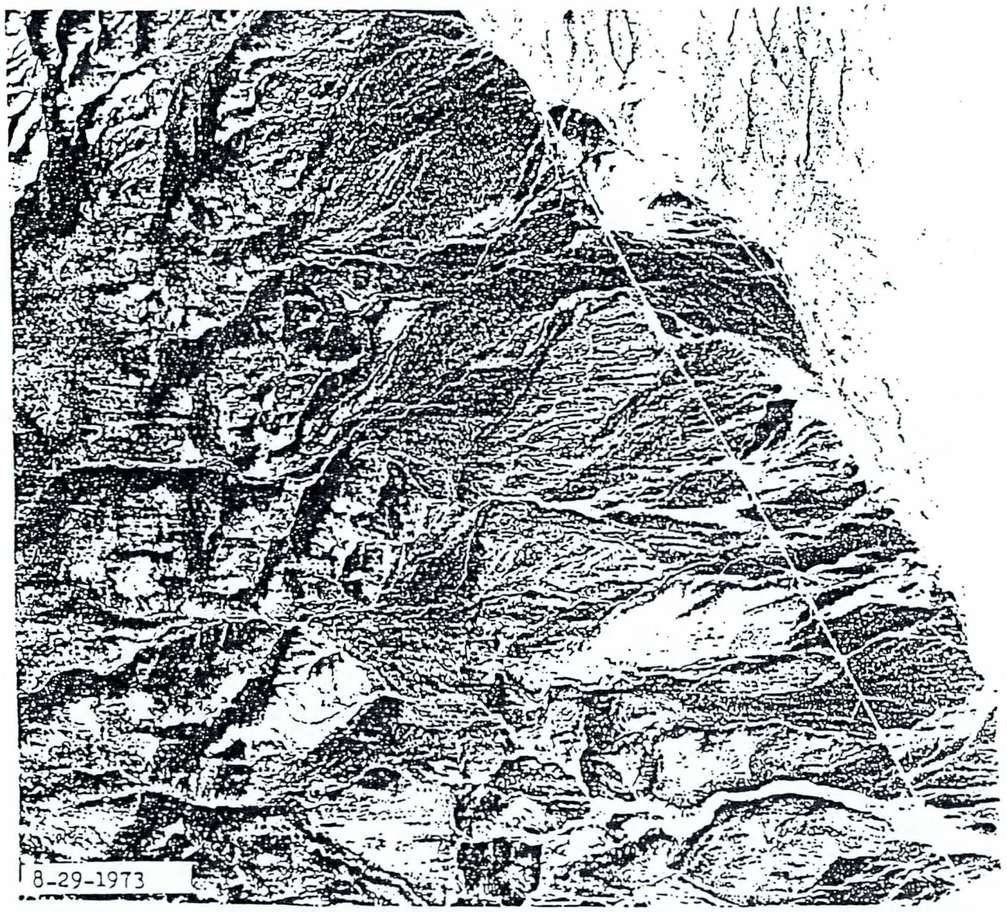
by tributaries originating from the eastern slopes of the San Antonio Mountains. The upland watersheds are sparsely vegetated and the fan floods result from summer thunderstorms. USGS gaging station #10249135 is situated near the toe of one of the alluvial fans in the area. The upstream watershed above the gaging station has a drainage area of 3.42 square miles and is drained by a canyon with a slope of 0.070. The alluvial fan below the gaging station has an expansion angle of 60 degrees and a slope of 0.053. The maximum recorded fan flood had a peak discharge of 660 cfs on August 13, 1972. An aerial photograph taken on August 29, 1973 (see Figure 7) was used to determine the channel patterns for the fan floods. The aerial photographs showed an elevated ridge with three openings spanning across the fan width about two miles below the apex. Several isolated hills are located downstream from the ridge on the southern section of the fan. The flood water flowed in a single channel near the northern boundary of the fan for a distance of 2,250 feet from the mouth of the canyon. Below this point it branched into numerous channels covering the northern half of the fan. Those channels, obstructed by the cross-fan ridge, concentrated and passed through the ridge at three openings to lead to three individual downstream alluvial fans. For the northern downstream alluvial fan the flow stayed in a single channel for 3,000 feet below the opening of the ridge. Beyond this point the channel bifurcated and rejoined within 1,750 feet and stayed as a single channel to the fan toe. For the middle downstream alluvial fan the flood water flowed in a single channel along the southern boundary of this fan. It collected flows from two small channels originating outside the fan before reaching the fan toe. For the southern downstream alluvial fan there was no evidence of flood channels. A well defined channel was, however, located slightly off and parallel to the southern border of the fan.



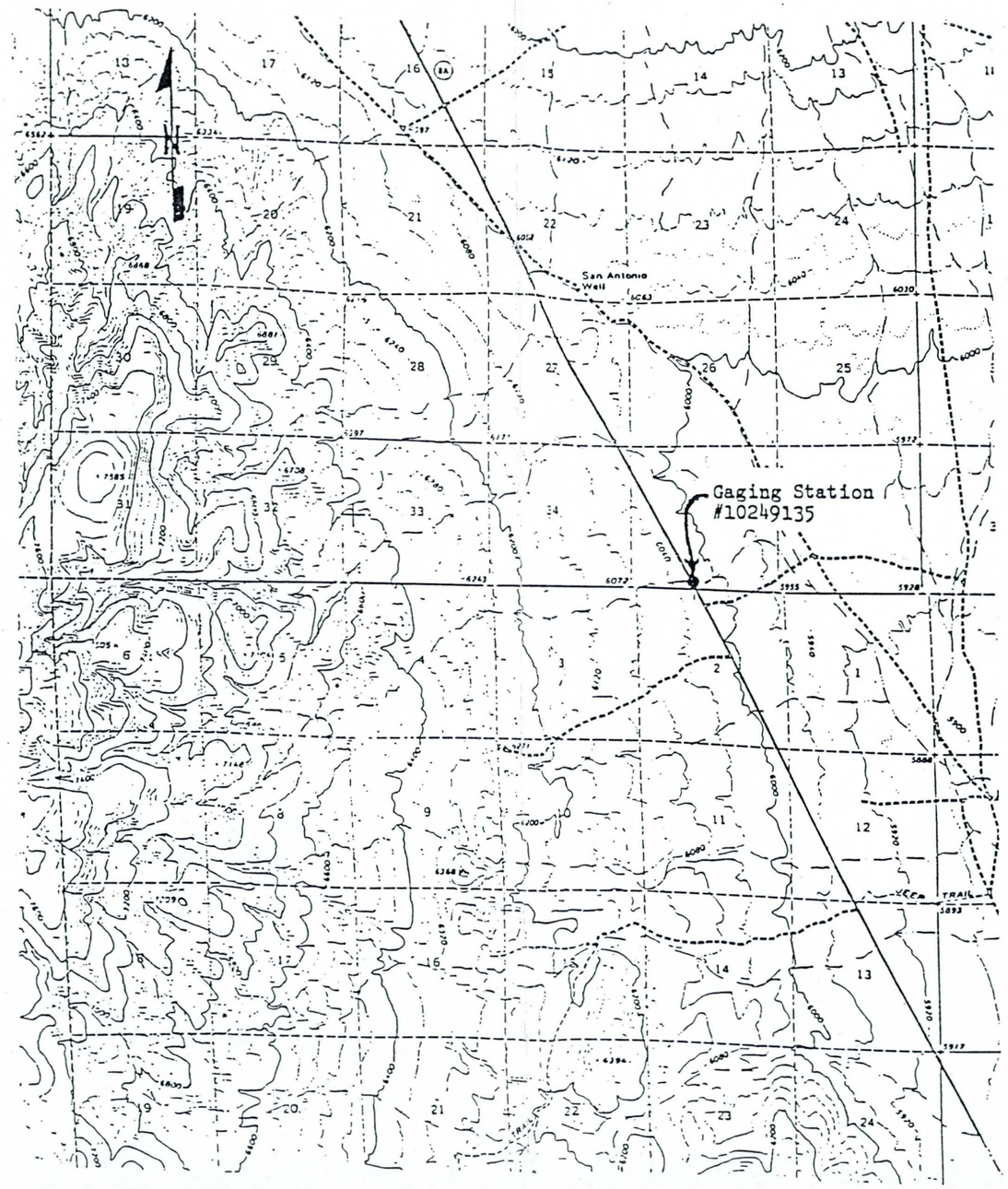


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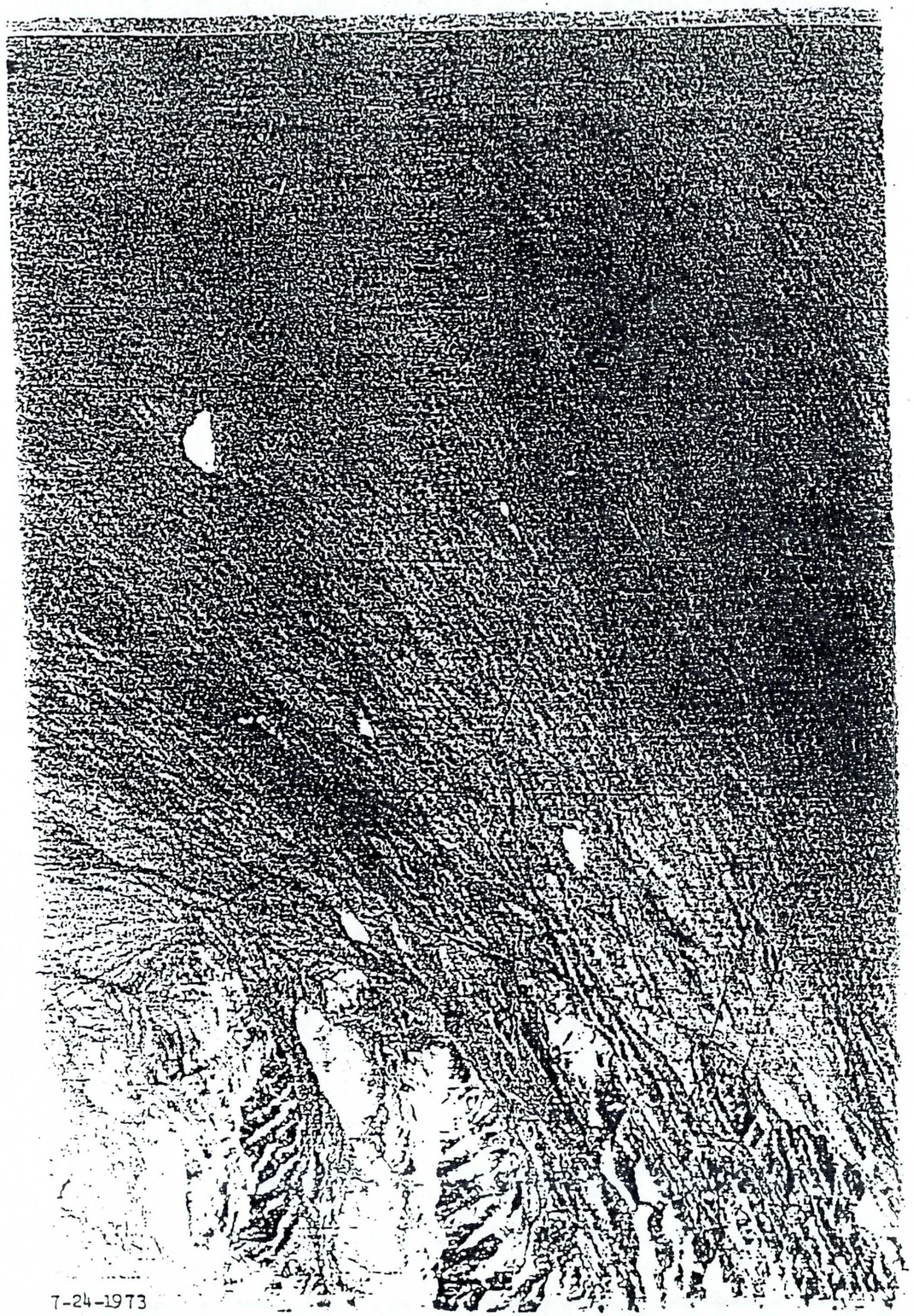
FIGURE 7
Topographic Map and Aerial Photograph of the Alluvial Fan below San Antonio Wash Tributary near Tonopah, Nevada

Eldorado Valley Tributary near Nelson, Nevada

These alluvial fans are developed by tributaries originating from the Eldorado Mountains near Nelson, Nevada. The upstream watersheds for these tributaries have little vegetation and floods result from thunderstorm activity. The alluvial fans coalesce to form an alluvial apron a short distance below the canyon. USGS gaging station #10248510 is located at one of the canyons, which drains an upstream watershed of 1.4 square miles. The alluvial deposit extends into the canyon above the mountain front to result in a canyon slope of 0.036 near the canyon mouth. The alluvial fan below this canyon has a similar slope of 0.036. The gaging station has recorded floods with peak discharges of 530 cfs on August 4, 1970, and 232 cfs on June 8, 1972. Two sets of aerial photographs, taken on May 12, 1972, and July 24, 1973 (see Figure 8 for the latter), respectively, were used to identify the flood channel pattern on the fan. The aerial photographs showed that the flood water flowed in a wide, shallow, and not well-defined channel for about 2000 feet below the canyon mouth. Downstream of that point it changed into a braided-sheet flow pattern and eventually coalesced with the flows from the adjacent fans in a complete sheet flow pattern. The above observed flood channel pattern seemed to be typical for the fans in this area.

A comparison of the two sets of aerial photographs indicated that there was no obvious change in channel pattern and locations although a flow of 232 cfs occurred in the period between the times that these two sets of aerial photographs were taken.



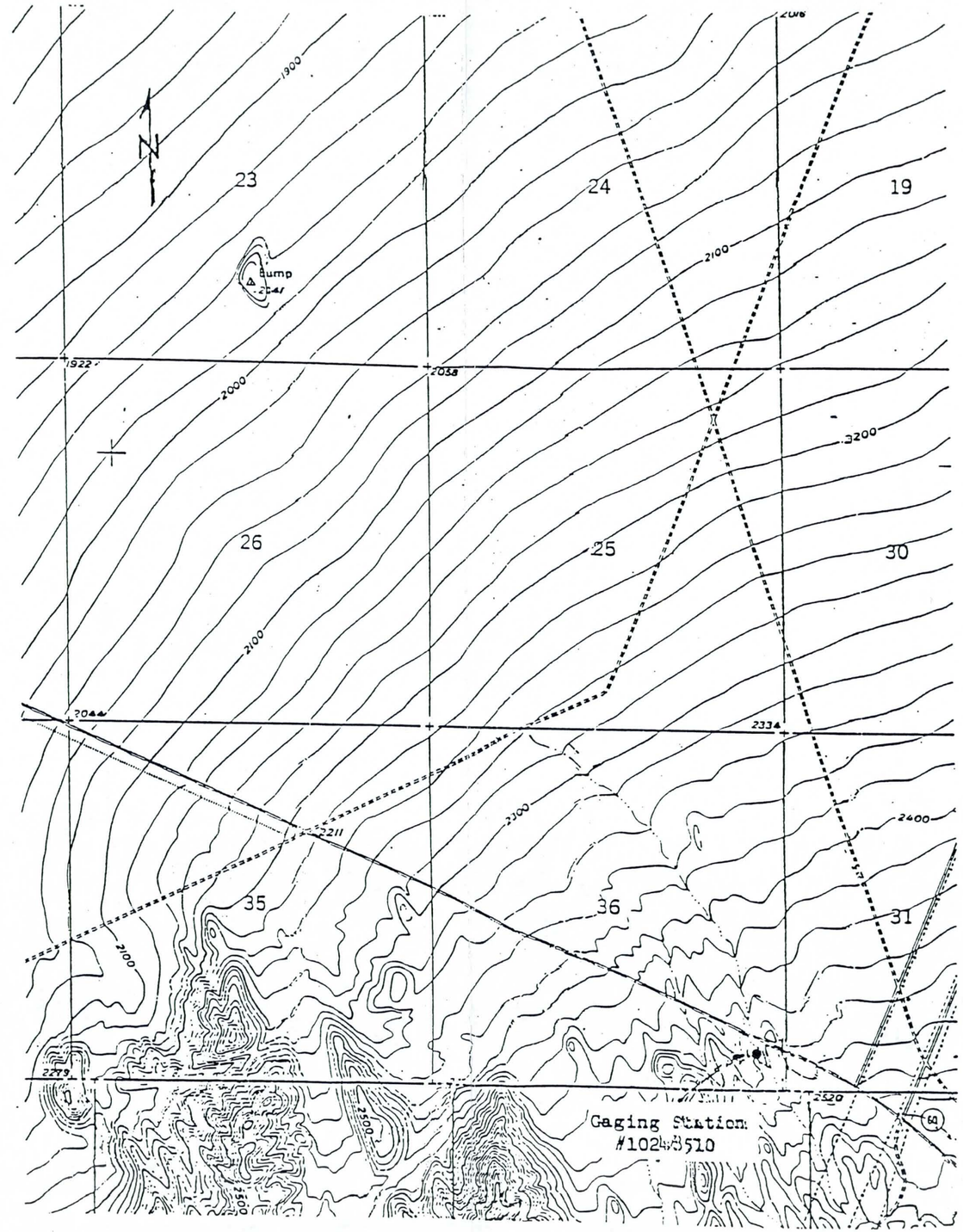


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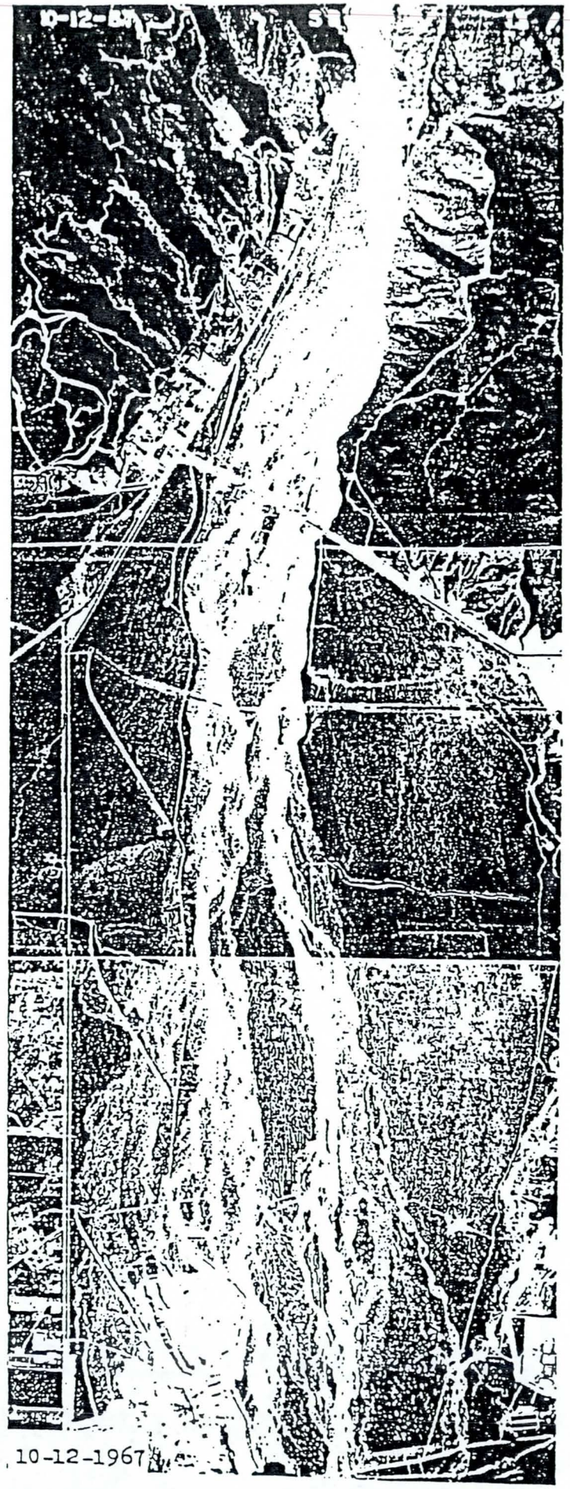
FIGURE 8
Topographic Map and Aerial Ph
graph of the Alluvial Fan b
Eldorado Valley Tributary
Nelson, Nevada

Lytle Creek near Fontana, California

The alluvial fan developed by the outwash from Lytle Creek is located at the northern end of Fontana, California. Lytle Creek, originating from the San Gabriel Mountains, has an upstream watershed of 46.3 square miles. The canyon slope is about 0.031 near the mouth of the canyon. The upstream watershed is vegetated with sparse forests. The climate is mesothermal humid, of Mediterranean type with hot dry summers, and abundant winter rainfall in the mountains. The major fan floods are usually caused by the winter storms with intensive short duration rainfall. The alluvial fan below Lytle Creek has an expansion angle of 95 degrees and a slope of 0.026 at the upfan area. Lytle Creek flows on the fan to meet Cajon Creek about three miles below the mouth of the canyon. The alluvial fan is densely developed and is protected by levees along many sections of the creek. USGS gaging station #11062000 is situated about one mile above the mouth of the canyon. The discharge recorded by the gaging station shows great variation over the observation period. For instance, the annual peak discharge ranged from 65 cfs on April 28, 1951, to 25,200 cfs on March 2, 1938, and 35,900 cfs on January 25, 1969.

The fan flood patterns and their potential changes due to major floods were identified using the aerial photographs of April 13, 1933, September 8, 1935, March 10, 1938, April 17, 1967, October 12, 1967 (see Figure 9), January 30, 1969, and March 4, 1969. Examination of the aerial photographs indicated that the canyon became wider below the Penstock Ridge, located about one mile above the mouth of the canyon, and that the flood waters flowed in almost a single



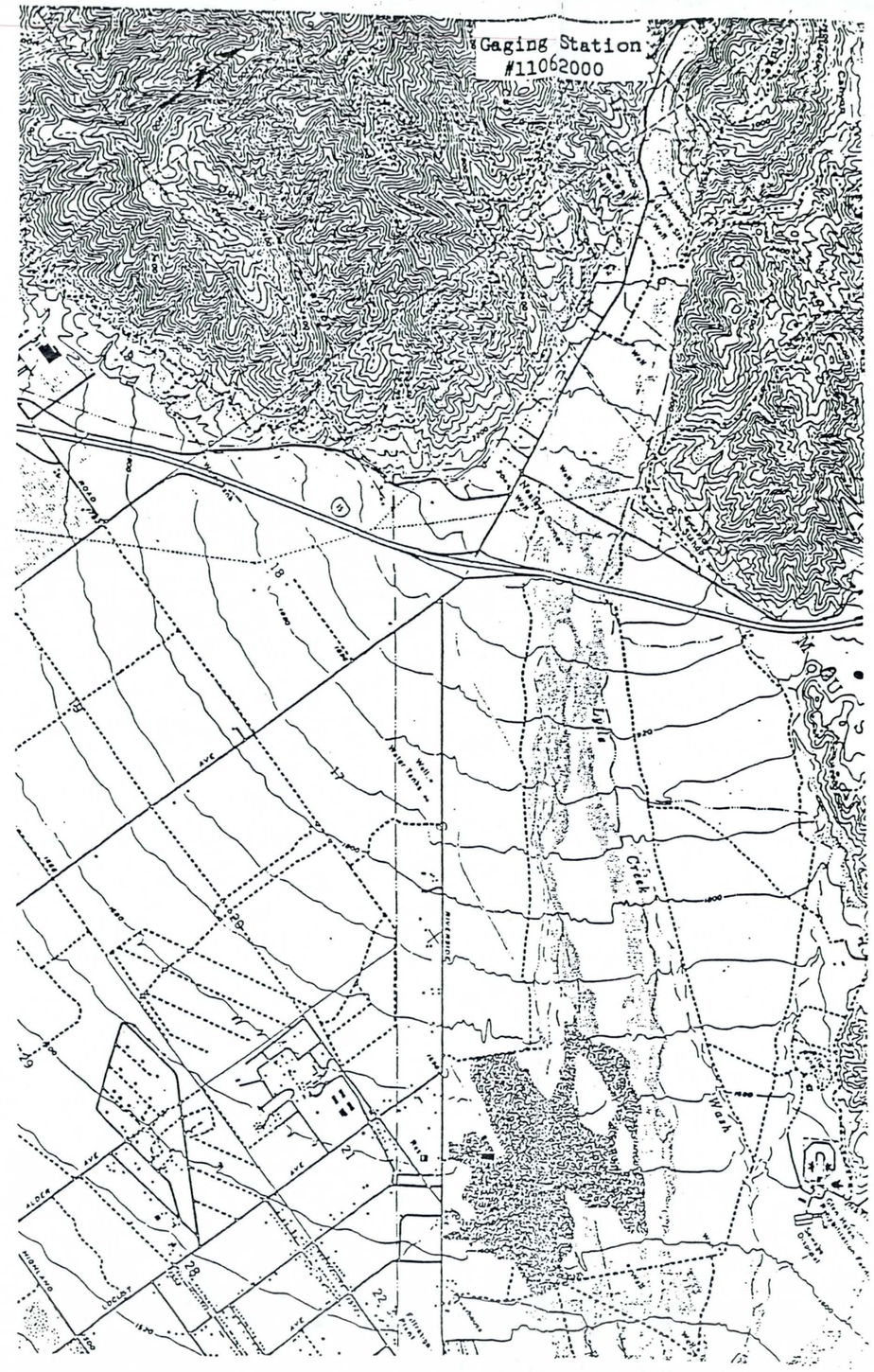


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FIGURE 9
Topographic Map and Aerial Photograph of the Alluvial Fan below Lytle Creek near Fontana, California

channel with some isolated dry patches. The flood however, became highly braided from about one mile below the mouth of the canyon to its confluence with Cajon Creek.

Comparison of aerial photographs of 1935 and March 10, 1938 indicated that the flood of March 2, 1938, with a peak discharge of 25,200 cfs, essentially followed the old channels developed by previous floods from the mouth of the canyon to its confluence with Cajon Creek. Comparison of aerial photographs of 1967 and 1969 also indicated similar flood channel patterns and channel locations before and after the 1969 flood with 35,900 cfs peak discharge. The above findings indicated that the major fan floods essentially follow the previous channels and, if they exceeded the channel capacity, widened and deepened the channels by erosion to accommodate the flood flow.

Day Creek near Etiwanda, California

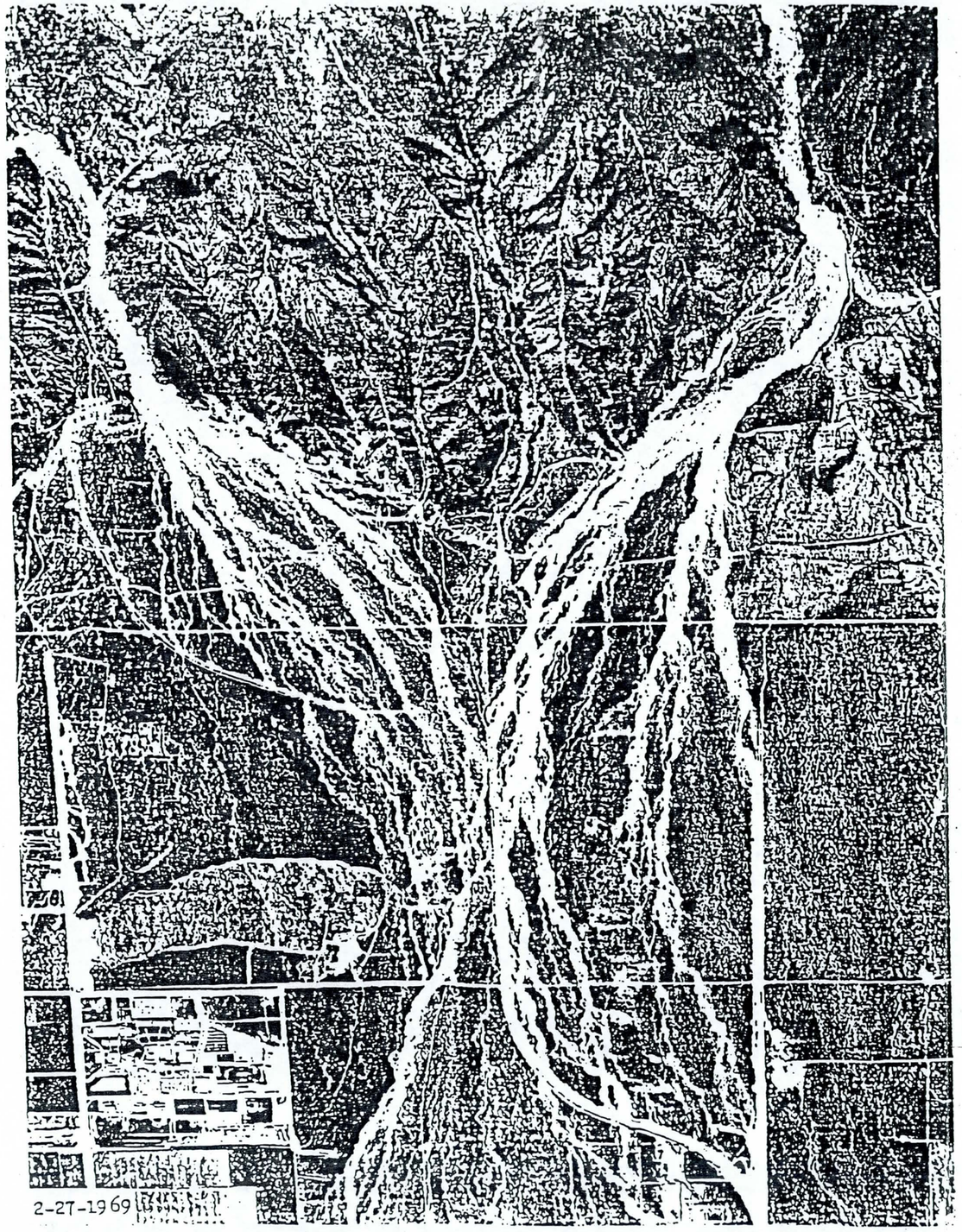
Day Creek originates in the southern part of the San Gabriel Mountains, has a canyon slope of 0.149 near the canyon mouth, and drains an upstream watershed of 11.9 square miles. The upstream watershed is covered with sparse forests. The alluvial fan has a slope of 0.103 near the fan head and gradually decreases in the radial direction. The expansion angle of the fan is about 80 degrees. The fan floods in Day Creek are usually caused by winter storms between November and April. The annual peak discharge in Day Creek varied from 16 cfs on April 1, 1964, to 4,200 cfs on March 2, 1938, and 9,500 cfs on January 25, 1969, as recorded by USGS gaging station #11067000, located at the mouth of Day Canyon. The alluvial fan has been only sparsely developed in the far fan area, and

vineyards and orchards are the most common land use of the fan. To protect those developments, levees have been built to confine the flood water to the western part of the fan, and they eventually direct the flow to a lined channel at the far fan area.

The channel pattern for major fan floods was identified using the aerial photographs of September 8, 1935, March 10, 1938, March 30, 1966, January 30, 1969, and February 27, 1969 (see Figure 10). The aerial photographs show that the flood water flowed in a single channel about 268 feet wide along the west boundary of the fan for 2,400 feet below the mouth of the canyon. Below this point, the width of the channel increased to about 870 feet at a point about 3,660 feet below the canyon mouth. Beyond, the flood channel repeatedly bifurcated to cover almost the entire eastern half of the fan (see Appendix A). The flood water within this region, however, was confined by two levees, which gradually tapered to form a single channel for Day Creek to pass through Etiwanda.

The aerial photographs of 1935 and 1938 were used to determine changes in flood channel patterns due to the fan flood occurring on March 2, 1938. Except for a new channel about 15 feet wide and 5700 feet long branched from the single channel reach, no apparent change in channel pattern was detected.

Comparisons of the aerial photographs of 1938 and 1966 showed that the flood channel pattern remained essentially unchanged except for those areas affected by the levees constructed after 1938.



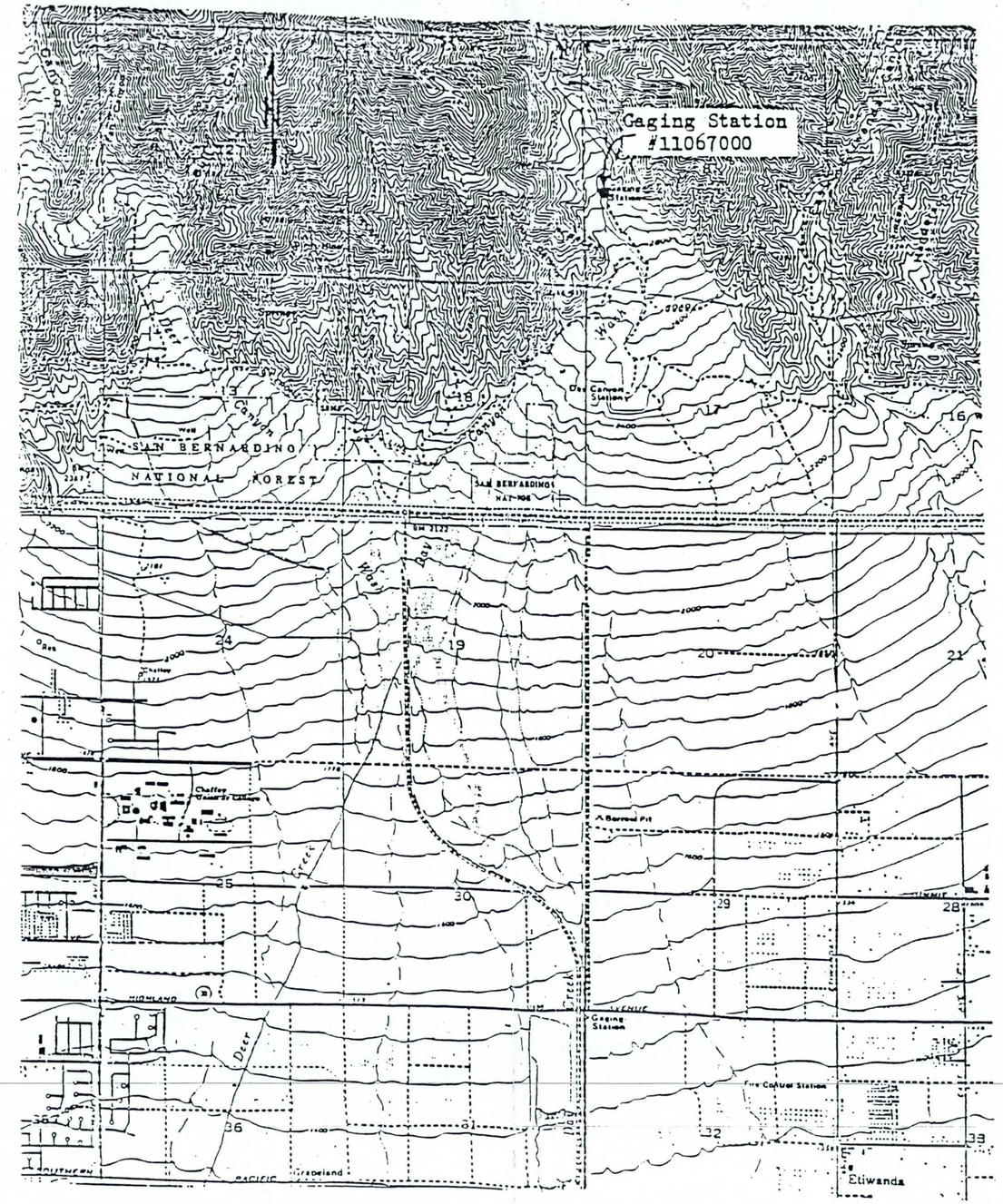


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FIGURE 10
Topographic Map and Aerial Photograph of the Alluvial Fan between Day and Deer Canyons near Etiwanda, California

Comparison of the aerial photographs of 1966 and 1969 also showed that the flood of January 25, 1969 flowed essentially in the channels developed by previous floods.

The above findings on the flood channel patterns tends to indicate that the flood channels in this case are rather stable even when subjected to a wide range of flood discharge.

Deer Creek near Guasti, California

Deer Creek alluvial fan is located west of and adjacent to Day Creek alluvial fan at the southern foothills of the San Gabriel Mountains. Deer Canyon has a slope of 0.168 and drains an upstream watershed of 3.4 square miles and is covered with sparse forests. The alluvial fan below Deer Canyon has an expansion angle of 90 degrees and a slope of 0.109 near the fanhead. There is no gaging station installed at Deer Canyon. However, it is reasonable to assume that the same winter storms that caused floods to the adjacent Day Creek would also cause floods on Deer Creek. Therefore, the aerial photographs used to determine the flood channel pattern for Day Creek could be used for Deer Creek as long as they covered the Deer Creek area (See Figure 10).

Examination of aerial photographs indicated that at about 600 feet immediately below the mouth of the canyon the flood flow changed from a single channel flow to a highly braided-sheet flow covering the eastern half of the alluvial fan. The flood water continued to flow southeastward until it was deflected back to the southwest direction at the boundary between the Deer and Day alluvial fans.

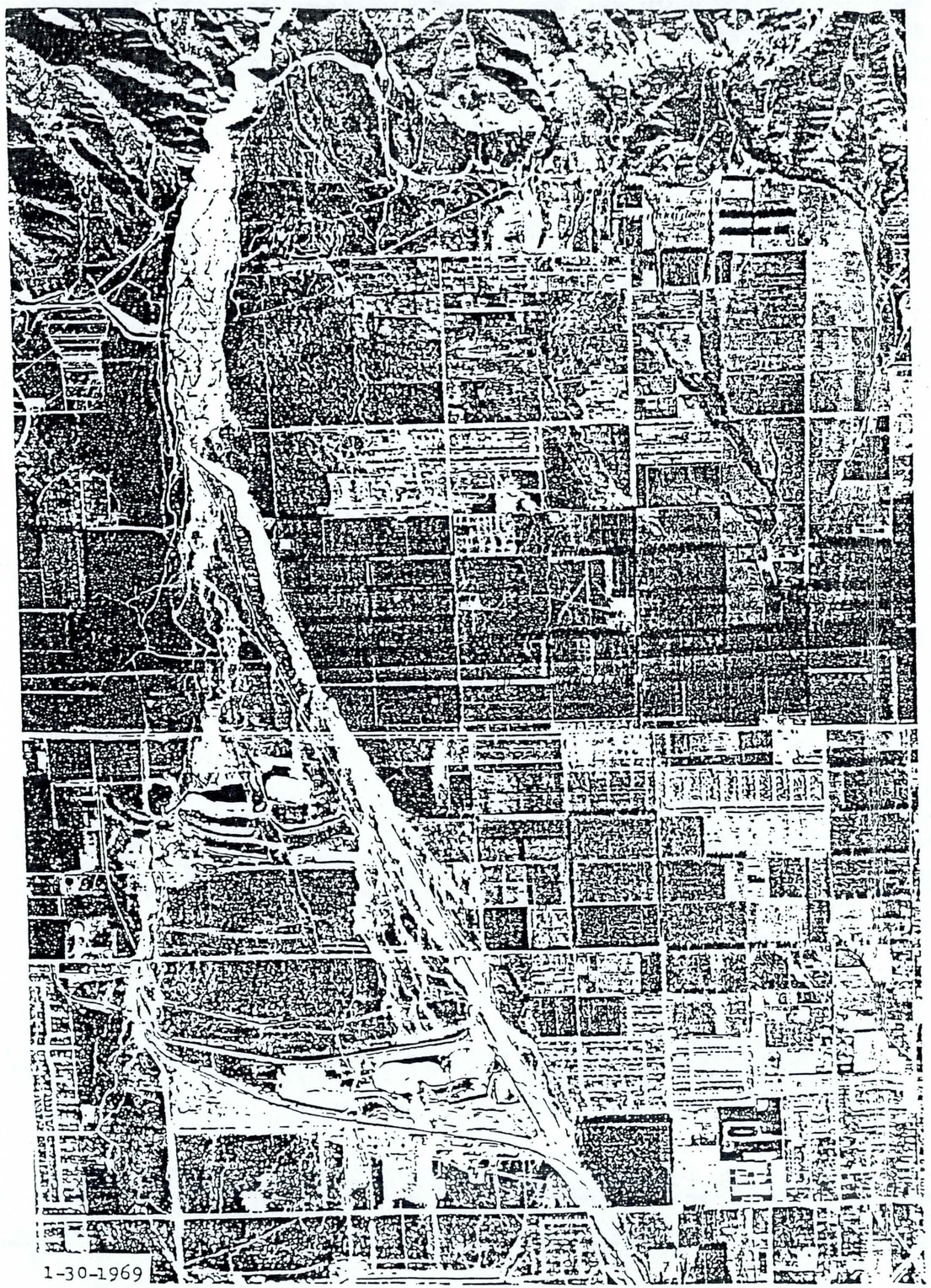
Comparison of aerial photographs for January 30 and February 27, 1969, indicated no apparent change in flood channels as a result of February 25, 1969 flood. The Deer Creek channels may be considered stable in this case.

