APPEAL TO THE RESTUDY OF THE PIMA COUNTY FLOOD INSURANCE STUDY

(Community No. 040073)

Prepared By:

Pima County Department Of Transportation

And Flood Control District

MARCH 1987

PIMA COUNTY
TRANSPORTATION AND FLOOD CONTROL DISTRICT
1313 SOUTH MISSION ROAD
TUCSON, ARIZONA 85713-1396

CHARLES HUCKELBERRY
DIRECTOR

March 3, 1987

Mr. John L. Matticks
Acting Chief, Risk Studies Division
Federal Insurance Administration
Federal Emergency Management Agency
Washington, D.C. 20472

Re: Appeal of Proposed Based Flood Elevations, Pima County Flood Insurance Study, Arizona

Dear Mr. Matticks:

Reference is made to your November 14, 1986 letter transmitting several preliminary copies of the revised Flood Insurance Study (FIS) for Pima County Arizona (Community No. 040073). The preliminary copies of the revised Flood Insurance Rate Maps (FIRMs) are intended to revise portions of the effective FIS as a result of a restudy by the Federal Emergency Management Agency (FEMA). Public notification of the proposed base flood elevations was given, with the second notification occuring on December 5, 1986. As you are aware, the 90-day appeal period was initiated with the second notification. The purpose of this letter is to formally submit appeals both by Pima County and private property owners to the proposed base flood elevations contained in the revised FIRMs.

Pima County has determined it necessary to submit an appeal of the Tortolita Alluvial Fan portion of the restudy. The alluvial fan analysis, based on procedures by FEMA is scientifically deficient in light of new and previously unavailable data regarding activity of alluvial fan processes in the study area. Futhermore, the study is technically deficient when examined in relationship to the technical guidelines issued by FEMA and the alluvial fan flooding literature cited by FEMA. FEMA has also not provided the community with adequate regulations which discuss how to implement the depth-velocity designations in developing regulatory requirements for finished floor elevations and to assess or mitigate the erosion potential for proposed and existing developments. As required, Pima County Department of Transportation and Flood Control District is submitting a report entitled "Appeal to the Restudy of the Pima County Flood Insurance Study" which contains information indicating that the proposed Tortolita Alluvial Fan base flood determinations are both scientifically and technically incorrect. In addition the original analysis did not include the construction of the Central Arizona Project Aqueduct which includes a 10- to 15-foot high dike and drainage overchute structures. This project significantly impacts the alluvial fan analysis.

As required in your November 14, 1986 letter, Pima County has collected and consolidated on behalf of private property owners additional appeal data. The following additional report are submitted which appeal portions of the Tortolita Alluvial Fan Analysis:

1. Existing Conditions: Hydrologic/Hydraulic Report for Northeast Corner of Thornydale and Tangerine Roads; Osborn, Petterson, Walbert & Associates, January, 1987.

2. Appeal of Preliminary Flood Insurance Rate Maps 1605B and 1610B in Unincorporated Pima County, Arizona; Anderson Passarelli & Associates, February 24, 1987.

3. Hydrologic/Hydraulic Report for Stone Creek; Osborn, Petterson Walbert & Associates, May 9, 1986.

As requested by FEMA and where time permitted, Pima County reviewed the appeals submitted by private property owners. The following discussion summarizes our review.

With respect to appeal Number one by Osborn, Petterson Walbert (OPW), Pima County endorses the report and its conclusions which are consistent with Pima County's appeal. Pima County has not had sufficient time to review the second appeal by Anderson Passarelli & Associates and has no formal recommendation. Appeal number three by OPW, has not been completely reviewed by Pima County specifically for the purpose of an appeal. We have previously reviewed the report as part of our normal subdivision review process and found the report to be acceptable. Due to the uncertainity of the outcome of Pima County's appeal, the OPW appeal is being transmitted to FEMA.

In addition, an appeal is being submitted for the Canada Del Oro Wash. The results of FEMA's restudy for the Canada Del Oro Wash indicate significant rises in the regulatory water-surface elevations and subsequent floodplain boundaries. The results of the FEMA study contradict the results of previous studies performed for both Pima County Department of Transportaton and Flood Control District and the Arizona Department of Water Resources for the Oro Valley Flood Control Project. The FEMA restudy for the Canada Del Oro Wash has been reviewed and is summarized in a report entitled "Lambert Lane Estates on Canada Del Oro Wash, Oro Valley" by Dooley-Jones & Associates, March, 1987. The report includes a revised HEC-II backwater analysis and floodplain delineations which are supported by Pima County.

In conclusion, the enclosed reports include technical and scientific data which either negate or contradict the results of the preliminary FIS for the Tortolita Alluvial Fan Area and Canada Del Oro Wash. We believe these appeals must be resolved in consultation with the Pima County Flood Control District Staff. If you have any questions or comments, please contact Mr. David Smutzer at (602) 882-2608.

Sincerely,

Craig V. McConnell

Craig V. McConnell, R.L.S., P.E.
Director (Acting)

CVM/ib/DAS
Enclosure: 2 copies as stated
xc: Charles Huckelberry, Assistant County Manager
Raymond Lenaburg, FEMA Region IX
Jim Morris, ADWR

EXECUTIVE SUMMARY

A restudy of the effective Flood Insurance Study (FIS) for Pima County, Arizona (Community No. 040073) was undertaken for the Tortolita Alluvial Fan Area. The methodology used for analyzing the flood hazards of the Tortolita Alluvial Fan Area was based on procedures developed by Dawdy (1979) for the Federal Emergency Management Agency (FEMA). The purpose of this report is to submit technical documentation in support of an appeal of the application and results of the alluvial fan flooding analysis performed by FEMA's Study Contractor and subsequently revised by the Technical Evaluation Contractor. The alluvial fan analysis results are scientifically deficient in light of new and previously unavailable data regarding activity of alluvial fan processes in the study area. Furthermore, the study is technically deficient when examined in relationship to the technical guidelines issued by FEMA and the alluvial fan flooding literature cited by FEMA. In addition, utilization of shallow sheetflow designations on the Flood Insurance Rate Maps (FIRMs) is contradictory and technically incorrect when compared to the results of the alluvial fan flooding analysis.

FEMA also has not provided the community with adequate guidelines which discuss how to use the shallow sheetflow depth and velocity designations to develop regulatory requirements for finished floor elevations, and to assess or mitigate the erosion potential for both proposed and existing developments. The study results also place existing developments approved by Pima County within the regulatory floodplain which were previously not included within the 100-year floodplain on the effective FIRMs. These developments have complied with the drainage design standards and floodplain management regulations enforced by Pima County. Their inclusion within the revised regulatory floodplain based on the restudy is incorrect and places undue burden on private homeowners and Pima County to refine the arbitrary flood limits which disregard the existing drainage improvements.

INTRODUCTION

Pima County has determined that it is necessary to appeal the Tortolita Alluvial Fan portion of the restudy to the effective Flood Insurance Study (FIS) for Unincorporated Pima County transmitted to the community by the Federal Emergency Management Agency (FEMA) on November 14, 1986. Section 110 of the Flood Disaster Protection Act of 1973 provides for appealing Flood Insurance Studies on scientific or technical grounds. From both technical and scientific standpoints, the appeal is based on several points: 1) documentation showing mathematical or measurement errors in the analysis; 2) improved application of the alluvial fan flooding methodology; and 3) revised materials including new soils map and other scientific data which were unavailable to the Study Contractor at the time of analysis. The report will document specific errors within the alluvial fan flooding methodology and in its application to the Tortolita Alluvial Fan Area, and will provide previously unavailable data regarding activity of alluvial fan processes in the study area.

From a regulatory standpoint, the appeal is based upon the following factors: 1) lack of appropriate floodplain management regulations for determining both finished floor elevations and assessment and mitigation of erosion potential for new and existing developments; 2) use of shallow sheet flow zone (AO) designation, which is contradictory to the intent of the results of the alluvial fan methodology; and 3) inclusion of existing developments within the floodplain which have met the drainage design standards and floodplain management regulations of Pima County.

This appeal includes a summary report discussing the new scientific data, application of the alluvial fan methodology, supporting engineering analyses, and regulatory issues which support the appeal.

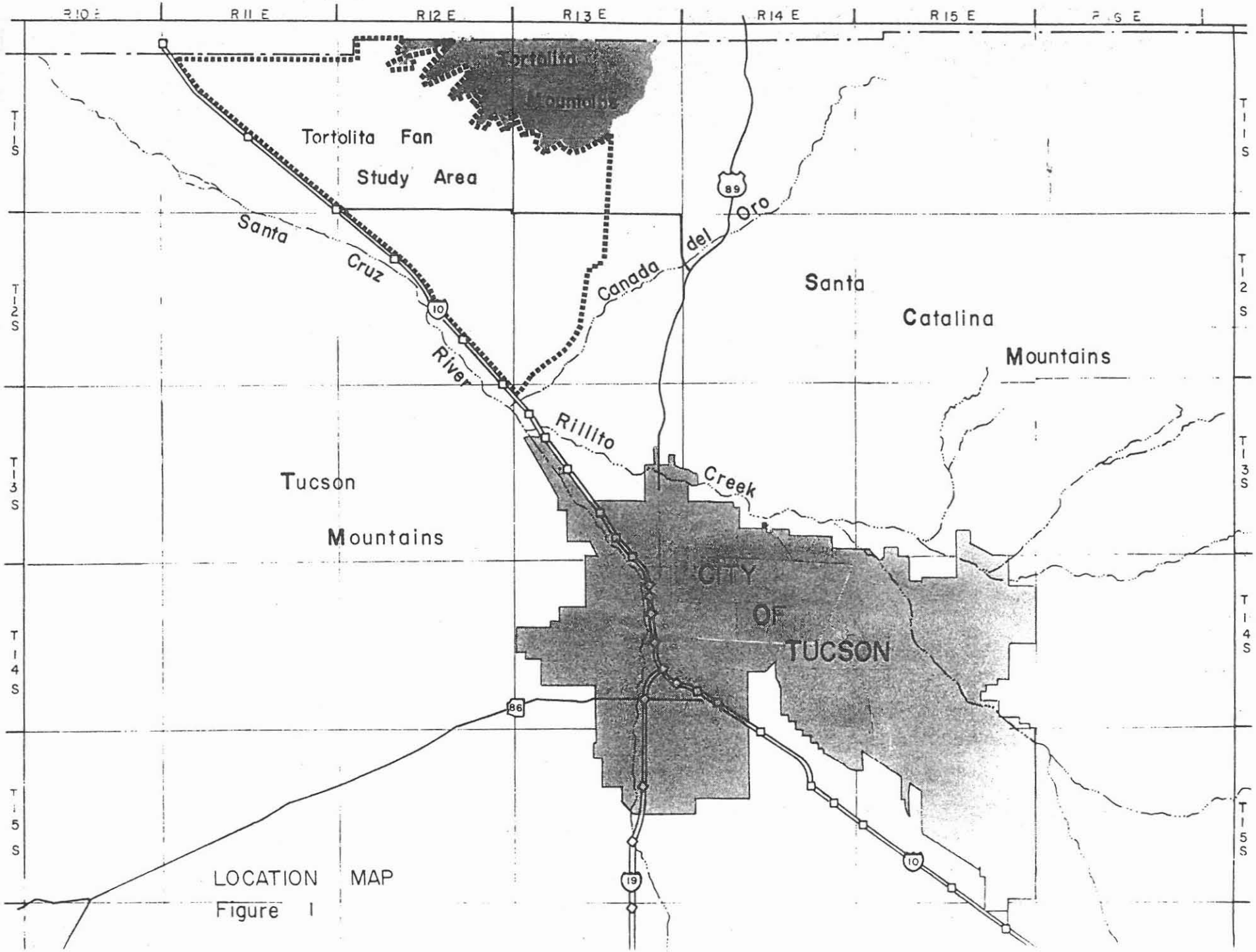
STUDY AREA

The study area is located in northern Pima County and covers approximately 80 square miles of the alluvial deposits which extend southwest of the Tortolita Mountains (Figure 1). The appeal involves Flood Insurance Rate Map Panel Numbers 040073-980, 985, 995, 1015, 1020, 1025, 1605, and 1610, dated November 14, 1986.

Geology

The geologic units of the Tortolita Mountains range in age from Precambrian (600 million years and older) to Mid-Tertiary (about 70 million years before the present). The Pinal Schist is the oldest unit contributing sediment to the alluvial fans, but Late Cretaceous to mid-Tertiary granitic intrusions comprise the bulk of the central and southern Tortolita Mountains (Cella Barr and Associates, 1986). Though once affected by high-angle normal faulting, the area is now tectonically inactive.

The Tortolita alluvial fans are composed of gravel to silt-sized fragments of schist, granite, calcium carbonate, quartz, and feldspar. Heavy mineral analysis shows that the alluvial fan material is predominantly derived from reworking of old alluvial fan deposits (Field, 1985). Well logs, field evidence, and gravimetric surveys show that the alluvial deposits are relatively thin, ranging from 1 to 700 feet in thickness.



LOCATION MAP
Figure 1

Vegetation and Climate

The naturally occurring vegetation in the study area is Sonoran desert scrub, such as mesquite, creosote bush, palo verde, ironwood, and annual and perennial grasses. Cacti include saguaros, prickly pear, and cholla. The average vegetative cover density has been estimated at 20 percent (Cella Barr Associates, 1986).

The study area has a warm, semi-arid continental climate. Daily maximum temperatures average more than 90 degrees Fahrenheit from May to September. Winters are mild, with infrequent freezing temperatures. Average annual precipitation is between 10 and 16 inches.

