ADOBE
DAM/DESERT
HILLS

AREA DRAINAGE MASTER PLAN

Part 5

Sedimentation Engineering and Geomorphology Evaluation

Flood Control District of Maricopa County

September 2003

Part 5

Sedimentation Engineering and Geomorphology Evaluation

JE Fuller Hydrology & Geomorphology, Inc.
6101 S. Rural Road, Suite 110
Tempe, AZ 85283
(480) 752-2124
www.jefuller.com

Registered Geologist
CERTIFICATE NO.
38732
JONATHAN E.
FULLER
Date Signed 9/29/03
ARIZONA U.S.A.

Registered Professional Engineer (Civil)
CERTIFICATE NO.
26846
JONATHAN E.
FULLER
Date Signed 9/29/03
ARIZONA U.S.A.

TABLE OF CONTENTS

Section 1: Introduction

1.1 Objectives

The major objectives of the Adobe Dam/Desert Hills Area Drainage Master Plan (Adobe ADMP) included the following:

- Quantify selected drainage, flooding, and erosion hazards within the project area.
- Alleviate potential flood and erosion damage within the watershed by mitigating the expected increase in runoff due to development and preserving the ability of the primary wash corridors to convey stormwater.
- Couple watershed management tools with recently adopted Watercourse Master Plan corridor management tools developed for Apache Wash, Paradise Wash, Desert Hills Wash, Skunk Creek and Sonoran Wash.
- Develop a plan that area floodplain managers, municipalities, and developers will use as a basis for drainage and watershed regulation, improvements, and design.
- Identify cost-effective, sustainable flood and erosion control solutions for the project area.

The sedimentation engineering and geomorphic evaluation is a key component of the Adobe ADMP. The primary objective of the sedimentation engineering and geomorphic evaluation was to provide a qualitative assessment of potential erosion and scour for the significant streams in the Adobe ADMP watershed to better facilitate the overall project goals itemized above.

This analysis was performed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) for the Flood Control District of Maricopa County (District) under Task 2.7 of contract FCD 2002C001.

1.2 Stream Reaches

The stream network in the study area is shown in Figure 1-1, with the small tributaries shown on Figure 3-1 and Exhibit 3-1. The following stream reaches were specifically considered in the sedimentation engineering and geomorphic analysis summarized in this report:

- Buchanan Wash, Skunk Creek to study limit
- CAP Tributary West Branch, CAP to study limit
- CAP Tributray East Branch, CAP to study limit
- Sonoran Wash, Skunk Ck to CAP
- Skunk Creek, New River Road to study limit (Tonto National Forest)
- Skunk Creek, Adobe Dam to I-17

TABLE OF CONTENTS

Section 1: Introduction

1.1 Objectives

The major objectives of the Adobe Dam/Desert Hills Area Drainage Master Plan (Adobe ADMP) included the following:

- Quantify selected drainage, flooding, and erosion hazards within the project area.
- Alleviate potential flood and erosion damage within the watershed by mitigating the expected increase in runoff due to development and preserving the ability of the primary wash corridors to convey stormwater.
- Couple watershed management tools with recently adopted Watercourse Master Plan corridor management tools developed for Apache Wash, Paradise Wash, Desert Hills Wash, Skunk Creek and Sonoran Wash.
- Develop a plan that area floodplain managers, municipalities, and developers will use as a basis for drainage and watershed regulation, improvements, and design.
- Identify cost-effective, sustainable flood and erosion control solutions for the project area.

The sedimentation engineering and geomorphic evaluation is a key component of the Adobe ADMP. The primary objective of the sedimentation engineering and geomorphic evaluation was to provide a qualitative assessment of potential erosion and scour for the significant streams in the Adobe ADMP watershed to better facilitate the overall project goals itemized above.

This analysis was performed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) for the Flood Control District of Maricopa County (District) under Task 2.7 of contract FCD 2002C001.

1.2 Stream Reaches

The stream network in the study area is shown in Figure 1-1, with the small tributaries shown on Figure 3-1 and Exhibit 3-1. The following stream reaches were specifically considered in the sedimentation engineering and geomorphic analysis summarized in this report:

- Buchanan Wash, Skunk Creek to study limit
- CAP Tributary West Branch, CAP to study limit
- CAP Tributray East Branch, CAP to study limit
- Sonoran Wash, Skunk Ck to CAP
- Skunk Creek, New River Road to study limit (Tonto National Forest)
- Skunk Creek, Adobe Dam to I-17

- King Well Wash, Skunk Creek to study limit
- Skunk Creek Tributary 6C, Skunk Creek to study limit
- Skunk Creek Tributary 10A, Skunk Creek to study limit
- Skunk Creek Tributary 12, Skunk Creek to study limit (Tonto National Forest)
- Shoemaker Spring Wash, Skunk Creek to study limit (Tonto National Forest)
- Desert Hills Wash, City of Phoenix boundary to study limit
- Desert Hills Wash Tributary 1, Desert Hills Wash to study limit
- Desert Hills Wash Tributary 2, Desert Hills Wash to study limit
- Desert Hills Wash Tributary 3, Desert Hills Tributary #4 to study limit
- Desert Hills Wash Tributary 4, Desert Hills Wash to study limit
- Desert Hills Wash Tributary 5, Desert Hills Wash to study limit
- Desert Hills Wash Tributary 6, Desert Hills Wash to study limit
- Desert Hills Wash Tributary 7, Desert Hills Wash to study limit
- Desert Lake Wash, Desert Hills Wash to study limit
- Desert Lake Wash Tributary 2, Desert Lake Wash to study limit
- East Fork Desert Lake Wash, Desert Lake Wash to study limit
- Apache Wash, Carefree Highway to study limit
- Apache Wash Tributary 1, Apache Wash to study limit
- Apache Wash Tributary 2, Apache Wash to study limit
- Apache Wash Tributary 3, Apache Wash to study limit
- Apache Wash Tributary 4, Apache Wash to study limit
- Apache Wash Tributary 5, Apache Wash to study limit
- Apache Wash Tributary 6, Apache Wash to study limit
- Apache Wash Tributary 7, Apache Wash to study limit
- West Fork Apache Wash, Apache Wash to study limit
- West Fork Apache Wash Tributary 1, West Fork Apache Wash to study limit
- West Fork Apache Wash Tributary 2, West Fork Apache Wash to study limit
- Paradise Wash, Carefree Highway to study limit
- Paradise Wash West Branch, Carefree Highway to study limit
- Ranieri Tank Wash, Paradise Wash to study limit
- Ranieri Tank Wash Tributary 1, Paradise Wash to study limit
- Ranieri Tank Wash Tributary 2, Paradise Wash to study limit
- Cline Creek, Skunk Creek to study limit (Tonto National Forest)
- Cline Creek Tributary X5, Cline Creek to study limit
- Cline Creek Tributary X4A, Cline Creek to study limit
- Cline Creek Tributary X4B, Cline Creek Tributary X4A to study limit
- Cline Creek Tributary C6, Cline Creek to study limit
- Cline Creek Tributary X3, Cline Creek Tributary C6 to study limit
- Cline Creek Tributary X2, Cline Creek Tributary C6 to study limit
- Cline Creek Tributary C8, Cline Creek Tributary C6 to study limit

Several other significant streams located in the Adobe ADMP study area are not listed above, because they have been previously studied by the District. These streams include Skunk Creek from the CAP to the New River Road Bridge, Sonoran Wash, Rodger Creek, and Skunk Tank Wash. For this report, information on previously studied streams will be presented only with respect to the planning aspects of the ADMP, and citations to the appropriate reports will be provided within the each discussion.

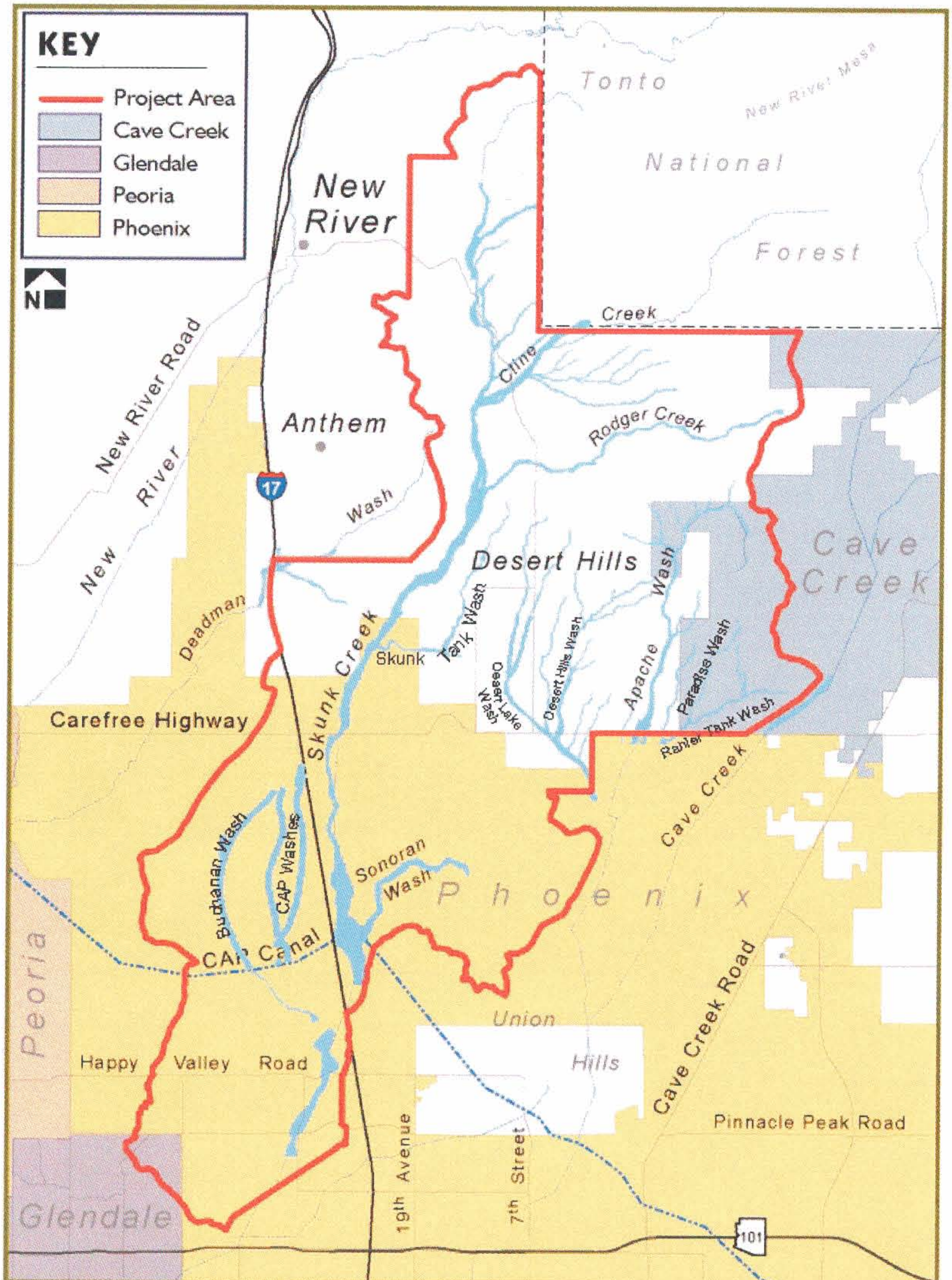


Figure 1-1. General location map for Adobe ADMP study area stream network.

The stream names listed above were obtained from existing floodplain delineation studies wherever possible. However, during the course of the study, it became apparent that a variety of names had been used for some stream segments in the study area, and that the tributaries to main stem streams in the Desert Hills areas had been incorrectly labeled on early internal work products. These incorrect tributary names were used on field notes and field forms used in the geomorphic assessment. Streams with multiple names are listed in Table 1-1.

Table 1-1.
Correlation of Stream Names Used in Adobe ADMP, Floodplain Studies, and Field Notes

Adobe ADMP Stream Name	FDS Stream Name	Stream Name Used in Geomorphology Field Notes
Apache Wash (u/s of Tributary #7)		Apache Wash Tributary #7
Apache Wash Tributary #1		Apache Wash Tributary #1
Apache Wash Tributary #2		Apache Wash Tributary #2
Apache Wash Tributary #3		Apache Wash Tributary #3
Apache Wash Tributary #4		West Branch Apache Wash
Apache Wash Tributary #5		Apache Wash Tributary #4
Apache Wash Tributary #6		Apache Wash Tributary #5
Apache Wash Tributary #7		Apache Wash Tributary #6
Apache Wash West Fork		Apache Wash West Branch Tributary #2
Apache Wash West Fork Tributary #1		Apache Wash West Branch Tributary #1
Desert Hills Tributary #1		Desert Hills Tributary #6
Desert Hills Tributary #2		Desert Hills Tributary #5
Desert Hills Tributary #3		Desert Hills Tributary #4 South
Desert Hills Tributary #4		Desert Hills Tributary #4 North
Desert Hills Tributary #5		Desert Hills Tributary #3
Desert Hills Tributary #6		Desert Hills Tributary #2
Desert Hills Tributary #7	Unnamed Wash (Stanley, 1999)	Desert Hills Tributary #1
Desert Lake Wash	Jonathan Wash (JRJ, 1993)	Jonathan Wash West Branch
Desert Lake Wash East Fork		Desert Hills Wash West Branch
Desert Lake Wash Tributary #2	Jonathan Wash (JRJ, 1993)	Jonathan Wash East Branch
King Well Wash	Skunk Creek Tributary #6B (SLA, 2000)	King Well Wash (#6B)
Paradise Wash West Fork		Left Branch Paradise Wash
Ranieri Tank Wash Tributary #3	Ranieri Tank Tributary #3 (Stanley, 1999)	Ranieri Tank Wash (u/s of Tributary #3)
Shoemaker Spring Wash	Skunk Creek Tributary #10B (SLA, 2000)	Shoemaker Spring Wash (#10B)

Note:
1. Blank fields indicate no change in name from ADMP & FDS.

1.3 Report Overview

The sedimentation engineering and geomorphic evaluation report consists of the following sections:

- Section 1. Introduction
- Section 2. Existing Conditions Assessment
- Section 3. Erosion Hazard Zones
- Section 4. Sediment Yield
- Section 5. Development Guidelines

Section 2: Existing Conditions Assessment

An assessment of existing watershed and stream channel conditions (Task 2.7.1) was conducted using field observations, interpretation of aerial photographs and topographic mapping, and consideration of existing studies. The objective of the existing conditions assessment was to evaluate the sedimentation and erosion characteristics of the main watercourses in the study area and identify problem areas for incorporation into the drainage master plan. The existing conditions analysis focused on the following elements:

- Identifying stream reaches with historical or recent long-term degradation or aggradation
- Identifying stream reaches with historical or recent lateral instability or stability
- Identifying sedimentation problems at road crossings or hydraulic structures
- Identifying stream responses to watershed and stream corridor development
- Identifying points of natural grade control along significant watercourses
- Identifying existing sediment sources in the watershed

This report directly addresses the tributaries to Skunk Creek and the streams in the Apache Wash watershed north of the Carefree Highway or west of the City of Phoenix boundary. An existing conditions assessment of Skunk Creek and Sonoran Wash was included in the *Skunk Creek/ Sonoran Wash Watercourse Master Plan – Attachment 6: Lateral Stability Assessment* (JEF, 2001). Existing sedimentation and erosion conditions for Rodger Creek and Skunk Tank Wash were discussed in the *Rodger Creek Erosion Hazard Study* (JEF, 2001) and the *Skunk Tank Wash Erosion Hazard Study* (JEF, 2000), respectively. An existing conditions assessment of Apache Wash, Paradise Wash, and Desert Hills Wash downstream of the City of Phoenix boundary was presented in the *Upper Cave Creek/Apache Wash Lateral Migration Report* (JEF, 2000).

2.1 Evidence of Long-Term Degradation or Aggradation

Long-term degradation occurs due to changes in base level or due to decreased sediment supply relative to runoff. Field evidence of long-term degradation includes undercut bank vegetation, leaning or fallen bank vegetation, high or multiple terraces, abundant cutbanks, headcutting, armoring, perched channels, and excessive erosion at structures. The two most common natural barriers to long-term degradation include bedrock and armoring by coarse bed material. Long-term aggradation occurs when the sediment supply exceeds the sediment transport capacity due to excessive upland erosion, channel obstructions, or flow attenuation and infiltration. Field evidence of aggradation includes loss of channel capacity relative to adjacent reaches, decreasing bank heights, distributary or braided channel patterns, buried vegetation, and minimal topographic relief across the floodplain. The following trends in degradation and aggradation were identified:

- Upper Skunk Creek & Tributaries. The Upper Skunk Creek Tributaries include Rodger Creek, Cline Creek and its tributaries, Shoemaker Spring Wash, King Well Wash, and Skunk Creek Tributaries 6, 10, and 12. On average, the tributary streams in the Upper Skunk Creek watershed are stable or slightly degradational. The smaller tributary streams are generally more in an equilibrium condition, except for localized reaches that have been significantly altered by development. Because the disturbance is relatively recent and few large floods have occurred, the expected response to disturbance is not apparent in the field. Based on channel responses to disturbance elsewhere along Skunk Creek, the likely response is degradation. Bedrock crops out in the beds of many of the Upper Skunk Creek tributaries, effectively limiting the potential for long-term degradation.

- Skunk Creek. The main stem of Skunk Creek between the CAP overchute and New River Road has experienced up to four feet of long-term degradation over the past century (JEF, 2001), except where structure impacts overwrite the general trend in the reach, as noted later in this section. Immediately upstream of the CAP, some long-term aggradation has occurred in the backwater area upstream of the CAP overchute. Downstream of the CAP, relatively recent channelization and grading of Skunk Creek obscures any field evidence of aggradation or degradation. Large drop structures/grade controls were constructed at the I-17 overpass, at the CAP overchute, and upstream of Pinnacle Peak Road. No evidence of significant long-term degradation between the grade control structures was observed downstream of the CAP. Some local aggradation occurs in Skunk Creek downstream of the I-17 Bridge near the channelized reach adjacent to the Landfill where dense vegetation on the channel bottom slows velocities and traps sediment. Such aggradation may reduce channel capacity if it is not removed or maintained.

- Sonoran Wash. Sonoran Wash has experienced up to two feet of long-term degradation (JEF, 2001), although future long-term degradation will be limited by bedrock outcrops and armoring in bouldery riffles. Immediately upstream of the CAP overchute, Sonoran Wash is aggrading due to backwater ponding at the CAP overchute. Immediately downstream of the CAP overchute, some long-term degradation has occurred.

- Apache Wash System. No evidence of significant long-term degradation or aggradation was observed in Apache Wash or its tributaries, including Paradise Wash and Ranieri Tank Wash. Evidence of minor long-term degradation on the main stem of Apache Wash is shown in Figure 2-1. Grade control is provided by numerous culverts and paved dip crossings along Apache Wash and its tributaries. Near the headwaters of Apache Wash upstream of Desert Hills Drive, bedrock crops out in the bed in some reaches and provides permanent grade control.

- Desert Hills Wash System. The foothills reaches of Desert Hills Wash and Desert Lake Wash are well-defined, incised, and slightly degradational. Downstream of about Joy

Ranch Road, these streams become less well defined, lose capacity, and transition to distributary and sheet flow channel patterns that are more subject to aggradation. Downstream of Carefree Highway to the Apache Wash confluence, Desert Hills Wash has incised about six feet (JEF, 2000), with evidence of about one foot of historically recent long-term degradation, although paved dip crossings now provide some degree of grade control in this reach.

- Buchanan Wash. Near their headwaters, Buchanan Wash and the two CAP tributaries are non-incised streams best described as broad swales. However, headcuts located upstream of the CAP near stock ponds appear to be moving upstream and will result in minor incision of the floodplain swale geometry at some point in the future. Downstream of the stock ponds, Buchanan Wash has an incised channel up to six feet deep that gradually becomes less incised near the CAP. Channel incision may be related to sediment discontinuities caused by the stock ponds, or by failure of the stock ponds. Currently, incision extends several hundred meters upstream of the stock ponds and ends at very small headcuts. Downstream of the CAP, Buchanan Wash experiences local aggradation, particularly near obstructions caused by channelization or road crossings.

Summary: For existing conditions, long-term degradation or aggradation generally has not been significant on the watercourses in the study area. Local degradation and aggradation has occurred at some structures. Possible aggradation in Skunk Creek downstream of I-17 is a significant concern and should be investigated in more detail. Headwater reaches tend to be slightly degradational. Streams located in the Desert Hills region of the study area between Joy Ranch Road and the Carefree Highway have some potential for long-term aggradation, though future development may encroach the naturally broad floodplains and alter the natural tendency for aggradation. Sediment maintenance should be adequately addressed for design of structural alternatives and road crossings in this area.

Field photographs showing evidence of long-term or local aggradation or degradation are shown in Figures 2-1 to 2-8. Table 2-1 lists field observations with respect to aggradation and degradation and other geomorphic parameters. Table 2-4 lists specific sites with sedimentation-related problems.

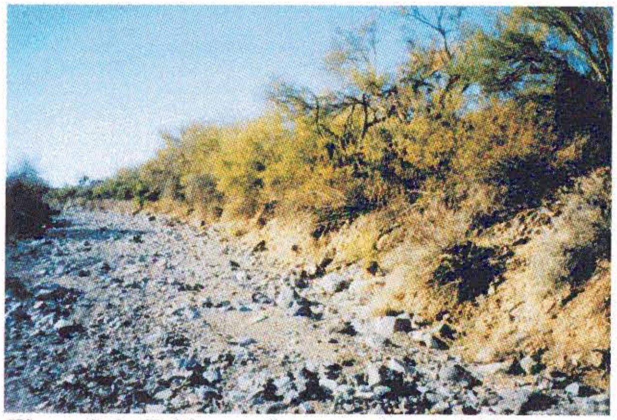


Figure 2-1. Evidence of recent minor (~1 ft.) long-term degradation on Apache Wash. Note unvegetated, oversteepened toe of right bank and incipient bed armoring.

Figure 2-2. Minor incision and bank erosion on Desert Lake Wash.

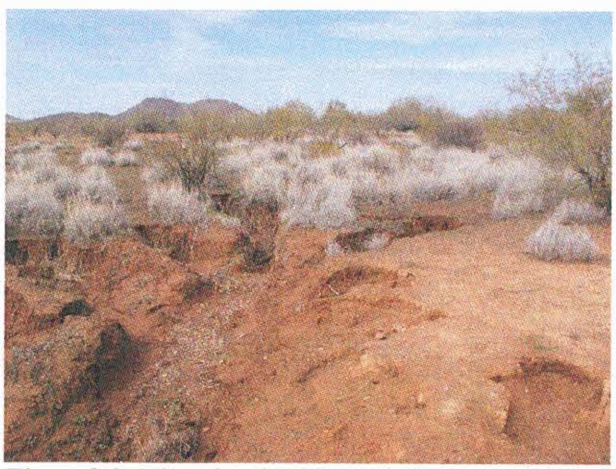


Figure 2-3. Minor headcutting upstream of CAP ponding area on CAP Wash West Branch.

Figure 2-4. Upstream limit of minor headcut incision on CAP Wash West Branch at transition to non-incised reach.

Figure 2-5. Cobbles buried by fine-grained alluvium in non-incised Buchanan Wash headwater reaches upstream of the CAP.

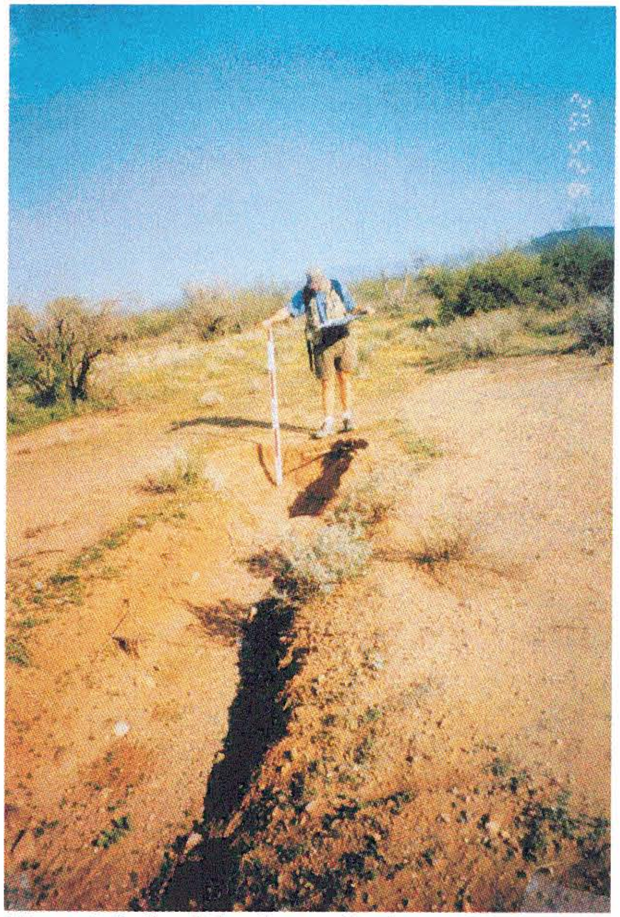


Figure 2-6. Small headcut on Buchanan Wash between stock ponds & non-incised reach.