Cucamonga Creek near Upland, California

Cucamonga Canyon, with a slope of 0.075, drains a sparsely forested upstream watershed of 10.1 square miles in the southern margin of the San Gabriel Mountains. The alluvial fan has a slope of 0.048 near the fanhead. An entrenched channel about 20 feet deep has developed within the 1.5 mile reach below the mouth of the canyon. A series of percolation basins has been built in this reach. For the next two miles, more percolation basins, incorporating levees, have been built to confine the flood water along the east side of the percolation basins. Further downstream, Cucamonga Creek is confined by levees on both banks to transport the flood water through the alluvial fan.

The discharge for Cucamonga Creek is usually less than 5 cfs for most of the year. Major floods, however, result from high-intensity short-duration winter storms. USGS gaging station #11073470, located at the mouth of the canyon, has recorded major floods with peak discharges of 10,300 cfs on March 2, 1938, 14,100 cfs on January 25, 1969, and 4,090 cfs on February 25, 1969.

The channel patterns for major floods were identified using the aerial photographs of March 10, 1938, January 30, 1969 (see Figure 11), and February 27, 1969, each taken shortly after a major flood event.



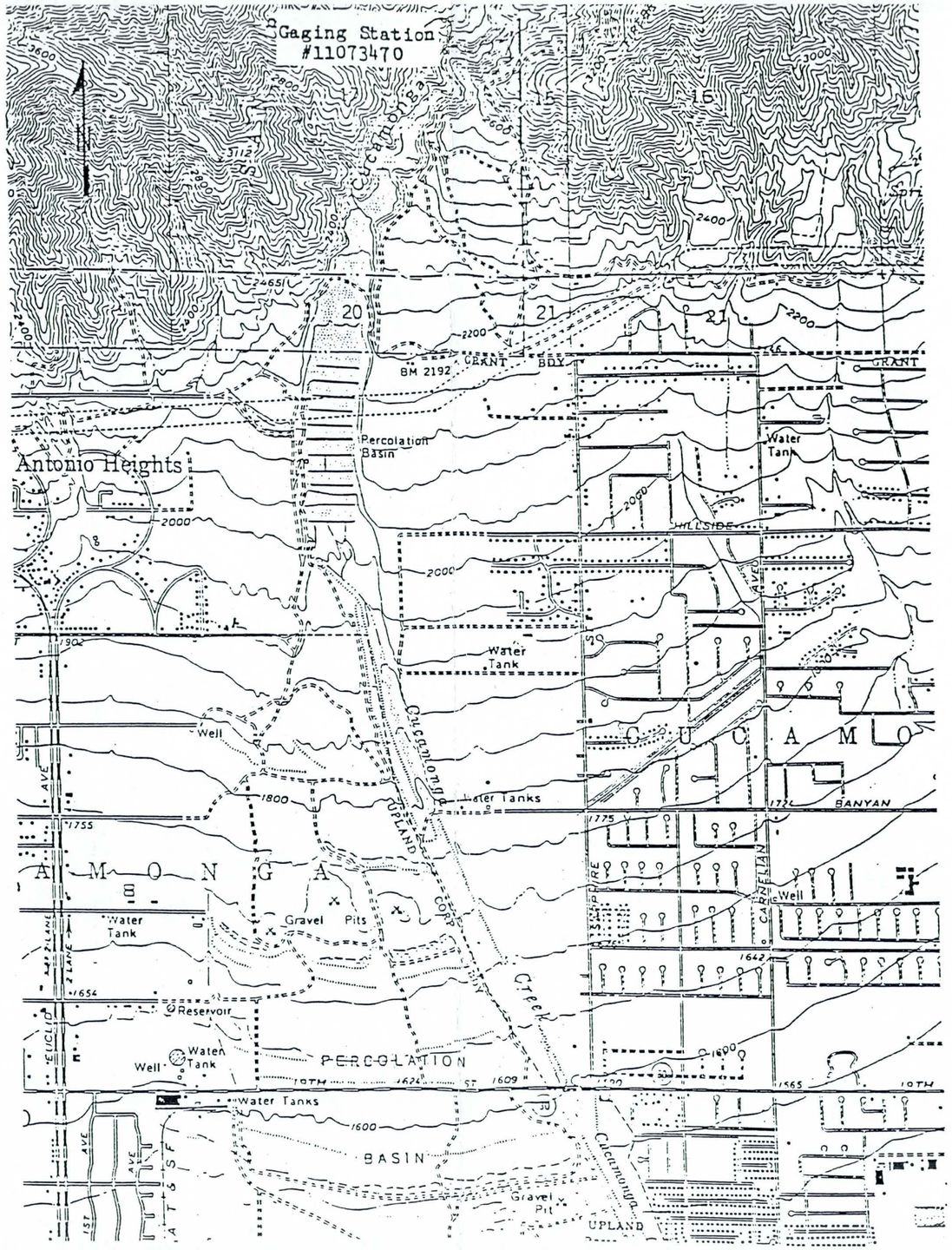


FIGURE 11
Topographic Map and Aerial Photo graph of the Alluvial Fan belo Cucamonga Creek near Upland, California

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Examination of aerial photographs indicated that the flood water occupied the entire channel within the 1.5 mile reach below the canyon mouth probably as a result of the obstruction by percolation basins. Below that reach the flood water was mainly transported by the channel located east of the lower percolation basins. When flood water exceeded the channel capacity it spilled over the levees to form small braided-sheet flows in the lower percolation basins and split-braided flow along Cucamonga Creek. Channel patterns remained essentially unchanged except for those areas being affected by new structures constructed after 1938, and for a slightly wider flooded area for the larger flood of 1969. Aerial photographs of January 30 and February 27, 1969, indicated that the flood water for the smaller flood of February 25, 1969 essentially followed the old channels developed by the previous flood of January 25, 1969. The above findings on the flood channel patterns tend to support the conclusion that the flood channels are relatively stable in this case.

San Antonio Creek near Claremont, California

San Antonio Creek alluvial fan is located near Claremont, California. San Antonio Canyon has a slope of 0.055 and drains a sparsely forested upstream watershed of 26.2 square miles in the southern margin of the San Gabriel Mountains. The alluvial fan expands from the apex with a 90 degree angle and has a slope of 0.046 for the upfan area. San Antonio Dam, a flood-control reservoir with a capacity of 7,620 acre-feet, is located at the mouth of the canyon. A spillway is situated at the west end of the dam to release flood water to San Antonio Creek. Percolation basins are built on either side of the channel for

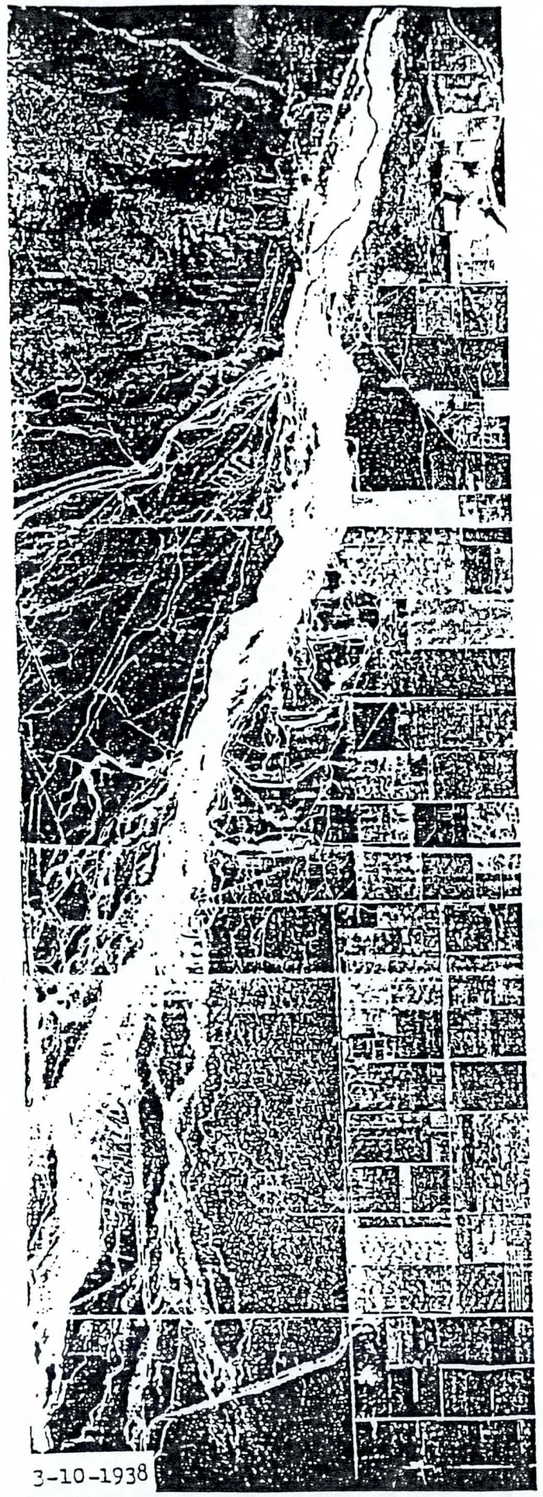
groundwater recharge. The major fan floods here are usually caused by winter storms. USGS gaging station #110730000, located about 4 miles above the mouth of the canyon, recorded a peak discharge of 21,400 cfs for the flood on March 2, 1938. USGS gaging station #11073200, located at the outlet channel of San Antonio Dam, recorded a maximum flood water release of 8,420 cfs on January 25, 1969, the largest since the initial operation of the gaging station in 1962.

The only set of aerial photographs available to identify the flood channel pattern on San Antonio alluvial fan were taken on March 10, 1938 (see Figure 12), about one week after the major flood of March 2, 1938. San Antonio Dam had not yet been built. The aerial photographs show that the flood water flowed in a single channel, restricted along the east bank by a series of percolation basins and levees for about 8,200 feet below the mouth of the canyon. Below this reach the channel bifurcated. The variation of channel width with distance measured from the mouth of the canyon is as follows:

DISTANCE IN FEET	0	1200	3400	4950	7900
WIDTH IN FEET	810	355	690	410	550

Tahquitz Creek near Palm Springs, California

Tahquitz Canyon drains an upstream watershed of 43.5 square miles in the San Jacinto Mountains with a slope of 0.111. It is well vegetated in the highlands but barely vegetated in the lowlands. The alluvial fan, with a slope of 0.046, has experienced development as part of the growth of the city of Palm Springs.



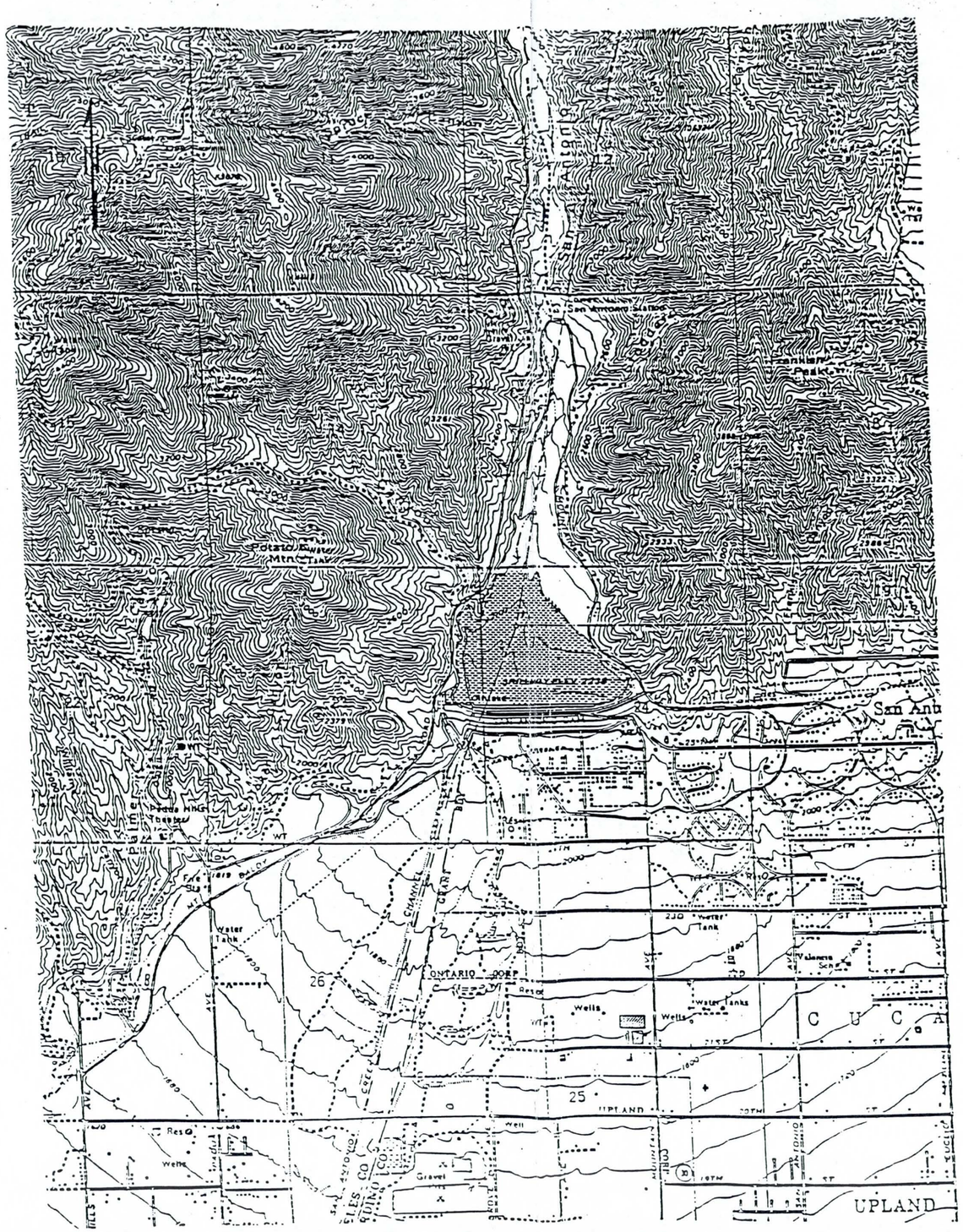


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FIGURE 12
Topographic Map and Aerial Photo
graph of the Alluvial Fan belo
San Antonio Creek near Claremor
California

Floods on the fan result from winter storms, although most of the year the creek is completely dry. A peak discharge of 2,900 cfs was recorded on November 22, 1965, and on January 25, 1969. The only set of aerial photographs available to identify the flood channel pattern was taken on April 20, 1959 (see Figure 13). A peak discharge of 1570 cfs occurred on August 31, 1954. The aerial photograph showed that the flood water flowed in a northeastern direction and bifurcated at a point about 2,000 feet above the mouth of the canyon. The south channel turned toward the east at a location about 600 feet below the mouth of the canyon to lead to a lined channel to pass Palm Springs. The north channel flowed in a northerly direction to meet the flood flow from an adjacent fan. The channel banks for both channels seemed naturally stabilized with trees. Numerous abandoned small braided channels, however, were developed between those two channels. Currently the alluvial fan has been densely developed and is protected by levees on the upfan area.

Palm Canyon near Palm Springs, California

Palm Canyon originates from the San Jacinto Mountains and flows in a northerly direction to develop Palm Canyon Wash, on which part of Palm Springs is now located. It has a slope of 0.058 and drains an upstream watershed of 93.3 square miles. The watershed is covered with sparse forests above 4000 feet in elevation and is lightly vegetated below. Below the canyon mouth, two small alluvial fans have been developed by the easterly flowing Murray and Andreas Canyons against the northerly flowing Palm Canyon flow. This forced the alluvial channel below Palm Canyon to develop along the eastern wall of the valley. The alluvial

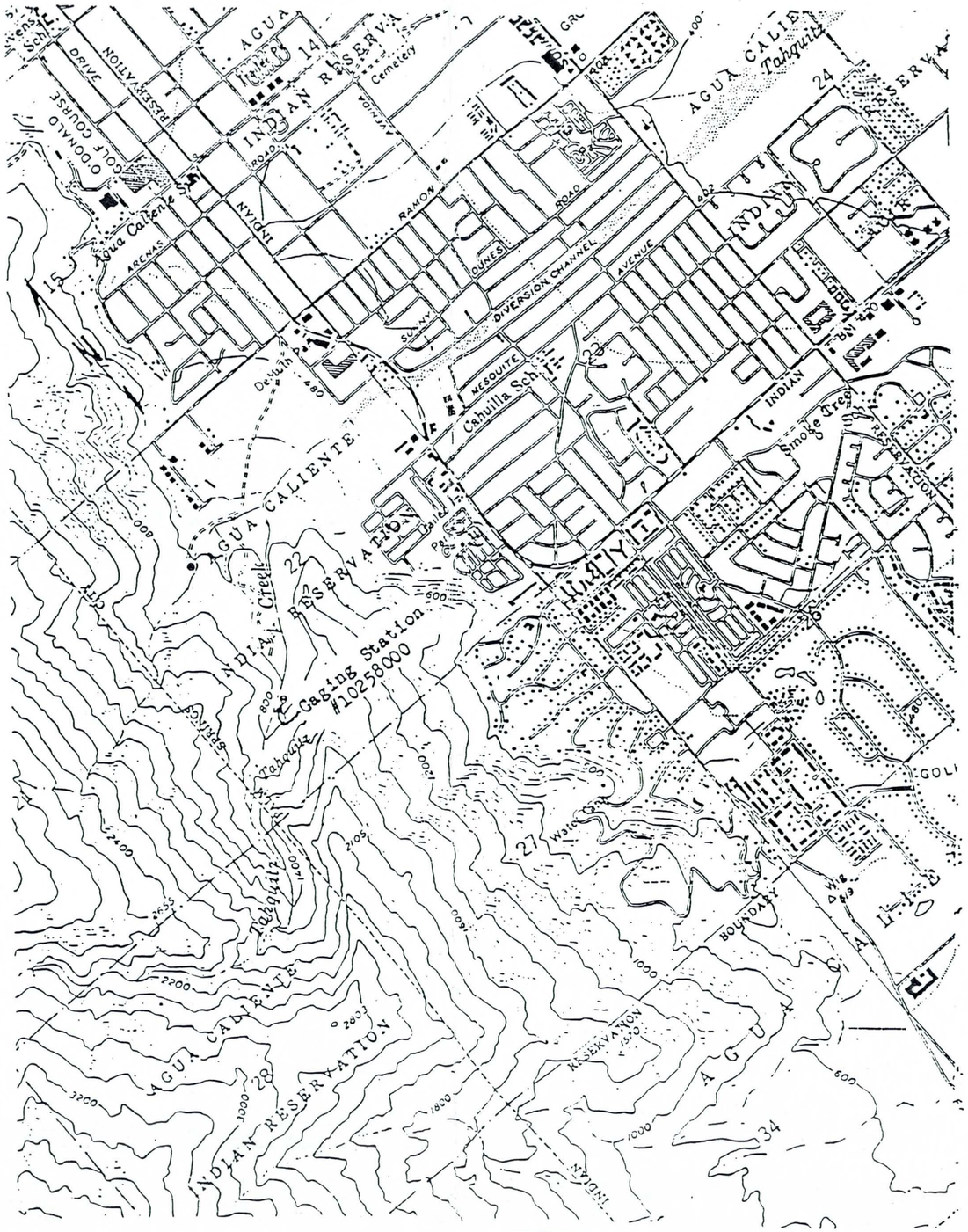


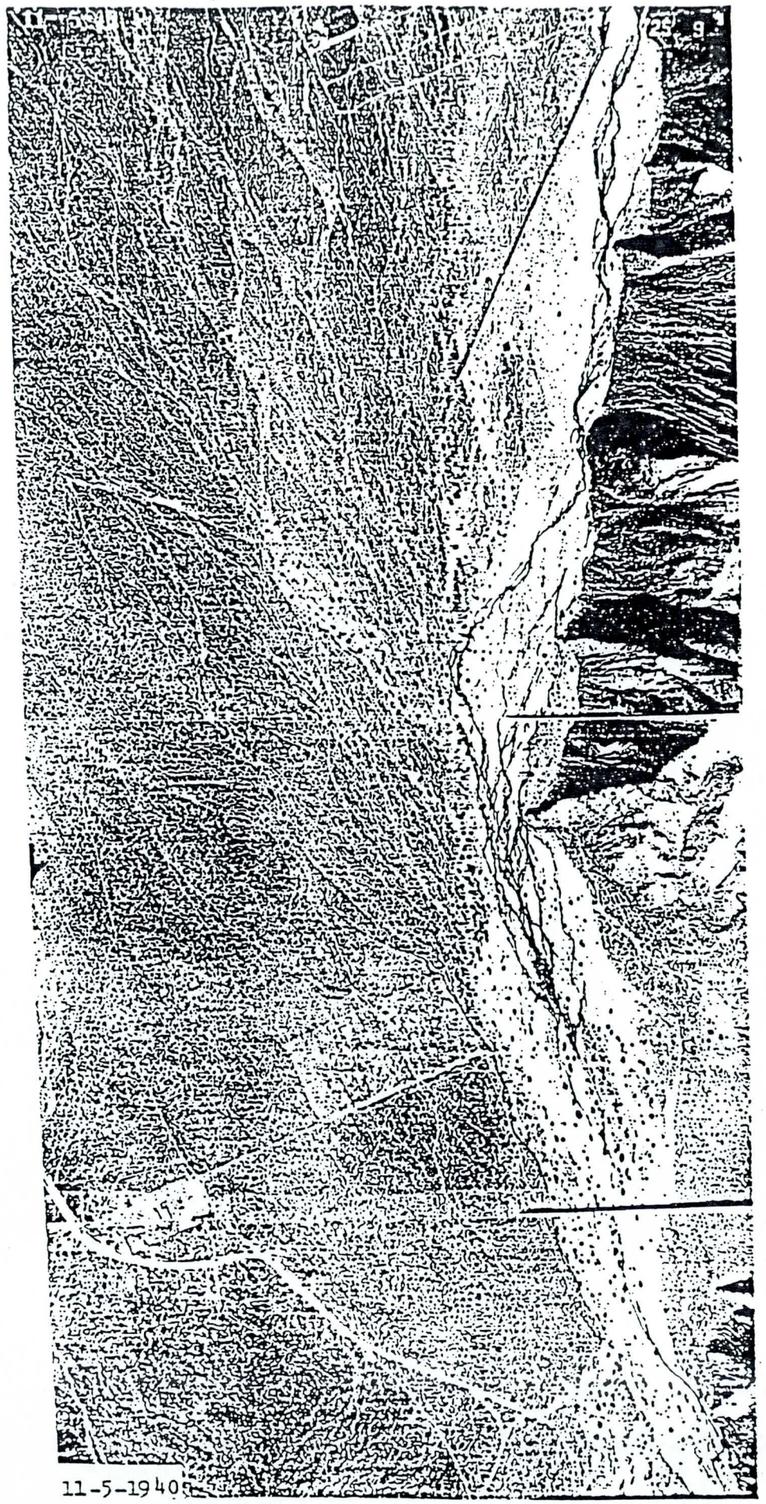
FIGURE 13
Topographic Map and Aerial Photograph of the Alluvial Fan below Tahquitz Creek near Palm Springs

fan has an expansion angle of 25 degrees and a slope of 0.055. The floods are usually caused by winter storms. USGS gaging station #10258500 has recorded peak discharges of 3,850 cfs on February 6, 1937, 2,380 cfs on March 2, 1938, and 2,900 cfs on December 24, 1941.

There is one set of aerial photographs available to correlate the flood channel patterns on the alluvial fan. This set of aerial photographs was taken on November 5, 1940 (see Figure 14), some three years after the flood on March 2, 1938. Examination of the aerial photograph indicated that the flood water flowed in a single channel 550 feet wide for about 3,825 feet below the mouth of the canyon. It then gradually widened to 3,000 feet at 1.92 miles below the mouth of the canyon. Below this point, numerous small channels branched out from the west bank of the flood channel to flow down the alluvial fan. The major portion of the floodwater, however, continued to flow in the main channel to its junction with Tahquitz Creek.

Devil Canyon near San Bernardino, California

Devil Canyon, near San Bernardino, California, has a slope of 0.085 and drains a sparsely vegetated upstream watershed of 5.61 square miles. The alluvial fan has a radius of 6,400 feet and an expansion angle of 33 degrees. The fan slope is 0.062 at the upfan area. Below the mouth of the canyon are three percolation basins, with levees to guide flood water into the basins. Downstream of those percolation basins levees are built to further divert the flood water through the opening of an elevated cross-fan ridge at the fan toe to a lined channel leading to Cajon Creek. A percolation basin is also located at the eastern side



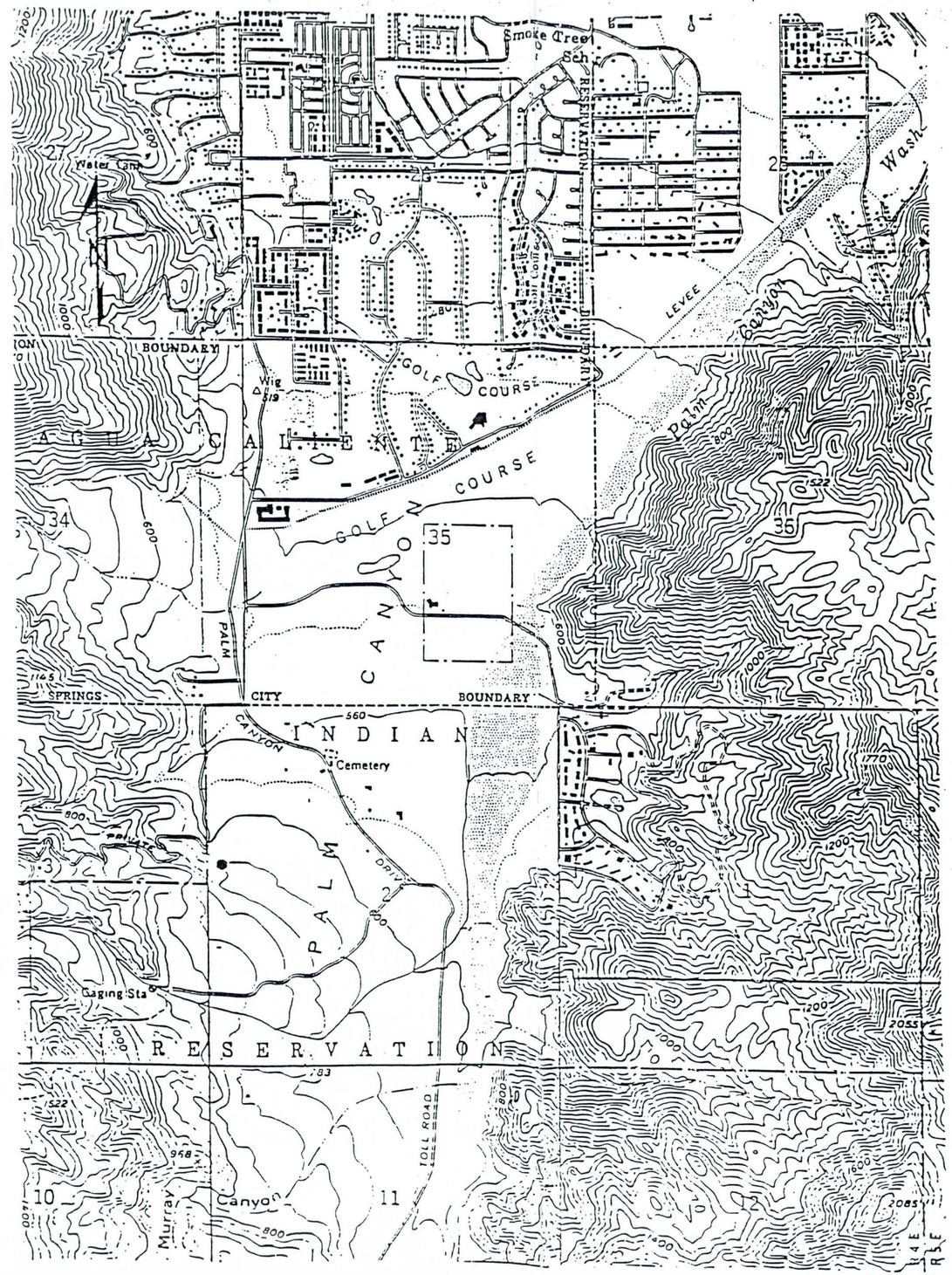


FIGURE 14
Topographic Map and Aerial Photograph of the Alluvial Fan below Palm Canyon near Palm Springs, California

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of the fan toe immediately above the cross-fan ridge.

Flooding is generally caused by winter storms. USGS gaging station #11063680, situated at the mouth of the canyon, recorded peak discharges of 3,320 cfs on March 2, 1938, 3,720 cfs on January 25, 1969, and 1,800 cfs on February 25, 1969. The flood channel pattern on the alluvial fan was identified using aerial photographs taken on February 17, 1937, and March 10, 1938 (see Figure 15), respectively, before and after the flood on March 2, 1938.

Comparison of the above two sets of aerial photographs indicated that the flood water of March 2, 1938, essentially flowed in the old channels developed by previous floods. The flood water, which entered the percolation basins, however, overtopped the downstream levees of the basins to develop a sheet flow pattern below the levees. The flood water eventually discharged into the percolation basin at the eastern side of the fan toe. Discharges of the magnitude of the 1938 peak are apparently controlled by the man-made structures.

Whitewater River near Whitewater, California

The Whitewater River flows in a north-to-south direction, discharging onto an alluvial fan just upstream of its junction with the San Gorgonio River. Near the toe of the fan, the Whitewater River collects the flow from the San Gorgonio River and then turns eastward downstream. The upstream watershed is sparsely vegetated in the highlands. The river has an average slope of 0.034 and a width of about 1500 ft. USGS gaging station #102560000, operated from 1948 to 1981, was located near Whitewater with a drainage area of 57.4 square miles. The river

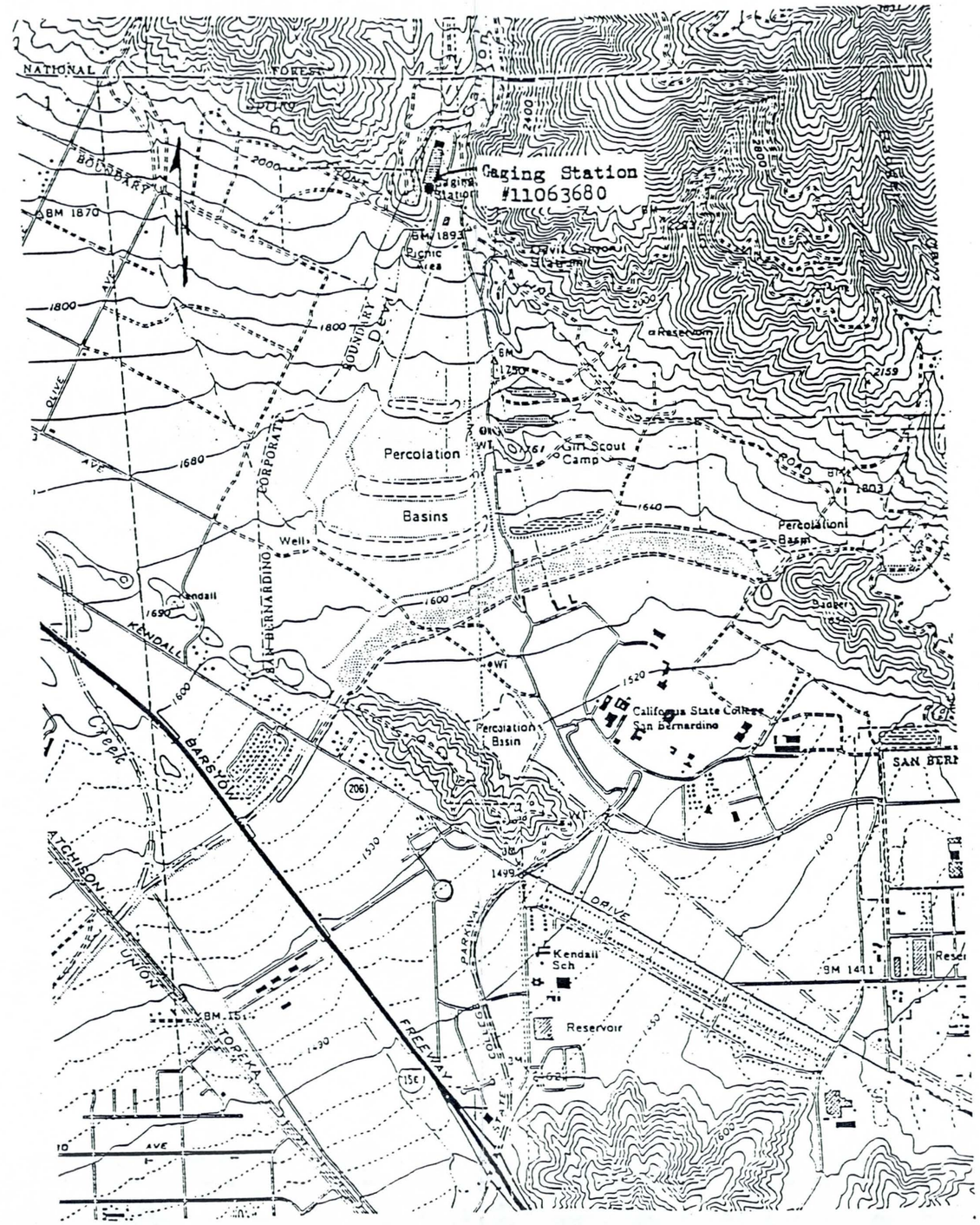

FIGURE 15
Topographic Map and Aerial Photo graph of the Alluvial Fan belo Devil Canyon near San Bernardir California

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discharges are generally derived from winter rainstorms. Peak discharges were recorded of 42,000 cfs on March 2, 1938, 24,000 cfs on November 22, 1965, 16,200 cfs on January 25, 1969, and 13,500 cfs on February 25, 1969. The alluvial fan below the river mouth has an expansion angle of 70 degrees and a radius of 1.7 miles from the apex, the fan slope is 0.030. The alluvial fan is undeveloped, however, Interstate Highway 10 crosses the fan near the apex, and State Highway 111 and the Southern Pacific Railroad cross the fan near the toe.

The flood channel patterns on the alluvial fan was identified using an aerial photograph taken on June 8, 1936 (see Figure 16). No major peaks prior to that date were available. State Highway 111 had not yet been built and Highway 66, the predecessor to Highway 10 crossed the Whitewater River, at a location slightly above the river mouth. The flow approach to the bridge was constricted by upstream dikes and the embankments of the bridge. The flow passed under the bridge in a single channel, which gradually widened to 640 feet at a location about 880 feet below the bridge. Below this point, the flow bifurcated to form one large and one small channel. The large channel again bifurcated within a distance of 800 feet to two channels of approximately the same width. Further downstream, numerous small channels branched out from those three channels to form a complex braided channel pattern before meeting the flow from the San Gorgonio River.

There is only one set of aerial photographs available for the present study, therefore, no comparison of aerial photographs of different dates were made to detect if the channel locations were random. However, judging from the shallow flood channels and the braided channel pattern it is likely that shifting of channels might occur for different floods.

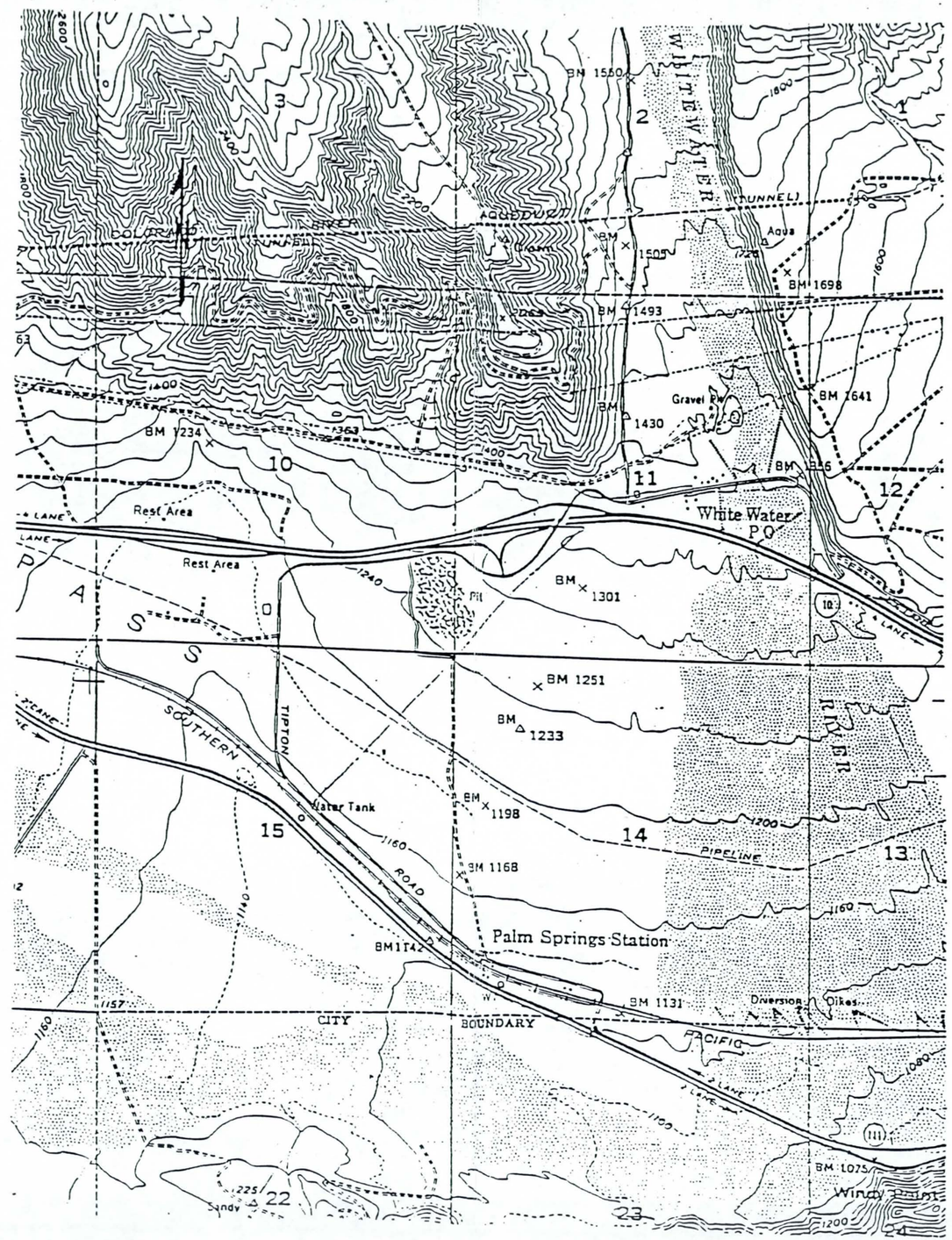

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FIGURE 16
Topographic Map and Aerial Photograph of the Alluvial Fan below Whitewater River near Whitewater, California

3.2.3 Results of Case Studies

Case studies have been conducted to cover alluvial fans in California and Nevada. The characteristics of flood channel patterns included single channels, split channels, and braided channels. The factors that may affect the fan flood including upstream watershed drainage area, canyon slope, alluvial fan slope, angle of expansion and radius of alluvial fan, were also determined using aerial photographs and USGS topographic maps. Table 2 summarizes those characteristics of alluvial fans in the present study.

The results of the present case studies can be summarized as follows:

Channel Pattern

The flood channels on alluvial fans were found to occur in three patterns, namely; single channel, split channel, and braided channel. The flood channel generally was found to be a single channel immediately below the mouth of the canyon, followed by a split channel segment, and finally terminating in a braided channel.

