INUNDATION MAPPING OF THE SEPTEMBER 1997 FLOOD, SURFICIAL GEOLOGIC MAPPING, AND EVALUATION OF THE PIEDMONT FLOOD HAZARD ASSESSMENT MANUAL

for

portions of the

TIGER WASH PIEDMONT

FCD CONTRACT NO. 98-48
Assignment No. 2

March 2000

Prepared for:

Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, AZ 85009
(602) 506-1501

By:

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

5235 South Kyrene, Suite 205
(480) 752-2124 voice
(480) 839-2193 fax
Tempe, Arizona 85283
www.jefuller.com

2881 North Silverspur Drive
Tucson, Arizona 85745
(520) 623-3112 voice
(520) 623-3130 fax

Registered Professional Engineer
Certificate No. 26846
JONATHAN E. FULLER
Date Signed 3/24/00
ARIZONA, U. S. A.

In association with:

Arizona Geological Survey
416 W. Congress, Suite 100
Tucson, AZ 85701
(520) 770-3500

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ASSIGNMENT NO. 2

Registered Professional Engineer (Civil)
CERTIFICATE NO.
26846
JONATHAN E.
FULLER
Date Signed 3/21/00
ARIZONA, U. S. A.

DETAILED INUNDATION MAPPING
OF THE
SEPTEMBER 1997 FLOOD
ON THE
TIGER WASH PIEDMONT
DISTRIBUTARY SYSTEM

FCD 98-48
Assignment No. 2
Subtask 1, Detailed Inundation Mapping

March 2000

Prepared for:

Flood Control District of Maricopa County
2801 W. Durango Street
Phoenix, AZ 85009
(602) 506-1501

By:

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

5235 South Kyrene, Suite 205
Tempe, Arizona 85283
(480) 752-2124 voice
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(520) 770-3500

Introduction

The area inundated by the 1997 flood on Tiger Wash was mapped in the field and on post-flood aerial photographs during 1999. Extensive field mapping was compiled on a post-flood, 1:15,000 black-and-white aerial photomosaic provided by the District. A preliminary inundation map based on this field work was provided to the District in a previous report. Areas that were inundated show up much better, however, on larger-scale color aerial photographs acquired for this project in March, 1999. These new photos were interpreted to revise and extend the field mapping of inundation. Areas that were inundated were subdivided into several flow categories based on spot field observations and detailed topographic transects that were surveyed across various parts of the Tiger Wash system. This detailed inundation mapping was then rectified and georeferenced, so that map patterns of inundation may be quantified and compared with the distribution of surficial geologic units of various ages.

Several kinds of field evidence were used to map the extent of inundation. The most ubiquitous evidence of the flood is freshly transported sediment. In areas of deeper inundation, fresh sediment typically is light-colored sand and locally gravel. This sediment partially buries vegetation of various sizes, and in many places sandbars were deposited on the lee sides of vegetation. In areas of shallower flow, fresh sediment typically is fine sand, silt and clay. The color of this fine-grained sediment is typically slightly redder than deposits that pre-date the flood. In true slackwater areas, the fine sediment deposited by the flood commonly developed moderately large mud cracks as it dried. Flotsam (floated organic debris) is also a very common indicator of flow. Flotsam around the margins of inundation is especially valuable, because it floats and may mark the maximum extent of the water surface. Flotsam was also observed in trees and bushes in areas of deeper flow. Evidence of fresh scour and formation or modification of gullies of various sizes was also common. In these areas, it was evident that the surface had recently been swept clean or substantially altered. In some areas, relatively old (Pleistocene) deposits were freshly exposed in stream channels. In areas of sheet flooding, scour commonly was focused between bushes or animal burrows.

Using all of these kinds of evidence of flood inundation, the maximum extent of 1997 flood inundation was mapped in the field using a composite, black-and-white, ~1:15,000-scale aerial photo map made from photos taken in February, 1998. The composite map is a mosaic of digital aerial photos, with some cultural information superimposed on them from GIS data. Several walking transects across the distributary system to identify areas of inundation and non-inundation. The margins of the many flow paths in the Tiger Wash system were traced in the field and mapped. Possible islands of no flow within flow paths were identified on the aerial photos and field checked. Field mapping data were then compiled over the photo mosaic base map. This preliminary inundation map was previously submitted to the District.

Larger-scale color aerial photos (scale 1:9,600) of the west branch of the Tiger Wash distributary system were obtained after most of the field mapping was complete. Depositional and erosional features left by the 1997 flood are very evident on these high-quality photos, and color contrasts between 1997 flood deposits and pre-existing deposits in the distributary system show up very well. In addition, it is much easier to be certain of locations on these new photos because of variations in surface color and better resolution of vegetation and channels. By field-checking parts of the distributary system and surveying several detailed topographic cross sections perpendicular to drainage, some conclusions were drawn about the character of flow based on indicators of flow depth and the nature of sedimentation. These different categories of flow form distinctive patterns on 1:9,600-scale color aerial photographs. Areas of different flow depths were delineated on the aerial photographs. In addition, inundation boundaries were relocated in some areas and mapping was extended downslope in the western part of the distributary system using these photos.

Flow categories are defined as follows:

1) Channel flow – flow in areas that are recognizable as channels based on their light-colored sediment and lack of vegetation on the post-flood aerial photos; this unit does not include many small channels that cannot be mapped at 1:9,600 scale; flow depths are extremely variable; based on our transect data and spot depth estimates, channel flow depths varied from less than 1 ft to 5 ft.

2) Deep unconfined flow – broad areas of relatively deep, unconfined flow that did not occur in mappable channels; this flow typically occurred along the margins and downslope of channels; areas typically consist of alternating small channels and sand bars, resulting in a corrugated surface perpendicular to the flow direction (Figure 1); substantial variations in flow depths over short distances typify deep unconfined flow areas; flow was at least 1 ft deep in the small channels in these areas.

3) Shallow sheetflooding – very broad areas of shallow unconfined flow; this flow typically occurred along the margins of the flood or in topographically high areas in the upper part of the distributary system; shallow sheetflooding was increasingly extensive downslope, so that it comprised nearly all of the inundated area at the lower margin of mapping; flow was very wide and sheet-like, and less than 1 ft deep; local topography in these areas is generally minimal, and higher areas around bushes commonly were not inundated.

There are several sources of uncertainty in the detailed flood inundation map (Figure 2).

(1) Uncertainty in the mapped flow boundaries in areas where flood lapped onto fine-grained, young deposits. The principal problem in these areas is the lack of contrast between the color and grain size of the 1997 flood deposits and deposits from older floods. Contrast between inundated and non-inundated areas is much greater on the post-flood color aerial photos than on the black-and-white aerial photos that were used in the initial field mapping. Therefore, many inundation boundaries were revised from the preliminary inundation map using the color photos, with limited field checking.

(2) Uncertainty in the mapped flow boundaries throughout the map due to location uncertainty on the aerial photos that were used as a base map. In areas with low relief and few trees, it was especially difficult to identify precise locations on the black-and-white

aerial photos while in the field. Location uncertainties tended to be worst in the same areas where shallow flow lapped onto young, fine-grained deposits. Use of the new color aerial photos greatly reduced position uncertainty.

(3) Distortion in the aerial photographs and uncertainty in georeferencing the mapping. The aerial photos are not rectified, so there are some variations in scale through the photos and adjacent photos do not join perfectly. Therefore, when the flow boundaries and inundation categories were transferred to a topographic or GIS framework, there was uncertainty related to distortion in the aerial photo base. Every effort was made to remove distortion in the aerial photos and registered the inundation mapping to a GIS framework using geographic features and section corners.

Characteristics of the 1997 Flood Flow

The 1997 flood inundated essentially all of the young alluvial fan areas on the west branch of Tiger Wash and caused some dramatic changes in the channel system. Several large new channels formed during the flood, and numerous pre-existing channels were enlarged or extended. Some of these were very minor prior to the 1997 event. In the upper part of the west branch where the single large channel Tiger Wash is confined between Qy1 and older surfaces, flow was contained in the channel with minor overbank flow. High water marks are evident on channel banks and tributary channel mouths were backflooded. As flow became unconfined farther downslope, inundation was widespread in the active alluvial fan areas. Deep flow occurred in preexisting channels and deep unconfined flow occurred in overbank areas adjacent to main channels. Deep flow in channels was responsible for the transport of bedload up to small boulders and erosion of channel beds and stream banks formed in Pleistocene and Holocene deposits. Deep unconfined flow transported some gravel, but mainly sand-size and finer particles, from main channels into overbank areas. This sediment was deposited as broad sheets and in streamlined pendant bars downstream of creosote bushes and other vegetation. Many areas of deep unconfined flow are characterized by alternating small, narrow channels and sand bars, which results in a corrugated topography (Figure 1). Shallow sheetflooding occurred at the margins of deep unconfined flow, where water reached its maximum distance away from the main channels. In areas of shallow sheetflooding, low sand deposits or "fingers" record flow and deposition around creosote bushes and areas between bushes are typically are slightly to moderately scoured. At the very margins of flow, thin silt layers typically cover the surface.

The usefulness of surficial geologic mapping as a predictive tool in piedmont flood hazard assessment can begin to be evaluated by comparing the extent of inundated areas of the 1997 flood with the pre-flood surficial geology. Based on the ages of surfaces, it is predicted that older surfaces such as Qm, Ql, and Qy1 would be unlikely to experience flooding, and that the younger surfaces, Qyc and Qy2, would likely be inundated in a large flood. Our inundation mapping shows that this generally was the case. Flow remained confined in the upper part of west branch Tiger Wash where older deposits exist along the banks, and it broke out and spread widely where Qy2 deposits are adjacent to the main channel. There are locations, however, where older Holocene and Pleistocene surfaces adjacent to younger surfaces were inundated in

1997. This occurred along the margins of active alluvial fan areas where topographic relief between surfaces of different ages is minimal.

In several cases, flow not only inundated Qy2 surfaces, but also formed new channels along drainages that were small or weakly defined prior to the flood. These channel changes are illustrated dramatically by comparing pre-flood and post-flood photos. Photos taken in 1953, 1979, and 1999 document the formation a large new channel during the 1997 flood (Figure 3). The new channel approximately followed the course of a small channel that existed within an area of fine-grained late Holocene overbank deposits (unit Qy2). The new channel probably formed as 1997 floodwater inundated the overbank areas and began to downcut into the Holocene deposits. Flow funneled through the new channel, eroding the bed down to Pleistocene soil in places and laterally eroding the Holocene channel banks. This new channel is much wider and somewhat shallower than the pre-existing main channel in that area (Figure 1). The new channel may narrow and deepen with time if larger riparian vegetation becomes established along it.

There are also numerous examples of less dramatic channel changes where flood waters widened or lengthened preexisting channels. These changes occurred in areas of channel flow and deep unconfined flow, flow depth zones where both erosive and depositional settings exist. Changes include channel widening, bank erosion along outside bends, bed scour, and formation of discontinuous well-defined channels. In addition, the apex of the most prominent active alluvial fan on west branch of Tiger Wash has migrated about 1500 ft [500 m] upslope between 1953 and 1999. About ½ of this migration occurred as a result of the formation of the new western channel in 1997, but it appears from the 1979 aerial photos that upslope migration of the fan apex also occurred between 1953 and 1979 (Figure 3).

Historical aerial photographs from 1953 suggest that the east branch was the dominant wash at that time (JE Fuller, 1999). By the time the 1979 aerial photographs were flown, the west branch seemed to be dominant. The 1997 flow event was a much larger event on the west branch than on the east branch. It is uncertain whether this change may have been caused by alterations of the channels due to gravel mining in the area of the first distributary split, a natural shifting of flow from one branch to the other, or some combination of these factors.

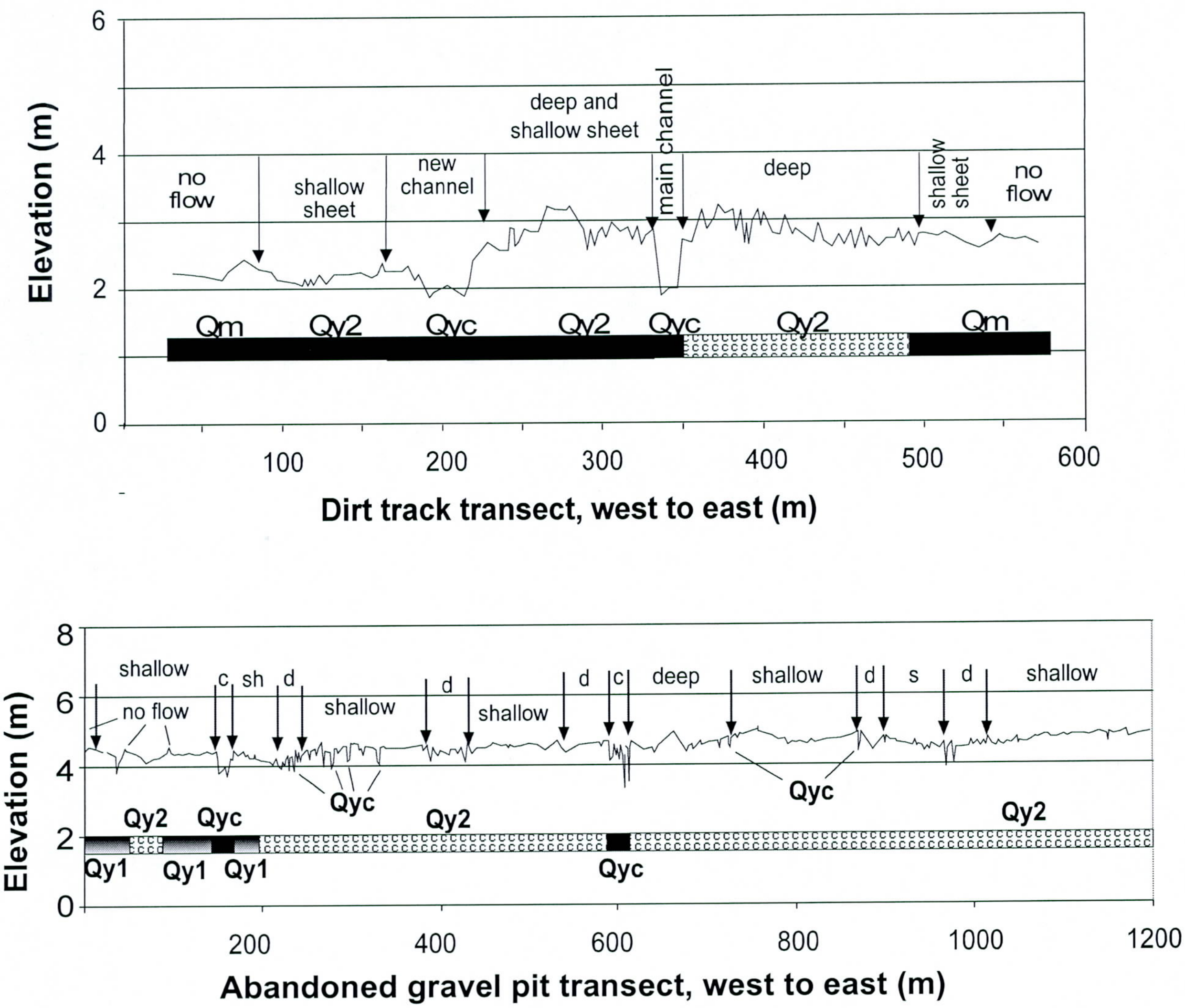
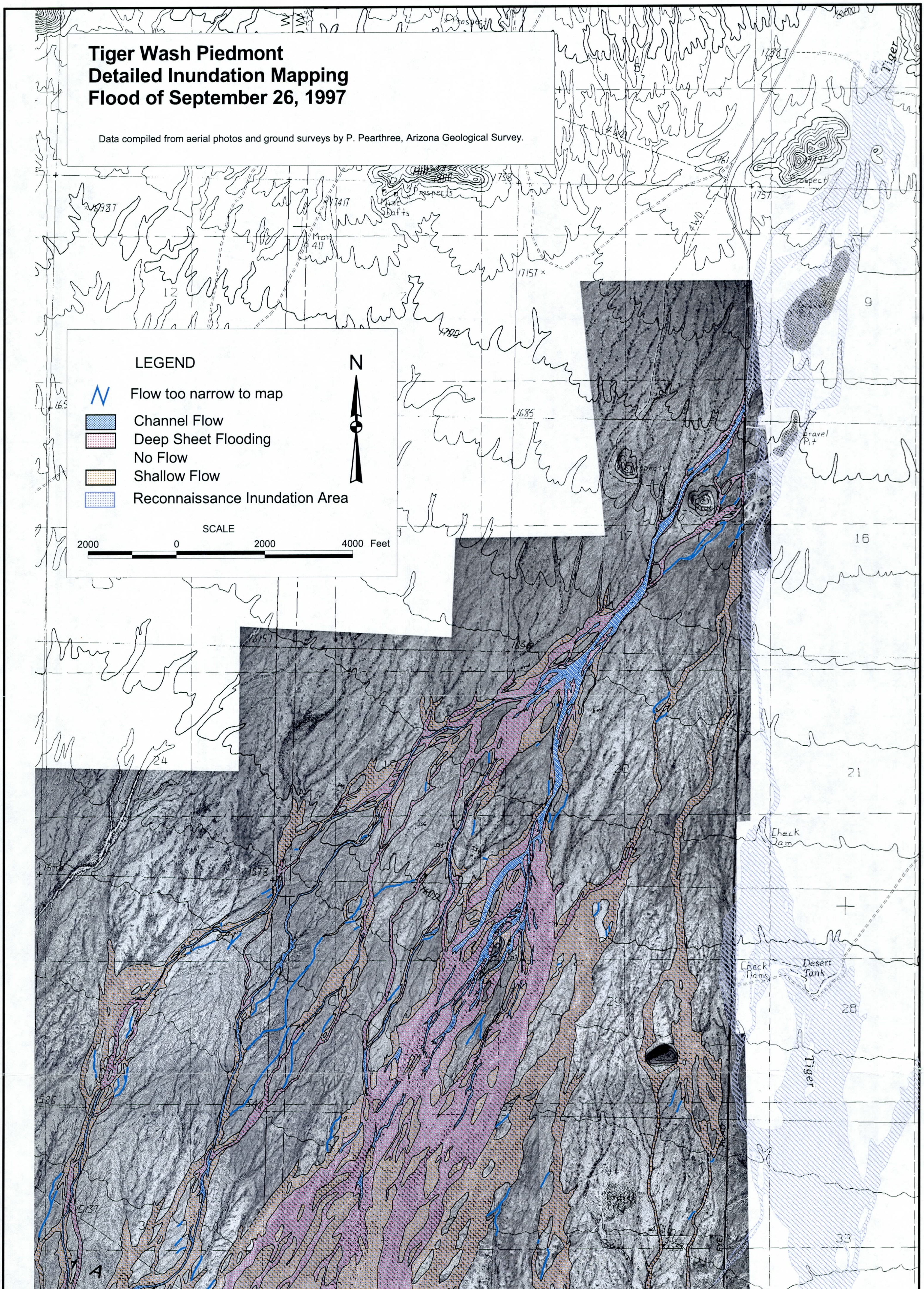