The area is subject to storms during three seasons. During the winter months, rain falls in response to Pacific storms. These storms tend to be widespread, causing gentle, prolonged rainfall. The summer months are characterized by intense, short-duration, localized thunderstorms produced by moist air from the Gulf of Mexico. During the third season, from late summer to fall, tropical thunderstorms from the Pacific Ocean can cause prolonged and intense rainfall over extremely large areas. All three types of storms must deliver the precipitation to the mountainous portion of the basin to generate the discharges modelled in the alluvial fan flooding analysis. Alluvial fan floods of the type used in the model by the Study Contractor are not generated by rainfall on the fan itself.

Existing and Projected Land Uses

The Tortolita Alluvial Fan Area is a rapidly urbanizing portion of Pima County. Currently the majority of the area is rurally zoned, but the Tortolita Area Plan and Tortolita Community Plan both project urban and suburban land uses.

The majority of development to date has occurred in the Canada Agua and North Ranch basins, south of Tangerine Road. The subdivisions have fairly high density zoning, typically in excess of three units per acre. Many of these subdivisions have been required by Pima County to construct detention/-retention basins in order to mitigate the additional runoff generated by these developments.

The recently completed Reach 3 of the Central Arizona Project (CAP) will significantly affect land uses. The CAP, constructed by the U. S. Bureau of Reclamation, is designed to bring water from the Lower Colorado River to Tucson via an open concrete aqueduct. The aqueduct crosses the Derrio, Cottonwood, Cochie, and Wild Burro alluvial fans (Figure 6, in pocket). A compacted earthen dike ten to twelve feet high, located on the upstream side of the aqueduct, obstructs normal alluvial fan flooding processes. A collector channel along the dike will convey discharges to overchutes. The original analysis by the Study Contractor did not include CAP inpacts. The effects of CAP construction on flooding conditions are a significant concern of Pima County, and will be further discussed in the Technical Appeal.

ALLUVIAL FAN FLOODING ANALYSIS

Alluvial fan flooding analysis refers to flooding which initiates within a mountainous watershed, and extends downstream to the alluvial fan. Alluvial fan flooding is of great concern throughout the western United States, because of the uncertainty of flow paths and the high velocities and depths of erosion which characterize these floods. To address these concerns, FEMA has adopted a probabilistic methodology adapted from Dawdy (1979). Not included in this type of analysis is flooding which is generated on the fan itself. The latter type of flooding tends to produce sheetfloods on fans with low topographic relief, and ordinary channelized flooding on fans with high topographic relief.

The alluvial fan flooding methodology adapted from Dawdy (1979) depends on the validity of several assumptions. The first assumption is that the location of the channel formed by a given flood event is random. In other words, each major event is just as likely to form a new channel and take a new course as to follow the path of a previous event. Secondly, Dawdy (1979) also states that the channels must be shaped by the flow events themselves. As noted in FEMA's Guidelines and Specifications for Study Contractors (1982, 1985), the method applies only to natural flow conditions on active alluvial fans. Where these assumptions are not met, Study Contractors are urged by FEMA to exercise good engineering judgment in determining the most appropriate methodology to use.

The alluvial fan flooding methodology uses a variety of empirically derived formulae to compute the probability of given discharges at the apex of a fan to the probability of various depths and velocities of flow occurring on the fan below the apex. The resulting maps delineate zones having discrete

depth and velocity values. These zones extend over the entire area determined to be at risk from alluvial fan flooding. The depth values on the resulting FIRMs indicate the depth of the channel that would carry the regulatory discharge to the toe of the fan. The velocity values refer to the velocity of flow in the channel that carries the discharge (FEMA, 1985).

THE BASIS OF THE APPEAL

Pima County finds is appealing the alluvial fan flooding analysis of the proposed Flood Insurance Restudy on both scientific and technical grounds. The scientific basis for the appeal is provided by a detailed soil survey recently completed by the U. S. Soil Conservation Service and by new and previously unavailable geomorphic studies of alluvial fan deposits in the Tortolita Area. The scientific appeal identifies deficiencies in the delineation of active versus inactive portions of the alluvial fans, and in the selection of fan apices.

The technical basis for the appeal is provided by a review of Dawdy's 1979 paper and FEMA's Guidelines and Specifications for Study Contractors (1982, 1985) and by analysis of the results shown on the preliminary FIRMs. The technical appeal describes deficiencies in the application of Dawdy's discharge derivation and in the use of the coalescent fan technique. FIRM panels which demonstrate lack of agreement between the alluvial fan restudy area and the adjacent areas of the Pima County Flood Insurance Study are also identified. The technical appeal also discusses the implication of using the Zone AO flood hazard zone designation and the need for an alternative means of flood hazard analysis in areas downstream of the Central Arizona Project canal and collector dike.

SCIENTIFIC BASIS OF THE APPEAL

SOILS

Soil Development

The term "soil" has various meanings, depending upon who is using the term. For example, to engineers "soil" is unconsolidated surficial material, whereas soil scientists and geomorphologists distinguish soil from unaltered parent material. Birkeland (1980) describes a soil as "a natural body consisting of layers or horizons... of variable thicknesses, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics." The scientific work upon which this appeal is based uses the term soil in the stricter latter sense, not the former.

Soils differ from the parent material in which they form because of various processes occurring near the earth's surface. These processes include addition of clays and calcium carbonate from atmospheric dust, the breakdown of original minerals into chemically different weathering products, the formation of unique soil structures, and the segregation of certain weathering products into different horizons within the soil profile. A soil profile is the vertical arrangement of all soil horizons down to the unaltered parent material.

For soils to form in semi-arid regions, deposition must cease or nearly cease because the weathering processes which create a soil proceed slowly and only near the earth's surface. Likewise, if erosion is occurring more rapidly than weathering, a soil cannot form because the weathering products at the surface would be carried away more quickly than they could form.

In alluvial fans in semi-arid areas such as the Tucson Basin, soils form only on the more stable alluvial surfaces, which are the upper portions of fan deposits. The slow soil-forming processes are easily overwhelmed if alluvial fan processes are active, because only one alluvial fan flooding event could easily erode or deposit more material than has been produced by a thousand years of weathering.

Distinguishing Active versus Inactive Alluvial Fans

Stable alluvial surfaces develop increasingly distinct soil profiles with time, and the degree of soil profile development can be used to estimate relative or absolute ages of alluvial fan deposits (Harden, 1982; Harden and Taylor, 1983). The age of the soil provides a minimum age for the alluvial deposit in which it forms because the alluvium must have been carried to that position and have remained relatively stable for the soil to form in place. Usually it is assumed that soil formation begins as soon as the last alluvial fan flooding event ends, unless other data suggest otherwise.

In the semi-arid Southwest, the dominant soil characteristics used to estimate ages of alluvial fans are the development of a clay-rich, reddened soil horizon (the "argillic horizon"), and the accumulation of a whitened calcium carbonate or silica horizon (the "carbonate horizon" or "duripan") (Harden and Taylor, 1983). Soil color charts and special field and laboratory measurements are needed to quantify the development of these diagnostic horizons. A very young soil is likely to be very similar in outward appearance to the original alluvial fan deposit except for a faint reddening of a soil layer, or a nearly imperceptible (to the eye) accumulation of

calcium carbonate. A very old soil will have a thick, very red, clay-rich argillic horizon, and is often underlain by a thick, white layer of parent material cemented by calcium carbonate or silica. This cemented layer is very durable, and can persist for millions of years, even if the overlying red argillic horizon is eroded. An example of the correlation of soil development to absolute age is provided in Table 1, which relates age of alluvial surfaces in southern New Mexico to soil development.

In addition to soil development, other criteria may be used to determine the age of alluvial fan deposits. The topography of the alluvial fan surface is useful because older fans generally exhibit progressively more dissected morphologies as drainage networks develop on the fan deposits (Figure 2). As Dawdy (1979) points out, local relief across active alluvial fans tends to be small, on the order of 5 to 10 feet. By contrast, relief on old fans may be as much as 50 to 100 feet. Grain size and degree of sorting of the deposits may be useful as well; for example, alluvial fan deposits in the nearby Santa Catalina Mountains (see Figure 1 for location) containing large, rounded boulders indicate that higher peak flow discharges existed to transport sediment during the Pleistocene, over 11,000 years ago (McFadden, 1978). Stratigraphic relationships also help subdivide alluvial units because younger deposits are often inset into the older units (Figure 2). The development of rock varnish on alluvial fan surfaces has also been used as a dating tool in the arid Southwest.

The alluvial fan methodology used by the Federal Emergency Management Agency (FEMA) applies to natural flow conditions on active alluvial fans (Federal Emergency Management Agency, 1982, 1985). While no cutoff age for alluvial fans appears to have been adopted by FEMA in its Guidelines and Specifications for Study Contractors (1985) to differentiate active and

Table 1 . Influence of Age of Geomorphic Surface on Soil Characteristics[a]

Age of surface (years)	Soil name	Soil characteristics
100(?)	Entisol (torripsamment)	Thin gray A horizon; vesicular in places; slight accumulation of organic carbon
100(?) to 1000	Entisol (torrifluvent)	Slight evidence of carbonate accumulation; thin strata absent
1100 to 2100	Entisol (torrifluvent)	Weak distinct horizon of carbonate accumulation in gravelly materials
2200 to 4600	Aridisol (calciorthid)	Weak calcic horizon of carbonate accumulation in low-gravel matetrials; prismatic and subangular blocky structure
Late Pleistocene	Aridisol (haplargid) (paleorthid)	Haplargid: Oriented clay coatings in Bt horizon; calcic horizon Paleorthid: Indurated calcic horizon; single laminar layer
Mid-Pleistocene	Aridisol (paleorthid)	Indurated calcic horizon; multiple laminar layers

[a]Data from Gile and Hawley (1968).

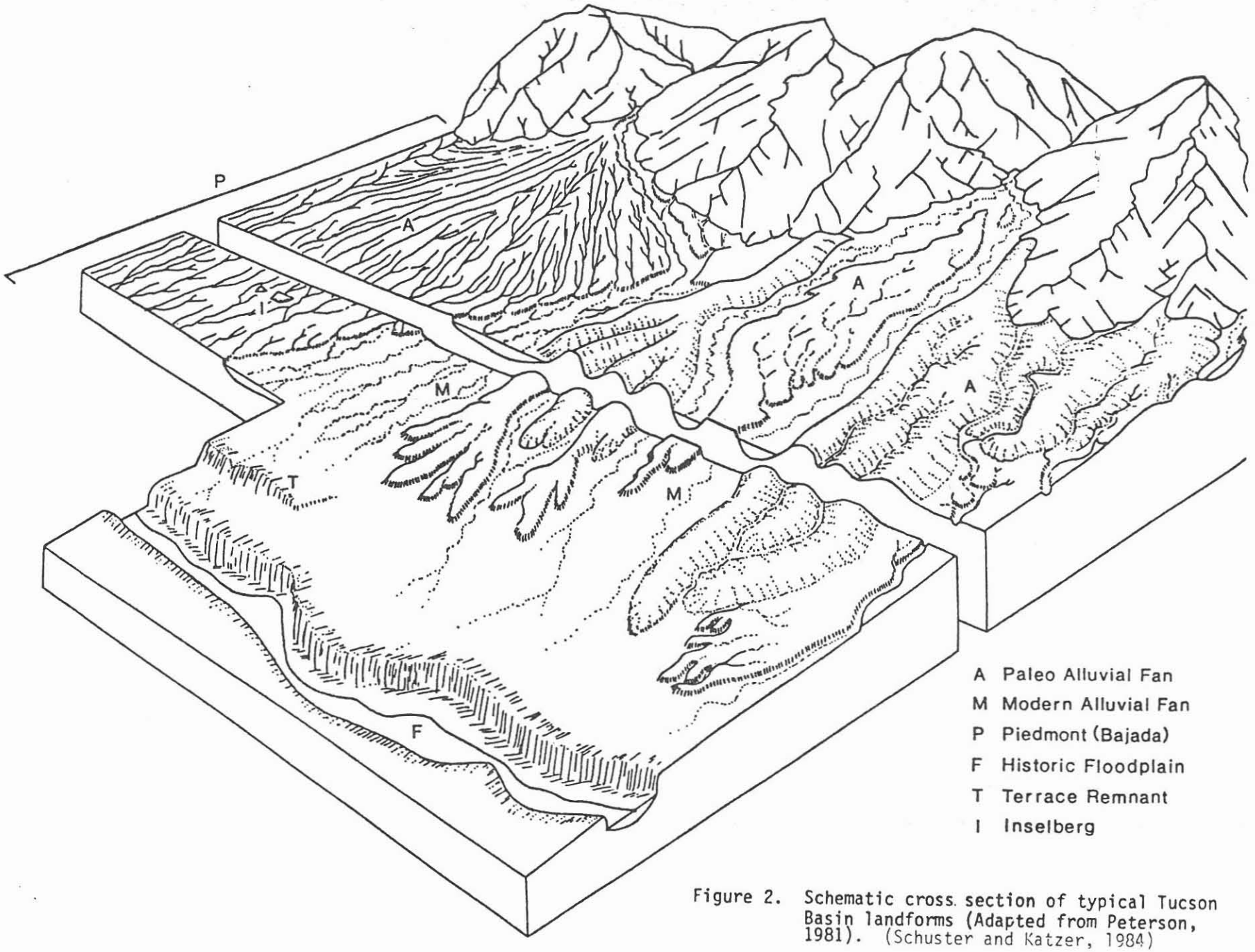


Figure 2. Schematic cross section of typical Tucson Basin landforms (Adapted from Peterson, 1981). (Schuster and Katzer, 1984)

inactive fans, FEMA does use a 10,000-year cutoff age to define active faults. In this appeal, we assume that areas of the fan characterized by Pleistocene soils (10,000 years or older) are inactive. All areas having Holocene soils (younger than 10,000 years) will be considered active. To consider active areas as those subjected to as few as one alluvial fan flooding event in ten thousand years is a conservative approach.