Channel Location

Treating the studied alluvial fans as a group, the relative location of a single channel immediately below the mouth of the canyon on an alluvial fan was found to be random as shown in Figure 17. Each data point in Figure 17 represents the relative location of a single channel on an alluvial fan, defined as the

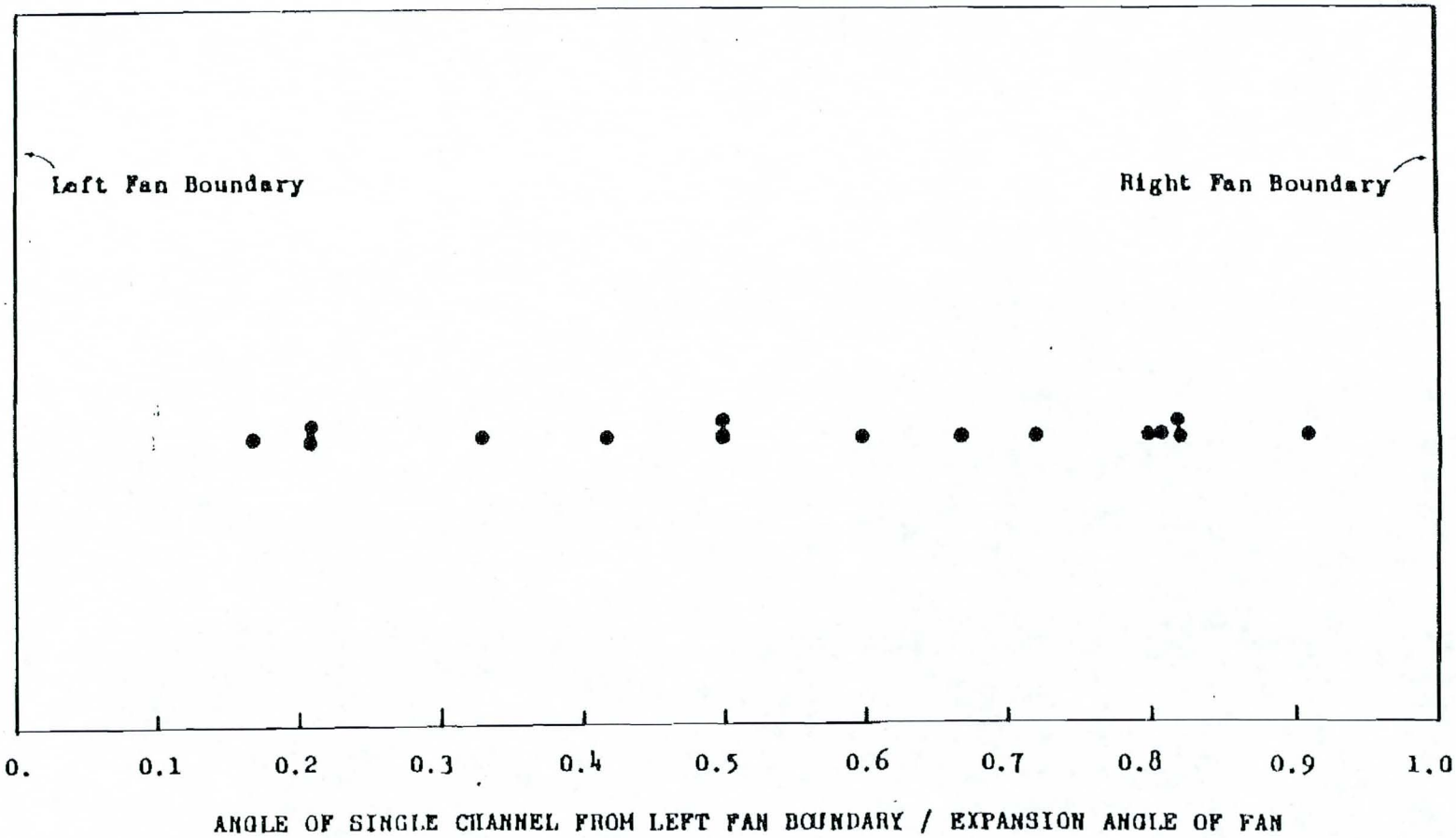

FIGURE 17
Normalized Locations of Single Channels on Alluvial Fans

ratio of the angle between a single channel and left fan boundary, when looking downstream, to the expansion angle of an alluvial fan. The relative locations of the single channels on alluvial fans are summarized in Table 2. It can be seen from Figure 17 that the data points spread rather uniformly over the entire range of relative single channel location from 0.0, which represents left fan boundary, to 1.0, which represents right fan boundary. This finding indicates that there is no preferential location for forming a single channel on an alluvial fan when compared with the relative locations of the single channels on other alluvial fans.

The present FEMA method assumes a random location for the 100-year event. Therefore, the random distribution across the fan as shown in Figure 17 is germane only if the process is ergodic, that is, if the synoptic view in space holds in the time domain at a fan. Figure 17 thus presents supportive evidence of the present method.

Although the locations of the flood channels were found to be stable for some of the alluvial fans which are subjected to urbanization and well vegetated upstream watersheds, such as those at Lytle, Day, and Deer Creeks in California, relocations of flood channels were evident for those undeveloped alluvial fans with barely vegetated upstream watersheds in Nevada. Based on the present study, the assumption of random channel location should be retained in the analysis.

Single Channel Pattern

The length of a single channel below the mouth of the canyon on an alluvial fan

TABLE 2

SUMMARY OF ALLUVIAL FAN AND FLOOD CHANNEL CHARACTERISTICS

ALLUVIAL FAN	DRAINAGE AREA SQ. MI.	CANYON SLOPE S_{cyn}	FAN SLOPE S_{fan}	EXPAN. ANGLE DEG	FAN RADIUS FT	OBSERVED SINGLE CHANNEL LENGTH FT	OBSERVED SINGLE CHANNEL WIDTH[a] FT	DIRECTION[b] OF CHANNEL DEG	S_{cyn}/S_{fan}	DATE OF PHOTO
Northumberland Cyn near Austin, NV	15.1	.032[d]	.033	60	20000	14500	390	40	1.00	6-19-81
Moses Teller Trib. near Moses, NV	2.5	.058	.035	75	3500	--[f]	--[f]	--[f]	1.66	10-7-68
Humboldt River Trib. near Rye Patch, NV	.68	.110	.071	90	7300	1060	50	45	1.55	6-23-73
Rocky Canyon near Orovada, NV	4.06	.108	.056	110	12500	--[f]	--[f]	90	1.86	6-23-73
Humboldt River Trib. near Orovada, NV	.70	.124	.070	90	13000	--[f]	--[f]	36	1.77	6-23-73
Las Vegas Wash near Boulder, NV	.06	.058[c]	.050	50	3200	3075	68	30	1.16	7-4-60
Las Vegas Wash Fan near Boulder, NV	—	.061[c]	.056	40	6500	3250	183	20	1.09	7-4-60
Plate Wand Trib. at Searchlight, NV	3.40	.016[c]	.018	--[e]	--[e]	10500	90	--[e]	1.00	10-7-68
San Antonio Rock near Tonopah, NV	3.43	.070	.053	80	17700	--[f]	--[f]	10	1.32	8-22-73
Eldorado Valley Trib. nr Nelson, NV	1.40	.036[c]	.036	30	5800	2000	--[h]	--[h]	1.00	7-24-73
Lytle Creek near Fontana, CA	46.3	.031	.026	35	49000	4400	781	20	1.18	1-10-69
Day Creek near Etiwanda, CA	11.2	.149	.103	80	41200	2400	268	65	1.45	3-10-38
Deer Creek near Guasti, CA	3.4	.168	.108	90	27500	600	275	30	1.54	3-10-38
Cucamonga Creek near Upland, CA	10.1	.075	.046	55	42200	7900[d]	358[d]	45	1.58	3-10-38
San Antonio Creek near Claremont, CA	28.2	.055	.046	90	57800	8150[d]	370[d]	65	1.20	3-10-38
Tahquitz Creek nr Palm Springs, CA	42.5	.111	.046	90	7200	--[f]	--[f]	80	2.41	4-10-53
Palm Canyon nr Palm Springs	92.3	.058[e]	.035	25	16000	3825	550	20	1.35	11-5-40
Devil Canyon nr San Bernardino, CA	5.81	.085	.062	33	6400	1500[d]	216[d]	30	1.37	3-10-38
Whitewater River nr Whitewater, CA	57.40	.034[e]	.030	70	5980	880[d]	640[d]	15	1.13	8-8-38

a. Channel width was measured within a well-defined reach.

b. Direction of the single channel was measured as the angle between the single channel and the left fan boundary, when looking downstream. For an alluvial fan without a single channel region, it was approximated with the direction of a major channel.

c. Fan slope extends into canyon upstream of mountain front.

d. The channels on the alluvial fans were affected by levees, percolation basins, dikes, etc.

e. Not a well-defined alluvial fan, which is generally characterized by a rather uniform radial slope from the apex.

f. Without a single channel region on the alluvial fan.

g. No flood channels could be identified.

h. Width of a single channel not well-defined.

was found to be correlated to the ratio of canyon slope to fan slope as shown in Figure 18. It can be seen from this figure that the length of a single channel decreases with the ratio of canyon slope to fan slope. This indicates that flood flow can sustain a longer single channel when emerging from a canyon onto a fan of a similar slope than onto a fan of a smaller slope. An empirical relationship between the single channel length and the ratio of canyon slope to fan slope is proposed in Figure 18 based on the data of the present case studies.

The width of a single channel on an alluvial fan can be reasonably predicted by the FEMA method. Figure 19 shows the relationship between the fan slope and the ratio of calculated width using the FEMA method to observed width for a single channel. The calculated single channel widths and the ratios of calculated width to observed width for alluvial fans are summarized in Table 3. It can be seen from this figure that most data points are scattered around the line of perfect agreement between the calculated and observed widths, except for the data points associated with questionably high flood discharges for Las Vegas Wash and Humboldt River tributary near Rye Patch in Nevada. Based on the flood discharges reported by the USGS, the amounts of peak discharge contributed by a unit area of upstream watershed were 10,517 cfs per square mile for the tributary of Humboldt

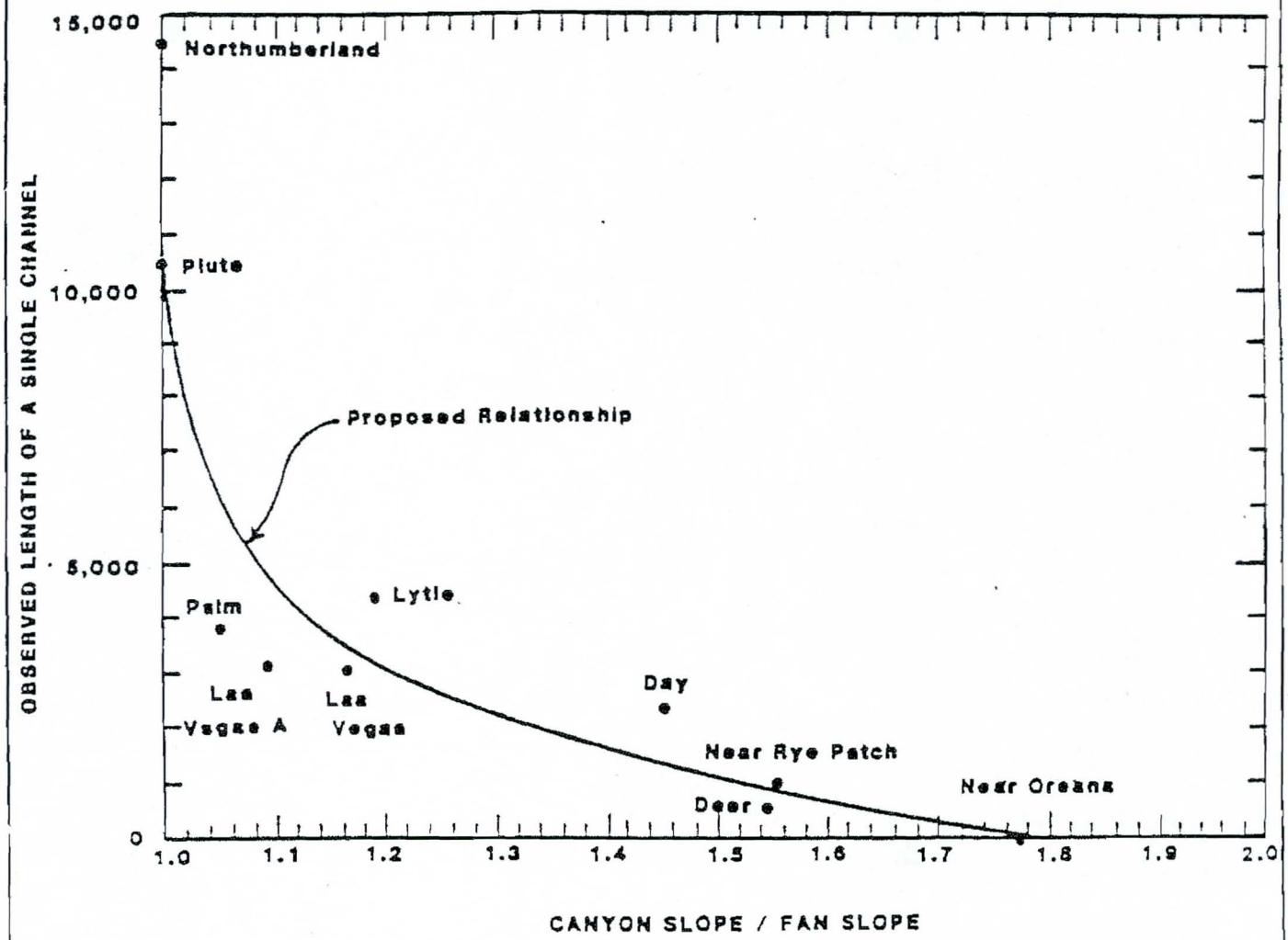

FIGURE 18
Relationship Between Observed Length of a Single Channel and the Ratio of Canyon Slope to Fan Slope

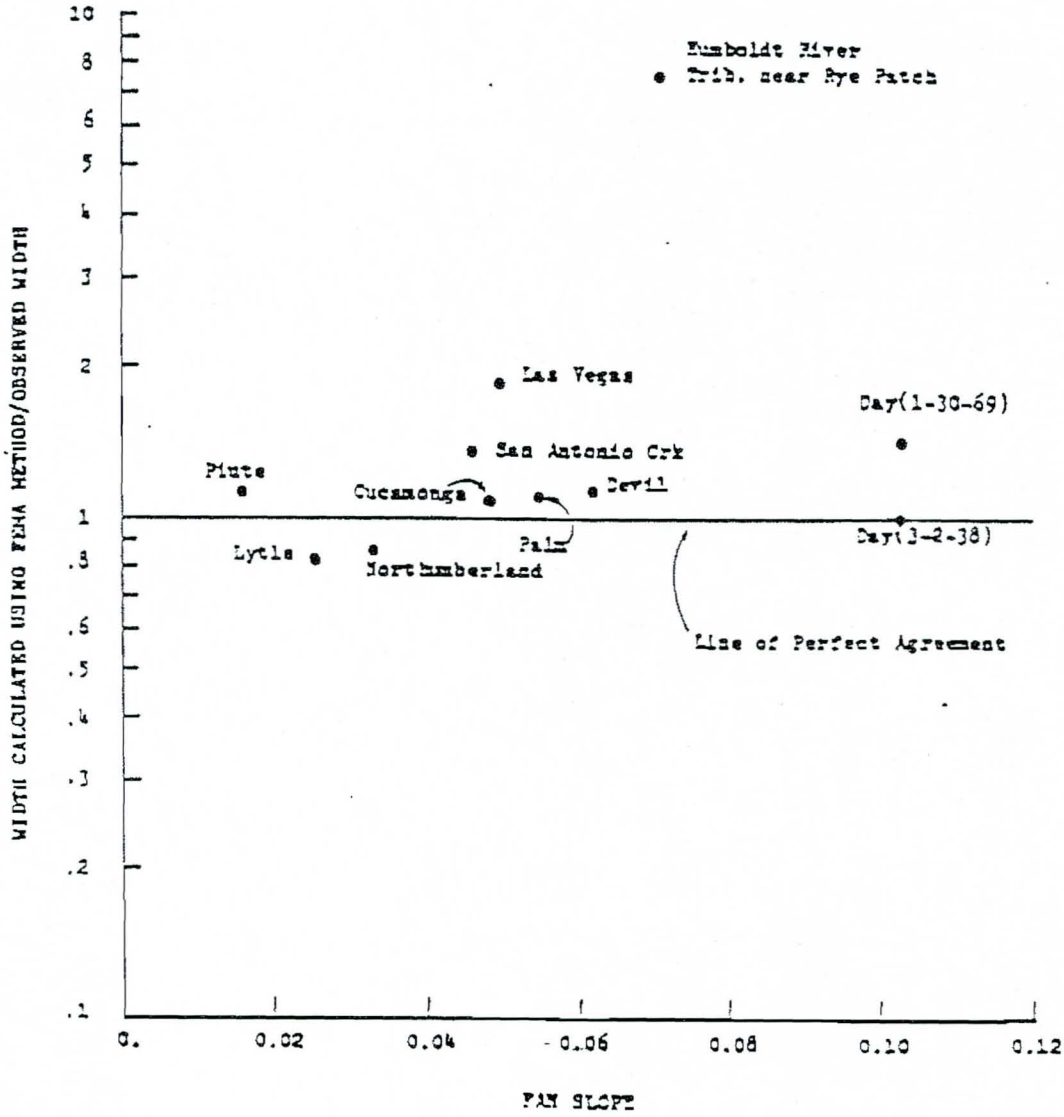

FIGURE 19
Relationship Between Fan Slope and the Ratio of Width Calculated Using the FEMA Method to Observed Width for a Single Channel

TABLE 2

SUMMARY OF THE SINGLE CHANNEL WIDTHS CALCULATED USING THE FEMA AND EDWARDS & THIELMANN'S METHODS

ALLUVIAL FAN	DRAINAGE AREA, A	CANYON SLOPE	FAN SLOPE	OBS. CHANNEL WIDTH, We	S cfs / Sfan	DISCH. Qp	DATE FLOOD	Qp / A	CAL. WIDTH (FEMA), We	We / We	CAL. WIDTH (EDWARDS & THIELMANN), FT		
	SQ. MI.	S cfs	S fan	FT		CFS			FT		n=.25	n=.30	n=.35
Tertamberland Cyn near Austin, NV	15.1	.033	.022	390	1.00	7880	8-7-73	50	346	.87	233	258	285
Humboldt River Trib. near Rye Patch, NV	.85	.110	.071	80	1.58	8940	8-31-73	10517	381	7.48	214	238	261
Las Vegas Wash near Henderson, NV	.08	.058	.058	86	1.16	686	9-30-86	10317	127	1.80	85	92	97
Pinto Wash Trib. at Searchlight, NV	3.40	.018	.018	90	1.00	270	9-11-76	108	101	1.12	88	92	97
Lytle Creek near Fontana, CA	46.3	.021	.026	781	1.19	25906	1-25-88	775	438	.83	435	468	494
Day Creek near Etiwanda, CA	11.9	.148	.102	263	1.45	9509	1-26-68	798	370	1.41	204	215	233
Day Creek near Etiwanda, CA	11.9	.149	.102	288	1.45	4206	3-2-38	353	287	1.00	150	161	171
Cucamonga Creek near Upland, CA	10.1	.076	.048	350	1.38	10306	3-2-38	1019	382	1.08	242	260	276
San Antonio Creek near Claremont, CA	28.2	.055	.048	370	1.20	21400	3-2-38	817	513	1.38	222	245	268
Palm Canyon near Palm Springs, CA	93.3	.058	.058	580	1.08	3850	2-6-27	41	258	1.09	164	175	186
Devil Canyon near San Bernardino, CA	5.81	.065	.062	218	1.37	3320	3-2-38	592	243	1.13	151	162	172

River near Rye Patch on May 31, 1973, and 10,917 cfs per square mile for Las Vegas Wash on July 30, 1968.

It is also to be noted in Figure 19 that the observed single channel width for Day Creek stayed almost unchanged for the floods with peak discharges of 4,200 cfs on March 2, 1938, and of 9,500 cfs on January 25, 1969. This indicated that the single channel width did not vary with flood discharge, perhaps, because of the relatively stable channel banks of Day Creek. In this case, if the flood of 1938 flowed at bank full, the flood in 1969 deepened the channel to increase the channel capacity in order to accommodate the flood discharge.

Split Channel Pattern

The total width of multiple channels across the fan width for a given radius from the apex in a split channel region was found to be approximately 3.8 times the channel width in a single channel region as shown in Figure 20. This finding was derived based on the detailed accounts of multiple channel widths for the alluvial fans of Rocky Canyon and Las Vegas Wash Fan A in Nevada and Day Canyon and Deer Canyon in California, which displayed well-defined multiple channels on aerial photographs used in the present case studies. The detailed accounts of the multiple channel widths for the alluvial fans shown in Figure 20 are included in Appendix A. This assumes that all split channels were flowing in a set pattern during the peak flow which formed them. On the other hand, they may have resulted in some cases from an avulsion, or an "almost avulsion", in that near the peak one of the channels formed and robbed most of the flow from the previously main channel. If the flow split evenly between two branches, the combined width would

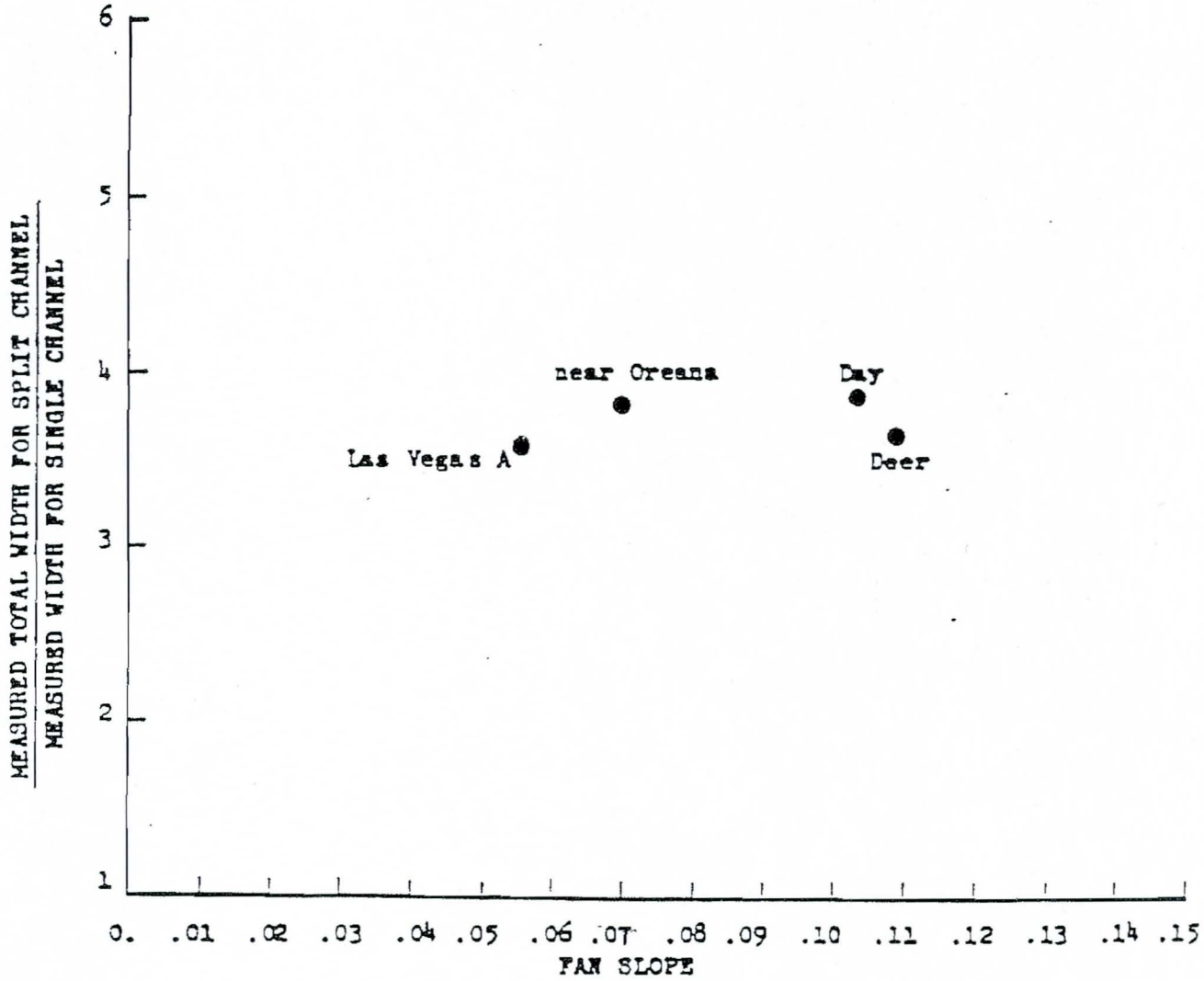

FIGURE 20
Relationship Between the Ratio of the Total Width for a Split Channel to the Width for a Single Channel and the Fan Slope

be predicted by the present method to be 1.5 times the width prior to branching, and four equal channels would have a combined width 2.3 times the single flow channel. Unequal branches would produce smaller expected combined widths.

Avulsion Coefficient

The present method assumes that a new channel is formed with every other occurrence of a 100-year flood, on the average. Some of the fan floods caused relocation of the channels as a result of the floods, and some of the floods studied were probably not 100-year floods. More flood occurrences and an analysis of their return periods are necessary before the assumption of 1.5 for an avulsion coefficient can be better defined. On the basis of the present study, no change should be made.

4.0 FAN FLOOD ANALYSIS METHODOLOGY

In this chapter, the current methods for the analysis of fan floods are discussed first. Then alluvial fans are classified according to their characteristics from the standpoint of flood analysis. Finally, the practical considerations for fan flood analysis are presented.

4.1 Current Methods For Fan Flood Analysis

There are two methods published for the calculation of alluvial fan floods, namely, the standard FEMA method and Edwards and Thielmann's modification.

4.1.1 FEMA Method

The FEMA method is based primarily on the following assumptions:

1. The fan flood is in a critical flow condition. Therefore the flow velocity can be calculated from the flow depth.
2. An alluvial channel will continue to widen by lateral erosion with a corresponding decrease in flow depth until the point is reached where a decrease in depth results in a two hundred fold increase in width.

Therefore for a given peak discharge of a fan flood, the flow depth, channel width, and the flow velocity can be calculated. To calculate the risk of a fan flood at a particular location on the fan, it is further assumed that the probability of a flood channel occurring at any location across the fan width at the same radial distance from the apex is equal. The equations for the

calculation of channel width, W, flow velocity, V, and flow depth, D, are as follows:

$$W = 9.5\ Q^{0.4}$$

$$V = 1.5\ Q^{0.2}$$

$$D = .07\ Q^{0.4}$$

4.1.2 Edwards and Thielmann's Modification

Edwards and Thielmann (1982) modified the FEMA method by assuming that the flood water would flow at normal depth as described by Manning's equation, instead of at critical depth. The modification results in the following equation for the calculation of channel width, flow depth, and flow velocity:

$$W = 17.16\ \frac{Q^2}{S}\frac{n^2}{}^{3/16}$$

$$D = 0.14\ \frac{Q\ n}{S^{1/2}}^{3/8}$$

$$V = 0.14\ \frac{Q^{1/4}\ S^{3/8}}{n^{3/4}}$$

In the above equation, n is Manning's roughness coefficient, S is the fan slope, W is the width of a single channel, D is the flow depth, and V is the flow velocity. It may be shown that under most situations, the width of a single channel calculated using Edwards and Thielmann's modification is smaller than that calculated using the FEMA method (see Figure 21 and Table 3). For the comparison shown in Figure 21 and Table 3, Manning's roughness, n, is taken as 0.020, 0.025, and 0.030 respectively. It is noted in Figure 21 that the data points for the tributary of Humboldt River near Rye Patch and Las Vegas Wash in

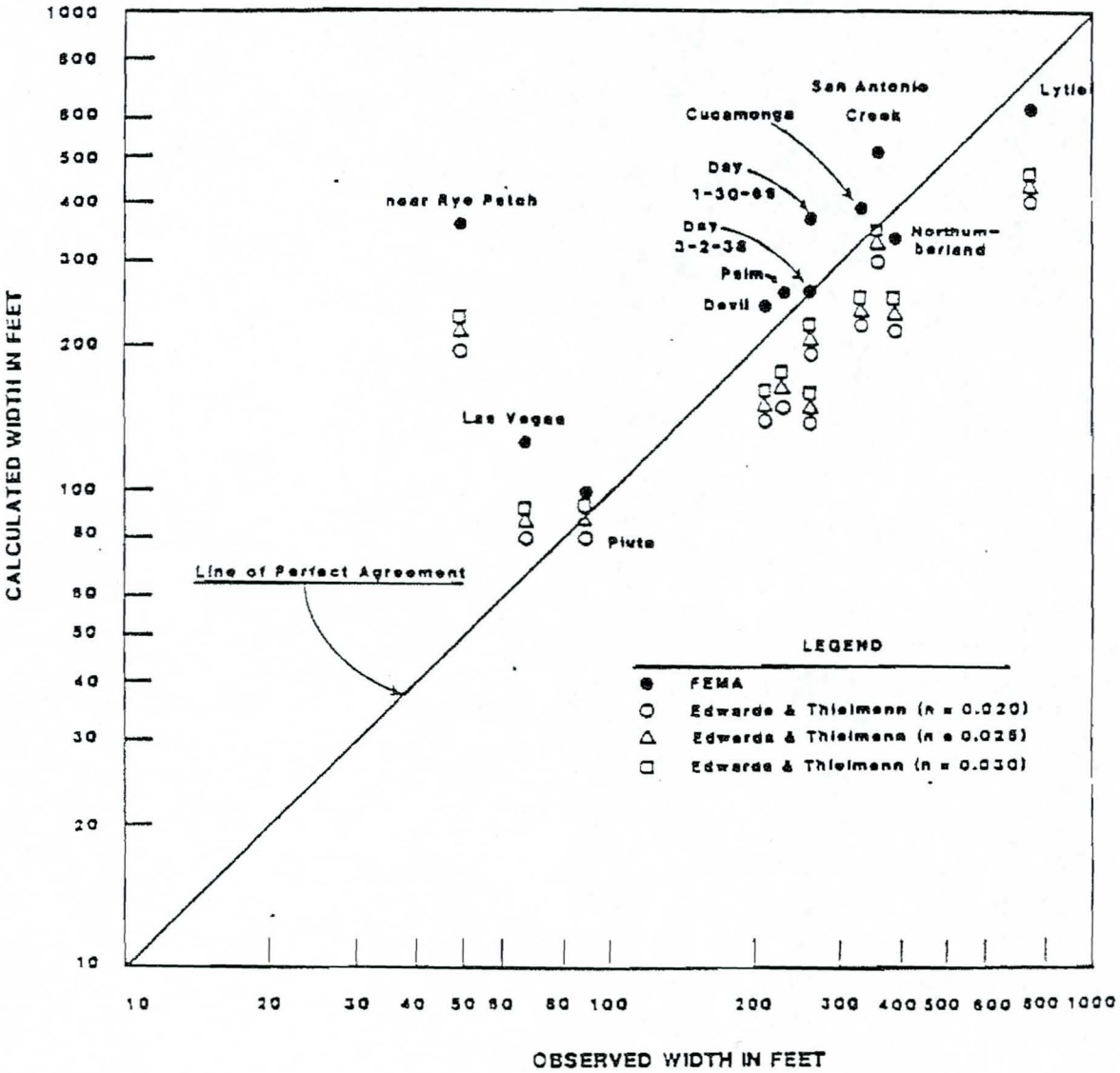

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FIGURE 21
Comparison of Observed Widths Against Calculated Widths for Single Channels Using FEMA and Edwards & Thielmann's Methods

Nevada are a considerable distance from the line of perfect agreement. The reported peak discharges were 10,517 cfs per square mile for the Humboldt River tributary near Rye Patch on May 31, 1973, and 10,917 cfs per square miles for Las Vegas Wash on July 30, 1968, as mentioned earlier these values are questionably high.

4.1.3 Discussion of the Current Methods

The major assumptions used in the FEMA method and Edwards and Thielmann's modification, are discussed as follows:

1. Assumption of single channel pattern: The results of the present case studies indicate that the flood channel remains in a single channel for a distance below the mouth of the canyon. The length of the single channel can be estimated by use of Figure 18. Below the single channel region, there is a split channel segment and then a braided channel pattern forms.

2. Assumption of random channel location: The results of the present case studies reveal evidence of channel relocations for the undeveloped alluvial fans with sparesly vegetated watersheds in Nevada, even though channel locations were found to be stable within the study period for some of the alluvial fans in California, which tend to have well-vegetated watersheds. The present study data base does not provide sufficient evidence to indicate that channel relocations will not occur during the FEMA regulatory 100-year flood.

4.2 Major Factors Affecting Alluvial Fan Floods

The major factors that shape the flood flow on alluvial fans include the alluvial fan characteristics, canyon flow characteristics, and watershed characteristics. They are briefly discussed as follows:

Alluvial fan characteristics:

1. Fan slope: The fan slope is the natural topographic feature that guides the flood flow. The distinct feature of an ideal alluvial fan is that the slopes in all radial directions from the apex are approximately the same. Therefore an initial channel direction at the fanhead may very well determine the general direction for the rest of the fan flood. In addition, the fan slope represents the relative efficiency of an alluvial fan to transport the flood water to the area below the fan.

2. Man-made structures on alluvial fans: Levees, dikes, and lined channels, when able to withstand the major floods on alluvial fans, will guide the floodwaters to follow the designated paths, unless overtopped by the floods exceeding the design capacity. Man-made structures where they exist determine the boundaries of alluvial fan flooding during the fan floods.

Canyon Flow Characteristics:

Canyon Slope: The flow conditions at the mouth of the canyon may

significantly affect the flood channel pattern at the upfan area. The canyon flow characteristics may be represented by the canyon slope. For instance, a flood flow can sustain a longer single channel when emerging from a canyon onto an alluvial fan of a similar slope than onto an alluvial fan of a much smaller slope.

Upstream Watershed Characteristics:

1. Water discharge hydrograph: A hydrograph describes the rate and time distribution of flood water delivered from the upstream watershed onto the alluvial fan. A hydrograph with a longer duration and more gradual discharge increase will allow more time for the flood to adjust the existing channels to accommodate any flood which exceeds the existing channel capacity than a hydrograph with a short duration and sharp increase in discharge. This will reduce the possibility of channel avulsion. Floods which result from frontal storms will tend to be less flashy than those which result from summer thunderstorms. In addition, a water discharge hydrograph reflects the general vegetative coverage condition of the upstream watershed. A well-vegetated upstream watershed tends to yield a hydrograph with a more smooth increase in discharge than a barely-vegetated upstream watershed.

2. Sediment discharge: Debris flow, resulting from rapid sediment deposition along flood channels, has been cited to be the major cause for channel avulsion. High sediment discharge is related to poor upstream watershed coverage. A well-vegetated upstream watershed tends to deliver less sediment onto the alluvial fan than a barely-vegetated upstream watershed.

4.3 Classification of Alluvial Fan Floods

Alluvial fans may be classified based on the major factors affecting fan flooding as discussed in the last section.

1. Urbanized vs. Unurbanized Alluvial Fans: The urbanized alluvial fans are often modified by man-made structures such as levees, dikes and lined channels to guide the flood waters; upstream water retention dams to reduce the peak water discharge; and debris basins to reduce the mud and debris entering the alluvial fan. The above structures all aim to, and, in some cases do confine the flood channels to be within designated portions of the alluvial fan. Many of the alluvial fans in California fit this category. For the unurbanized alluvial fans, the flood flows have less constraint in developing channels and therefore the flood channels may be more randomly located over the alluvial fans.

2. Alluvial fans with well-vegetated vs. barely-vegetated watersheds: The probability of debris flows from a well-vegetated watershed is generally smaller than from a barely-vegetated watershed. Thus factors to trigger the channel avulsion process are less likely to occur, and flood channels are more stable and less likely to shift location for an alluvial fan with a well-vegetated watershed than for one with a barely-vegetated watershed.

In summary, urbanization and a well-vegetated upstream watershed may be the main reasons why the flood channels on those alluvial fans located in the southern San

Gabriel Mountains area show a high degree of stability.

4.4 Practical Considerations for the Analysis of Alluvial Fan Flooding

Practical considerations in the development of a valid method for the analysis of alluvial fan floods are as follows:

Stability of Flood Channels

The channels developed by previous floods, especially deeply entrenched channels, may be used by future floods. The smaller flood tends to develop thalwegs within the existing channels while a larger flood tends to widen and deepen the existing channels, or develop additional channels to accommodate the flood waters. The stability of flood channels for some of the alluvial fans in California, which are subjected to urbanization and well-vegetated watersheds, support these findings.

Some evidence of random channel relocation exists for some of the alluvial fans in Nevada, which are not subject to urbanization and have barely-vegetated watershed. Channel relocation should result mainly from channel avulsion. It does not appear that channel avulsions associated with debris flow occur for every 100-year flood. (The present FEMA method uses an avulsion coefficient of 1.5, which implicitly assumes that half of the 100-year flood events create avulsions).

Probability of Channel Avulsion

The channel avulsion is the main factor responsible for the random nature of channel relocation for fan floods. Channel avulsion is triggered by the rapid deposition of sediment and debris along the flood channel or by rapid bank erosion. Thus, it can occur under the combination of high water and sediment discharges such as debris flow or under the condition of side scour creating or exposing a new or different path for flow. The sediment discharge is dependent on the erodibility of the upstream watershed. Therefore, one would conclude that debris flow, and consequently channel avulsion, is most likely to occur for an alluvial fan with a barely-vegetated watershed, or a watershed which has recently suffered a brush or forest fire and then is hit by a severe rain storm. However, there is insufficient evidence in the present study to better define the probability of an avulsion and its relation to causative factors.

Flood Channel Patterns

The flood channels for most of the case study alluvial fans exhibit three distinct patterns, namely, single channel, split channel, and braided channel patterns. The flood flows remain in a single channel for a distance below the mouth of the canyon. That distance may be estimated by use of Figure 18. Channel splitting, mostly by bifurcation, starts to occur along the channels at some point below the apex of the fan. Eventually, a braided channel pattern prevails at the toe of the fan. The applications of the existing methods, specifically, FEMA and Edwards and Thielmann's methods, are limited to the single channel reach. The extension of the current methods to the split and braided channel patterns is needed.

Boundaries for Alluvial Fan Floods

Man-made structures such as levees, dikes, and lined channels may restrict the flood channels to be within only portions of the alluvial fans. Therefore the boundaries of fan flood should be defined in the analysis of the FEMA 100-year regulatory flood by accounting for the effects of those man-made structures if they are considered capable to withstand the 100-year flood.

4.5 Proposed Modification of the FEMA Method

Although more studies are needed to identify the process of alluvial fan floods, modification of the present FEMA method may be made based on the present study results to improve the analysis of alluvial fan floods. The modifications are proposed as follows.

Single Channel Region

The present FEMA method should continue to be used in the single channel region of the fan, which is determined by the length of a single channel reach, and in turn is related to the canyon and fan slopes as shown in Figure 18.

Split Channel Region

The present FEMA method should be modified for the alluvial fan flood analysis in

the split channel region. An equivalent single channel with its width equal to 3.8 times the channel width in the single channel region may be substituted for the split channel region as indicated by Figure 20. This indicates that the major current is not necessarily constant, but migrates from sub-channel to sub-channel if the basic width formula still holds. Normal flow conditions may be assumed for the equivalent single channel flow. The fan slope usually decreases with the radial distance to result in a smaller fan slope in the split channel region than in the single channel region. Incorporation of the above assumptions into the present FEMA method yields the equations for channel width, W, velocity, V, and depth, D, as follows:

$$W = 36.1\ Q^{.4}$$

$$V = 0.303\ n^{-.6}\ S^{.3}\ Q^{.24}$$

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

Manning's equation was used in the derivation of the above equations. The width of the equivalent single channel may be used for the calculation of the probability of 100-year flood at any given location on an alluvial fan.

Braided Channel Region

The flooding process in braided channel regions is more complicated than that for split channel or single channel regions. More studies are needed in order to develop an accurate method for flood analysis in that region. For the present stage it is reasonable to propose that the method modified for the split channel region be extended to the braided channel region because the flooding process in

the braided channel region is more similar to the split channel region than the single channel region.