Figure 1. Topographic transects surveyed across the main flow path on the west branch of Tiger Wash. Surficial geologic units are shown on the bars below each transect. The upper transect follows the dirt track in the area of the fan apex identified in previous studies. On the upper transect, local topographic relief is much greater on the young alluvial surfaces that were flooded than on adjacent Pleistocene surfaces. Also note that the Qy surfaces are higher than adjacent Qm surfaces because of young deposition associated with the active alluvial fan. On the lower transect, inundation was generally shallow and very widespread. Topographic relief is minimal except for several narrow, steep-sided gullies that are too small to map at 1:9,600-scale. No exposed Pleistocene surfaces were encountered on this transect.



Tiger Wash Piedmont
Detailed Inundation Mapping
Flood of September 26, 1997
Data compiled from aerial photos and ground surveys by P. Pearthree, Arizona Geological Survey.
LEGEND
Flow too narrow to map
Channel Flow
Deep Sheet Flooding
No Flow
Shallow Flow
Reconnaissance Inundation Area
N
SCALE
2000
0
2000
4000
Feet
Tiger
Prospect
Gravel Pit
Check Dam
Check Dams
Desert Tank
Tiger
Wash
9
12
16
21
24
28
33

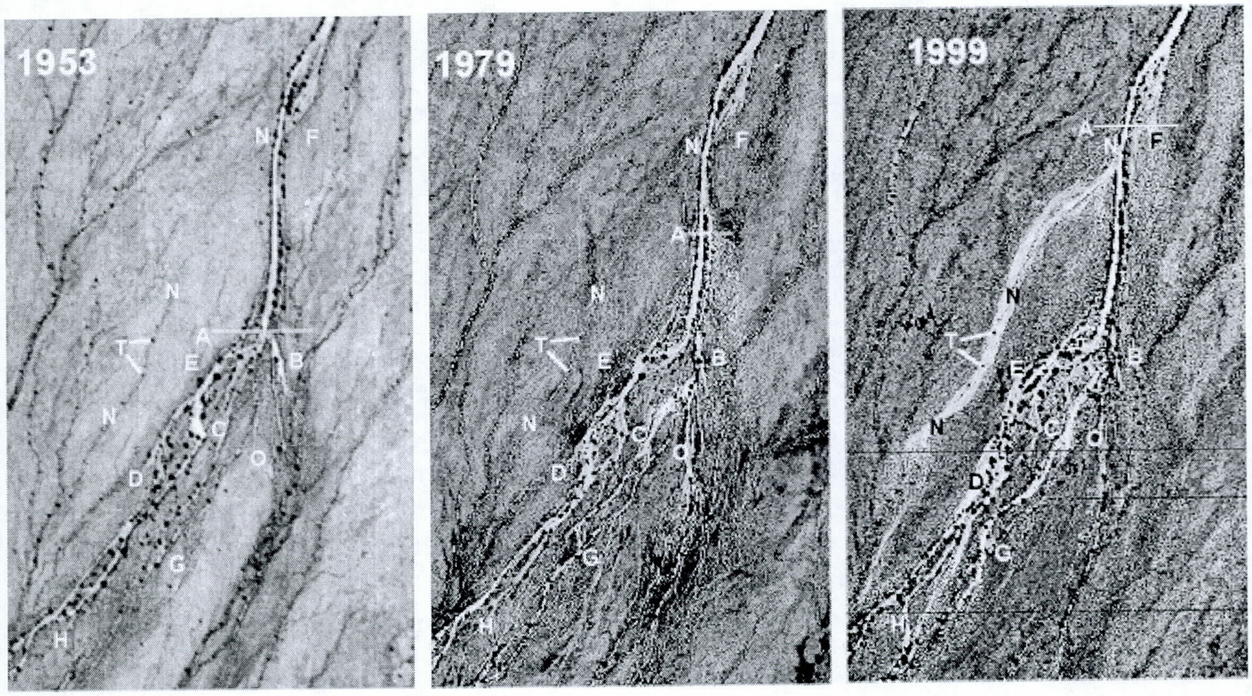


Figure 3. Repeated aerial photographs documenting changes in channel position and character near the apex of an alluvial fan within the west branch of the Tiger Wash system. Letters identify similar positions in each photograph, generally where fairly dramatic changes have occurred. The letters N point out the future position of the new channel that developed in 1997. Two sizable trees along this channel that are visible in all three photos are identified by the letters T. The letters A with horizontal lines identify approximate positions of the alluvial fan apex, where the first major expansion in this part of the distributary system exists. Apparently, the fan apex has been migrating upslope since 1953, and made a major jump upslope in 1997.


Tiger Wash Piedmont
Detailed Inundation Mapping
Flood of September 26, 1997
Data compiled from aerial photos and ground surveys by P. Pearthree, Arizona Geological Survey.
LEGEND
N
Flow too narrow to map
Channel Flow
Deep Sheet Flooding
No Flow
Shallow Flow
Reconnaissance Inundation Area
SCALE
2000
0
2000
4000 Feet
Weldon Hill
Prospect
Prospects
Mine Shafts
Tiger
Gravel Pit
Check Dam
Check Dams
Desert Tank
Tiger
Wash
9
16
18
21
28
33
12
24
1685
1757
BM 1491
PLA

RECONNAISSANCE MAPPING
OF THE
SEPTEMBER 1997 FLOOD
ON THE
TIGER WASH PIEDMONT
DISTRIBUTARY SYSTEM

FCD 98-48
Assignment No. 2
Subtask 2, Reconnaissance Mapping

March 2000

Prepared for:

Flood Control District of Maricopa County
2801 W. Durango Street
Phoenix, AZ 85009
(602) 506-1501

By:

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

5235 South Kyrene, Suite 205
Tempe, Arizona 85283
(480) 752-2124 voice
(480) 839-2193 fax
www.jefuller.com

2881 North Silverspur Dr.
Tucson, Arizona 85745
(520) 623-3112 voice
(520) 623-3130 fax

In association with:

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416 W. Congress, Suite 100
Tucson, Arizona 85701
(520) 770-3500

Introduction

On September 25, 1997 dissipating Hurricane Nora entered southwestern Arizona. As it decreased in intensity and was downgraded to a tropical storm, the storm traveled north and east across the northwest corner of Maricopa County, Arizona which includes the Tiger Wash watershed. As the storm system traveled it dumped large quantities of rain in its path. In a 24 hour period spanning parts of September 25th and 26th, three rain gages in the Tiger Wash watershed recorded 3.78, 4.17, and 11.97 inches of rainfall respectively (Waters, 1998). As a result of this precipitation a very large flood occurred on Tiger Wash. The U.S. Geological Survey (USGS) estimated a maximum discharge of 8,070 cfs at their gaging station upstream of Blue Tank Canyon (Tadayon, et al., 1997), by far the largest discharge ever recorded in the 27 years of record at this station. The Nora flood peak discharge was almost two times greater than the next largest recorded discharge of 4,550 cfs which occurred in 1970.

The 1997 flood on Tiger Wash provides an unusual opportunity to characterize the spatial characteristics of flow during a large flood in a distributary flow system. The 1997 flood on the Tiger Wash distributary system left abundant evidence of the extent of inundation. In the spring of 1999, Arizona Geological Survey geologists J.E. Klawon and P.A. Pearthree used indicators such as fresh sediment, flotsam, and fresh scour to document the maximum extent of flood inundation. The extent of inundation was then mapped on a post-flood aerial photo base provided by the Flood Control District of Maricopa County (FCDMC, 1998). The resultant composite map of flood inundation details the spatial characteristics of this large flood through much of the Tiger Wash distributary system.

Methodology

Several types of evidence were used to map the extent of inundation in the field.

- *Flood Sediment*: The most ubiquitous evidence of the flood was freshly transported sediment. In areas of deeper inundation, fresh sediment typically was light-colored sand and locally gravel. This sediment partially buried vegetation of various sizes, and in many places sand bars were deposited on the lee sides of vegetation. In areas of shallower flow, the fresh sediment typically consisted of fine sand, silt and clay. The color of this fine-grained sediment was typically slightly redder than deposits that pre-date the flood. In true slackwater areas, the very fine sediment deposited by the flood commonly developed moderately large mud cracks as it dried.
- *Flotsam*: Flotsam, floated organic debris, was a very common indicator of flow. Flotsam around the margins of inundation was especially valuable, because it floated and marked the maximum extent of the water surface. Flotsam was also observed and recorded in trees and bushes in areas of deeper flow.
- *Scour*: Evidence of fresh scour and gully formation was also very common. In these areas, it was evident that the surface had recently been swept clean or substantially altered. In some areas, relatively old (Pleistocene) deposits were freshly exposed in stream channels. In areas of sheet flooding, scour commonly was focused between bushes or into animal burrows.

Using all of these kinds of evidence of flood inundation, the maximum extent of the flood was mapped in the field using a composite, black-and-white, ~1:15,000-scale aerial photo map made from post-flood photos taken in February, 1998. The composite map is a mosaic of digital aerial photos, with some geographic information superimposed on them from the District's GIS database. Several walking transects were made across the distributary system to identify areas of inundation and non-inundation. The margins of the many flow paths in the Tiger Wash system were traced in the field and mapped in the composite aerial photograph. Possible islands of no flow within flow paths were also identified on the aerial photos and field checked. Field mapping data were then compiled over the photo mosaic base map.

Results

The results of the reconnaissance mapping are presented in Figure 1. The limits of inundation from the September 1997 flood are shown for the East and West Branches of Tiger Wash to approximately the limit of BLM land at the south edge of Township 4N.

Limitations

- *Holocene Soils:* There is some uncertainty in the mapped flow boundaries in areas where flood lapped onto fine-grained, late Holocene deposits. As indicated above, these are generally areas of very shallow inundation less than a foot deep. The most difficult areas to delineate are located along the eastern edge of the West Branch inundation area downstream of the FCDMC ALERT gage # 5140. Adjustments from the inundation mapping to the flood hazard mapping were made with the aid of the 1999 color aerial photographs and additional field observations.
- *Map Error*: There is some uncertainty in the mapped flow boundaries throughout the map due to location uncertainty on composite aerial photos. The photo mosaic was registered by the FCDMC primarily using cultural features such as roads. Therefore, the photo registration for the study area is best in the vicinity of Eagle Eye Road and Salome Highway. For the remainder of the areas horizontal errors are likely in the range of a couple of hundred feet or less. To resolve this source of error, adjustments were made from the inundation mapping to the flood hazard mapping with the aid of the 1999 color aerial photographs and additional field observations. The USGS quadrangles were also used to correct distortions introduced by the photo mosaic. Additional features such as hills and other contour cues such as incised channel locations were used in the determination of the final flood hazard boundaries.

Summary of Tropical Storm Nora Flood Peak Discharge Estimates

In addition to the inundation limits mapping, several indirect estimates of peak discharges were also performed at sites on the piedmont. Six sites were surveyed in April 1999 by JE Fuller / Hydrology & Geomorphology, Inc. (JEF) staff to estimate the magnitude and distribution of peak discharges on Tiger. JEF also surveyed the Nora flood high water marks relative to the paleoflood site investigated by CH2MHill for the FCDMC in 1992. The USGS also made a slope-area estimate of the peak discharge near their gaging station upstream of Blue Tank Canyon in October 1997.

The results from the six sites investigated by JEF are summarized in Table 1 and are also shown in Figure 1. They indicate that most of the flow was conveyed in the West Branch channel. The results also indicate a significant decrease in discharge in the downstream direction. Part of this is due to the losses at the breakout channels, but much of it is likely due to a combination of attenuation of the peak discharge and to transmission losses into the alluvium along the channel.

The maximum stage of flow near the USGS gaging station was about 2 feet lower than the maximum paleoflood indicators investigated by CH2M Hill (1992). The CH2M Hill report indicated the maximum paleoflood magnitude at between 10,000 and 13,000 cfs. However, CH2M Hill also found evidence indicating that at least 3 floods between 6,000 and 10,000 cfs had occurred in the past 100 years (through 1992). Therefore, the Nora flood was about as big as any flood in that reach in the past 100 years. Repeat cross section surveys taken by the USGS at the gaging station indicate that about 1 foot of the channel bottom and a large channel bar near the gage were removed during the Nora flood. These same data show that since 1970 the bed has degraded about 2 feet (Capesius and Lehman, in press). While the cross sectional geometry of Tiger Wash during the paleofloods cannot be known certainly, the repeat cross section survey data suggest that the Nora flood may have been even larger relative to the largest paleofloods in spite of its somewhat lesser maximum absolute water surface elevation. Conversely, given the uncertainty of paleo-bed elevations, the paleoflood estimates might also be underestimated.

Characteristics of the 1997 Flood Flow

The 1997 flood inundated essentially all of the young alluvial fan areas on the West Branch of Tiger Wash and caused some dramatic changes in the channel system. Several large new channels formed during the flood, and numerous pre-existing channels were enlarged or extended. Some of these channels were very minor prior to the 1997 event. In the upper part of the West Branch single channel reach, Tiger Wash is confined between the Qy1[1] and older surfaces[2], flow was contained in the channel with minor overbank flow. High water marks are evident on channel banks and within tributary channel mouths that were backflooded. As flow became unconfined farther downslope, inundation was widespread on the active alluvial fan complex. Deep flow occurred in preexisting channels and deep unconfined flow occurred in overbank areas adjacent to main channels. Deep flow in channels was responsible for the transport of bedload up to small boulders and the erosion of channel beds and stream banks formed in Pleistocene and Holocene deposits. Deep unconfined flow transported some gravel, but mainly sand-size and finer particles, from main channels into overbank areas. Overbank sediment was deposited as broad sheets and in streamlined pendant bars downstream of creosote bushes and other vegetation. Many areas of deep unconfined flow are characterized by alternating small, narrow channels and sand bars, which results in a corrugated appearance to the surface. Shallow sheetflooding occurred at the margins of deep unconfined flow, where water reached its maximum distance away from the main channels. In areas of shallow sheetflooding, low sand deposits or "fingers" record flow and deposition around creosote bushes and areas

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[1] Qy1 are identified as early to late Holocene relict alluvial fan and terrace deposits (Klawon and Pearthree, 1999).

[2] See Klawon and Pearthree (1999) for a complete discussion of the surficial geology of the Tiger Wash piedmont.

between bushes are typically slightly to moderately scoured. At the very margins of flow, thin silt layers typically cover the surface.