Soils on the Tortolita Alluvial Fans

The Soil Conservation Service (SCS) completed describing and mapping the soils of eastern Pima County in 1986. An earlier soil survey included the lower portions of the Tortolita alluvial fans (SCS, 1972). This earlier study is out of print (Chris Cochran, SCS, pers. comm.), but the maps and key are included in Appendix 1. Slight differences exist in the terminology of the two studies; the equivalent soil names are included in the key.

Table 2 lists the soils that occur in the Tortolita alluvial fan area. Table 2 also lists the soil classification, which summarizes some of the most important soil characteristics. Detailed descriptions of the soils are contained in Appendix 2.

The soils maps produced by the SCS contain various map units on the Tortolita alluvial fan (Table 3; Appendix 2). Each map unit generally consists of two soils. Although the soils maps for the Tortolita study area are not yet published, the SCS has made the information available to the public upon request. Because of the accuracy of the new mapping compared to much older studies, the Pima County Department of Transportation and Flood

Table 2

Soils in the Tortolita Alluvial Fan Area*

Mimbres	Typic Camborthids
Hayhook	Typic Camborthids
Anthony	Typic Torrifluvents
Arizo	Typic Torriorthents
Palos Verdes	Haplic Durargids
Sonoita	Typic Haplargids
Jaynes	Entic Durorthids
Continental	Typic Haplargids
Pinaleno	Typic Calciorthids
Nickel	Typic Calciorthids

Camborthids: soils having a reddened horizon but without much accumulation of clay or other diagnostic soil features.

Haplargids: soils having an argillic horizon but no carbonate or duripan horizons.

Durorthids: soils having a duripan but no argillic horizon.

Durargids: soils having an argillic horizon and a duripan.

Calciorthids: soils having a carbonate horizon but no argillic horizon.

Torriorthents: soils lacking diagnostic accumulations of clay, carbonate or silica.

Torrifluvents: soils lacking diagnostic accumulations of clay, carbonate or silica, and that differ in organic carbon content from Torriorthents.

*Not listed: Soils formed in bedrock

Table 3

MAP UNITS IN THE TORTOLITA ALLUVIAL FAN AREA

1A	Hayhook sandy loam
1B	Hayhook-Sonoita complex
11A	Continental gravelly loam
26A	Palos Verdes-Jaynes complex
26B	Palos Verdes-Sonoita complex
28A	Pinaleno very cobbly sandy loam
28C	Pinaleno-Nickel-Palos Verdes complex
34	Arizo-Riverwash complex
35A	Mimbres silt loam
51A	Anthony fine sandy loam

Control District is now requiring consulting engineers to use the new maps in rainfall-runoff computations and other flood-control design procedures. (Pima County Department of Transportation and Flood Control District, 1986)

Age Estimates for Tortolita Alluvial Fan Deposits

In the Tucson Basin, soil development has been used to estimate the relative and absolute ages of alluvial fan deposits from the Tortolita, Santa Catalina, Tucson and Santa Rita Mountains (Pearthree and Calvo, 1982; Fields, 1985; Schuster and Katzer, 1984; McFadden, 1978; Pashley, 1966, Blissenbach, 1952; Soil Conservation Service, 1972; Soil Conservation Service, 1979; Soil Conservation Service, in press). As mentioned previously, the soil age is a minimum age estimate for the alluvial fan deposit in which it formed.

Table 4 summarizes previous age estimates for alluvial fans in the Tucson Basin. Of particular interest to this appeal is the work of Schuster and Katzer (1984), in the northern Tucson Basin. They broadly divided the Tortolita Alluvial Fan Area into areas of Pleistocene fan deposits (Q1) and Holocene fan deposits (Q2) (Figure 3), based on soil development and archaeological evidence. According to Schuster and Katzer (1984), there are two reasons that Holocene-age alluvium in the Tortolita Alluvial Fan Area is characterized by poorly developed soils as compared to the Pleistocene-age alluvium. First, most Pleistocene soils are at least ten times older than that of the Holocene, and secondly, Holocene soils have developed in a drier climate than their Pleistocene counterparts. Additional rainfall during the wetter Pleistocene probably enhanced rates of soil formation.

Table 4 Soil properties of the Desert Project, New Mexico (compiled from Gile, Hawley and Grossman, 1981).

Geomorphic Surface	Estimated Age (10^3 yrs)	Maximum Redness	Maximum % clay	Max. Stage Carbonate Development
ORGAN	Mid- to late Holocene (1.1-4,6)	5YR-10YR	12-18	I-II
ISAAC'S RANCH	Latest Pleistocene (8-15)	5YR	16-28	I-III
JORNADA II	Late Pleist-ocene (25-75)	2.5YR-5YR	28-32	III-IV
JORNADA I	Late Mid-Pleistocene (250-400)	2.5YR-5YR	33-47	III-V
DONA ANA	Early to Mid-Pleistocene	10YR-5YR	15-74	IV-V

Soil properties of the Santa Rita piedmont (from Pearthree and Calvo, 1982).

Geomorphic Surface	Estimated Age (10^3 yrs)	Maximum Redness	Maximum % Clay	Max. Stage Carbonate Development
Q3b	4	7.5YR4/3	7.2	I (weak) or none
Q3a	4-8	7.5YR3/4	4.3	II
Q2d	8-15	5YR4/6	6.5	I (weak)
Q2c	75-130	5YR3/6	22.3	I-III
Q2b-2	200-300	2.5YR3/6	31.2	III
Q2b-1	400+	2.5YR3/6	44.2	II-IV
Q2a	1,000-2,000	10YR3/6 (weak)	66.7	(not known)

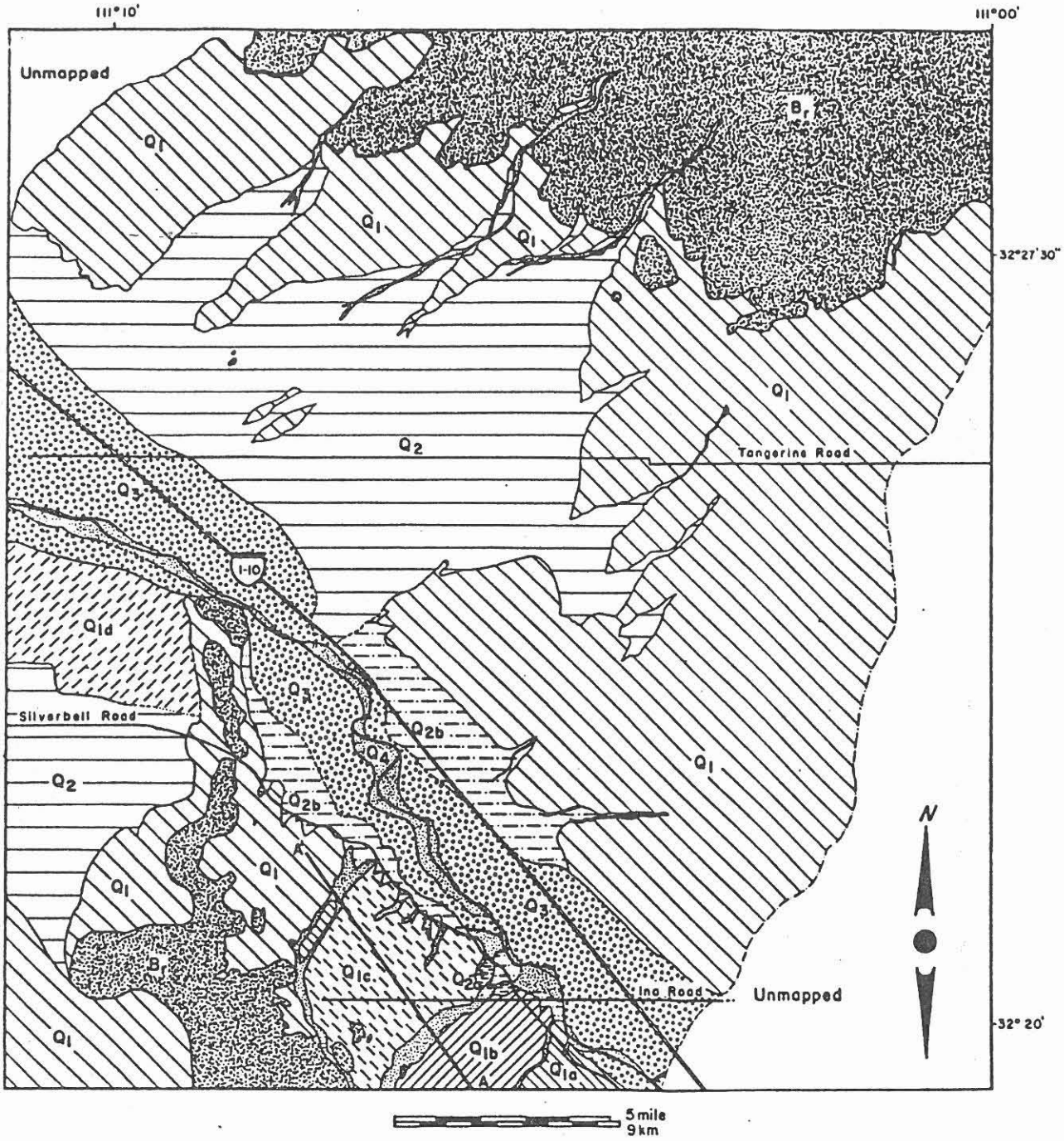
Soil properties of the Canada del Oro valley (from McFadden, 1978)

Geomorphic Surface	Estimated Age (10^3 yrs)	Maximum Redness	Maximum % Clay	Max. Stage Carbonate Development
Qv	Recent	10YR*	no B hz	0
Golder Terrace	Mid- to Late Holocene (4)	7.5YR*	25.8	0
Brave Bull Terrace	Late Pleist-ocene (7.5-25)	5YR	11.7	0
Catalina Terrace	Late Pleist. (75-100)	2.5YR	15.5	I
Twin Lakes Surface	Mid-Pleist. (at least 500)	10R	46.8	III,IV
Cordonnes Surface	Mid- to Early Pleist. (>1,000)	2.5YR	20.6s	IV

*No argillic horizon; color on BKm horizon.

Soil properties of the Tucson Mountain piedmont (Schuster and Katzer, 1984)

Geomorphic Surface	Estimated Age (10^3 yrs)	Maximum Redness	Maximum % Clay*	Max. Stage Carbonate Development
Q2a	Mid-Holocene (4-8)	10YR 4/4	10.0	II
Q1c	Mid-to Late Pleist. (100-300)	5YR 4/6	29.5	V
Q1b	Mid-Pleist. (>400)	2.5YR3/6	36.5	V
Q1a	Early to Mid-Pleistocene	5YR4/6	35.3	V



KEY

	Q_4	ACTIVE ALLUVIAL CHANNELS AND FANS
	Q_3	HISTORIC FLOODPLAIN
	Q_2	UNDIFFERENTIATED HOLOCENE FANS
	Q_1	UNDIFFERENTIATED PLEISTOCENE FANS
	B_r	BEDROCK

Figure 3

Table 5, Soil Properties and Age Estimates for Tortolita Alluvial Fan Soils, relates the SCS soils to the Q1 and Q2 fan deposits defined by Schuster and Katzer (1984). The unpublished Soil Survey of Eastern Pima County (SCS, in press) defines older and younger alluvial fan deposits in the survey area but does not assign age estimates, as we have done. Age estimates for the Tortolita Alluvial Fan Area Holocene deposits are more reliable because archaeological remains buried within the deposits have been used to constrain the ages. Age estimates for Pleistocene deposits are less accurate; they are based on correlation with the well-studied, independently dated soils sequence from southern New Mexico, presented earlier in Table 1 (see also Gile, Hawley and Grossman, 1981). The southern New Mexican soils have been used to estimate soils ages previously in the Tucson Basin (McFadden, 1978; Pearthree and Calvo, 1982; Schuster and Katzer, 1984). The soil characteristics of the New Mexico soils probably developed slightly more rapidly than the Tortolita soils due to the higher effective precipitation of the New Mexican location.

According to Schuster and Katzer (1984), the Q1 Pleistocene alluvial fan deposits consist of both debris flow deposits and fluvial deposits of the Tortolita Alluvial Fan Area. Based on the amount of calcium carbonate in the profile and the maximum soil redness, we have tentatively divided the Q1 deposits into three different Pleistocene units, whose ages are estimated in Table 5.