The proposed multiple-channel method (for both split-channel and braided-channel regions) of the present study was compared with the current FEMA method and two other alternatives chosen to test the robustness of the flow boundary prediction. The comparison is included in Appendix B.

5.0 STUDY FINDINGS AND RECOMMENDATIONS

In the present study, a literature review was made for alluvial fan floods. The report "Flood Plain Management Tools for Alluvial Fans," by Anderson-Nichols & Company of Palo Alto, California was reviewed in detail. Case studies were conducted to identify the geomorphic characteristics of fan floods using aerial photographs of alluvial fans in California and Nevada. Finally, the FEMA method for the determination of depth, velocity and frequency of flooding on alluvial fans was assessed using the data gathered from the present case studies. The study findings and recommendations for the present study are presented herein.

5.1 Study Findings

- The flood channels on an alluvial fan can be divided into three patterns, namely; single channel, split channel, and braided channel. The occurrence of those patterns generally follow the above order from the fan apex to the toe of the fan.

- Based on the results of the present case studies, the length of a single channel immediately below the mouth of the canyon is related to the ratio of canyon slope to fan slope as shown in Figure 18. The width of a single channel can be reasonably determined by the present FEMA method.

- In the split channel region, the total width of all channels across the fan width at a given radius from the apex is about 3.8 times the channel width in the single channel region.

- The flood channels appear to be more stable for the alluvial fans which are subject to urbanization and well-vegetated watersheds than the alluvial fans which are nearly undeveloped and originate from sparesly vegetated watersheds. However, on the basis of the present study, there is insufficient evidence to conclude that channel relocations will not occur on those apparently stable alluvial fans for future floods. The assumption of random channel location should continue to be used in the fan flood analysis.

- The present data base is insufficient to better define the value of the avulsion coefficient. Therefore the present value of the avulsion coefficient should continue to be used.

5.2 Recommendations

- The current FEMA method should continue to be used in the single channel region of alluvial fan floods. The single channel region, defined by the length of the single channel, may be determined using the relationship shown in Figure 18.

- The alluvial fan floods in split and braided channel regions may be analyzed by modifying the current FEMA method. An equivalent single channel may be used to substitute for the multiple channels in that region. The width of the equivalent single channel will be 3.8 times the channel width in the single channel region. The equations for the calculations of width, depth, and velocity for this equivalent single channel are included in Section 4.5. The width calculated in this manner may be used to evaluate the probability of 100-year flood occurring at any location on an alluvial fan.

- Avulsions and channel relocations result from debris flows. Further studies are needed to determine the frequency of debris flows on an alluvial fan, which, once determined, may be incorporated into the alluvial fan flood analysis to assess the randomness of channel relocation on an alluvial fan.

- Stability of existing flood channels should be given proper consideration in the analysis of the FEMA regulatory 100-year floods by analyzing the historical flood events using aerial photographs and conducting field inspection of flood channels. The occurrence of debris flows in a 100-year flood should be verified in a future study.

- Future study based on a broad range of alluvial fan conditions is needed in order to further develop the method for alluvial fan flood analysis.

- A proposed modification of the FEMA's FLOOD INSURANCE STUDY : "Guidelines and Specifications for Study Contractors -- Appendix 6. Alluvial Fan Studies" based on the present study is included in Appendix C.

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APPENDIX A

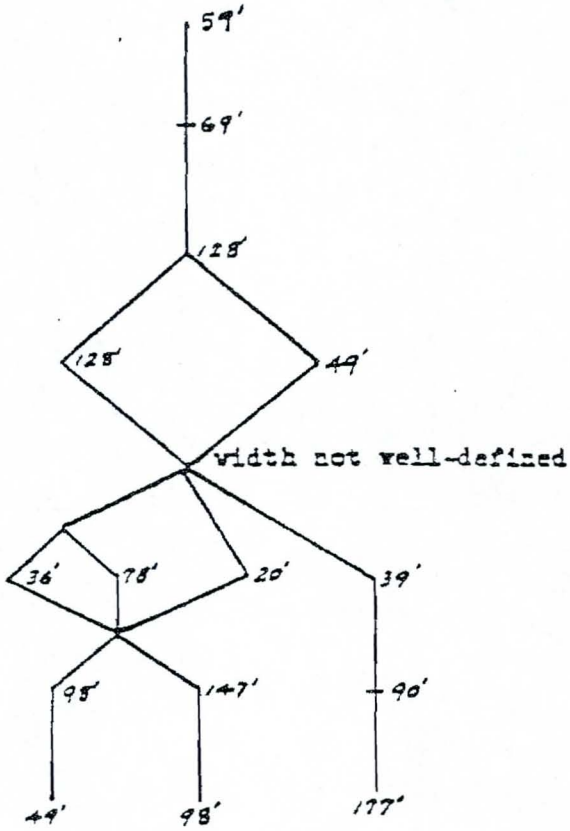
APPENDIX A

SELECTED OBSERVATIONS OF CHANNEL BRANCHING

TABLE A-1

OBSERVED CHANNEL BRANCHINGS FOR ROCKY CANYON

NEAR OREANA, NEVADA (USING AERIAL PHOTOGRAPHS OF JUNE 23, 1973)

CHANNEL BRANCHING	RADIAL DISTANCE, FT	SUM OF WIDTH, FT	SUM OF WIDTH/ SINGLE CHANNEL WIDTH
	340	59	1.00
	340	59	1.00
	570	69	
	1003	128	2.17
	1550	177	3.00
	2000		
	2500	167	2.83
	3500	335	5.68
	4250	324	5.49
		AVERAGE	3.83

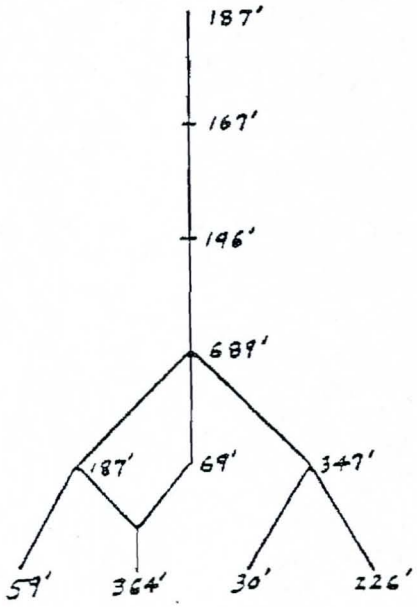
Remark: The channel bifurcated at a point above the mouth of the canyon with the north channel being wider than the south. The south channel was neglected in this analysis.

TABLE A-2

OBSERVED CHANNEL BRANCHINGS FOR LAS VEGAS WASH,

ALLUVIAL FAN A NEAR HENDERSON, NEVADA

(USING AERIAL PHOTOGRAPH OF OCTOBER 21, 1971)

CHANNEL BRANCHING	RADIAL DISTANCE, FT	SUM OF WIDTH, FT	SUM OF WIDTH/ SINGLE CHANNEL WIDTH
	1250	187	
	2000	167	
	2875	196	
	3250	689	3.77
	3625	603	3.30
	4375	679	3.71
		AVERAGE	3.59

Remark: The width of the single channel was taken as the average of the three 167 observed values, namely, (187 + 167 + 196)/3 = 183.

TABLE A-3

OBSERVED CHANNEL BRANCHINGS FOR DAY CREEK

NEAR ETIWANDA, CALIFORNIA (USING AERIAL PHOTOGRAPHS OF JANUARY 30, 1969)

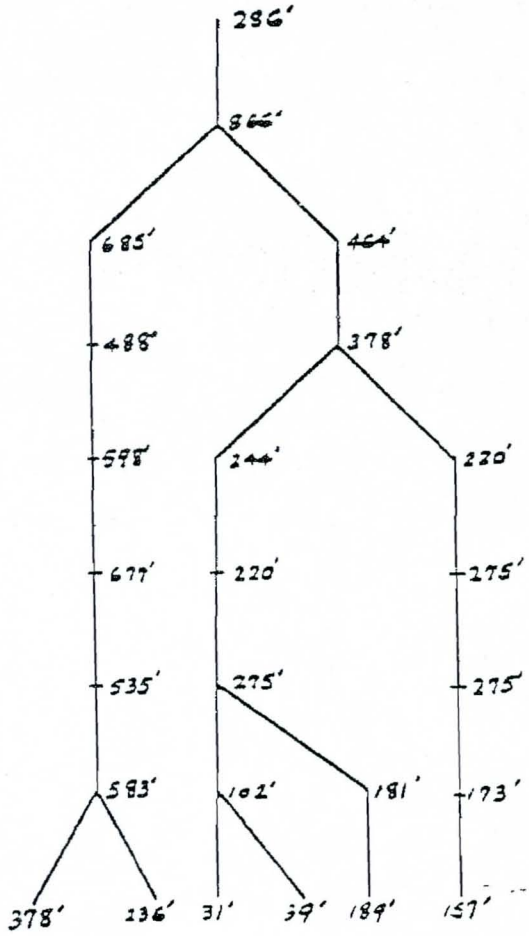
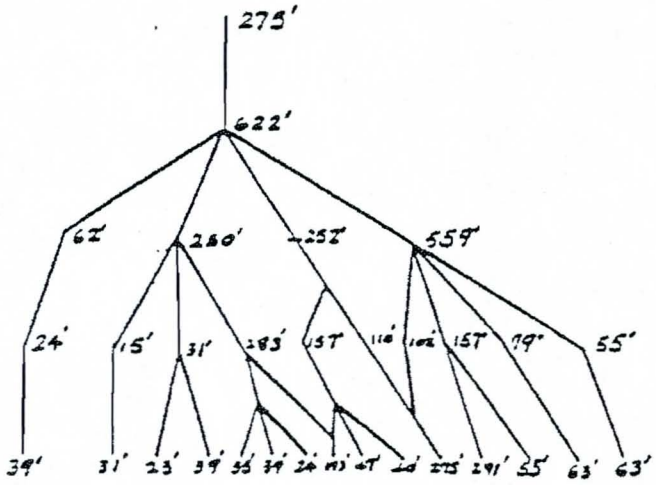
CHANNEL BRANCHING	RADIAL DISTANCE, FT	SUM OF WIDTH, FT	SUM OF WIDTH/ SINGLE CHANNEL WIDTH
	2400	286	1.00
	3660	866	3.24
	4400	1149	4.30
	4800	866	3.24
	5700	1068	4.00
	6200	1172	4.39
	6800	1085	4.06
	7200	1038	3.89
	9740	1030	3.86
		AVERAGE	3.37

TABLE A-4

OBSERVED CHANNEL BRANCHINGS FOR DEER CREEK

NEAR GUSTI, CALIFORNIA (USING AERIAL PHOTOGRAPHS OF JANUARY 30, 1969)

CHANNEL BRANCHINGS	RADIAL DISTANCE, FT	SUM OF WIDTH, FT	SUM OF WIDTH/ SINGLE CHANNEL WIDTH
	300	275	1.00
	600	622	2.26
	1600	1133	4.12
	2840	1013	3.68
	3900	1257	4.57
		AVERAGE	3.66

APPENDIX B

APPENDIX B

COMPARISON OF DIFFERENT ALLUVIAL FAN FLOOD ANALYSIS METHODS

APPENDIX B

COMPARISON OF DIFFERENT ALLUVIAL FAN FLOOD ANALYSIS METHODS

The proposed multiple-channel method of the present study was compared with the current FEMA single-channel method and two other alternatives (designated as Alternative I and Alternative II), chosen to test the robustness of the flow boundary predictions. Alternative I assumed critical flow conditions for the calculations of the flow velocity and depth in the multiple channel region. The method also assumed that the channel width for the multiple channel region is 3.8 times the channel width in the single channel region. Therefore, it is essentially the present FEMA method with a channel 3.8 times as wide. Alternative II assumed that, below the single channel region on the alluvial fan, the flood channel split into two sets of sub-channels of the same width, each being equal to 1.9 times the channel width predicted by the present FEMA single-channel method with two-thirds of the peak discharge creating the width of each set. Thus two-thirds of the peak discharge was assumed to shift alternatively between the two sub-channels during the flood. This results in a smaller flood causing a wider channel system because it migrates between channels. That smaller flood hypothetically flows in a set of channels 1.9 times the present FEMA method. The comparsion of the four alternative methods was based on the flood analysis for three hypothetical alluvial fans of different sizes, each being typical of a small, a medium, and a large alluvial fan. All three alluvial fans were assumed to have a 90 degree angle of expansion for the purpose of illustration. Log-Pearson III parameters assumed for the flood frequency distribution for the fans are shown in Table B-1.

TABLE B-1

LOG PEARSON III FLOOD FREQUENCY DISTRIBUTION PARAMETERS

ASSIGNED FOR THE HYPOTHETICAL ALLUVIAL FANS

Distribution Parameters	Fan #1	Fan #2	Fan #3
Log Mean, X	2.0	2.5	3.0
Log Standard Dev., S	0.5	0.5	0.5
Log Skewness, G	0.3	0.3	0.3
100-year Flood, cfs	1870	5920	18700

The transformed parameters for the log Pearson III distribution for the calculation of flood depth boundaries on those three alluvial fans are shown in Table B-2.

TABLE B-2

TRANSFORMED PARAMETERS FOR LOG PEARSON III DISTRIBUTION
FOR THE ALLUVIAL FANS IN THE COMPARISON

Transformed Parameters	Fan #1	Fan #2	Fan #3
$m = X-2S/G$	-1.333	-0.833	-0.333
$\alpha = 2/GS$	13.333	13.333	13.333
$\lambda = 4/G^2$	44.444	44.444	44.444
$a = \alpha - 0.92$	12.413	12.413	12.413
$C = \exp[0.92X + 0.42S^2]$	6.994	11.078	17.555
$Z = m + \lambda/a$	2.247	2.747	3.247
$S_z = \lambda^{1/2}/a$	0.537	0.537	0.537
$G_z = 2/\lambda^{1/2}$	0.300	0.300	0.300

Using the above transformed parameters for the log Pearson III distribution, the boundaries for various flood depths, in terms of radial distance from the apex to those boundaries, were calculated and compared for the proposed multiple-channel method, the FEMA single-channel method, and Alternatives I and II in Tables B-3 through B-6.

TABLE B-3

FLOOD DEPTH BOUNDARIES FOR THE HYPOTHETICAL ALLUVIAL FANS CALCULATED USING THE FEMA SINGLE-CHANNEL METHOD

FLOOD CHARACTERISTICS	Flood Depth	
	0.5 ft	1.5 ft
Flood Discharge, cfs	49.5	772.
Boundary for Fan #1, ft	5359.(1.07)	786.(1.50)
Boundary for Fan #2, ft	9879.(1.01)	3819.(1.14)****
Boundary for Fan #3, ft	15914.(1.00)*	11734.(1.00)

Note: see footnotes for Table B-6.

TABLE B-4

FLOOD DEPTH BOUNDARIES FOR THE HYPOTHETICAL ALLUVIAL FANS CALCULATED USING THEPROPOSED MULTIPLE-CHANNEL METHOD

FLOOD CHARACTERISTICS	Flood Depth	
	0.5 ft	1.5 ft
Flood Discharge, cfs	300.	1500.
Boundary for Fan #1, ft	7727.(1.02)	1196.(1.48)
Boundary for Fan #2, ft	25915.(1.00)*	7917.(1.02)****
Boundary for Fan #3, ft	46706.(1.00)*	32247.(1.00)

Note: see footnotes for Table B-6.

TABLE B-5

FLOOD DEPTH BOUNDARIES FOR THE HYPOTHETICAL ALLUVIAL FANS CALCULATED USING ALTERNATIVE I

FLOOD CHARACTERISTICS	Flood Depth	
	0.5 ft	1.5 ft
Flood Discharge, cfs	450.	7021.
Boundary for Fan #1, ft	5304.(1.07)**	96.(1.75)***
Boundary for Fan #2, ft	21015.(1.00)*	1069.(1.53)****
Boundary for Fan #3, ft	52302.(1.00)*	11271.(1.00)

Note: see footnotes for Table B-6.

TABLE B-6

FLOOD DEPTH BOUNDARIES FOR THE HYPOTHETICAL ALLUVIAL FANS CALCULATED USING ALTERNATIVE II

FLOOD CHARACTERISTICS	Flood Depth	
	0.5 ft	1.5 ft
Flood Discharge, cfs	218.	3400.
Boundary for Fan #1, ft	8480.(1.01)	298.(1.69)
Boundary for Fan #2, ft	29357.(1.00)*	4907.(1.09)
Boundary for Fan #3, ft	49613.(1.00)*	14767.(1.00)

( ) Slope ratio from Figure 18 for the calculated distance

* Multiple-channel method applicable

** 1-ft flood depth boundary at channel bifurcation point, if less than for single-channel method

*** Single-channel method applicable

**** For slope ratio less than 1.14, single channel method applies

For 1.14 < slope ratio < 1.53, single channel method applies to point of bifurcation, multiple-channel method applies downstream.

For slope ratio greater than or equal to 1.53, single-channel method applies to point of bifurcation, which defines the downstream extent of flood hazard.

For comparison, the computational results of flood depth boundaries for the above-mentioned methods are shown in Figure B-1. It can be seen from this figure that both 0.5-ft and 1.5-ft flood depth boundaries are longer for the proposed method than for the FEMA single-channel method, and the difference in the flood depth boundary between those two methods increases with the alluvial fan size. In comparison to Alternatives I and II, it can be seen from this figure that the 1.5-ft flood depth boundary for the proposed method is larger than those for Alternatives I and II. For the 0.5-ft flood depth boundary, the value for the proposed method is larger than that for Alternative I but smaller than that for Alternative II for the small and medium alluvial fans. For the large alluvial fan, the 1.5-ft flood depth boundary for the proposed method is smaller than those for Alternatives I and II.

It is also noted in Figure B-1 that the 0.5-ft flood depth boundary is almost the same for both Alternative I and the FEMA single-channel method for Fan #1. As the size of the alluvial fan increases, the flood depth boundary becomes longer for Alternative I than for the FEMA single-channel method. The 1.5-ft flood depth boundary, however, is shorter for Fan #1 for Alternative I than for the FEMA single-channel method. As the size of the fan increases, the difference in the flood depth boundary becomes smaller. The flood depth boundaries calculated using both methods are almost the same for Fan #3.

The 0.5-ft flood depth boundaries for Alternative II as shown in Figure B-1 is longer than for that for the FEMA single-channel method for all the fan sizes. The 1.5-ft flood depth boundary for Alternative II is, however, smaller than that for the FEMA single-channel method for the small fan but larger than that for the FEMA single-channel method for the large alluvial fan.

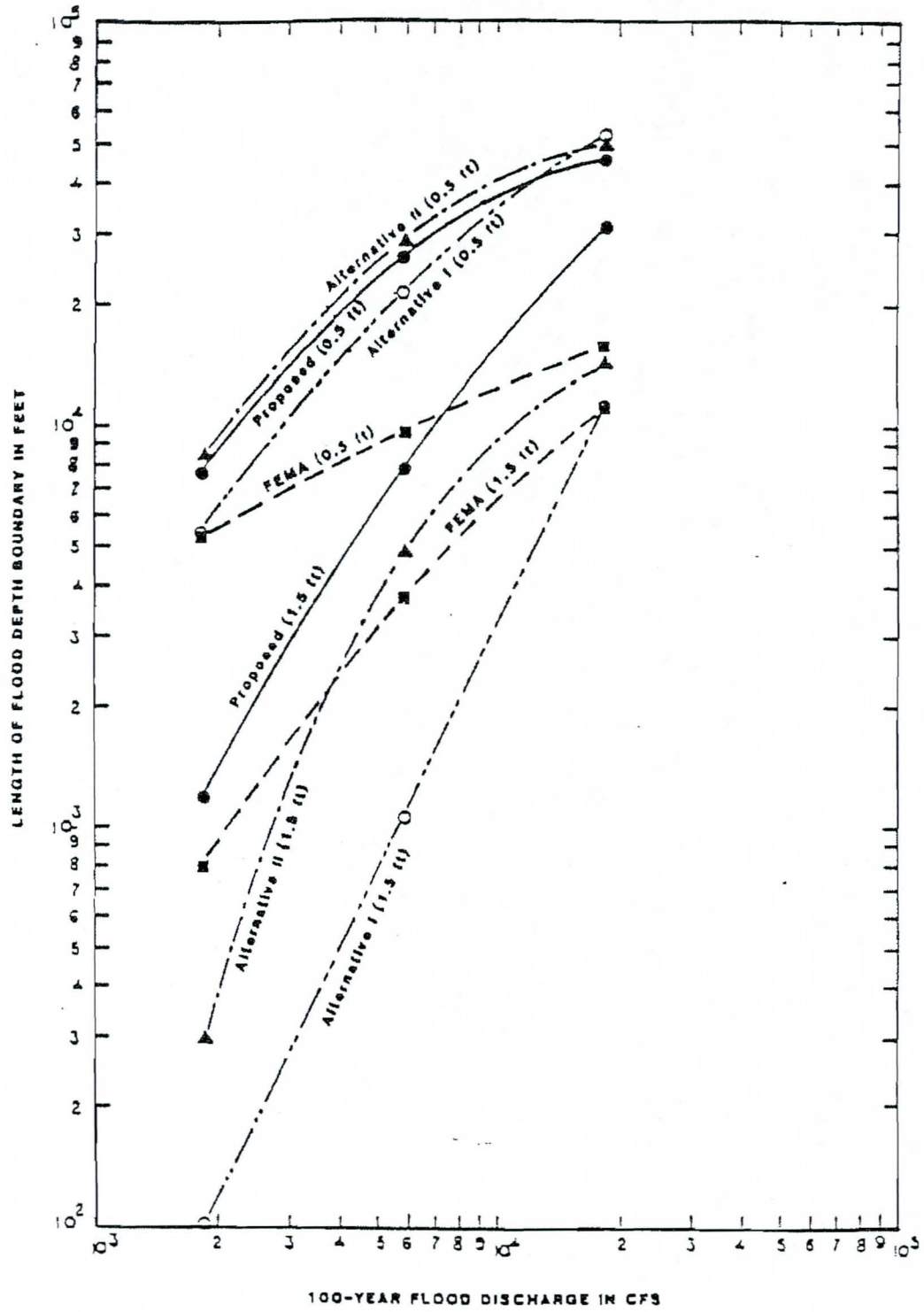


FIGURE B - 1
Comparison of Flood Depth
Boundaries Calculated Using

In summary, the shapes of the three alternative methods are quite similar for the definition of the contour for 0.5 foot depth of flooding. That is the relation which would most often be used. Flooding will extend further down the fan. The definition of the contour for 1.5 feet of flooding will be less used, because the single channel equation would apply more often at that contour than at the contour further down the fan where the 0.5 foot depth is defined. For the 1.5 feet depth contour, the proposed method predicts its occurence further down the fan than any other methods considered for comparison.

All of the comparison are based on the hypothetical fans shown in Table B-1, and all were assumed to have an expansion angle of 90 degrees. Changes in those assumptions would change the points plotted in Figure B-1, but for a given fan the points for all the methods would change in a similar manner, so that the qualitative comparison described above will not change substantially.

APPENDIX C

APPENDIX C

PROPOSED MODIFICATION OF FEMA'S "GUIDELINES AND SPECIFICATIONS FOR STUDY CONTRACTORS: APPENDIX 6. ALLUVIAL FAN STUDIES"

A6-4 COMPUTATIONAL INSTRUCTIONS

e. Determine Discharges for Depth and Velocity Zones

The discharges, depths, and velocity zones for alluvial fan flooding can be determined by a combination of two methods. They are based on a single channel region and a multiple channel region in the analysis. The single channel region is defined by the length of the single channel measured from the mouth of the canyon to the point where the flood channel splits. The length of the single channel can be determined using Figure A6.1. Below the single channel region of the fan is the multiple channel channel region. The fan width along the boundary between the single channel and multiple channel regions can be measured from the topographic map, once the length of the single channel is known.

I. Single Channel Region

Within this region, discharge, Q (in cubic feet per second), that correspond to the various depth zone boundaries should be selected using the table below. This table was derived from the relationship

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

where D is the total depth in feet due to pressure head and velocity head.

Q	49.5	772	2770	6420	12000
D	0.5	1.5	2.5	3.5	4.5

Depth zones are designated from zone boundaries as follows:

Depth of Zone	Depth of Lower Boundary	Depth of Upper Boundary
1	0.5	1.5
2	1.5	2.5
3	2.5	3.5
4	3.5	4.5

Discharges, Q (in cubic feet per second), that correspond to the various velocity zone boundaries should be selected using the table below. This table was derived from the relationship

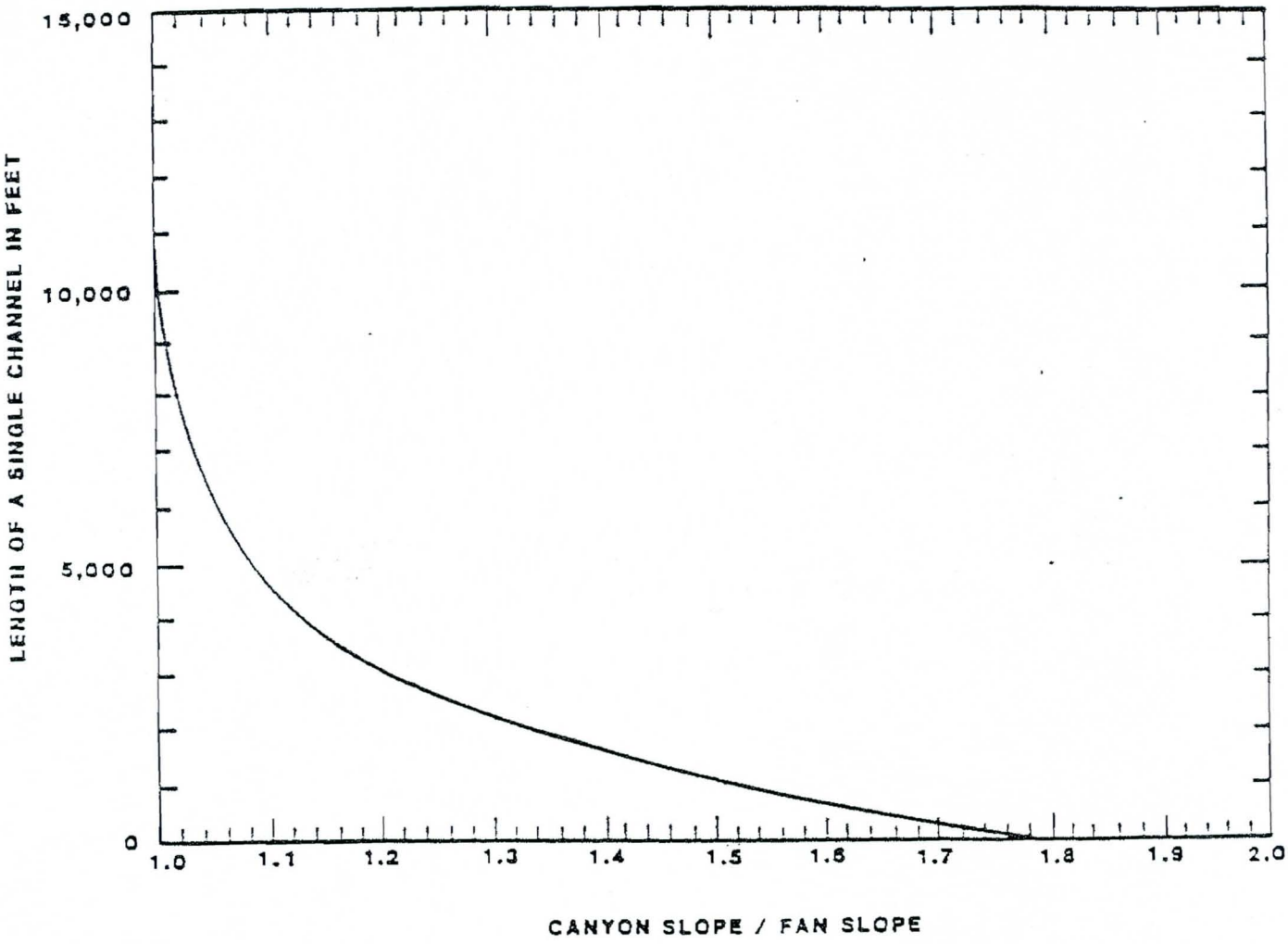
$$Q = 0.13\ V^{5}$$

where V is velocity in feet per second.

FIGURE A6-1

RELATIONSHIP BETWEEN LENGTH OF A SINGLE CHANNEL

AND RATIO OF CANYON SLOPE TO FAN SLOPE



Q	68	240	654	1510	3080	5770
V	3.5	4.5	5.5	6.5	7.5	8.5

Velocity zones are designated from zone boundaries as follows:

Zone Velocity	Velocity of Lower Boundary	Velocity of Upper Boundary
4.0	3.5	4.5
5.0	4.5	5.5
6.0	5.5	6.5
7.0	6.5	7.5
8.0	7.5	8.5

II. Multiple Channel Region

Within the multiple channel region, discharges, Q (in cubic feet per second), that correspond to the various depth zone boundaries may be calculated by iteratively solving the following equation:

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

where D is the total depth in feet due to pressure head and velocity head, S is the fan slope, and n is Manning's roughness coefficient for the alluvial fan flood channel.

Discharges, Q (in cubic feet per second), that correspond to the various velocity zone boundaries should be calculated using the equation.

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

where V is velocity in feet per second and S is the fan slope.

Depth zones and velocity zones are designated from zone boundaries in the same manner as shown in the analysis for the single channel region.

h. Compute Fan Widths for Zone Boundaries

The fan widths (i.e., arc lengths from one lateral limit of the fan to the other taken parallel to contours) that correspond to each upper and lower zone boundary depth and velocity listed in Section A6-4e should be computed both for the single channel region and the multiple channel region. The following formulas should be used.

I. Single Channel Region

Fan Width = 950 ACP

II. Multiple Channel Region

Fan Width = 3610 ACP

In the above two formulas, A is the avulsion coefficient, C is the transformation constant, and P is the probability of the discharge that corresponds to each given depth and velocity.

An avulsion coefficient (factor) greater than 1 should be selected by the Study Contractor in consultation with the Project Officer. A factor of 1.5 is recommended in the absence of other data.

In summary, the steps for the determination of the flood velocity and depth boundaries are listed as follows:

1. Compute all flood depth and velocity zone boundaries by the standard single channel method.

2. Determine point of bifurcation into multiple channel region through use of Figure A6.1 and the calculation of near fanhead canyon slope to fan slope ratio.

3. If the point of bifurcation is downfan from the lower boundary of the one-foot depth zone as computed by the standard single channel method, the standard single channel method will be used for the determination of all flood boundaries on the fan.

4. If the point of bifurcation is upfan from upper the boundary of the one-foot depth zone as computed by the standard single channel method, the one-foot depth zone boundaries will be changed to that computed for the multiple channel case.

5. If the point of bifurcation is upfan from the one-foot depth zone boundaries as computed by the standard single channel method, compute the depth and velocity at the point of bifurcation by the standard single channel method. Compute the velocity and depth boundaries for velocities and depth less than those determined for the point of bifurcation by use of the multiple channel method. Substitute those boundaries for the boundaries computed by the standard single channel method.

A6-7 SAMPLE STUDY

c. Determination of Discharges for Depth and Velocity Zones

The discharges that correspond to the various depth and velocity zone boundaries were selected from the tables for the single channel region and calculated by use of the equations for the multiple channel region shown in Section A6-4e of this Appendix. For Number One Canyon, with the fan slope of 0.03 and Manning's n of 0.02, these discharges are as follows:

I. Single Channel Region

Depth	Discharge
0.5	49.5
1.5	772.0
2.5	2770.0

Velocity	Discharge
3.5	68
4.5	240
5.5	654
6.5	1510

II. Multiple Channel Region

Depth	Discharge
0.5	310
1.5	3835

Velocity	Discharge
3.5	122
4.5	348
5.5	803
6.5	1611

d. Determine Probabilities of Transformed Discharges and Fan Widths at Zone Boundaries

The log-Pearson Type III standard deviates (K) were computed for the discharges (Q) that correspond to each depth zone boundary and each velocity zone boundary, using the equation

$$K = \frac{\log Q - \bar{Z}}{S_z}$$

The probability of occurrence (P) of the discharges for the required depth and velocity boundaries were determined by interpolation of the deviate values (K) listed in Appendix 3 of Bulletin 17B.

Fan arc widths (W) were computed for each special flood hazard zone boundary using the equation

$$W = 950\ ACP$$

for the single channel region and the equation

$$W = 3610\ ACP$$

for the multiple channel region.

An avulsion coefficient (A) of 1.5 was assumed for each case.

Computations for Number One Canyon were made as follows:

Based on the fan slope of 0.03 and near fanhead canyon slope of 0.036, the ratio of canyon slope to fan slope is calculated as 1.2. The single channel length of 3200 feet was determined from Figure A6.1 using the calculated ratio of canyon slope to fan slope of 1.2. The fan width along the boundary dividing the single channel region and multiple channel region was determined as 1680 feet from the topographic map based on the calculated value of the single channel length.

I. Single Channel Region

For the 0.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 49.5 - 2.29}{0.4965} = \frac{1.695 - 2.29}{0.4965} = -1.199$$

$$P\{Q>49.5\} = P\{K> -1.199\} = 0.881$$

$$W = 950\ ACP = 950 \times 1.5 \times 7.4 \times 0.881 = 9290 \text{ feet}$$

For the 1.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 772 - 2.29}{0.4965} = \frac{2.888 - 2.29}{0.4965} = 1.204$$

$$P\{Q>772\} = P\{K> 1.204\} = 0.118$$

$$W = 950\ ACP = 950 \times 1.5 \times 7.4 \times 0.118 = 1240 \text{ feet}$$

For the 2.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 2770 - 2.29}{0.4965} = \frac{3.44 - 2.29}{0.4965} = 2.316$$

$P \{ Q > 2770 \} = P \{ K > 2.316 \} = 0.0104$

$W = 950 \text{ ACP} = 950 \times 1.5 \times 7.4 \times 0.0104 = 110$ feet

For the 3.5-feet per second (fps) velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 68 - 2.29}{0.4965} = \frac{1.83 - 2.29}{0.4965} = -0.926$$

$P \{ Q > 68 \} = P \{ K > -0.926 \} = 0.819$

$W = 950 \text{ ACP} = 950 \times 1.5 \times 7.4 \times 0.819 = 8640$ feet

For the 4.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 240 - 2.29}{0.4965} = \frac{2.38 - 2.29}{0.4965} = 0.181$$

$P \{ Q > 240 \} = P \{ K > 0.181 \} = 0.428$

$W = 950 \text{ ACP} = 950 \times 1.5 \times 7.4 \times 0.428 = 4510$ feet

For the 5.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 654 - 2.29}{0.4965} = \frac{2.816 - 2.29}{0.4965} = 1.059$$

$P \{ Q > 654 \} = P \{ K > 1.059 \} = 0.15$

$W = 950 \text{ ACP} = 950 \times 1.5 \times 7.4 \times 0.15 = 1580$ feet

For the 6.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 1510 - 2.29}{0.4965} = \frac{3.18 - 2.29}{0.4965} = 1.793$$

$P \{ Q > 1510 \} = P \{ K > 1.793 \} = 0.037$

$W = 950 \text{ ACP} = 950 \times 1.5 \times 7.4 \times 0.037 = 390$

II. Multiple Channel Region

For the 0.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 310 - 2.29}{0.4965} = 0.4055$$

$$P\{Q > 310\} = P\{K > 0.4055\} = 0.3438$$

$$W = 3610 \text{ ACP} = 3610 \times 1.5 \times 7.4 \times 0.3438 = 13780 \text{ feet}$$

For the 1.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 3835 - 2.29}{0.4965} = 2.6058$$

$$P\{Q > 3835\} = P\{K > 2.6058\} = 0.0047$$

$$W = 3610 \text{ ACP} = 3610 \times 1.5 \times 7.4 \times 0.0047 = 190 \text{ feet}$$

For the 3.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 122 - 2.29}{0.4965} = -0.4102$$

$$P\{Q > 122\} = P\{K > -0.4102\} = 0.6578$$

$$W = 3610 \text{ ACP} = 3610 \times 1.5 \times 7.4 \times 0.6578 = 26360 \text{ feet}$$

For the 4.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 348 - 2.29}{0.4965} = 0.5067$$

$$P\{Q > 348\} = P\{K > 0.5067\} = 0.3065$$

$$W = 3610 \text{ ACP} = 3610 \times 1.5 \times 7.4 \times 0.3065 = 12280 \text{ feet}$$

For the 5.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 803 - 2.29}{0.4965} = 1.2381$$

$$P\{Q > 803\} = P\{K > 1.2381\} = 0.1099$$

$$W = 3610\ ACP = 3610 \times 1.5 \times 7.4 \times 0.1099 = 4400 \text{ feet}$$

For the 6.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_z} = \frac{\text{Log } 1611 - 2.29}{0.4965} = 1.8471$$

$$P\{Q > 1611\} = P\{K > 1.8471\} = 0.0331$$

$$W = 3610\ ACP = 3610 \times 1.5 \times 7.4 \times 0.0331 = 1330 \text{ feet}$$

III. Fow Velocity and Depth at Bifurcation Point

The fan width at the bifurcation point is 1680 feet. The probability of occurrence (P) of the discharge for the velocity and depth at the bifurcation point can be calculated using the equations for the standard single channel method as follows:

$$P = \frac{W}{950\ A\ C} = \frac{1680}{950 \times 1.5 \times 7.4} = 0.1593$$

The standard deviate, K, is then determined to be 1.0207 by interpolation of probabilities and standard deviates, with skewness G equal to zero, listed in Appendix 3 of Bulletin 17B. The corresponding discharge, velocity, and depth may be calculated using the following formulas,

$$\text{Log } Q = \bar{Z} + K\ S_z = 2.29 + 1.0207 \times 0.4965 = 2.797$$

Thus $Q = 626$ cfs

$$V = 1.5\ Q^{0.2} = 1.5 \times (626)^{0.2} = 5.4 \text{ fps}$$

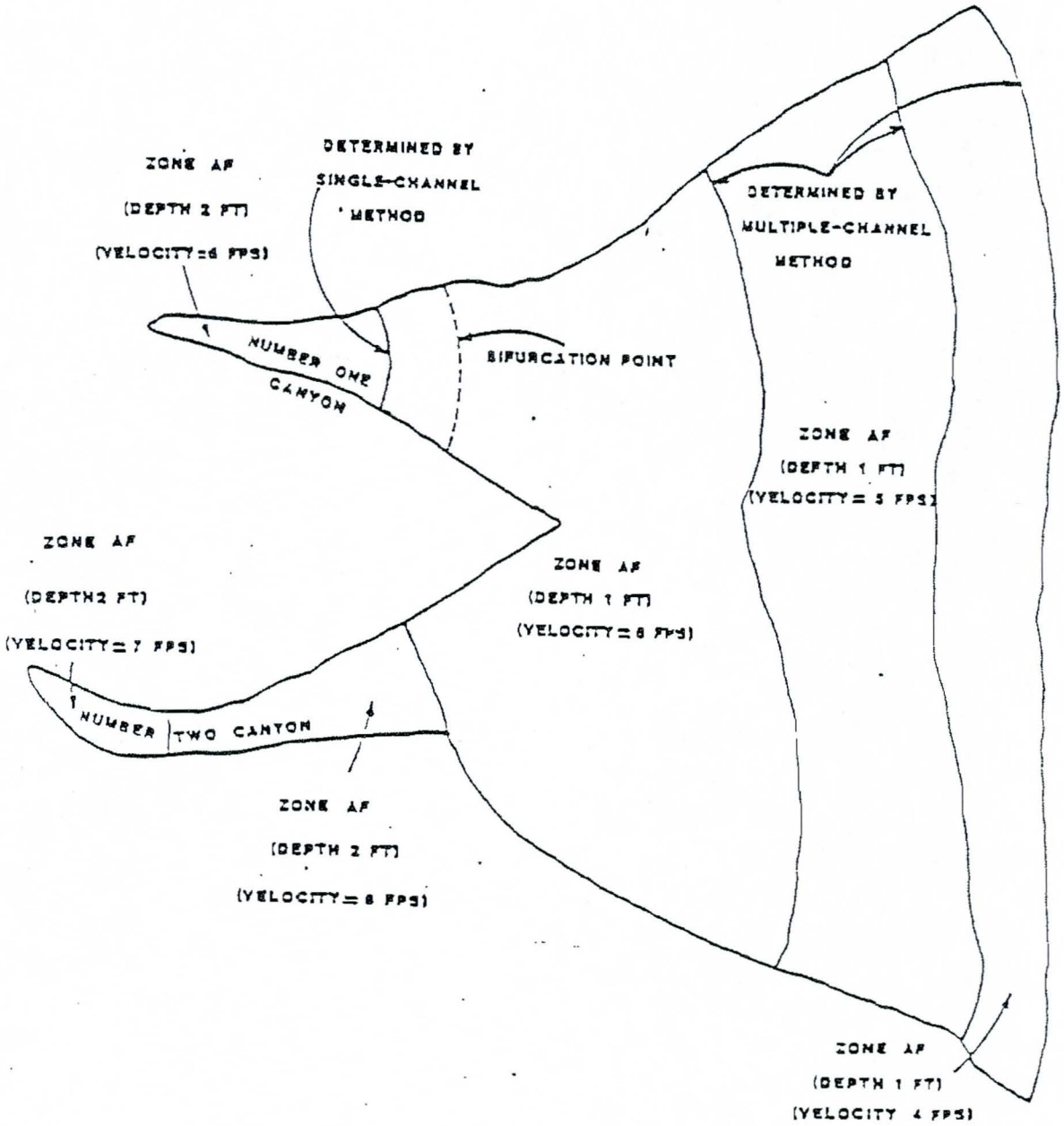
$$D = 0.10\ Q^{0.4} = 0.10 \times (626)^{0.4} = 1.3 \text{ feet}$$

So, the 0.5 foot depth contour and the 5.5, 4.5 and 3.5 ft/sec velocity boundaries are determined by the multiple-channel method. All other boundaries are determined by the single-channel method. Fan widths were computed independently for the fan originating from Number Two Canyon. The computed widths were then fit to the proper contours on the fans to produce the flood hazard zone boundaries as shown on the map (see Figure A6.2).