The usefulness of surficial geologic mapping (refer to Subtask 3.1 report for details on the surficial geologic mapping) as a predictive tool in piedmont flood hazard assessment may be evaluated by comparing the extent of inundated areas of the 1997 flood with the pre-flood surficial geology. Based on the ages of surfaces, we predict that older surfaces such as Qm (middle Pleistocene alluvial fan deposits), Ql (late Pleistocene alluvium), and Qy1 would be unlikely to experience flooding, and that the younger surfaces, Qyc (late Holocene active channel deposits) and Qy2 (late Holocene sheetflood and overbank deposits), would likely be inundated in a large flood. Our inundation mapping shows that this generally was the case. Flow remained confined in the upper part of West Branch Tiger Wash where older deposits exist along the banks, and it broke out and spread widely where Qy2 deposits are adjacent to the main channel. There are locations, however, where older Holocene and Pleistocene surfaces adjacent to younger surfaces were inundated in 1997. This occurred along the margins of active alluvial fan areas where topographic relief between surfaces of different ages is minimal.

In several cases, flow not only inundated Qy2 surfaces, but also formed new channels along drainages that were small or weakly defined prior to the flood. These channel changes can be seen most dramatically by comparing pre-flood and post-flood photos. Photos taken in 1953, 1979, and 1999 illustrate the formation a large new channel during the 1997 flood (Figure 2). The new channel approximately followed the course of a small channel that existed within an area of fine-grained late Holocene overbank deposits (unit Qy2). The new channel probably formed as 1997 floodwater inundated the overbank areas and began to downcut into the Holocene deposits. Flow funneled through the new channel, eroding the bed down to Pleistocene soil in places and laterally eroding the Holocene channel banks. This new channel is much wider and somewhat shallower than the pre-existing main channel from which the breakout occurred (Figure 3). The new channel may narrow and deepen with time as riparian vegetation becomes established along its banks, and as smaller flows deposit fine sediment at the channel margins.

There are also numerous examples of less dramatic channel changes where flood waters widened or lengthened preexisting channels. These changes occurred in areas of channel flow and deep unconfined flow; flow depth zones where both erosive and depositional settings exist. Changes include channel widening, bank erosion along the outside of bends, bed scour, and formation of discontinuous well-defined channels. In addition, the apex of the most prominent active alluvial fan on West Branch of Tiger Wash has migrated about 500 m upslope between 1953 and 1999. About half of this migration occurred as a result of the formation of the new western channel in 1997, but it appears from the 1979 aerial photos that there was some upslope migration of the fan apex occurred between 1953 and 1979 (Figure 2).

Historical aerial photographs from 1953 suggest that the East Branch was the dominant wash at that time (JE Fuller, 1999). By the time the 1979 aerial photographs were flown, the West Branch seemed to be dominant. The 1997 flow event was clearly a much larger event on the West Branch than on the East Branch. It is uncertain whether this change may have been caused by alterations of the channels due to gravel mining in the area of the first distributary split, a natural shifting of flow from one branch to the other, or some combination of these factors.

Conclusions

Tropical Storm Nora caused extensive flooding on the Tiger Wash piedmont in September 1997. The evidence of this event still exists in the landscape today. The use of aerial photographs and field evidence allowed for a very reasonable depiction of the extents of this significant flood event on Tiger Wash. A majority of the flood water flowed down the West Branch of Tiger Wash. Two significant new channels formed by divergence of flow from the main channel into neighboring tributary channels which experienced significant channel adjustments to the captured floodwaters. The reconnaissance mapping also clearly shows the distributary nature of flooding on the Tiger Wash piedmont and that the number of channels and width of inundation increase significantly down the piedmont.

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Table 1. Summary of Indirect Peak Disharge Estimates

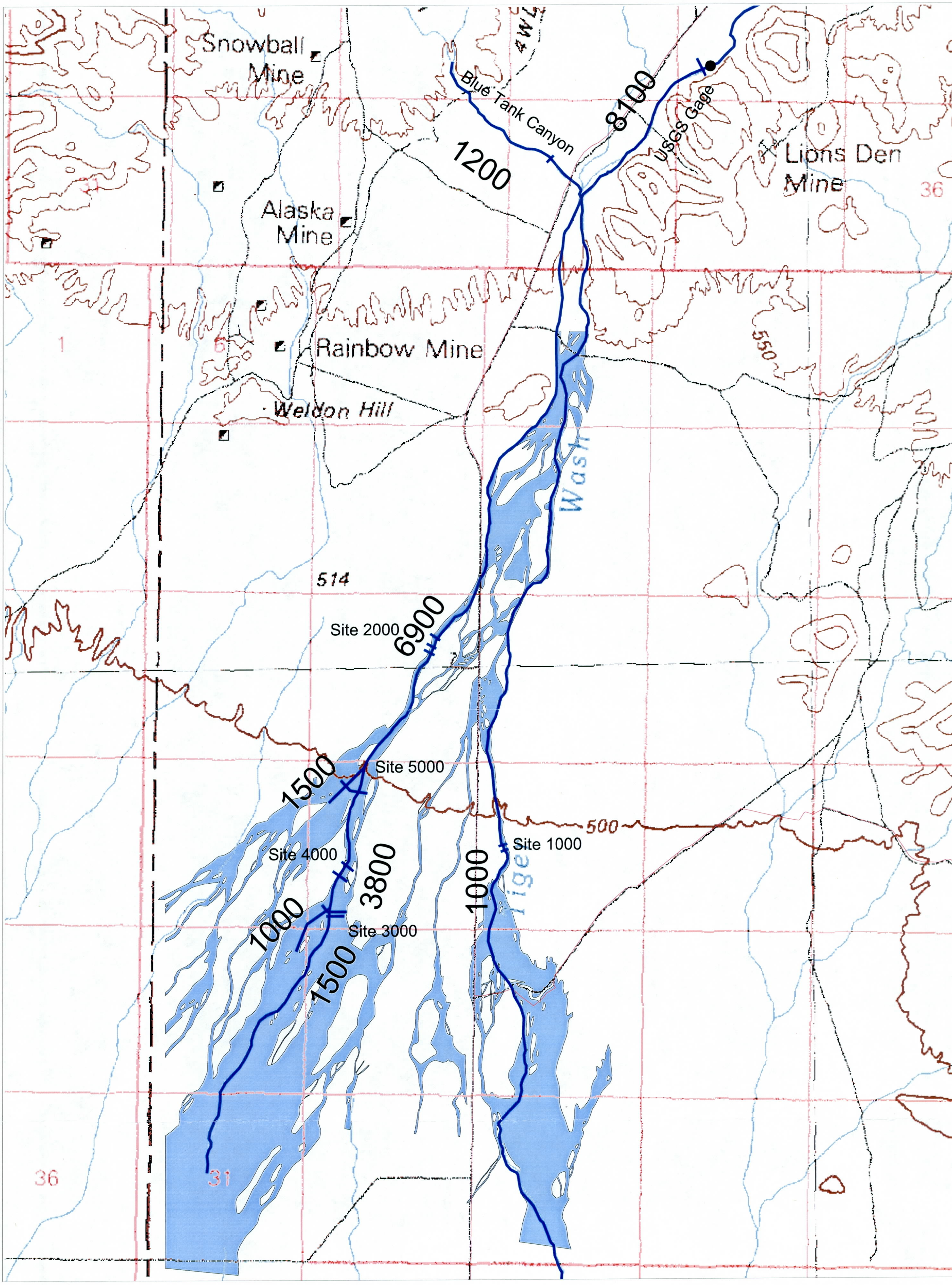
Site name[3]	Vavg (ft/s)	Froude No. average	Slope water surface[1]	Slope bed	n-value[4]	Width, channel (feet)	Q fixed bed (cfs)	Q w/xtra A[2] (cfs)	Q final (cfs)
Blue Tank Canyon	9.7	1.02	0.0156		0.035	40	1220		1200
1000	4.7	0.50	0.0048	0.0048	0.044	35	820	1000	1000
2000	11	0.90	0.0086	0.0051	0.029	70	5170	6910	6900
3000 -- AV2	4	0.41	0.01-0.0056	0.0054	0.040	105	1000		1000
3000 -- Main	3	0.53	0.01-0.0056	0.0039	0.040	65	1250-1500		1500
4000	9	0.70	0.0042	0.0049	0.030	75	2440	3820	3800
5000 -- AV1	3.0	0.37		0.0074	0.045	470	1480		1500
5000 -- Main	6.2	0.63		0.0125	0.035	520	4850		4800
USGS Gage	12	0.86	0.0085		0.027	100	8070		

[1] Water surface slope as indicated by survey of high water marks.

[2] Q w/xtra A = peak discharge estimate including additional cross sectional area as indicated by depth of scour seen in pits dug in channel beds.

[3] See summary figure for locations.

[4] Composite n-value or value for main channel at sites with subdivided cross sections.



Note: All discharges given in cubic feet per second.

Figure 1. TS Nora Flood Inundation, September 26, 1997

N

3000 0 3000 6000 Feet

1:36000

FCD No. 98-48
Assignment No. 2
Subtask 2
JE Fuller / Hydrology & Geomorphology, Inc.
in association with the Arizona Geological Survey
March 2000

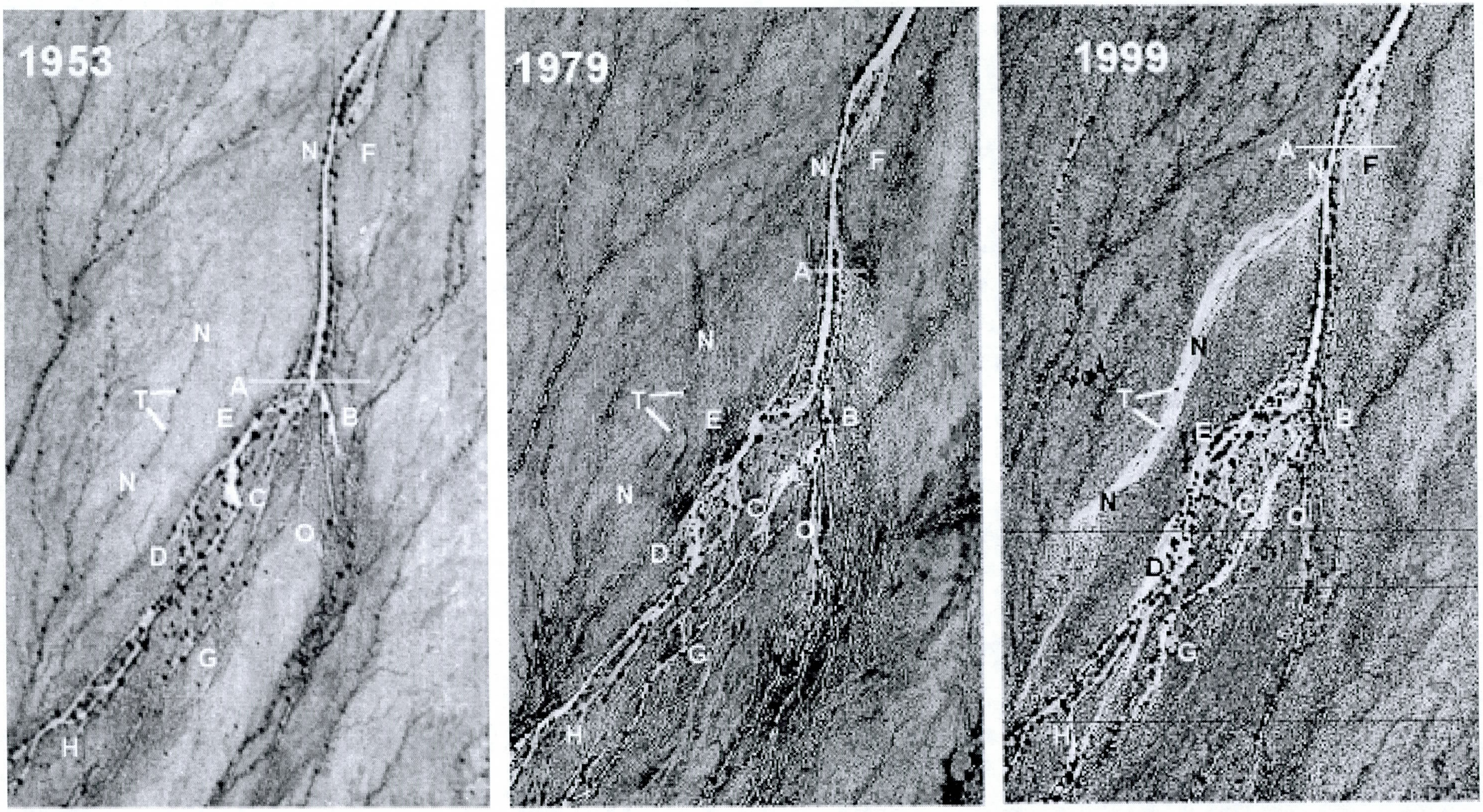


Figure 2. Repeated aerial photographs documenting changes in channel position and character near the apex of an alluvial fan within the west branch of the Tiger Wash system. Letters identify similar positions in each photograph, generally where fairly dramatic changes have occurred. The letters N point out the future position of the new channel that developed in 1997. Two sizable trees along this channel that are visible in all three photos are identified by the letters T. The letters A with horizontal lines identify approximate positions of the alluvial fan apex, where the first major expansion in this part of the distributary system exists. Apparently, the fan apex has been migrating upslope since 1953, and made a major jump upslope in 1997.

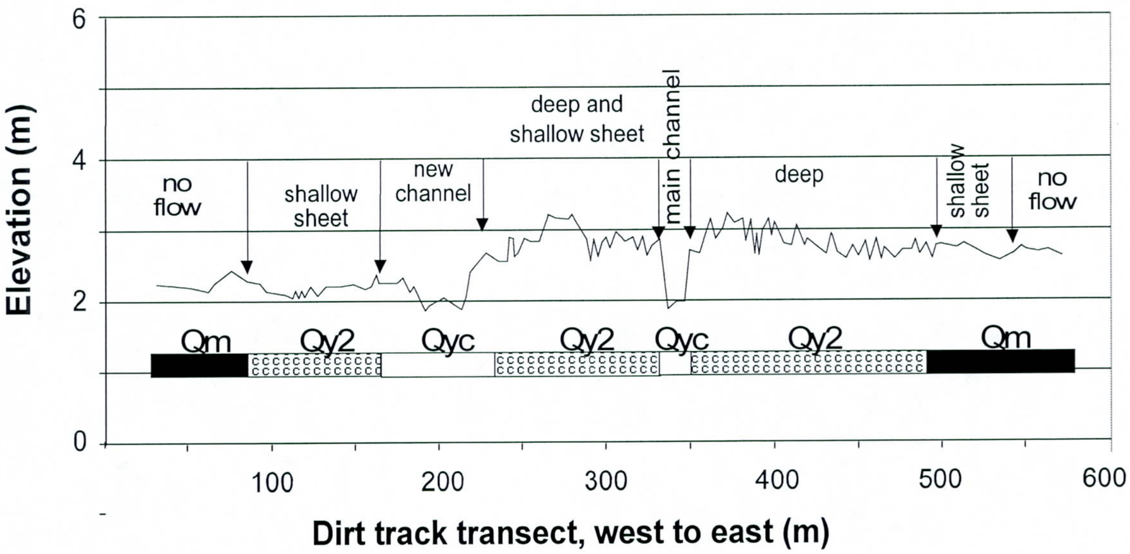


Figure 3. Topographic transects surveyed across the main flow path on the west branch of Tiger Wash. Surficial geologic units are shown on the bars below each transect. The upper transect follows the dirt track in the area of the fan apex identified in previous studies. On the upper transect, local topographic relief is much greater on the young alluvial surfaces that were flooded than on adjacent Pleistocene surfaces. Also note that the Qy surfaces are higher than adjacent Qm surfaces because of young deposition associated with the active alluvial fan. On the lower transect, inundation was generally shallow and very widespread. Topographic relief is minimal except for several narrow, steep-sided gullies that are too small to map at 1:9,600-scale. No exposed Pleistocene surfaces were encountered on this transect.

SURFICIAL GEOLOGY OF THE TIGER WASH PIEDMONT DISTRIBUTARY SYSTEM

FCD 98-48
Assignment No. 2
Subtask 3.1, Detailed Surficial Geologic Mapping

March 2000

Prepared for:

Flood Control District of Maricopa County
2801 W. Durango Street
Phoenix, AZ 85009
(602) 506-1501

By:

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

5235 South Kyrene, Suite 205
Tempe, Arizona 85283
(480) 752-2124 voice
(480) 839-2193 fax
www.jefuller.com

2881 North Silverspur Dr.
Tucson, Arizona 85745
(520) 623-3112 voice
(520) 623-3130 fax

In association with:

Arizona Geological Survey
416 W. Congress, Suite 100
Tucson, Arizona 85701
(520) 770-3500

Authors
Jeanne E. Klawon and Philip A. Pearthree

Introduction

Surficial geologic mapping provides a long-term perspective on the behavior of distributary drainage systems on piedmonts that can be used to delineate the extent of active alluvial fans. Active alluvial fans are depositional systems, and thus they leave a record of their activity in the form of extensive late Holocene deposits. Surface characteristics, soils, local topography, channel patterns, and exposures of surficial deposits record the character and extent of fluvial activity on piedmonts over decades to tens or hundreds of thousands of years. Surface color, black and red varnish on surface gravel, development of desert pavement, local surface topography, drainage network character and development, relief between channels and adjacent alluvial surfaces, and soil development can be used to differentiate alluvial surfaces by age.