Schuster and Katzer (1984) found that Q2 alluvium consists of a series of coalescing alluvial deposits from the Ruelas, Wild Burro, Cochie and Prospect Washes. This alluvium thinly to discontinuously (3 to 7 feet) mantles an underlying Pleistocene age fan deposit. The soil developed in the Q2 alluvium (the Hayhook soil) is estimated to be middle Holocene in age by Schuster and Katzer, based on comparison to soil development in the Tucson Mountains fan

Table 5. Soil Properties and Age Estimates for Tortolita Fan Soils

Geomorphic Surface	Soil Name	Est. Age (10^3 year)	Max. Redness	Max. % clay	Max. Carb. Stage*
Q2	Mimbres	4-8	10YR6/4	27	None
	Hayhook	4-8	7.5YR5/4	20	None
	Anthony	0-4	10YR6/4	<18	I
	Arizo	0-4	10YR6/4	27	I
Q1	Palos Verdes	400+	5YR4/6	35	V
	Sonoita	10-20	5YR5/4	18	None
	Conti-nental	100-400	2.5YR4/6	45	II-IV
	Pinaleno	100-400	2.5YR4/6	27	II

*Carbonate stages are used to indicate the relative amount and morphology of calcium carbonate in the soil profile.

area. Both Schuster and Katzer (1984) and Field (1985) found that the Q2 alluvium does not appear to be deposited by debris flows, but by sheetflow and channel flow. This observation is significant, because debris flows would present additional hazards to the public as a function of their greater stream competence and momentum of debris flows.

Schuster and Katzer (1984) suggests that alluvial deposition is more active on the lower Q2 area than the upper fan area. They noted that the Q2 deposits of the lower Tortolita Alluvial Fan Area lack the soil development of the middle and upper fan area Q2 deposits. Also, the depth to the underlying Pleistocene soil increases from 7 feet in the upper fan area to approximately 30 feet in the lower fan area. Their attempts to delineate a contact between the two Q2 subunits on a reconnaissance basis proved unsuccessful, due to a lack of variation in surface expression.

The third alluvial deposit in the area is the historic floodplain of the Santa Cruz River (Figure 3). The area northeast of the Interstate Highway 10 has been effectively removed from the floodplain of the river due to construction of the Southern Pacific Railroad and Interstate, but is subject to inundation hazards from the Tortolita Alluvial Fan Area due to inadequate flow capacity of drainage structures under the Southern Pacific Railroad, which parallels Interstate Highway 10.

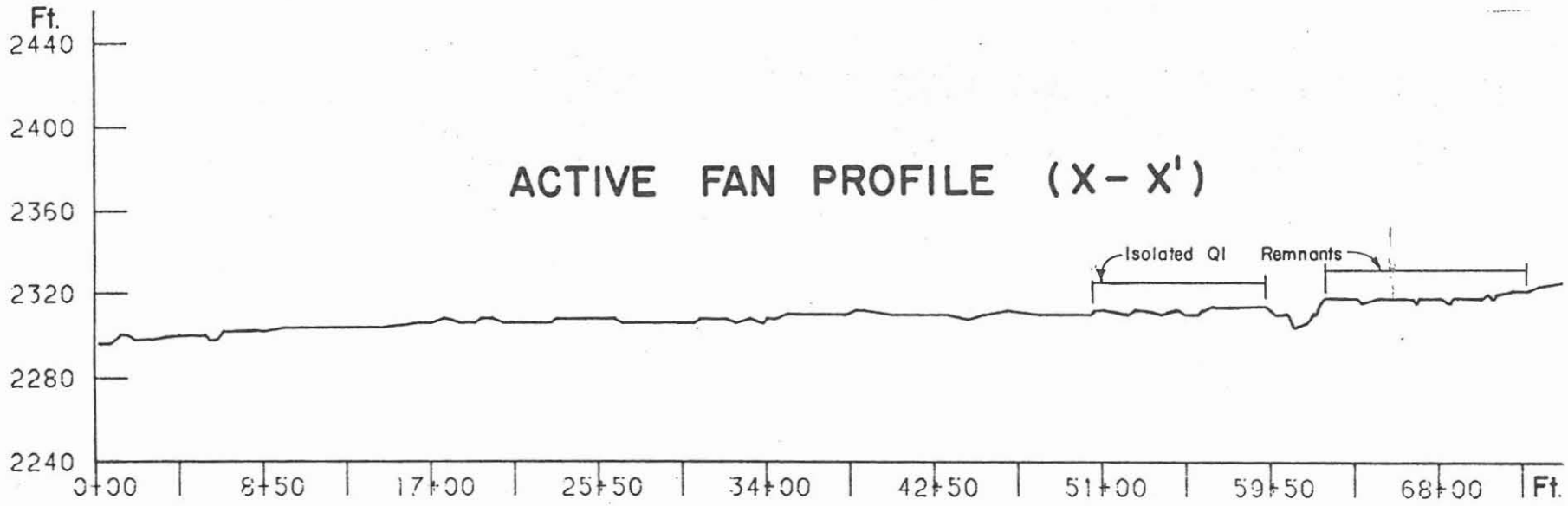
More detailed information is available from the recent work of Field (1985), who studied depositional patterns on nine Holocene alluvial fans in the Tortolita Alluvial Fan Area. Site-specific findings will be discussed later.

Activity of Fans in the Tortolita Alluvial Fan Area

Based on soil development, a great deal of the Tortolita Alluvial Fan area has not been subject to active alluvial fan processes for periods exceeding 10,000 years. Figure 3, Pleistocene and Holocene fan deposits in the Tortolita Alluvial Fan Area, depicting the Q1 and Q2 deposits of Schuster and Katzer (1984), effectively separates areas of alluvial fan activity from inactive areas.

Figure 4 contrasts the cross-sectional relief of active (Q2) versus inactive (Q1) fan surfaces (see Figure 6 for location of cross-sections). As noted by Dawdy (1979), relief on active fans tends to be small, on the order of 5 to 10 feet. The relief of inactive Q1 areas varies from 20 to 100 feet, greatly exceeding the relief on Q2 fan surfaces.

Inactive fan areas are no longer subject to flooding from the mountain watershed because the inactive areas are higher than the adjacent present-day channels issuing from the mountains. In other words, water would have to flow uphill from the channel onto the inactive fan surfaces. This is not to say inactive fans are no longer subject to flooding of any kind, only that they are no longer subject to flooding from the mountain watersheds. For instance, portions of inactive Q1 fans clearly include Holocene soils such as the Hayhook. These Holocene soils are located within the floodplain of existing channels; these channels, however, head on the inactive alluvial fan, not in the mountains. The drainage net in Figure 5, Drainage net illustrating hydraulic isolation of Q1 deposits, illustrates the lack of a hydraulic connection to the mountain watershed for inactive (Q1) portions of



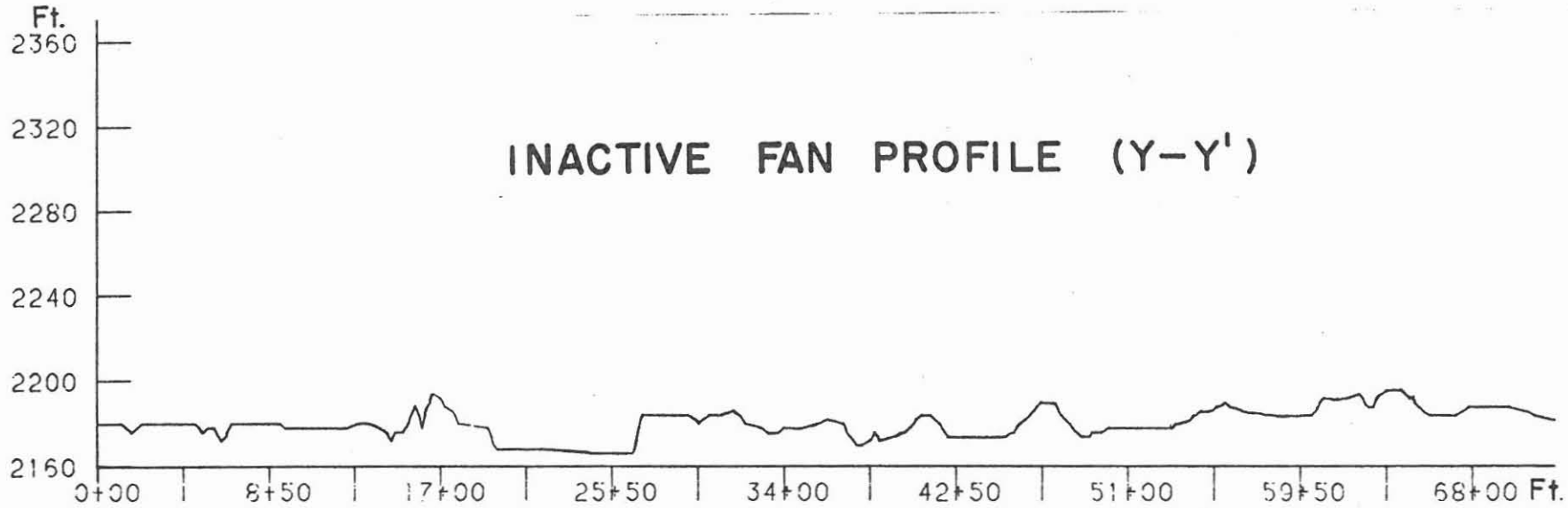
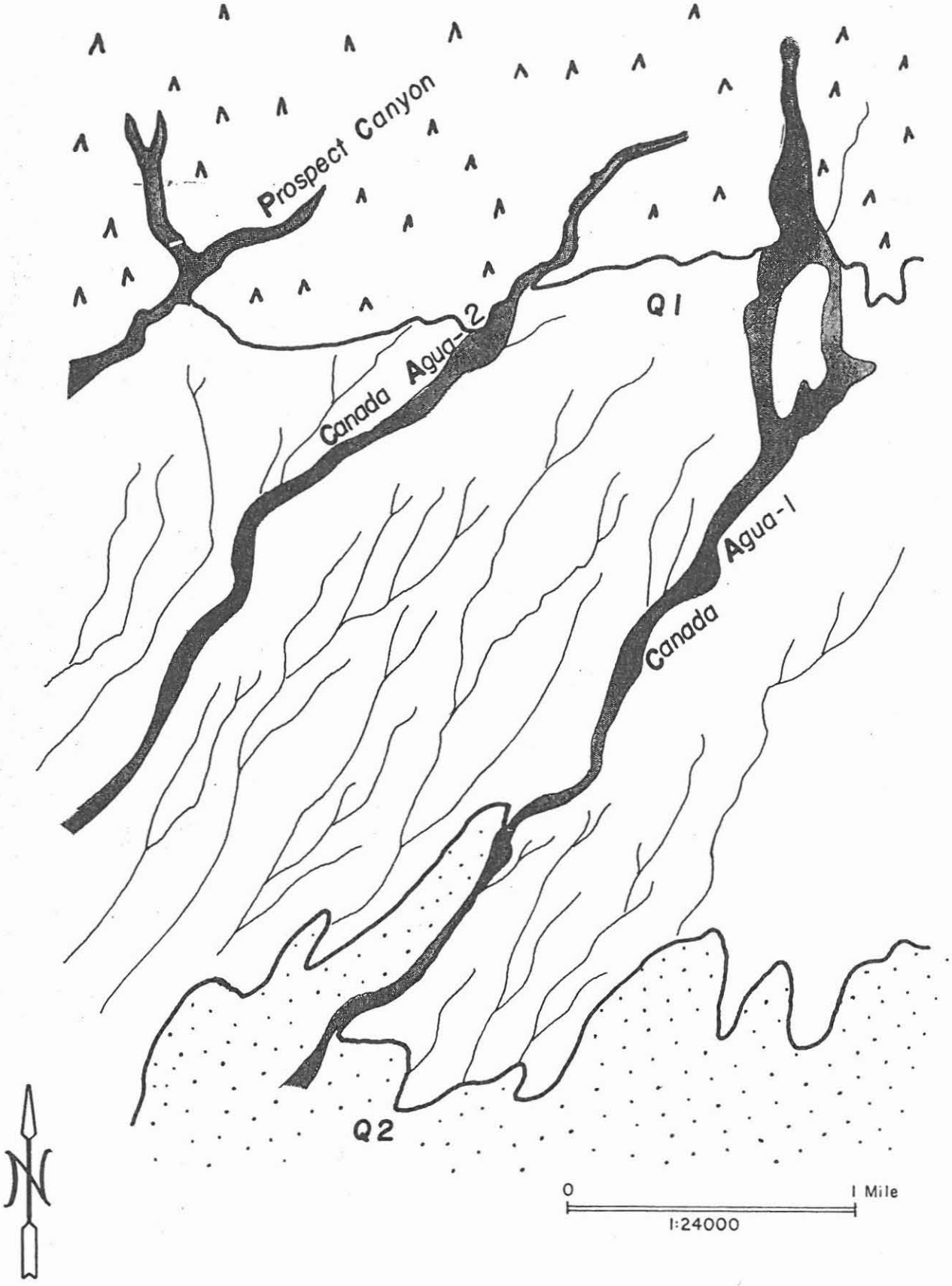


Figure 4 Topographic Relief Comparison

Vertical Exaggeration ~10X



Illustrating Hydraulic Isolation Of The Q1 Deposit

Figure 5

the fan area. Examination of the topographic maps will demonstrate that this is the case with other inactive fan areas. Areas of Q1, therefore, have been isolated from the main watershed for 10,000 years or more, and will continue to be isolated because the hydraulic connection to the trunk stream draining the mountains no longer exists.

An exception to the hydraulic isolation of Q1 deposits exists at the toe of the Tortolita Alluvial Fan Area, where as much as 30 feet of Holocene aggradation has buried late Pleistocene fan deposits, and has lifted the active fan surface high enough to possibly flood mid-Pleistocene fan deposits (Figure 4). The Q1 fan deposits in the lower fan area do warrant inclusion, then, into the alluvial fan flooding methodology.