FIGURE A 6-2

DISTRIBUTION OF SPECIAL FLOOD HAZARDS ZONES

SAMPLE STUDY

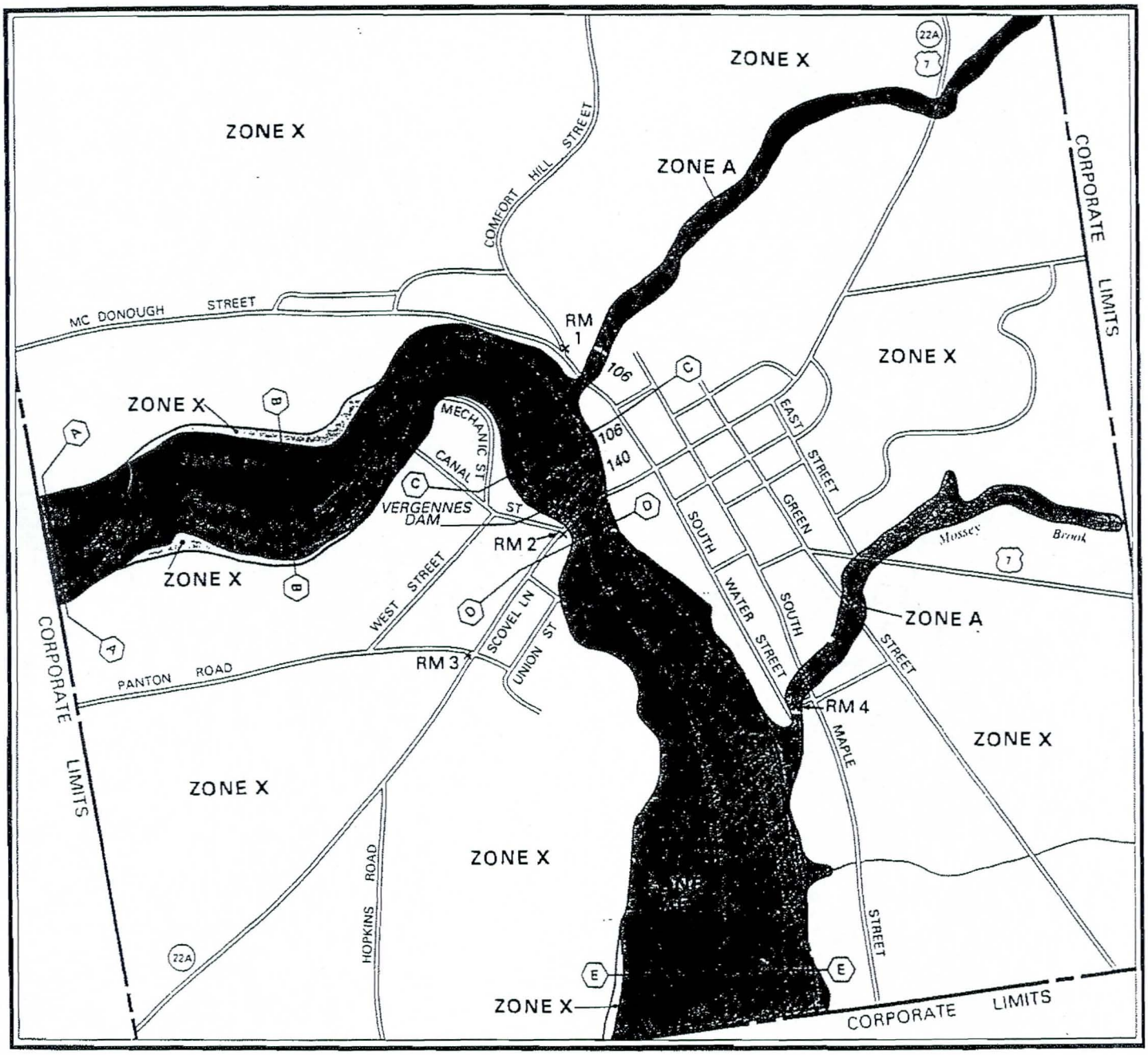


APPENDIX I.-- FEMA 37 sections on alluvial fans

FLOOD INSURANCE STUDY

FEMA 37

Guidelines and Specifications for Study Contractors



FEDERAL EMERGENCY MANAGEMENT AGENCY

Federal Insurance Administration

MARCH 1993

APPENDIX 5. STUDIES OF ALLUVIAL FAN FLOODING

A5-1 INTRODUCTION

"Alluvial fan flooding" means flooding occurring on the surface of an alluvial fan or similar landform, which originates at the apex and is characterized by high-velocity flows; active processes of erosion, sediment transport, and deposition; and unpredictable flow paths. For the purposes of the NFIP, "apex" means a point on an alluvial fan or similar landform below which the flowpath of the major stream that formed the fan becomes unpredictable and alluvial fan flooding can occur. The degree to which the processes that characterize alluvial fan flooding are present can vary greatly. For example, the fact that active deposition has not recently occurred on some portion of the fan surface does not necessarily preclude the use of FEMA's methodology for determining hazards from alluvial fan flooding.

The methodology follows directly from the definition of the 100-year flood as the flood having a 1-percent chance of being exceeded (at the point at which the definition is being applied) in any given year. Because the path of an alluvial fan flood is unpredictable, the probability of the point in question being inundated by a flood, given that that flood is realized at the apex, contributes to the definition of the 100-year flood. Therefore, if H denotes the event of the point in question being flooded, then, by definition, the 100-year flood discharge at that point is the q_{100} given by

$$.01 = \int_{q_{100}}^{\infty} P(H|Q=q)\, f_Q(q)\, dq \qquad (1)$$

where $P(H|Q=q)$ is the probability of the point being flooded, given that a flood with a magnitude of q cubic feet per second (cfs) is realized at the apex; and $f_Q(q)$ is the probability density function (pdf) of the discharge Q occurring at the apex. Replacing Q with D or V and q with d or v in equation (1) to denote depth or velocity yields the definition of the 100-year flood depth or flood velocity, respectively. Note that when the flood path is predictable, then $P(H|Q=q) = 1$ and the 100-year flood discharge, q_{100}, is determined by the definition familiar to those who model riverine flooding:

$$.01 = \int_{q_{100}}^{\infty} f_Q(q)\, dq \qquad (2)$$

If the flowpaths cannot be predicted with certainty, then equation (1) (i.e., the methodology) must be applied. The reader should note that equation (1) is not an assumption, but is rather the definition of the 100-year flood discharge.

The methodology was first described by Dawdy (Reference 1). In his paper Dawdy uses three assumptions to solve equation (1) for q_{100}.

1. The pdf, $f_Q(q)$, is log-Pearson Type III. This assumption is in accordance with the recommendation of the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (Reference 2).

2. The conditional probability, $P(H|Q=q)$, on any contour is equal to the width of the channel carrying the discharge divided by the width of the area subject to flooding measured along the contour. That is, the locations of flowpaths are uniformly distributed within the area subject to flooding. This assumption follows from the reasoning that the alluvial fan was formed, over "geologic" time, by the accumulation of sediment deposited during flood events. Thus, over the long term, one can assume that points, where there is an equal accumulation of sediment (i.e., on the same contour), have experienced, and will experience in the future, the same frequency of flooding. The modeler must exercise caution when considering this assumption to be valid for "engineering" time scales.

3. The width of the "channel" followed by the flood is proportional to the four-tenths power of the flood discharge. This relationship is based on observations in New Mexico that floods on alluvial fans flow at critical depth in wide approximately rectangular channels and that the depth of flow decreases until a further decrease results in a 200-fold increase in the width. Further investigations of alluvial fan flooding in California and Nevada (Reference 3) support the relationship. From that relationship, one can compute not only the width of the flood path but also the depth and velocity of the flow if the discharge is given.

Consequent to adopting the methodology outlined by Dawdy, FEMA commissioned DMA Consulting Engineers to investigate the validity of the aforementioned assumptions. The results of that investigation indicate that the assumptions were reasonable in the upper regions of the alluvial fan flooding studied, but that on many alluvial fans, the flowpaths in the upper regions (single-channel regions) split into several paths in the lower regions (multiple-channel regions) (Reference 3). That study further indicated that the combined width of those multiple channels was consistently approximately 3.8 times the width of the single channel from which they were formed. The study also indicated that the flow within those multiple channels was not at critical depth but rather was at normal depth.

The SC shall assess the reasonableness of each assumption given above in light of the existing conditions of the particular area being studied. That assessment must be fully documented. If the assessment indicates that one or more of the aforementioned assumptions should be modified, the SC shall explain, in writing, the proposed modifications and how they would be used to determine flood depths and velocities. That explanation must be approved by the Regional PO before the modifications are implemented.

A5-2 MAPPING OF ALLUVIAL FAN FLOOD HAZARDS

Before analyzing alluvial fan flooding, the SC should review the available literature on the subject--especially those documents that discuss the methodology or its application. Several such documents are listed in the References and Bibliography section of this Appendix.

The SC may obtain a copy of FAN: An Alluvial Fan Flooding Computer Program, including the user's manual and the compiled program on a 5¼" disk, from FEMA by writing to:

Federal Emergency Management Agency
Federal Insurance Administration
Office of Risk Assessment
Risk Studies Division
500 C Street, SW
Room 422
Washington, DC 20472

A5-2A Reconnaissance

When it is determined that an area in a community is subject to alluvial fan flooding, a thorough reconnaissance of the area should be made in order to determine the source of flooding, the apex, the boundaries of the area, the limits of entrenched channels and the locations of barriers to flow (natural or manmade) that render some areas more flood prone than others, and locations of single- and multiple-channel regions. The reconnaissance should make use of available topographic, geologic, and soil maps; aerial photographs; historic records; and site inspections.

A5-2B Channel Location

As stated in the introduction, the degree to which the processes that characterize alluvial fan flooding are present can vary greatly. The following description is intended to help the reader understand the use of equation (1) in determining the flood hazards associated with alluvial fan flooding. It is not a set of conditions to be used as a prerequisite for applying the methodology.

During a major flood event on an active fan, flow does not spread evenly over the fan, but is confined to only a portion of the fan surface that carries the water from the apex to the toe of the fan. In the upper region of the fan, flood flows are typically confined to a single channel, which is formed by the flow itself through erosion of the loose material that makes up the fan. Because of the relatively steep slopes in the upper region, flood flows are at critical depth and critical velocity. Below the apex of the fan, the flood follows a random path down the fan surface; under natural conditions, the flood is no more likely to follow an existing channel than it is to follow a new flowpath. The flowpath has an approximately rectangular cross section for which depth, width, and velocity of flow can be expressed as functions of discharge.

In the lower region of the fan, flood flows may split and form multiple channels. Normal flow conditions exist in the multiple-channel region.

A5-2C Depth of Flooding

For purposes of mapping alluvial fan flooding, the depth of flooding is the depth of flow in the channel that carries a given discharge plus the velocity head associated with that flow.

A5-2D Velocity of Flooding

For purposes of mapping alluvial fan flooding, the velocity of flooding is the velocity of flow in the channel that carries the given discharge.

A5-2E Avulsions

During a flood event, the flow may abandon the path it has been taking and follow a new one. That occurrence, termed an avulsion, can result from floodwater overtopping a channel bank and creating a new channel. The overtopping may be caused by the sudden deposition of sediment and/or debris or by undercutting and subsequent failure of a channel bank. Because points below the avulsion may be in the path taken by the floodflow either before or after the avulsion occurs, the probability of those points being inundated by the flood is greater than if the avulsion had not occurred.

A5-2F Coalescent Areas

In areas subject to alluvial fan flooding from more than one flooding source, flood depths and velocities are computed by assuming that the event of inundation by a flood from any canyon is independent of the event of inundation by a flood from any other canyon. Thus, the union of such events, which has a probability of 0.01, is used to define depths and velocities in areas where multiple alluvial fans intersect.

A5-3 FLOOD HAZARD ZONES

Special Flood Hazard Areas subject to alluvial fan flooding are identified as Zone AO with the following definition:

Zone AO: Special Flood Hazard Areas inundated by types of 100-year shallow flooding where average depths are between 1.0 and 3.0 feet.

Alluvial fan flood hazard areas are shown on the Flood Insurance Rate Map as Zone AO, and average depths and velocities of flow are shown. In those areas, the 100-year flood depths may exceed 3.0 feet. Development on alluvial fans is subject to a more severe flood hazard than would normally be encountered in Zone AO because the velocities of flows on the alluvial fan are high and the locations of the flowpaths on the alluvial fan are unpredictable.

The Special Flood Hazard Area on each alluvial fan is subdivided into separate AO zones. Those zones are labeled with depths and velocities rounded to the nearest whole foot and foot per second, respectively. For example, all points that are subject to alluvial fan flooding with a 100-year depth between 1.5 and 2.5 feet and a 100-year velocity between 6.5 and 7.5 feet per second are included in an area labeled Zone AO (Depth 2 FT, Velocity 7 FPS).

A5-4 COMPUTATIONS

The solution to equation (1) for the discharges associated with the depths and velocities that define the flood hazard zone boundaries may be obtained through the use of FEMA's computer program (Reference 4). That program solves equation (1) under the simple boundary conditions described in the introduction. The net results of those computations are the values of the widths of the area subject to alluvial fan flooding at which 100-year depths equal n + 0.5 foot and 100-year velocities equal n + 0.5 foot per second (where n is an integer). Other data given in the output of the program can be used to determine the flood hazard zone boundaries under more complicated boundary conditions (such as entrenched channels and barriers to flow). If, however, because of field conditions, the program is of no use, the SC shall describe in writing the field conditions, the reason those conditions render the use of the program to be of little value, and the proposed alternative.

A5-5 INTERMEDIATE DATA SUBMISSION FOR ALLUVIAL FAN FLOODING STUDIES

Alluvial fan flooding analyses are performed in three basic steps. Those steps are.

1. Determine the flood frequency curve at the apex [i.e., $f_Q(q)$ in equation (1)].

2. Determine the boundaries of the area subject to flooding from the apex and the probabilities of points within that area being flooded by a given discharge [i.e., $P(H|Q=q)$ in equation (1)].

3. Calculate the 100-year discharges from equation (1).

Because the accuracy of the results of Step 3 depends on that of Steps 1 and 2, an intermediate data submission is required in an alluvial fan flooding FIS. After notifying the Regional PO, the SC shall submit the data described in A5-5A and A5-5B below. The SC will be informed of the results of that review within 45 days of the intermediate submission.

A5-5A Step 1: Define the Flood Frequency Curve and Apex for Each Flooding Source

The following information shall be submitted in support of the flood frequency curve defined at each apex:

1. A topographic map showing the boundary of the drainage area above the apex, as well as the location of the apex.

2. An explanation demonstrating that flowpaths below the apex are unpredictable.

3. A report describing in detail the hydrologic analysis performed to determine the flood frequency curve.

4. Data and references used in the hydrologic analysis.

5. A plot of the flood frequency curve on log-normal probability paper (including the name of the flooding source, the drainage area above the apex, and the mean, standard deviation, and skew coefficient of the curve).

A5-5B Step 2: Determine the Boundaries of the Area Subject to Alluvial Fan Flooding

The following information shall be submitted in support of the conditional probabilities of points subject to alluvial fan flooding being inundated by a flood, given the flood's magnitude:

1. A topographic map showing the boundaries of the areas subject to alluvial fan flooding. If barriers (either natural or manmade) to the possible flowpaths or channels exist and warrant consideration in defining the conditional probabilities, they should be shown and clearly labeled (including any "threshold" discharges or depths necessary to breach them). This map should also show the division between the single-channel and multiple-channel regions.

2. An aerial photograph (if available) at the same scale as and showing the same information as that described for the topographic map.

3. A soils classification map (if available) at the same scale as and showing the same information as that described for the topographic map.

4. A report describing the topographic and geomorphologic analysis performed.

5. Data and references used in the analysis.

The report should describe, in detail, and justify the use of all assumptions made in the analysis. (Those described by Dawdy can serve as a starting point.)

A5-5C Step 3: Determine and Delineate Flood Insurance Zone Boundaries

After all issues raised during the technical review of Steps 1 and 2 have been resolved and upon receiving approval from the Regional PO, the SC shall proceed with the computations of the 100-year depths and velocities that are to be shown on the FIRM. The results of this analysis are the final product to be submitted as the draft FIS.

The following information shall be submitted to complete this final step:

1. A topographic map showing the flood insurance zones, including 100-year depths and velocities.

2. Backup data and calculations supporting those depths and velocities.

3. A draft FIS Report with adequate descriptions of the analyses performed in the appropriate sections.

A5-6 BIBLIOGRAPHY AND REFERENCES

1. Dawdy, D. R., "Flood Frequency Estimates on Alluvial Fans," Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY11, pp. 1407-1413, November 1979.

2. U.S. Department of the Interior, Geological Survey, Interagency Advisory Committee on Water Data, Office of Water Data Coordination, Hydrology Subcommittee, "Guidelines for Determining Flood Flow Frequency," Bulletin No. 17B, September 1981, Revised March 1982.

3. DMA Consulting Engineers, Alluvial Fan Flooding Methodology - An Analysis, for the Federal Emergency Management Agency, August 1985.

4. Federal Emergency Management Agency, FAN: An Alluvial Fan Flooding Computer Program, September 1990.

Dawdy, D. R., Hill, J. C., and Hanson, K. C., "Implementation of FEMA Guidelines on Alluvial Fans," Hydraulic Engineering, Proceedings of the 1989 National Conference, ASCE, Hydraulics Division, 1989.

Faltas, M. E., "Evaluating Flood Hazards on Alluvial Fans," Hydraulic Engineering, Proceedings of the 1988 National Conference, ASCE, Hydraulics Division, 1988.

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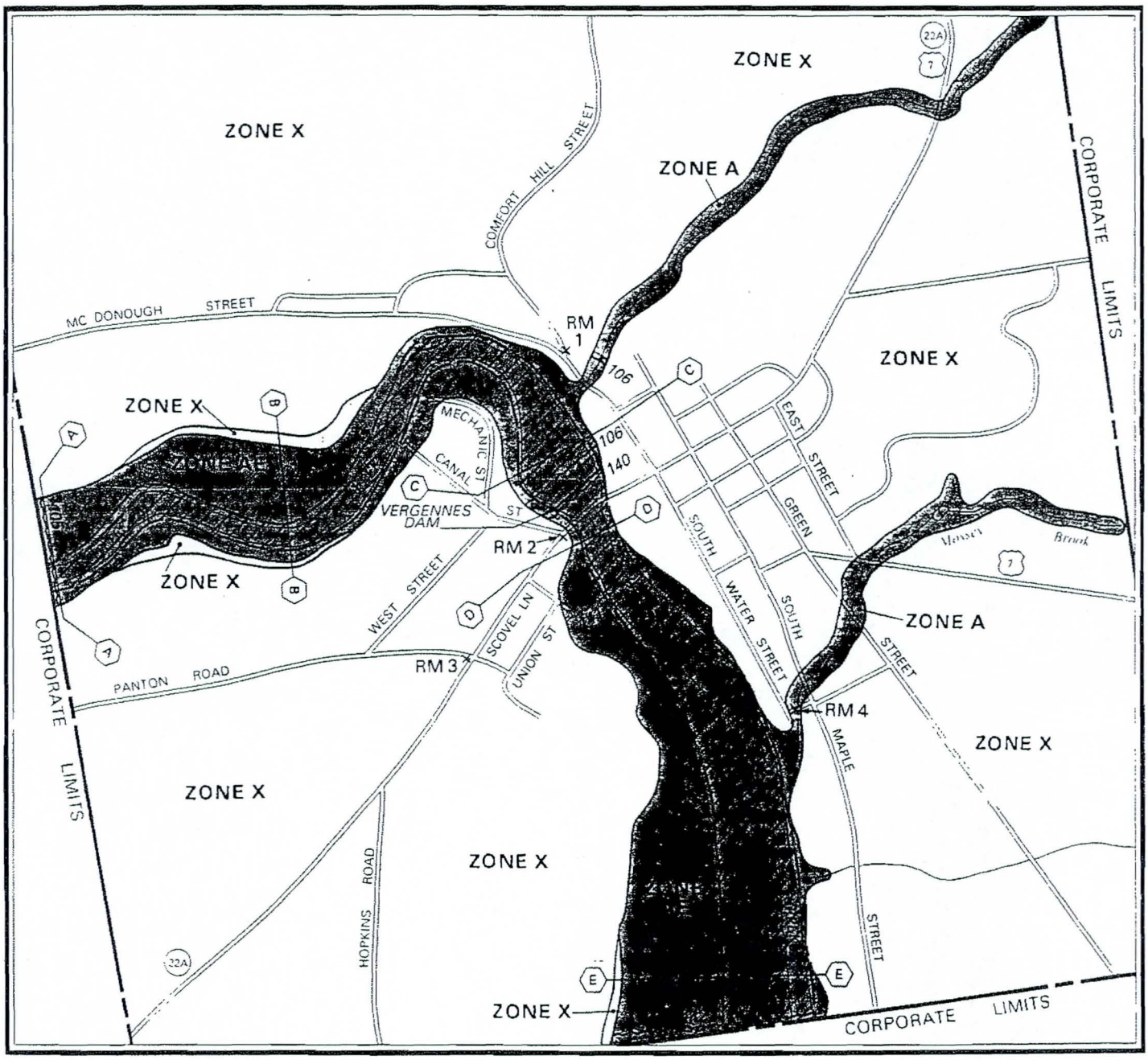
FLOOD INSURANCE STUDY

FEMA 37

Guidelines and Specifications for Study Contractors



FEDERAL EMERGENCY MANAGEMENT AGENCY

Federal Insurance Administration

March 1991

APPENDIX 5. STUDIES OF ALLUVIAL FAN FLOODING

A5-1 INTRODUCTION

"Alluvial fan flooding" means flooding occurring on the surface of an alluvial fan or similar landform, which originates at the apex and is characterized by high-velocity flows; active processes of erosion, sediment transport, and deposition; and unpredictable flow paths. For the purposes of the NFIP, "apex" means a point on an alluvial fan or similar landform below which the flowpath of the major stream that formed the fan becomes unpredictable and alluvial fan flooding can occur. The degree to which the processes that characterize alluvial fan flooding are present can vary greatly. For example, the fact that active deposition has not recently occurred on some portion of the fan surface does not necessarily preclude the use of FEMA's methodology for determining hazards from alluvial fan flooding.

The methodology follows directly from the definition of the 100-year flood as the flood having a 1-percent chance of being exceeded (at the point at which the definition is being applied) in any given year. Because the path of an alluvial fan flood is unpredictable, the probability of the point in question being inundated by a flood, given that that flood is realized at the apex, contributes to the definition of the 100-year flood. Therefore, if H denotes the event of the point in question being flooded, then, by definition, the 100-year flood discharge at that point is the q_{100} given by

$$.01 = \int_{q_{100}}^{\infty} P(H|Q=q) f_Q(q) dq \qquad (1)$$

where $P(H|Q=q)$ is the probability of the point being flooded, given that a flood with a magnitude of q cubic feet per second (cfs) is realized at the apex; and $f_Q(q)$ is the probability density function (pdf) of the discharge Q occurring at the apex. Replacing Q with D or V and q with d or v in equation (1) to denote depth or velocity yields the definition of the 100-year flood depth or flood velocity, respectively. Note that when the flood path is predictable, then $P(H|Q=q) = 1$ and the 100-year flood discharge, q_{100}, is determined by the definition familiar to those who model riverine flooding:

$$.01 = \int_{q_{100}}^{\infty} f_Q(q) dq \qquad (2)$$

If the flowpaths cannot be predicted with certainty, then equation (1) (i.e., the methodology) must be applied. The reader should note that equation (1) is not an assumption, but is rather the definition of the 100-year flood discharge.

The methodology was first described by Dawdy (Reference 1). In his paper Dawdy uses three assumptions to solve equation (1) for q_{100}.

1. The pdf, $f_Q(q)$, is log-Pearson Type III. This assumption is in accordance with the recommendation of the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (Reference 2).

2. The conditional probability, $P(H|Q=q)$, on any contour is equal to the width of the channel carrying the discharge divided by the width of the area subject to flooding measured along the contour. That is, the locations of flowpaths are uniformly distributed within the area subject to flooding. This assumption follows from the reasoning that the alluvial fan was formed, over "geologic" time, by the accumulation of sediment deposited during flood events. Thus, over the long term, one can assume that points, where there is an equal accumulation of sediment (i.e., on the same contour), have experienced, and will experience in the future, the same frequency of flooding. The modeler must exercise caution when considering this assumption to be valid for "engineering" time scales.

3. The width of the "channel" followed by the flood is proportional to the four-tenths power of the flood discharge. This relationship is based on observations in New Mexico that floods on alluvial fans flow at critical depth in wide approximately rectangular channels and that the depth of flow decreases until a further decrease results in a 200-fold increase in the width. Further investigations of alluvial fan flooding in California and Nevada (Reference 3) support the relationship. From that relationship, one can compute not only the width of the flood path but also the depth and velocity of the flow if the discharge is given.

Consequent to adopting the methodology outlined by Dawdy, FEMA commissioned DMA Consulting Engineers to investigate the validity of the aforementioned assumptions. The results of that investigation indicate that the assumptions were reasonable in the upper regions of the alluvial fan flooding studied, but that on many alluvial fans, the flowpaths in the upper regions (single-channel regions) split into several paths in the lower regions (multiple-channel regions) (Reference 3). That study further indicated that the combined width of those multiple channels was consistently approximately 3.8 times the width of the single channel from which they were formed. The study also indicated that the flow within those multiple channels was not at critical depth but rather was at normal depth.

The SC shall assess the reasonableness of each assumption given above in light of the existing conditions of the particular area being studied. That assessment must be fully documented. If the assessment indicates that one or more of the aforementioned assumptions should be modified, the SC shall explain, in writing, the proposed modifications and how they would be used to determine flood depths and velocities. That explanation must be approved by the Regional PO before the modifications are implemented.

A5-2 MAPPING OF ALLUVIAL FAN FLOOD HAZARDS

Before analyzing alluvial fan flooding, the SC should review the available literature on the subject--especially those documents that discuss the methodology or its application. Several such documents are listed in the References and Bibliography section of this Appendix.

The SC may obtain a copy of FAN: An Alluvial Fan Flooding Computer Program, including the user's manual and the compiled program on a 5¼" disk, from FEMA by writing to:

Federal Emergency Management Agency
Federal Insurance Administration
Office of Risk Assessment
Risk Studies Division
500 C Street, SW
Room 422
Washington, DC 20472

A5-2A Reconnaissance

When it is determined that an area in a community is subject to alluvial fan flooding, a thorough reconnaissance of the area should be made in order to determine the source of flooding, the apex, the boundaries of the area, the limits of entrenched channels and the locations of barriers to flow (natural or manmade) that render some areas more flood prone than others, and locations of single- and multiple-channel regions. The reconnaissance should make use of available topographic, geologic, and soil maps; aerial photographs; historic records; and site inspections.

A5-2B Channel Location

As stated in the introduction, the degree to which the processes that characterize alluvial fan flooding are present can vary greatly. The following description is intended to help the reader understand the use of equation (1) in determining the flood hazards associated with alluvial fan flooding. It is not a set of conditions to be used as a prerequisite for applying the methodology.

During a major flood event on an active fan, flow does not spread evenly over the fan, but is confined to only a portion of the fan surface that carries the water from the apex to the toe of the fan. In the upper region of the fan, flood flows are typically confined to a single channel, which is formed by the flow itself through erosion of the loose material that makes up the fan. Because of the relatively steep slopes in the upper region, flood flows are at critical depth and critical velocity. Below the apex of the fan, the flood follows a random path down the fan surface; under natural conditions, the flood is no more likely to follow an existing channel than it is to follow a new flowpath. The flowpath has an approximately rectangular cross section for which depth, width, and velocity of flow can be expressed as functions of discharge.

In the lower region of the fan, flood flows may split and form multiple channels. Normal flow conditions exist in the multiple-channel region.

A5-2C Depth of Flooding

For purposes of mapping alluvial fan flooding, the depth of flooding is the depth of flow in the channel that carries a given discharge plus the velocity head associated with that flow.

A5-2D Velocity of Flooding

For purposes of mapping alluvial fan flooding, the velocity of flooding is the velocity of flow in the channel that carries the given discharge.

A5-2E Avulsions

During a flood event, the flow may abandon the path it has been taking and follow a new one. That occurrence, termed an avulsion, can result from floodwater overtopping a channel bank and creating a new channel. The overtopping may be caused by the sudden deposition of sediment and/or debris or by undercutting and subsequent failure of a channel bank. Because points below the avulsion may be in the path taken by the floodflow either before or after the avulsion occurs, the probability of those points being inundated by the flood is greater than if the avulsion had not occurred.

A5-2F Coalescent Areas

In areas subject to alluvial fan flooding from more than one flooding source, flood depths and velocities are computed by assuming that the event of inundation by a flood from any canyon is independent of the event of inundation by a flood from any other canyon. Thus, the union of such events, which has a probability of 0.01, is used to define depths and velocities in areas where multiple alluvial fans intersect.

A5-3 FLOOD HAZARD ZONES

Special Flood Hazard Areas subject to alluvial fan flooding are identified as Zone AO with the following definition:

Zone AO: Special Flood Hazard Areas inundated by types of 100-year shallow flooding where average depths are between 1.0 and 3.0 feet.

Alluvial fan flood hazard areas are shown on the Flood Insurance Rate Map as Zone AO, and average depths and velocities of flow are shown. In those areas, the 100-year flood depths may exceed 3.0 feet. Development on alluvial fans is subject to a more severe flood hazard than would normally be encountered in Zone AO because the velocities of flows on the alluvial fan are high and the locations of the flowpaths on the alluvial fan are unpredictable.

The Special Flood Hazard Area on each alluvial fan is subdivided into separate AO zones. Those zones are labeled with depths and velocities rounded to the nearest whole foot and foot per second, respectively. For example, all points that are subject to alluvial fan flooding with a 100-year depth between 1.5 and 2.5 feet and a 100-year velocity between 6.5 and 7.5 feet per second are included in an area labeled Zone AO (Depth 2 FT, Velocity 7 FPS).

A5-4 COMPUTATIONS

The solution to equation (1) for the discharges associated with the depths and velocities that define the flood hazard zone boundaries may be obtained through the use of FEMA's computer program (Reference 4). That program solves equation (1) under the simple boundary conditions described in the introduction. The net results of those computations are the values of the widths of the area subject to alluvial fan flooding at which 100-year depths equal n + 0.5 foot and 100-year velocities equal n + 0.5 foot per second (where n is an integer). Other data given in the output of the program can be used to determine the flood hazard zone boundaries under more complicated boundary conditions (such as entrenched channels and barriers to flow). If, however, because of field conditions, the program is of no use, the SC shall describe in writing the field conditions, the reason those conditions render the use of the program to be of little value, and the proposed alternative.

A5-5 INTERMEDIATE DATA SUBMISSION FOR ALLUVIAL FAN FLOODING STUDIES

Alluvial fan flooding analyses are performed in three basic steps. Those steps are.

1. Determine the flood frequency curve at the apex [i.e., $f_Q(q)$ in equation (1)].

2. Determine the boundaries of the area subject to flooding from the apex and the probabilities of points within that area being flooded by a given discharge [i.e., $P(H|Q=q)$ in equation (1)].

3. Calculate the 100-year discharges from equation (1).

Because the accuracy of the results of Step 3 depends on that of Steps 1 and 2, an intermediate data submission is required in an alluvial fan flooding FIS. After notifying the Regional PO, the SC shall submit the data described in A5-5A and A5-5B below. The SC will be informed of the results of that review within 45 days of the intermediate submission.

A5-5A Step 1: Define the Flood Frequency Curve and Apex for Each Flooding Source

The following information shall be submitted in support of the flood frequency curve defined at each apex:

1. A topographic map showing the boundary of the drainage area above the apex, as well as the location of the apex.

2. An explanation demonstrating that flowpaths below the apex are unpredictable.

3. A report describing in detail the hydrologic analysis performed to determine the flood frequency curve.

4. Data and references used in the hydrologic analysis.

5. A plot of the flood frequency curve on log-normal probability paper (including the name of the flooding source, the drainage area above the apex, and the mean, standard deviation, and skew coefficient of the curve).

A5-5B Step 2: Determine the Boundaries of the Area Subject to Alluvial Fan Flooding

The following information shall be submitted in support of the conditional probabilities of points subject to alluvial fan flooding being inundated by a flood, given the flood's magnitude:

1. A topographic map showing the boundaries of the areas subject to alluvial fan flooding. If barriers (either natural or manmade) to the possible flowpaths or channels exist and warrant consideration in defining the conditional probabilities, they should be shown and clearly labeled (including any "threshold" discharges or depths necessary to breach them). This map should also show the division between the single-channel and multiple-channel regions.

2. An aerial photograph (if available) at the same scale as and showing the same information as that described for the topographic map.

3. A soils classification map (if available) at the same scale as and showing the same information as that described for the topographic map.

4. A report describing the topographic and geomorphologic analysis performed.

5. Data and references used in the analysis.

The report should describe, in detail, and justify the use of all assumptions made in the analysis. (Those described by Dawdy can serve as a starting point.)

A5-5C Step 3: Determine and Delineate Flood Insurance Zone Boundaries

After all issues raised during the technical review of Steps 1 and 2 have been resolved and upon receiving approval from the Regional PO, the SC shall proceed with the computations of the 100-year depths and velocities that are to be shown on the FIRM. The results of this analysis are the final product to be submitted as the draft FIS.

The following information shall be submitted to complete this final step:

1. A topographic map showing the flood insurance zones, including 100-year depths and velocities.

2. Backup data and calculations supporting those depths and velocities.

3. A draft FIS Report with adequate descriptions of the analyses performed in the appropriate sections.

A5-6 BIBLIOGRAPHY AND REFERENCES

1. Dawdy, D. R., "Flood Frequency Estimates on Alluvial Fans," Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY11, pp. 1407-1413, November 1979.

2. U.S. Department of the Interior, Geological Survey, Interagency Advisory Committee on Water Data, Office of Water Data Coordination, Hydrology Subcommittee, "Guidelines for Determining Flood Flow Frequency," Bulletin No. 17B, September 1981, Revised March 1982.

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4. Federal Emergency Management Agency, FAN: An Alluvial Fan Flooding Computer Program, September 1990.

Dawdy, D. R., Hill, J. C., and Hanson, K. C., "Implementation of FEMA Guidelines on Alluvial Fans," Hydraulic Engineering, Proceedings of the 1989 National Conference, ASCE, Hydraulics Division, 1989.

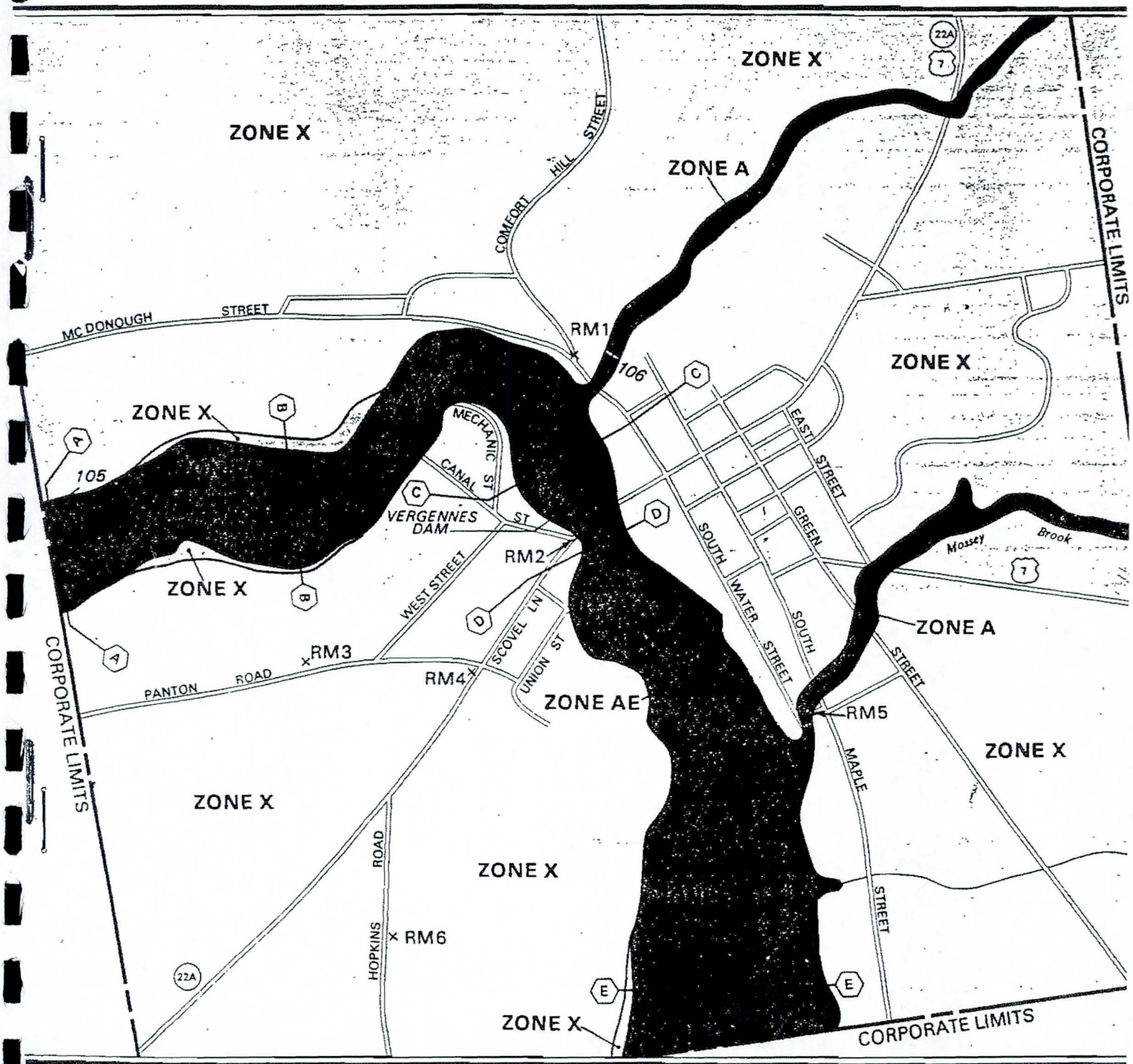
Faltas, M. E., "Evaluating Flood Hazards on Alluvial Fans," Hydraulic Engineering, Proceedings of the 1988 National Conference, ASCE, Hydraulics Division, 1988.