Alluvial surfaces of similar age have a distinctive appearance and soil character because they have undergone similar post-depositional modifications. Young alluvial fan surfaces that are less than a few thousand years old still retain clear evidence of the original depositional topography, such as bars of coarse gravel deposits, swales (trough-like depressions) where low flows passed between bars, and distributary channel networks. Young fan surfaces also show minimal development of soil, desert pavement, and rock varnish, and dissection. Old alluvial fan surfaces, in contrast, have been isolated from substantial fluvial deposition or reworking for tens to hundreds of thousands of years. These surfaces are characterized by strongly developed soils with clay- and calcium-carbonate-rich horizons, smooth, closely packed desert pavements between drainages, dark varnish on surface rocks, and well-developed tributary stream networks that are entrenched below the fan surface. The ages of alluvial surfaces in the southwestern United States may be roughly estimated based on these surface characteristics, especially soil development (Gile and others, 1981; Bull, 1991).

The surficial geology of the Tiger Wash distributary system was mapped primarily using color 1:24,000-scale aerial photographs from 1979, which were provided by the U.S. Bureau of Land Management. The Arizona Geological Survey (AZGS) also conducted field investigations to document surface characteristics and soil development associated with the various alluvial surfaces and to check contacts between map units. Although, the 1979 aerial photographs pre-date the large flood of 1997, the map was not modified to reflect any changes in the extent of various map units caused by the flood. Thus, the map produced may be evaluated for its predictive value regarding the inundation associated with this recent flood. In some areas away from the 1997 flood inundation, 1:9,600-scale color aerial photos obtained for this project in 1999 were used to augment the interpretation of the 1979 photos.

Surficial Geologic Map Units

The surficial geology of the Tiger Wash distributary system provides insights into the character of fluvial behavior and flood hazards throughout the system. Surficial map units can be grouped into Holocene and Pleistocene units. The following text and Table 1 summarize the characteristics of the surficial geologic map units in the Tiger Wash system. The map itself is shown in Figure 1 and the 1:24,000 sheet at the end of this report.

Qyc Late Holocene active channel deposits

General description. This unit consists of active channels of Tiger Wash large enough to be depicted at the 1:24,000 map scale. These channels convey the majority of bedload sediment from the upper Tiger Wash watershed into the Tiger Wash distributary system.

Distribution and drainage characteristics. In the northern map area, channels are topographically confined by middle Holocene to middle Pleistocene alluvial fan deposits (see below for descriptions of these units). In this area, channel character ranges from large, single channels to smaller, multiple braided channels with cohesive relict Pleistocene alluvial fan deposits exposed in channel bed and banks in many places. Farther to the south, topographic confinement of channels is minimal and the drainage pattern is distributary, with channels branching downstream. Channels also exhibit braided patterns, where an intricate network of channels diverge and converge within the active fan. As channels increase in number downslope, they decrease in size and become discontinuous. When channels become too small to represent on the map, they are included in unit Qy2.

Sedimentology. Channel sediment is very poorly sorted sand, cobbles, and boulders, with sand and silt deposited on banks and adjacent overbank locations.

Geomorphology/surface topography. Relatively flat-bottomed sandy channels are most common, but sand bars, coarser gravel bars, and finer channel fringe deposits are also common.

Soils. Primary depositional layering typically is well preserved, and there is essentially no soil development.

Vegetation. Vegetation consists of moderate to large ironwood, palo verde, and acacia trees and relatively dense cover of smaller bushes along channel banks, but vegetation is small and sparse within channels.

Appearance on aerial photos. Channels are light-colored on the ground and on aerial photographs due to minimal vegetation cover and weathering of surface deposits.

Qy2 Late Holocene sheetflood and overbank deposits

General description. This unit includes young deposits associated with broad sheetflood areas, terraces and limited overbank areas that are part of the modern drainage system and are at least occasionally inundated. Qy2 deposits comprise most of the active alluvial fan areas within the Tiger Wash distributary drainage system.

Distribution and drainage characteristics. These deposits flank more well-defined channels and are found downstream from them. In the former setting, Qy2 deposits reflect overbank deposition on fairly narrow terraces and on broader sheetflood areas, where channel capacity is exceeded during large floods. In the latter setting, Qy2 deposits reflect the downstream decrease in channel capacity and the increasing importance of unconfined sheetflooding. Qy2 deposits are increasingly extensive downstream in the system. They also occupy strips of variable width along smaller piedmont drainages.

Sedimentology. Qy2 sediments typically are fine-grained sand and silt, but they also contain narrow ribbons and broader sheets of coarse sand and fine gravel.

Geomorphology/surface topography. Active channels typically are incised less than 0.5 meter (m) below these surfaces, but locally Qy2 surfaces are up to 1.5 m above large, confined active channels and scoured gullies. Where flow in large floods is moderately deep, drainage networks on these surfaces typically consist of intricate, discontinuous, small to very small channels that form complex distributary or braided patterns. In these areas, streamlined vegetation mounds and sand bars are ubiquitous between channels, giving the surface a corrogated texture. Where flow is shallower, channels are very small and the surface between vegetation mounds is relatively smooth.

Soils and surface characteristics. Soil development associated with Qy2 surfaces is minimal, and thin, well-preserved bedding is preserved in many places. There is no desert pavement development or rock varnish on surface clasts unless they have been reworked from older deposits.

Vegetation. Creosote bushes are the predominant vegetation on Qy2 surfaces, but ironwood, palo verde, and acacia trees exist in proximity to some channels and grass and other small bushes are common locally.

Appearance on aerial photos. Except as noted above, Qy2 surfaces generally appear smooth with colors that are various shades of brown on color aerial photos. These characteristics reflect the general absence of dissection of these active depositional surfaces and the color of the deposits and variations in vegetative cover on the surfaces.

Qy1 Early to late Holocene relict alluvial fan and terrace deposits

General description. This unit includes young alluvial fan and terrace deposits that have been isolated from active deposition from the Tiger Wash distributary drainage system for hundreds of years to a few thousand years. Qy1 surfaces are extensive within the modern distributary network of both the East and West Branches of Tiger Wash. Their presence indicates that loci of fan deposition within the distributary system have shifted during the past few thousand years.

Distribution and drainage characteristics. Qy1 surfaces are drained by a combination of fairly large, entrenched distributary channels associated with Tiger Wash and small tributary drainage networks that head on Qy1 surfaces. Distributary channels are entrenched as much as 2 m below adjacent Qy1 surfaces. The smaller local drainages have formed extensive, unentrenched tributary networks on Qy1 surfaces. These local drainages commonly follow what appear to be abandoned distributary drainage channels ("ghost" channels). On the ground, these abandoned channels are wide and shallow, presumably having been filled in somewhat since they were part of the active distributary system.

Sedimentology. Qy1 sediments consist primarily of very poorly sorted sand, pebbles, and cobbles, with lesser amounts of small boulders and silt.

Geomorphology/surface topography. Surface topography typically is undulating, with local relief of about 0.5 m between coarse gravel bars and finer-grained swales. In areas where Qy1 deposits contain less coarse material, surfaces may be quite smooth. Mounds of eolian sand and silt around creosote bushes are very common on Qy1 surfaces; these mounds typically are 10 to 30 cm higher than the surrounding surface.

Soils and surface characteristics. Surfaces are commonly partially covered by loose pebbles and cobbles forming weak desert pavements. These surface clasts have minimal rock varnish unless they have been reworked from older deposits, in which case they may have considerable varnish or relict carbonate coatings. Coarse bedding may be preserved, but finer sedimentary structures have been obscured by bioturbation and soil development. Soil development associated with Qy1 surfaces is weak, with slight development of soil structure and thin, discontinuous carbonate coatings on gravel clasts. Qy1 surfaces typically are slightly higher than surrounding younger and older surfaces.

Vegetation. Vegetation on Qy1 surfaces is sparse; creosote is the dominant shrub, with lesser amounts of small cactus and ocotillo. Scattered trees survive along some drainages.

Appearance on aerial photos. Qy1 surfaces have a mottled, light to dark gray appearance on color aerial photos.

Ql Late Pleistocene alluvium

General description. This unit consists of moderately old relict alluvial fan and terrace deposits that have been isolated from active deposition from the Tiger Wash distributary system for at least 10,000 years. Ql deposits record locations of major fan deposition during the late Pleistocene that were significantly different from the modern system.

Distribution and drainage characteristics. Ql deposits are found on the fringes of the Tiger Wash system in the northern part of the map area; farther south, they are found primarily between the main East and West Branches of Tiger Wash within the distributary drainage network. Ql surfaces are drained primarily by local tributary channel networks, although they are traversed by a few distributary channels of the Tiger Wash system. These distributary channels are incised 0.5 to 2 m below adjacent Ql surfaces. As with Qy1 surfaces, local drainages appear to follow former distributary channels that are now partially filled with young sediment.

Sedimentology. Ql sediments consist of very poorly sorted cobbles, pebbles, sand, small boulders, and silt. Ql deposits are probably the coarsest of any of the surficial units associated with Tiger Wash.

Deposit character/surface topography. Ql surfaces are broadly rounded and minimally dissected by local tributary drainages, with obvious erosion limited to areas adjacent to larger channels. Ql surfaces have moderate local topographic relief because the primary bars and swales are well preserved, although excavations reveal that substantial infilling of swales by younger sediment has occurred. Ql surfaces are distinguished from older Qm surfaces by more local relief from the well preserved bars and swales and commonly, larger clast size. Some Ql surfaces may be higher in elevation than adjacent Qm surfaces.

Soils and surface characteristics. Ql surfaces typically are covered with moderately packed desert pavements composed of varnished pebbles, cobbles and boulders. Exposed surfaces of gravel clasts on relict bars typically are moderately to darkly varnished, with bright orange varnish on their undersides. Pavements are also developed in most swales, but are finer and less varnished. Coarse bedding associated with gravel deposits is preserved, but finer sedimentary structures are not evident. Soil development is weak to moderate, with slight reddening, weak soil structure, and thin, discontinuous carbonate coatings on subsurface gravel clasts.

Vegetation. Vegetation on Ql surfaces is sparse; creosote is the dominant shrub, with lesser amounts of small cactus and ocotillo.

Appearance on aerial photos. The Ql surface can be distinguished on aerial photos by its medium gray color and "plumose" (feathery) texture where varnished bars appear to fan out in the downslope direction.

Qm Middle Pleistocene alluvial fan deposits

General description. This unit consists of old relict alluvial fan deposits that have been isolated from active deposition from the Tiger Wash distributary system for 100,000 years or more.

Distribution and drainage characteristics. Extensive Qm relict alluvial fans form both the east and west margins of the Tiger Wash distributary system in the central and northern parts of the map area. Many less extensive Qm surface remnants are preserved within the distributary system. Based on numerous exposures of Qm deposits in channel bottoms and banks, they also underlie relatively thin younger deposits in many areas. Qm surfaces are drained by well-developed tributary drainage networks that head on the piedmont. Tributary channels are entrenched from up to 3 m below adjacent Qm surfaces.

Sedimentology. Qm sediments consist of very poorly sorted cobbles, pebbles, sand, small boulders, and silt. Qm deposits are quite similar in composition to Ql deposits.

Deposit character/surface topography. Qm surfaces are remarkably planar between the channels and swales of the tributary drainage network. Concentrations of coarser gravel on Qm surfaces are evidence for relict gravel bars, but topographic relief between bars and swales is commonly less than 10 cm.

Soils and surface characteristics. Qm surfaces are covered by strongly developed, closely packed desert pavements. Surface clasts have dark brown to black varnish, with red coatings on their undersides. Pavement development and varnish are similar on bars and swales. Coarse sedimentary structure in gravel deposits is preserved. Soil development is moderate, with reddened zones of clay accumulation, continuous carbonate coatings and bottom pendants on gravel clasts, and locally weak carbonate cementation. Where Qm surfaces have been eroded, exposure of soil horizons results in slightly red or white surface color.

Vegetation. Vegetation on Qm surfaces is sparse. It consists primarily of clusters of creosote bushes, sparse grasses, and occasional saguaro cactus. Vegetation is concentrated along drainages.

Appearance on aerial photos. Qm surfaces appear mottled medium to dark gray and orange on aerial photographs. The gray colors reflect well-preserved desert pavements; the orange color reflects more eroded portions of Qm. Tributary drainages stand out as distinctly darker than adjacent Qm surfaces because of the vegetation concentrated along them.

Qmo Older middle Pleistocene alluvial fan deposits

General description. This unit consists of very old relict alluvial fan deposits derived from tributary stream systems that drain the southeast flank of the Harquahala Mountains. They are found only in the northernmost part of the map area and are not part of the Tiger Wash distributary system, so they are only described briefly here. Qmo surfaces are as high or slightly higher than adjacent Qm surfaces, but Qmo surfaces are much more deeply dissected; they consist of rounded ridges and moderately deep valleys; soil development may be fairly strong on ridgecrests, but is generally weak to moderate on side-slopes and in valley bottoms. Qmo surfaces have been isolated from active deposition for several hundred thousand years.

G Gravel Pits

Areas that have been profoundly disturbed by sand and gravel mining operations. They are found mainly found along the East Branch Tiger Wash, exploiting the gravels of units Qy and Ql.

Table 1. Summary of Distinguishing Characteristics of Surficial Geologic Units

Unit	Drainage characteristics	Sedimentology	Surface topography	Soils
Qyc Modern channels	single, braided, distributary	very poorly sorted sand, cobbles, and boulders	flat-bottomed sandy channels, sand and gravel bars	depositional layering, essentially no soil development
Qy2 sheetflood areas and terraces	poorly defined, discontinuous small channels and gullies	sand and silt, with local fine gravel deposits	fairly planar with local topography around vegetation	depositional layering preserved, soil development is weak
Qy1 young alluvial fans and terraces, generally not part of active system	moderately large, entrenched distributary channels and smaller local swales and channels	very poorly sorted sand, pebbles, and cobbles, with small boulders and silt	undulating, with coarse gravel bars and finer-grained swales; may be quite smooth where fine-grained	slight development of soil structure and thin, discontinuous carbonate coatings on gravel clasts, gravel lag but minimal varnish
Ql moderately old relict alluvial fan and terrace deposits	drained primarily by local tributary channels, with a few distributary channels	very poorly sorted cobbles, pebbles, sand, small boulders, and silt	broadly rounded and minimally dissected, bars and swales are well preserved	moderately packed, varnished desert pavements; soil development is weak to moderate, with slight reddening, weak soil structure, and thin, discontinuous carbonate coatings
Qm old relict alluvial fan deposits	well-developed tributary drainage networks entrenched up to 3 m below Qm surfaces	very poorly sorted cobbles, pebbles, sand, small boulders, and silt	planar between the channels and swales; relict gravel bars commonly less than 10 cm above swales	strongly developed, darkly varnished desert pavements; soil development is moderate, with reddened zones of clay accumulation, weak carbonate cementation and bottom pendants on gravel clasts
Qmo very old relict alluvial fan deposits	deeply dissected tributary drainage networks, not part of Tiger Wash distributary system	not described	rouded ridges and moderately deep valleys	strongly developed on ridge crests, but weak to moderate on eroding side slopes
G gravel pits	localized holes which trap water and sediment locally, outflow only when filled	profoundly disturbed ground by sand and gravel mining	disturbed ground often into or through petrocalcic soil horizons (caliche)	removed, often subsurface petrocalcic horizons (caliche) exposed, may be very white in appearance in aerial photos

Summary of Surficial Geologic Units

Holocene units include Qyc, Qy2 and Qy1. The active fluvial system is outlined by the extent of modern channels (Qyc) and overbank and sheetflood areas (Qy2). Older Holocene deposits (Qy1) cover areas that have been part of the active depositional system quite recently but which now appear to have been isolated from flood inundation. Qyc deposits are light-colored, freshly deposited channel sediment ranging in size from sand to small to medium boulders. Sediment is typically deposited on flat, generally sandy channel bottoms with some sheets of gravel, gravel bars, and lower-relief sand bars. Qy2 deposits are generally much finer grained sandy to silty overbank and sheetflood deposits, but they also include sheet gravel deposits at the downslope margins of channels and fine gravel deposits on the beds of small channels. Soils developed on Qy2 deposits are very weak, reflecting the periodic deposition of fresh sediment in these areas during large floods. Qy1 surfaces have minimal rock varnish and desert pavement development and are weakly dissected. Qy1 surface relief is quite variable, depending on particle size and post-depositional entrenchment by local drainages. Commonly, however, local relief on Qy1 surfaces is greater than on adjacent Pleistocene surfaces because of well-preserved bar and swale depositional topography and burrowed areas. Relict distributary channels ("ghost channels") can commonly be observed on Qy1 surfaces. Many of these relict channels are now parts of the local tributary drainage networks developed on Qy1 surfaces. Broad areas covered by Qy1 deposits within and along the margins of the distributary drainage system imply that substantial changes in the loci of flooding and deposition have occurred during the past few thousand years.