Figure 6 (in pocket) shows the areas of Holocene channel alluvium and Pleistocene fan deposits which are hydraulically isolated from active alluvial fan flooding. This map was produced by combining soil data from the SCS (in press and 1972), topographic information, in-house aerial photography analysis and field inspections, and the previously described data from Schuster and Katzer (1984). Large areas of Pleistocene deposits in the mid and lower fan are not shown on this map because they are surrounded on most sides by aggrading, active (Q2) fan deposits.

Figure 6 shows that roughly 35 percent of the area shown as active in the alluvial fan flooding analysis of the Flood Insurance Restudy performed by the study contractor has not been subject to alluvial fan flooding during the last 10,000 years or more. Pima County considers the discrepancy between the FIS results and the new scientific information which has been presented sufficient to warrant revision to the resulting FIRMs.

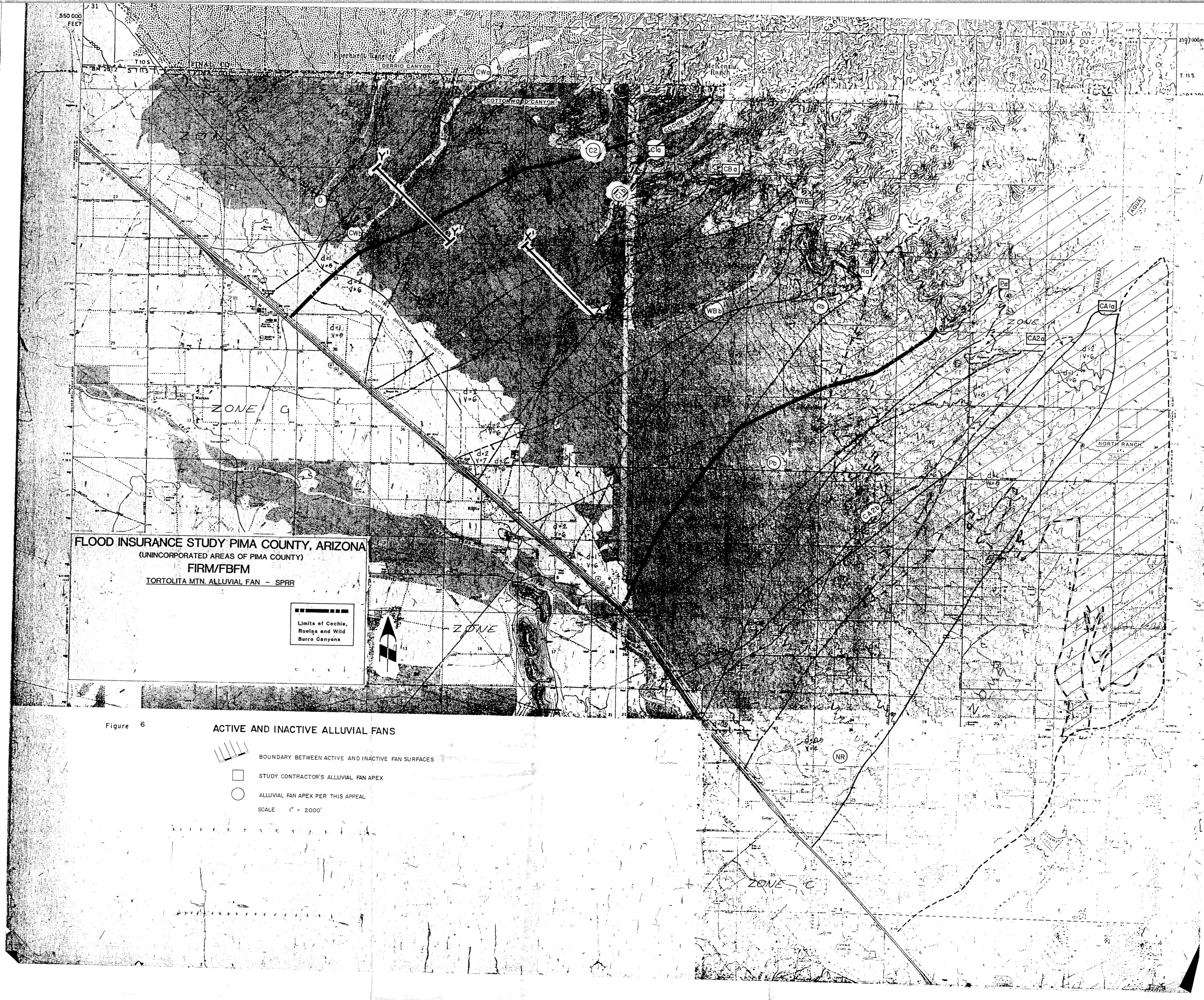

FLOOD INSURANCE STUDY PIMA COUNTY, ARIZONA
(UNINCORPORATED AREAS OF PIMA COUNTY)
FIRM/FBFM
TORTOLITA MTN. ALLUVIAL FAN - SPRR
Limits of Cochie, Ruelas and Wild Burro Canyons
ACTIVE AND INACTIVE ALLUVIAL FANS
BOUNDARY BETWEEN ACTIVE AND INACTIVE FAN SURFACES
STUDY CONTRACTOR'S ALLUVIAL FAN APEX
ALLUVIAL FAN APEX PER THIS APPEAL
SCALE 1" = 2000'
DERRIO CANYON
COTTONWOOD CANYON
COCHIE CANYON
WILD BURRO CANYON
RUELAS CANYON
CENTRAL ARIZONA PROJECT
NORTH RANCH
ZONE C
ZONE
CWa
CWb
C2
C1a
C1b
CBa
WBa
WBb
Ra
Rb
Pa
Pb
CA1a
CA2a
CA2b
NR
D
Y
Y'
X
X'
d=1 V=6
d=2 V=6
d=2 V=7
d=0.5 V=4

Figure 6

APEX LOCATIONS

Proper determination of the location of the apex of an alluvial fan is essential in obtaining accurate results from the alluvial fan flooding methodology adopted by FEMA because, "the behavior of flood flows, and the associated flood hazard, is largely a function of location below the fan apex" (Dawdy, 1979). However, simply locating the apex of an alluvial fan is not sufficient. Soils, topographic and geologic information must be used to distinguish apices of active versus inactive fans. For instance, at Wild Burro Canyon, the apex of a Pleistocene-aged fan is adjacent to a deeply entrenched channel. The use of the Pleistocene fan apex for the method would be inappropriate if debris flows and/or aggradational conditions did not exist. The Introduction to Appendix 6 of the Flood Insurance Study Guidelines and Specifications for Study Contractors (Federal Emergency Management Agency, 1985) recommends that good engineering judgement be used in areas where "natural alluvial fan processes may not occur." This would include areas of entrenched channels. Dawdy (1979) also cautions that while a probabilistic methodology is a reasonable approach to delineate alluvial fan flooding, specific alluvial fan features may indicate that "...other concepts must apply by physical reasoning."

The active alluvial fans in the study area deposit sand and silt-sized material, rather than coarse boulders or gravels (Field, 1985). These deposits are characteristic of flooding below the intersection point of the alluvial fan (Packard, 1974, p. 93, in Fields, 1985, p. 12). The intersection point on a fan is where channel depth approaches zero and this is generally the location for the revised apex locations suggested in this report.

Therefore, delineation of the areas of silts and sands on alluvial fans provides the investigator with a clearer understanding of the boundaries between active and inactive surfaces.

The flood hazard areas delineated on the preliminary FIRMs for the Tortolita Alluvial Fan Area are based on improper location of the fan apices. The assumption was made during the Study Contractor's modeling process, based on guidance supplied by FEMA, that all apices are located at the base of the topographic mountain front. Such a uniform assumption ignores topographic, geomorphic and geologic information which results in flood zones which encompass areas of inactive alluvial fans as well as active.

Due to the entrenched nature of many of the Tortolita alluvial fans, it was decided that HEC-2 analysis would be valuable in determining freeboard conditions of natural channels, proper apex location and the point where flow becomes unconfined for a given channel. The purpose of this analysis was strictly limited to these items. Modeling of the flow was simplified by designating the channel banks as the starting and ending offsets of the cross sections. This approach was taken because determination of water surface elevations within the entrenched channels was the primary goal. To account for local variations of Manning's "N" (roughness value) along given cross sections, NH cards were used. All computer runs used one-hundred year discharges obtained from the "Pima County Flood Insurance Study Hydrologic Investigation" (1984) prepared by the Study Contractor. Only supercritical analyses for Wild Burro, Cottonwood and Ruelas Canyons are presented here. This decision was based on indications of supercritical flow from subcritical runs, channel slope and review of current alluvial fan literature that indicates that flow approaches critical depth.

Three watercourses were considered to be representative of entrenched conditions in the Tortolita Alluvial Fan Area. Cottonwood Canyon and Wild Burro Canyon are entrenched for a significant distance through Pleistocene-aged alluvial fan deposits. Ruelas Canyon is entrenched through Holocene-aged deposits. The HEC-2 analyses show that the 100-year discharges for all three of these canyons are well contained within the entrenched areas. Minimum freeboard conditions upstream from the suggested apex locations for all three watercourses exceed ten feet.

The cross sections for the HEC-2 analyses begin at our suggested apex locations. These locations were chosen because topographic features indicate that flow is unconfined at and below these points and the areas downstream are subject to typical alluvial fan flooding. The Tortolita Mountain front represents the upstream limit of the analyses.

The results of the HEC-2 analyses indicate that much of the area currently designated on the FIRMs is not subject to alluvial fan flooding.
The entrenched channels contain the full 100-year discharges with an abundance of freeboard, from three to fifty feet. The surrounding Pleistocene- and Holocene-aged deposits show no indication of overbank flooding, which is supported by the HEC-2 analyses (Appendices 3 and 4). As discussed earlier in this report there is no evidence of debris flows or significant aggradation in the area. Therefore, the channel geometry and calculated 100-year water surface elevations are expected to be valid for both existing and future conditions. Field investigations indicate stable banks in these areas, and the potential for significant channel migration is small.

Following is a discussion of each watercourse in the study area, comparing the Study Contractor's apex locations with this report's suggested locations. Freeboard conditions and soil types are used to indicate active or inactive fan surfaces.

Derrio Canyon(D)

Derrio Canyon is located in the extreme northwestern section of the study area (Figure 6). The alluvial fan area associated with the Derrio Canyon watercourse was not analyzed by the Study Contractor for the development of the FIRMs. Typical alluvial fan flooding problems pose threats to the projected development of the Town of Marana, however, and the alluvial fan flooding methodology should be applied. The proper apex is identified on Figure 6 as D. Entrenchment of the Derrio Canyon wash lessens at this point and the presence of young Anthony soils indicates active fan development. Derrio Canyon and its active fan were studied by Field(1985), who found the Q1 deposits upstream of the apex serve to channelize flow. A 984-foot long trench across the Derrio Canyon fan and a 4265-foot long trench cut parallel to the direction of flow provided evidence for recent depositional activities. These trenches and others allowed Field (1985) to differentiate the Derrio Canyon fan from the Cottonwood Canyon fan immediately to the south.

The Central Arizona Project (CAP) Aqueduct has been constructed immediately downstream from apex D of the Holocene fan. Clearly, natural stream processes will be obstructed by the 10 to 12 foot high dike and overchute structures of the CAP. Whether the structures engineered by the Bureau of Reclamation meet FEMA's Safety and Design Standards is of significant concern to Pima County and the local community.

Cottonwood Canyon(CW):

Cottonwood Canyon is located in the northwest portion of the study area (Figure 6). The Study Contractor chose CW_A as the location for the apex of the Cottonwood Canyon alluvial fan. The correct apex (CW_B) for use with the alluvial fan flooding methodology is approximately 3.8 miles downstream from the apex used in the development of the FIRMs (Figure 6). The reason for the change in apex location is two-fold. First, the existing channel at Cottonwood Canyon is entrenched to a depth of over 50 feet at CW_A and only 2 feet at CW_B. Secondly, the soils indicate that active fan deposition begins downstream of CW_B. The expected depth of flow for the 100-year flood at CW_A as determined by HEC-2 analysis is 6.69 feet (Appendix 4). This depth of flow is well contained within the channel until it reaches CW_B. Debris flows have not occurred during the Holocene in the Tortolita Alluvial Fan area (Field,1985) and therefore pose no threat to the capacity of the channel. While aggradation does occur in the channel, archaeological evidence shows net aggradation in the channel has amounted to only 3 feet during the past 800 years (Fields, 1985). This rate of aggradation would not significantly decrease the channel capacity over the life of the floodplain maps. Field investigation of the bank material in this area reveals a cohesive, stable structure not easily eroded, limiting the possibility of channel migration.

Further support for the CW_B apex location is given by the presence and extent of old Palos Verdes soil surfaces adjoining the channel (Appendix 1). The presence of these soils indicates that there have been no flood flows from the upper watershed on these fan areas for at least 100,000 years. The

proposed fan apex location for Cottonwood Canyon (CW_B) is more realistic given the assumptions and limitations of the alluvial fan flooding methodology and the preceding information concerning soil types. The channel at this location loses definition and below this point, only young soils are present indicating an active alluvial fan surface. This is a logical point to begin application of the alluvial fan flooding methodology.

As with Derrio Canyon, the CAP aqueduct has been constructed across the active fan surface below apex CW_B (Figure 6). Without a detailed study it is not clear what effect the dike and overshoot structures will have on the natural alluvial fan processes. The alluvial fan flooding methodology adopted by FEMA is not capable of modeling flood-control structures on fan surfaces.