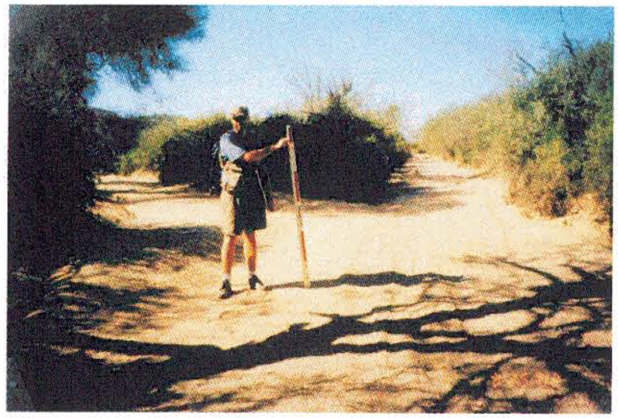


Figure 2-7. Hanging tributary on Buchanan Wash upstream of CAP & downstream of stock ponds.

Figure 2-8. Long-term degradation (~3 ft) and resulting lateral erosion on Buchanan Wash between stock ponds and CAP.

2.2 Evidence of Lateral Instability or Stability

Lateral stability assessments for each of the major watercourses in the study area are presented in Section 3 of this report. In general, historical and field evidence suggest that the Holocene floodplains of the watercourses in the study area are subject to long-term lateral erosion due to bank erosion on channel bends or channel avulsions. Field photographs of evidence of lateral erosion are shown Figures 2-9 to 2-20. A summary of field assessments of relative channel stability for each stream segment considered is shown in Table 2-1. Specific sites with lateral erosion concerns are listed in Table 2-4.

Examples of Lateral Bank Erosion

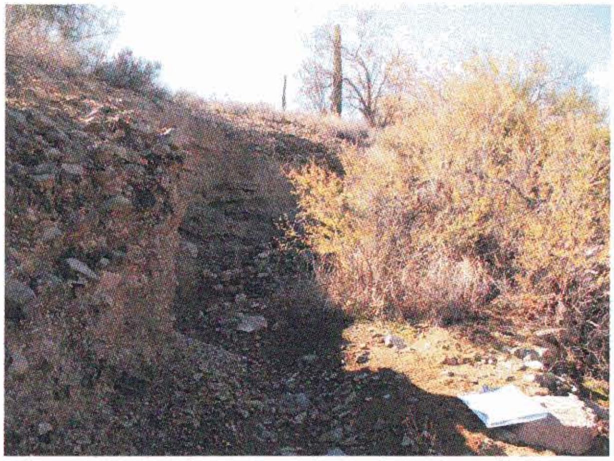


Figure 2-9. High cut bank in moderately cohesive material on Apache Wash West Fork Tributary 1.

Figure 2-12. Exposed roots and leaning bank vegetation with cut banks on King Well Wash.

Figure 2-10. Actively eroding cutbank on Upper Skunk Creek.

Figure 2-13. Erosion by block failure erosion in caliche-cemented bank.

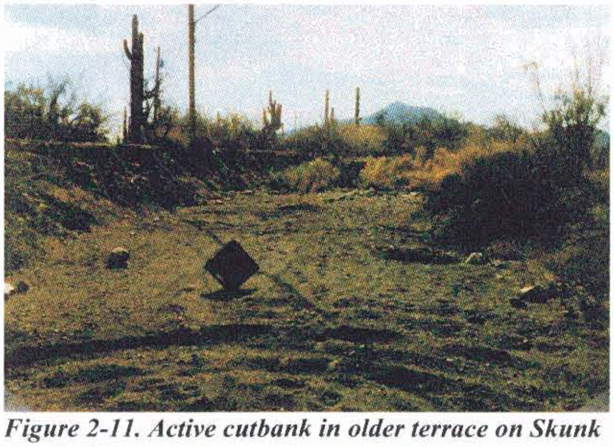


Figure 2-11. Active cutbank in older terrace on Skunk Creek. Note saguaro cacti near top of bank.

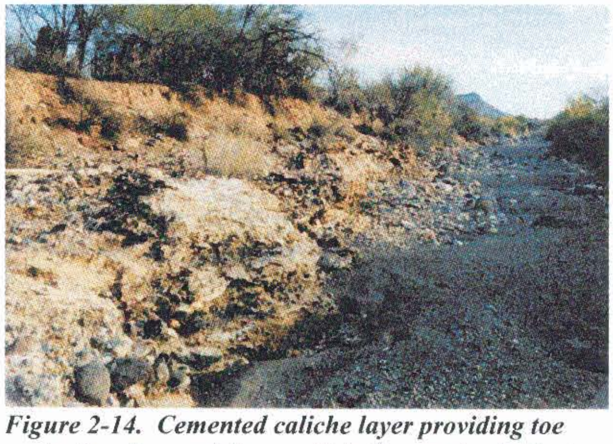


Figure 2-14. Cemented caliche layer providing toe protection for overlying erodible fine-grained alluvium on Upper Skunk Creek.

Examples of Avulsive Channel Change

Figure 2-15. Avulsive channel formation in the left overbank floodplain of Cline Creek Tributary C6.

Figure 2-17. Avulsive channel split on Skunk Creek Tributary 12.

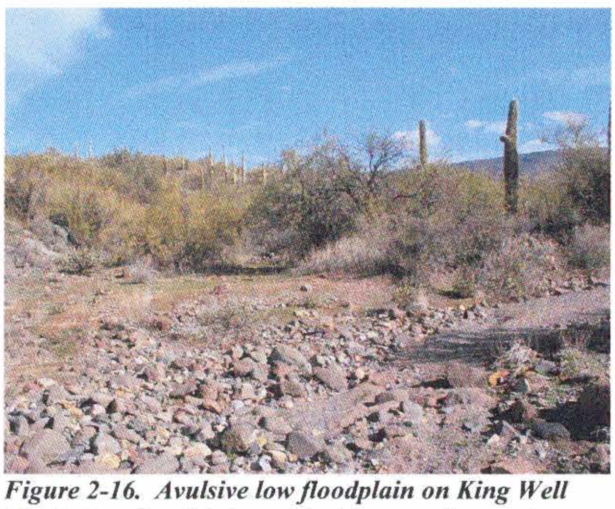


Figure 2-16. Avulsive low floodplain on King Well Wash. Low floodplains subject to more frequent inundation are prone to avulsions.

Figure 2-18. Low avulsive floodplain on Shoemaker Spring Wash.

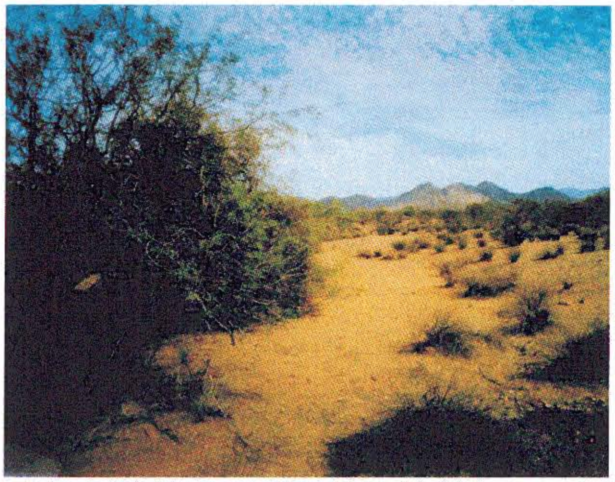


Figure 2-19. Proto-avulsive channel in right overbank of Desert Hills Wash. Note that the avulsive channel forms well outside the swath of dense riparian vegetation lining the channel banks.

Figure 2-20. Impact of bank vegetation on bank stability from partially graded site on Desert Hills Wash Tributary 6.

Table 2-1. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis
Channel Stability Field Assessment Data Summary – Percent of Observations for Given Characteristic

Stream Segment	# Xns	Degrading	Aggrading	Lateral Erosion Rate			Cohesive Banks	Avulsion Hazard	Sediment Source		
				None	Slow	Fast			Bed	Banks	Upland
Apache Wash Tributaries	16	88%	0%	9%	84%	6%	59%	19%	100%	69%	0%
Apache Wash	13	46%	8%	15%	73%	19%	35%	31%	100%	38%	0%
Desert Hills Wash Tributaries	22	91%	5%	14%	93%	27%	48%	45%	100%	5%	14%
Desert Hills Wash	14	93%	0%	7%	86%	21%	75%	54%	100%	64%	7%
Desert Lake Wash Tributaries	17	71%	29%	0%	94%	15%	71%	74%	94%	0%	53%
Desert Lake Wash	14	93%	7%	4%	82%	25%	86%	57%	100%	29%	7%
Paradise Wash Tributaries	19	32%	5%	39%	68%	0%	63%	47%	89%	0%	32%
Paradise Wash	4	100%	0%	25%	100%	0%	75%	63%	100%	100%	0%
Buchanan Wash Tributaries	4	50%	0%	50%	50%	0%	0%	100%	0%	50%	100%
Buchanan Wash	2	0%	50%	0%	100%	0%	0%	100%	100%	0%	100%
Cline Creek Tributaries	36	78%	11%	13%	78%	19%	56%	26%	86%	11%	19%
Cline Creek	4	50%	25%	0%	88%	13%	63%	63%	100%	50%	0%
Skunk Creek Tributaries	19	58%	42%	13%	71%	21%	42%	29%	100%	47%	26%
Skunk Creek	7	57%	0%	36%	86%	21%	36%	43%	100%	43%	0%
Apache Wash System	119	74%	8%	14%	84%	16%	62%	47%	97%	29%	17%
Skunk Creek System	72	65%	19%	16%	76%	18%	46%	37%	88%	28%	25%
Total Study Area	191	71%	12%	15%	81%	16%	56%	43%	94%	28%	20%

Table Codes
1. Degrading – field assessment by geomorphologist that net long-term degradation was occurring at observation point.
2. Aggrading – field assessment by geomorphologist that net long-term aggradation was occurring at observation point.
3. Lateral Erosion Rate – field assessment by geomorphologist of overall rate of lateral erosion, not including avulsions.
4. Cohesive Banks – field assessment by geomorphologist of whether bank materials were cohesive and would resist lateral erosion.
5. Avulsion Hazard – field assessment by geomorphologist of whether avulsion hazard exists in floodplain.
6. Sediment Source – field assessment of primary source of observed bed-material load.

Notes:
1. Lateral erosion rate and sediment source percentages sum to more than 100% because field crews often used combination ratings, e.g., none-slow, for intermediate sites.

In general, lateral erosion hazards in the study area occupy the entire modern floodplain, as illustrated in Figures 2-21 and 2-22. The "canyon" depth (topographic variation between floodplain and terraces) and channel pattern (sinuous single channel, braided multiple channel, distributary) varies from a few feet to up to twenty feet between stream reaches, but the general nature of the erosion hazard does not. Most channel sections are subject to avulsions over the long-term as shown by analysis of historical aerial photographs, interpretation of field evidence, soil and surficial characteristics, and topographic features. The rate of lateral migration or widening of the Holocene floodplain is quite slow, except on sharp channel bends where the main channel has cut into the older surface.

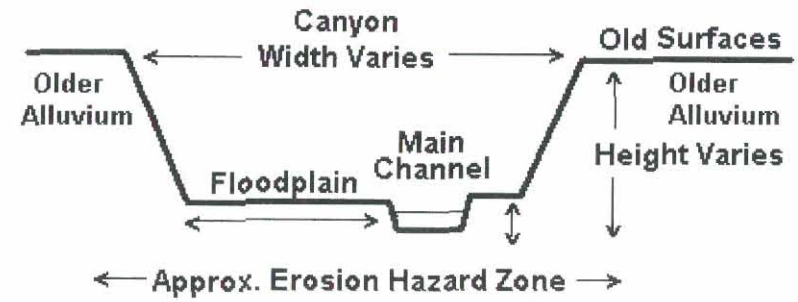


Figure 2-21. Typical channel and floodplain cross section. "Canyon" may be formed of alluvial fill material or bedrock.

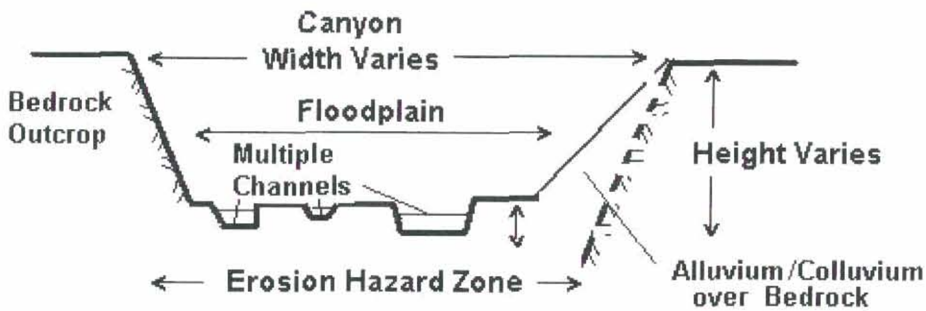


Figure 2-22. Typical cross section of multiple channel reach with floodplain in canyon formed of alluvial fill and bedrock.

Non-"canyon" reaches also exist in the study area, particularly on the Desert Lake/Desert Hills Wash system between Joy Ranch Road and Carefree Highway. In this area, topographic differences between the modern floodplain and Pleistocene surfaces are imperceptible, or no Pleistocene surface exists. In the non-canyon reaches, lateral stability is generally a function of avulsion hazard, although erosion associated with manmade flow concentration is also a concern.

Summary. Historical and field evidence indicate that lateral erosion hazards extend across the entire floodplain and the margins of older terraces in the streams in the study area. Lateral erosion of canyon walls is prevented only where the canyon is formed by bedrock. Evidence of lateral erosion considered included historical data and field observations of cut banks, avulsion channels, leaning vegetation, oversteepened banks, and scour. Lateral erosion hazards are discussed in more detail in the next section of this report.

2.3 Sedimentation Problems at Existing Structures

The sedimentation engineering and geomorphic analysis identified sedimentation problems at the following types of existing structures in the study area:

- Unpaved Dip Crossings. In general, unpaved dip crossings have few sedimentation problems since the crossing closely matches the existing channel and floodplain geometry and the elevation of the unpaved road is free to adjust with changes in the channel elevation. Unpaved dip sections observed in the study area typically had insignificant sedimentation concerns.

- Paved Dip Crossings. Paved dip crossings in the study area typically have one or more of the following local sedimentation problems:
  - Downstream Scour. Scour holes form downstream of paved dip section because of flow acceleration and increased turbulence at the transition from the paved surface to the natural channel bottom. Downstream scour can also occur when either the road surface is raised (often during road maintenance and re-surfacing), or simply because the road surface is flatter than the channel slope, both resulting an elevated sill at the downstream side. Flow over the sill creates a scour hole.
  - Upstream Deposition. If the roadway invert (or crown) is higher than the natural channel invert sediment will deposit upstream and fill to the road elevation.
  - Road Surface Deposition. If the dip section significantly widens the natural channel cross section, the flow velocity in the dip section will decrease and induce sediment deposition. If deposition occurs in the roadway, it may not only be a traffic hazard, but may also create a backwater condition in the upstream channel that increases flood elevations.

  About 24% of paved dip sections in the study area had minor downstream scour holes, with minor upstream deposition (Table 2-2). Paved dip sections on stream segments with low slopes, such as those in the lower Desert Hills Wash and Desert Lake Wash watersheds experienced sediment deposition on the road surface with upstream backwater flooding. Most paved dip crossings experience sediment deposition during floods to the degree that traffic flow was altered or maintenance is required. Differences in road crossings scour between subwatersheds were minimal (Table 2-2).

Table 2-2. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Percent of Road Crossings Experiencing Sedimentation Problems by Watershed					
Watershed	#	Upstream		Downstream	
	Observations	Scour	Scour	Scour	Deposition
Upper Skunk	38	0%	0%	26%	18%
Desert Hills	55	2%	2%	22%	27%
Apache/Paradise	24	17%	17%	13%	21%
Cline	26	0%	0%	38%	0%
Lower Skunk	10	30%	30%	20%	10%
Total Study Area	204	6%	6%	24%	22%

As shown in Table 2-3, unpaved dip sections have substantially fewer observed scour problems than paved dip sections or culverts. Dip sections typically have fewer upstream deposition or lateral migration problems than pipe culverts.

Table 2-3. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Percent of Roadway Crossings Experiencing Sedimentation Problems by Structure Type						
Structure Type	Upstream			Downstream		
	Scour	Deposition	Lateral Erosion	Scour	Deposition	Lateral Erosion
CMP Culverts	8%	45%	21%	33%	32%	24%
RCB Culverts	10%	25%	10%	15%	30%	5%
RCP Culverts	13%	50%	0%	13%	25%	13%
All Culverts	9%	42%	16%	27%	30%	19%
Paved Dips	0%	40%	13%	43%	27%	17%
Unpaved Dips	5%	4%	4%	5%	9%	5%
All Dips	3%	16%	7%	21%	12%	9%

- Undersized Culverts. Undersized culverts create backwater that induces upstream sediment deposition and downstream scour. If overtopping occurs, flow can be diverted to adjacent watersheds via the raised right-of-way. Several undersized culverts were observed in the study area, particularly on private roads.

- Oversized Culverts. Culvert sections that are wider than the natural bankfull channel dimensions will experience sediment deposition because of the reduced velocity, downstream backwater at the transition to the natural narrower section. The channel will try to reestablish the natural channel form by filling the outer culvert cells. Oversized culverts have been constructed at several of the major drainage crossings on County and State roadways such as the Carefree Highway, 7th Street, and New River Road.

- Bridges. Bridge impacts are similar to culvert impacts (too narrow or too wide), except that no grade control is provided at most bridges. There are four bridges in the study area, not including private driveway bridges. The Carefree Highway and New River Road Bridges over Skunk Creek were discussed in detail in the Skunk Creek Watercourse Master Plan Reports (JEF, 2001). The I-17 Bridge over Skunk Creek is a fully lined constructed and regularly maintained channel. The New River Road Bridge over Cline Creek is an oversized structure with no known impact on channel morphology, aside from slight constriction of the regulatory floodplain.

- Stock Ponds. Stock ponds that capture the low flow channel also capture and store the majority of the sediment load. Therefore, deltaic deposition occurs upstream of the stock pond at the inlet. If flow is released from a stock pond, it is typically deprived of sediment resulting in long-term degradation and increased lateral erosion. However, since most stock ponds are not designed to release flow except through an emergency spillway, overflows tend to have high peaks that cause significant scour. Furthermore, if stock ponds are breached or removed as development occurs around them, a pulse of fine grained sediment into the reaches immediately downstream should be expected that may reduce channel capacity, induce overbank flooding, initiate channel avulsions, or clog drainage crossing structures. Finally, failure from overtopping has occurred at least once (Skunk Tank) in the study area. Catastrophic breaches of stock tanks could cause peak flows to exceed regulatory discharges and flood homes outside or above the regulatory floodplain. Stock ponds exist through the non-urbanized portion of the study area.

- Bank Protection. Engineered bank protection exists in the most urbanized portions of the study area. Construction of bank protection sometimes results in increased lateral erosion of downstream reaches, although no such impacts were observed during the field work for this analysis. Non-engineered bank protection in various states of failure that appears to have been constructed by local homeowners occurs throughout the unincorporated parts of the study area. Common causes of failure include inadequate toe-down, flanking, poor construction practice, undersized materials, and overtopping.

- Grade Control Structures. No significant sedimentation problems were observed at the engineered grade control structures on Skunk Creek and Sonoran Wash. Small scour holes have formed at the downstream side of the some of the structures, but do not appear to have exceeded the design parameters.

- CAP Overchutes. Significant sediment deposition has occurred upstream of the CAP overchutes on Skunk Creek and Sonoran Wash (JEF, 2001). Sediment deposition upstream of the CAP has induced channel braiding, reduced channel capacity, expanded the regulatory floodplain, and caused diversion of flow into adjacent watersheds.

Specific sediment problem locations are summarized in Table 2-4.

Table 2-4. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Known Sedimentation Problem Areas		
Watercourse	**Problem Description**	**Location**
King Well Wash	Home in EHZ south of Fig Springs Road on 7th St. alignment.	7N-3E-29
Skunk Creek	Home in EHZ south of Fig Springs Road on 7th Ave. alignment. Complicated floodplain reach – may require 2d modeling.	7N-3E-30
	Four (4) homes in EHZ in Skunk Creek – King Well Wash confluence area. Complicated floodplain reach – may require detailed analysis.	7N-3E-30
	Erosion of left bank threatens local access road @ 7th Ave downstream of Fig Springs Road. Also dip crossing of Fig Springs Rd diverts flow to river right around house in floodway, utilities, local bank protection installed, several related issues of erosion, deposition and flooding	7N-3E-30
	Potential capture of King Well Wash	7N-3E-30
	New River Road Bridge to CAP - See Skunk Creek WMP	7N-3E-30
	Channelized reach downstream I-17 at landfill – potential aggradation & vegetative growth in channel limit capacity	4N-2E-2
Skunk Trib 6C	No sedimentation problems identified – some unimproved crossings	7N-3E-29
Skunk Trib 10A	No sedimentation problems identified – currently undeveloped	7N-3E-32
Shoemaker Spring	Venado Dr. - dip crossing at high skew angle, deposition in roadway	6N-3E-5
	Building 300 ft upstream of New River Road on left bank in EHZ above eroding bank. Homeowner dumping rock on bank.	6N-3E-5
	Homeowner 300 ft. downstream of New River Road placing fill on right bank in floodplain.	6N-3E-5
Skunk Trib 12	Building partially in EHZ 350 ft. upstream of New River Road.	6N-3E-5
Cline Creek	Nine (9) homes in EHZ between USFS and Skunk Creek	6N-3E-4,5
	Home west of 12th St. behind unstable levee near eroding banks	6N-3E-4
	Massive dumped fill and rock in floodway west of 7th St. & Venado Dr.	6N-3E-4
	Circle Mountain Road embankment east of New River Road unprotected – risk of erosion	6N-3E-5
	Fill dumped on right bank in floodplain and channel off Circle Mountain Road west of New River Road.	6N-3E-8
	Utility pole on erodible left bank upstream 3rd Ave.	6N-3E-8
	Fill dumped on right bank in floodplain and channel at 3rd Ave	6N-3E-8
Cline Trib X5	No sedimentation problems identified – some unimproved crossings	6N-3E-4
Cline Trib X4A	Small earthen levees downstream 10th St may divert flow	6N-3E-4
Cline Trib X4B	Channel diversion and excess grading upstream 12th St. – erosion likely Excessive grading and channel disturbance – 12th St. to Gaffney Rd.	6N-3E-4
Cline Trib X3	New home at edge of EHZ between 18th St & 16th St on right bank	6N-3E-4
	Building in EHZ avulsion area 100 ft. upstream of 14th St on right bank	6N-3E-4
Cline Trib X2	Recommend erosion protection for two homes south side Johnson Rd, one of which is in EHZ.	6N-3E-3
	Recommend erosion protection for home on left bank between Johnson Rd & 20th St., 400 ft upstream of 20th St.	6N-3E-3
Cline Trib C6	Structure (home?) in EHZ 200 ft. upstream 22nd St.	6N-3E-3
	Building encroaches floodplain in EHZ 100 ft. upstream of 16th St.	6N-3E-3
	Home in EHZ on right bank 400 ft west of 16th St	6N-3E-4
Cline Trib C8	Structures in EHZ at Cline Creek confluence	6N-3E-5
	10th St. dip crossing raised on fill with no culvert – will fail	6N-3E-9
	Structure in EHZ on right bank 400 ft. downstream of 12th St.	6N-3E-9

Table 2-4. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Known Sedimentation Problem Areas