Pleistocene surficial geologic units record the longer-term evolution of the Tiger Wash distributary system. They include Ql, Qm, and Qmo, with Ql being the youngest (late to latest Pleistocene) and Qmo the oldest (early to middle Pleistocene) Qmo surfaces are found only in the northernmost part of Figure 1, and are not part of the Tiger Wash distributary system. Pleistocene Ql and Qm surfaces are the relict alluvial fans of Tiger Wash that have been isolated from active fluvial deposition or reworking for at least 10,000 years. In upper piedmont areas, these surfaces are substantially higher than adjacent Holocene channels and terraces. In middle and lower piedmont areas, however, topographic relief between Holocene and Pleistocene surfaces in minimal. In these areas, some Pleistocene surfaces have been partially buried by Holocene deposits within and along the margins of active deposition. Pleistocene surficial geologic units typically have moderately to strongly developed rock varnish. Smooth desert pavements are well developed on the Qm surfaces. Surface clasts are mostly pebbles and cobbles, which are poorly sorted on Ql surfaces and moderately sorted on Qm surfaces. Local topographic relief is greater on Ql surfaces than Qm surfaces due to much better preservation of bar and swale topography. Former bars and swales may be recognized on Qm surfaces by variations in particle size, but original depositional topography has been almost completely smoothed by local deposition and erosion. Pleistocene soils show an increase in soil development with increase in age of the map unit. For example, Ql soils have slight clay accumulation, weak structure, and thin discontinuous carbonate coatings on clasts. Qm soils have moderately developed structure, reddened zones of clay accumulation, and continuous carbonate coatings on clasts and local cementation in the calcic horizon.

Implications for the Extent of Active Alluvial Fan Flooding in the Tiger Wash Distributary System

Tiger Wash is typical of many drainage systems in southern and central Arizona in that the channel network changes from tributary to distributary (branching and diverging downstream) on the piedmont downslope from the mountains. Distributary systems spread water and sediment over wide portions of the piedmont, but the existence of distributary channel networks alone does not imply that the entire system is an active alluvial fan. All or parts of distributary drainage systems may be considered active alluvial fans if: (1) topographic relief between channels and surfaces between channels is low enough that channel banks along most reaches are overtopped during large floods; and (2) the surfaces between channels are primarily composed of Holocene deposits. The predominance of Holocene deposits in parts of a distributary system implies that these areas have been inundated in the past few thousand years either by sheetflooding, changes in channel positions, or both. On active alluvial fans, channels typically are discontinuous and decrease in size downfan. Channels typically are a minor element in the lower parts of these fans, which are covered with young, fine-grained deposits indicative of extensive unconfined sheetflooding between channels. Another criteria for active alluvial fans is the stability of the channels which transport sediment and water. In stable, inactive, fan areas, floodwater and sediment tends to stay confined to existing channels. These inactive areas are strongly associated with older geomorphic surfaces.

The mapped distribution of surficial deposits of different ages points to areas that are likely to be subject to alluvial fan flooding. Young deposits are quite limited in the northern part of the map area, where Tiger Wash is a tributary drainage system that is topographically confined by bedrock hills and Pleistocene alluvial fan deposits. Along this reach of Tiger Wash, the channel pattern is braided and young terraces (units Qy2 and Qy1) are extensive, but the limits of the flood-prone area are well defined by topography and geology.

Extensive Holocene deposits exist along both branches of Tiger Wash in the area of the first major distributary channel split, but very young deposits (units Qy2 and Qyc) are restricted to narrow areas along the main channel systems. Qy2 deposits are actually more extensive along the East Branch of Tiger Wash, which suggests that this branch may have been relatively more important in the recent past. During the 1997 flood, however, most of the flow went down the West Branch and much of the area covered by Qy2 deposits on the East Branch was not inundated. This is also the area where humans excavated sizable gravel pits on the East Branch, but it is not clear whether this gravel mining resulted in diversion of flow to the West Branch. The distribution of young surficial deposits in the area of the most upstream distributary split implies that substantial changes in depositional patterns have occurred recently; these deposits may record a shift in flow and deposition from the East Branch to the West Branch over the past several decades. The moderate topographic relief between active channels and adjacent fan surfaces (up to 3 m) and the existence of relict Pleistocene alluvial fan surfaces within and bounding the distributary system implies that the general configuration of the distributary channel system in this area is reasonably stable.

Well downstream of the distributary split into the East and West Branches of Tiger Wash, the lateral extent of Qy2 deposits increases dramatically. In these same areas, channel systems branch and become smaller downstream and local topographic relief generally is less than about 1 m. These areas of extensive Qy2 deposits and downstream-branching channel networks are considered to be active alluvial fans within the larger distributary drainage system. Most of these areas would be inundated in large floods, and the potential exists for significant changes in channel patterns. Farther downslope, Qy2 deposits are very extensive and channels are narrow and discontinuous. These areas are subject to very broad, relatively shallow sheetflooding during large flow events, with localized deeper, higher velocity flow in channels and gullies.

Topographic relief across the piedmont decreases gradually downslope in conjunction with the increase in extent of very young deposits, so that the topography associated with the lateral boundaries of young deposition in the middle and lower piedmont is minimal. Relief between Pleistocene remnants and Holocene deposits is also very small, and in some situations Pleistocene surfaces are actually lower than adjacent Qy2 and Qy1 surfaces. The margins of the active alluvial fan areas are evolving over time, and the contacts between young and older surficial deposits along the fan margins are modified during large floods. Although the vast majority of the inundation during the 1997 flood occurred in areas covered by young deposits, field evidence showed local burial and erosion of Pleistocene alluvial fan surfaces during the 1997 flood.

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Gile, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology of the Basin and Range area of southern New Mexico – Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources Memoir 39, 222 p.

Geologic Map Units

G	Gravel pits
Qyc	Late Holocene active channel deposits
Qy2	Late Holocene sheetflood and overbank deposits
Qy1	Early to late Holocene relict alluvial fan and terrace deposits
Ql	Late Pleistocene alluvium
Qm	Middle Pleistocene alluvial fan deposits
Qmo	Early to Middle Pleistocene alluvial fan deposits
R	Bedrock

Geologic Map Symbols

Contact; dashed where approximate

Map boundary

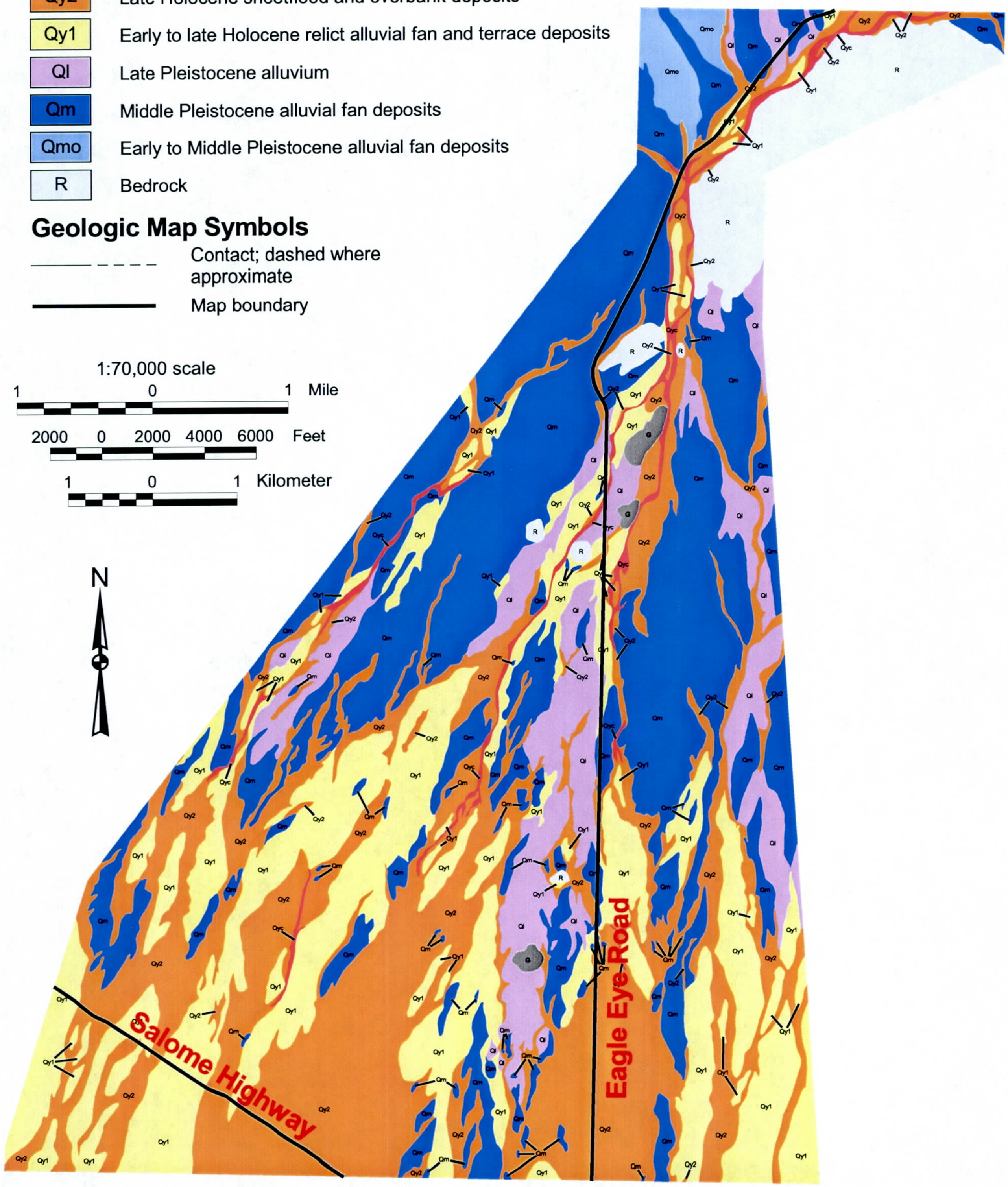
1:70,000 scale

1 0 1 Mile

2000 0 2000 4000 6000 Feet

1 0 1 Kilometer

N



Surficial Geology of the Tiger Wash Distributary System

By Jeanne E. Klawon and Philip A. Pearthree, 1999

Geologic Map Units

G	Gravel pits
Qyc	Late Holocene active channel deposits
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Qmo	Early to Middle Pleistocene alluvial fan deposits
R	Bedrock

1:24,000 scale

1 0 1 Mile

1000 0 1000 2000 3000 4000 5000 6000 7000 Feet

1 0 1 Kilometer

Geologic Map Symbols

———— - - - -	Contact; dashed where approximate
————	Map boundary
Qyc	Map unit label with text lead-in line

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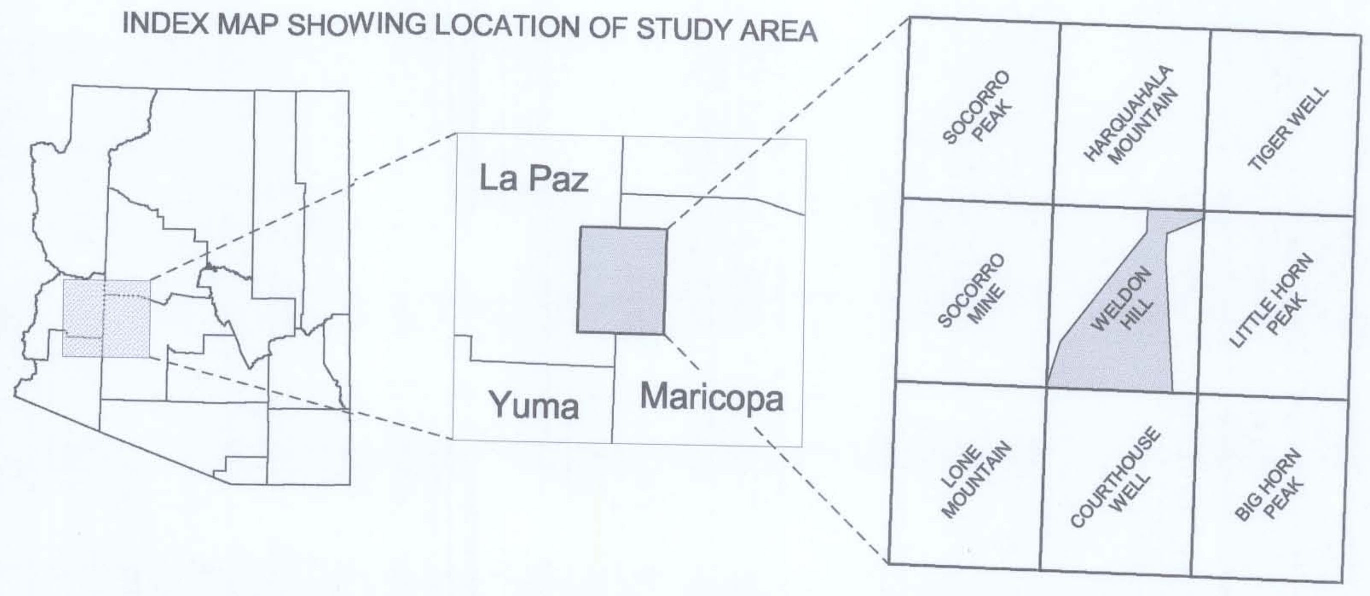
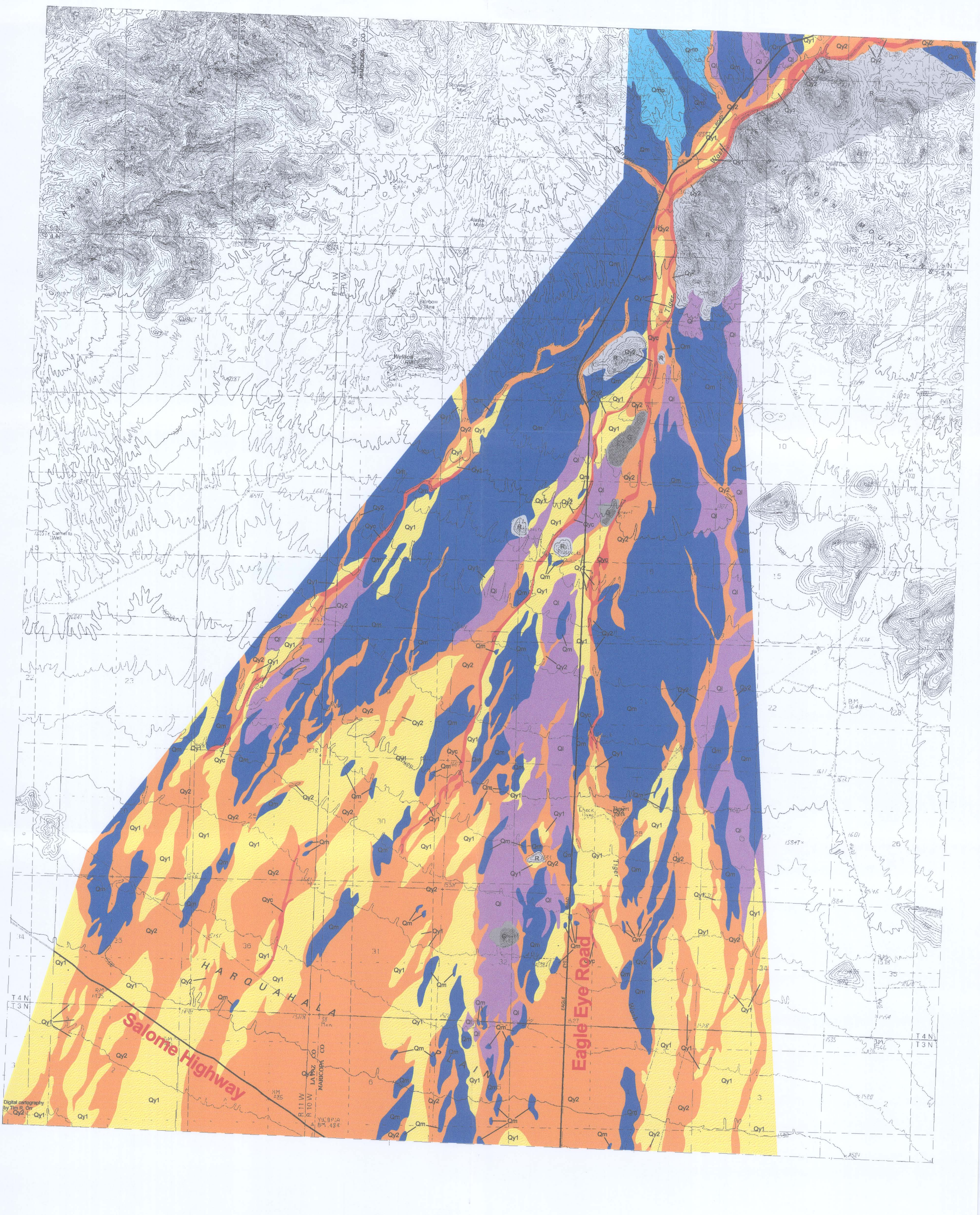
INDEX MAP SHOWING LOCATION OF STUDY AREA





PIEDMONT FLOOD HAZARD ASSESSMENT MANUAL FOR MARICOPA COUNTY, ARIZONA

CASE STUDY OF

TIGER WASH PIEDMONT DISTRIBUTARY SYSTEM

BEFORE AND AFTER THE SEPTEMBER 1997 FLOOD

FCD 98-48
Assignment No. 2
Subtask 3.2-3.3

March 2000

Prepared for:

Flood Control District of Maricopa County
2801 W. Durango Street
Phoenix, AZ 85009
(602) 506-1501

By:

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

5235 South Kyrene, Suite 205
Tempe, Arizona 85283
(480) 752-2124 voice
(480) 839-2193 fax
www.jefuller.com

2881 North Silverspur Dr.
Tucson, Arizona 85745
(520) 623-3112 voice
(520) 623-3130 fax

In association with:

Arizona Geological Survey
416 W. Congress, Suite 100
Tucson, Arizona 85701
(520) 770-3500

Introduction

The Tiger Wash distributary system has been previously examined by a number of investigators for its flood hazard and as an example of the behavior of alluvial fans. In September 1997, the watershed experienced a very large flood. This provides a unique opportunity to evaluate the *Piedmont Flood Hazard Assessment Manual for Maricopa County, Arizona*. (Hjalmarson, 1998).