Mifflin, E. R., "Design Depths and Velocities on Alluvial Fans," Hydraulic Engineering, Proceedings of the 1988 National Conference, ASCE, Hydraulics Division, 1988.

FLOOD INSURANCE STUDY

FEMA 37

Guidelines and Specifications for Study Contractors



FEDERAL EMERGENCY MANAGEMENT AGENCY
Federal Insurance Administration

September 1985

APPENDIX 5. ALLUVIAL FAN STUDIES

A5-1 INTRODUCTION

The methodology outlined in this Appendix is based on procedures developed by Dawdy (Reference 1) and later modified (Reference 2) to account for split flow conditions generally found in the lower reaches of active alluvial fans. It is recommended that the Study Contractor review these publications for a complete discussion of the theory, rationale, and assumptions used to develop this methodology. In portions of alluvial fans in which natural alluvial fan processes may not occur, such as in areas of entrenched channels, areas protected by flood control works, and heavily developed areas, the Study Contractor should exercise good engineering judgment in determining the most appropriate methodology or combinations of methodologies.

When it is determined that an area in a community is subject to alluvial fan flooding, 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. The reconnaissance should make use of available topographic, geologic, and soil maps; aerial photographs; historic records; and site inspection.

Prior to undertaking any computations, the Study Contractor should obtain approval from the PO for the use of the methodology outlined in this Appendix.

A5-2 ASSUMPTIONS AND OBSERVATIONS

The approach outlined in this Appendix makes use of statistical analyses that relate the probability of given discharges at the apex of a fan to the probability of certain depths and velocity of flow occurring at any point on the fan below the apex. The methodology presented in this Appendix is based on the assumptions and observations regarding floodflows on active alluvial fans outlined in the following sections.

a. Channel Pattern and Location

At the time of maximum flow during a major flood event on an active fan, flow does not spread evenly over the fan but is confined to only a portion of the fan surface that carries the water from the apex to the toe of the fan. In the upper region of the fan, flood flows are confined to a single channel which is formed by the flow itself through erosion of the loose material that makes up the fan. Because of the relatively steep slopes in the upper region, flood flows are at critical depth and critical velocity. Below the apex of the fan (or the zone of entrenchment in the case of mature fans), the channel will occur at random locations at any place on the fan surface; under natural conditions, it is no more likely to follow a pre-existing flowpath than it is to follow a new flowpath. This channel has an approximately rectangular cross section for which depth, width, and velocity of flow can be expressed as functions of discharge at the apex of the fan.

In the lower region of the fan, flood flows split and form multiple channels. For purposes of this procedure, the concept of a single equivalent channel is used to compute flood depths and velocities. Normal flow conditions are considered to exist in the multiple channel region due to the relatively flatter slopes.

The probability of a point being flooded in a given flood event decreases from the apex to the toe of the fan because the downslope widening of the fan surface provides a greater area over which a channel of given width may occur.

b. Depth of Flooding

For flood mapping purposes, the depth of flooding computed on alluvial fans is the depth of flow (depth of channel) in the channel that carries a given discharge to the toe of the fan surface.

c. Velocity of Flooding

For alluvial fan flood mapping, the velocity of flooding computed for alluvial fan flood mapping is the velocity of flow in the channel that carries the given discharge to the toe of the fan surface.

d. Avulsions

During major floods on active alluvial fans, peak flows may abruptly abandon one channel that had been formed during the flood, and form a new channel. This phenomenon, termed an avulsion, can cause a significant increase in the probability of flooding at a given point on a fan because of the increased channel widths that may cross a given contour during a given flood event. The treatment of avulsions is an important factor in the application of the methodology presented in this Appendix.

A5-3 FLOOD HAZARD ZONES

Special Flood Hazard Areas on alluvial fans are identified as Zone AO with the following definition:

*Zone AO: Zone AO is the flood insurance rate zone that corresponds to the areas of 100-year shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average whole-foot depths derived from the detailed hydraulic analyses are shown within this zone.

The Special Flood Hazard Area on each alluvial fan is subdivided into separate AO zones with similar depths and velocities. Zones are delineated that have depths or velocities differing by an average of 1.0 foot in depth or 1.0 foot per second (fps) in velocity.

*Exception to the 3-foot depth limit for Zone AO is permitted for alluvial fans when approved by the PO.

In areas of coalescent alluvial fans, separate depth-frequency relationships should be developed for each source of flooding and combined based on the probability of the union of independent events.

A5-4 COMPUTATIONAL INSTRUCTIONS

Step-by-step instructions are provided below for computing the boundaries of flood hazard zones on alluvial fans using log-Pearson Type III analyses in accordance with Bulletin No. 17B (Reference 3).

a. Determine Flood Discharge-Frequency Distribution

For the source of flooding at the apex of each alluvial fan, a complete flood discharge-frequency distribution should be determined using log-Pearson Type III analyses in accordance with Bulletin No. 17B. The determination of flood discharges in arid regions, where alluvial fans are most typically found, should be closely coordinated with the PO to ensure agreement on methodology.

The skew coefficient, standard deviation, and mean of logarithms of discharges must be determined for the flooding source at the apex of the fan. When an analysis according to Bulletin No. 17B is done, these statistics are known. For most alluvial fans, however, these statistics will not be available. Therefore, flows of various recurrence intervals should be computed from appropriate regional methods, and the synthetic log-Pearson Type III parameters should be derived.

(1) Derivation of Skew Coefficient. Derive the skew coefficient using the following equations:

$$G = -2.50 + 3.12 \frac{\mathrm{Log}(Q_{.01}/Q_{.10})}{\mathrm{Log}(Q_{.10}/Q_{.50})} \qquad (1)$$

Using the skew coefficient computed above and the K values for the skew as shown in Bulletin No. 17B, the standard deviation should be derived according to the following equation:

$$S = \frac{\log(Q_{.01}/Q_{.50})}{K_{.01} - K_{.50}} \qquad (2)$$

(2) Derivation of Mean of Logarithms. Using the values determined in Equations 1 and 2, the mean of logarithms should be derived according to the following equation:

$$\bar{X} = \log(Q_{.50}) - K_{.50}(S) \qquad (3)$$

where S and $\bar{X}$ are the standard deviation and mean, respectively; $Q_{.01}$, $Q_{.10}$, and $Q_{.50}$ are discharges with 0.01, and 0.10, and 0.50 exceedance probabilities, respectively; and $K_{.01}$ and $K_{.50}$ are Pearson Type III deviates for respective exceedance probabilities of 0.01 and 0.50 and skew coefficient G. Equation (1) above is an approximation appropriate for use between skew values of +2.5 and -2.0.

b. Compute Transformation Variables

To permit solutions by use of log-Pearson Type III analysis and Bulletin No. 17B, the log-Pearson Type III parameters must be transformed.

Variables for transforming these parameters should be computed as follows:

$m = \bar{X} - 2S/G$

$\alpha = 2/GS$

$\lambda = 4/G^2$

and

$a = \alpha - 0.92$

If the skew coefficient is zero (log normal distribution), the transformation variables should not be computed.

c. Transform log-Pearson Type III Parameters

Where skew coefficients are not zero, the log-Pearson Type III parameters should be transformed using the variables computed above according to the following equations:

$\bar{Z} = m + \lambda/a$

$S_Z^2 = \lambda/a^2$

$G_Z = 2/\lambda^{1/2}$

Where the skew coefficient is zero (log normal distribution), compute the parameters as follows:

$\bar{Z} = \bar{X} + 0.92S^2$

$S_Z = S$

$G_Z = G$

d. Compute Transformation Constant

Where the skew coefficient is not zero, a transformation constant should be computed as follows:

$$C = \left(\frac{\alpha}{a}\right) \lambda e^{0.92m}$$

Where the skew coefficient is zero (log normal distribution), the transformation constant should be computed as follows:

$$C = e^{0.92\bar{X} + 0.42S^2}$$

e. Determine Discharges for Depth and Velocity Zones

The alluvial fan flooding can be determined by a combination of two methods. They are based on a single channel region and a multiple channel region in the analyses. The single channel region is defined by the length of the single channel measured from the mouth of the canyon to the point where the flood channel splits. If there is no clear indication as to the length of the single channel from data collected during the reconnaissance phase, the length of the single channel can be determined using Figure 5-1. Below the single channel region of the fan is the multiple channel region. The fan width along the boundary between the single channel and multiple channel regions can be measured from the topographic map, once the length of the single channel is known.

I. Single Channel Region

Within this region, discharges, Q (in cubic feet per second), that correspond to the various depth zone boundaries should be selected using the table below. This table was derived from the relationship

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

where D is the total depth in feet due to pressure head and velocity head.

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

Depth zones are designated from zone boundaries as follows:

Depth of Zone	Depth of Lower Boundary	Depth of Upper Boundary
1	0.5	1.5
2	1.5	2.5
3	2.5	3.5
4	3.5	4.5

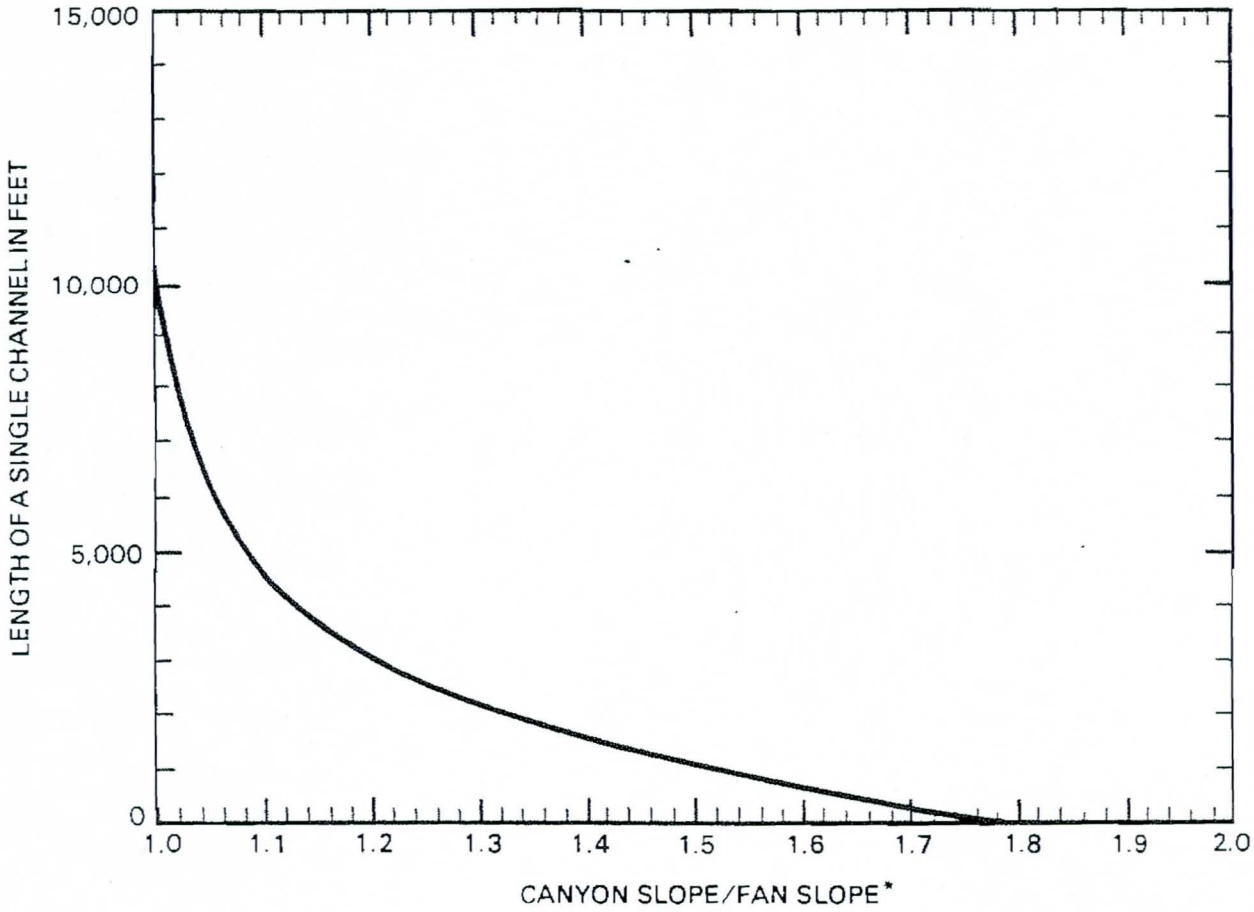
Discharges, Q (in cubic feet per second), that correspond to the various velocity zone boundaries should be selected using the table below. This table was derived from the relationship

$$Q = 0.13\ V^5$$

where V is velocity in feet per second.

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

FIGURE A5-1
RELATIONSHIP BETWEEN LENGTH OF A SINGLE CHANNEL
AND RATIO OF CANYON SLOPE TO FAN SLOPE



* Canyon slope should normally be computed along the stream bed of the lower canyon to a point upstream of the canyon mouth where there is a notable change to a steeper gradient. Fan slope should normally be computed for the upper portion of the fan to a point downstream of the fan apex where there is a notable change to a flatter gradient.

Velocity zones are designated from zone boundaries as follows:

Zone Velocity	Velocity of Lower Boundary	Velocity of Upper Boundary
4.0	3.5	4.5
5.0	4.5	5.5
6.0	5.5	6.5
7.0	6.5	7.5
8.0	7.5	8.5

II. Multiple Channel Region

Within the multiple channel region, discharges, Q (in cubic feet per second), that correspond to the various depth zone boundaries may be calculated by iteratively solving the following equation:

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

where D is the total depth in feet due to pressure head and velocity head, S is the fan slope, and n is Manning's roughness coefficient for the alluvial fan flood channel.

Discharges, Q (in cubic feet per second), that correspond to the various velocity zone boundaries should be calculated using the equation:

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

where V is velocity in feet per second and S is the fan slope.

Depth zones and velocity zones are designated from zone boundaries in the same manner as shown in the analysis for the single channel region.

h. Compute Fan Widths for Zone Boundaries

The fan widths (i.e., arc lengths from one lateral limit of the fan to the other taken parallel to contours) that correspond to each upper and lower zone boundary depth and velocity listed in Section A5-4e should be computed both for the single channel region and the multiple channel region. The following formulas should be used:

I. Single Channel Region

Fan Width = 950ACP

II. Multiple Channel Region

Fan Width = 3610ACP

In the above two formulas, A is the avulsion coefficient, C is the transformation constant, and P is the probability of the discharge that corresponds to each given depth and velocity.

An avulsion coefficient (factor) greater than 1 should be selected by the Study Contractor in consultation with the PO. A factor of 1.5 is recommended in the absence of other data.

In summary, the steps for the determination of the flood velocity and depth boundaries are listed as follows:

1. Compute all flood depth and velocity zone boundaries by the standard single channel method.

2. Determine point of bifurcation into multiple channel region through use of Figure A5-1 and the calculation of near fanhead canyon slope to fan slope ratio.

3. If the point of bifurcation is downfan from the lower boundary of the one-foot depth zone as computed by the standard single channel method, the standard single channel method will be used for the determination of all flood boundaries on the fan.

4. If the point of bifurcation is upfan from the upper boundary of the one-foot depth zone as computed by the standard single channel method, the one-foot depth zone boundaries will be changed to that computed for the multiple channel case.

5. If the point of bifurcation is upfan from the one-foot depth zone boundaries as computed by the standard single channel method, compute the depth and velocity at the point of bifurcation by the standard single channel method. Compute the velocity and depth boundaries for velocities and depth less than those determined for the point of bifurcation by use of the multiple channel method. Substitute those boundaries for the boundaries computed by the standard single channel method.

A5-5 FIRM

When the fan arc widths that form flood hazard zone boundaries have been computed, these distances should be scaled onto topographic base maps, taking care to make the boundaries parallel to contours.

The sketch map shown in Figure A5-1 depicts the typical distribution of flood insurance rate zones on an active alluvial fan, as determined by the methodology outlined in this Appendix.

A5-6 REFERENCES

1. David R. Dawdy, "Flood Frquency Estimates on Alluvial Fans," Journal of the Hydraulics Division ASCE, Proceedings, Vol. 105, No. HYII, pp. 1407-1413, 1979.

2. DMA Consulting Engineers for FEMA, Alluvial Fan Flooding Methodology - An Analysis, August 1985.

3. U.S. Department of the Interior, Interagency Advisory Committee on Water Data, Office of Water Data Coordination, Hydrology Subcommittee, Bulletin No. 17B, "Guidelines for Determining Flood Flow Frequency," September 1981, Revised March 1982.

A5-7 SAMPLE STUDY

The following sample study is presented to demonstrate the mapping of special flood hazard zones on active alluvial fans using the methodology described in this Appendix. The computational steps are generally carried out in the same sequence as they are listed in the Appendix.

a. Identification of Alluvial Fans

In this sample study, topographic map inspection, airphoto interpretation, and field inspection were used to identify two coalescing, active alluvial fans that fell partly within the study area. To determine the flood hazard zone boundaries within the study area, it was necessary to determine them for both alluvial fans. The principal source of flooding was identified for each fan and designated Number One Canyon and Number Two Canyon. The overall boundaries of the fans were delineated on the best available topographic map, which in this case was a U.S. Geological Survey quadrangle at a scale of 1:24,000, with a contour interval of 20 feet.

b. Determination of Discharges for Depth and Velocity Zones

The discharges that correspond to the various depth and velocity zone boundaries were selected from the tables for the single channel region and calculated by use of the equations for the multiple channel region shown in Section A5-4e of this Appendix. For Number One Canyon, with the fan slope of 0.03 and Manning's "n" of 0.02, these discharges are as follows:

I. Single Channel Region

Depth	Discharge
0.5	49.5
1.5	772.0
2.5	2,770.0

Velocity	Discharge
3.5	68
4.5	240
5.5	654
6.5	1,510

II. Multiple Channel Region

Depth	Discharge
0.5	310
1.5	3,835

Velocity	Discharge
3.5	122
4.5	348
5.5	803
6.5	1,611

d. Determine Probabilities of Transformed Discharges and Fan Widths at Zone Boundaries

The log-Pearson Type III standard deviates (K) were computed for the discharges (Q) that correspond to each depth zone boundary and each velocity zone boundary, using the equation:

$$K = \frac{\log Q - \bar{Z}}{S_Z}$$

The probability of occurrence (P) of the discharges for the required depth and velocity boundaries were determined by interpolation of the deviate values (K) listed in Appendix 3 of Bulletin No. 17B.

Fan arc widths (W) were computed for each special flood hazard zone boundary using the equation:

$$W = 950ACP$$

for the single channel region and the equation:

$$W = 3610ACP$$

for the multiple channel region.

An avulsion coefficient (A) of 1.5 was assumed for each case.

Computations for Number One Canyon were made as follows:

Based on the fan slope of 0.03 and near fanhead canyon slope of 0.036, the ratio of canyon slope to fan slope is calculated as 1.2. The single channel length of 3,200 feet was determined from Figure A5-1, using the calculated ratio of canyon slope to fan slope of 1.2. The fan width along the boundary dividing the single channel region and multiple channel region was determined as 1,680 feet from the topographic map based on the calculated value of the single channel length.

I. Single Channel Region

For the 0.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 49.5 - 2.29}{0.4965} = \frac{1.695 - 2.29}{0.4965} = -1.199$$

$P[Q \geq 49.5] = P[K \geq -1.199] = 0.881$

$W = 950ACP = 950 \times 1.5 \times 7.4 \times 0.881 = 9{,}290$ feet

For the 1.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 772 - 2.29}{0.4965} = \frac{2.888 - 2.29}{0.4965} = 1.204$$

$P[Q \geq 772] = P[K \geq 1.204] = 0.118$

$W = 950ACP = 950 \times 1.5 \times 7.4 \times 0.118 = 1{,}240$ feet

For the 2.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 2770 - 2.29}{0.4965} = \frac{3.44 - 2.29}{0.4965} = 2.316$$

$P[Q \geq 2770] = P[K \geq 2.316] = 0.0104$

$W = 950ACP = 950 \times 1.5 \times 7.4 \times 0.0104 = 110$ feet

For the 3.5-feet per second (fps) velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 68 - 2.29}{0.4965} = \frac{1.83 - 2.29}{0.4965} = -0.926$$

$P[Q \geq 68] = P[K \geq -0.926] = 0.819$

$W = 950ACP = 950 \times 1.5 \times 7.4 \times 0.819 = 8{,}640$ feet

For the 4.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 240 - 2.29}{0.4965} = \frac{2.38 - 2.29}{0.4965} = 0.181$$

$P[Q \geq 240] = P[K \geq 0.181] = 0.428$

$W = 950ACP = 950 \times 1.5 \times 7.4 \times 0.428 = 4{,}510$ feet

For the 5.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 654 - 2.29}{0.4965} = \frac{2.816 - 2.29}{0.4965} = 1.059$$

$P[Q \geq 654] = P[K \geq 1.059] = 0.15$

$W = 950ACP = 950 \times 1.5 \times 7.4 \times 0.15 = 1{,}580$ feet

For the 6.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 1510 - 2.29}{0.4965} = \frac{3.18 - 2.29}{0.4965} = 1.793$$

$$P\ [\ Q \geq 1510\ ] = P\ [\ K \geq 1.793\ ] = 0.037$$

$$W = 950ACP = 950 \times 1.5 \times 7.4 \times 0.037 = 390$$

II. Multiple Channel Region

For the 0.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 310 - 2.29}{0.4965} = 0.4055$$

$$P\ [\ Q \geq 310\ ] = P\ [\ K \geq 0.4055\ ] = 0.3438$$

$$W = 3610ACP = 3610 \times 1.5 \times 7.4 \times 0.3438 = 13{,}780 \text{ feet}$$

For the 1.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 3835 - 2.29}{0.4965} = 2.6058$$

$$P\ [\ Q \geq 3835\ ] = P\ [\ K \geq 2.6058\ ] = 0.0047$$

$$W = 3610ACP = 3610 \times 1.5 \times 7.4 \times 0.0047 = 190 \text{ feet}$$

For the 3.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 122 - 2.29}{0.4965} = -0.4102$$

$$P\ [\ Q \geq 122\ ] = P\ [\ K \geq -0.4102\ ] = 0.6578$$

$$W = 3610ACP = 3610 \times 1.5 \times 7.4 \times 0.6578 = 26{,}360 \text{ feet}$$

For the 4.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Lot } 348 - 2.29}{0.4965} = 0.5067$$

$$P\ [\ Q \geq 348\ ] = P\ [\ K \geq 0.5067\ ] = 0.3065$$

$$W = 3610ACP = 3610 \times 1.5 \times 7.4 \times 0.3065 = 12{,}280 \text{ feet}$$

For the 5.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 803 - 2.29}{0.4965} = 1.2381$$

$$P [Q \geq 803] = P [K \geq 1.2381] = 0.1099$$

$$W = 3610ACP = 3610 \times 1.5 \times 7.4 \times 0.1099 = 4{,}400 \text{ feet}$$

For the 6.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 1611 - 2.29}{0.4965} = 1.8471$$

$$P [Q \geq 1611] = P [K \geq 1.8471] = 0.0331$$

$$W = 3610ACP = 3610 \times 1.5 \times 7.4 \times 0.0331 = 1{,}330 \text{ feet}$$

III. Flow Velocity and Depth at Bifurcation Point

The fan width at the bifurcation point is 1,680 feet. The probability of occurrence (P) of the discharge for the velocity and depth at the bifurcation point can be calculated using the equations for the standard single channel method as follows:

$$P = \frac{W}{950AC} = \frac{1680}{950 \times 1.5 \times 7.4} = 0.1593$$

The standard deviate, K, is then determined to be 1.0207 by interpolation of probabilities and standard deviates, with skewness, G, equal to zero, listed in Appendix 3 of Bulletin No. 17B. The corresponding discharge, velocity, and depth may be calculated using the following formulas:

$$\text{Log } Q = \bar{Z} + KS_Z = 2.29 + 1.0207 \times 0.4965 = 2.797$$

Thus $Q = 626$ cfs

$$v = 1.5\ Q^{0.2} = 1.5 \times (626)^{0.2} = 5.4 \text{ fps}$$

$$D = 0.10\ Q^{0.4} = 0.10 \times (626)^{0.4} = 1.3 \text{ feet}$$

So, the 0.5-foot depth contour and the 5.5-, 4.5-, and 3.5-ft/sec velocity boundaries are determined by the multiple channel method. All other boundaries are determined by the single channel method. Fan widths were computed independently for the fan originating from Number Two Canyon. The computed widths were then fit to the proper contours on the fans to produce the special flood hazard zone boundaries as shown on the map (see Figure A5-2).

FLOOD INSURANCE STUDY

GUIDELINES AND SPECIFICATIONS FOR STUDY CONTRACTORS

Federal Emergency
Management Agency

SEPTEMBER 1982

APPENDIX 6. ALLUVIAL FAN STUDIES

A6-1 INTRODUCTION

The methodology outlined in this Appendix is based on procedures developed by Dawdy (Reference 1) and applies to natural flow conditions on active alluvial fans. It is recommended that the Study Contractor review this publication for a complete discussion of the theory, rationale, and assumptions used to develop this methodology. In portions of alluvial fans in which natural alluvial fan processes may not occur, such as in areas of entrenched channels, areas protected by flood control works, and heavily developed areas, the Study Contractor should exercise good engineering judgment in determining the most appropriate methodology or combinations of methodologies.

When it is determined that an area in a community is subject to alluvial fan flooding, 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, and the areas of active alluvial fan processes. The reconnaissance should make use of available topographic, geologic, and soil maps; aerial photographs; historic records; and site reconnaissance.

Prior to undertaking any computations, the Study Contractor should obtain approval from the PO for the use of the methodology outlined in this Appendix.

A6-2 ASSUMPTIONS AND OBSERVATIONS

The approach outlined in this Appendix makes use of statistical analyses that relate the probability of given discharges at the apex of a fan to the probability of certain depths and velocity of flow occurring at any point on the fan below the apex. The methodology presented in this Appendix is based on the assumptions and observations regarding floodflows on active alluvial fans outlined in the following sections.

a. Channel Location

At the time of maximum flow during a major flood event on an active fan, flow does not spread evenly over the fan but is confined to only a portion of the fan surface that carries the water from the apex to the toe of the fan. Floodflows are at critical depth and critical velocity, and the channel is formed by the flow itself through erosion of the loose material that makes up the fan. Below the apex of the fan (or the zone of entrenchment in the case of mature fans), the channel will occur at random locations at any place on the fan surface; under natural conditions, it is no more likely to follow a pre-existing flowpath than it is to follow a new flowpath. This channel has an approximately rectangular cross section for which depth, width, and velocity of flow can be expressed as functions of discharge at the apex of the fan.

The probability of a point being flooded in a given flood event decreases from the apex to the toe of a fan because the downslope widening of the fan surface provides a greater area over which a channel of given width may occur.

b. Depth of Flooding

For flood mapping purposes, the depth of flooding computed on alluvial fans is the depth of flow (depth of channel) in the channel that carries a given discharge to the toe of the fan surface. Depth is computed as the total depth resulting from the sum of the pressure head and the velocity head.

c. Velocity of Flooding

For alluvial fan flood mapping, the velocity of flooding computed for alluvial fan flood mapping is the velocity of flow in the channel that carries the given discharge to the toe of the fan surface.

d. Avulsions

During major floods on active alluvial fans, peak flows may abruptly abandon one channel that had been formed during the flood, and form a new channel. This phenomenon, termed an avulsion, can cause a significant increase in the probability of flooding at a given point on a fan because of the increased channel widths that may cross a given contour during a given flood event. The treatment of avulsions is an important factor in the application of the methodology presented in this Appendix.

A6-3 FLOOD HAZARD ZONES

Special Flood Hazard Areas on alluvial fans are identified as Zone AF with the following definition:

Zone AF: Alluvial fan high hazard area subject to a one percent or greater annual chance of flooding, to a depth of 0.5 foot or greater, which is characterized by variable flowpaths, high flow velocity, erosion, and debris deposition.

The Special Flood Hazard Area on each alluvial fan is subdivided into separate AF zones with similar depths and velocities. Zones are delineated that have depths or velocities differing by an average of 1.0 foot in depth or 1.0 foot per second (fps) in velocity.

In areas of coalescent alluvial fans, separate depth-frequency relationships should be developed for each source of flooding and combined based on the probability of the union of independent events.

A6-4 COMPUTATIONAL INSTRUCTIONS

Step-by-step instructions are provided below for computing the boundaries of flood hazard zones on alluvial fans using log-Pearson Type III analyses in accordance with U.S. Water Resources Council Bulletin 17B (Reference 2).

a. Determine Flood-Discharge Frequency Distribution

For the source of flooding at the apex of each alluvial fan, a complete flood discharge-frequency distribution should be determined using log-Pearson Type III analyses in accordance with U.S. Water Resources Council Bulletin 17B. The determination of flood

discharges in arid regions, where alluvial fans are most typically found, should be closely coordinated with the PO to ensure agreement on methodology.

The skew coefficient, standard deviation, and mean of logarithms of discharges must be determined for the flooding source at the apex of the fan. When an analysis according to Water Resources Council Bulletin 17B is done, these statistics are known. For most alluvial fans, however, these statistics will not be available. Therefore, flows of various recurrence intervals should be computed from appropriate regional methods, and the synthetic log-Pearson Type III parameters should be derived.

(1) Derivation of Skew Coefficient. Derive the skew coefficient using the following equation:

$$G = -2.50 + 3.12 \frac{\mathrm{Log}(Q_{.01}/Q_{.10})}{\mathrm{Log}(Q_{.10}/Q_{.50})} \qquad (1)$$

Using the skew coefficient computed above and the K values for the skew as shown in Bulletin 17B, the standard deviation should be derived according to the following equation:

$$S = \frac{\log(Q_{.01}/Q_{.50})}{K_{.01} - K_{.50}} \qquad (2)$$

(2) Derivation of Mean of Logarithms. Using the values determined in Equations 1 and 2, the mean of logarithms should be derived according to the following equation:

$$\bar{X} = \log(Q_{.50}) - K_{.50}(S) \qquad (3)$$

where S and $\bar{X}$ are the standard deviation and mean, respectively; $Q_{.01}$, $Q_{.10}$, and $Q_{.50}$ are discharges with 0.01, and 0.10, and 0.50 exceedance probabilities respectively; and $K_{.01}$ and $K_{.50}$ are Pearson Type III deviates for respective exceedance probabilities of 0.01 and 0.50 and skew coefficient G. Equation (1) above is an approximation appropriate for use between skew values of +2.5 and -2.0.

b. Compute Transformation Variables

To permit solutions by use of log-Pearson Type III analysis and U.S. Water Resources Council Bulletin 17B, the log-Pearson Type III parameters must be transformed.

Variables for transforming these parameters should be computed as follows:

$m = \bar{X} - 2S/G$

$\alpha = 2/GS$

$\lambda = 4/G^2$

and

$a = \alpha - 0.92$

If the skew coefficient is zero (log normal distribution), the transformation variables should not be computed.

c. Transform Log-Pearson Type III Parameters

Where skew coefficients are not zero, the log-Pearson Type III parameters should be transformed using the variables computed above according to the following equations:

$$\bar{Z} = m + \lambda/a$$

$$S_Z^2 = \lambda/a^2$$

$$G_Z = 2/\lambda^{1/2}$$

Where the skew coefficient is zero (log normal distribution), compute the parameters as follows:

$$\bar{Z} = \bar{X} + 0.92S^2$$

$$S_Z = S$$

$$G_Z = G$$

d. Compute Transformation Constant

Where the skew coefficient is not zero, a transformation constant should be computed as follows:

$$C = \left(\frac{a}{a}\right)\lambda e^{0.92m}$$

Where the skew coefficient is zero (log normal distribution), the transformation constant should be computed as follows:

$$C = e^{0.92\bar{X} + 0.42S^2}$$

e. Determine Discharges for Depth and Velocity Zones

Discharges, Q (in cubic feet per second), that correspond to the various depth zone boundaries should be selected using the table below. This table was derived from the relationship

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

where D is the total depth in feet due to pressure head and velocity head.

Q	49.5	772	2770	6420	12000
D	0.5	1.5	2.5	3.5	4.5

Depth zones are designated from zone boundaries as follows:

Depth of Zone	Depth of Lower Boundary	Depth of Upper Boundary
1	0.5	1.5
2	1.5	2.5
3	2.5	3.5
4	3.5	4.5

Discharges, Q (in cubic feet per second), that correspond to the various velocity zone boundaries should be selected using the table below. This table was derived from the relationship $Q = 0.13V^3$, where V is velocity in feet per second.

Q	68	240	654	1510	3080	5770
V	3.5	4.5	5.5	6.5	7.5	8.5

Velocity zones are designated from zone boundaries as follows:

Zone Velocity	Velocity of Lower Boundary	Velocity of Upper Boundary
4.0	3.5	4.5
5.0	4.5	5.5
6.0	5.5	6.5
7.0	6.5	7.5
8.0	7.5	8.5

f. Compute Log-Pearson Type III Deviate

The log-Pearson Type III deviate (K) should be computed using the transformed parameters derived above for the discharges that correspond to each depth zone boundary and velocity zone boundary by the following equation:

$$K = \frac{\log Q - \bar{Z}}{S_Z}$$

g. Determine Probability of Transformed Discharge

The probability of the discharges that correspond to each depth zone boundary and each velocity zone boundary should be determined from Appendix 3 in Bulletin 17B, based on the transformed distribution using K and G_Z as follows:

$$P = \text{Prob.}\left\{Z \geq \log Q\right\}$$

h. Compute Fan Widths for Zone Boundaries

The fan widths (i.e., arc lengths from one lateral limit of the fan to the other taken parallel to contours) that correspond to each upper and lower zone boundary depth and velocity listed in Section A6-4e should be computed. The following formula should be used:

Fan Width = 950 ACP

where A is the avulsion coefficient, C is the transformation constant, and P is the probability of the discharge that corresponds to each given depth and velocity.

An avulsion coefficent (factor) greater than 1 should be selected by the Study Contractor in consultation with the PO. A factor of 1.5 is recommended in the absence of other data.

A6-5 FIRM

When the fan arc widths that form flood hazard zone boundaries have been computed, these distances should be scaled onto topographic base maps, taking care to make the boundaries parallel to contours.

The sketch map shown in Figure A6-1 depicts the typical distribution of flood insurance rate zones on an active alluvial fan, as determined by the methodology outlined in this Appendix.

A6-6 REFERENCES

1. David R. Dawdy, "Flood Frequency Estimates on Alluvial Fans," Journal of the Hydraulics Division ASCE, Proceedings, Vol. 105, No. HY11, pp. 1407-1413, 1979.

2. U.S. Water Resources Council, Hydrology Committee, Bulletin 17B, "Guidelines for Determining Flood Flow Frequency," September 1981.

A6-7 SAMPLE STUDY

The following sample study is presented to demonstrate the mapping of special flood hazard zones on active alluvial fans using the methodology described in this Appendix. The computational steps are generally carried out in the same sequence as they are listed in the Appendix.

a. Identification of Alluvial Fans

In this sample study, topographic map inspection, airphoto interpretation, and field reconnaissance were used to identify two coalescing, active alluvial fans that fell partly within the study area. To determine the flood hazard zone boundaries within the study area, it was necessary to determine them for the entire alluvial fans. The principal source of flooding was identified for each fan and designated Number One Canyon and Number Two Canyon. The overall boundaries of the fans were delineated on the best available topographic map, which in this case was a U.S. Geological Survey quadrangle at a scale of 1:24,000, with a contour interval of 20 feet.

b. Determination of Flood Discharge-Frequency Distribution

Previously published flood discharge-frequency studies were available for the source of flooding on the fans in this area. The corresponding log-Pearson Type III distribution parameters for discharges at the apex of Number One Canyon were as follows:

$\bar{X} = 2.06$

$S = 0.4965$

$G = 0.0$

Because the data for Number One Canyon showed a log normal (zero skew) distribution, it was not necessary to compute transformation variables. The transformation constant and transformed parameters were computed as follows:

$G_Z = G = 0.0$

$S_Z = S = 0.4965$

$\bar{Z} = \bar{X} + 0.92S^2 = 2.06 + 0.92 \times (0.4965)^2 = 2.29$

$C = e^{0.92\bar{X} + 0.42S^2} = e^{0.92 \times 2.06 + 0.42 \times (0.4965)^2} = 7.4$

c. Determination of Discharges for Depth and Velocity Zones

The discharges that correspond to the various depth zone boundaries were selected from the table shown in Section A6-4e of this Appendix. For Number One Canyon, these discharges are as follows:

Depth	Discharge
0.5	49.5
1.5	772.0
2.5	2770.0

The discharges that correspond to the various velocity zone boundaries were selected from the second table shown in Section A6-4e of this Appendix. For Number One Canyon, these discharges are as follows:

Velocity	Discharge
3.5	68
4.5	240
5.5	654
6.5	1510

d. Determine Probabilities of Transformed Discharges and Fan Widths at Zone Boundaries

The log-Pearson Type III standard deviates (K) were computed for the discharges (Q) that correspond to each depth zone boundary and each velocity zone boundary, using the equation

$$K = \frac{\log Q - \bar{Z}}{S_Z}$$

The probability of occurrence (P) of the discharges for the required depth and velocity boundaries were determined by interpolation of the deviate values (K) listed in Appendix 3 of Bulletin 17B.

Fan arc widths (W) were computed for each special flood hazard zone boundary using the equation

$$W = 950\ ACP$$

An avulsion coefficient (A) of 1.5 was assumed for each case.