Watercourse	Problem Description	Location
	Three (3) homes in EHZ near 16th St – probably on island, access issue	6N-3E-9,10
	Home near EHZ 200 ft west of 20th St.	6N-3E-10
	Chain link fence block floodplain and main channel at 2 locations	6N-3E-10
Apache Wash	Four (4) homes in EHZ between of Desert Hills Dr. and La Salle Rd alignments - left and right banks. Mobile home on right bank in EHZ above active cut bank, dumped fill in channel.	6N-3E-23,26
	Small sand & gravel excavation ¾ mile upstream Joy Ranch Rd alignment at right angle bend	6N-3E-26
	Homeowners remove bank vegetation & place fill in main channel for horse property, will experience erosion problems. Same on right bank from Joy Ranch Road to Carlise Road alignment	6N-3E-35
	Building in EHZ on right overbank between Carlise Rd & Maddock Rd	6N-3E-35
	Structure in EHZ 100 ft downstream Old New River Rd alignment	6N-3E-35
	Two (2) homes and junkyard in EHZ upstream Cloud Rd	6N-3E-35
	Apache @ 24th Street - 24th St. in EHZ for approximately ¾ mile - 24th St. diverts flow to left channels, causing incision & widening - 24th St. divert flow from channels to right-of-way	
Apache West Fork	Home & structures in EHZ 400 ft. east of 26th St.	6N-3E-23
Apache Tribs 1-7	No sedimentation problems observed	6N-3E-23,24
Paradise Wash	Minor degradation upstream of Cloud Rd	5N-3E-2
Paradise West Branch	Home in EHZ between Cloud Rd & 28th St.	5N-3E-2
	Ranch buildings in EHZ at Maddock Rd, footbridges & small culverts block channel	6N-3E-35
Ranieri Tank Wash	Stock ponds upstream & downstream of 32nd St. change flow pattern Concrete diversion upstream of 32nd St to river right & tank New active erosion of left bank downstream of culverts	5N-3E-1
Ranieri Tank Tribs	No sedimentation problems observed	5N-3E-1
Desert Hills Wash	Future headcutting of small tributaries to Desert Hills Wash downstream of Carefree Highway – response to main stem incision	5N-3E-9
	Potential diversion along 12th St north of Carefree Hwy – widens EHZ	5N-3E-4
	Two structures in EHZ right bank 600 ft. north of Carefree Hwy	5N-3E-4
	Stock pond west of 200 ft. west of 12th St, 600 ft. downstream of Cloud Rd. – breach hazard and possible avulsion puts two homes in EHZ	5N-3E-4
	Structure in EHZ left bank 500 ft. downstream Cloud Rd	5N-3E-4
	Home in EHZ left bank downstream Cloud Rd	5N-3E-4
	Two homes in EHZ right and left bank 600 ft. upstream Cloud Rd	6N-3E-33
	Home in EHZ left bank upstream of Trib 6 confluence	6N-3E-33
Desert Hills Trib 1	Stock pond west of 14th St & south of Carefree Highway – breach risk, widens EHZ, downstream erosion	5N-3E-9
	Undersized culvert at 16th St. diverts flow to south, creates avulsion hazard & widens EHZ	5N-3E-3,4
Desert Hills Trib 2	Floodplain blocked by development upstream 14th St, expect erosion & upstream deposition	5N-3E-4
	Floodplain graded & grubbed, channel realigned & undersized from 16th St to Galvin St., expect erosion & avulsion Deposition in Galvin St., sediment maintenance dumped berm blocking channel	5N-3E-4

Table 2-4. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Known Sedimentation Problem Areas

Watercourse	Problem Description	Location
	16th St. alignment in natural channel alignment, will divert & erode outside of right-of-way	5N-3E-3
Desert Hills Trib 3	Block wall obstructs main channel and floodplain @ Delores Rd. and 18th St. alignment, diverts flow to south adjacent property	6N-3E-34
Desert Hills Trib 4	No sedimentation problems observed	6N-3E-33
Desert Hills Trib 5	No sedimentation problems observed	6N-3E-28
Desert Hills Trib 6	Home in EHZ right bank 400 ft. upstream of Joy Ranch Rd.	6N-3E-33
	Poor culvert design @ Joy Ranch Rd and driveway culverts divert flow, eroding banks of ditch along right-of-way	6N-3E-27,34
	Stock pond in main channel between 18th & 20th St widens EHZ & has upstream and downstream impacts	6N-3E-27
Desert Hills Trib 7	No sedimentation problems observed	6N-3E-27
Desert Lake Wash	Non-incised channel with sheet flow component sensitive to encroachment and diversion.	5N-3E-5
	Overwidened culvert @ 7th St.	5N-3E-5
	Low flow channel realignment at 3rd St to flow in right of way	5N-3E-5
	Home in EHZ left bank downstream Galvin St.	5N-3E-5
	Home in EHZ right bank between Leisure Ln & Restin Rd	5N-3E-5
	Wash follows Central Ave for ¼ mile upstream Restin Rd	5N-3E-5
	Four homes in EHZ downstream Cloud Rd	5N-3E-5
	Sediment deposition on Cloud Rd from overwidened dip section	5N-3E-5
	Unconfined sheet and distributary flow from Joy Ranch to Cloud Rd.	6N-3E-32
	Sediment deposition on Joy Ranch Rd from overwidened dip section, creates backwater that inundates upstream properties	6N-3E-29,32
	Split flow branches from distributary channel pattern in subdivision north of Joy Ranch Rd flow into roads. Expect erosion & inundation. Examples at Lavitt Ln, Jordan Ln, & Tanya Ln. Numerous homes abut EHZ in the subdivision, some wall & fences in floodplain.	6N-3E-29
	Sediment maintenance practices block channels from dumped fill at Lavitt Ln.	6N-3E-29
	Home in EHZ right bank @ Ridgecrest Rd alignment downstream 7th St	6N-3E-20
	Structure in EHZ left bank upstream 7th St	6N-3E-20
	Fill placed in floodplain & channel downstream New River Rd	6N-3E-21
Desert Lake Trib 2	Sediment deposition on Joy Ranch Rd from overwidened dip section, creates backwater that inundates upstream properties	6N-3E-29,32
	Subdivision grading, raised 7th St, and natural distributary branch split channel and divert wash to south along 7th St.	6N-3E-28
	Numerous structures in or abut EHZ 600 ft. north of Desert Hills Dr.	6N-3E-21
Desert Lake East Fork	Wash follows 10th St alignment for ¾ mile between Cloud Rd & Carefree Hwy – road erosion, diversion of natural flow, maintenance	5N-3E-4
	Home in EHZ left bank between Cloud Rd & 10th St.	5N-3E-4
	Narrow channelized reach with fences in floodplain downstream Cloud	5N-3E-4
	Home in EHZ left bank upstream Cloud Rd	6N-3E-33
	Home & structures in natural floodplain at Dolores Rd, wash diverted with detention basin. Appears functional but diverts flow to adjacent property. Some avulsion & erosion hazards in design flood.	6N-3E-33
	Home in EHZ left bank downstream Maddock Rd.	6N-3E-33
Buchanan Wash	Stock ponds upstream CAP – incision & erosion downstream	5N-2E-21,28

Table 2-4. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis
Known Sedimentation Problem Areas

Watercourse	Problem Description	Location
CAP Wash – West Br	Non-incised floodplain upstream CAP may be sensitive to development and encroachment	5N-2E-15,16
	Significant sediment deposition during 2002 floods @ 39th Ave	5N-2E-34
	New subdivision abuts EHZ from Pinnacle Vista to 35th Ave	5N-2E-34
	Stock ponds widen EHZ, upstream deposition, downstream erosion	5N-2E-27
	Non-incised floodplain upstream CAP may be sensitive to development and encroachment	5N-2E-22,27
	No outlet at CAP, long-term sediment deposition expected	5N-2E-27
CAP Wash – East Br	Non-incised floodplain upstream CAP may be sensitive to development and encroachment	5N-2E-22,27
Skunk Tank Wash	See Skunk Tank Wash Report (JEF, 2000)	
Rodger Creek	See Rodger Creek Report (JEF, 2001)	
Sonoran Wash	See watercourse master plan reports (JEF, 2001)	

Notes:
1. This table does not list sediment likely maintenance problems at the numerous dip section and culvert crossings unless some unusual condition exists or the problem was identified by residents met in the field.
2. This table does not list all of the many fences that cross the floodplain and main channel.

Field photographs of existing structures in the study area are shown in Figures 2-23 to 2-40 on the following pages.

Summary. Sedimentation problems in the study area tend to be minor, localized and directly connected to specific disturbances of the natural stream system. However, it is noted that since urbanization is a recent phenomenon in most of the study area and few large floods have occurred during this period, some imminent sedimentation problems may not yet have developed to the point where they can be identified in the field.

Examples of Sedimentation Concerns at Road Crossings and Drainage Structures

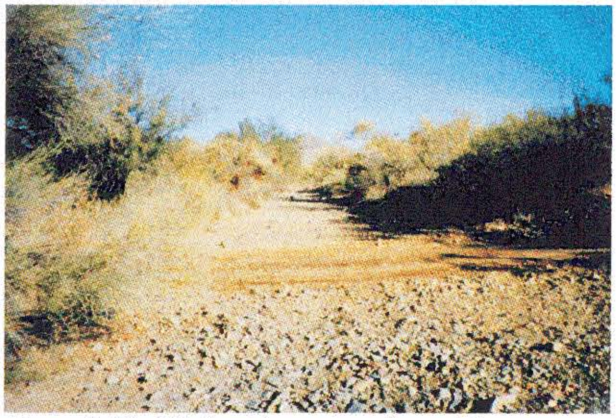


Figure 2-23. Minimal impact on channel from unpaved dip section road crossing on Apache Wash.

Figure 2-26. Raised dip section with no culvert at unpaved crossing on Cline Creek Tributary C8. Small floods will destroy crossing.

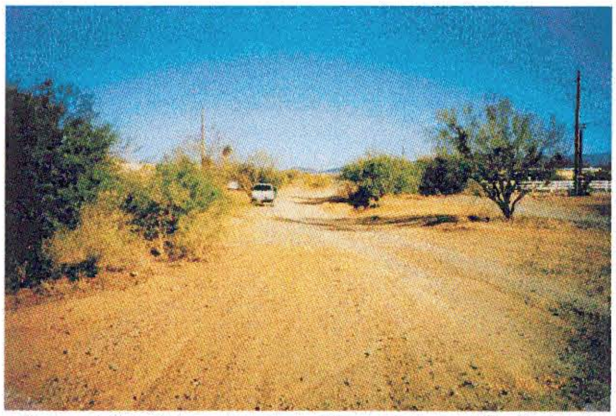


Figure 2-24. Dip crossing of Desert Lake Wash East Fork with high skew angle resulting in flow in road.

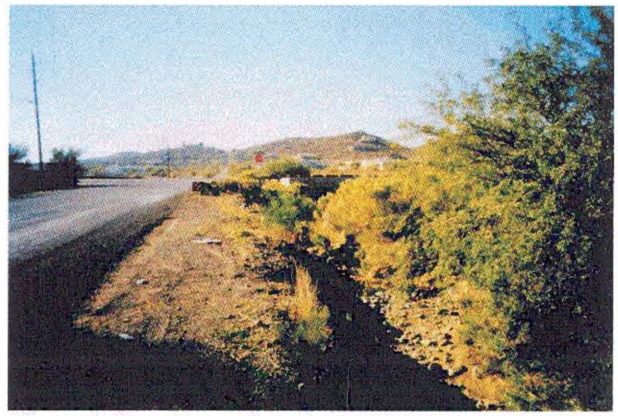


Figure 2-27. Channel realigned for road construction on Desert Lake Wash East Fork.

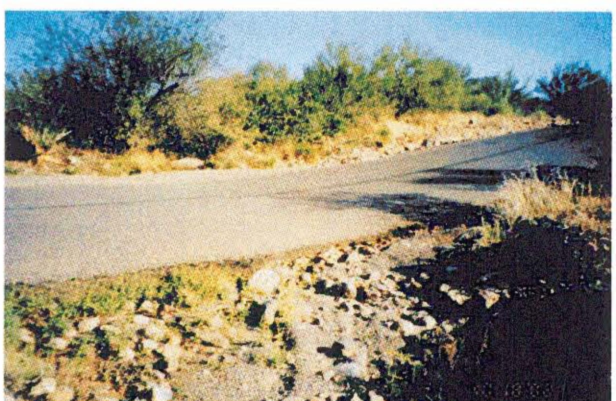


Figure 2-25. Paved dip section raised above natural channel invert on Cline Creek Tributary C6. Upstream deposition and downstream scour expected.

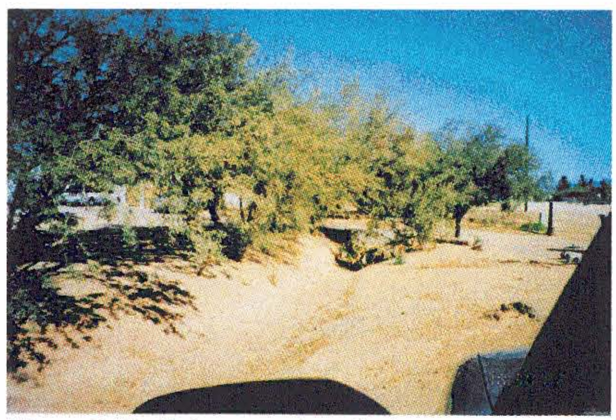


Figure 2-28. Driveway culvert limits stream capacity on Desert Lake Wash East Fork. Drainage plans must accommodate resident access.

Figure 2-29. Overwidened channel at culvert crossing on Desert Lake Wash. Sediment deposition is expected in overwidened sections.

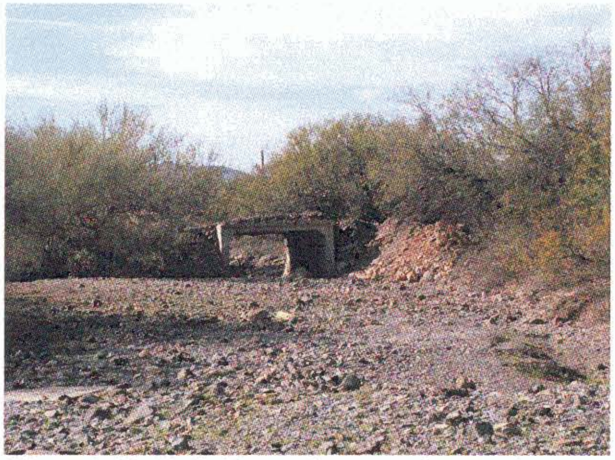


Figure 2-30. Failed box culvert crossing at private road on King Well Wash. Crossing is too narrow and doesn't address erosion by flanking.

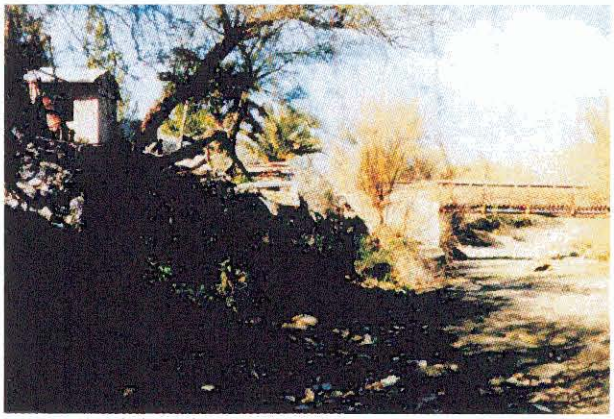


Figure 2-31. Private bridge over Upper Skunk Creek.

Figure 2-32. Desert Lake Wash geometry modified by road construction and development. Wide shallow dip section induces sediment deposition and causes upstream backwater inundation.

Figure 2-33. Channel and floodplain disturbed by driveway and lot grading on Cline Creek Tributary X4a.

Figure 2-34. Fence obstructing main channel at unpaved dip crossing on Cline Creek Tributary X5. Fence captures debris and causes deposition.

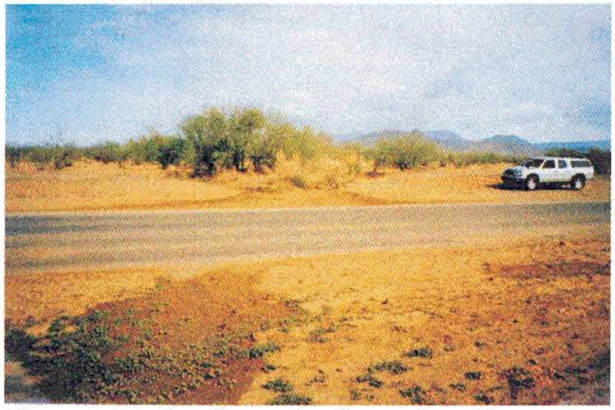


Figure 2-35. Ponding and sediment deposition at overwidened dip section on Desert Lake Wash.

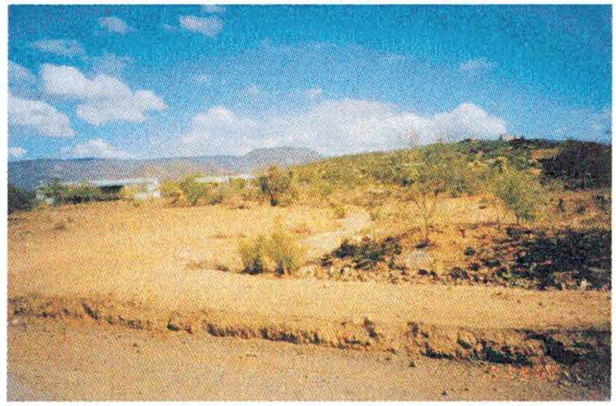


Figure 2-38. Channel diverted for development on Cline Creek Tributary X4b.

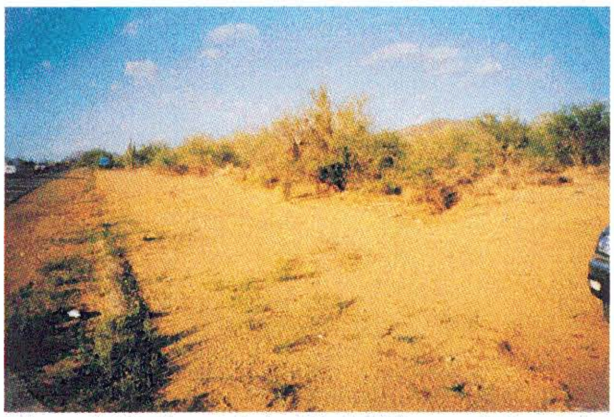


Figure 2-36. Desert Lake Wash Tributary 2 diverted by raised road section. Road crown diverts runoff in low sloped channels with low lateral relief.

Figure 2-39. Incision and lateral erosion near stock pond breach on Buchanan Wash. Long-term degradation due to sediment trapped by pond.

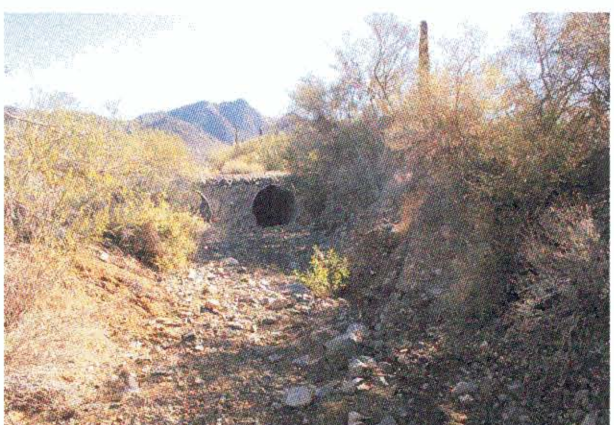


Figure 2-37. Undersized culvert relative to channel capacity on Apache Wash West Fork. Expect upstream sediment deposition.

Figure 2-40. Sediment deposition upstream of stock pond on CAP Wash West Branch.

2.4 Stream Responses to Development in the Watershed

Significant watershed development is a relatively recent phenomenon in the Adobe ADMP study area. Therefore, many of the channels may not have yet responded to the impacts of urbanization, particularly in the portions of the watershed located within the City of Phoenix where dense urbanization is currently under construction. In the unincorporated areas, historical development consisted primarily of rural and suburban homes and horse properties. Recently the pace of rural development has accelerated with numerous lot splits and large lot subdivisions, particularly in the Desert Hills area, and the Cline Creek watershed. Prior to development, most of the watershed was heavily grazed by sheep or cattle. The following types of stream responses to watershed development were noted:

- Driveway Culverts. Numerous residents in the unincorporated areas install undersized culverts under their private driveways that cross regulatory floodplain and their tributaries. The undersized culverts obstruct the main channel, induce sediment deposition, and divert flooding from the main channel into the floodplain or adjacent roadways. The expected channel responses to undersized culverts are upstream sediment deposition and occasional avulsions resulting from diversion of channel flow into the floodplain.

- Grading and Clearing. Many of the landowners in the watershed raise horses and other ungulates. Consequently, a significant portion, if not all, of the developed land is completely cleared of the natural vegetation and/or covered by impervious surfaces. The hydrologic impacts of these land management practices are described elsewhere in the Adobe ADMP report. The sedimentation impacts result from the increased runoff volume delivered to the trunk watercourses and the consequent increase in sediment transport capacity. In addition, removal of bank vegetation significantly decreases resistance to lateral erosion. The expected channel response to grading and clearing is increased lateral erosion, scour, and long-term degradation.

- Illegal Trash Dumping. Unfortunately, some of the washes have been used as illegal dumps for trash, landscaping materials, and fill. Because these materials are typically not compacted and are not resistant to erosion, they will be removed by future floods. However, trash and landscaping materials can clog culverts, collect on fences and block the channel or floodplain, and kill native vegetation, all of which accelerate erosion. Fill material can divert and redirect low flows and cause reflective scour on the opposite bank or downstream reaches. If sufficient fill material is dumped, the encroachment can cause increased flow depths and velocities, and accelerate lateral erosion and long-term scour.

- Fences. A wide variety of solid and wire fences were observed in the channels and floodplains of the watercourses in the study area. At best, fences are destroyed during floods. At worst, fences divert and block runoff, create obstructions, concentrate flow, redirect overbank flow paths, collect debris and form small dams, trap sediment, and accelerate scour and erosion.

- Landscaping. Some residents extensively grade and landscape the channels and flow conveyance corridors. While landscaping generally has minimal impacts on channel function (other than aesthetic differences), floods typically have destructive impacts on the landscaping. Where landscaping results in decreased roughness, flow velocities can accelerate increasing erosion and scour.

- Channelization. Some short reaches of the stream system in the study area have been channnelized, typically to convey flow around new construction. Except for the major channelization projects on Skunk Creek downstream of the CAP, in no instance did any of the local channelization projects appear to be stable or adequately maintaining the natural floodplain form and function. Typical channel responses to channelization included lateral erosion (no bank protection provided, poor alignment chosen), failure of bank protection measures (inadequate design criteria), inadequate capacity (overflow), sediment deposition (evidence of frequent maintenance), or loss of capacity due to vegetation growth (need for maintenance).

- Bank Vegetation Removal. One of the more ironic stream responses to development occurs when landowners remove bank vegetation to improve their access to, or view of the wash. Once the bank vegetation is removed, the stream experiences increased bank erosion. Bank erosion often leaves vertical cut banks which make access difficult, threatens their homesite with erosion, and necessitates construction of bank protection which is often unsightly.

- Road Crossings. Stream responses to road crossings were discussed previously.

Field photographs of development impacts on stream channel morphology are shown in Figures 2-41 to 2-52 on the following pages.

Examples of Development Impacts on Stream Morphology

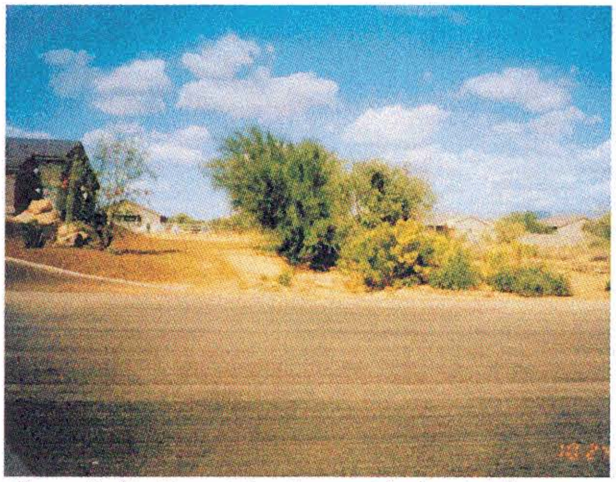


Figure 2-41. Recent development in floodplain elevated on fill along Desert Lake Wash.

Figure 2-44. Dumped fill in Upper Skunk Creek.

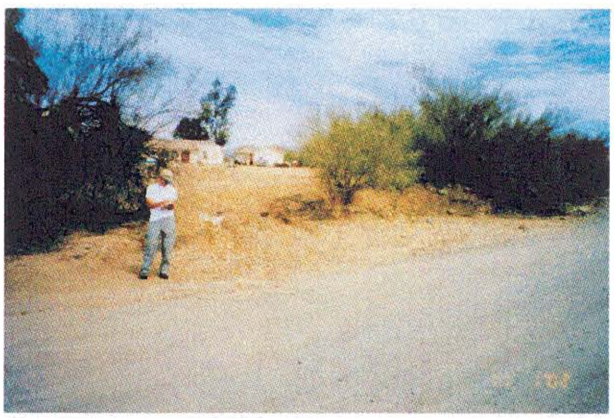


Figure 2-42. Grading obscures channel and floodplain of Desert Hills Wash.

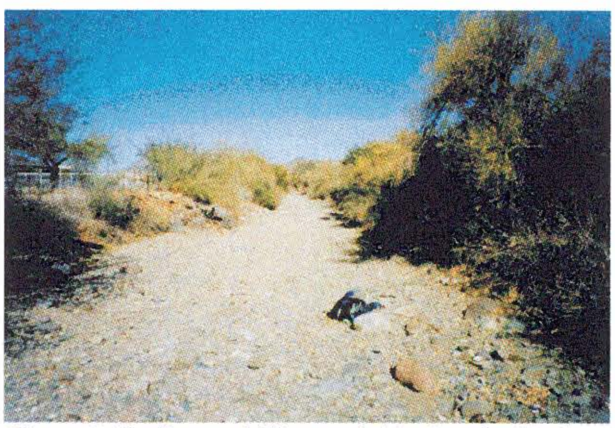


Figure 2-43. Dumped fill material in Apache Wash channel. Bank vegetation removed by local residents.