Project Description

This study will compare pre- and post-1997 flood evaluations of the flood hazard on the Tiger Wash piedmont using the *Piedmont Flood Hazard Assessment Manual for Maricopa County, Arizona (PFHAM)* (Hjalmarson, 1998). Differences between the two assessments will be discussed as a test of the methodology outlined in the *PFHAM*.

Objectives

The objective of this study is to determine whether the occurrence of a very large flood in September 1997 would have impacted the delineation made using the *PFHAM* procedures. This was tested by using pre-1997 aerial photographs and previously completed geomorphic reports, and comparing the results to the post-1997 flood hazard boundaries developed for the recent approximate floodplain delineation study (JEF, 1999).

Background

In an effort to establish more realistic identification of flood hazards on alluvial fans, the Flood Control District of Maricopa County commissioned the *Piedmont Flood Hazard Assessment Manual for Maricopa County, Arizona*. (Hjalmarson, 1998). The *PFHAM* is the direct outgrowth of a report published by the National Research Council (NRC) entitled *Alluvial Fan Flooding* (1996). The NRC report was the result of a request by the Federal Emergency Management Agency (FEMA) to revise the definition of alluvial fan flooding and develop criteria to determine if an area is subject to alluvial fan flooding. The *PFHAM* builds on the NRC report and focuses the application of the NRC recommendations on alluvial fan flooding in the geographic area of Maricopa County, Arizona.

Since the draft publication of the Manual in August 1998, FEMA has recently published its own new revised *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 1999). These guidelines also incorporate the NRC report recommendations.

Tiger Wash has been examined by earlier investigators for its degree and extent of flood hazard in a more general way. In 1992, CH2M Hill conducted a study for the Flood Control District which among other things estimated an approximate floodplain for the West Branch of Tiger Wash. Hjalmarson and Kemna also investigated the flood hazard of the West Branch of Tiger Wash alluvial fan. They determined that the degree flood hazard for this distributary flow system was a 10 on a scale of 1 to 10 where 10 is the most hazardous.

The *PFHAM* has been applied to 3 sites to date (Skyline Wash, NW McDowell Mountains piedmont, and Tiger Wash), and is currently under application to a fourth site (White Tank fan, Site 36) in Maricopa County.

This report will present and discuss an evaluation of the flood hazard assessment of the Tiger Wash piedmont using the *PFHAM* before and after the large flood of September 1997. The post-1997 assessment was previously conducted by JE Fuller / Hydrology and Geomorphology, Inc. (JEF, 1999) and has been submitted to FEMA. This will serve as the basis of the post-flood evaluation.

Methodology

In the spring of 1999, JE Fuller, Inc. was contracted by the FCDMC to perform an approximate floodplain delineation of the Tiger Wash piedmont using the *PFHAM*. This study resulted in a Technical Data Notebook and flood hazard map which was submitted to the FCDMC for FEMA for approval in September 1999. Figure 1 shows the resulting approximate flood hazard delineation. The three stage method of the manual was followed to produce the flood hazard map shown in Figure 1. The delineation was the result of a combination of interpretation of the detailed surficial geology (Klawon and Pearthree, 1999), the inundation area of the September 1997 flood (JEF/AZGS, 1999), and engineering judgment.

These results will be compared to a couple of different pre-flood evaluations. First, in 1992 CH2M Hill made an estimate of the approximate floodplain limits in their report. While not using the *PFHAM* directly, the methods employed were similar to those outline in the Manual; namely, examination of historical aerial photographs, evaluation of landforms, and examination of surface characteristics for signs of stability and historical inundation. The approximate limits from the CH2M Hill study along with the 1999 delineation are shown in Figure 2.

This study along with other previous investigators focused their attention on the central portion of the West Branch of Tiger Wash as the locus of the active alluvial fan. Prior to 1997, the most obvious signs of active channel splitting, extensive aggradation, and channel relocation were located in Section 20, T 4N, R10W (Figure 1).

In addition to the CH2M Hill (1992) flood hazard evaluation, the surficial geologic mapping (Klawon and Pearthree, 1999) was based upon the 1979 color aerial photographs (BLM, 1979). Field investigations, however, were conducted following the September 1997 flood. Therefore, while the attempt was made to perform a truly blind, pre-flood evaluation, by necessity 1) foreknowledge of the results of the 1997 flood cannot be completely removed from the interpretations, and 2) certain locations cannot be observed in the field for pre-flood surficial characteristics, etc. Figure 3 shows the surficial geology for the Tiger Wash piedmont.

The surficial geology can be used as a fundamental basis for the 3 stage *PFHAM* method. Landforms can be identified (Figure 5). Areas of stability can be evaluated based on the distribution of various aged surfaces, USGS 7.5 minute topography, interpretation of the pre-flood aerial photographs, examination of historical channel changes prior to 1997, and field observations. Again, use of 1999 observations must be filtered carefully. However, Dr. Pearthree, Mr. Jonathan Fuller, and Mr. Ted Lehman, who all worked on this study, have all examined the Tiger Wash piedmont prior to 1997. Mr. Fuller and Dr. Pearthree were both intimately involved in the 1992 CH2M Hill report. Mr. Lehman worked for the FCDMC from 1991-1999 and visited the piedmont numerous times during his tenure. Therefore, it is believed that the authors of this study do possess some reasonable sense of the pre-flood piedmont conditions as well as well-informed opinions about the nature and distribution of flood hazards on the piedmont.

Results

CH2M Hill

The CH2M Hill report presented an approximate floodplain map that covers only the West Branch of Tiger Wash. The limits of the floodplain begin at about the location of the first large channel avulsion of the 1997 flood in the NW ¼ Sec. 20 (AV1, Figure 2). This in itself is very enlightening. A reach of channelized flood hazard is identified downstream for about 4,500 feet to the location of the second 1997 channel avulsion. From this location, which they identified as the hydrologic apex, downstream, their approximate floodplain begins to widen significantly. Downstream another 1,500 feet, at the area of the sudden increase in the number of channels, the flood hazard is identified as channel and sheet type flooding. At a point about another 4,000 feet downstream, they show the flood hazard transitioning to a wide area of sheetflood hazard.

It is important to note that the primary objective of the CH2M Hill report was not to delineate the approximate floodplain. The floodplain delineation was only performed in order to provide a reasonable evaluation of where potential monitoring equipment would be required to gage flood discharges on the alluvial fan.

1979 Surficial Geology

Proceeding forward from the 1979 based surficial geology, it is believed that the flood hazard area identified would have been similar to the 1999 evaluation in its overall shape and location (Figure 1 and 4). However, a few important exceptions are noted. First, the extent of the active alluvial fan hazard onto the adjacent Pleistocene surfaces along its east edge near the FCDMC ALERT weather station may have been underestimated. Second, the west margin of the AFHH zone on the West Branch may have been set somewhat too far east. That is, the west extent of the flood hazard onto the adjacent inactive fan surfaces may have been underestimated (Figure 4). During the 1997 flood, a couple of large channel scour scars formed along and into this western margin (Figure 6). Also, the inundation limits extended up and into this area leading to the locations of significant scour.

The surficial geology does seem to indicate the potential for significant overbank flooding and deposition in the area of the upstream avulsion, AV1 (Figure 2, 3, & 4). A fingery area of Qy2, late Holocene deposits, was discernable and identified from the 1979 photographs (Figure 3 & 4). However, the authors are in consensus that the magnitude of the avulsion and its associated erosion and depositional hazards would probably have been underestimated. The result would have been a potentially smaller area of active alluvial fan hazard identified. That is, the Zone A flood hazard zone would likely have extended further upstream out toward the main channel of the West Branch of Tiger Wash.

The other significant difference is a general under appreciation for the significance of the erosion hazard within the downstream portion of the piedmont. As indicated in the CH2M Hill report, prior to the 1997 flood, it is likely that the flood hazard designation for Zone AFHH would not have extended much beyond the area they identified as channel and sheet flood hazard (Figure 2). However, the 1997 flood showed numerous instances where relatively small disturbances to the flow resulted in rather significant areas of scour. Generally this seems to have occurred in locations where areas of sheet flow were slightly concentrated by redirection from some feature. This is especially noticable upstream from Salome Highway near the County boundary where significant arroyo development occurred during the 1997 flood (Figure 8a and 8b).

Discussion

The evidence presented by the September 1997 flood had a definite influence on the interpretation of the flood hazard on the Tiger Wash piedmont. The discussion of these influences will be organized relative to the 3 stage process presented in the *PFHAM.*

Stage 1. Landform Identification

The landform identification process was generally not affected by the information revealed by the 1997 flood. Since the surficial geology (based on the 1979 photographs) served as the basis of the landform identification, the 1997 flood did not enter into the differentiation of the various landforms on the piedmont (Figure 5). However, the identification of the boundaries of the alluvial plain may have been affected as will be discussed further in the discussion of the stability analysis below.

Stage 2. Stability Analysis

The stability analysis was greatly affected by the knowledge about the effects for the 1997 flood creating different results. There are two categories of differences. First, the margins of the active vs. inactive and/or relict fans would likely have been different. In a couple of locations, areas of relict fan were inundated, deposited upon, and scoured. So while identified as relict fan based on the surficial characteristics, their position spatially and topographically put them at risk from areas of active alluvial fan. Given the 20 foot contour interval mapping available from the USGS topographic quadrangles, it is unlikely that all of these topographically low areas would have been correctly identified without more detailed mapping. Similarly, the boundary between the active and inactive portions of the fan would likely have been affected. Specifically, along the west boundary between active and inactive fan on the West Branch of Tiger Wash, the pre-flood evaluation may have underestimated the extent of active fan area by a couple of hundred feet locally where older surfaces were inundated by the 1997 flood (Figure 3,4, & 6).

The second category of difference between a pre-1997 flood and post-1997 flood stability analysis would have been the boundary between the active alluvial fan and the alluvial plain.

The CH2M Hill report indicated a transition from a combination of channel and sheet flooding hazards to a zone of predominantly sheet flooding hazard. Their basis for this transition was the dramatic decrease in the number and size of observable channels available to carry flood waters. Much of this lower piedmont area appears largely absent of channels. However, the 1997 flood showed that during significant floods, new channels are capable of being (re)formed on the lower piedmont. The 1997 flood showed that erosion hazards on the lower piedmont can be significant. Related to these new areas of erosion are sizeable areas of deposition where the material eroded from these new channels is eventually deposited (Figure 6, 8a & 8b). Therefore, having seen the effects of the 1997 flood, the lower portion of the piedmont was included in the active alluvial fan rather than being identified as an area of shallow sheet flooding which might be experienced on a true alluvial plain.

The identification of the alluvial plain is one area in the *PFHAM* that requires some additional resources. The 1997 flood identified a need for better tools to assist in the differentiation between unstable areas and stable areas on the lower portions of piedmonts in Maricopa County.

Stage 3. Flood Hazard Identification

Some of the differences identified in Stage 1 and Stage 2 have logical consequences for the flood hazard identification process. For example, areas identified as active alluvial fan become Zone AFHH in Stage 3. Therefore, any areas identified differently in Stage 2 as active alluvial fan result in differences in the areas of Zone AFHH. In some of those instances, the effect is a difference between shaded Zone X and Zone AFHH; that is, being located essentially out of the floodplain versus in a floodway district. In other instances, the difference might be between Zone AFHH and Zone A, i.e. floodway vs. floodplain (fringe). Another difference would be the areas of the lower piedmont identified as active alluvial fan versus potentially a sheet flooding designation if the areas had been called alluvial plain. Where judgment of the exact location of the boundary between active and inactive alluvial fan area was influenced, flood hazard designation would also have been affected.

A recommendation is that additional types of flood hazard zones be considered. Perhaps two or three categories of alluvial fan flooding zones could be designated. One of the difficulties experienced by the authors was the idea that areas closer to the hydrologic apex ought to be considered higher hazard that those areas of the lower piedmont. The erosion and deposition hazard on the lower piedmont is believed to be significant as well as unpredictable in a way that uncertainty cannot be set aside. Therefore, it fits into the definition of an alluvial fan flooding hazard. However, it is also acknowledged that this hazard seems different in degree than the areas nearer the apex. Consequently, the suggestion arises for a possible differentiation of types or degrees of alluvial fan flooding hazards that should be considered.

Summary

The 1997 flood on Tiger Wash highlighted the fact that surface age alone is not a sufficient indicator of stability and consequently the type or degree of flood hazard on alluvial fans. Position is also very important. The NRC report points this out (NRC, 1996, p. 43-45). Areas adjacent laterally and/or downstream of active alluvial fans can be subject to alluvial fan flooding in the near future whether they have been in the geologic past IF lateral relief is minimal. Where laterally and how much vertically is sufficient distance to preclude future alluvial fan flooding in engineering time scales remains a difficult question to answer. The *PFHAM* provides many useful guidelines and resources to help answer these questions. However, the value of detailed topographic data cannot be understated if precise definition of the limits of the alluvial fan hazards is desired. Without such detailed topographic data, reasonable definitions of the bulk of the flood hazard area can still be accomplished. However, areas laterally adjacent to active alluvial fans should be examined carefully. Similarly, erosion hazards downstream in areas dominated by sheet flooding should be considered. The predominance of fine-grained sediments and steep slopes creates a situation ripe for the formation of new channels, significant local scour, and aggradation.

Another significant question in the identification of the flood hazard, as well as the stability analysis, is what is the (appropriate) time scale for these analyses? Conventionally, the flood hazard is related to the one percent chance event. Is the 1% chance the appropriate time frame for examination of alluvial fan flooding? The NRC report (1996) points out that "although (such) flooding occurs on the active part of an alluvial fan, the fact that an area is defined as active does not mandate that it also is subject to the 100-year alluvial fan flooding." (NRC, 1996, p. 69-70). The analyses presented here attempted to identify a reasonable 1% chance flood hazard map for Tiger Wash.

Finally, the opportunity presented by infrequent large floods should not be overlooked. The results of significant floods left on piedmont surfaces can provide valuable insight to the nature and extent of alluvial fan flooding. Moreover, the evidence of such extreme floods remains present in the landscape for months and sometimes years. Good large scale color photography and field observations can lead to reasonable determination of the nature and extent of alluvial fan flooding on these piedmont surfaces. Therefore, it is recommended that future large floods on piedmonts be documented.