Computations for Number One Canyon were made as follows:

For the 0.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 49.5 - 2.29}{0.4965} = \frac{1.695 - 2.29}{0.4965} = -1.199$$

$$P\{Q \geq 49.5\} = 950 \times 1.5 \times 7.4 \times 0.881 = 9290 \text{ feet}$$

For the 1.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 772 - 2.29}{0.4965} = \frac{2.888 - 2.29}{0.4965} = 1.204$$

$$P\{Q \geq 772\} = P\{K \geq 1.204\} = 0.118$$

$$W = 950\ ACP = 950 \times 1.5 \times 7.4 \times 0.118 = 1240 \text{ feet}$$

For the 2.5-foot depth boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 2770 - 2.29}{0.4965} = \frac{3.44 - 2.29}{0.4965} = 2.316$$

$$P\{Q \geq 2770\} = P\{K \geq 2.316\} = 0.0104$$

$$W = 950\ ACP = 950 \times 1.5 \times 7.4 \times 0.0104 = 110 \text{ feet}$$

For the 3.5-feet per second (fps) velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 68 - 2.29}{0.4965} = \frac{1.83 - 2.29}{0.4965} = -0.926$$

$$P\{Q \geq 68\} = P\{K \geq 0.926\} = 0.819$$

$$W = 950\ ACP = 950 \times 1.5 \times 7.4 \times 0.819 = 8640 \text{ feet}$$

For the 4.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 240 - 2.29}{0.4965} = \frac{2.39 - 2.29}{0.4965} = 0.201$$

$$P\{Q \geq 240\} = P\{K \geq 0.201\} = 0.42$$

$$W = 950\ ACP = 950 \times 1.5 \times 7.4 \times 0.42 = 4430 \text{ feet}$$

For the 5.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 654 - 2.29}{0.4965} = \frac{2.816 - 2.29}{0.4965} = 1.059$$

$$P\{Q \geq 654\} = P\{K \geq 1.059\} = 0.15$$

$$W = 950 \cdot ACP = 950 \times 1.5 \times 7.4 \times 0.15 = 1580 \text{ feet}$$

For the 6.5-fps velocity zone boundary:

$$K = \frac{\text{Log } Q - \bar{Z}}{S_Z} = \frac{\text{Log } 1510 - 2.29}{0.4965} = \frac{3.18 - 2.29}{0.4965} = 1.793$$

$$P\{Q \geq 1510\} = P\{K \geq 1.793\} = 0.037$$

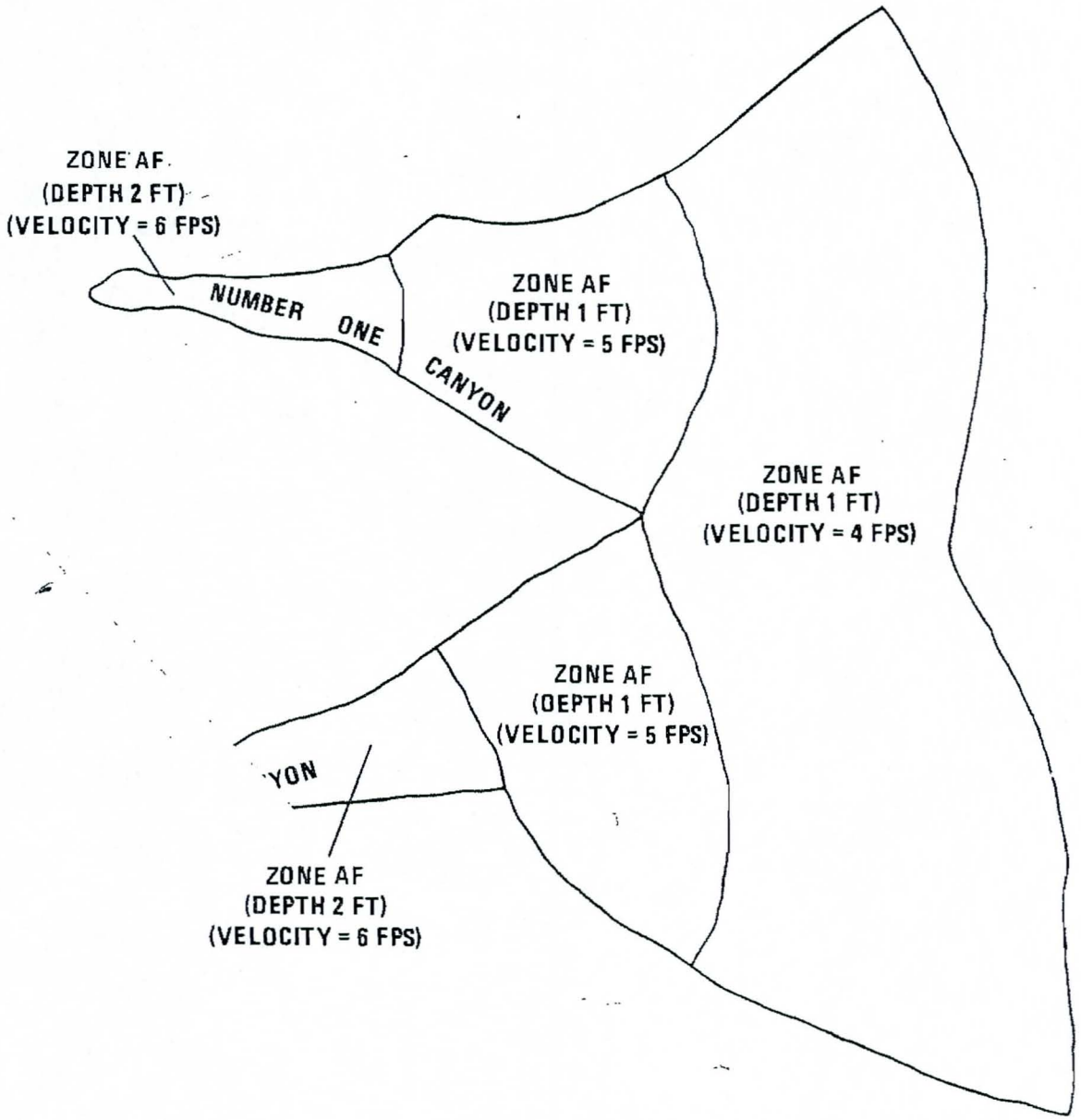
$$W = 950 \text{ ACP} = 950 \times 1.5 \times 7.4 \times 0.037 = 390 \text{ feet}$$

Fan arc widths were computed independently for the fan originating from Number Two Canyon. The computed widths were then fit to the proper contours on the fans to produce the flood hazard zone boundaries as shown on the map.

FIGURE A6-1.

DISTRIBUTION OF SPECIAL FLOOD HAZARDS ZONES

SAMPLE STUDY



APPENDIX J.--Sample computation of hydraulic geometry exponents

HYDRAULIC GEOMETRY

The following cross section was surveyed by hand level during June, 1993 at the location shown in fiqure 5. The reach was uniform and there were no sign of recent bank erosion. The tables and figure are self explanatory.

Table J1.--Surveyed stations and elevations for cross section at 1969 ft. elevation.

Dist. (ft.)	Elev. (ft.)	Dist. (ft.)	Elev. (ft.)	Dist. (ft.)	Elev. (ft.)	Dist. (ft.)	Elev. (ft.)
.0	70.30	4.0	70.10	7.0	69.60	10.0	69.10
11.0	68.80	12.0	68.60	15.0	68.50	20.0	68.50
22.5	68.45	23.5	68.75	25.0	69.40	27.0	70.20
30.5	70.40						

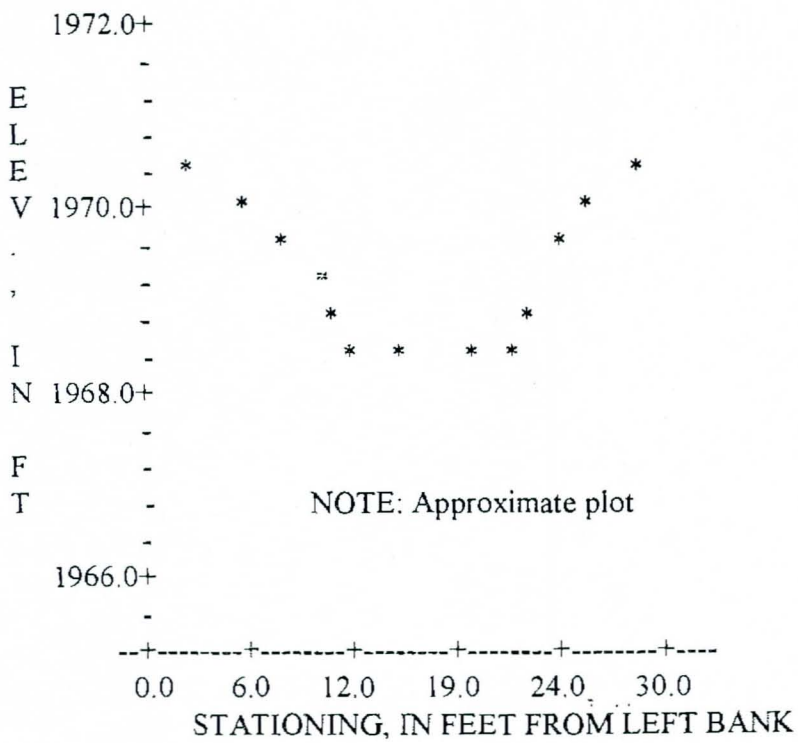


Figure J1.-- Cross section at 1969 ft. elevation

The range of water surface elevation is selected where the width, depth and velocity exponents are constant. In other words, the shape and roughness of the channel is uniform for the range of stage. The discharge, width, mean depth, and mean velocity are converted to logs and the exponents are determined using linear regression as shown below. See "Hydraulic geometry" on page 39.

Table J2.--Hydraulic parameters of cross-section at 1969 ft. elevation.

Water-surface elevation (ft.)	Area (sq. ft.)	Conveyance (cfs)	Top width (ft.)	Wetted perim- (ft.)	Left edge (ft.)	Right edge (ft.)	Discharge at critical depth (cfs)
1969.00	6.	128.	14.	14.	10.	24.	23.
1969.10	7.	176.	14.	14.	10.	24.	30.
1969.20	9.	229.	15.	15.	9.	25.	39.
1969.30	10.	290.	16.	16.	9.	25.	48.
1969.40	12.	357.	17.	17.	8.	25.	58.
1969.50	14.	431.	18.	18.	8.	25.	72.
1969.60	16.	513.	18.	19.	7.	25.	81.
1969.70	17.	602.	19.	20.	6.	26.	94.
1969.80	19.	699.	20.	21.	6.	26.	108.
1969.90	22.	804.	21.	21.	5.	26.	124.
1970.00	24.	917.	22.	22.	5.	26.	140.
1970.10	26.	1039.	23.	23.	4.	27.	157.
1970.20	28.	1130.	25.	25.	2.	27.	171.
1970.30	31.	1200.	29.	29.	0.	29.	183.

The following is output from Minitab. Row C1 is the water surface elevation + 1900 ft. corresponding to the elevation in table J2.

ROW	C1	width	depth	vel	disch	Vc	Qc
1	69.1	14	0.50000	3.54514	24.816	4.28571	30
2	69.2	15	0.60000	3.58767	32.289	4.33333	39
3	69.3	16	0.62500	4.08900	40.890	4.80000	48
4	69.4	17	0.70588	4.19475	50.337	4.83333	58
5	69.5	18	0.77778	4.34079	60.771	4.92857	69
6	69.6	18	0.88889	4.52081	72.333	5.06250	81
7	69.7	19	0.89474	4.99306	84.882	5.52941	94
8	69.8	20	0.95000	5.18732	98.559	5.68421	108
9	69.9	21	1.04762	5.15291	113.364	5.63636	124
10	70.0	22	1.09091	5.38737	129.297	5.83333	140
11	70.1	23	1.13043	5.63458	146.499	6.03846	157
12	70.2	25	1.12000	5.69036	159.330	6.10714	171

MTB > OH=24

MTB > plot 'l-w' vs 'l-q' (a plot of log Qc versus log width)

```
        -
   1.40+                                  *
        -
l-w     -                                *
        -                              *
        -                            *
   1.30+                         *
        -                      *
        -                  *   *
        -              *
        -
   1.20+           *
        -       *
        -
        - *
        -
   1.10+
        ------+-------+-------+-------+-------+------l-q
            1.50    1.65    1.80    1.95    2.10
```

NOTE: Plot is approximate

MTB > regress 'l-w' 1 'l-q'

The regression equation is
l-w = 0.741 + 0.286 l-q (the exponent for width is 0.29 as shown in table 5 of this report)

Predictor	Coef	Stdev	t-ratio	p
Constant	0.74053	0.02593	28.55	0.000
l-q	0.28610	0.01382	20.70	0.000

s = 0.01210 R-sq = 97.7% R-sq(adj) = 97.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	0.062749	0.062749	428.68	0.000
Error	10	0.001464	0.000146		
Total	11	0.064213			

MTB > plot 'l-d' vs 'l-q' (plot of log Qc versus log depth)

```
l-d      -
         -                                  * * *
         -                              *
       0.00+
         -                          *
         -                      *   *
         -
         -
      -0.12+                  *
         -              *
         -
         -
         -       *   *     NOTE: Plot is approximate
      -0.24+
         -
         -
         - *
        ------+-------+-------+-------+-------+------l-q
            1.50    1.65    1.80    1.95    2.10
```

Y
MTB > regress 'l-d' 1 'l-q'

The regression equation is
l-d = - 0.906 + 0.445 l-q

Predictor	Coef	Stdev	t-ratio	p
Constant	-0.90616	0.03188	-28.42	0.000
l-q	0.44474	0.01699	26.18	0.000

s = 0.01487 R-sq = 98.6% R-sq(adj) = 98.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	0.15162	0.15162	685.39	0.000
Error	10	0.00221	0.00022		
Total	11	0.15383			

MTB > plot 'l-v' vs 'l-q' (plot of log Qc versus log Vc)

```
      -                                  * *
l-v   -
      -                                   *
      -                              *  *
  0.700+                         *
      -
      -
      -                     *
      -                 *
  0.630+
      -           *   *
      -
      -
      -
  0.560+        *  NOTE: Plot is approximate
      - *
      -
      ------+-------+-------+-------+-------+------l-q
          1.50    1.65    1.80    1.95    2.10
```

Y
MTB > regress 'l-v' 1 'l-q'

The regression equation is
l-v = 0.166 + 0.269 l-q

Predictor	Coef	Stdev	t-ratio	p
Constant	0.16562	0.02257	7.34	0.000
l-q	0.26916	0.01203	22.38	0.000

s = 0.01053 R-sq = 98.0% R-sq(adj) = 97.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	0.055537	0.055537	501.00	0.000
Error	10	0.001109	0.000111		
Total	11	0.056645			

```
  T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

  T2           SEC 100 FT WEST OF 40th St & 1950 FT S. OF DYNAMITE BLVD

  T3            COARSE SAND bed(firm) , CEMENTED BANKS

  *

1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
            SEC 100 FT WEST OF 40th St & 1950 FT S. OF DYNAMITE BLVD
             COARSE SAND bed(firm) , CEMENTED BANKS
            *** RUN DATE & TIME: 06-10-93  19:10

 *** START PROCESSING CROSS SECTION - "S1755"
  XS   S1755

  GR        0,5.9 9,5.9 13,5.6 18.5,4.4 20,4.0 22,4.2 26,4.3

  GR        31,4.3 34,5.2 40,5.7 50,5.9

  N               .040

  *

  HP 1 S1755 4.4,.1,5.9


 *** FINISH PROCESSING CROSS SECTION - "S1755"
 *** CROSS SECTION "S1755" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S1755" AT SRD =********  ERR-CODE =      0

      SKEW      IHFNO     VSLOPE        EK        CK
       .0         0.  *********       .50       .00

 X-Y COORDINATE PAIRS  (NGP =  11):
        X       Y          X       Y          X       Y          X       Y
       .0    5.90        9.0    5.90       13.0    5.60       18.5    4.40
     20.0    4.00       22.0    4.20       26.0    4.30       31.0    4.30
     34.0    5.20       40.0    5.70       50.0    5.90

  X-Y MAX-MIN POINTS:
      XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0    5.90       20.0    4.00       50.0    5.90         .0    5.90

 ROUGHNESS COEFFICIENTS (NSA =  1):
          .040
1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
            SEC 100 FT WEST OF 40th St & 1950 FT S. OF DYNAMITE BLVD
             COARSE SAND bed(firm) , CEMENTED BANKS
            *** RUN DATE & TIME: 06-10-93  19:10
     CROSS SECTION PROPERTIES:  ISEQ =  1:  SECID = S1755:  SRD =*********
```

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	2.	22.	13.	13.				5.
4.40		2.	22.	13.	13.	1.00	19.	31.	5.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	3.	48.	14.	14.				9.
4.50		3.	48.	14.	14.	1.00	18.	32.	9.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	5.	84.	14.	15.				15.
4.60		5.	84.	14.	15.	1.00	18.	32.	15.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	6.	127.	15.	15.				23.
4.70		6.	127.	15.	15.	1.00	17.	32.	23.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	8.	178.	16.	16.				31.
4.80		8.	178.	16.	16.	1.00	17.	33.	31.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	9.	237.	17.	17.				40.
4.90		9.	237.	17.	17.	1.00	16.	33.	40.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	11.	304.	18.	18.				50.
5.00		11.	304.	18.	18.	1.00	16.	33.	50.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	13.	378.	18.	19.				62.
5.10		13.	378.	18.	19.	1.00	15.	34.	62.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	15.	460.	19.	19.				74.
5.20		15.	460.	19.	19.	1.00	15.	34.	74.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	17.	538.	21.	21.				86.
5.30		17.	538.	21.	21.	1.00	14.	35.	86.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	19.	626.	22.	23.				99.
5.40		19.	626.	22.	23.	1.00	14.	36.	99.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	21.	724.	24.	24.				114.
5.50		21.	724.	24.	24.	1.00	13.	38.	114.

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 100 FT WEST OF 40th St & 1950 FT S. OF DYNAMITE BLVD
COARSE SAND bed(firm) , CEMENTED BANKS
*** RUN DATE & TIME: 06-10-93 19:10
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1755; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	24.	833.	26.	26.				130.
5.60		24.	833.	26.	26.	1.00	13.	39.	130.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	27.	937.	28.	29.				146.
5.70		27.	937.	28.	29.	1.00	12.	40.	146.

```
WSEL   SA#     AREA        K   TOPW   WETP   ALPH    LEW    REW     QCR
          1     30.      989.   35.    35.                          156.
5.80            30.      989.   35.    35.   1.00    10.    45.     156.

WSEL   SA#     AREA        K   TOPW   WETP   ALPH    LEW    REW     QCR
          1     33.     1082.   41.    41.                          171.
5.90            33.     1082.   41.    41.   1.00     9.    50.     171.

WSEL   SA#     AREA        K   TOPW   WETP   ALPH    LEW    REW     QCR
          1     33.     1082.   41.    41.                          171.
5.90            33.     1082.   41.    41.   1.00     9.    50.     171.
```

```
T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

T2           SEC 100 FT WEST OF 40th St & 750 FT S. OF DYNAMITE BLVD

T3            COARSE SAND 14.5-21, CEMENTED BANKS

*

1
WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 100 FT WEST OF 40th St & 750 FT S. OF DYNAMITE BLVD
            COARSE SAND 14.5-21, CEMENTED BANKS
           *** RUN DATE & TIME: 06-11-93  08:45

*** START PROCESSING CROSS SECTION - "S1763"
  XS   S1763

  GR        0,6.7 7,3.8 11,4.4 13,5.0 14.5,4.15 18,4.2 21,4.1

  GR        24,4.9 27,5.5 33,6.8 40,7.0

  N               .040

  *

  HP 1 S1763 4.4,.2,6.7

*** FINISH PROCESSING CROSS SECTION - "S1763"
*** CROSS SECTION "S1763" WRITTEN TO DISK, RECORD NO. =  1

--- OATA SUMMARY FOR SECID "S1763" AT SRD =********  ERR-CODE =      0

     SKEW     IHFNO    VSLOPE        EK        CK
       .0        0. *********      .50       .00

X-Y COORDINATE PAIRS  (NGP =  11):
      X       Y          X       Y          X       Y          X       Y
      .0    6.70       7.0    3.80       11.0    4.40       13.0    5.00
    14.5    4.15      18.0    4.20       21.0    4.10       24.0    4.90
    27.0    5.50      33.0    6.80       40.0    7.00
```

XMIN	Y	X	YMIN	XMAX	Y	X	YMAX
.0	6.70	7.0	3.80	40.0	7.00	40.0	7.00

ROUGHNESS COEFFICIENTS (NSA = 1):
.040

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 100 FT WEST OF 40th St & 750 FT S. OF DYNAMITE BLVD
COARSE SAND 14.5-21, CEMENTED BANKS
*** RUN DATE & TIME: 06-11-93 08:45
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1763; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	3.	50.	14.	14.				10.
4.40		3.	50.	14.	14.	1.00	6.	22.	10.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	6.	126.	16.	16.				23.
4.60		6.	126.	16.	16.	1.00	5.	23.	23.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	10.	234.	18.	19.				40.
4.80		10.	234.	18.	19.	1.00	5.	24.	40.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	14.	375.	20.	21.				63.
5.00		14.	375.	20.	21.	1.00	4.	24.	63.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	18.	563.	22.	23.				91.
5.20		18.	563.	22.	23.	1.00	4.	25.	91.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	22.	786.	23.	24.				124.
5.40		22.	786.	23.	24.	1.00	3.	26.	124.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	27.	1046.	25.	26.				161.
5.60		27.	1046.	25.	26.	1.00	3.	27.	161.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	32.	1344.	26.	27.				203.
5.80		32.	1344.	26.	27.	1.00	2.	28.	203.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	38.	1679.	28.	29.				249.
6.00		38.	1679.	28.	29.	1.00	2.	29.	249.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	43.	2052.	29.	30.				300.
6.20		43.	2052.	29.	30.	1.00	1.	30.	300.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	49.	2464.	30.	32.				355.
6.40		49.	2464.	30.	32.	1.00	1.	31.	355.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	55.	2916.	32.	33.				415.
6.60		55.	2916.	32.	33.	1.00	0.	32.	415.

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

```
          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 100 FT WEST OF 40th St & 750 FT S. OF DYNAMITE BLVD
            COARSE SAND 14.5-21, CEMENTED BANKS
           *** RUN DATE & TIME: 06-11-93  08:45
     CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1763;  SRD =*********

      WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       59.     3157.    33.    34.                          447.
      6.70           59.     3157.    33.    34.  1.00     0.    33.     447.
1
```

```
   T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

   T2           SEC 1270 FT WEST OF TATUM BLVD & 2010 FT S. OF DYNAMITE BLVD

   T3            COARSE SAND bed(firm) , CEMENTED BANKS

   *

1
 WSPRO          FEDERAL HIGHWAY AOMINISTRATION - U. S. GEOLOGICAL SURVEY
 P0601B8            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 1270 FT WEST OF TATUM BLVD & 2010 FT S. OF DYNAMITE BLVD
            COARSE SAND bed(firm) , CEMENTED BANKS
           *** RUN OATE & TIME: 06-10-93  17:38

 *** START PROCESSING CROSS SECTION - "S1808"
   XS   S1808

   GR        0,6.2 10,6 15,5.3 17,5 19,4.7 23,4.6

   GR        26.5,4.4 26.5,5.2 30,5.7 35,6.4 100,6.2

   N                .040

   *

   HP 1 S1808 5.0,.1,6.2


 *** FINISH PROCESSING CROSS SECTION - "S1808"
 *** CROSS SECTION "S1808" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S1808" AT SRD =********  ERR-COOE =       0

      SKEW     IHFNO    VSLOPE        EK        CK
       .0        0. *********       .50       .00

 X-Y COORDINATE PAIRS  (NGP =  11):
        X       Y          X       Y          X       Y          X       Y
       .0    6.20       10.0    6.00       15.0    5.30       17.0    5.00
     19.0    4.70       23.0    4.60       26.5    4.40       26.5    5.20
     30.0    5.70       35.0    6.40      100.0    6.20

  X-Y MAX-MIN POINTS:
      XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0    6.20       26.5    4.40      100.0    6.20       35.0    6.40
```

ROUGHNESS COEFFICIENTS (NSA = 1):
.040

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 1270 FT WEST OF TATUM BLVD & 2010 FT S. OF DYNAMITE BLVD
COARSE SAND bed(firm) , CEMENTED BANKS
*** RUN DATE & TIME: 06-10-93 17:38
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1808; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	3.	63.	10.	10.				12.
5.00		3.	63.	10.	10.	1.00	17.	27.	12.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	4.	91.	10.	11.				17.
5.10		4.	91.	10.	11.	1.00	16.	27.	17.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	5.	123.	11.	12.				22.
5.20		5.	123.	11.	12.	1.00	16.	27.	22.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	7.	157.	12.	13.				28.
5.30		7.	157.	12.	13.	1.00	15.	27.	28.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	8.	197.	14.	14.				34.
5.40		8.	197.	14.	14.	1.00	14.	28.	34.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	9.	245.	15.	16.				42.
5.50		9.	245.	15.	16.	1.00	14.	29.	42.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	11.	299.	16.	17.				51.
5.60		11.	299.	16.	17.	1.00	13.	29.	51.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	13.	362.	18.	19.				60.
5.70		13.	362.	18.	19.	1.00	12.	30.	60.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	15.	433.	19.	20.				71.
5.80		15.	433.	19.	20.	1.00	11.	31.	71.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	17.	513.	21.	22.				84.
5.90		17.	513.	21.	22.	1.00	11.	31.	84.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	19.	602.	22.	23.				97.
6.00		19.	602.	22.	23.	1.00	10.	32.	97.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	21.	641.	28.	29.				105.
6.10		21.	641.	28.	29.	1.00	5.	33.	105.

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MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 1270 FT WEST OF TATUM BLVD & 2010 FT S. OF DYNAMITE BLVD

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          *** RUN DATE & TIME: 06-10-93  17:38
    CROSS-SECTION PROPERTIES:  ISEQ =  1:  SECID = S1808;  SRD =*********

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       24.      712.    34.    35.                         117.
     6.20            24.      712.    34.    35.  1.00     0.    34.     117.

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       24.      712.    34.    35.                         117.
     6.20            24.      712.    34.    35.  1.00     0.    34.     117.
1

                    Note: Channel altered upstream and downstream
                          of reach.  Not used for hydraulic geometry
                          relations.
  T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

  T2           SEC 630 FT WEST OF TATUM BLVD & 2500 FT S. OF DYNAMITE BLVD

  T3            COARSE SAND 15.5-20, CEMENTED BANKS

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 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
            SEC 630 FT WEST OF TATUM BLVD & 2500 FT S. OF DYNAMITE BLVD
             COARSE SAND 15.5-20, CEMENTED BANKS
            *** RUN DATE & TIME: 06-10-93  16:58

 *** START PROCESSING CROSS SECTION - "S1815"
   XS   S1815

   GR        0,7.3 10,7.1 11.5,7.0 13.4,6.3 15.2,5.3 15.5,4.5 20,4.6

   GR        22,5.5 24,5.8 30,6.3 38,6.6 100,6.6

   N                .040

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   HP 1 S1815 5.0,.1,6.6


 *** FINISH PROCESSING CROSS SECTION - "S1815"
 *** CROSS SECTION "S1815" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S1815" AT SRD =********  ERR-CODE =      0

      SKEW      IHFNO    VSLOPE        EK        CK
       .0         0.  *********      .50       .00

 X-Y COORDINATE PAIRS  (NGP =  12):
        X       Y          X       Y          X       Y          X       Y
       .0    7.30       10.0    7.10       11.5    7.00       13.4    6.30
     15.2    5.30       15.5    4.50       20.0    4.60       22.0    5.50
     24.0    5.80       30.0    6.30       38.0    6.60      100.0    6.60

  X-Y MAX-MIN POINTS:
      XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0    7.30       15.5    4.50      100.0    6.60         .0    7.30

 ROUGHNESS COEFFICIENTS (NSA =  1):
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MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 630 FT WEST OF TATUM BLVD & 2500 FT S. OF DYNAMITE BLVD
COARSE SAND 15.5-20, CEMENTED BANKS
*** RUN DATE & TIME: 06-10-93 16:58

CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1815; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	2.	44.	6.	6.				8.
5.00		2.	44.	6.	6.	1.00	15.	21.	8.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	3.	61.	6.	6.				11.
5.10		3.	61.	6.	6.	1.00	15.	21.	11.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	3.	81.	6.	7.				15.
5.20		3.	81.	6.	7.	1.00	15.	21.	15.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	4.	104.	6.	7.				18.
5.30		4.	104.	6.	7.	1.00	15.	22.	18.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	5.	128.	7.	8.				22.
5.40		5.	128.	7.	8.	1.00	15.	22.	22.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	5.	155.	7.	8.				27.
5.50		5.	155.	7.	8.	1.00	15.	22.	27.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	6.	180.	8.	9.				31.
5.60		6.	180.	8.	9.	1.00	15.	23.	31.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	7.	209.	9.	10.				35.
5.70		7.	209.	9.	10.	1.00	14.	23.	35.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	8.	243.	10.	11.				41.
5.80		8.	243.	10.	11.	1.00	14.	24.	41.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	9.	274.	11.	12.				46.
5.90		9.	274.	11.	12.	1.00	14.	25.	46.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	10.	313.	12.	13.				52.
6.00		10.	313.	12.	13.	1.00	14.	26.	52.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	11.	359.	14.	15.				59.
6.10		11.	359.	14.	15.	1.00	14.	28.	59.

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MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 630 FT WEST OF TATUM BLVD & 2500 FT S. OF DYNAMITE BLVD
COARSE SAND 15.5-20, CEMENTED BANKS
*** RUN DATE & TIME: 06-10-93 16:58
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1815; SRD =*********

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WSEL   SA#      AREA        K    TOPW    WETP   ALPH     LEW     REW     QCR
         1       13.      412.    15.     16.                             67.
6.20             13.      412.    15.     16.   1.00     14.     29.     67.

WSEL   SA#      AREA        K    TOPW    WETP   ALPH     LEW     REW     QCR
         1       14.      473.    17.     18.                             77.
6.30             14.      473.    17.     18.   1.00     13.     30.     77.

WSEL   SA#      AREA        K    TOPW    WETP   ALPH     LEW     REW     QCR
         1       16.      519.    20.     21.                             84.
6.40             16.      519.    20.     21.   1.00     13.     33.     84.

WSEL   SA#      AREA        K    TOPW    WETP   ALPH     LEW     REW     QCR
         1       18.      581.    22.     24.                             94.
6.50             18.      581.    22.     24.   1.00     13.     35.     94.

WSEL   SA#      AREA        K    TOPW    WETP   ALPH     LEW     REW     QCR
         1       21.      659.    25.     27.                            107.
6.60             21.      659.    25.     27.   1.00     13.     38.    107.

WSEL   SA#      AREA        K    TOPW    WETP   ALPH     LEW     REW     QCR
         1       21.      659.    25.     27.                            107.
6.60             21.      659.    25.     27.   1.00     13.     38.    107.
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T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

T2           SEC 130 FT DWNSTR OF TATUM BLVD & 190 FT N. OF DYNAMITE BLVD

T3            COARSE SAND 19.5-34.5

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WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 130 FT DWNSTR OF TATUM BLVD & 190 FT N. OF DYNAMITE BLVD
            COARSE SAND 19.5-34.5
           *** RUN DATE & TIME: 06-10-93  15:31

*** START PROCESSING CROSS SECTION - "S1843"
  XS   S1843

  GR        0,6.9 10,6.8 13,6.5 17,5.8 19.5,4.5 21,4.4 25,3.9 30,3.9

  GR        34.5,3.9 38,4.3 39,5.6 41,6.0 47,6.6 53,6.6 110,6.6

  N               .040

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  HP 1 S1843 4.4,.1,6.6

*** FINISH PROCESSING CROSS SECTION - "S1843"
*** CROSS SECTION "S1843" WRITTEN TO DISK, RECORD NO. =  1

--- DATA SUMMARY FOR SECID "S1843" AT SRD =********  ERR-CODE =       0
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SKEW	IHFNO	VSLOPE	EK	CK
.0	0.	*********	.50	.00

X-Y COORDINATE PAIRS (NGP = 15):

X	Y	X	Y	X	Y	X	Y
.0	6.90	10.0	6.80	13.0	6.50	17.0	5.80
19.5	4.50	21.0	4.40	25.0	3.90	30.0	3.90
34.5	3.90	38.0	4.30	39.0	5.60	41.0	6.00
47.0	6.60	53.0	6.60	110.0	6.60		

X-Y MAX-MIN POINTS:

XMIN	Y	X	YMIN	XMAX	Y	X	YMAX
.0	6.90	25.0	3.90	110.0	6.60	.0	6.90

ROUGHNESS COEFFICIENTS (NSA = 1):
.040

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 130 FT DWNSTR OF TATUM BLVD & 190 FT N. OF DYNAMITE BLVD
COARSE SAND 19.5-34.5
*** RUN DATE & TIME: 06-10-93 15:31

CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1843; SRO =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	7.	137.	17.	17.				24.
4.40		7.	137.	17.	17.	1.00	21.	38.	24.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	9.	190.	19.	19.				33.
4.50		9.	190.	19.	19.	1.00	20.	38.	33.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	10.	261.	19.	19.				44.
4.60		10.	261.	19.	19.	1.00	19.	38.	44.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	12.	340.	19.	19.				56.
4.70		12.	340.	19.	19.	1.00	19.	38.	56.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	14.	429.	19.	20.				70.
4.80		14.	429.	19.	20.	1.00	19.	38.	70.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	16.	525.	20.	20.				84.
4.90		16.	525.	20.	20.	1.00	19.	38.	84.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	18.	629.	20.	21.				99.
5.00		18.	629.	20.	21.	1.00	19.	39.	99.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	20.	740.	20.	21.				115.
5.10		20.	740.	20.	21.	1.00	18.	39.	115.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	22.	859.	21.	21.				132.
5.20		22.	859.	21.	21.	1.00	18.	39.	132.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	24.	986.	21.	22.				150.
5.30		24.	986.	21.	22.	1.00	18.	39.	150.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	26.	1119.	21.	22.				168.
5.40		26.	1119.	21.	22.	1.00	18.	39.	168.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	29.	1259.	21.	22.				188.
5.50		29.	1259.	21.	22.	1.00	18.	39.	188.

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MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 130 FT DWNSTR OF TATUM BLVD & 190 FT N. OF DYNAMITE BLVD
COARSE SAND 19.5-34.5
*** RUN DATE & TIME: 06-10-93 15:31
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1843; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	31.	1406.	22.	23.				208.
5.60		31.	1406.	22.	23.	1.00	17.	39.	208.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	33.	1545.	22.	23.				227.
5.70		33.	1545.	22.	23.	1.00	17.	39.	227.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	35.	1691.	23.	24.				247.
5.80		35.	1691.	23.	24.	1.00	17.	40.	247.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	38.	1829.	24.	25.				266.
5.90		38.	1829.	24.	25.	1.00	16.	40.	266.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	40.	1976.	25.	26.				286.
6.00		40.	1976.	25.	26.	1.00	16.	41.	286.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	43.	2110.	27.	28.				305.
6.10		43.	2110.	27.	28.	1.00	15.	42.	305.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	45.	2257.	28.	29.				326.
6.20		45.	2257.	28.	29.	1.00	15.	43.	326.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	48.	2417.	30.	31.				348.
6.30		48.	2417.	30.	31.	1.00	14.	44.	348.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	51.	2590.	31.	33.				372.
6.40		51.	2590.	31.	33.	1.00	14.	45.	372.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	55.	2777.	33.	34.				398.
6.50		55.	2777.	33.	34.	1.00	13.	46.	398.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	58.	2957.	35.	36.				423.
6.60		58.	2957.	35.	36.	1.00	12.	47.	423.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	58.	2957.	35.	36.				423.
6.60		58.	2957.	35.	36.	1.00	12.	47.	423.

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  T1          MARICOPA CO.  REGIME STUDY    HJALMARSON 6/9/93

  T2           SEC 100 FT UPSTR OF TATUM BLVD & 770 FT N. OF DYNAMITE BLVD

  T3            COARSE SAND 21-36

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 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY    HJALMARSON 6/9/93
            SEC 100 FT UPSTR OF TATUM BLVD & 770 FT N. OF DYNAMITE BLVD
             COARSE SAND 21-36
            *** RUN DATE & TIME: 06-10-93  12:49

 *** START PROCESSING CROSS SECTION - "S1850"
  XS   S1850

  GR        0,7.1 10,6.6 19,6.1 20,5.7 21,5.1 25,5.1 26,4.8 30,4.9 36,4.8

  GR        38,5.0 40,5.5 44,6.2 50,6.5 60,7.0 130,7.0

  N               .040

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  HP 1 S1850 5.3,.1,7.0

 +++008 INVALID DATA NEAR COLUMN  21

 *** FINISH PROCESSING CROSS SECTION - "S1850"
 *** CROSS SECTION "S1850" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S1850" AT SRD =********  ERR-CODE =      0

      SKEW      IHFNO    VSLOPE        EK        CK
       .0         0. *********       .50       .00

 X-Y COORDINATE PAIRS  (NGP =  15):
       X       Y          X       Y          X       Y          X       Y
      .0     7.10       10.0    6.60       19.0    6.10       20.0    5.70
    21.0     5.10       25.0    5.10       26.0    4.80       30.0    4.90
    36.0     4.80       38.0    5.00       40.0    5.50       44.0    6.20
    50.0     6.50       60.0    7.00      130.0    7.00

  X-Y MAX-MIN POINTS:
      XMIN       Y          X    YMIN      XMAX       Y          X    YMAX
       .0     7.10       26.0    4.80     130.0    7.00         .0    7.10

 ROUGHNESS COEFFICIENTS (NSA =  1):
          .040
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY    HJALMARSON 6/9/93
            SEC 100 FT UPSTR OF TATUM BLVD & 770 FT N. OF DYNAMITE BLVD
             COARSE SAND 21-36
            *** RUN DATE & TIME: 06-10-93  12:49
      CROSS SECTION PROPERTIES:  ICSC =  1   SECID =  S1850:  SRD =*********
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WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	7.	125.	19.	19.				23.
5.30		7.	125.	19.	19.	1.00	21.	39.	23.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	9.	185.	19.	19.				32.
5.40		9.	185.	19.	19.	1.00	21.	40.	32.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	10.	255.	20.	20.				43.
5.50		10.	255.	20.	20.	1.00	20.	40.	43.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	12.	332.	20.	21.				55.
5.60		12.	332.	20.	21.	1.00	20.	41.	55.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	15.	419.	21.	21.				69.
5.70		15.	419.	21.	21.	1.00	20.	41.	69.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	17.	514.	22.	22.				83.
5.80		17.	514.	22.	22.	1.00	20.	42.	83.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	19.	618.	23.	23.				98.
5.90		19.	618.	23.	23.	1.00	20.	42.	98.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	21.	732.	24.	24.				115.
6.00		21.	732.	24.	24.	1.00	19.	43.	115.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	24.	854.	24.	25.				132.
6.10		24.	854.	24.	25.	1.00	19.	43.	132.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	26.	954.	27.	27.				147.
6.20		26.	954.	27.	27.	1.00	17.	44.	147.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	29.	1039.	31.	31.				161.
6.30		29.	1039.	31.	31.	1.00	15.	46.	161.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	32.	1148.	34.	35.				178.
6.40		32.	1148.	34.	35.	1.00	14.	48.	178.

1

WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON 6/9/93
SEC 100 FT UPSTR OF TATUM BLVD & 770 FT N. OF DYNAMITE BLVD
COARSE SAND 21-36
*** RUN DATE & TIME: 06-10-93 12:49
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1850; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	36.	1279.	38.	39.				198.
6.50		36.	1279.	38.	39.	1.00	12.	50.	198.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	40.	1432.	42.	42.				222.
6.60		40.	1432.	42.	42.	1.00	10.	52.	222.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	44.	1605.	46.	46.				248.
6.70		44.	1605.	46.	46.	1.00	8.	54.	248.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	49.	1802.	50.	50.				277.
6.80		49.	1802.	50.	50.	1.00	6.	56.	277.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	54.	2025.	54.	54.				310.
6.90		54.	2025.	54.	54.	1.00	4.	58.	310.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	60.	2274.	58.	58.				346.
7.00		60.	2274.	58.	58.	1.00	2.	60.	346.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	60.	2274.	58.	58.				346.
7.00		60.	2274.	58.	58.	1.00	2.	60.	346.

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/18/93
370 FT n. of dynamite Blvd & 110 FT W. OF 50TH ST
COARSE SAND, CEMENTED BANKS-2nd small channel to north
*** RUN DATE & TIME: 06-21-93 08:26

2.0	68.80	4.0	68.30	5.0	67.90	8.0	66.90
9.0	66.50	10.0	66.10	15.0	66.20	19.5	66.20
21.0	67.00	24.0	67.80	28.0	68.50	30.0	69.05
32.0	69.10						

X-Y MAX-MIN POINTS:

XMIN	Y	X	YMIN	XMAX	Y	X	YMAX
2.0	68.80	10.0	66.10	32.0	69.10	32.0	69.10

ROUGHNESS COEFFICIENTS (NSA = 1):
.040

1

WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/18/93
370 FT n. of dynamite Blvd & 110 FT W. OF 50TH ST
COARSE SAND, CEMENTED BANKS-2nd small channel to north
*** RUN DATE & TIME: 06-21-93 08:26

CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1866; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	5.	89.	11.	12.				16.
66.60		5.	89.	11.	12.	1.00	9.	20.	16.
66.80		7.	171.	12.	13.	1.00	8.	21.	29.
67.00		9.	276.	13.	14.	1.00	8.	21.	45.
67.20		12.	398.	15.	15.	1.00	7.	22.	64.
67.40		15.	544.	16.	16.	1.00	7.	22.	85.
67.60		19.	715.	17.	18.	1.00	6.	23.	110.
67.80		22.	912.	19.	19.	1.00	5.	24.	138.
68.00		26.	1128.	20.	21.	1.00	5.	25.	168.
68.20		30.	1375.	22.	23.	1.00	4.	26.	203.
68.40		35.	1649.	24.	25.	1.00	4.	27.	241.
68.60		40.	1963.	26.	26.	1.00	3.	28.	283.
68.80		45.	2321.	27.	28.	1.00	2.	29.	331.

1

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P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
           370 FT n. of dynamite Blvd & 110 FT W. OF 50TH ST
            COARSE SAND, CEMENTED BANKS-2nd small channel to north
           *** RUN DATE & TIME: 06-21-93  08:26
    CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1866;  SRD =*********

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       45.     2321.    27.    28.                          331.
    68.80            45.     2321.    27.    28.  1.00     2.    29.     331.