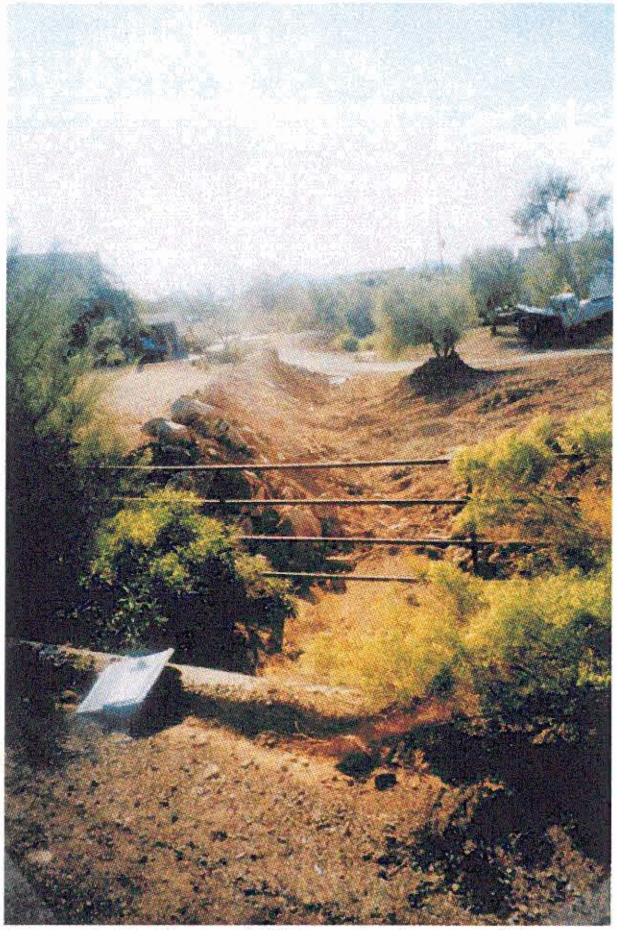


Figure 2-45. Dumped fill in main channel of Desert Lake Wash near headwaters.

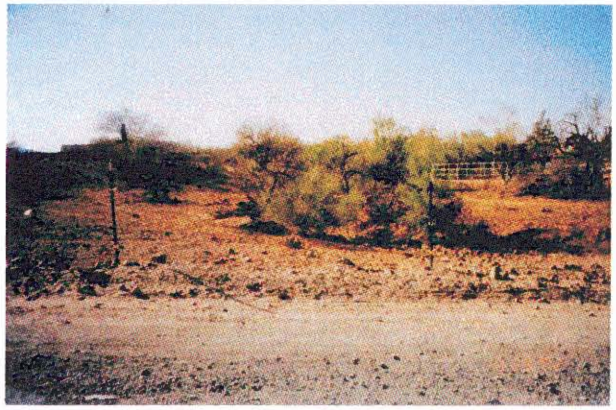


Figure 2-47. Impact of grazing on floodplain and channel vegetation on Desert Hills Wash Tributary 6.

Figure 2-48. Ungrazed floodplain and channel vegetation on Desert Hills Wash Tributary 6.

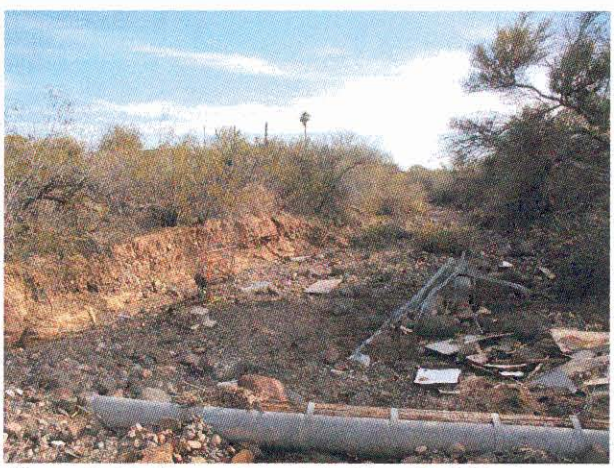


Figure 2-46. Dumped trash in King Well Wash.

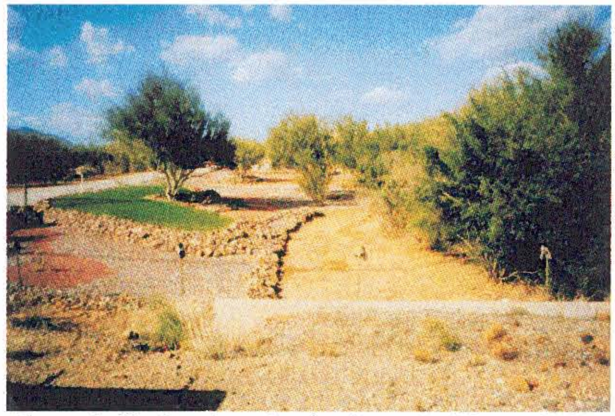


Figure 2-49. Landscaping in channel of Desert Lake Wash.

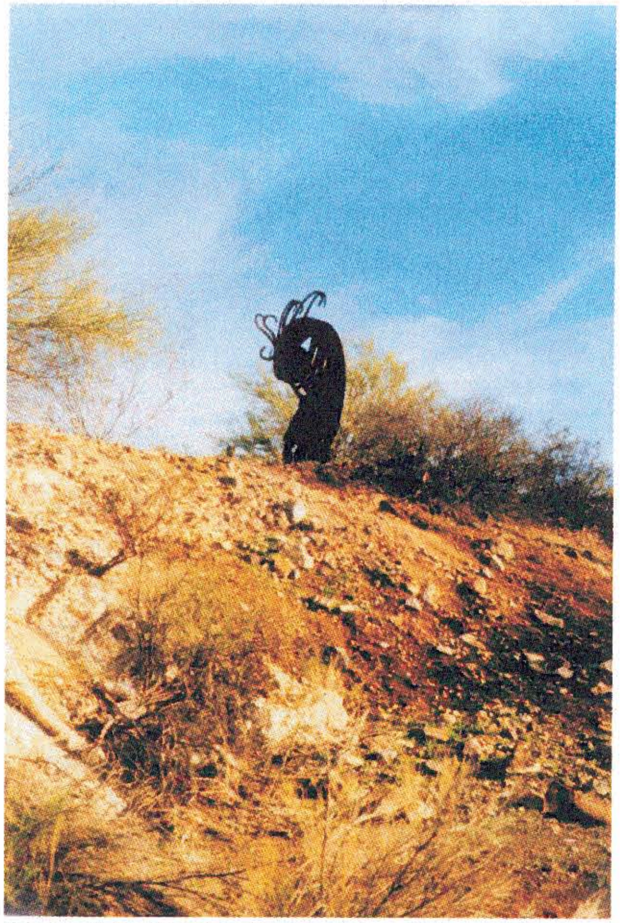


Figure 2-50. Praying figure asking, "Please, God, don't let it rain! And forgive me for what I did to the bank vegetation."

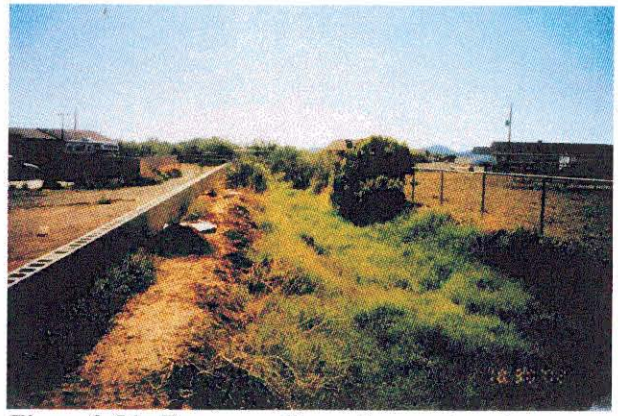


Figure 2-51. Fences, walls, realignment, and irrigation impacts on Desert Lake Wash East Fork.

Figure 2-52. Hog wire fence in channel of Skunk Creek Tributary 12.

Summary. Human activities in the Adobe ADMP study area have locally impacted channel stability and morphology by encroaching the natural floodplain, obstructing streams at roadway crossings, obstructing natural flow paths with fences, walls, and grading, and altered natural land use patterns in upland areas. So far, impacts from human activities have not significantly altered the trunk streams in the study area except in localized areas. Continued future development without restrictions on use or alteration of the floodplain is likely to accelerate and magnify the response of watercourses. Such responses would be most likely to include channel incision, accelerated lateral erosion, and decreased performance of drainage structures. Human impacts on specific watercourses are discussed in more detail in Section 3 of this report.

2.5 Natural Grade Control

Natural grade control observed in the study area consisted of bedrock that underlies many of the tributary stream segments near their headwaters. In general, bedrock is more common in the foothill areas of the watershed than in the piedmont areas. Where bedrock crops out in the banks of a stream segment it is likely that bedrock may underlie the main channels at shallow depths and provide some degree of grade control or prevent significant long-term degradation. Bedrock crops out in the following general areas of the study area:

- Upper Skunk Creek Tributaries. All of the Upper Skunk Creek tributaries north of Desert Hills Drive flow in foothill areas or in bedrock canyons with relatively shallow bedrock. No bedrock control was observed in Cline Creek or Rodger Creek west of New River Road.
- Upper Skunk Creek. Bedrock crops in portions of the bed of Skunk Creek upstream of Zorrillo Drive, as well as near the Union Hills gaps near the Tramonto subdivision.
- Apache Wash. Bedrock controls vertical and lateral erosion of Apache Wash north of Saddle Mountain Road. The Apache Wash tributaries north of Joy Ranch Road are underlain by shallow bedrock or resistant carbonate units.
- Desert Hills Wash. Bedrock crops out in limited parts of the headwater reaches of Desert Hills Wash and its tributaries north of the Irvine Road alignment.

Some degree of natural grade control is provided by the size of the bed material in the study area. Boulders and cobbles that form riffles in the beds of most of the larger streams may provide grade control through formation of a pool and riffle sequence with alternating flatter and steeper segments. Coarse sediment riffles were observed throughout the watershed except on the lower reaches of Desert Hills and Desert Lake Washes, Buchanan Wash, the East and West CAP Tributaries, and Skunk Creek downstream of I-17. Equilibrium slope equations typically indicate that channels with coarse bed materials are stable at steeper slopes than channels with fine-grained bed materials. Therefore, the presence of boulder-sized sediment probably allows the channel to resist watershed impacts that might otherwise cause long-term degradation.

Man-made grade control is provided at paved road crossings with engineering drainage crossing structures, at concrete overchutes and culverts crossing the CAP. Field observations of drainage crossing condition indicate that while local scour has occurred at many road crossings, system-wide long-term scour has not been significant during the period of record.

Summary. Grade control is provided by bedrock, coarse sediment, and man-made structures at various points along the major watercourses in the Adobe ADMP study area. Long-term degradation has been limited in the study area. Therefore, grade control has not been a significant factor in development or maintenance of the natural stream system.

2.6 Existing Sediment Sources in the Watershed

An analysis of sediment yield is provided in Section 4 of this report. The available sources of sediment in the study area are from erosion of uplands and erosion of channel bed and banks. Fine-grained sediment is derived primarily from erosion of upland areas, and is deposited on floodplains or is transported through the study area to Adobe Dam or Cave Buttes Dam. The coarse sediments observed in the main channels are derived primarily from erosion of channel bed and banks. The coarsest sediments are transported as bed-material load and remain in the main channels. As shown in Table 2-1, field observations indicate that bed sediments were the dominant supply source, followed by bank erosion. Upland erosion was a significant source of sediment only on the upstream reaches of Buchanan Wash, the CAP tributaries, and some of the smaller Desert Lake Wash tributaries.

No natural sediment sinks were identified in the watershed, although significant sediment storage occurs in braided reaches (splays) downstream of single channel reaches (chutes). Chute/splay patterns occur on some of the larger streams in the study area such as Skunk Creek, Sonoran Wash, Apache Wash, and Paradise Wash. Some sediment storage also occurs in braided stream reaches. Man-made sediment sinks occur upstream of obstructions. The most significant man-made sediment storage areas include the ponding areas upstream of the CAP on Skunk Creek, Sonoran Wash, and the CAP tributaries. Sediment storage also occurs upstream of undersized road crossings (many locations), within the crossing section of oversized bridges (Skunk Creek at New River Road and Carefree Highway), local detention basins, and stock ponds.

Summary. Sediment transported in the stream network is derived primarily from natural channel erosion. Upland sediment supply does not appear to be a significant source of sediment in the main stem stream segments. Therefore, development of upland areas will tend to have minimal impact on stream stability unless urbanization increases peak discharge and runoff volume. Development near significant man-made floodplain obstructions should account for the affects of sediment deposition (long-term aggradation) on regulatory water surface elevations and avulsive channel movement.

2.7 Summary

The existing conditions analysis indicates that there are few significant existing or historical sedimentation problems in the Adobe ADMP study area. The degree of development that has occurred to date has not significantly impacted channel stability or induced sedimentation problems, except in localized areas in response to specific disturbances of the actual watercourses rather than upland areas. A list of observed sedimentation problems was provided in Table 2-4. However, new and increased sedimentation problems are likely to occur if the development density increases in the watershed and direct modifications of the trunk streams are made. The magnitude of future development-related erosion problems will be greatest in the reaches with flatter slopes, least topographic confinement, least amount of bedrock control, densest development, and lowest regulatory control of development practices. Lateral erosion of the major watercourses occurs naturally within the canyons throughout the study area and is expected to continue to occur in the future.

2.8 References

JE Fuller/ Hydrology & Geomorphology, Inc, 2000, Upper Cave Creek/Apache Wash Lateral Migration Report, Appendix to the Upper Cave Creek/Apache Wash Watercourse Master Plan. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2000, Skunk Tank Wash Erosion Hazard Study. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2001, Agua Fria River Watercourse Master Plan, Lateral Migration Report. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2001, Rodger Creek Erosion Hazard Study. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2001, Skunk Creek/Sonoran Wash Watercourse Master Plan – Attachment 6: Lateral Stability Assessment. Report to the Flood Control District of Maricopa County and ASL Consulting.

Section 3: Erosion Hazard Zones

3.1 Introduction

Erosion hazard zones were delineated for all the watercourses within the Adobe ADMP study area that have detailed floodplain delineations (Figure 3-1, Table 3-1; Task 2.7.2). A total of 75 miles of new erosion hazard zones were delineated as part of the Adobe ADMP study. As shown in Table 3-1, another 17 miles of erosion hazard zones (EHZ) were previously delineated in the study area and approved by the District. Previously delineated EHZ were incorporated without modification into this study from the following studies:

- Skunk Tank Wash Erosion Hazard Study (JEF, 2000)
- Skunk Creek Lateral Stability Assessment (JEF, 2001)
- Sonoran Wash Lateral Stability Assessment (JEF, 2001)
- Rodger Creek Erosion Hazard Study (JEF, 2001)

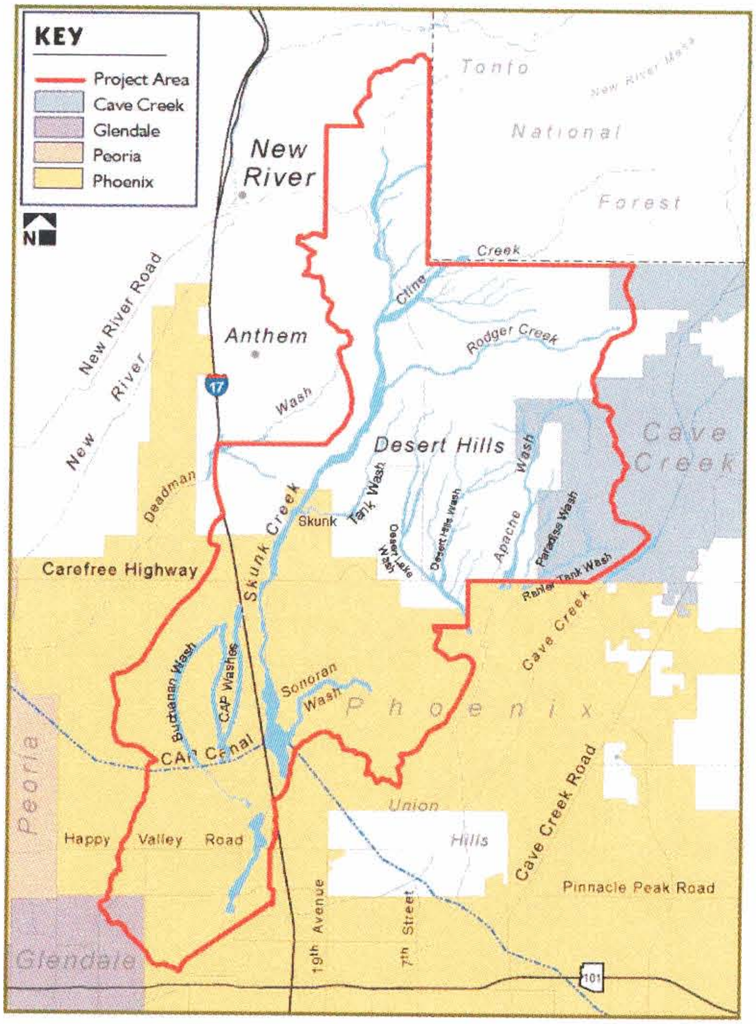


Figure 3-1. Study limits of the streams located in the Adobe ADMP study area.

Table 3-1. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis. Erosion Hazard Zone Stream Reaches

Stream Segment	Upstream Limit	Downstream Limit	Length	Method
Buchanan Wash	Study limit	CAP	3	Walk
Buchanan Wash	CAP	Skunk Ck	2	Car
CAP Tributary West Branch	Study limit	CAP	2	Walk
CAP Tributary East Branch	Study limit	CAP	3	Walk
Sonoran Wash	CAP	Skunk Ck	0.5	Walk
Sonoran Wash*	Headwaters	CAP	3.2	Previous
Skunk Creek	Study limit	New River Road	2	Walk
Skunk Creek*	New River Rd	CAP	13	Previous
Skunk Creek	CAP	I-17	1	Walk
Skunk Creek	I-17	Adobe Dam	3	Car
Skunk Tank Wash*	Headwaters	Skunk Creek	4.5	Previous
King Well Wash (Skunk Tributary #6B)	Study limit	Skunk Creek	2	Walk
Skunk Creek Tributary #6C	Study limit	Skunk Creek	1	Walk

Table 3-1. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis. Erosion Hazard Zone Stream Reaches

Stream Segment	Upstream Limit	Downstream Limit	Length	Method
Skunk Creek Tributary #10A	Study limit	Skunk Creek	1	Walk
Skunk Creek Tributary #12	USFS	Skunk Creek	1.5	Walk
Shoemaker Spring Wash (Skunk Trib. #10B)	USFS	Skunk Creek	1	Walk
Cline Creek	USFS	Skunk Ck	2	Walk
Cline Creek Tributary X5	Study limit	Cline Creek	1	Car
Cline Creek Tributary X4A	Study limit	Cline Creek	1	Car
Cline Creek Tributary X4B	Study limit	Cline Trib X4A	0.5	Car
Cline Creek Tributary C6	Study limit	Cline Creek	2	Car
Cline Creek Tributary X3	Study limit	Cline Trib C6	1	Car
Cline Creek Tributary X2	Study limit	Cline Trib C6	1	Car
Cline Creek Tributary C8	Study limit	Cline Trib C6	2	Car
Rodger Creek*	USFS	Skunk Creek	6.4	Previous
Desert Hills Wash	Study limit	Carefree Hwy	3.5	Car
Desert Hills Wash	Carefree Hwy	Phoenix City Limit	1	Walk
Desert Hills Wash - West Branch	Study limit	Desert Hills Wash	3	Car
Desert Hills Wash Tributary 7	Study limit	Desert Hills Wash	0.5	Car
Desert Hills Wash Tributary 6	Study limit	Desert Hills Wash	2	Car
Desert Hills Wash Tributary 5	Study limit	Desert Hills Wash	2	Walk
Desert Hills Wash Tributary 4	Study limit	Desert Hills Wash	0.5	Car
Desert Hills Wash Tributary 3	Study limit	Desert Hills Wash	0.5	Car
Desert Hills Wash Tributary 2	Study limit	Desert Hills Wash	1.5	Walk
Desert Hills Wash Tributary 1	Study limit	Desert Hills Wash	2	Walk
Desert Lake Wash	Study limit	Desert Hills Wash	2	Car
Desert Lake Wash Tributary 2	Study limit	Desert Hills Wash	2	Car
Apache Wash	Study limit	Carefree Hwy	5	Walk
Apache Wash Tributary 7	Study limit	Apache Wash	0.5	Walk
Apache Wash Tributary 6	Study limit	Apache Wash	0.25	Walk
Apache Wash Tributary 5	Study limit	Apache Wash	0.25	Walk
Apache Wash Tributary 4	Study limit	Apache Wash	0.5	Car
Apache Wash Tributary 3	Study limit	Apache Wash	0.5	Walk
Apache Wash Tributary 2	Study limit	Apache Wash	1	Walk
Apache Wash Tributary 1	Study limit	Carefree Hwy	1	Walk
West Fork of Apache Wash	Study limit	Apache Wash	1	Car
West Fork of Apache Wash Tributary 1	Study limit	West Branch	0.5	Car
Paradise Wash	Study limit	Carefree Hwy	3	Walk
Paradise Wash West Branch	Study limit	Carefree Hwy	2	Walk
Ranieri Tank Wash	Study limit	Paradise Wash	2	Walk
Ranieri Tank Wash Tributary 1	Study limit	Paradise Wash	0.5	Car
Ranieri Tank Wash Tributary 2	Study limit	Paradise Trib 1	1	Car

* Indicates EHZ delineation previously completed and approved by the District.

The locations of all stream reaches are also shown in Figure 3-2 and Exhibit 3-1.

3.2 Methodology & Results

The methodology used to delineate the erosion hazard for the watercourses in the Adobe ADMP study area generally followed the Level 3 non-detailed analysis procedures outlined in the District's draft *Erosion Hazard Zone Delineation and Development Guidelines*. Erosion hazard zones were delineated using the following types of information and analyses:

- Interpretation of geomorphic mapping
- Interpretation of recent aerial photographs
- Comparison of existing and historical channel position
- Field observations
- Estimation of the Pleistocene/Holocene surface lateral erosion rate
- Interpretation of detailed floodplain/floodway mapping
- Identification of potential channel avulsion areas

The scope of work states that the Arizona Department of Water Resources (ADWR) State Standard (SSA 5-96) Level 1 Methodology be used to establish an initial erosion hazard zone. However, as previously reported to the District (JEF, 2000; 2001, 2002), the SSA 5-96 has a number of deficiencies when applied to streams in central Arizona. In addition, the District and the ADWR State Standards Work Group are currently revising their erosion hazard delineation methodologies. Such revisions would make the existing SSA 5-96 Level 1 procedures obsolete. Therefore, SSA 5-96 Level 1 erosion hazard setbacks were not delineated as part of the Adobe ADMP sedimentation engineering and geomorphic evaluation, and a more detailed (Level 3) methodology was used that incorporated in the types of information and analyses described in the following paragraphs. The Level 3 EHZ methodology used for this study is consistent with the existing SSA 5-96 procedures, the draft District Level 3 EHZ procedures, and the methodologies under consideration by the ADWR State Standards Work Group.

Geomorphic Mapping. Geomorphic mapping for the study area has been completed by the Arizona Geological Survey (AZGS) and is described in the following publications:

- Leighty, R.S., and Huckleberry, G., 1998, Geologic Map of the Biscuit Flat 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-19.
- Leighty, R.S., and Huckleberry, G., 1998, Geologic Map of the Hedgpeth Hills 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-18.
- Leighty, R.S., Geologic Map of the Daisy Mountain 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-22.
- Leighty, R.S., and Holloway, S.D., 1998, Geologic Map of the New River SE 7.5' Quadrangle, Maricopa County, Arizona. AZGS Open-File Report 98-21.

Geomorphic mapping identifies and classifies differences in the physical characteristics of land surfaces. The physical characteristics of a geomorphic surface give clues as to its depositional history, stability, and flood potential. If a land surface ceases to receive new deposits (i.e., is not flooded), it will begin to age. As it ages, the surface develops distinctive physical and chemical characteristics indicative of its age. As a soil develops, its structure, color and content change. Soils become redder with increased age due to oxidation of iron, a process called rubification. Clay and carbonate also accumulate as a soil ages, causing the soil to develop layers and internal structure (clay), and become whiter (carbonate) and more cemented (carbonate). Soils with high clay and carbonate content are generally more resistant to erosion. As they age, surfaces may also develop gravel lag coverings known as desert pavement. The large clasts on the surface, if they contain sufficient ferromagnesian minerals, will develop a dark black patina called desert varnish on their tops and an orange coating underneath. Surfaces free from new deposition will also begin to erode and develop new tributary channel networks, creating a greater degree of relief between the channel bottoms and the ridges which separate them. Because many of these characteristics take thousands of years to develop, it can be concluded that surfaces that exhibit well-developed soils, red color, significant carbonate development, desert pavements composed of strongly varnished gravels, and tributary drainage networks have been relatively free from flooding and erosion for thousands of years. Therefore, without external disturbance, it can be assumed that the flood and erosion hazard potential in the future will remain low.