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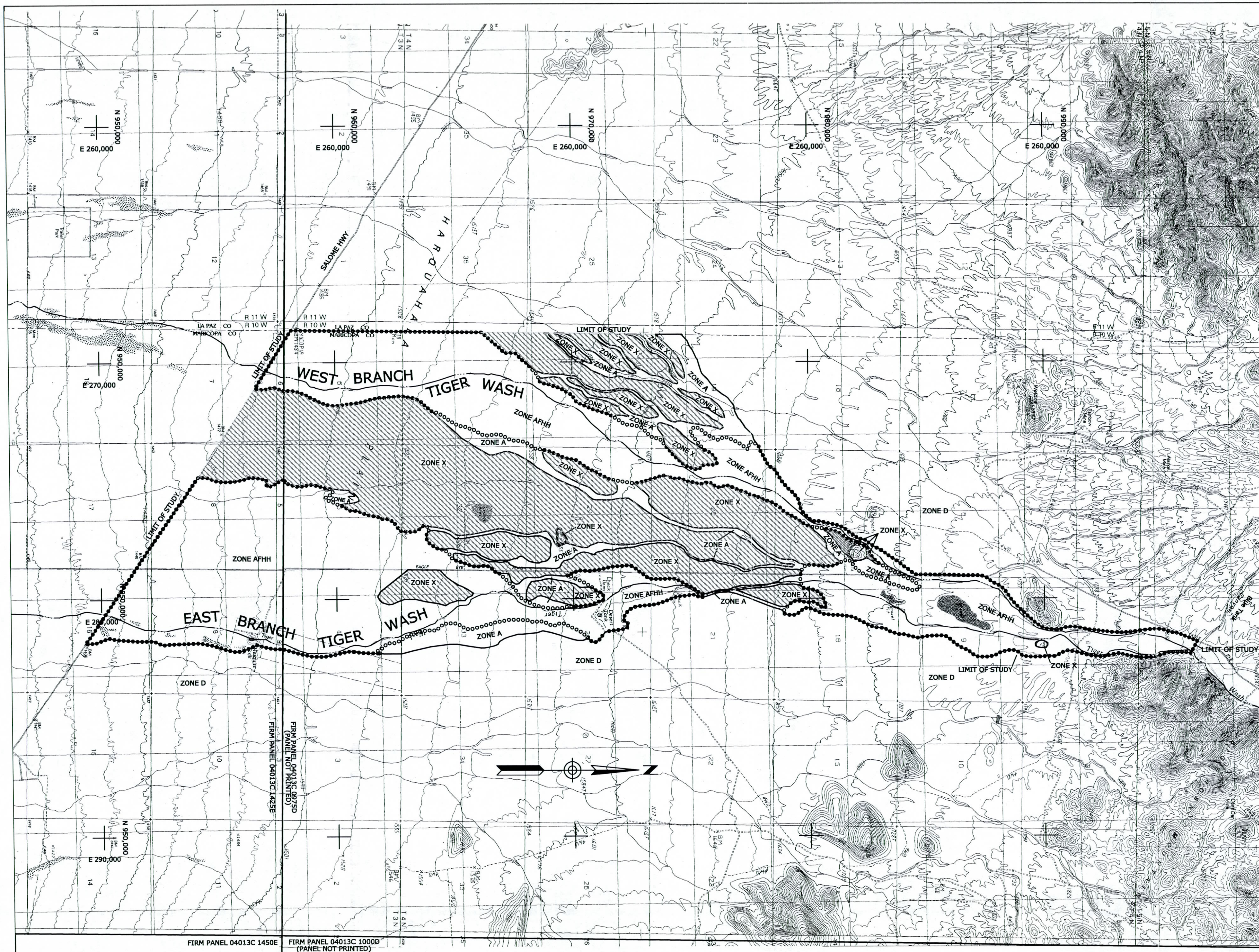


FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

TIGER WASH APPROXIMATE FLOODPLAIN DELINEATION STUDY

FCD 98-48
ASSIGNMENT NO. 1

FLOODPLAIN MAP

DRAFT

SEPTEMBER, 1999

LEGEND

ZONE A

ZONE AFHH

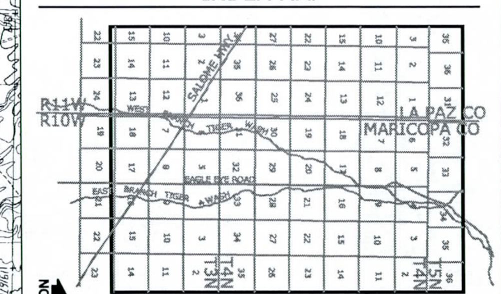
ZONE X

ZONE X (SHADED)

NOTES

1. USGS DIGITAL RASTER GRAPHICS PROJECTED TO STATEPLANE NORTH AMERICAN DATUM OF 1983 AND TILED BY FCDMC.
2. ALL ELEVATIONS ARE BASED ON NATIONAL GEODETIC VERTICAL DATUM OF 1929

INDEX MAP



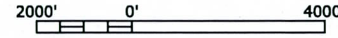


FIGURE 1
APPROXIMATE FLOODPLAIN DELINEATION

BY

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DESIGN CHK.	JEF	9-99	
PLANS	TWL	9-99	APPROVED BY: DATE
PLANS CHK.	BRI	9-99	CHIEF ENGINEER AND GENERAL MANAGER
SUBMITTED BY: DATE:			SHEET 4 OF 4

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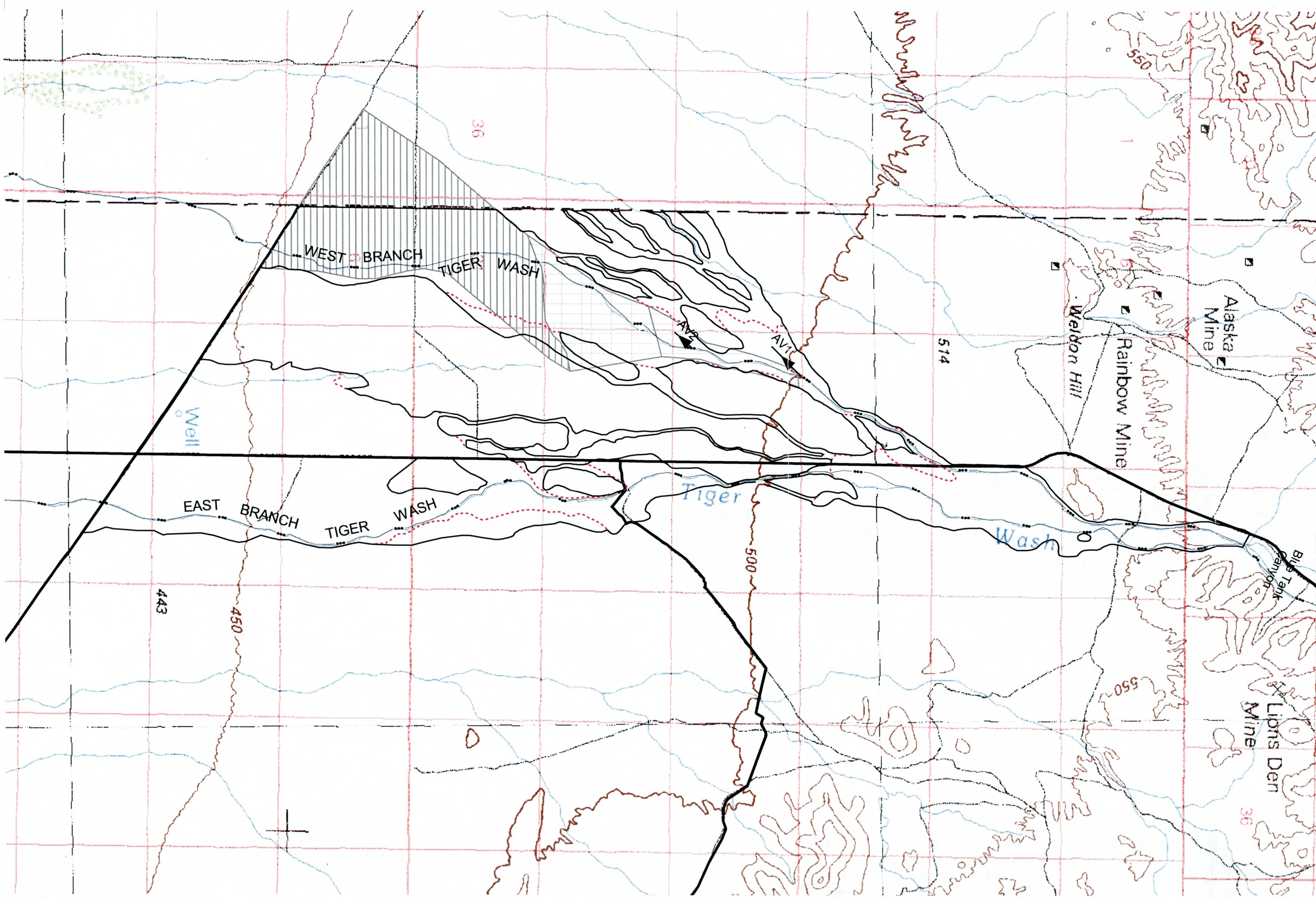
FCD 98-48
ASSIGNMENT NO. 2
SUBTASK 3.2-3.3



LEGEND

1999 Approximate Floodplain

Alluvial Fan High Hazard (Zone AFHH)

Floodplain Zone A

CH2M Hill (1992) Approximate Floodplain

Channelized flooding

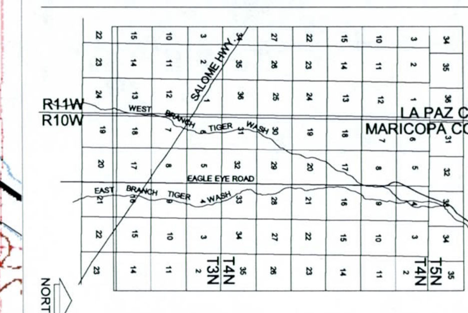
Channel & sheet flooding

Sheet flooding

NOTES

Background map source:
USGS 100,000 series Digital Raster Graphics.
Elevations in meters.

INDEX MAP



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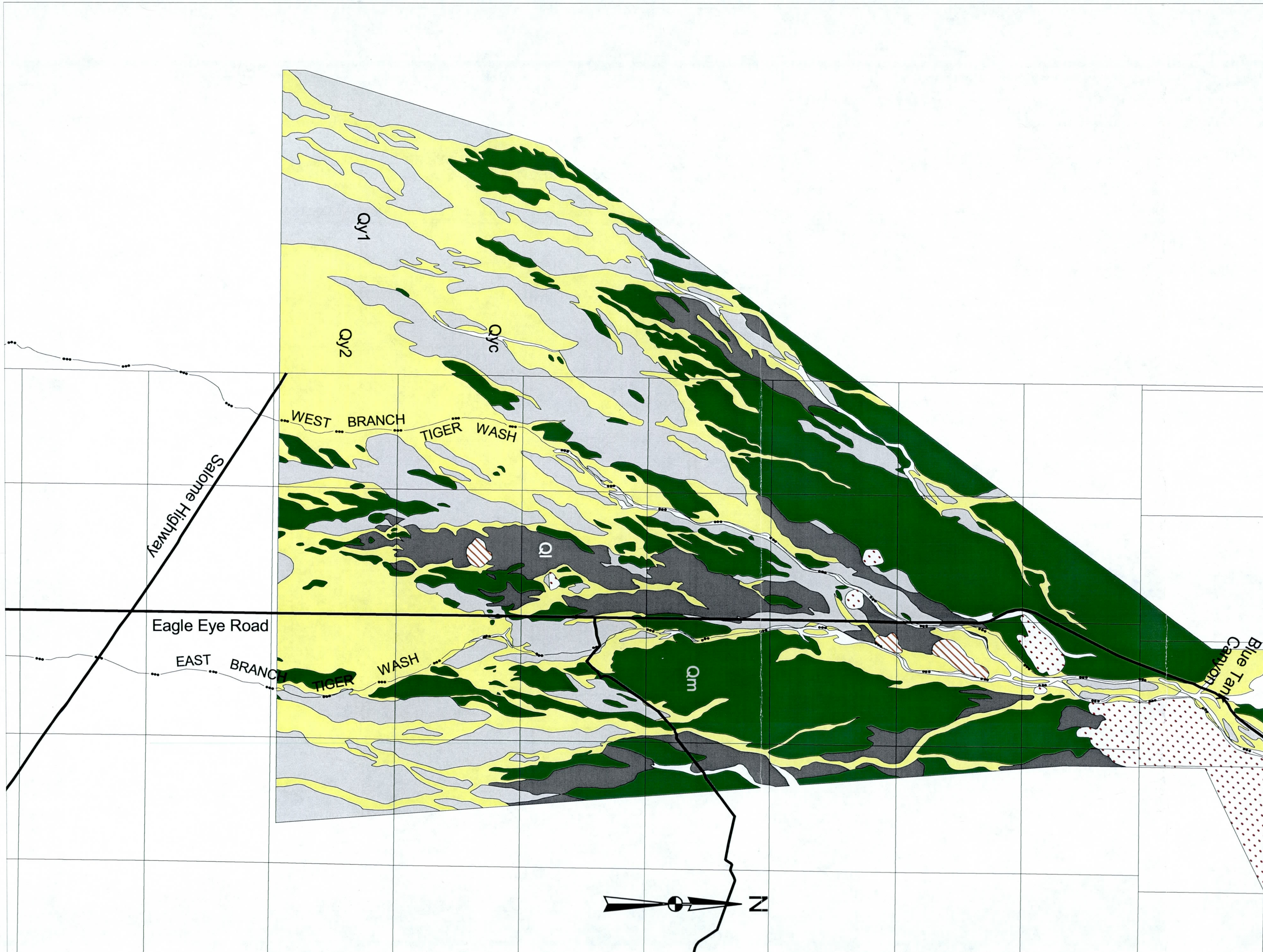
SUBMITTED BY:		DATE:	Figure 2



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

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SURFICIAL GEOLOGY MAP

LEGEND

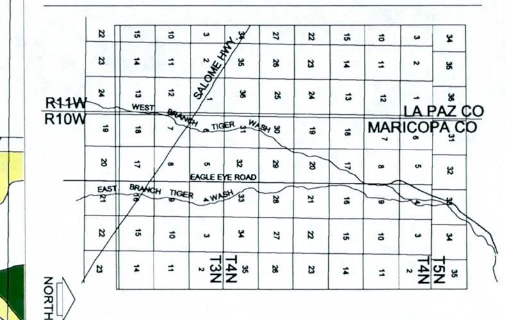
Surficial Geology

- Qyc - Late Holocene active channel deposits
- Qy2 - Late Holocene sheetflood and overbank deposits
- Qy1 - Early to late Holocene relict alluvial fan and terrace deposits
- Ql - Late Pleistocene alluvium (>10,000 years)
- Qm - Middle Pleistocene alluvial fan deposits (> 100,000 years
- R - Bedrock outcrops
- G - Gravel pits

NOTES

SURFICIAL GEOLOGY FROM: FCD 98-48, ASSIGNMENT #2
ARIZONA GEOLOGICAL SURVEY, KLAWON, J., PEARTHREE, P.

INDEX MAP



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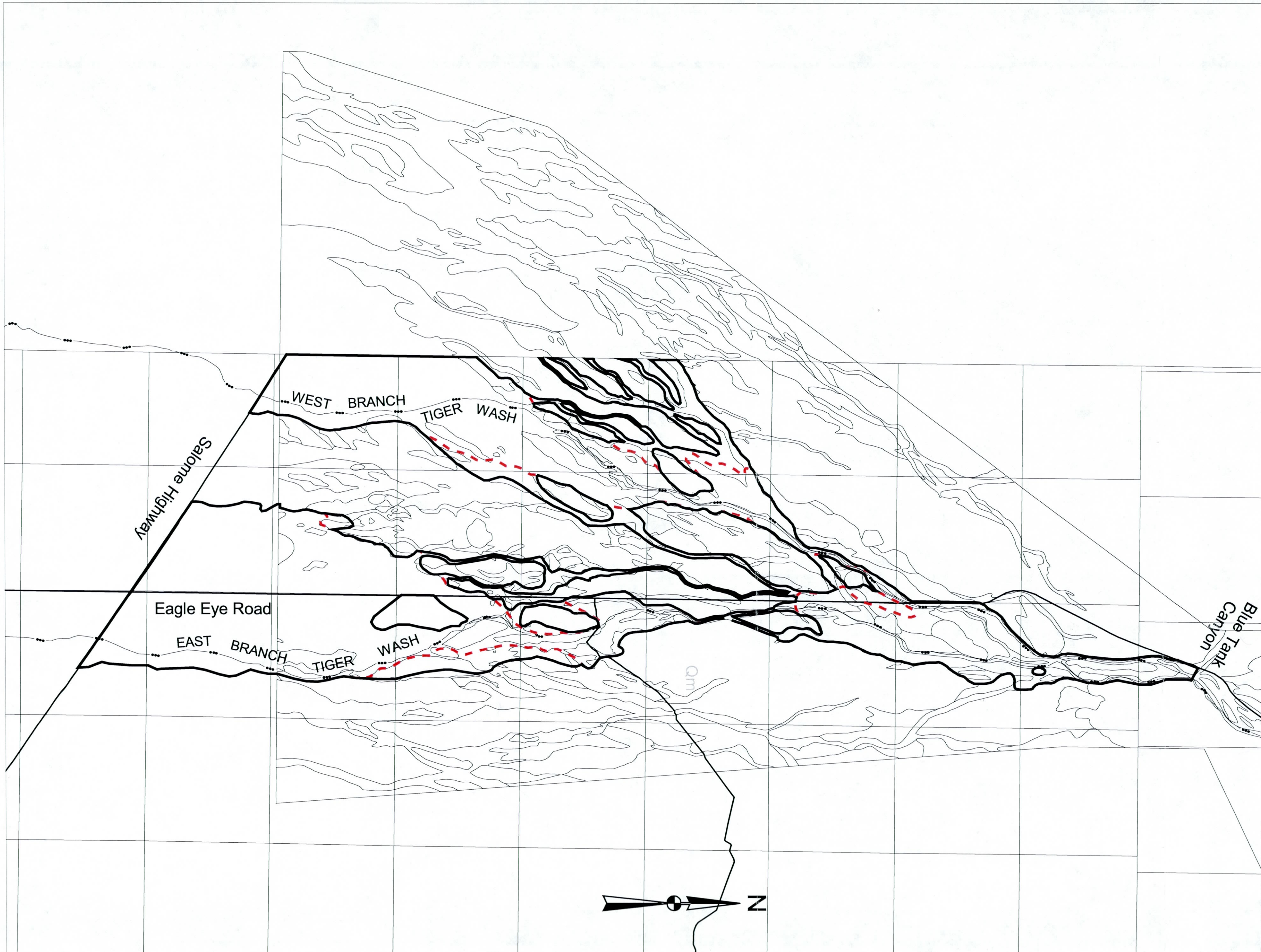
APPROVED BY: DATE

CHIEF ENGINEER AND GENERAL MANAGER

Figure 3



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SUBTASK 3.2-3.3

1999 FLOOD HAZARD ZONES AND SURFICIAL GEOLOGY

LEGEND

Surficial Geology Unit Boundaries
See Figure 3 for unit designations

Alluvial Fan High Hazard
(Zone AFHH)

Floodplain
Zone A

NOTES

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ARIZONA GEOLOGICAL SURVEY, KLAWON, J., PEARTHREE, P.