  T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93

  T2           200 FT SOUTH OF dynamite blvd & 1380 FT W.oF 53TH ST

  T3            1920 ft e. of tatum COARSE SAND CEMENTED BANKS

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1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
           200 FT SOUTH OF dynamite blvd & 1380 FT W.oF 53TH ST
            1920 ft e. of tatum COARSE SAND CEMENTED BANKS
           *** RUN DATE & TIME: 06-21-93  11:40

 *** START PROCESSING CROSS SECTION - "S1872"
   XS   S1872

   GR        0,73.2 5,73.05 8,72.4 9.5,72.05 10,71.75 12,71.75

   GR        14,71.6 15,72.15 18,72.5 21,72.6 27,73.25 31,73.3

   N              .040

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   HP 1 S1872 72,.1,72.5


 *** FINISH PROCESSING CROSS SECTION - "S1872"
 *** CROSS SECTION "S1872" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S1872" AT SRD =********  ERR-CODE =      0

      SKEW     IHFNO    VSLOPE        EK        CK
       .0        0.  *********      .50       .00

 X-Y COORDINATE PAIRS  (NGP =  12):
        X       Y          X       Y          X       Y          X       Y
       .0   73.20        5.0   73.05        8.0   72.40        9.5   72.05
     10.0   71.75       12.0   71.75       14.0   71.60       15.0   72.15
     18.0   72.50       21.0   72.60       27.0   73.25       31.0   73.30

  X-Y MAX-MIN POINTS:
     XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0   73.20       14.0   71.60       31.0   73.30       31.0   73.30

 ROUGHNESS COEFFICIENTS (NGA =  1)
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        .040
1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
            200 FT SOUTH OF dynamite blvd & 1380 FT W.oF 53TH ST
             1920 ft e. of tatum COARSE SAND CEMENTED BANKS
            *** RUN DATE & TIME: 06-21-93  11:40
     CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1872;  SRD =*********

      WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW    QCR
              1        1.       20.     5.     5.                         4.
     72.00             1.       20.     5.     5.  1.00    10.    15.     4.
     72.10             2.       33.     6.     6.  1.00     9.    15.     6.
     72.20             2.       47.     7.     7.  1.00     9.    15.     9.
     72.30             3.       64.     8.     8.  1.00     8.    16.    12.
     72.40             4.       86.     9.     9.  1.00     8.    17.    15.
     72.50             5.      113.    10.    11.  1.00     8.    18.    20.

      WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW    QCR
              1        5.      113.    10.    11.                        20.
     72.50             5.      113.    10.    11.  1.00     8.    1B.    20.


   T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93

   T2           1300 ft N of Dynamite and 100 ft upstr(east) of 50TH ST

   T3            COARSE SAND, CEMENTED  8ANKS

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1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
            1300 ft N of Dynamite and 100 ft upstr(east) of 50TH ST
             COARSE SAND, CEMENTED  BANKS
            *** RUN DATE & TIME: 06-21-93  10:00

 *** START PROCESSING CROSS SECTION - "S1874"
   XS   S1874

   GR        0,76.6 5,76.7 8,76.3 10,76.2 11,75.6 12.5,75.2 13,74.4

   GR        20,74.6 25,74.7 30,74.6 34,75.7 37,76.6 42,77.05

   N                .040

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   HP 1 S1874 75,.2,76.6


 *** FINISH PROCESSING CROSS SECTION - "S1B74"
 *** CROSS SECTION "S1874" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S1874" AT SRD =********  ERR-CODE =       0
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      .0        0. *********        .50        .00

 X-Y COORDINATE PAIRS  (NGP =  13):
        X       Y          X       Y          X       Y          X       Y
       .0   76.60        5.0   76.70        8.0   76.30       10.0   76.20
     11.0   75.60       12.5   75.20       13.0   74.40       20.0   74.60
     25.0   74.70       30.0   74.60       34.0   75.70       37.0   76.60
     42.0   77.05

  X-Y MAX-MIN POINTS:
     XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0   76.60       13.0   74.40       42.0   77.05       42.0   77.05

 ROUGHNESS COEFFICIENTS (NSA =  1):
          .040
1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
            1300 ft N of Dynamite and 100 ft upstr(east) of 50TH ST
             COARSE SAND, CEMENTED  BANKS
            *** RUN DATE & TIME: 06-21-93  10:00
     CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1874;  SRD =*********

      WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1        7.      146.    19.    19.                          26.
     75.00            7.      146.    19.    19.  1.00     13.    31.     26.
     75.20           11.      284.    20.    20.  1.00     13.    32.     48.
     75.40           15.      453.    21.    22.  1.00     12.    33.     74.
     75.60           20.      658.    23.    23.  1.00     11.    34.    104.
     75.80           24.      906.    24.    24.  1.00     11.    34.    140.
     76.00           29.     1190.    25.    25.  1.00     10.    35.    180.
     76.20           34.     1509.    26.    27.  1.00     10.    36.    224.
     76.40           40.     1786.    29.    30.  1.00      7.    36.    264.
     76.60           46.     2156.    31.    32.  1.00      6.    37.    314.

      WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       46.     2156.    31.    32.                         315.
     76.60           46.     2156.    31.    32.  1.00      6.    37.    315.


   T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93

   T2           1700 ft N. of Dynamite and 80 ft west of 50TH ST

   T3            COARSE SAND, CEMENTED BANKS

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 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
            1700 ft N. of Dynamite and 80 ft west of 50TH ST
             COARSE SAND, CEMENTED BANKS
            *** RUN DATE & TIME: 06-21-93  10:2B

 *** START PROCESSING CROSS SECTION - "S1876"
   XS   S1B76
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GR          0,77.1 8,77 12,76.7 14,76.1 18,75.8 20.5,75.95

GR          21,76.15 25,76.4 28.5,76.9 32.77

N                .040

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HP 1 S1876 76,.1,77


*** FINISH PROCESSING CROSS SECTION - "S1876"
*** CROSS SECTION "S1876" WRITTEN TO DISK, RECORD NO. =  1

--- DATA SUMMARY FOR SECID "S1876" AT SRD =********  ERR-CODE =      0

     SKEW      IHFNO     VSLOPE         EK         CK
       .0         0. *********        .50        .00

X-Y COORDINATE PAIRS  (NGP =  10):
       X       Y          X       Y          X       Y          X       Y
       .0   77.10        8.0   77.00       12.0   76.70       14.0   76.10
     18.0   75.80       20.5   75.95       21.0   76.15       25.0   76.40
     28.5   76.90       32.0   77.00

 X-Y MAX-MIN POINTS:
     XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0   77.10       18.0   75.80       32.0   77.00         .0   77.10

ROUGHNESS COEFFICIENTS (NSA =  1):
         .040
1
WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
           1700 ft N. of Dynamite and 80 ft west of 50TH ST
            COARSE SAND, CEMENTED BANKS
           *** RUN DATE & TIME: 06-21-93  10:28
    CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1876;  SRD =*********

     WSEL  SA#      AREA         K    TOPW    WETP   ALPH     LEW     REW     QCR
             1        1.        5.      5.      5.                             1.
    76.00             1.        5.      5.      5.   1.00     15.     21.      1.
    76.10             1.       14.      7.      7.   1.00     14.     21.      3.
    76.20             2.       27.      8.      8.   1.00     14.     22.      5.
    76.30             3.       45.     10.     10.   1.00     13.     23.      9.
    76.40             4.       69.     12.     12.   1.00     13.     25.     13.
    76.50             5.      104.     13.     13.   1.00     13.     26.     19.
    76.60             7.      145.     14.     14.   1.00     12.     26.     25.
    76.70             8.      194.     15.     15.   1.00     12.     27.     33.
    76.80            10.      242.     17.     17.   1.00     11.     28.     41.
    76.90            11.      300.     19.     19.   1.00      9.     28.     50.
    77.00            14.      344.     24.     24.   1.00      8.     32.     58.

     WSEL  SA#      AREA         K    TOPW    WETP   ALPH     LEW     REW     QCR
             1       14.      344.     24.     24.                            58.
    77.00            14.      344.     24.     24.   1.00      8.     32.     58.


T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
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  T2            580 FT SOUTH OF PEAK VIEW RD & 930 FT E. OF 56TH ST

  T3             COARSE SAND, CEMENTED BED & BANKS=BED HIGHLY CEMENTED

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1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
            580 FT SOUTH OF PEAK VIEW RD & 930 FT E. OF 56TH ST
             COARSE SAND, CEMENTED BED & BANKS=BED HIGHLY CEMENTED
            *** RUN DATE & TIME: 06-11-93  15:00

 *** START PROCESSING CROSS SECTION - "S1960"
  XS   S1960

  GR        0,7.9 3,7.8 5,7.1 6,4.6 14,4.7 20,5.1 22.5,5.2

  GR        26,6.3 33,7.3

  N                .040

  *

  HP 1 S1960 4.8,.2,7.3


 *** FINISH PROCESSING CROSS SECTION - "S1960"
 *** CROSS SECTION "S1960" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S1960" AT SRD =********  ERR-CODE =      0

      SKEW      IHFNO    VSLOPE        EK        CK
        .0         0. *********      .50       .00

 X-Y COORDINATE PAIRS  (NGP =   9):
        X       Y          X       Y          X       Y          X       Y
       .0    7.90        3.0    7.80        5.0    7.10        6.0    4.60
     14.0    4.70       20.0    5.10       22.5    5.20       26.0    6.30
     33.0    7.30

  X-Y MAX-MIN POINTS:
      XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0    7.90        6.0    4.60       33.0    7.30         .0    7.90

 ROUGHNESS COEFFICIENTS (NSA =  1):
         .040
1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
            580 FT SOUTH OF PEAK VIEW RD & 930 FT E. OF 56TH ST
             COARSE SAND, CEMENTED BED & BANKS=BED HIGHLY CEMENTED
            *** RUN DATE & TIME: 06-11-93  15:00
     CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1960;  SRD =*********

      WSEL  SA#      AREA         K    TOPW    WETP   ALPH     LEW     REW     QCR
             1        4.       55.     13.     13.                             10.
      5.00            4.       55.     13.     13.   1.00      6.     19.     10.

      WSEL  SA#      AREA         K    TOPW    WETP   ALPH     LEW     REW     QCR
             1        6.      123.     17.     17.                             22.
```

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	10.	244.	17.	18.				42.
5.40		10.	244.	17.	18.	1.00	6.	23.	42.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	13.	395.	18.	19.				65.
5.60		13.	395.	18.	19.	1.00	6.	24.	65.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	17.	577.	19.	20.				92.
5.80		17.	577.	19.	20.	1.00	6.	24.	92.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	21.	786.	20.	21.				123.
6.00		21.	786.	20.	21.	1.00	5.	25.	123.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	25.	1022.	20.	22.				157.
6.20		25.	1022.	20.	22.	1.00	5.	26.	157.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	29.	1273.	21.	23.				192.
6.40		29.	1273.	21.	23.	1.00	5.	27.	192.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	34.	1540.	23.	24.				230.
6.60		34.	1540.	23.	24.	1.00	5.	28.	230.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	38.	1838.	24.	26.				272.
6.80		38.	1838.	24.	26.	1.00	5.	29.	272.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	43.	2169.	26.	28.				318.
7.00		43.	2169.	26.	28.	1.00	5.	31.	318.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	49.	2523.	28.	30.				366.
7.20		49.	2523.	28.	30.	1.00	5.	32.	366.

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
580 FT SOUTH OF PEAK VIEW RD & 930 FT E. OF 56TH ST
COARSE SAND, CEMENTED BED & BANKS=BED HIGHLY CEMENTED
*** RUN DATE & TIME: 06-11-93 15:00
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1960; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	51.	2709.	29.	31.				391.
7.30		51.	2709.	29.	31.	1.00	4.	33.	391.

T1 MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/18/93

T2 240 FT south OF dixileta Dr. & 300 FT W.oF 56TH ST

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WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
           240 FT south OF dixileta Dr. & 300 FT W.oF 56TH ST
            340 ft dwnstr from cl of DIX.   COARSE SAND CEMENTEO BANKS
           *** RUN OATE & TIME: 06-21-93  11:57

*** START PROCESSING CROSS SECTION - "S1969"
  XS   S1969

  GR        0,70.3 4,70.1 7,69.6 10,69.1 11,68.8 12,68.6 15,68.5

  GR        20,68.5 22.5,68.45 23.5,68.75 25,69.4 27,70.2 30.5,70.4

  N                .040

  *

  HP 1 S1969 69,.1,70.3


*** FINISH PROCESSING CROSS SECTION - "S1969"
*** CROSS SECTION "S1969" WRITTEN TO DISK, RECORD NO. =  1

--- DATA SUMMARY FOR SECID "S1969" AT SRD =********  ERR-CODE =      0

     SKEW     IHFNO    VSLOPE        EK        CK
       .0        0. *********      .50       .00

X-Y COORDINATE PAIRS  (NGP =  13):
       X       Y          X       Y          X       Y          X       Y
      .0   70.30        4.0   70.10        7.0   69.60       10.0   69.10
    11.0   68.80       12.0   68.60       15.0   68.50       20.0   68.50
    22.5   68.45       23.5   68.75       25.0   69.40       27.0   70.20
    30.5   70.40

 X-Y MAX-MIN POINTS:
     XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
      .0   70.30       22.5   68.45       30.5   70.40       30.5   70.40

ROUGHNESS COEFFICIENTS (NSA =  1):
         .040
1
WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/18/93
           240 FT south OF dixileta Dr. & 300 FT W.oF 56TH ST
            340 ft dwnstr from cl of DIX.   COARSE SAND CEMENTEO BANKS
           *** RUN DATE & TIME: 06-21-93  11:57
    CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1969;  SRD =*********

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW    QCR
            1       6.     128.    14.    14.                         23.
    69.00           6.     128.    14.    14.  1.00    10.    24.    23.
    69.10           7.     176.    14.    14.  1.00    10.    24.    30.
    69.20           9.     229.    15.    15.  1.00     9.    25.    39.
    69.30          10.     290.    16.    16.  1.00     9.    25.    48.
    69.40          12.     357.    17.    17.  1.00     8.    25.    58.
    69.50          14.     431.    18.    18.  1.00     8.    25.    69.
    69.60          16.     513.    18.    19.  1.00     7.    25.    81.
```

69.70	17.	602.	19.	20.	1.00	6.	26.	94.
69.80	19.	699.	20.	21.	1.00	6.	26.	108.
69.90	22.	804.	21.	21.	1.00	5.	26.	124.
70.00	24.	917.	22.	22.	1.00	5.	26.	140.
70.10	26.	1039.	23.	23.	1.00	4.	27.	157.
70.20	28.	1130.	25.	25.	1.00	2.	27.	171.
70.30	31.	1200.	29.	29.	1.00	0.	29.	183.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	31.	1200.	29.	29.				183.
70.30		31.	1200.	29.	29.	1.00	0.	29.	183.

```
T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

T2           SEC 40 FT EAST OF 59th St & 1240 FT S. OF DIXILETA DR

T3            COARSE SAND, CEMENTED BANKS--POSSIBLE MAN AFFECTS

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1
WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 40 FT EAST OF 59th St & 1240 FT S. OF DIXILETA DR
            COARSE SAND, CEMENTED BANKS--POSSIBLE MAN AFFECTS
           *** RUN DATE & TIME: 06-11-93  13:59

*** START PROCESSING CROSS SECTION - "S1998"
  XS   S1998

  GR        0,8.1 5,8.1 6.5,7 7,4.6 8,4.6 14,4.7 19.5,4.7

  GR        22,5.3 23,6.4 29,8.0

  N               .040

  *

  HP 1 S1998 5.0,.2,8.0

*** FINISH PROCESSING CROSS SECTION - "S1998"
*** CROSS SECTION "S1998" WRITTEN TO DISK, RECORD NO. =  1

--- DATA SUMMARY FOR SECID "S1998" AT SRD =********  ERR-CODE =      0

     SKEW      IHFND     VSLOPE        EK        CK
       .0         0.  *********      .50       .00

X-Y COORDINATE PAIRS  (NGP =  10):
       X       Y          X       Y          X       Y          X       Y
      .0    8.10        5.0    8.10        6.5    7.00        7.0    4.60
     8.0    4.60       14.0    4.70       19.5    4.70       22.0    5.30
    23.0    6.40       29.0    8.00

X-Y MAX MIN POINTS
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XMIN	Y	X	YMIN	XMAX	Y	X	YMAX
.0	8.10	7.0	4.60	29.0	8.00	.0	8.10

ROUGHNESS COEFFICIENTS (NSA = 1):
.040

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 40 FT EAST OF 59th St & 1240 FT S. OF DIXILETA DR
COARSE SAND, CEMENTED BANKS--POSSIBLE MAN AFFECTS
*** RUN DATE & TIME: 06-11-93 13:59

CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S1998; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	4.	74.	14.	14.				14.
5.00		4.	74.	14.	14.	1.00	7.	21.	14.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	7.	163.	15.	15.				29.
5.20		7.	163.	15.	15.	1.00	7.	22.	29.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	10.	282.	15.	16.				47.
5.40		10.	282.	15.	16.	1.00	7.	22.	47.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	13.	429.	15.	16.				70.
5.60		13.	429.	15.	16.	1.00	7.	22.	70.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	16.	598.	16.	17.				95.
5.80		16.	598.	16.	17.	1.00	7.	22.	95.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	20.	787.	16.	17.				123.
6.00		20.	787.	16.	17.	1.00	7.	23.	123.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	23.	996.	16.	18.				154.
6.20		23.	996.	16.	18.	1.00	7.	23.	154.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	26.	1223.	16.	18.				186.
6.40		26.	1223.	16.	18.	1.00	7.	23.	186.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	29.	1445.	17.	19.				218.
6.60		29.	1445.	17.	19.	1.00	7.	24.	218.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	33.	1688.	18.	20.				253.
6.80		33.	1688.	18.	20.	1.00	7.	24.	253.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	37.	1951.	19.	21.				290.
7.00		37.	1951.	19.	21.	1.00	7.	25.	290.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	40.	2229.	20.	22.				328.
7.20		40.	2229.	20.	22.	1.00	6.	26.	328.

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WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

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          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 40 FT EAST OF 59th St & 1240 FT S. OF DIXILETA DR
            COARSE SAND, CEMENTED BANKS--POSSIBLE MAN AFFECTS
           *** RUN DATE & TIME: 06-11-93  13:59
    CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S1998:  SRD =*********

     WSEL  SA#      AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       44.    2531.    21.    24.                         369.
     7.40            44.    2531.    21.    24.  1.00     6.    27.    369.

     WSEL  SA#      AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       49.    2858.    22.    25.                         413.
     7.60            49.    2858.    22.    25.  1.00     6.    27.    413.

     WSEL  SA#      AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       53.    3212.    23.    26.                         461.
     7.80            53.    3212.    23.    26.  1.00     5.    28.    461.

     WSEL  SA#      AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       58.    3593.    24.    27.                         512.
     8.00            58.    3593.    24.    27.  1.00     5.    29.    512.

     WSEL  SA#      AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       58.    3593.    24.    27.                         512.
     8.00            58.    3593.    24.    27.  1.00     5.    29.    512.


   T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

   T2           SEC 80 FT WEST OF 59th St & 750 FT S. OF DIXILETA DR

   T3            COARSE SAND 9.5-12, CEMENTED BANKS

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1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 80 FT WEST OF 59th St & 750 FT S. OF DIXILETA DR
            COARSE SAND 9.5-12, CEMENTED BANKS
           *** RUN DATE & TIME: 06-11-93  13:36

 *** START PROCESSING CROSS SECTION - "S2002"
   XS   S2002

   GR        0,7.1 3,7 5,6.5 8,5.1 9.5,4.6 12,4.6 16,5.15

   GR        21,6.1 28,6.9

   N                .040

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   HP 1 S2002 4.8,.2,6.9


 *** FINISH PROCESSING CROSS SECTION - "S2002"
 *** CROSS SECTION "S2002" WRITTEN TO DISK, RECORD NO. =  1
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SKEW	IHFNO	VSLOPE	EK	CK
.0	0.	*********	.50	.00

X-Y COORDINATE PAIRS (NGP = 9):

X	Y	X	Y	X	Y	X	Y
.0	7.10	3.0	7.00	5.0	6.50	8.0	5.10
9.5	4.60	12.0	4.60	16.0	5.15	21.0	6.10
28.0	6.90						

X-Y MAX-MIN POINTS:

XMIN	Y	X	YMIN	XMAX	Y	X	YMAX
.0	7.10	9.5	4.60	28.0	6.90	.0	7.10

ROUGHNESS COEFFICIENTS (NSA = 1):
.040

1
WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 80 FT WEST OF 59th St & 750 FT S. OF DIXILETA DR
COARSE SAND 9.5-12, CEMENTED BANKS
*** RUN DATE & TIME: 06-11-93 13:36
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S2002; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	2.	28.	7.	7.				5.
5.00		2.	28.	7.	7.	1.00	8.	15.	5.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	3.	66.	8.	9.				12.
5.20		3.	66.	8.	9.	1.00	8.	16.	12.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	5.	123.	10.	10.				21.
5.40		5.	123.	10.	10.	1.00	7.	17.	21.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	7.	200.	11.	12.				33.
5.60		7.	200.	11.	12.	1.00	7.	18.	33.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	10.	297.	13.	13.				48.
5.80		10.	297.	13.	13.	1.00	7.	19.	48.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	12.	416.	14.	15.				66.
6.00		12.	416.	14.	15.	1.00	6.	20.	66.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	16.	552.	16.	17.				86.
6.20		16.	552.	16.	17.	1.00	6.	22.	86.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	19.	710.	18.	19.				110.
6.40		19.	710.	18.	19.	1.00	5.	24.	110.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	23.	895.	21.	21.				137.
6.60		23.	895.	21.	21.	1.00	5.	25.	137.
WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	27.	1112.	23.	24.				168.
6.80		27.	1112.	23.	24.	1.00	4.	27.	168.

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    WSEL  SA#      AREA        K    TOPW    WETP   ALPH     LEW     REW     WCR
          1         30.     1235.    25.     25.                             185.
    6.90            30.     1235.    25.     25.   1.00      3.     28.     185.


  T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

  T2           SEC 90 FT WEST OF 59th St & 360 FT S. OF DIXILETA DR

  T3            COARSE SAND 4.5-9, CEMENTED BANKS

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1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 90 FT WEST OF 59th St & 360 FT S. OF DIXILETA DR
            COARSE SAND 4.5-9, CEMENTED BANKS
           *** RUN DATE & TIME: 06-11-93  13:17

 *** START PROCESSING CROSS SECTION - "S2006"
  XS   S2006

  GR        0,6.4 3,6.3 4,5.8 4.5,4.3 9,4.4

  GR        14,5.5 19,6.3 26,6.3 100,6.3

  N               .040

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  HP 1 S2006 4.4,.2,6.3


 *** FINISH PROCESSING CROSS SECTION - "S2006"
 *** CROSS SECTION "S2006" WRITTEN TO DISK, RECORD NO. =  1

 --- DATA SUMMARY FOR SECID "S2006" AT SRD =********  ERR-CODE =       0

      SKEW     IHFNO    VSLOPE        EK        CK
       .0        0.  *********      .50       .00

 X-Y COORDINATE PAIRS  (NGP =   9):
       X       Y          X       Y          X       Y          X       Y
       .0    6.40       3.0    6.30        4.0    5.80        4.5    4.30
      9.0    4.40      14.0    5.50       19.0    6.30       26.0    6.30
    100.0    6.30

  X-Y MAX-MIN POINTS:
     XMIN       Y          X    YMIN       XMAX       Y          X    YMAX
       .0    6.40       4.5    4.30      100.0    6.30         .0    6.40

 ROUGHNESS COEFFICIENTS (NSA =  1):
         .040
1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PRDFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 90 FT WEST OF 59th St & 360 FT S. OF DIXILETA DR
            COARSE SAND 4.5-9, CEMENTED BANKS
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        *** RUN DATE & TIME: 06-11-93  13:17
   CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S2006;  SRD =*********

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1       4.       87.     7.     8.                         16.
    5.00            4.       87.     7.     8.  1.00     4.    12.     16.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1       5.      142.     8.     9.                         25.
    5.20            5.      142.     8.     9.  1.00     4.    13.     25.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1       7.      211.     9.    10.                         36.
    5.40            7.      211.     9.    10.  1.00     4.    14.     36.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1       9.      293.    11.    12.                         49.
    5.60            9.      293.    11.    12.  1.00     4.    15.     49.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      11.      389.    12.    13.                         64.
    5.80           11.      389.    12.    13.  1.00     4.    16.     64.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      14.      501.    14.    15.                         81.
    6.00           14.      501.    14.    15.  1.00     4.    17.     81.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      17.      635.    15.    17.                        101.
    6.20           17.      635.    15.    17.  1.00     3.    18.    101.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      18.      712.    16.    17.                        112.
    6.30           18.      712.    16.    17.  1.00     3.    19.    112.


  T1          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93

  T2           SEC 200 FT WEST OF SCOTTSDALE ROAD AND 1680 FT S. OF LONE MTN

  T3            HIGHLY CEMENTED BED-ALMOST LIKE GRANITE OR GNIESS=STABLE SEC

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1
 WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 200 FT WEST OF SCOTTSDALE ROAD AND 1680 FT S. OF LONE MTN.RD
            HIGHLY CEMENTED BED-ALMOST LIKE GRANITE OR GNIESS=STABLE SEC.
           *** RUN OATE & TIME: 06-11-93  10:32

 *** START PROCESSING CROSS SECTION - "S2191"
   XS   S2191

   GR        0,2203 20,2202 30,2199.1 34,2197 47,2193.1 50,2191.6

   GR        54,2191.7 64,2191.5 68,2191.B 73,2192.6 78,2193.7 88,2195.9

   GR        99,2196.5 135,2196 150,2198 165,2200 170,2200.5 190,2198 400,219

   N                .037
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HP 1 S2191 2192,.5,2200


*** FINISH PROCESSING CROSS SECTION - "S2191"
*** CROSS SECTION "S2191" WRITTEN TO DISK, RECORD NO. =  1

--- DATA SUMMARY FOR SECID "S2191" AT SRD =********  ERR-CODE =      0

     SKEW      IHFNO     VSLOPE        EK        CK
       .0         0. *********       .50       .00

X-Y COORDINATE PAIRS  (NGP =  19):
       X       Y           X       Y           X       Y           X       Y
       .0 2203.00       20.0 2202.00       30.0 2199.10       34.0 2197.00
     47.0 2193.10       50.0 2191.60       54.0 2191.70       64.0 2191.50
     68.0 2191.80       73.0 2192.60       78.0 2193.70       88.0 2195.90
     99.0 2196.50      135.0 2196.00      150.0 2198.00      165.0 2200.00
    170.0 2200.50      190.0 2198.00      400.0 2198.00

 X-Y MAX-MIN POINTS:
     XMIN       Y           X    YMIN       XMAX       Y           X    YMAX
       .0 2203.00       64.0 2191.50      400.0 2198.00         .0 2203.00

ROUGHNESS COEFFICIENTS (NSA =  1):
         .037
1
WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

          MARICOPA CO.  REGIME STUDY  HJALMARSON  survey of 6/9/93
           SEC 200 FT WEST OF SCOTTSDALE ROAD AND 1680 FT S. OF LONE MTN.RD
            HIGHLY CEMENTED BED-ALMOST LIKE GRANITE OR GNIESS=STABLE SEC.
           *** RUN DATE & TIME: 06-11-93  10:32
    CROSS-SECTION PROPERTIES:  ISEQ =  1;  SECID = S2191;  SRD =********

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1        7.       142.    20.    20.                         24.
  2192.00             7.       142.    20.    20.  1.00    49.    69.     24.

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       18.       599.    24.    24.                         89.
  2192.50            18.       599.    24.    24.  1.00    48.    72.     89.

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       31.      1343.    28.    28.                        187.
  2193.00            31.      1343.    28.    28.  1.00    47.    75.    187.

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       46.      2347.    31.    32.                        314.
  2193.50            46.      2347.    31.    32.  1.00    46.    77.    314.

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       63.      3635.    35.    36.                        472.
  2194.00            63.      3635.    35.    36.  1.00    44.    79.    472.

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       81.      5232.    39.    40.                        663.
  2194.50            81.      5232.    39.    40.  1.00    42.    82.    663.

     WSEL  SA#      AREA         K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      102.      7155.    43.    44.                        887.
  2195.00           102.      7155.    43.    44.  1.00    41.    84.    887.
```

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	124.	9423.	47.	48.				1147.
2195.50		124.	9423.	47.	48.	1.00	39.	86.	1147.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	149.	11859.	53.	54.				1426.
2196.00		149.	11859.	53.	54.	1.00	37.	90.	1426.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	188.	11204.	103.	104.				1441.
2196.50		188.	11204.	103.	104.	1.00	36.	139.	1441.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	241.	16365.	109.	110.				2037.
2197.00		241.	16365.	109.	110.	1.00	34.	143.	2037.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	296.	22454.	113.	115.				2721.
2197.50		296.	22454.	113.	115.	1.00	33.	146.	2721.

1

WSPRO FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P060188 MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS

MARICOPA CO. REGIME STUDY HJALMARSON survey of 6/9/93
SEC 200 FT WEST OF SCOTTSDALE ROAD AND 1680 FT S. OF LONE MTN.RD
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*** RUN DATE & TIME: 06-11-93 10:32
CROSS-SECTION PROPERTIES: ISEQ = 1; SECID = S2191; SRD =*********

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	354.	29391.	118.	120.				3482.
2198.00		354.	29391.	118.	120.	1.00	32.	150.	3482.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	520.	27869.	337.	339.				3670.
2198.50		520.	27869.	337.	339.	1.00	31.	400.	3670.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	691.	43892.	345.	348.				5543.
2199.00		691.	43892.	345.	348.	1.00	30.	400.	5543.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	866.	62754.	355.	358.				7675.
2199.50		866.	62754.	355.	358.	1.00	29.	400.	7675.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	1045.	84355.	364.	369.				10051.
2200.00		1045.	84355.	364.	369.	1.00	27.	400.	10051.

APPENDIX K.--Letter from FEMA to FCD.

Federal Emergency Management Agency

Washington, D.C. 20472

OCT 16 1992

FLOOD CONTROL DISTRICT
RECEIVED
OCT 23

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Mr. Joe Tram
Special Projects Branch Manager
Flood Control District of
Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009

Dear Mr. Tram:

This is in response to your letter dated September 22, 1992. In that letter you requested copies of the field and technical data that documents and substantiates Equation 2.5 of our publication entitled FAN, An Alluvial Fan Flooding Computer Program, User's Manual and Program Disk, dated September, 1990.

That equation comes from the paper entitled Flood Frequency Estimates on Alluvial Fans, written by Mr. David R. Dawdy and published in the Journal of the Hydraulics Division, American Society of Civil Engineers dated November 1979. Mr. Dawdy references personal communication with personnel from the U.S. Army Corps of Engineers (ACE) as the source of the relationship. We do not have the ACE's data. Mr. Dawdy devotes an entire page (out of six) of his paper to a discussion of the reasonableness of the relationship. In that discussion he compares the relationship to similar relationships given in The Hydraulic Geometry of Stream Channels and Some Physiographic Implications, written by Mr. Luna B. Leopald and Mr. Thomas Maddock, Jr.

Another publication that addresses the relationship is entitled Alluvial Fan Flooding Methodology, An Analysis, prepared for the Federal Emergency Management Agency (FEMA) by DMA Consulting Engineers, and dated October 1985. That report concludes that "the width of a single channel on an alluvial fan can be reasonably predicted by the FEMA method." That statement is based on the data presented in Table 3 (Page 58) and on Figure 19 (Page 57) of the report.

Because you have sent copies of the reports/papers referenced above to us we have not enclosed them with this letter.

If you have any questions regarding this matter, please call Mr. Karl Mohr of my staff in Washington, D.C., at (202) 646-2770.

Sincerely,

William R. Locke
Chief, Risk Studies Division
Federal Insurance Administration

Federal Emergency Management Agency

Washington, D.C. 20472

RECEIVED
JAN 15 1993

JAN 12 1993

Mr. Joe Tram
Flood Control District of
Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009

Dear ~~Mr. Tram~~ Joe:

Over the last several years we have been involved in many discussions with you both orally and through written correspondence regarding our methodology for analyzing alluvial fan flooding. Because we have responded more than once to what appear to be the same questions, we assume that we may not have appropriately discerned your point. This letter is in response to your letter of November 20, 1992.

In a letter dated January 5, 1990, you asked several questions regarding our methodology and its applicability. The subject of one of those questions was the estimate of the width-depth-discharge relationship given in a paper entitled "Flood Frequency Estimates on Alluvial Fans," written by Mr. David R. Dawdy, and published by the American Society of Civil Engineers in the November 1979 Journal of the Hydraulics Division. In particular, you questioned the estimate that on an alluvial fan the channel conveying a flood stabilizes at that point where a decrease in depth creates a two hundred-fold increase in width. You asked, "Is this a correct assumption?"

In our response dated March 7, 1990, we noted that the "reasonableness" of the relationship is discussed in Dawdy's paper and subsequently verified in case studies performed by DMA Consulting Engineers (DMA), and published in a report dated October 1985 and entitled Alluvial Fan Flooding Methodology, An Analysis. We noted in our response that to that extent, the relationship is "correct." We also noted, however, that if site-specific information exists that demonstrates that some other relationship between peak discharge, width of the flood path, and depth and velocity of the floodwaters should be used, the methodology can be modified to incorporate it.

Then, in a letter, dated September 22, 1992, you requested copies of the field and technical data that document and substantiate Dawdy's estimate.

In our response, dated October 16, 1992, we noted that Dawdy references personal communication with personnel from the U.S. Army Corps of Engineers (COE) as the source of the relationship and we explained that we do not have the COE's data. Again, we referred to Dawdy's paper and the DMA report for a discussion of the reasonableness of the relationship and the data collected by DMA which verifies that reasonableness.

In the letter dated November 20, 1992, having read Dawdy's paper and the DMA report as well as two additional papers concerning the hydraulic geometry of stream channels, you asked several questions regarding the relationship. Our response is organized with the same format as that letter with the cited references and your questions followed by our response.

1. The Hydraulic Geometry of Stream Channels and Some Physiographic Applications, by Leopold and Maddock, published by the U.S. Geological Survey, 1953.

   In your letter, you state that on pages 50 and 51 of the paper the authors reference "eight equations that are necessary in order to define the equilibrium profile of a stream," and then ask the following questions:

   Is this point equal to the stabilization point referenced by Dawdy?

   For what recurrence interval does the Dawdy methodology apply?

   Does your reference to the Leopold and Maddock report imply a similarity between the flood used by Dawdy and the mean annual flood used by Leopold and Maddock?

   Does the mean annual event generate the same hydraulic geometry properties as the one hundred year event?

   Please note that Leopold and Maddock do not present the eight questions, (A) through (H), in their paper as "necessary in order to define the equilibrium profile of a stream." They do introduce the equations as a summary of the reasoning in their paper. Dawdy's reasoning is particular to the steeper slopes found on alluvial fans and the more dynamic nature of the flooding in that environment. Although both papers invoke the idea of an equilibrium point, as a point of stability, they take a different approach in defining that point.

   Leopold's and Maddock's approach considers the mean annual flow as the most prevalent condition and, therefore, the condition that formed the channels that they studied. Dawdy, on the other hand, treats alluvial fan flooding of any flow magnitude as capable of defining its own path or channel. In his paper Dawdy discusses where the results of the two approaches should be comparable and where they differ. Note that because the mean annual flow on an alluvial fan is most likely no flow, there can be no direct comparison with the 100-year or any other flow.

2. Alluvial Fan Flooding Methodology, An Analysis, by DMA Consulting Engineers, published by the Federal Emergency Management Agency, October 1985.

   In our previous letter regarding the relationship we noted that DMA Consulting Engineers performed some case studies and concluded that "the width of a single channel on an alluvial fan can be reasonably predicted by the FEMA method." In our letter dated October 16, 1992, we pointed out that that statement was based on data presented in Table 3 and on Figure 19 of the DMA report. You note that one of the entries in Table 3 of that report indicates that the predicted width is approximately 7.5 times the observed width. You go on to state that, to you, "this does not support" DMA's conclusion.

   Obviously, it is the set of data, not any particular point, that supports the conclusion. From your statement it is not clear whether or not you agree with the conclusion. Presumably, if you think the entire data set shows the estimates to be unreasonable, you would have addressed the entire data set.

3. World-wide Variations in Hydraulic Exponents of Stream Channels: An Analysis and Some Observations, by Park, published in the Journal of Hydrology, 1977.

   You state "that just because Mr. Dawdy devoted one page to discuss the reasonableness of the equation that FEMA is satisfied that it is substantiated."

   We trust that you know that we do not draw conclusions about something because someone devotes a page to discussing its reasonableness.

   In the letter, you ask "where is the technical data that substantiates that average values are valid for site specific application of the method," and "isn't this contrary to what is discussed in the cited reference...."

   We believe that the technical data contained in the DMA report demonstrates that using Dawdy's estimate in the absence of data to the contrary is reasonable. However, as we stated in our letter of March 7, 1990, if site-specific information exists that demonstrates that some other relationship should be used, then it can be.

   Regarding the cited reference, please note that investigations into the variability of the hydraulic geometry of stream channels has focused on established

stream courses worldwide. In modeling alluvial fan flooding one deals with flood paths that are not well defined and with a much narrower range of hydraulic conditions than is found worldwide or nationwide. We recognize that the width-discharge relationship in alluvial fan flooding will not be precisely as Dawdy estimated either from fan to fan, flood to flood, or at different locations during a given flood. Recognizing that situation, we funded the DMA study to investigate how reasonable it was to use Dawdy's estimate.

Perhaps your letter may be addressed more clearly if we try to summarize the concerns. It seems you are questioning the use of the equation

$$\frac{dw}{dd} = -200$$

from Dawdy's paper. The questions seems to revolve around the following reasoning:

1. The equation leads to the relationship that the width of a flood path on an alluvial fan will be proportional to the four-tenths power of the discharge.

2. Several authors have reported much variability in that exponent of the discharge when investigating the hydraulic geometry of streams worldwide.

3. Because the exponent varies so much it should not be replaced by some mean value.

Please note that the exponent of the discharge does <u>not</u> depend on the subject equation. The value of 0.4 used by Dawdy comes from the reasoning that a cross section of the flood path is approximately rectangular and that the flow is at or near critical depth. If the value -200 is replaced by any value then the resulting width is proportional to the four-tenths power of the discharge. That dependence or lack of dependence can be clearly seen in the derivation of the methodology under simple boundary conditions. You have, in past written correspondence, quoted from two documents, that you received from us, that provide that derivation.

In addition, with little effort and using that derivation, it can be shown that the probability of a given point being inundated by a flood which exceeds a certain discharge depends on the mean value of any function used to describe uncertainty in the width of the flow path. That is true regardless of the variance in that uncertainty. For flood insurance purposes, it is that probability with which we are concerned.

You conclude your letter with the following paragraph:

> From my perspective, sound floodplain management through technical documentation of flood hazards and enforcement of floodplain regulations is crucial in preventing flood damage. However, it is very difficult to justify the use of the FEMA methodology at specific sites when FEMA has not addressed guidelines for: 1) defining landforms based upon geomorphic and engineering parameters, 2) defining guidelines for determining stability of the landforms, 3) documenting geomorphic and engineering field parameters to define the applicability and validity of the hydraulic geometry parameters, 4) quantifying and qualifying the specific application of the current methodology based upon geomorphic and engineering parameters, 5) defining methods for modification of the hydraulic geometry parameters based upon data assessed in the field for site specific conditions, and 6) technically substantiating the universal applicability of their methodology through geomorphic and engineering documentation.

As we are all aware, little is known about the details of alluvial fan flooding. However, what is known about the nature of such flooding is alarming. Alluvial fan flooding strikes without warning. Although it is relatively shallow, the velocities and sediment loads associated with alluvial fan flooding pose a tremendous threat to life and property. We would agree that with a better understanding of the details of these floods we can improve upon floodplain management practices. However, we certainly do believe that any lack of detailed knowledge or a paucity of data precludes sound floodplain management. We are concerned that that may be what your are suggesting.

We remain concerned about your correspondence. Because of the difficulty in discerning your point from the inferences you make from references that you quote, the level at which we should direct our response is not clear. We want to be of assistance to the Flood Control District of Maricopa County and as forthcoming as possible about methodologies used in our studies; however, we do not have the resources to maintain protracted technical discussions that seem to be offered for their own sake.

If you have any questions regarding this matter, please call me or Mr. Karl Mohr of my staff in Washington, DC at (202) 646-2770.

Sincerely,

John L. Matticks
Assistant Administrator
Office of Risk Assessment
Federal Insurance Administration

cc: Mr. Stanley L. Smith, Jr., P.E.
Acting Chief, Flood Control District
of Maricopa County