The AZGS surficial geologic mapping distinguishes the following geomorphic surfaces in the vicinity of the major watercourses in the Adobe ADMP study area:

- Active channel deposits (Q_{yc}). The Q_{yc} unit consists of predominantly sand, gravel and silt deposits found in the active channels of Skunk Creek, Apache Wash, and their principal tributaries. Alluvium in Q_{yc} units is typically well-stratified and lacks any appreciable soil development. For the small tributaries, a Q_{yc} unit is not distinguished from the wider Q_y unit at a 1:24,000 map scale.

- Holocene alluvium (Q_y). The Q_y unit consists of river deposits younger than about 10,000 years, and is generally found in small active channels and on low terraces. The unit is characterized by unconsolidated, stratified, poorly to moderately sorted sand, gravel, cobble and boulder deposits along the drainageways. Alluvial surfaces exhibit bar and swale topography, with the ridges typically being slightly more vegetated. Q_y surfaces typically lack desert varnish or pavement, and often have a sandy loam mantle. Surface colors are usually light brown to yellowish brown, with slight reddening due to iron oxidation. Q_y surfaces are considered subject to flooding and erosion.

- Late Pleistocene alluvium (Q_l). The Q_l unit consists of alluvial fan surfaces and terraces that are 10,000 to 250,000 years old. The unit may be moderately incised by stream channels, but has some constructional, relatively flat interfluvial surfaces with a subdued bar and swale topography. The surfaces have no to moderately developed desert pavement and varnish, with slightly more red color than Q_y surfaces. Soil profiles have weak to moderate argillic horizons and stage II-III carbonate development. Q_l surfaces are generally not flood prone, except where they are immediately adjacent to active washes.

- Middle Pleistocene alluvium (Q_m). The Q_m unit consists of relict alluvial fan and river terraces greater than 250,000 years old. The soil units are characterized by tan, sandy to loamy materials with sand- to boulder-sized clasts. Q_m surfaces have generally been eroded into shallow valleys and ridges due to development of an internal drainage pattern. The surfaces typically have moderate to strongly developed desert pavement and varnish, except where surface erosion has removed them, and are brown to reddish brown. The soils are strongly developed with reddened argillic horizons and stage II-IV calcic horizons. Q_m surfaces are generally not flood prone.

- Early Pleistocene alluvial fan deposits (Q_o). The Q_o unit consists of relict alluvial fan and river terraces greater than 750,000 years old. The Q_o deposits are moderately consolidated and indurated by carbonate. The surfaces are typically deeply dissected by larger drainages, and have strongly developed reddish brown argillic and stage III-IV calcic horizons. Q_o surfaces are generally not flood prone.

For the purposes of this study, as per the Level 3 limited detail EHZ delineation procedures, the Q_{yc} and Q_y (Holocene) surfaces were considered to be within the erosion hazard zone. In addition, portions of some Q_l (Late Pleistocene) surfaces and the margins of Q_m surfaces were delineated in the erosion hazard zone because of their proximity to actively eroding cut banks or position on channel bends.

Detailed soils mapping also has been completed by the USDA Soil Conservation Service (SCS) in the following publication:

- Camp, P.D., 1986, Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona

Nearly all of the soil units near the new erosion hazard delineation reaches in the study area were designated by the SCS as fan terraces. A few soil units along the major watercourses were mapped as drainageway or floodplain soils. The relationship of surface age with soil class is supported by the presence of clay and caliche in the soil profiles. Designation of the soils in the study area as fan terraces appears to indicate that the erosion hazard outside the main channel and active floodplain is slight. However, the designation as fan terrace for these surfaces is probably more of a reflection of the macro-scale of the SCS mapping and unit descriptions than a precise interpretation of the existing surficial processes. Field evidence and the District's 100-year floodplain mapping clearly indicate potential inundation of broader areas than indicated by the SCS map units. The degree of soil development recorded by the SCS does indicate that erosion of the areas outside the main channel and floodplain corridor has been relatively rare during the past 10,000 years, and has generally been confined within the floodplain for the past 250,000 years.

Interpretation of Aerial Photographs. Erosion hazards were also evaluated by interpreting fluvial landforms and surficial characteristics visible on aerial photographs. For the Adobe ADMP, both high-quality 2002 orthorectified digital photography and 1:12,000 color contact prints were available. As described above, the age of stream terraces adjacent to the main channels provides information on past stream bed elevations and positions that can be used to help forecast where the stream may be located in the future. Geomorphic surface characteristics were used to compare terraces within the study limits to surfaces in the local area previously evaluated by the AZGS and SCS, as described above. Those characteristics included the following:

- Soil development
- Surface color
- Desert pavement
- Desert varnish
- Topographic relief
- Vegetative characteristics

Individually, any one of these age-indicating characteristics provide a relatively low degree of confidence in age estimates. Considered together, and with information obtained from AZGS and SCS mapping, those characteristics provide a high degree of confidence in interpretation of erosion hazards.

Existing and Historical Channel Position. The positions of the main channel banks or thalweg of the major watercourses in the study area were digitized from the oldest available historical aerial photographs and from the District's most recent digital orthophotography of the study area. A list of the aerial photographs used is shown in Table 3-2. The historical aerial photographs were scanned to create digital images which were then semi-rectified using ArcMap 8.2 software and the digital USGS quadrangles as the map base. Plots of historical and modern channel positions are shown in Figure 3-2. Reaches where the comparison of historical and recent channel position indicated significant channel change has occurred were field-verified. In general, the channel position has not significantly changed during the 50 year period of record, except on Skunk Creek (JEF, 2001) and Cline Creek, or where the watercourses have been channelized and developed.

Table 3-2. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Historical Aerial Photographs

Year	Description	Scale	Source
1953	Black & white aerial photo (3-11-53)	1:9,600	Army Mapping Service
2002	Black & white aerial photo (5-28-02)	1:7,200	Cooper/FCDMC
2002	Digital orthophotographs (1-02)	n/a	FCDMC

Field Observations. Field visits were conducted to each of the stream reaches in the study area. Field visits consisted of walking the channels, photographing and mapping key features, and recording descriptions of existing channel conditions. The objectives of the field visits included the following:

- Document stream conditions
- Identify stream reaches with evidence of recent or historical lateral erosion
- Identify reaches with evidence of recent or historical degradation or aggradation
- Identify evidence of lateral erosion within recent geologic time
- Identify evidence of limits to future lateral erosion (bedrock, carbonate, structures)
- Identify stream responses to human impacts or structures
- Identify points of natural grade control

Specific types of field evidence considered included the following:

- Avulsion Potential. Evidence of channel avulsions was observed and noted in the field using the characteristics discussed later in this report.

- Bank Conditions. The physical condition of the stream banks provides evidence of whether the stream has been subject to recent lateral erosion and may be subject to future bank erosion.
    - Bank Height. Higher, steeper banks are typically more erodible than low banks, particularly if bank height was increased by channel degradation.
    - Bank Materials. Bank materials provide resistance to lateral erosion through a variety of properties such as cohesion, armoring (sediment material size), angle of repose, ability to transmit and store water, susceptibility to piping, stratigraphy, and the ability to promote or prevent root growth.
    - Bank Protection. Properly designed and constructed bank protection is an effective barrier against erosion.
    - Bank Vegetation Type, Density and Age. Bank vegetation can reduce the rate of lateral erosion by increasing the hydraulic roughness (lower velocity), anchoring soil material, and decreasing the amount of soil to water contact. Different plant species provide different levels of bank stability and resistance to erosion, depending on root density, rooting depth, trunk strength, canopy density, and malleability to flow.
    - Cut Banks. A cutbank is defined as a vertical or near vertical, unstable, unvegetated stream bank that has been recently eroded or trimmed by lateral erosion. If a stream does not continue to erode the bank to a vertical face, slope processes will work to flatten the bank slope to its angle of repose (typically, about a 2:1 or greater slope). The rate at which slope processes act on a stream bank is a function of the resistance of the bank slope material, the climate, interference by stream processes, and other hydrologic and geologic factors.

- Bed Sediment. Bed sediment characteristics such as size, imbrication, sorting, or armoring are indicative of channel processes, flow velocities, and rate of sediment movement. Channels with high velocities are subject to higher rates of lateral erosion than channels with low velocities. Channels with high rates of sediment movement are typically subject to higher rates of lateral erosion. Bed armoring may lead to increased lateral erosion.

- Bedrock Outcrop. The types of bedrock that occur in the study area are resistant and effectively prevent lateral erosion and long-term scour where they crop out in the channel bed and banks. In some cases, bedrock outcrops on one bank may redirect flow at the opposite bank and induce lateral erosion.

- Caliche Outcrop. Accumulation of calcium carbonate ($CaCO_3$, a.k.a. "caliche") in the bank materials can significantly increase resistance to bank erosion, although field evidence in the Adobe study area suggests that banks with caliche have experienced some lateral erosion, particularly where underlying soil layers are less resistant.

- Channel Characteristics.
  - Bankfull Width/Depth Ratio. Streams with high width to depth ratios are subject to higher rates of lateral erosion than streams with low width to depth ratios.
  - Channel Bend Angle. Sinuous stream reaches and channels with sharp bends are subject to higher rates of lateral erosion and more frequent avulsions than straight channels.
  - Channel Pattern and Sinuosity. Sinuous and meandering streams tend to experience lateral migration by erosion of the banks on the outside of bends. Straight or braided channels tend to erode by widening both banks.

- Development.
  - Watershed. Urbanization often causes changes in the natural hydrology of a watershed that result in erosive channel changes such as increased flooding, depletion of sediment supply, and/or long-term degradation.
  - Floodplain. Floodplain encroachment displaces floodwater into the channel, resulting in higher channel velocities and increased channel bank and bed erosion. Encroachment may also divert flow from the floodplain and initiate avulsions or stream piracy.

- Floodplain Vegetation. The type, density, and alignment of floodplain vegetation provides clues as to the frequency, depth, and velocity of overbank flooding, the rate of lateral channel movement, the potential for channel avulsions, and a record of past floods.

- Headcuts. Channel degradation is closely linked to increased lateral erosion of the incised channel. Conversely, long-term aggradation leads to channel widening and/or avulsive channel change.

- Historical Channel Changes. Historical documentation of past channel movement or changes in channel pattern is the best method for establishing the scale and risk of future channel change. Plots of historical channel bank stations on modern aerial photographs were used in the field to verify and document locations of known channel change or stability.

- Manmade Channel Disturbance. Manmade disturbances of the natural channel such as floodplain encroachment, in-stream sand and gravel mining, highway encroachments, construction of bank protection or channelization often leads to accelerated rates of lateral erosion in adjacent reaches relative to natural erosion rates.

- Terrace Characteristics. Surficial soil, vegetative, geomorphic, and topographic characteristics can be used to estimate the relative age of stream terraces and the history of past erosion, as described earlier in this section. The height of the floodplain and terraces above the main channel indicates the frequency of flood inundation, the potential for avulsion, and the relative risk of erosion.

- Topography. Topographic mapping of the floodplain and channel can be used to indicate the type of floodplain processes that have occurred in recent history, to identify potential avulsive channel areas, and to identify relative stable depositional landforms.

Photographs of typical sections of each of the individual stream segments considered are provided in Figures 3-3 to 3-45.

Field Photographs Documenting Typical Channel Conditions in the Adobe Study Area.

Figure 3-3. Upper Skunk Creek typical pool & riffle channel pattern and bimodal bed sediment distribution. Note bank materials and vegetation.

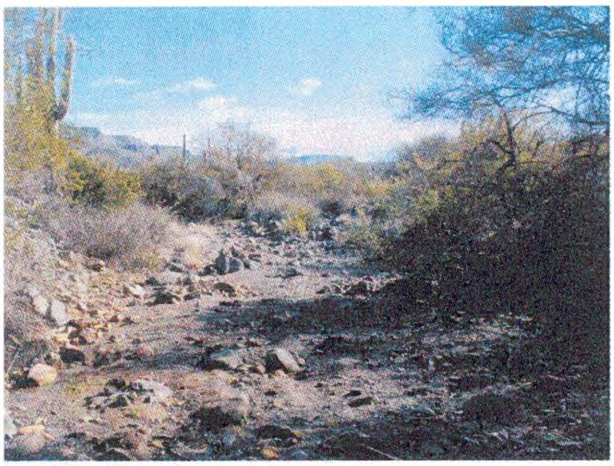


Figure 3-4. King Well Wash typical channel with shallow bedrock and coarse bed material.

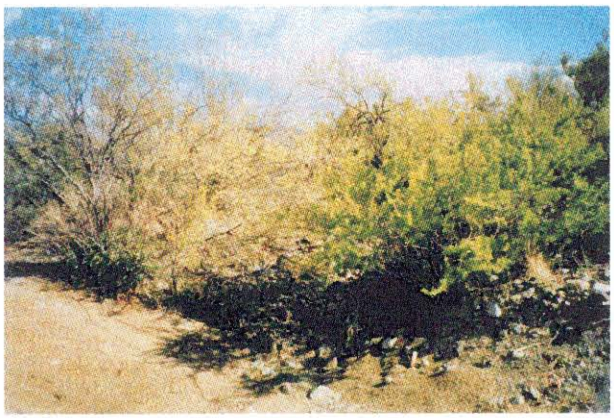


Figure 3-5. Skunk Creek Tributary 12 typical channel. Note contrast in bed and bank material.

Figure 3-6. Skunk Creek Tributary 10a typical channel cross section. Note slight mounding of bed material toward center of channel.

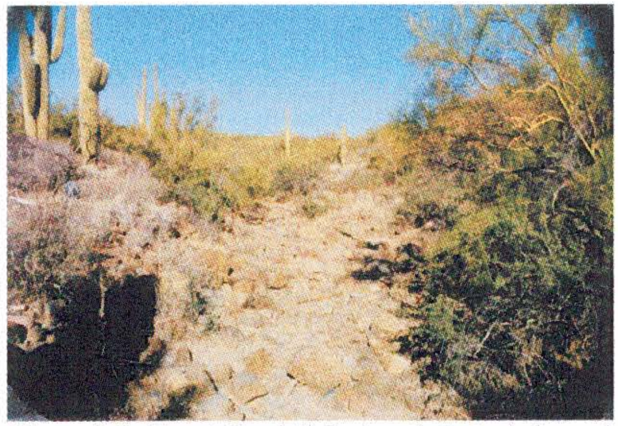


Figure 3-7. Skunk Creek Tributary 6c typical channel section with narrow main channel, coarse bed material, bedrock outcrop, and dense vegetation.

Figure 3-8. Shoemaker Spring Wash typical channel. Note vegetation encroachment of main channel.

Figure 3-9. Cline Creek Tributary C6 typical channel.

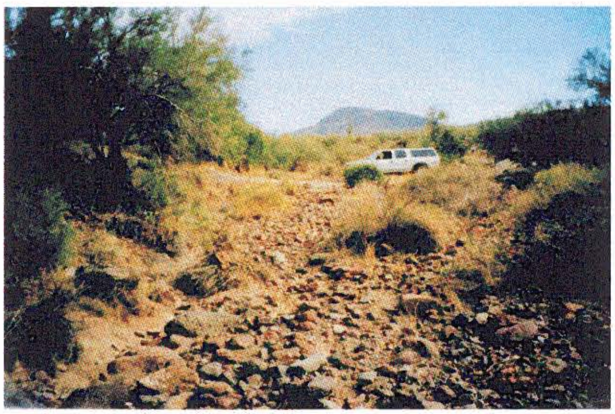


Figure 3-10. Cline Creek Tributary C8 typical channel near paved dip section crossing.

Figure 3-11. Cline Creek Tributary X2 typical channel.

Figure 3-12. Cline Creek Tributary X3 typical channel.

Figure 3-13. Cline Creek Tributary X4a typical channel section near headwaters.

Figure 3-14. Cline Creek Tributary X4b typical channel with floodplain grading and removal of bank vegetation.

Figure 3-15. Cline Creek Tributary X5 typical channel near headwaters with dense grass vegetation.

Figure 3-16. Apache Wash typical channel section upstream of Carefree Highway.

Figure 3-17. Apache Wash Tributary 1 typical channel with minor cut bank and channel vegetation.

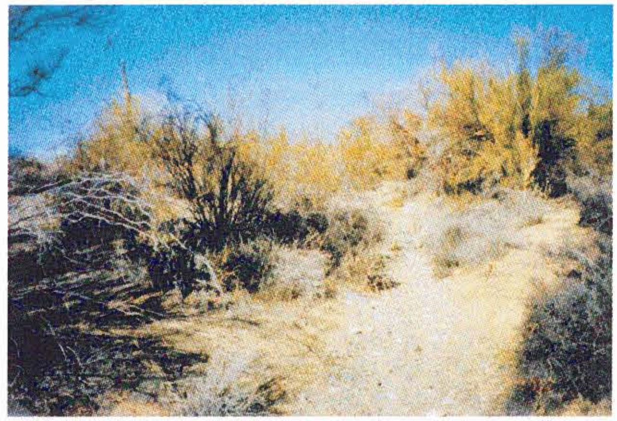


Figure 3-18. Apache Wash Tributary 3 typical channel near headwaters in foothills terrain.

Figure 3-19. Apache Wash Tributary 4 typical channel with coarse bed material and channel vegetation.

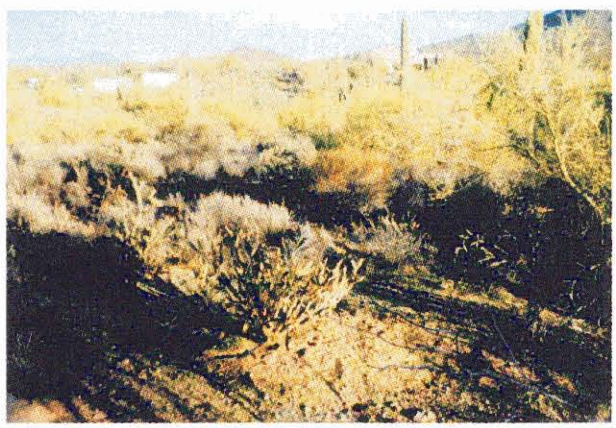


Figure 3-20. Apache Wash Tributary 5 typical channel. Small channel in foothills terrain.

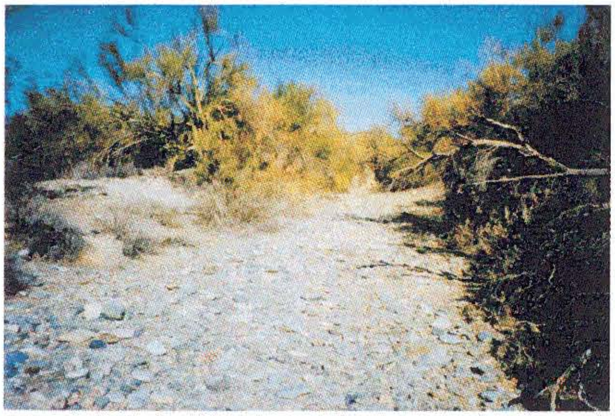


Figure 3-21. Apache Wash Tributary 6 typical channel. Riffle reach with low floodplain.

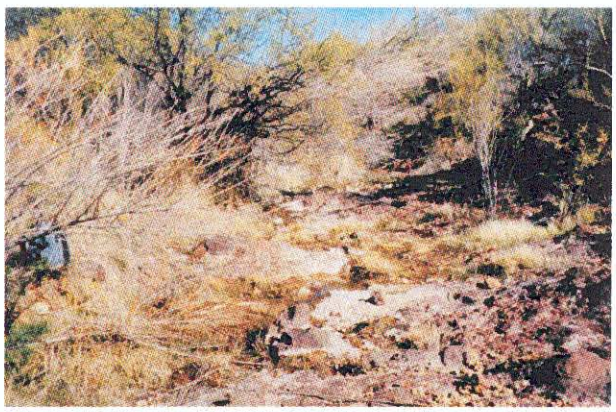


Figure 3-22. Apache Wash Tributary 7 typical channel in bedrock canyon reach.

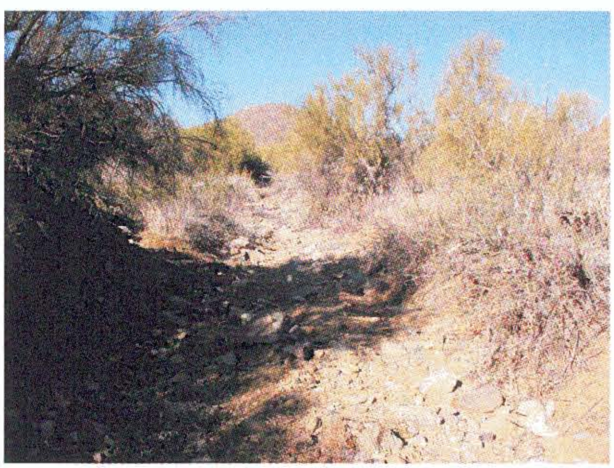


Figure 3-23. West Fork Apache Wash typical channel.

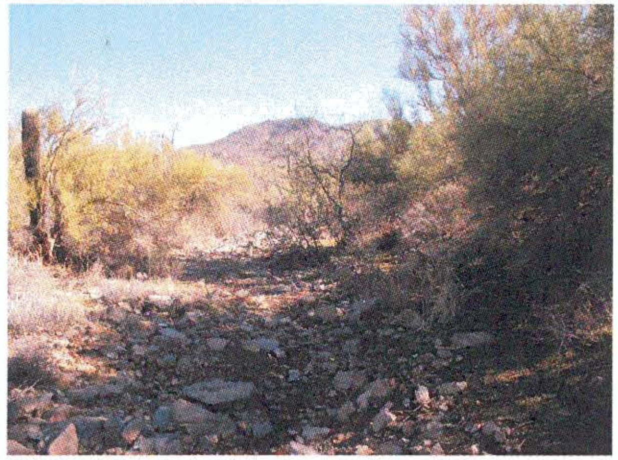


Figure 3-24. West Fork Apache Wash Tributary 1 typical channel. Note elevation of saguaro on left bank relative to channel bed elevation.

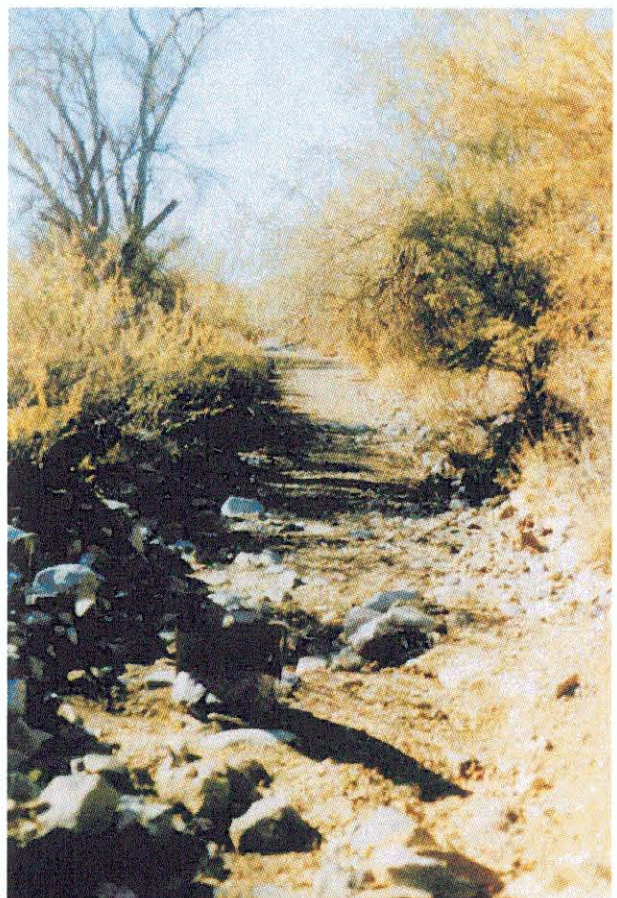


Figure 3-25. Paradise Wash typical channel.

Figure 3-26. Paradise Wash West Fork typical channel.

Figure 3-27. Ranieri Tank Wash typical channel. Note small channel and minimal floodplain topographic containment.

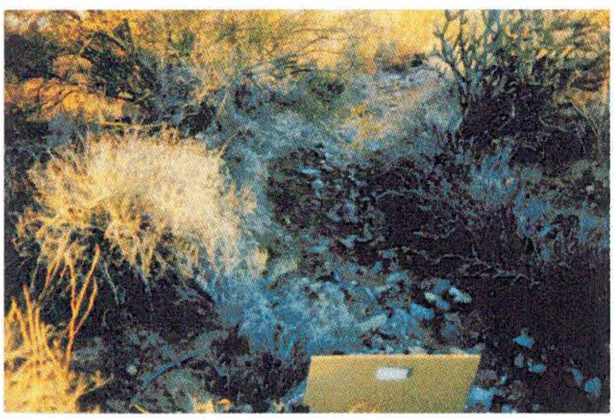


Figure 3-28. Ranieri Tank Tributary 2 typical channel.