INDEX MAP

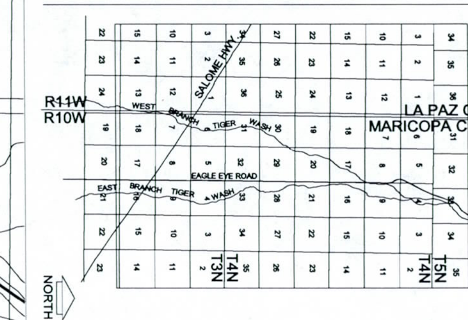

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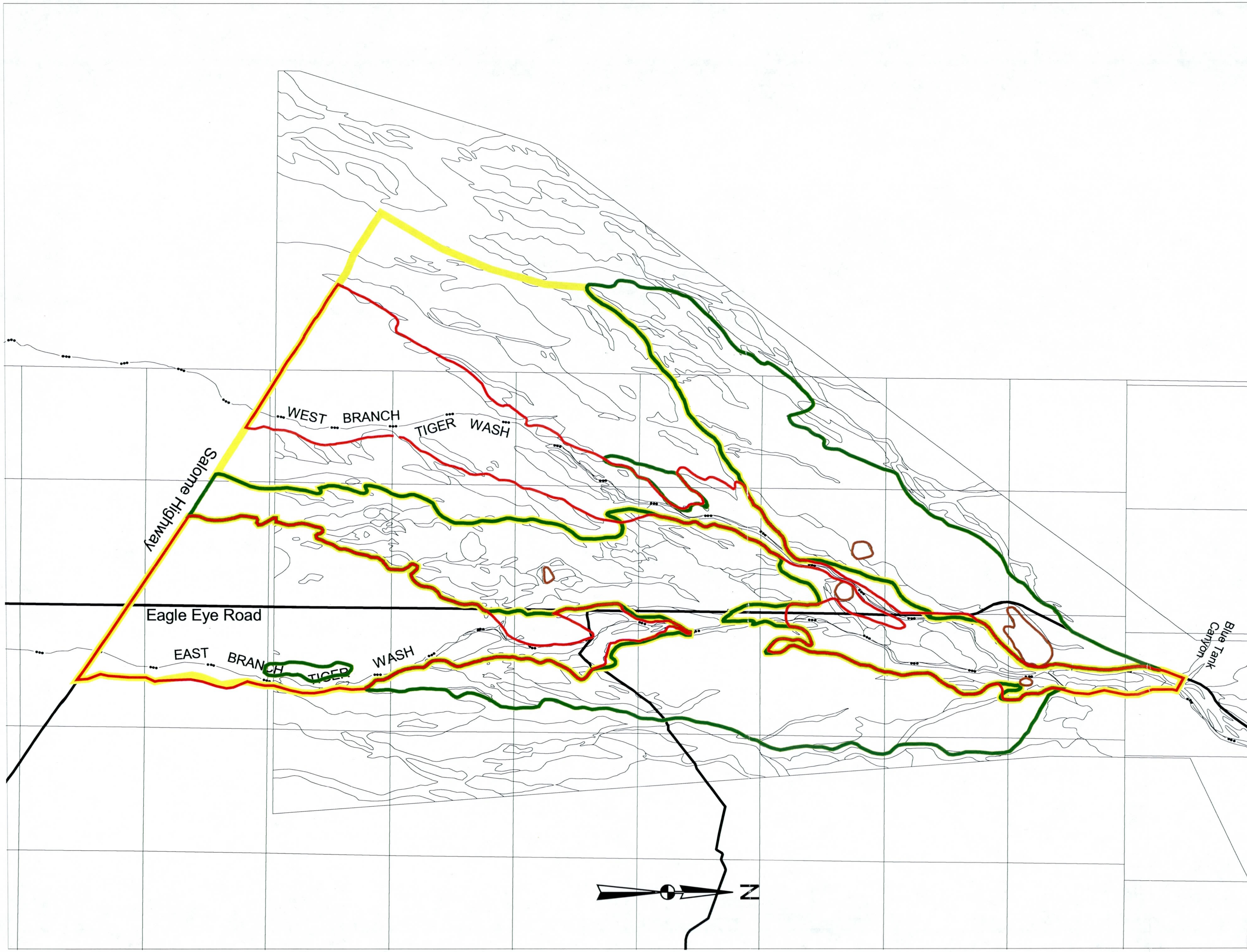
Figure 4



FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

FCD 98-48
ASSIGNMENT NO.2
SUBTASK 3.2-3.3

SURFICIAL GEOLOGY
AND LANDFORM MAP

LEGEND

Landform

Active Fan
Alluvial Fan
Relict Fan
Bedrock

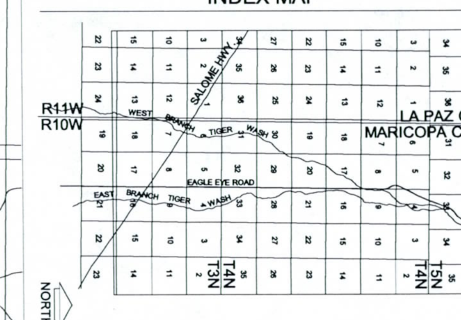
Surficial Geology

Unit boundaries.
See Figure 3 for identification.

NOTES

1. SURFICIAL GEOLOGY FROM KLAWON AND PEARTHREE (1999), FCD 98-48, ASSIGNMENT NO. 2, SUBTASK 3.1
2. LANDFORMS FROM FCD 98-48, ASSIGNMENT NO. 1, TIGER WASH APPROXIMATE FLOODPLAIN DELINEATION, TECHNICAL DATA NOTEBOOK

INDEX MAP



2000' 0' 4000'

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

	BY	DATE
DESIGN	TWL	8-99
DESIGN CHK.	JEF	8-99
PLANS	TWL	8-99
PLANS CHK.	BRI	8-99
SUBMITTED BY:		DATE:

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

RECOMMENDED BY: DATE

APPROVED BY: DATE

CHIEF ENGINEER AND GENERAL MANAGER

Figure 5

Figure 6. 1999 aerial photograph of portion of the Tiger Wash piedmont along the West Branch. AV2 is the wide bright channel about one inch from the upper right corner of the photo. New channels formed by the 1997 flood along the west margin of the active alluvial fan into older surfaces are shown at locations A, B, and C. The ground photos shown in Figure 7a and 7b are at the upstream end of the new channel at location C and B respectively.

Figure 7a. View downstream of new channel formed at location C shown in Figure 6.

Figure 7b. Ground photograph near upstream end of new channel at location B in Figure 6. Note old, reddish Pleistocene surface upon which person is standing.

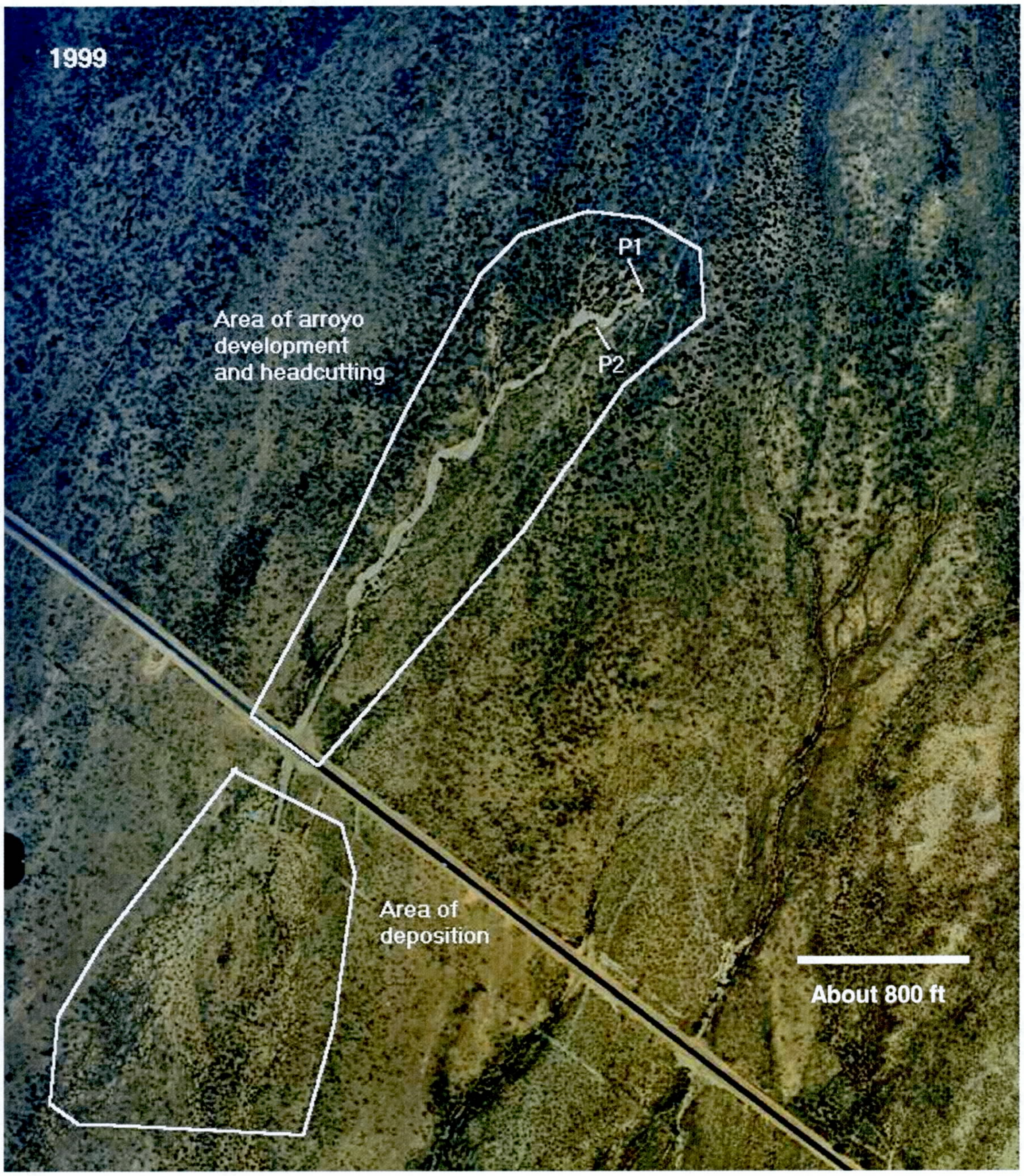


Figure 8a. Aerial photograph from 1999 of area of lower piedmont of West Branch of Tiger Wash. Approximate length of arroyo development area is 2,400 feet. P1 and P2 refer to photos 1 and 2 shown in Figures 7a and 7b respectively. The roadway is the Salome Highway and the arroyo intersects the road almost exactly at the county boundary.

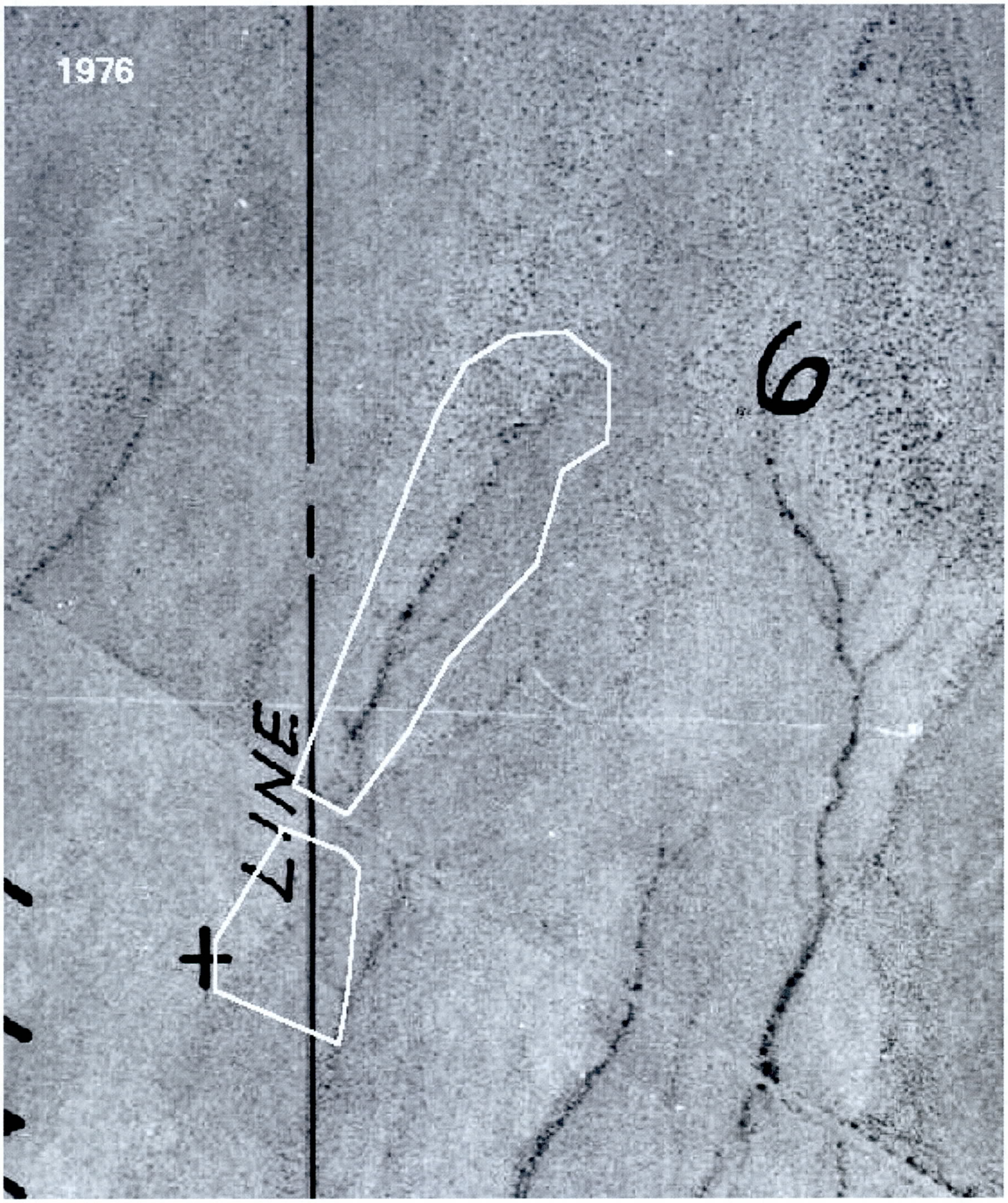


Figure 8b. Aerial photograph from 1976 of portion of lower piedmont on the West Branch of Tiger Wash. Areas in white approximately match areas of arroyo development and deposition shown in Figure 8a.

Figure 9a. Ground photo of headcutting near upstream end of arroyo shown as P1 in Figure 8a.

Figure 9b. Ground photo of imminent stream piracy along arroyo shown at P2 in Figure 8a. Also note depth of incision is more than 4 feet.