Cochie Canyon (C)

Cochie Canyon is located in the north central portion of the study area (Figure 6). The Study Contractor chose Cl_A as the apex for the Cochie Canyon alluvial fan (Figure 6). In doing so, the entire area downstream was considered to be subject to alluvial fan flooding (Figure 6). This is unsubstantiated since the channel at Cl_A is deeply entrenched to a depth of over 50 feet. Depths of flow at Cl_A for the 100-year flood as determined by Manning's ratings indicate that flow would be contained within the entrenched area (Cella Barr Associates, 1984). As with most of the Tortolita stream channels, debris flows and aggradation will not significantly decrease channel capacity or divert flows. The soils in the inactive areas of the fan, between Cl_A and Cl_B, include Pinaleno, Sonoita and Palos Verdes, indicating alluvial fan flooding has not occurred on the surfaces for at least 10,000 years.

Location $C1_B$ is a more realistic site for the apex of Cochie Canyon (Figure 6). The channel depth at this point decreases and becomes unconfined. In addition, younger soils, particularly Arizo and Hayhook, begin to dominate below this point indicating active areas of the alluvial fan.

The Study Contractor also did not consider a parallel drainage from Cochie Canyon, labelled C2 on Figure 6. This drainage has developed an alluvial fan of its own, superimposed upon the older, inactive fan deposits. The alluvial fan area associated with C2 should be treated separately from the area associated with $C1_A$.

The CAP aqueduct has been constructed across the active fan surface downstream from apex $C1_B$. Once again it is clear that natural stream processes will be obstructed by the aqueduct and associated structures. Dependence on the alluvial fan flooding methodology adopted by FEMA will produce erroneous results if used in this area.

Apex 6B

The canyon associated with apex 6B is unnamed and is located in the central portion of the study area (Figure 6). Apex 6B has been chosen as a fan apex by the Study Contractor despite the absence of a major trunk stream and an alluvial fan apex. Furthermore, the watershed area is less than one square mile at the Study Contractor's apex. Detailed study is normally terminated where the drainage area is less than one square mile, according to FEMA (1985).

Wild Burro Canyon (WB)

Wild Burro Canyon is located in the central portion of the study area (Figure 6). Apex WB_A was located by the Study Contractor at the Tortolita mountain front. This is not justified due to the deeply incised channel which is well over 50 feet deep at this point. Depth of flow for the 100-year event at this point, as determined by HEC-2 analysis, is predicted to be 3.67 feet with over 20 feet of freeboard. One hundred-year water surface elevations are shown in Appendix 5. The extensive area of mid to late Holocene Hayhook and Arizo younger soils below WB_B makes this site a more realistic fan apex (Figure 6 and Appendices 1 and 4). Channel depth also decreases significantly at WB_B until flow becomes unconfined.

The CAP aqueduct has been constructed across the toe of the Wild Burro Canyon alluvial fan surface downstream from apex WB_B. The alluvial fan flooding methodology should not be used to model this area.

Ruelas Canyon (R)

Ruelas Canyon is located in the southwestern portion of the study area (Figure 6). It exhibits many of the same features as Wild Burro Canyon. Point R_A was chosen by the Study Contractor as the apex for the Ruelas Canyon alluvial fan and point R_B is suggested by this report as the correct apex. There are both Holocene and Pleistocene soils between points R_A and RA_B, but because the channel in this reach is entrenched from greater than 100 feet at cross-section number 30 to unconfined flow conditions at cross section number 1, it is unlikely that significant overbank flooding will occur upstream from

cross-section number 1 (Appendix 4). HEC-2 analysis indicates a 100-year flood event depth of 2.85 feet with over 20 feet of freeboard at Point R_A. Point R_B represents the apex of the active fan area. Downstream from this location the areal extent of late- to mid-Holocene Hayhook and Arizo soils increases dramatically and the channel loses definition.

Prospect Canyon (P)

Prospect Canyon is located in the southeastern portion of the study area (Figure 6). The deeply entrenched channel and presence of Pleistocene age soils eliminates the apex chosen by the Study Contractor, Point P_A, as the correct apex in evaluating flood hazards for the Prospect Canyon alluvial fan (Figure 6). The channel is entrenched at Point P_A to a depth of over 50 feet. The adjacent Pleistocene soils represented by Palo Verdes-Sonoita complex indicate alluvial fan flooding has not occurred at point P_A for 10,000 to 400,000 years. Apex P_B is suggested as the proper apex for Prospect Canyon as it is located in an area of Holocene soil development along with a rapid decrease in channel depth (Figure 6).

Canada Agua Canyon(CA)

The Canada Agua Canyon is located in the southeastern portion of the study area (Figure 6). The Canada Agua Canyon is divided into two separate watercourses represented by CA_{1A} and CA_{2A}. Apices CA_{1A} and CA_{2A}, chosen by the Study Contractor, are similar to most of the preceding apices already discussed (Figure 6). The channels at these points indicate contained flow

within stable banks. Entrenchment at these apices exceeds 50 feet. In addition the presence of the Pleistocene Palos Verdes-Sonoita complex suggests that the areas between CA_{1A} and CA_{1B} and CA_{2A} and CA_{2B} have been inactive fan surfaces for at least 10,000 years, subject only to minor drainage originating on the fan surfaces themselves (Figure 6). This report suggests that apices CA_{1B} and CA_{2B} are the correct apices for use in the alluvial fan flooding methodology (Figure 6). Entrenchment of the channels at these points begins to decrease rapidly in the downstream direction.

North Ranch Basin

The Study Contractor did not apply FEMAs detailed alluvial fan flooding methodology to the North Ranch watershed. This basin contains the Hardy Wash, a stream estimated to have a 100-year discharge of approximately 4084 cfs (Cella Barr Associates, 1984). Hardy Wash has created an active alluvial fan where the stream debouches from confining Ql deposits (Sheet 13 of Appendix 1). Inasmuch as the Hardy Wash fan is in a rapidly urbanizing area, detailed and correct delineation of the Hardy Wash flood hazard zones is needed. As indicated by Field (1985) and the presence of the Palos Verdes soil, the Ql surfaces have not been subject to alluvial fan flooding for approximately 400,000 years.

TECHNICAL APPEAL

The need for a detailed inspection of the revised Tortolita Alluvial Fan area FIRM panels became obvious following attempts to use the panels for regulatory purposes. Determining flood probability on a particular portion of the Tortolita Alluvial Fan area is both unwieldy and difficult to justify using the revised FIRM panels. Recognition of these problems resulted in an in-depth review of both the alluvial fan flooding methodology and the associated FIRM panels.

Several aspects of the preliminary FIRM panels are considered in order to ensure a sound basis for the technical aspect of this appeal. First, the alluvial fan analysis methodology is discussed as presented in the original Dawdy paper (1979) and in the subsequent FEMA Guidelines (Appendices 5 and 6, 1982 and 1985, respectively). Next, the information and instructions supplied to the Study Contractor, who completed the initial FIS, are evaluated with respect to the original method description and the guidelines. Finally, the existence of the CAP and the potential effects of this structure are presented.

Following the discussion, a panel-by-panel description of deficiencies and regulatory problems is briefly discussed, then presented in tabular form. The comparison consists mainly of identifying those areas on each panel which are not reasonably designated with regard to flood risk within the context of the suggested study methodology.

ALLUVIAL FAN ANALYSIS

Dawdy (1979) first presented a technique for analyzing potential flood hazards on active alluvial fans. Discharge is related to width, depth, and velocity using power function regressions. These formulas are used in conjunction with log-Pearson Type III flood frequency analysis to define specific depth-velocity boundaries (e.g., depth = 1',velocity = 4 fps). Careful definition of individual fan boundaries is important to the successful application of this method because the calculations depend on the ability to accurately define radial fan widths parallel to topographic contours. The results of the method consist of zones delineated on the fan describing an area in which a channel of a certain depth and width will develop from a given return interval runoff event (in this case, the 100-year event).

FEMA has adopted this method for use in developing FIRM panels for active alluvial fans in the United States. To aid Study Contractors, and ensure consistency in application, FEMA provides an appendix in their Guidelines to Study Contractors (FEMA, 1982 and 1985) which explicitly describes the steps involved in conducting the study. One step involves rearranging the depth-discharge relationship presented in the Dawdy study (1979) such that discharge becomes a function of depth. The constant of the manipulated function should have the numerical value of 771, instead of 280, as presented in the Guidelines. This corrected derivation is developed as follows:

$$D = 0.07Q^{0.4}$$

$$Q = (1/0.07)^{2.5}D^{2.5}$$

$$Q = 771D^{2.5} \qquad (1)$$

Deviation from the original equation results from rounding the constant from the correct value of 0.07 to 0.10. At first glance, rounding should not greatly affect the calculations, but the actual difference in discharges calculated using Equation (1) is not simply a linear proportionality, but a power function difference (Figure 7). Discharges reported in the FEMA Guidelines and incorporated into their FAN computer program are erroneously low, which leads to inaccurate estimates of flood zone boundaries on the FIRM panels. Substituting revised discharge estimates into the example provided in the Guidelines produces widths less than those reported. Therefore, alluvial fan analyses using FEMA's Guidelines will result in FIRM panels which are not accurate within the limits of the alluvial fan method.

In addition, the FIRM panels do not portray reasonable coalescence of depth-velocity boundaries of individual fans. Anderson-Nichols, a consulting firm in Riverside, CA, developed a technique for evaluating overlapping fan areas while conducting an alluvial fan study in the Thousand Palms area of southern California (1984) using the Dawdy method. Their derivation is based on the fact that the width-depth probability associated with an area defined by the overlapping, coalesced alluvial fans is a combination of the probability calculated for each fan at that location. Resulting boundary adjustments reflect the relative contribution of each fan as a function of the distance from each fan apex. Final width-depth boundaries drawn on FIRM panels will not necessarily be smooth, but should make physical sense considering the overall coalesced alluvial fan system. As presented, this coalescent fan analysis is reasonable, but the application, as with all methodology, is limited by the assumptions of the basic concept and should

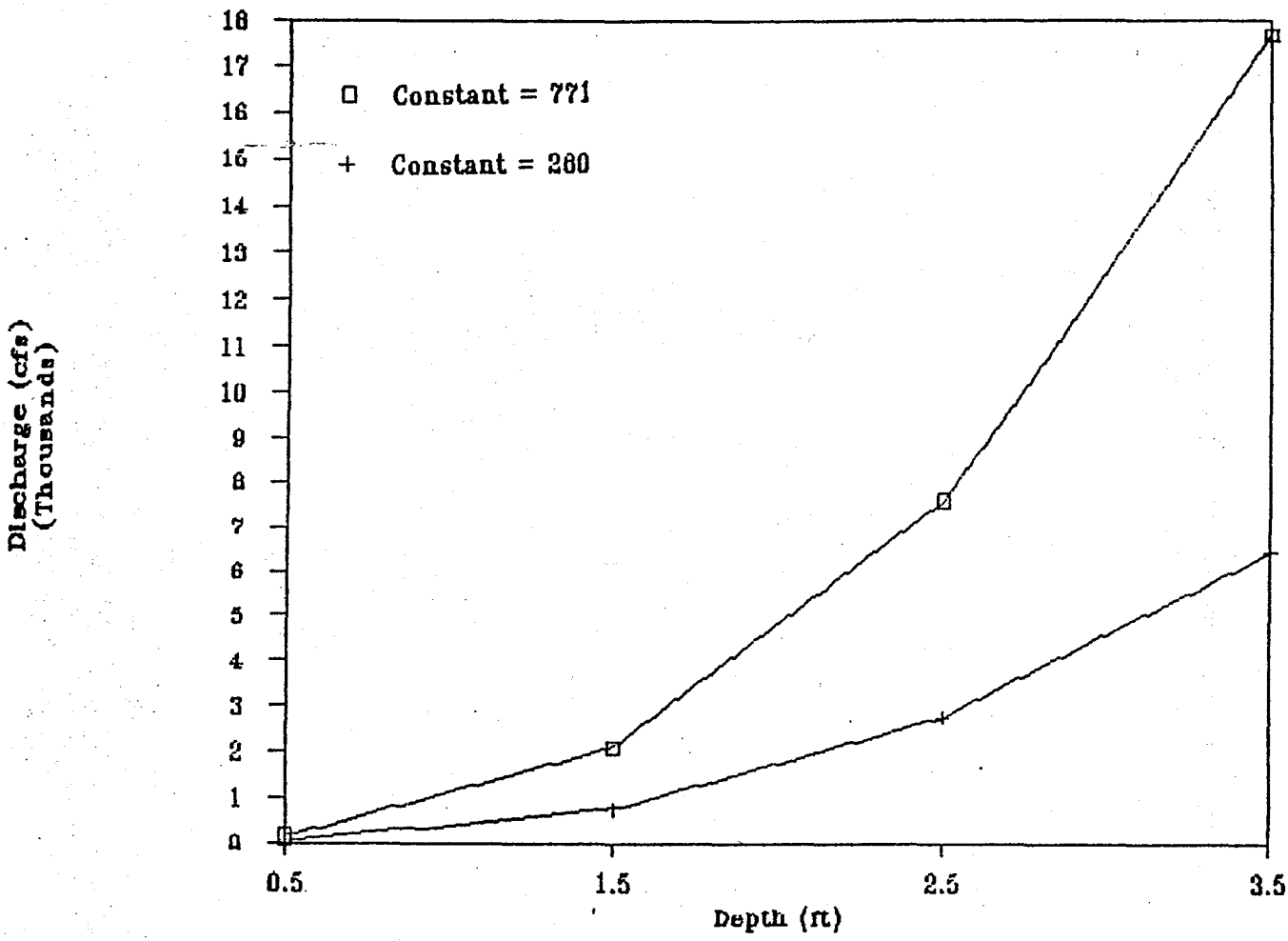


Figure 7 . Power function difference in discharges, calculated from the equation $Q = C\ D^{2.5}$ when C = 771 and 280. The first value of C corresponds to Dawdy's original equation (0.07) and the second value is the result of rounding 0.07 to 0.10.

produce physically reasonable results. Few of the revised Tortolita Fan FIRM panels support a reasonable application of the Anderson-Nichols coalescent alluvial fan analysis. A detailed description of problems associated with each FIRM panel is included in a later section of the text.