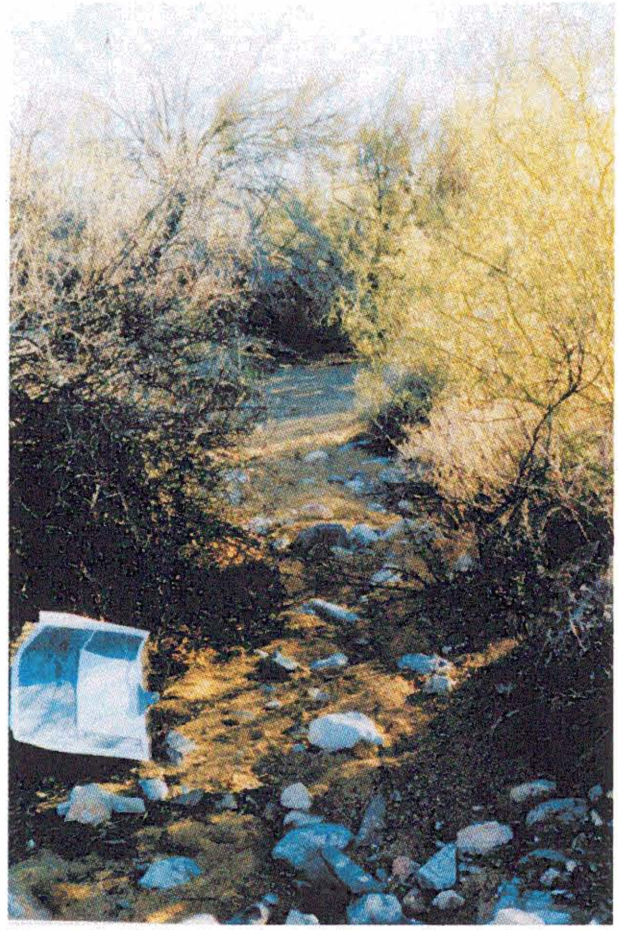


Figure 3-29. Ranieri Tank Tributary 1 typical channel with small channel and bimodal sediment distribution.

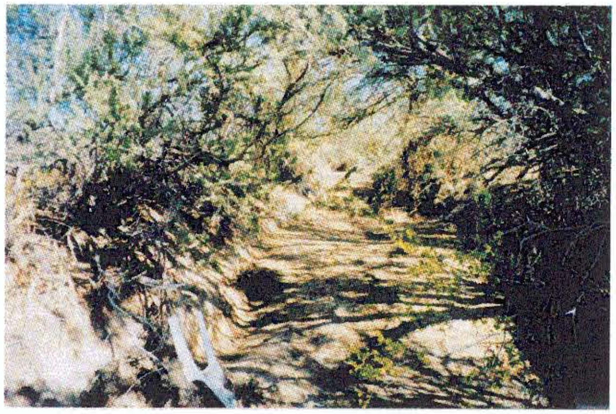


Figure 3-30. Desert Hills Wash typical channel with minor (~1 ft.) incision.

Figure 3-31. Desert Hills Wash typical channel north of Carefree Highway. Mid-channel vegetation suggests recent lateral movement.

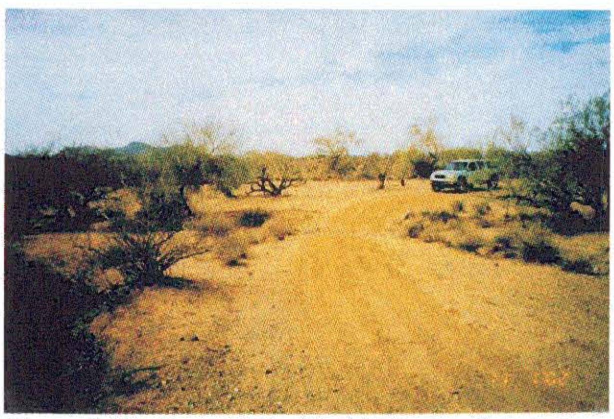


Figure 3-32. Desert Hills Wash Tributary 1 typical channel.

Figure 3-33. Desert Hills Wash Tributary 2 typical channel.

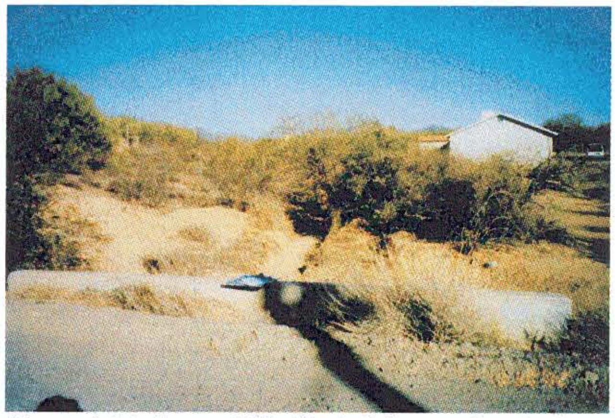


Figure 3-34. Desert Hills Wash Tributary 3 typical channel with home in floodplain adjacent to main channel.

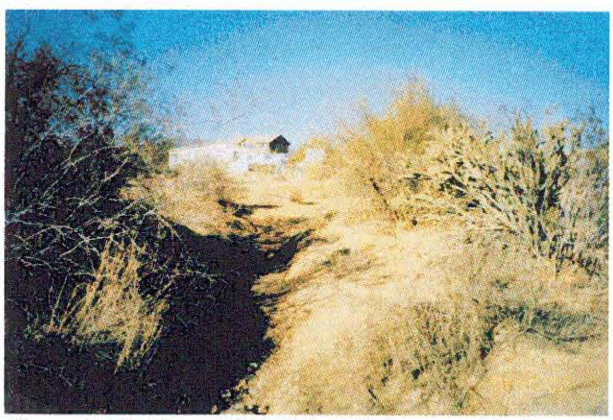


Figure 3-35. Desert Hills Wash Tributary 4 typical channel. Note downstream development.

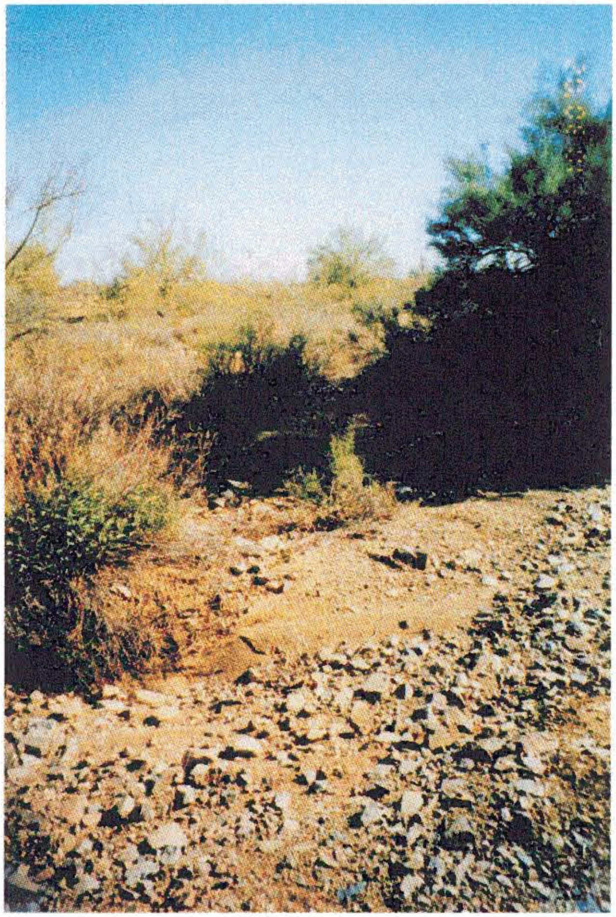


Figure 3-36. Desert Hills Wash Tributary 5 typical channel.

Figure 3-37. Desert Hills Wash Tributary 6 typical channel near headwaters.

Figure 3-38. Desert Lake Wash typical minor channel reach.

Figure 3-39. Desert Lake Wash typical channel in reach of dense floodplain vegetation.

Figure 3-40. Desert Lake Wash Tributary 2 typical channel.

Figure 3-41. Desert Lake Wash East Fork typical channel with extensive floodplain development.

Figure 3-42. Buchanan Wash typical channel section in non-incised reach upstream of the CAP.

Figure 3-43. Buchanan Wash typical channel section downstream of CAP.

Figure 3-44. CAP Wash East Branch typical channel.

Figure 3-45. CAP Wash West Branch typical channel.

Pleistocene/Holocene Lateral Erosion Rate. As required by the District's draft *Erosion Hazard Zone Delineation and Development Guidelines*, the entire Holocene floodplain is considered part of the erosion hazard zone for a Level 3 limited detail analysis. Where the main channel is actively eroding a Pleistocene surface, the rate of lateral erosion of the Pleistocene surface must be estimated to delineate the EHZ. For the Adobe ADMP erosion hazard zone delineation, the Pleistocene surface erosion rate was established by comparison of historical aerial photographs, use of results of previous detailed lateral migration studies (JEF, 2000; 2001, 2002), and by evaluation of Holocene surface corridor widths as illustrated in Figure 3-46. A rule of thumb established from previous detailed studies is that erosion of the Pleistocene surface on the largest streams in the study area is less than one foot per year, except at sharp channel bends with active cut banks. Previous watercourse master plans conducted for the District have used a 60-year planning period (i.e., 60 feet of erosion @ 1ft./yr.) for erosion hazard delineation. The long-term lateral erosion rate outside the Holocene floodplain over geologic time can be estimated from the width of the Holocene floodplain, as illustrated in Figure 3-46.

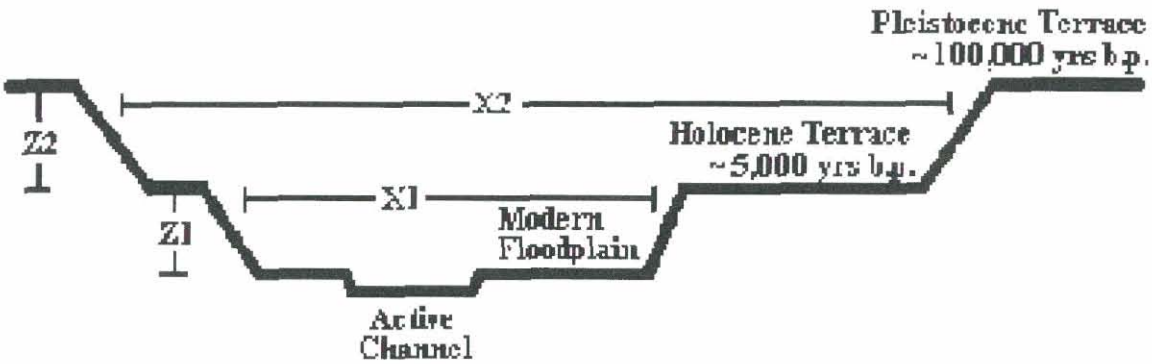


Figure 3-46. Idealized sketch of riverine terraces and implications for estimating minimum long-term lateral movement. The long-term average rate of erosion of the Pleistocene/Holocene terrace margin is equal to X2/surface age. For example, a 1,000 foot wide Holocene surface adjacent to a 100,000 year old late Pleistocene surface has a minimum rate of long-term movement of 0.01 ft/yr (maximum rate of corridor widening).

Where an active channel in the Adobe ADMP study area abutted a Pleistocene (or older) surface, the erosion hazard zone was delineated by considering the width of the Holocene floodplain, known rates of lateral migration established by comparing historical and modern aerial photographs, and the regional rate of corridor widening established from other studies.

Floodplain/Floodway Mapping. The existing regulatory floodplain and floodway delineations were considered for delineation of erosion hazard zones. Detailed floodplain and floodway delineations were available for all the stream reaches considered, and included the following studies:

- Floodplain Delineation Study of Cline Creek & Tributary Washes, 1990, Michael Baker
- Skunk Creek Flood Insurance Study, 1978, Harris Toups
- Rodger Creek Floodplain Delineation Study, 1990, Michael Baker, Jr.
- Apache Wash Floodplain Delineation Study, 1993, Jerry R. Jones & Associates.

- Skunk Creek Floodplain Delineation, 1995, Montgomery-Watson Engineering
- Floodplain Delineation Study of Skunk Tank Wash, 1997, EEC-MKE.
- Floodplain Delineation Study & Topographic Mapping of the Desert Hills Area, 1999, Stanley Consultants.
- Topographic Mapping & Floodplain Delineation Study for Tributaries to Skunk Creek, 2000, Simons Li & Associates.
- Sonoran Wash Floodplain Delineation Study, 2002, Stantec Consulting.
- Buchanan Wash Floodplain Delineation Study, 1987, AGK Engineers

The following floodplain and floodway characteristics were considered for the erosion hazard zone delineations:

- 100-Year Discharge. In general, the larger the 100-year peak discharge, the greater the risk of lateral erosion and scour. Streams with large regulatory discharges tend to have wider erosion hazard zones.
- Floodplain Flow Depth. The depth of flow on the floodplain is an important characteristic for identifying potential channel avulsions, as described below. The greater the depth of flow on the floodplain, the greater the potential for a channel avulsion. Floodplain flow depths were estimated by comparing topographic mapping and regulatory flood elevations shown on the floodplain delineation study work maps.
- Floodplain Limits. Common sense dictates that erosion hazards are greatest in areas that are flooded. Any area within the regulatory floodplain was considered for possible inclusion in the erosion hazard zone.
- Floodway Limits. Floodways include the areas of most frequent flow, as well as the portions of the channel subject to the greatest flow depths and velocities, and therefore have the greatest erosion potential. In general, the erosion hazard zones include the regulatory floodway.

Identification of Avulsion Areas. Channel avulsions are responsible for some of the largest magnitudes of known lateral channel movement in Arizona. An avulsion occurs when a new channel forms in an area that was formerly part of the floodplain, leaving an island of relatively high ground between the former and current channel locations. The potential for avulsive channel change increases as the frequency of inundation, depth of inundation, and duration of inundation increases. In order for an avulsion to occur, the floodplain must be subject to inundation for a long enough duration for erosion of a new channel to occur. Therefore, to be avulsive, a floodplain must be flooded at great enough depth, velocity and frequency to cause channel formation. Some of the floodplain and channel characteristics that are indicative of avulsive conditions are listed below. No single characteristic was considered solely diagnostic of avulsive conditions, but where several characteristics were observed in the field or on aerial photographs and maps, the stream corridor was considered subject to avulsions.

1. The 100-year maximum (not average) flow depth in the floodplain is greater than two feet.
2. The 100-year maximum velocity in the floodplain is greater than four feet per second, or the product of 100-year floodplain depth and velocity squared is greater than 18 ($dv^2 > 18$).

3. The 10-year flood is not contained in main channel.
4. Lack of, or minimal, topographic relief between main channel invert and floodplain elevation
5. Evidence of frequent overbank flooding such as flood damage records and high water marks.
6. Perched channels and swales observed in the overbanks and floodplain created by concentration of floodplain flow, tributary inflow to the floodplain, or physical modification of the floodplain.
7. Meander cutoff channels present in stream reaches located upstream or downstream.
8. The overbank topography indicates continuous flow paths have formed in the floodplain (floodplain contours bend in the upstream direction).
9. Lack of upland or mature vegetation in the floodplain.
10. Lack of bank vegetation along the main channel and/or minimal differences between the channel, channel bank, and floodplain vegetation.
11. Hummocky bar and swale terrain in the floodplain caused by sculpting of floodplain surface by flooding, sediment transport, and scour.
12. Fresh gravel and coarse sand deposits in continuous swales located within the floodplain or in overbank channels.
13. Alignments of large trees (living or dead) in the floodplain of similar species to bank vegetation that identify former or forming avulsive flow paths.
14. Islands of older geomorphic surfaces of low relief inset within younger floodplain deposits that indicate former incision of the floodplain.
15. Tributary channels that flow parallel to the main channel across the floodplain that may become conduits for future avulsive flows.
16. Rapid and significant changes in main channel geometry and capacity, particularly alternating single and highly braided reaches.

Information for identifying potential channel avulsions was obtained from floodplain delineation study work maps, detailed topographic mapping of floodplains, soil and surficial characteristics, field observations, aerial photographs, and geomorphic mapping.

Recommended Erosion Hazard Zone. Erosion hazards were delineated using the information summarized above. In addition, the following principles were applied when delineating the EHZ lines:

- Corridor width. The EHZ encompasses a width defined by the width of the main channel, including the width of the short braided reaches and small confined avulsive reaches that occur within the single channel reaches. That is, the EHZ allows a sufficient width for future braiding and small confined avulsions along the main channel.
- Bank vegetation. The EHZ was delineated along the outside of the canopy of the vegetation lining the main channel banks. *If bank vegetation is removed, the EHZ should be widened to account for increased bank erosion.*
- Channel bends. The EHZ is wider on the outside of channel bends than in straight reaches.
- Road crossings. The EHZ is wider at road crossing where undersized culverts increase the potential for erosion outside the main channel.

- Fences. The EHZ is widened to reflect the likely effect of fences that block or divert the main channel.
- Field judgment. The EHZ reflects the judgment of the project geomorphologist's interpretation of the field conditions with respect to future erosion potential.

The recommended erosion hazard zone lines shown on Exhibit 3-1 are intended to delineate the areas likely to be impacted by future lateral erosion, or the areas for which more detailed analysis is warranted prior to future development. The recommended erosion hazard zone is based on the engineering judgment and experience of the project engineer and geomorphologist, and therefore cannot be reduced to a single formula or series of equations. In general, the recommended erosion hazard zone is conservative. Exhibit 3-1 is intended for illustrative purposes only. The erosion hazard zone boundaries were delivered to the District in digital format for incorporation into the District's GIS. It is anticipated that the District's GIS will be used by Regulatory and Permitting staff.

3.3 Conclusions

Based on the methodologies described above used to evaluate the erosion hazards, the following general conclusions can be drawn for the streams in the Adobe ADMP study area:

- Cut banks, which are evidence of recent and ongoing bank erosion, occur throughout the study area, especially on channel bends, where the channels have experienced some degree of long-term degradation, and where bank vegetation has been removed.
- Lateral erosion should be expected within the Holocene floodplain.
- Lateral erosion will occur in response to two types of flooding:
    - Single floods – floods that fill the main channel and flow onto the floodplain will cause significant amounts of lateral erosion at specific locations. Floods greater than about the 5-year peak discharge will typically cause this type of erosion.
    - Series of floods – lateral erosion will occur in response to series of smaller floods that combine to produce significant amounts of cumulative erosion over time periods equivalent to the design life of the structures proposed in or near the streams in the study area.
- Holocene floodplain soils appear to be composed of highly erosive materials that lack resistance to lateral erosion or formation of avulsive channels.
- The streams in the study area have been subject to channel avulsions, local scour, and channel migration, all of which indicate significant lateral erosion hazards.
- The streams in the study area have a high sediment transport capacity, and could cause significant lateral erosion if sediment supply is decreased.
- Caliche or clay-rich soils do not prevent lateral erosion, though they may significantly slow the rate of lateral erosion.
- Bedrock does prevent lateral erosion.

- Except on portions of Skunk Creek, significant long-term degradation has not occurred in the study area, except where the channel has been disturbed by human impacts such as encroachment, construction of road crossings, or diversion for stock ponds.
- Erosion hazards are most significant on the largest watercourses in the study area.

3.4 Limitations and Assumptions

Any technical analysis is limited by the data available, the contracted scope of services, and the assumptions of the methodologies used. For the Adobe ADMP erosion hazard assessment, the following general limitations apply:

- Hydrologic Data. No streamflow gauging data were available for any of the streams in the study area except Skunk Creek. Estimates of the 100-year discharges were obtained from hydrologic modeling performed for this study and by others, and from floodplain delineation studies performed by others, as described below. Gauged streamflow data for these streams would improve the accuracy of the erosion hazard evaluation.
- Hydraulic Modeling. HEC-2 and HEC-RAS models were prepared for the streams in the study area by others for the purpose of delineating the 100-year floodplain and floodway. Optimization of the HEC-2 and HEC-RAS input files for modeling erosion hazards rather than 100-year floodplain may improve the accuracy of the delineation, but was not part of the scope of services for this study.
- Geotechnical Data. No geotechnical data were available for the study area. More accurate predictions of existing lateral erosion hazards could be made if extensive geotechnical investigations were completed along the stream corridors or at individual properties.
- Level of Detail. The erosion hazard zones determined for this evaluation are based on the draft Level 3 limited detail methodology, observations made during field reconnaissance, interpretation of historical aerial photographs and topographic maps, and consideration of previously published reports. It is possible that the recommended erosion hazard zones could be refined by applying the more detailed methodologies, such as those used in the District's Watercourse Master Plan studies (c.f., JEF, 2000).
- Additional Erosion Hazards. Riverine erosion and flood hazards exist along all of the watercourses in the study area, regardless of their size. In addition, erosion from slope processes will occur on steep slopes within the study area. This study is limited to evaluation of riverine erosion hazards on the stream segments listed above.
- Scale of Analysis. The evaluation described in this technical memorandum considered approximately 75 miles of river corridors. It is possible that more detailed evaluation of shorter reaches or specific sites could improve the accuracy of the predictions of future channel behavior in those reaches.

3.5 Reference

EEC-MKE, 1997, Floodplain Delineation Study of Skunk Tank Wash.

Flood Control District of Maricopa County, 2003, Draft Erosion Hazard Zone Delineation and Development Guidelines.

JE Fuller/ Hydrology & Geomorphology, Inc, 2000, Upper Cave Creek/Apache Wash Lateral Migration Report, Appendix to the Upper Cave Creek/Apache Wash Watercourse Master Plan. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2000, Skunk Tank Wash Erosion Hazard Study. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2001, Agua Fria River Watercourse Master Plan, Lateral Migration Report. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2001, Rodger Creek Erosion Hazard Study. Report to the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2001, Skunk Creek/Sonoran Wash Watercourse Master Plan – Attachment 6: Lateral Stability Assessment. Report to the Flood Control District of Maricopa County and ASL Consulting.

Jerry R. Jones & Associates 1993, Apache Wash Floodplain Delineation Study.

Michael Baker, Jr., 1990, Floodplain Delineation Study of Cline Creek & Tributary Washes.

Michael Baker, Jr., 1990, Rodger Creek Floodplain Delineation Study.

Montgomery-Watson Engineering, 1995, Skunk Creek Floodplain Delineation.

Simons Li & Associates, 2000, Topographic Mapping & Floodplain Delineation Study for Tributaries to Skunk Creek.

Stanley Consultants, 1999, Floodplain Delineation Study & Topographic Mapping of the Desert Hills Area.

Stantec Consulting, 2002, Sonoran Wash Floodplain Delineation Study.

Section 4: Sediment Yield

4.1 Introduction

Sediment yield is defined as the volume of soil material and stream sediment that is transported from a watershed through its stream network. Sediment yield is an important design parameter for flood control structures because sediment deposition in dams, reservoirs, or floodways reduces the storage or transport capacity. Reduced capacity of flood control structures increases the likelihood of a spillover during floods, increasing the chance of injuries, damage to the structure itself, downstream property damage, and even loss of human life. Sediment yield is also an important parameter for evaluating erosion and sedimentation hazards of stream systems because a sediment deficit or excess can lead to lateral erosion, long-term degradation, or increased flooding levels. Planning level estimates of existing and future condition sediment yield for the Adobe ADMP study area (Task 2.7.3) were made by applying the results from detailed sediment yield analyses performed for previous WCMP and ADMP studies. Sediment yield estimates will be used to predict sediment storage requirements for regional retention/ detention facilities and to predict channel responses to changing watershed conditions.

4.2 Sediment Yield Estimates From Previous Studies

Sediment yield estimates were previously prepared using a variety of detailed methodologies for the following District projects:

- North Peoria ADMP Sedimentation Engineering & Geomorphic Evaluation (JEF, 2002)
- Spook Hill ADMP Sedimentation Analysis (JEF, 2000)
- Upper Cave Creek/Apache Wash WMP (Hjalmarson, 1998)
- Tatum Wash Sedimentation Study (JEF, 1997)
- Casandro Dam Design Report (CH2M HILL, 1994)
- Rawhide Wash Feasibility Study (CH2M HILL, 1994)

For the Adobe ADMP, the results of previous sediment yield analyses were used to estimate sediment storage requirements and to predict the range of possible channel responses to changes in sediment supply caused by future development and management strategies. As shown in Figure 4-1 and Table 4-1, previous average annual sediment yield estimates in Maricopa County have ranged over several orders of magnitude depending on watershed cover, land use, slope, geology, soils, vegetation, and channel conditions. The arithmetic average of the yield estimates of 0.6 ac-ft/mi^2/yr (Table 4-1) reasonably depicts the upper limit of most of the previous sediment yield estimates (Figure 4-1), and therefore may be used as a conservative average annual sediment supply rate for planning level analysis for the Adobe ADMP. The U.S. Army Corps of Engineers estimated an average annual sediment yield of 0.3 ac-ft/mi^2/yr for the Cave Buttes Dam design (JEF, 2001).

Estimates of sediment yield for a single flood range more widely than estimates of average annual sediment yield, primarily because the sediment supply rate for a watershed is highly dependent on the duration and shape of the design hydrograph, in addition to the watershed parameters listed above. Previous sediment yield studies (JEF, 1997; JEF, 2000; JEF, 2002) have concluded that the sediment yield for individual flood events can be reasonably approximated using an assumed sediment concentration. Field measurements of sedimentation concentration by the USGS in Arizona indicate that the normal suspended sediment load is typically less than five percent (5%) of the water discharge, though values exceeding 50% have been measured during individual floods in some parts of the Southwest (JEF, 1997). The bed material load averages only about 10% of the total load. Therefore, a total sediment concentration of 5% should conservatively predict the sediment supply for typical floods in the Adobe ADMP study area.[1]

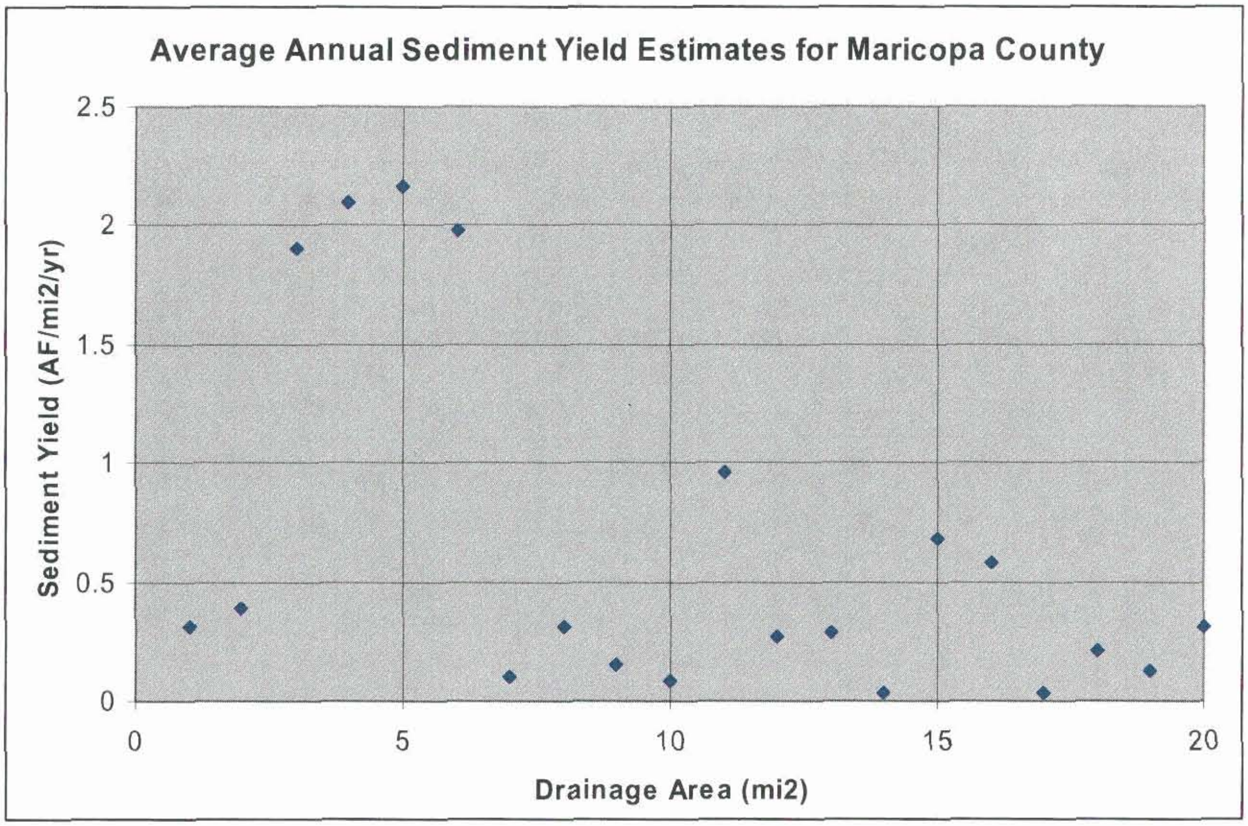


Figure 4-1. Average annual sediment yield estimates from previous studies of watersheds in Maricopa County.

[1] USGS records indicate that the average annual water volume at the Skunk Creek near Phoenix, AZ (#09513860) gage is 17.4 AF/mi^2/yr. 5% of the average annual water volume is 0.9 AF/mi^2/yr, which is reasonably close to the 0.6 AF/mi^2/yr recommended as the average annual sediment yield for the Adobe ADMP study area.

Table 4-1. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Summary of Previous Sediment Yield Results

Watershed Name	Area (mi^2)	Average Annual Sediment Yield (ac-ft/ mi^2/yr)
Casandro Wash[1]	1.2	0.31
Rawhide Wash[1]	13.6	0.39
Phoenix Mountain Preserve (Tatum Wash)[2]	1.9	1.9
Shea Boulevard (Tatum Wash)[2]	2.2	2.1
Western Tributary (Cherokee Wash)[3]	0.1	2.16
Desert Park Tributary (Cherokee Wash)[3]	0.3	1.98
Desert Greenbelt Project, AZ[4]	8.6	0.10
Cave Creek, AZ[4]	121.0	0.31
Spookhill Dam, AZ[4]	16.4	0.15
Saddleback Dam, AZ[4]	30.0	0.08
Davis Tank, AZ[5]	0.2	0.96
Kennedy Tank, AZ[5]	1.0	0.27
Juniper Wash, AZ[5]	2.0	0.29
Alhambra Tank, AZ[5]	6.6	0.03
Black Hills Tank, AZ[5]	1.1	0.68
Black Hills Tank, AZ[6]	1.6	0.58
Mesquite Tank, AZ[5]	9.0	0.03
Tank 76, AZ[5]	1.2	0.21
1.1.1.1.1 Spook Hill ADMP[7]	3.0 -14.0	0.13
1.1.1.1.2 North Peoria ADMP[8]	0.1-32.9	0.31
	Average	**0.65**

1. CH2M-Hill, 1994
2. JE Fuller, 1997
3. WEST Consulting, 1997
4. Hjalmarson, 1996
5. Peterson, 1962
6. Langbien, Hains and Culler, 1951
7. JE Fuller, 2000
8. JE Fuller, 2002

4.3 Sediment Yield Trends From Previous Studies

Previous sedimentation analyses conducted for the District have reported the following conclusions regarding sedimentation and flood control planning:

- Predicted and actual sediment yield vary widely. Regular inspection and maintenance of flood control facilities is required to assure performance.

- Sediment yield typically increases with watershed development, primarily due to the increased rate and volume of runoff. After initial urbanization is completed, and the percent of impervious cover increases, sediment yield typically decreases (JEF, 2000; 2002).
- Sediment yield is low for developed watersheds with low slopes (JEF, 2000)
- High sediment yield should be expected for watersheds that are steep, near a mountain front, poorly vegetated, and developed with no retention basins (JEF, 2000).
- Sediment yield decreases in watersheds where the County's 2-hour, 100-year on-site retention is enforced (JEF, 2002).
- On-line detention basins have greater impacts on sediment yield than side-weir detention basins (JEF, 2002).

4.4 Application to the Adobe ADMP Study Area

The results and conclusions of previous sediment yield studies can be applied to the Adobe ADMP study area to predict potential sedimentation impacts. Portions of the Adobe ADMP study area are currently undeveloped, although the pace of development in the watershed has increased dramatically in the past 10 years. Sedimentation impacts related to future development will depend on the style of development. The following sedimentation impacts related to future sediment yield should be expected:

- Unincorporated Maricopa County. The unincorporated portions of the study area include the areas north of Cloud Road in the Skunk Creek watershed, and the Desert Hills watershed.
    - Future Development. If current trends continue, the unincorporated areas will continue to develop as lot splits and small subdivisions with minimal drainage infrastructure and on-site retention.
    - Sediment Yield. Sediment yield from the unincorporated portions of the watershed will tend to increase with the increase in storm water runoff, as documented in the previous sediment yield studies. However, experience indicates that the increased impervious cover from development increases the water yield at a faster rate than the sediment yield, creating a sediment deficit.
    - Channel Response. The sediment deficit created by the increased transport capacity will be expressed as lateral erosion and incision (long-term degradation) of minor tributaries to the main stem elements of the Skunk Creek and Apache Wash stream system. Some areas of temporary local deposition may occur at tributary confluences with main stem stream segments, but will tend to be removed during floods on the main stem streams.
    - Mitigation Measures. Mitigation measures for expected channel erosion in the unincorporated areas may include designing road crossings to function as grade control structures, developing and enforcing single lot retention standards, construction of small regional retention facilities, minimizing floodplain encroachment to allow room for increased lateral erosion, and enforcing erosion hazard setbacks on all watercourses.

- Incorporated Communities. Currently, the City of Phoenix and the westernmost part of the Town of Cave Creek are the only incorporated areas in the Adobe ADMP study area. The incorporated portions of the study area are located generally downstream of Cloud Road in the Skunk Creek watershed.
    - Future Development. The City of Phoenix is likely to require on-site retention of the 2-hour, 100-year event in all new developments, which will significantly reduce the total water and sediment yield to the Skunk Creek stream system, although the frequency of runoff in reaches adjacent to impervious areas that drain directly to the stream system will increase.
    - Channel Response. Because the incorporated areas with retention are located downstream of the unincorporated areas without retention, the net sediment yield in the main stem of Skunk Creek is likely to increase. However, because most of Skunk Creek downstream of the CAP has been narrowed, channelized, and encroached by development, any increase in sediment yield (supply) from the upper watershed is unlikely to induce significant long-term deposition due to the increase in sediment transport capacity.
    - Mitigation Measures. Regular inspection and periodic maintenance should be performed to assure the adequacy of the existing channelized reach of Skunk Creek downstream of I-17.

The recommended value for average annual sediment yield of 0.6 ac-ft/mi^2/yr is conservative enough to accommodate evaluation of the expected short-term increase in sediment yield during urbanization, and thus may be used as the future conditions sediment yield rate for planning purposes.

4.5 Summary

Previously completed sediment yield analyses were used to predict planning-level sediment yield rates for the Adobe ADMP watershed. The recommended average annual and single event sediment yield rates are summarized in Table 4-2.

Table 4-2. Adobe ADMP Sedimentation Engineering & Geomorphic Analysis Recommended Sediment Yield Values

Event	Recommended Yield
Average Annual	0.6 AF/mi2/yr
Single Event	5% of water volume

Future development of the study area is likely cause changes in sediment yield. In unincorporated areas in the upper watershed, sediment yield will increase due to increased runoff rates and will cause long-term degradation and lateral erosion in minor tributaries and collector channels. In the incorporated areas, changes in sediment yield are unlikely to significantly impact the existing channelized reaches of Skunk Creek.

4.6 References

CH2M-Hill, March 1994, Casandro Wash Dam, Prepared for Flood Control District of Maricopa County.

CH2M-Hill, August 1994, Rawhide Wash Detention Basin, Prepared for Flood Control District of Maricopa County.

Hjalmarson, H. W., 1996, City of Scottsdale Desert Greenbelt Project, Review of Sediment Yield. Report prepared for George V. Sabol Consulting Engineers, Inc.

JE Fuller/Hydrology & Geomorphology, Inc., 1997, Tatum Wash Sedimentation Study. Report prepared for the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2000, Spook Hill Area Drainage Master Plan Update Sedimentation Analysis. Report prepared for Wood/Patel Associates & the Flood Control District of Maricopa County.

JE Fuller/Hydrology & Geomorphology, Inc., 2002, North Peoria Area Drainage Master Plan Sedimentation Engineering and Geomorphic Analysis. Report prepared for Stantec Consulting, & the Flood Control District of Maricopa County.

WEST Consulting, June 1997, Cherokee Wash Hydrologic, Hydraulic, and Sedimentation Study, Prepared for Flood Control District of Maricopa County.

Section 5: Development Guidelines

5.1 Introduction

This Section lists proposed best management practices for management of sediment and scour at drainage crossings and other structural flood control features (Task 2.7.4). The best management practice recommendations are intended for use by the City of Phoenix and Maricopa County for management of future development, and were developed based on the results of the sedimentation engineering and geomorphic evaluation performed for the Adobe ADMP. The following types of best management practices are recommended:

- Erosion Hazard Zones
- Maintenance of Bank Vegetation
- Maintenance of Riparian Corridors
- Drainage Crossing Design
- Conveyance Requirements
- Erosion Hazard Evaluation
- Downstream Impact Assessment
- Channel Restoration

In addition, general design guidelines for structures that may impact sedimentation, erosion, and sediment continuity are provided.

5.2 Erosion Hazard Zones

Erosion hazard zones were defined for the significant watercourses in the Adobe ADMP study area. The recommended best management practice for the erosion hazard zones is to prohibit construction of permanent or habitable structures within any delineated erosion hazard zone. Alternatives to the recommended best management practice for erosion include the following:

- Detailed Analyses. In some cases, the erosion hazard zones delineated for the Adobe ADMP sedimentation engineering and geomorphic analysis may be refined by a more detailed analysis. Such analyses should be completed by a registered professional engineer and qualified fluvial geomorphologist using a detailed Level 3 erosion hazard methodology as defined in the District's draft *Erosion Hazard Zone Delineation and Development Guidelines*.
- Low Impact Alternatives. Low impact alternatives for development within erosion hazard zones are provided in Conveyance Requirements discussion below and were detailed in the *North Peoria ADMP Sedimentation Engineering and Geomorphic Analysis* – Chapter 5 (JEF, 2002). Low impact alternatives consist of methods of constructing erosion protection that have minimal impacts on channel morphology, downstream channel reaches, and adjacent properties.

Erosion hazards exist to some degree on all watercourses in the Adobe ADMP study area. New development should be set back a safe distance from any watercourse.

5.3 Maintenance of Bank Vegetation & Riparian Corridors

Bank vegetation and riparian corridors provide habitat, erosion protection, aesthetic benefits, water quality, and other vital functions along stream corridors in the Adobe ADMP study area. The recommended best management practices for bank vegetation and riparian corridors include the following:

- Bank Vegetation. Bank vegetation should not be disturbed for any reason. Where vegetation must be removed for construction, it should be replaced with equivalent plants. Irrigation, inspection, and maintenance may be required to assure survival of replacement vegetation. The recommended low impact alternatives described in the Conveyance Requirements discussion below and detailed in the *North Peoria ADMP Sedimentation Engineering and Geomorphic Analysis* – Chapter 5 (JEF, 2002) assume that bank vegetation will not be disturbed. Therefore, the following best management practices for bank vegetation are recommended:
    - Subdivision lots should be platted so that individual homeowners do not own the channel banks. The erosion hazard zones or riparian corridors should be held as common areas or dedicated for public ownership. Along many streams in Arizona, homeowners cut or thin bank vegetation to gain better views of the stream, thus initiating or accelerating bank erosion.
    - Open space and common areas that include watercourses should be wide enough to encompass the bank vegetation and riparian zone adjacent to the main channel.
    - Educational material should be provided to homeowners, homeowner associations, and developers regarding the importance of maintaining healthy bank vegetation for flood and erosion control, as well as for habitat preservation.
    - In general, on-line retention is not recommended. Where on-line retention is used, irrigation of bank vegetation in downstream reaches should be required to preserve the health of the riparian corridor and limit the potential for decreased bank stability.

- Riparian Corridors. Riparian vegetation should be preserved or replaced where disturbed by floodplain development. The recommended low impact alternatives described in the Conveyance Requirements discussion below and outlined in the *North Peoria ADMP Sedimentation Engineering and Geomorphic Analysis* – Chapter 5 (JEF, 2002) assume that any disturbance of the riparian corridor will be mitigated, and that additional vegetation will be planted along the banks and within the floodplain. Planting of vegetation in active channels should be discouraged.

In general, the erosion hazard zones delineated for the Adobe ADMP encompass the entire riparian corridor and vegetated stream banks. Therefore, implementation of the erosion hazard zone best management practice will also help assure preservation of bank vegetation and riparian corridors.

5.4 Drainage Crossing Design

Poorly designed drainage crossings can have major sedimentation and erosion impacts on adjacent stream reaches. The types and severity of impacts vary with structure type, local geology, channel characteristics, and flood dynamics. Based on their likely impacts on channel stability, the following best management practices for roadway crossing design are recommended for the major watercourses in the Adobe ADMP study area:

- Bridges are preferable to culverts. Bridges typically have less impact on channel stability than culverts due to the wider opening, decreased likelihood of headwater ponding, minimal disturbance of channel geometry, and the natural stream bed.
- At-grade crossings are preferable to undersized culverts. Undersized culverts are those that do not meet the recommended span and rise criteria defined below. At-grade crossings should match the natural channel and floodplain geometry as closely as possible.
- Culvert span (width) should be as wide as the main channel (top of left bank to top of right bank). Culverts that do not obstruct the main channel will have less frequent impacts on channel stability than culverts that block the main channel. Culverts that do not widen the main channel will have less frequent problems with sediment deposition and will require less maintenance.
- Culvert rise (height) should be at least as high as the average main channel bank height. Culverts that do not obstruct the main channel will have less frequent impacts on channel stability than those that do.
- Because of the expected increase in channel instability in adjacent stream reaches, in-line detention facilities at roadway crossings are not recommended.
- Where braided or multiple channels exist, relief structures should be provided to maintain overbank flow paths, preserve overbank conveyance, and prevent floodplain sedimentation.
- Roadway crossings should be regularly maintained and inspected to identify potential problems and impacts to channel stability, and to assure structure performance. Maintenance should include removal of sediment from the roadway, replacement of material scoured from the downstream lip, and restoration of channel banks that are threatening roadway approaches. Sediment removed from the right of way should be placed in the channel downstream of the crossing and graded to the natural channel geometry. Sediment should never be placed in berms upstream of the crossing.
- To prevent formation of scour holes or ponding areas, erosion protection should be provided where roadway or subdivision clear-water runoff directly enters the stream channel.

5.5 Conveyance Requirements

The best management practice for conveyance requirements is to maintain the form and function of the natural stream system to the greatest degree possible. The following low impact definition criteria are intended to achieve the best management practice of minimum disturbance of the natural system:

- Minimal velocity increase.
  - The average 10-year velocity in the channel or overbank should not change (± 0.0 fps).
  - The average 100-year velocity in the channel or overbank should not change (increase or decrease) by more than 10 percent or 1 foot per second (fps), whichever is less.
- Minimal water surface elevation increase.
  - The 10-year water surface elevation or energy grade line should not change (± 0.0 ft.).
  - The 100-year water surface elevation or energy grade line should not increase or decrease by more than 0.1 foot.
- Minimal change in floodplain width
  - The 10-year floodplain width should not change (± 0.0 ft.).
  - Alteration of the natural vegetation and ground elevations within the 10-year floodplain should be minimized, except for purposes of restoration of disturbed areas to natural conditions.
- Minimal disturbance of the main channel.
  - The bankfull width of the main channel should not decrease.
  - The streambed in the main channel should not be excavated or deepened.
  - Bank vegetation should not be removed. Where bank vegetation is temporarily disturbed by construction, it should be replaced, monitored for health, and irrigated if required to assure its survival.
  - The low-flow channel should not be relocated within the floodplain.
- No offsite impacts.
  - No erosion, sedimentation, or flood impacts to adjacent properties should be permitted without the written permission of all affected property owners.
  - Engineering and geomorphic analysis will be required to demonstrate no long-term, short-term, or 100-year offsite impacts.
- Preservation of natural landscape character and habitat within the floodplain.

The less the natural channels and floodplains are disturbed, the less sedimentation, erosion and flood problems will occur. Where channelization and development cannot meet the low impact criteria, the developer should be required to evaluate downstream sedimentation impacts as defined below.

5.6 Erosion Hazard Evaluation

New erosion hazard zones may be delineated using the procedures provided in the District's draft *Erosion Hazard Zone Delineation and Development Guidelines*. Erosion hazard zones delineated for the Adobe ADMP should not be modified unless a Level 3 detailed analysis is performed as described in the *Erosion Hazard Zone Delineation and Development Guidelines*.

5.7 Downstream Impact Assessment

Development within the floodplain or erosion hazard zone can have impacts on the stability of adjacent stream reaches. Engineering analysis of potential downstream impacts should be required if the low impact criteria outlined above are not met. Detailed descriptions of the types of analyses required to demonstrate that a proposed stream alteration will not impact adjacent properties are provided in the District's draft *Erosion Hazard Zone Delineation and Development Guidelines* (Section 4.3) and the District's *Sand and Gravel Floodplain Use Permit Application Guidelines* (Section 6.5). At minimum, detailed evaluations of downstream impacts should include the following:

- Range of discharges. The hydrologic, hydraulic, and sediment impacts for a range of discharges, not just the 100-year event, should be considered.
- Long-term impacts. The probable long-term channel responses should be considered based on geomorphic analysis of the stream system and known historical responses, rather than on the expected response for a single flood event.

In general, if the low impact criteria are implemented, downstream impacts will be negligible.

5.8 Channel Restoration

If the best management practices for erosion hazard zones, maintenance of bank vegetation and riparian corridors, and drainage crossing design are implemented, there will be no need for channel restoration. However, in the event the human activities create local channel disturbances that require restoration, the following best management practices are recommended:

- Plant Species. Use of native vegetation is encouraged to assure high survival rates and to minimize environmental impacts. Plants should be selected using the following criteria:
    - Flood tolerance vs. planting zone. Only flood tolerant plants should be planted in areas likely to be flooded.
    - Drought tolerance. Drought tolerant plants are more likely to survive over the long-term.

- Deep rooting. Deep rooting plants withstand erosion better than shallow rooting plants, and are more likely to find a natural, sustained water supply.
- Habitat value. Use of plant species with high habitat value is encouraged.
- Ground cover. True ground cover species are generally not found in natural, non-irrigated settings. Plants with hanging branches may offer the same erosion protections as low growing ground cover.
- Native species. Use of plants native to central Arizona is encouraged.
- Vertical complexity. Design of a plant community with understory and overstory species is encouraged.

* Toe of Slope. Deep rooting, long-lived, woody species should be planted at the toe of bank slopes and along the bank slope up to the 10-year water surface elevation to minimize the potential for undercutting, to provide the greatest resistance to higher velocities, and to mimic natural riparian plant density and distribution. Planting of riparian vegetation at the toe of the bank is encouraged for the following reasons:
    - Toe protection. The root mass, trunk, and leaf canopy provide protection from erosion at the critical toe area of the bank.
    - Irrigation. Irrigation is easier to accomplish at the toe of the bank than on the bank slope.
    - Water table. Roots from species placed at the bank toe are more likely to reach the water table than those placed on the bank slope.
    - Undercutting. Plants at the bank toe are less likely to be undercut than plants on the bank slope.
    - Aesthetics. Use of larger plants at the floodplain elevation, with smaller upland species on the bank slope mimics the natural environment.
    - Water quality. Design of a denser swath of vegetation at the bank slope provides barrier, conduit, filter, and riparian sink functions for the stream corridor.
    - Water quantity. More frequent natural irrigation occurs at the toe of the bank than on the topographic higher parts of the floodplain.
* Bank Slope. Use of ground cover species is encouraged from the toe of slope to the 10-year water surface elevation.
* Top of Slope. Use of drought-tolerant desert species is recommended above the 10-year water surface elevation. Planting should mimic natural upland plant density and distribution.
* Irrigation. Irrigation may be required to assure plant survival, especially immediately after planting and for planting on upland slopes above the floodplain.
* Monitoring/Maintenance. A regular monitoring and maintenance program should be established to assure plant survival and assure that project goals are met. Monitoring should be conducted prior to the growing and planting seasons. Maintenance includes replacing dead plantings, removal of exotics, and other activities that preserve the natural form and function of the stream.
* Undercutting. Where the potential for long-term degradation to undercut bank vegetation is high, grade control should be provided to minimize the potential for undercutting of vegetated bank slopes.

- Landscape Character. Consideration of viewsheds and natural landscape character is recommended in design of revegetation.

Where channel change is caused by non-localized disturbances, such as watershed development, restoration activities must address the cause of channel change, rather than just the symptoms of instability occurring in the main channel. Where channel change is caused by natural disasters such as wildfire, the recommended best management practice is to allow the stream system to recover naturally. Only non-natural impacts should be addressed in restoration plans.

More detailed information on use of vegetation in channel restoration and design is provided in the following references:

- Briggs, M., 1996, Riparian Ecosystem Recovery in Arid Lands – Strategies and References. University of Arizona Press, Tucson, Arizona.

- Federal Interagency Stream Restoration Working Group, 1998, *Stream Corridor Restoration – Principles, Processes, and Practices.*

- Hoag et. al., 2001, Riparian Planting Zones in the Intermountain West, Information Series #16, Natural Resource Conservation Service – Plant Material Center, Aberdeen, Idaho.

5.9 General Design Guidelines

General sedimentation engineering design guidelines for development scenarios likely to occur in the Adobe ADMP study area were proposed for consideration for the recommended plan. The following development scenarios are discussed below:

- Floodplain Encroachment
- Channelization
- Roadway Crossings
- Utility Crossings

In addition, design of typical structural flood control solutions for sedimentation problems is discussed.