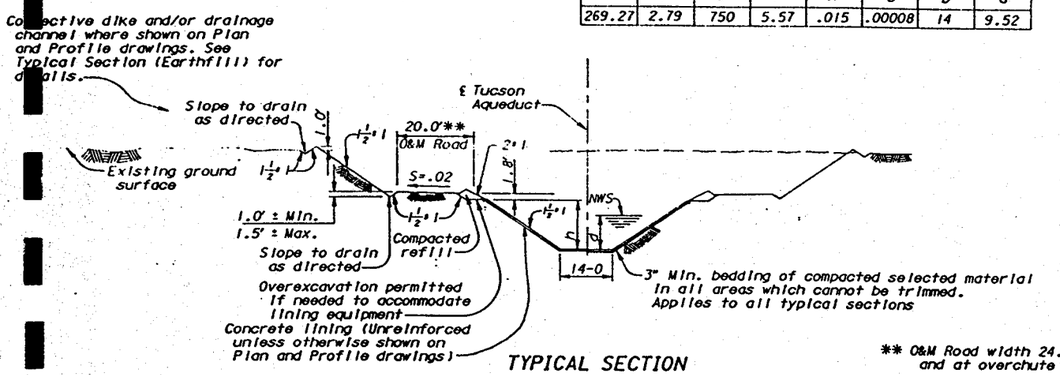
CENTRAL ARIZONA PROJECT

The presence of the Central Arizona Project (CAP) demands detailed analyses regarding its floodplain management implications for the Tortolita Alluvial Fan Area. Structures associated with the CAP significantly affect alluvial fan flooding (Figure 6). A ten- to fifteen- foot high dike and an adjacent drainage swale have been constructed upstream of the aqueduct itself (see typical section, Figure 8). Overchutes are located in line with major drainage channels in order to convey both the direct discharge and water captured in the drainage swale across the canal. Those Tortolita Fan FIRM panels affected by the presence of the CAP are: 980, 985, and 995. In addition, FEMA input is also needed to determine whether the dike has been constructed to FEMA minimum standards.

The analysis performed by the Study Contractor did not include the effects of the CAP. FEMA Guidelines for Study Contractors (1982, 1985) recommend that in portions of alluvial fans in which natural fan processes do not occur, such as "areas protected by flood control works" , the Study Contractor should exercise "good engineering judgment in determining the most appropriate methodology" for evaluating the flood hazard probability. Pima County suggests that an appropriate methodology to predict depths and widths of flood zones along the CAP dike is that which has been used by FEMA to analyze flooding conditions at the Southern Pacific Railroad embankment farther

HYDRAULIC PROPERTIES

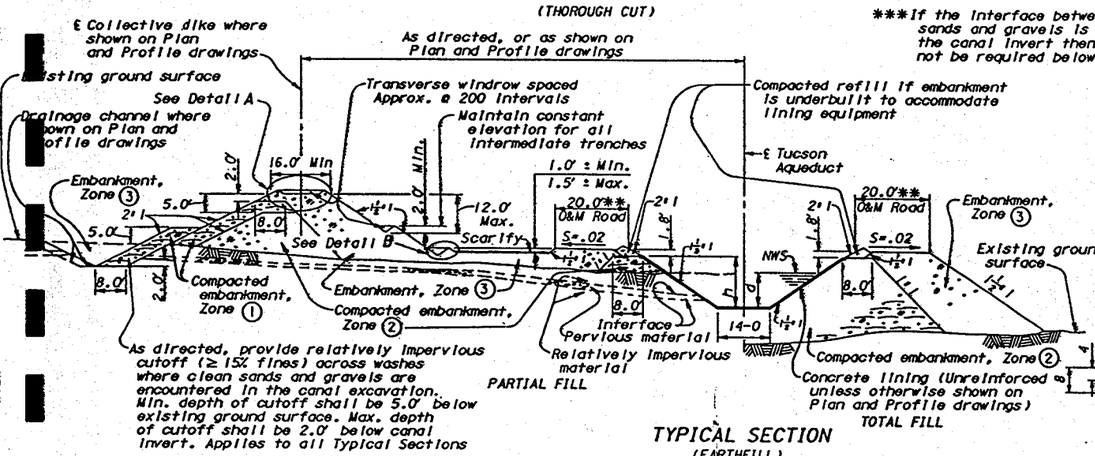
A	V	Q	r	n	s	b	d
269.27	2.79	750	5.57	.015	.00008	14	9.52



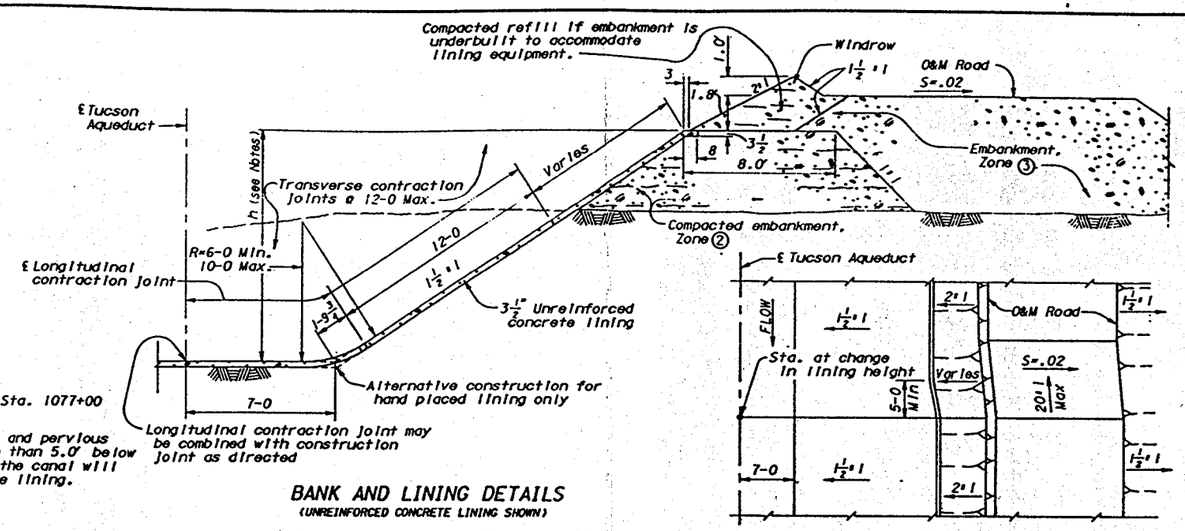
TYPICAL SECTION
(THOROUGH CUT)

** O&M Road width 24.0' from Sta. 1060+77.42 to Sta. 1077+00 and at overchute structures.

***If the interface between the dispersive clays and pervious sands and gravels is non-existent or is more than 5.0' below the canal invert then overexcavation around the canal will not be required below the top of the concrete lining.



TYPICAL SECTION
(EARTHFILL)



BANK AND LINING DETAILS
(UNREINFORCED CONCRETE LINING SHOWN)

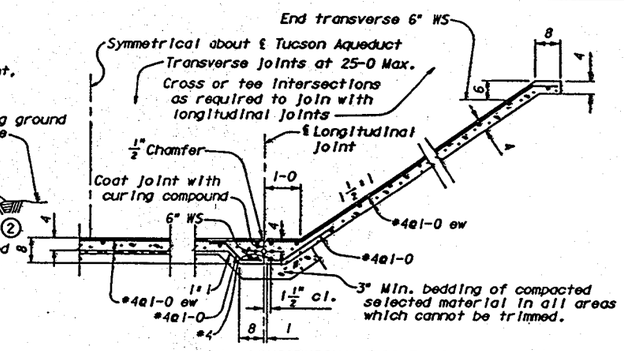
SCALE OF FEET

TYPICAL PLAN - LINING TRANSITION

SCALE OF FEET

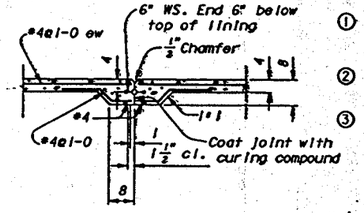
ZONE MATERIAL REQUIREMENTS

1. The compacted embankment material shall be nondispersive, shall have a PI≥10 and shall contain a minimum of 15 percent fines.
2. The compacted embankment materials shall be nondispersive and shall contain a minimum of 10 percent fines.
3. The embankment materials and waste banks shall consist of all material not required as Zone 1 Zone 2.

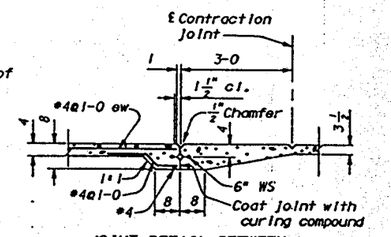


LONGITUDINAL JOINT DETAIL

NOTE: Place reinforcement in center of slab. Lap splice to be in a plane parallel to lining surface



TRANSVERSE JOINT DETAIL



JOINT DETAIL BETWEEN REINFORCED LINING AND UNREINFORCED LINING

REINFORCED CONCRETE LINING DETAILS

NOTES

Transverse contraction joints around curves shall be on radial lines at 12-0 centers, spaced along ℄ aqueduct.

For details of contraction joints for unreinforced lining, see 344-D-12017.

For details and spacing of safety ladders, see 40-D-6460.

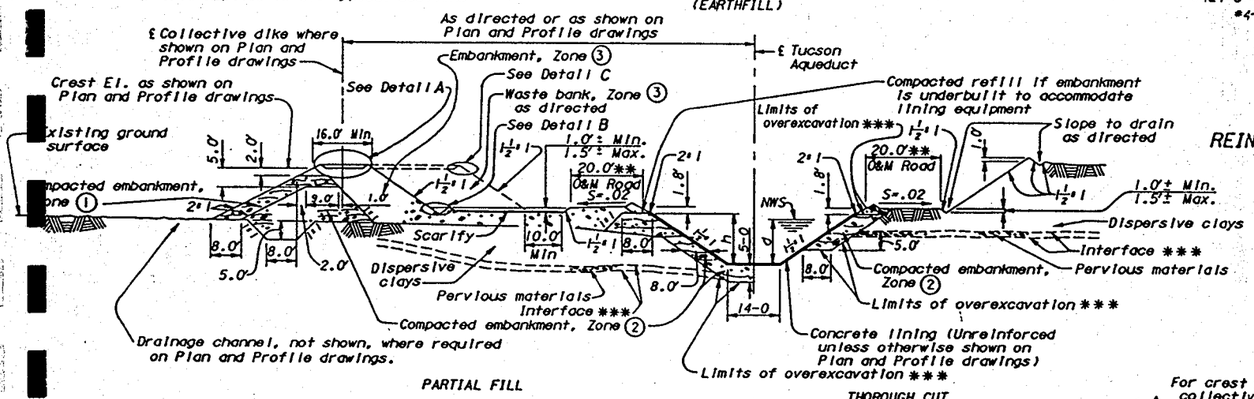
Concrete lining design is based on a compressive strength of 3,000 p.s.i. at 28 days.

For details of rubber waterstop, see 40-D-2867. For details of PVC waterstop, see 40-D-6463. Waterstop shall be continuous in reinforced lining joints.

For lining height "h", see 344-D-12016.

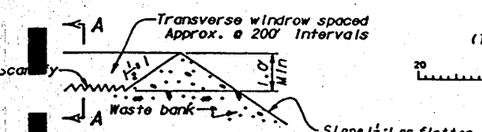
For location of reinforced concrete lining, see Plan and Profile drawings.

For drainage channel details, see 344-330-3910.

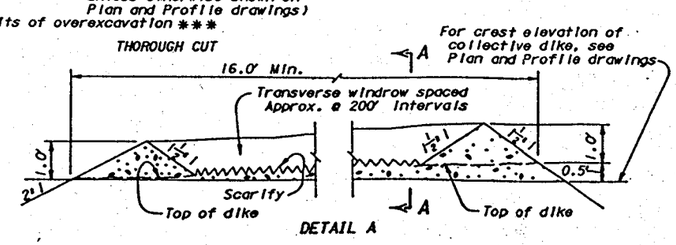


TYPICAL SECTION
(THROUGH DISPERSIVE CLAYS)

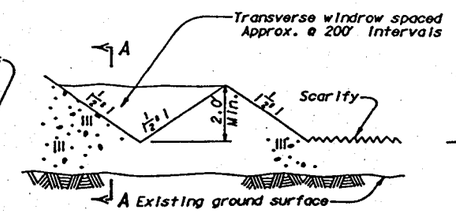
SCALE OF FEET



DETAIL C



DETAIL A



DETAIL B

SECTION A-A

Figure 8

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL ARIZONA PROJECT
TUCSON DIVISION-ARIZONA

TUCSON AQUEDUCT
REACH 3

TYPICAL SECTIONS

DESIGNED R.N. Ferris — TECHNICAL APPROVAL L. J. Fisher
DRAWN D.D. Drouillard, D.E.B. — SUBMITTED J.C. Cassity
CHECKED R.N. Ferris — APPROVED J. R. Schroeder, CHIEF, WATER CONVEYANCE BRANCH

DENVER, COLORADO COMPUTER DRAFTING — JUNE 30, 1984 — 344-D-12014

downstream. The CAP overchutes must be evaluated for their capacity to convey the regulatory one hundred-year flood. Because the overchutes are elevated, the extent of inundation must be determined for planning purposes. A sediment transport analysis is also needed. Below the dike, application of the alluvial fan methodology, which assumes a random distribution of flow paths, is entirely inappropriate. Analysis is needed to determine how much the CAP will change the depth and velocity of the regulatory flood downstream of the dike, and what areas will remain subject to flooding from the overchutes.

FIRM PANEL INVESTIGATION

Several regulatory problems, connected with using the Tortolita Alluvial Fan Area FIRM panels, have been identified through preliminary application and review of each panel. Implications of the Zone AO designations, justifying current panels with respect to regulatory decisions, and inconsistent delineation of flood zones are the most important issues arising from trying to use the FIRM panels in regulating flood hazards on the Tortolita Alluvial Fan Area.

Zone AO Designations

In 1985, FEMA revised Appendix 6 of their Guidelines for Study Contractors and renumbered the text as Appendix 5. One of the most notable changes contained in the new appendix was section A5-3, which discusses flood hazard zones and their delineation. In the 1982 Guidelines, flood hazard zones associated with alluvial fans were designated Zone AF. In addition, a

specific definition, consistent with the alluvial fan methodology was provided on each FIRM panel. According to the 1985 Guidelines, alluvial fan flood hazard zones are now designated as Zone AO and interpreted according to the standard definition. This designation implies that the values indicated on the FIRM panels represent the expected depths and velocities of shallow flooding (sheetflow) within the boundaries of the particular zone. Interpreting the depth values of an alluvial fan analysis as though it represents the expected depth of flooding is a severe departure from the intent of the original method. Subsections A5-2(b) and (c) of Appendix 5, taken almost verbatim from the Dawdy paper (1979), contradict the Zone AO definition listed in Section A5-3. From the standpoint of flood hazard regulation, this contradiction leads to ambiguous and indefensible flood evaluation decisions. It is clear from reading the alluvial fan analysis development, and considering the consequences of the present interpretation, that a new flood hazard zone designation is needed in order to correctly interpret the information generated by alluvial fan analyses.

Coalescent Fan Results

Misapplication of the coalescent fan analysis technique is the one problem most evident on the revised FIRM panels. It is not reasonable to generate a small zone of a given depth-width values, in an overlap area of two or more fans, surrounded by zones of lesser depth-width. The resulting boundary adjustment, below the point of coalescence, should produce smooth transitions radially across the fan as a function of the relative probability associated with each fan at that particular contour, as depicted in Figure A6-1 of Appendix 6 (1982 Guidelines). Several of the revised panels have

small, remnant areas which are not consistent with the technique described. Justifying the delineations shown on the revised Tortolita Alluvial Fan FIRM panels, both internally and to the receiving public, is difficult given the zones currently demarcated.

A panel-by-panel description of specific problems is listed in Table 6. Location, contributing fans (as numbered by the Study Contractor), and a brief explanation of each problem are contained in Table 6. Only those areas on each FIRM panel which are inconsistent with the alluvial fan methodology are referenced.

A comparison between revised and existing panels is provided in Table 7 in the same format as described for Table 6. One item of information included in Table 7 is the compatibility between the revised and existing FIRM panels at the limits of the study. Large areas within the limits of the study, which were formerly demarcated as Zone C, have been changed to Zone A with no justification provided for the new designation. This also means that along the limit of study boundary, topographically adjacent locations will have radically different regulatory interpretations with respect to floodplain management regulations and flood insurance evaluations.

Table 6. Inconsistencies within individual FIRM panels.

Panel	Location (Section)	Fan*	Description of Problem
980	23 SE1/4	6B,7	Change from 7 to 6 fps should be smooth because the combined probability effect of fan 6B isnegligible. Also affected by CAP.
985	20 NE1/4	6A,6B	Two triangular zones where the combined probability technique not properly applied. It is inconsistent with the method that a combined area would have depth-velocity greater than the surrounding areas of the contributing fans. Also affected by CAP.
	NW-SW1/4	6A,6B,5	2',7 fps zone is more likely 2', 6 fps as fan 5 is the major contributor at this overlap area. Also affected by CAP.
	29 SE-SW1/4 32 NW-NW1/4	6A,6B,5	Overlap areas (small triangles) should reflect Fan 5 more than Fans 6a and 6b given the relative widths along the along the contour at that location of the three fans. Also affected by CAP.
995	4	3,4,5	2', 6 fps surrounded by 1', 5 or 6 fps. Given widths of contours of contributing fans, it is unlikely that depths of 2' would develop. Also affected by CAP.
	6 NE1/4 31 SE1/4	4,5,6B	Fans of most influence are 4 and 5 with 5 probably the greatest. Therefore, it is likely that the depth is 1' and velocity either 5 or 6 fps. Also affected by CAP.
	32 SW-NW1/4	5,6B	0.5' depth probably 2', 6 fps given relative widths along the contour of contributing fans. Also affected by CAP.

Table 6. cont'd.

Panel	Location (Section)	Fan*	Description of Problem
1015	3,4	3,4	2' depth and 6 fps unlikely as surrounded by zones of 1' and 4 fps. Inconsistent with method.
	15 S1/2 22 NE-NW1/4	2A,2B,3	Velocity of 5 fps unlikely given surrounding values of 4 fps and less
1020	6	2A,2B	Velocity of 5 fps not likely to exist with surrounding velocities of 4 fps of less.
1025	15 SW-SW1/4 16 SE-SE1/4 21	5,6A	2' 7 fps unlikely at this combined area given the concepts of the methodology and widths of the contributing fans at that contour.
	22 SE-SE1/4 27 W 1/2 28 SE1/4	4,5	2', 7 fps unlikely at this combined area given the concepts of the methodology and widths of the contributing fans at that contour.

* Fan numbers correspond with the original designation used by the Study Contractor in their initial study.

Table 7. Comparison between Revised FIRM and the existing panels.

Panel	Location (Section)	Description of Change
980	14,23	Changed from A to AO as part of fan analysis.
	2,3,4,9,10 11,15	All zone C changed to zone A.
985	All	Majority of Zone C converted to Zone A. Other Zone A divided by fan analysis.
995	All	North of I-10 and the R.R, all Zone A changed to AO. In addition, R.R. HEC-II analysis defined WSEL's for new Zone AH.
1015	All	All Zone C redesignated as AO or A. Zone AH added along the R.R.. Zone C (Sec.24) changed to Zone B by the fan analysis.
1020	All	Zone C changed to A and AO by the fan analysis. Does not match with the adjacent panel (1040); e.g., Section 34 split by limit of study into Zone A and C with no apparent topographic justification.
1025	All	Zone C shifted northward by Zones A and AO as a result of the fan analysis. Section 22 and 27 changed to Zone A while adjacent panel (1030), with rest of each section, remains Zone C because of the limit of study. No topographic justification provided.
1610	All	Zone C northwest of the CDO changed to Zone A. Area of Zone C remains surrounded by Zones A and B with no apparent topographic justification.

REGULATORY ISSUES

With few exceptions, alluvial fans have been mapped, regulated, and insured as if they were flood hazard areas where flood depth is the major cause of damage. However, the hazards usually associated with alluvial fans are a complex combination of flood flows, erosion, debris and mud flows. Not all of these processes may exist on every alluvial fan and the mapping of these hazards may not accurately reflect these risks. Even though these limitations affect the engineering analuyses and mapping of these hazards, the greatest deficiency of the Flood Insurance Study Program exists in regulation of these hazards using generalized shallow flooding designations as a management standard for land use.

FEMA must develop improved and more detailed land management standards which distinguish fans from other shallow flooding areas. These standards might address high velocity, shallow flooding areas with debris and sediment problems more generally, and not simply alluvial fans. Such standards should reflect debris, velocity, and erosion factors (Kusler and Bloomgren, 1984). Structures either should be prohibited in high risk areas (similar to floodway restrictions) or be subjected to careful performance design criteria. These standards should be incorporated in guidelines to local communities and flood insurance guidelines.

Within Pima County, the use of the preliminary FIRMs as currently mapped raises a number of floodplain management issues. Specifically, the great number of existing subdivisions which were originally outside the regulatory floodplain, but are now included within the approximate zone A or alluvial fan

flooding boundary present both management and legal questions. In addition, FEMA has not provided any direction for regulating these developments as well the change in flood insurance requirements associated with the revised FIRM panels.

The study provides no justification or engineering support documenting the addition or the extension of approximate Zone A designations, many of which encompass existing subdivisions (see Table 8). The methodology used for approximate floodplain boundaries requires minimal engineering analysis. The Study Contractor guidelines (FEMA, 1985) recommend that unless otherwise instructed, the Study Contractor shall make use of the Flood Hazard Boundary maps or any other existing maps for areas to be studied by approximate methods. For restudies, approximate floodplain boundaries on the existing FIRMS should continue to be used unless determined to be incorrect.

Similarly, the inclusion of existing developments within the Zone AO designation with disregard to constructed drainage improvements approved by Pima County raises institutional and legal questions. All constructed subdivisions analyzed the existing and future flooding and erosion hazards based upon adopted and approved analytical methods and channel design standards accepted by Pima County.

At present, guidelines exist which describe criteria used to regulate floodplain development in shallow sheet flow areas, but these do not adequately regulate development affected by alluvial fan flooding hazards. Implicit in the application of the alluvial fan methodology is the assumption that the resulting depth-velocity values are interpreted as describing the dimensions of a channel expected to develop during the particular return interval event. Applying Zone AO designations, which are intended to

Table 8. Existing subdivisions within the Tortolita Alluvial Fan area which are affected by the Revised FIRM panels.

SUBDIVISION NAME	LOCATION (T,R,SEC)	EXISTING ZONE	REVISED ZONE
Tierra del Paraiso	Sec. 29 T12S,R13E	C	A
Hobby Horse Ranch Townhomes	SW1/4,Sec. 30 T12S,R13E	C	A
The Patios at Hobby Horse Ranch	SW1/4,Sec. 30 T12S,R13E	C	A
Cortaro Ridge	NE1/4,Sec. 30 T12S,R13E	C	A
Thornwood Apts.	SE1/4,Sec. 30 T12S,R13E	C	A
Gatewood Ranch	NW1/4,Sec. 31 T12S,R13E	C	A
Sunset Point	NE1/4,Sec. 25 T12S,R12E	C	A
Desert Shadows	NE1/4,Sec. 29 T12S,R13E	C	A
Star Trails	NE1/4,Sec. 29 T12S,R13E	C	A
Countryside	N1/2,Sec. 24 T12S,R12E	A	B
Northpointe Ridge	NE1/4,Sec. 20 T12S,R13E	C	A
Desert Crest	SE1/4,Sec. 20 T12S,R13E	C	A
Kachina Meadows	NW1/4,Sec. 20 T12S,R13E	C	A

indicate values of shallow overland flow, to the depth-velocity zones from the Dawdy methodology is incorrect and contradictory to the intent of the alluvial fan methodology.

Specifically, FEMA has no guidelines or regulations which discuss how to use these depth-velocity results for assessing and mitigating these hazards for development on an alluvial fan. The alluvial fan flooding method as applied does not give proper weight to topographic controls. For example, a site lying five to six feet higher in elevation than an adjacent channel should not be subject to the regulatory requirements of the FIRM panel depth-velocity designation. An FFE adjustment, in this situation, is more realistically related to erosion potential/protection than anticipated flood hazard. FEMA must provide guidance for defining appropriate erosion protection for use in conjunction with development within alluvial fan floodprone areas.

For areas of the Tortolita Alluvial Fan where the alluvial fan analysis and the approximate Zone A designations are inappropriate, a Zone D designation should be considered. This designation would allow Pima County to apply its hydrologic methodology, drainage design standards, erosion setback requirements and enforcement of the Floodplain Management Ordinance 1985-FC1, which is more restrictive than FEMA's minimum standards.

Following the submission of the Study Contractor's initial results, a complete review was conducted by the Technical Evaluation Contractor (TEC). The technical review resulted in several changes to the original analysis and subsequent changes to the FIRM panels. FIRM panels for the Tortolita Alluvial Fan Area were then finalized and sent to the Pima County Flood Control District without the opportunity to provide input on the reanalysis by the TEC.

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GLOSSARY

Active Alluvial Fan: For the purposes of this report, those areas which have been subject to active alluvial fan flooding processes in the last 10,000 years are regarded as active. Those which have not are regarded as inactive.

Alluvial Fan: An apron of convexly sloping alluvium usually shalped like an open fan or conic section.

Alluvial Fan Flooding: As used by FEMA, flooding which originates in the mountainous portion of the watershed and travel downstream, where it debouches onto an alluvial fan.

Alluvium: Material such as sand, silt or clay that has been deposited on land by streams.

Holocene: That period of time extending from approximately 10,000 years ago to the present.

Horizon: A soil layer formed by alteration of sediments in place by soil-forming processes. It is distinguishable from adjacent layers by distinct physical and chemical characteristics.

Pleistocene: That period of time extending from approximately 1.7 million years ago to approximately 10,000 years ago.

Relief: The elevations or inequalities of a land surface, considered collectively.

Rock Varnish: A glossy coating of dark-colored compounds, colored by iron and manganese, that forms on exposed rock surfaces in deserts.