Floodplain Encroachment. Floodplain encroachment is defined as any development in the 100-year floodplain that alters the natural hydraulic conditions of a stream. Floodplain encroachment is commonly known to have the following effects:

- Velocity. Encroachment generally increases channel and overbank velocities. Because velocity is exponentially related to sediment transport rate and erosion potential, higher velocities generally cause increased scour and lateral erosion rates.
- Flow Depth. Encroachment increases the flow depth by reducing the channel and floodplain area available for conveyance. Increased depth results in higher risk of avulsions, greater scour depths, and increased erosive force on the channel banks. In addition, velocity generally increases with depth.
- Discharge. Encroachment decreases the area available for storage of flood waters on the floodplain, resulting in decreased attenuation and increased peak discharges downstream. Increased discharge is directly related to increased flow depths and velocities. Therefore, increased peak discharges are directly related to increased sediment transport rates and erosion.
- Design Standard. Development in encroached areas is typically designed to a 100-year standard. Therefore, damage will occur to development and/or flood control structures in encroached areas at flow rates greater than those of the 100-year event.
- Degree of Encroachment. The greater the degree of encroachment of the floodplain and main channel, the greater the impact on channel stability. For example, encroachment that leaves the 10-year floodplain unchanged will have less impact on channel stability than encroachment that modifies the 2-year floodplain.

For some stream reaches in the Adobe ADMP study area, the floodplain and floodway are coincident. The coincident floodplain/floodway is due to the channel and floodplain geometry relative to the shallow canyon geology, as well as to the floodway modeling techniques used for the floodplain delineation studies. Therefore, in reaches where the floodway and floodplain are coincident, it is unlikely that any future floodplain encroachment will occur, except where public infrastructure crosses the floodplain.

Recommendation. Where floodway fringe areas exist in the Adobe ADMP study area, floodplain encroachment should be avoided except where it meets the low-impact criteria defined previously in this Section. Encroachment that exceeds the low-impact criteria should be allowed only where it can be demonstrated that no long-term or short-term offsite impacts to channel stability will occur, the encroachment is adequately protected from erosion and flooding, and a long-term maintenance and inspection program is adopted.

Channelization. Channelization is defined as construction of an engineered channel with bank protection and grade control structures, or any other human modification of the natural channel geometry. Channelization is generally known to have the following impacts on channel stability:

- Velocity. Channelization generally increases channel velocities. Velocity is exponentially related to sediment transport rate and erosion potential.
- Depth. Channelization increases the flow depth by eliminating floodplain area available for conveyance. Increased depths result in greater scour depths and higher velocities.

- Discharge. Channelization eliminates the area available for storage of flood waters on the floodplain, resulting in decreased attenuation and increased peak discharges downstream. Increased peak discharges are directly related to increased sediment transport rates and erosion.
- Design Standard. Engineered flood control channels are typically designed to a 100-year standard. Therefore, damage may occur to development adjacent to a 100-year channel (or to the channelization itself) if flow rates greater than the 100-year event occur. If design discharges change due to watershed changes or revisions to hydrologic modeling standards, retrofit solutions are required to maintain the same standard of protection.
- Design Life. Engineered structures have a limited design life, and require regular maintenance and inspection and eventual replacement.
- Equilibrium Slope. Because of the increase in discharge, velocity, and depth, the stable slope is generally flatter than the existing channel slope, which will cause long-term scour and require grade control to prevent undercutting of bank protection.
- Habitat. Channelization typically eliminates most of the natural floodplain and stream bank habitat, and requires mitigation measures.
- Sediment Supply. Bank erosion is an important source of sediment supply for the streams in the study area, and will become more important in the future as development increases. Construction of bank protection eliminates this source of sediment, increasing the likelihood of erosion of adjacent and downstream reaches.
- Downstream Impacts. Excessive instability should be expected at the outlet of a channelized reach due to the changes in velocity, sediment supply, and discharge. Depending on the channel geometry, the expected response can range from lateral erosion and scour to sediment deposition and overbank flooding.

Recommendation. Channelization is not recommended as a primary development alternative in the Adobe ADMP study area. Channelization should be allowed only where it can be demonstrated that no long-term or short-term offsite impacts to channel stability will occur, that downstream reaches are adequately protected from erosion and flooding, and that a long-term maintenance and inspection program is adopted. Failure to address the hydrologic and sedimentation impacts of extensive channelization will jeopardize the safety of numerous existing public and private structures.

Roadway Crossings. Roadway crossings of watercourses can be constructed at-grade (dip sections), or with culverts or bridges. The sedimentation and geomorphic impacts of road crossings were discussed in Chapter 4 of the *Carefree DMP Sedimentation Engineering & Geomorphic Evaluation Technical Memorandum* (JEF, 2002). The impacts of each crossing type on channel stability are summarized in the following paragraphs.

At-Grade Crossings. Well-designed at-grade crossings typically have only minimal or localized impacts on channel stability. More commonly, the streams impact the at-grade crossing, rather than vice-versa. Flow over the at-grade crossing periodically erodes the pavement and subgrade, deposits sediment in the road section, and disrupts traffic flow. Channel stability impacts commonly observed near at-grade crossings include the following:

- Scour Hole. A scour hole often forms on the downstream side of an at-grade crossing due to acceleration of flow over the hydraulically smooth pavement surface, increased turbulence as flow transitions back to the natural channel bed, and construction of a flat road cross section on a sloped streambed. In most cases, formation of a scour hole does not impact stream reaches located far from the at-grade crossing.
- Aggradation. If the at-grade crossing is constructed at an elevation slightly above the natural channel bed, deposition will occur upstream of the crossing. Deposition leads to expansion of the floodplain, and may increase the risk of avulsions and accelerate formation of the downstream scour hole.
- Road Maintenance Practices. During post-flood road cleanup, road maintenance crews often dump sediment that was deposited in the road section on the upstream side of the crossing, forming a small dam that may divert flow, induce further sedimentation, or simply be redeposited in the road section during the next flow event. Dumping of sediment on the downstream side of the crossing may similarly block flow and induce deposition unless it is graded flat or used to fill the downstream scour holes.

Culverts. The impacts of culvert crossings are primarily a function of their size. Culverts that have openings similar to the natural width and depth of the main channel pass the more frequent floods without impacting the natural flow conditions. Undersized culverts and culverts that create headwater ponding have impacts similar to those of on-line detention basins – upstream deposition and downstream scour and erosion. Oversized culverts that widen the natural channel width result in deposition of sediment in the outer cells of the culverts and loss of capacity. The impacts of improperly sized culverts on channel stability include the following:

- Sediment Deposition. Much of the stream's sediment load will be deposited in the headwater pool at the inlet of an undersized culvert. The volume of sediment deposited depends on the culvert capacity relative to the discharge, the duration of ponding condition, the geometry of the ponding area, and the size of the sediment in transport. Sediment deposition decreases channel (and culvert) capacity, increases the potential for overbank flooding and avulsions, and requires maintenance to restore natural conditions.
- Bed Elevation Changes. Culverts installed below the natural channel bed elevation normally will either fill with sediment as the stream reestablishes the natural channel slope. In some watersheds with sediment deficits and specific soil types, channels installed below the natural bed elevation can induce upstream headcutting.
- Floodplain Encroachment. A culvert is a form of floodplain encroachment, with the same types of encroachment impacts described above.
- Scour Hole. A scour hole may form at the culvert outlet due to accelerated velocity through the culvert, discharge of sediment-deprived water downstream of the undersized crossing, and turbulence at the culvert/natural channel interface.

- Long-Term Degradation. Where a significant percentage of the sediment load is deposited upstream of a culvert due to headwater ponding, discharge of clear water may result in degradation downstream until the channel slope adjusts to the new sediment supply downstream of the obstruction.

Bridges. Bridges that span the floodplain typically have no measurable impact on channel stability, as evidenced by the channel conditions observed at the Beardsley Canal flumes over Caterpillar Tank Wash and Twin Buttes Wash in the North Peoria ADMP study area. Bridges with narrow openings function like culverts, and have the impacts on channel stability described above.

Recommendations. Based on their likely impacts on channel stability, the following guidelines for roadway crossing design are recommended for the major watercourses in the Adobe ADMP study area:

- Bridges are preferable to culverts. Bridges typically have less impact on channel stability than culverts due to their wider opening, decreased likelihood of headwater ponding, and natural bed materials.
- Culvert span (width) should be as wide as the main channel (top of left bank to top of right bank). Culverts that do not obstruct the main channel will have less frequent impacts on channel stability than culverts that block the main channel.
- Culvert rise (height) should be as high as the average main channel bank height. Culverts that do not obstruct the main channel will have less frequent impacts on channel stability.
- Culvert invert should match the natural stream bed elevation wherever possible.
- Where braided or multiple channels exist, relief structures should be provided to maintain overbank flow paths, preserve overbank conveyance, and prevent floodplain sedimentation.
- Roadway crossings should be regularly maintained and inspected to identify potential problems and impacts to channel stability, and to assure structure performance.
- Road maintenance crews removing sediment deposition from the roadway after flow events should place the material on the downstream side of the road, rather than the upstream side.
- To prevent formation of scour holes or ponding areas, erosion protection should be provided where roadway runoff directly enters the stream channel. Use of large diameter rip rap in the expected scour hole also provides energy dissipation that can protect the road crossing during floods.

Utility Crossings. Utility crossings, if properly constructed, have no inherent impact on channel stability since they are typically buried beneath the channel or extended overhead. Direct impacts on channel stability can occur during utility construction due to disturbance of bank and floodplain vegetation. Where vegetation is removed, the underlying soils are more vulnerable to erosion and scour. If floods occur before the vegetation is reestablished, erosion of the construction alignment may occur and initiate erosion of adjacent channel reaches.

Recommendations. The following guidelines for utility construction in the floodplain and erosion hazard zone are recommended:

- Bank and floodplain vegetation removed or damaged during construction should be replaced immediately. Irrigation, inspection and maintenance may be required to assure survival of the replacement vegetation.
- Underground utilities should be buried below the 100-year main channel general scour depth plus the long-term scour depth, or elevated above the 100-year water surface elevation plus freeboard. Utility lines have been damaged due to exposure by long-term scour on numerous streams in Arizona.
- Where the potential for lateral movement exists, underground utilities should be buried at the same depth as in the main channel, to prevent exposure after movement of the main channel.
- Support structures for overhead utilities should not be located within the floodplain or erosion hazard zone, wherever possible. Where the length of the span requires that support structures be constructed in the erosion hazard zone or floodway fringe, the structures should be designed using the 100-year general scour depth plus the long-term scour depth. No structures should be placed in the main channel or floodway.

5.10 Summary

Best management practices for prevention of sedimentation and erosion problems in the Adobe ADMP study area were recommended based on the results of field investigation, interpretation of maps and photographs, and evaluation of existing sedimentation trends in the watershed. Application of best management practices during development review and construction can prevent future damage to public and private infrastructure, prevent threats to public safety and welfare, as well as prevent the expenditure of tax dollars to retrofit poorly designed flood control structures. The best management practices recommended in this Section should be considered for inclusion the Adobe ADMP.

5.11 References

Briggs, M., 1996, Riparian Ecosystem Recovery in Arid Lands – Strategies and References. University of Arizona Press, Tucson, Arizona.

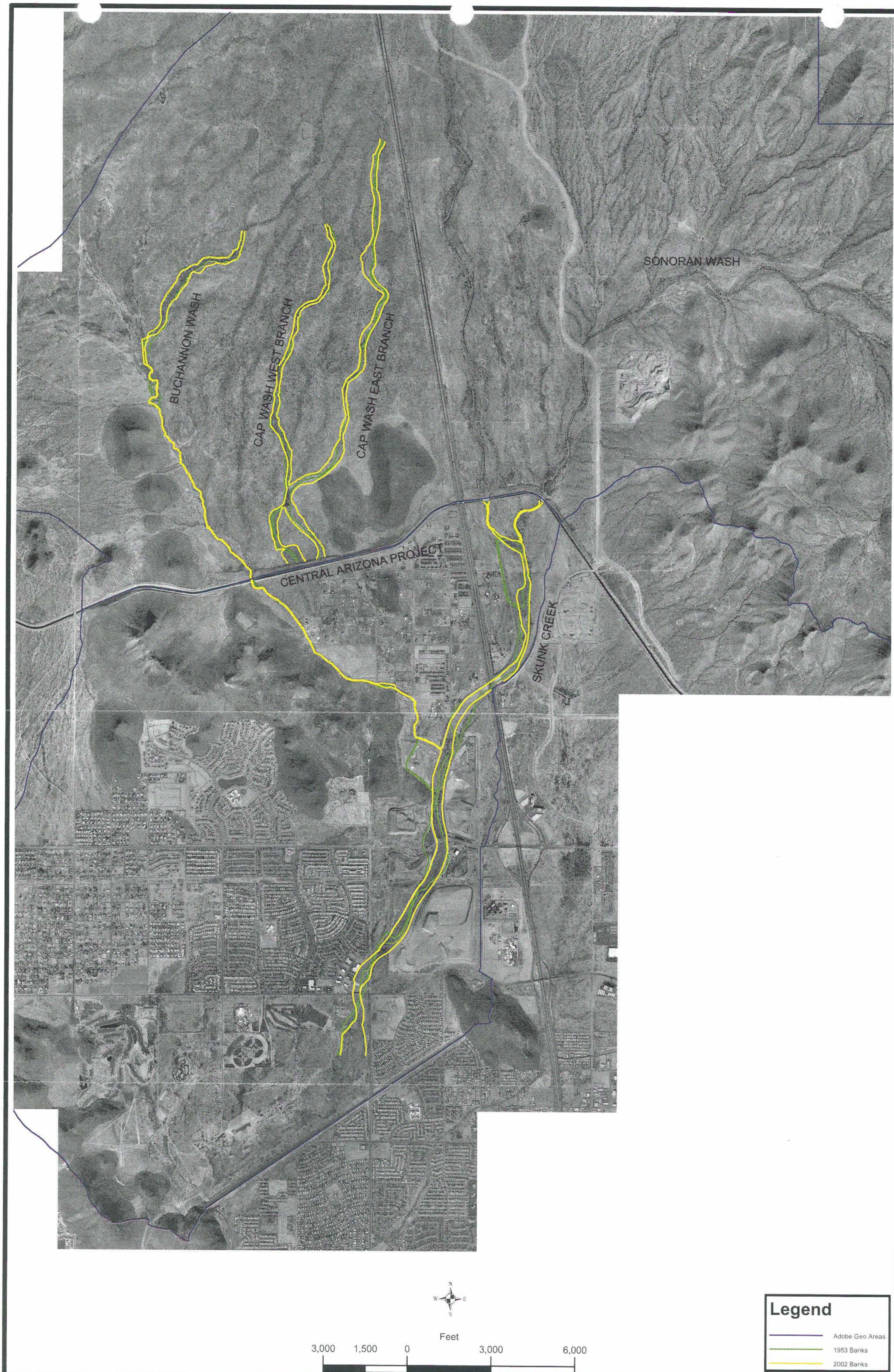
Federal Interagency Stream Restoration Working Group, 1998, *Stream Corridor Restoration – Principles, Processes, and Practices.*

Flood Control District of Maricopa County, 2003, Erosion Hazard Zone Delineation and Development Guidelines.

Flood Control District of Maricopa County, 2003, Sand and Gravel Floodplain Use Permit Application Guidelines.

JE Fuller/Hydrology & Geomorphology, Inc., 2002, North Peoria Area Drainage Master Plan Sedimentation Engineering and Geomorphic Analysis. Report prepared for Stantec Consulting, & the Flood Control District of Maricopa County.

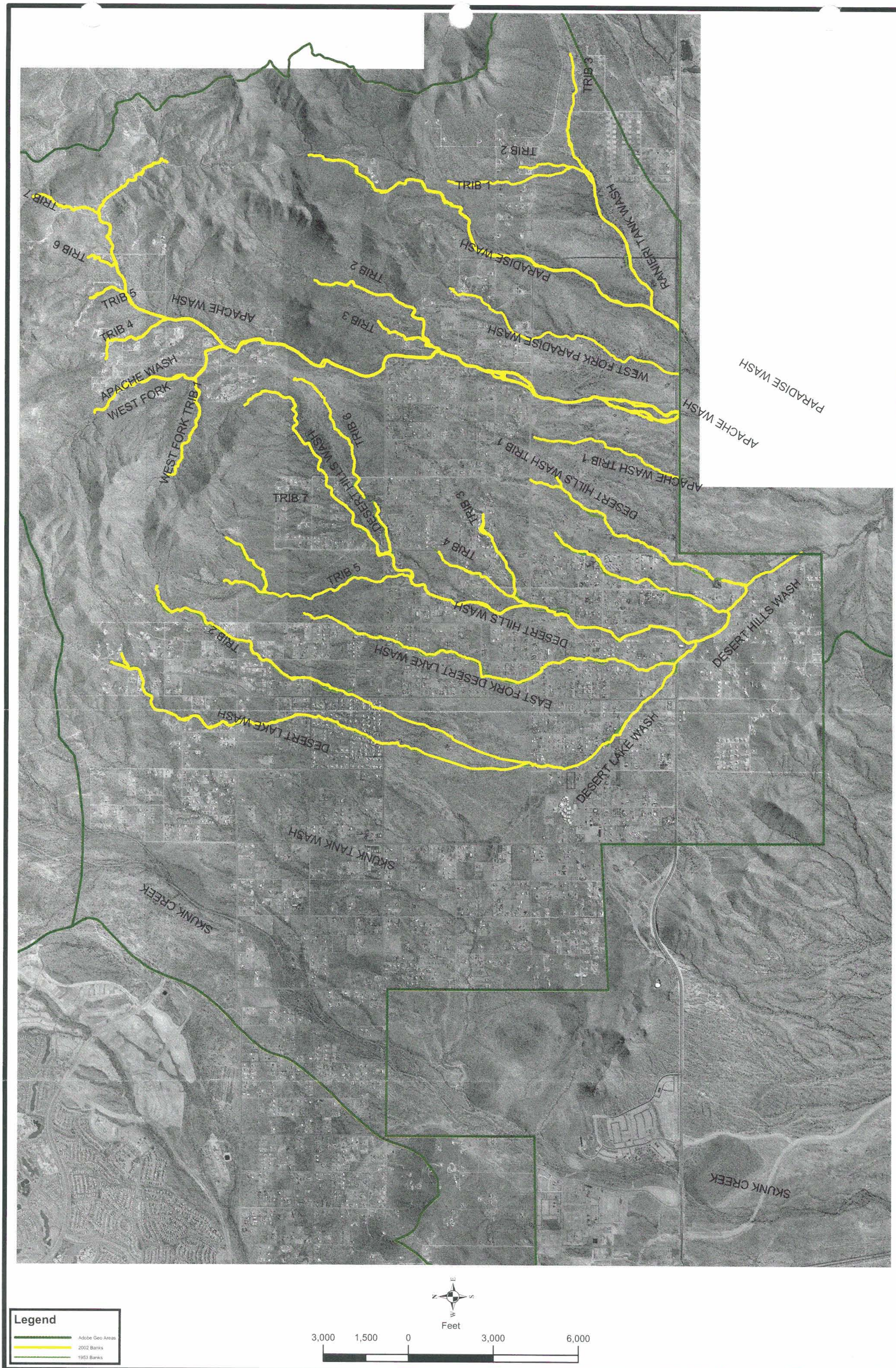
JE Fuller/Hydrology & Geomorphology, Inc., 2002, Carefree Drainage Master Plan Sedimentation Engineering and Geomorphic Analysis. Technical Memorandum prepared for CH2M HILL & the Flood Control District of Maricopa County.



JOB NO		REVISIONS	NO.	DATE	BY	CHKD
DESIGNED BY						
DRAWN BY						
CHECKED BY						
APPROVED BY						
DATE	9-28-03					

ADOBE DAM/DESERT HILLS AREA DRAINAGE MASTER PLAN
EROSION HAZARD LINES
FIGURE 3-2
(SHEET 1 OF 3)

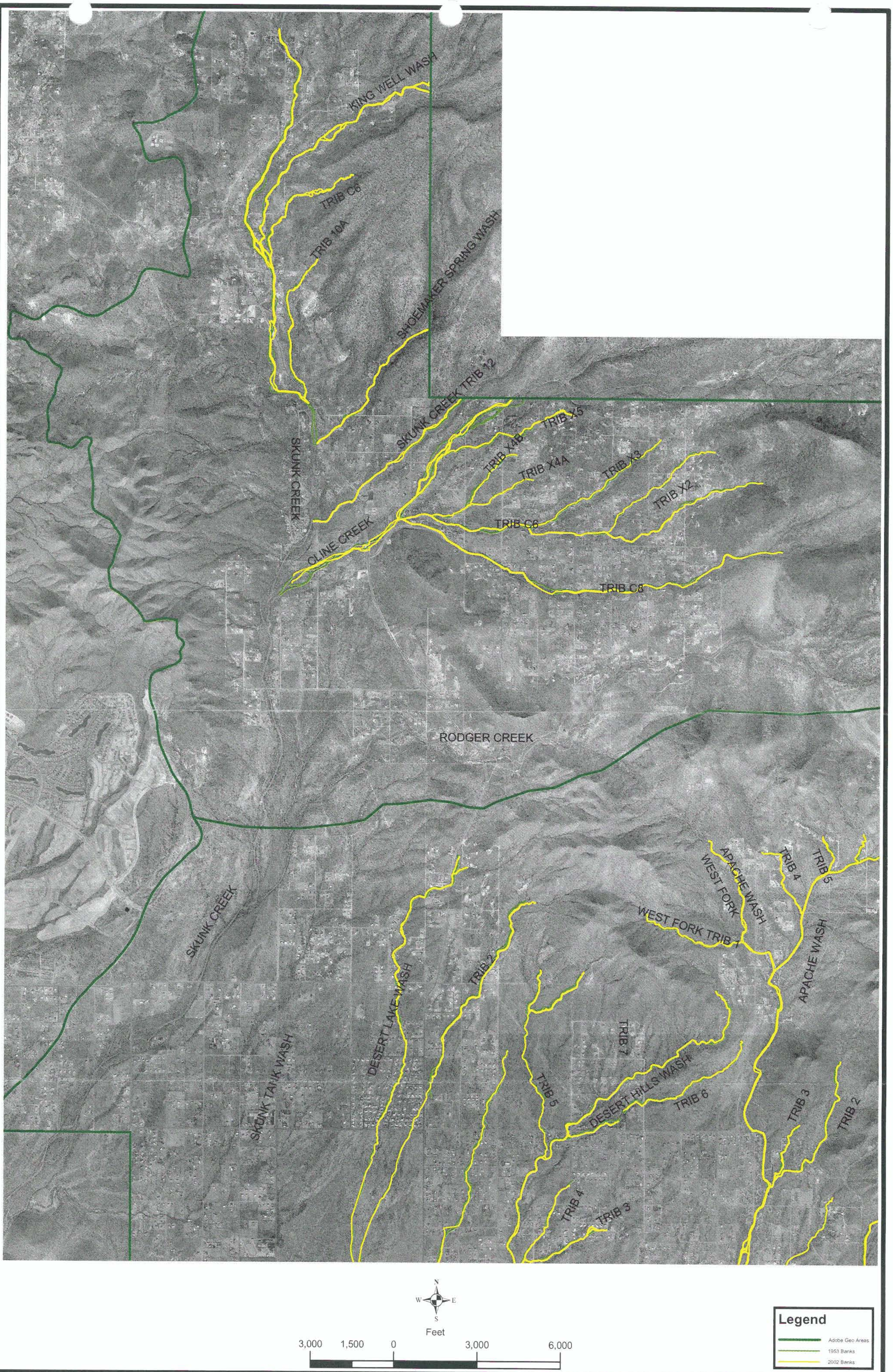
JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.



JOB NO		REVISIONS	NO	DATE	BY	CHKD
DRAWN BY						
DESIGNED BY						
APPROVED BY						
CHECKED BY						
DATE	6-26-03					

ADOBE DAM/DESERT HILLS AREA DRAINAGE MASTER PLAN
EROSION HAZARD LINES
EXHIBIT 3-2
(SHEET 2 OF 3)

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.



JOB NO.		REVISIONS	NO.	DATE	BY	CHKD
DESIGNED BY						
DRAWN BY						
CHECKED BY						
APPROVED BY						
DATE	9-28-03					

ADOBE DAM/DESERT HILLS AREA DRAINAGE MASTER PLAN
EROSION HAZARD LINES
EXHIBIT 3-2
(SHEET 3 OF 3)

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC
www.jefuller.com
7661 N. Silver Spur Dr.
Tucson, Arizona 85745
Phone (520) 823-3112
Fax (520) 823-3130

JEFuller / Hydrology & Geomorphology, Inc.

8400 S. Kyrene Rd., Suite 201
Tempe, AZ 85284
480-752-2124 (voice)
480-839-2193 (fax)
www.jefuller.com

November 12, 2004

TRANSMITTAL

Flood Control District of Maricopa County
ATT: Afshin Ahouraiyan
2801 W. Durango
Phoenix, AZ 85009

Attached are the following materials provided by JEFuller/ Hydrology & Geomorphology, Inc.:

2 copies of Exhibit 3-1, Erosion Hazard Lines for the Adobe Dam/Desert Hills ADMP, Part 5 Sedimentation Engineering and Geomorphology Evaluation Report, September, 2003.

The revisions are reflective of our finalized hydraulics in the Upper Skunk Creek/Trubutary 6B confluence area associated with the Final Floodplain Delineation Study of Upper Skunk Creek and Tributaries. Please use these copies to replace this figure in your two copies of the referenced report.

Brian R. Iserman   11/12/04

Brian R. Iserman, P.E.   Date

JOB NO.		REVISIONS	NO.	DATE	BY	CHKD
DESIGNED BY						
DRAWN BY						
CHECKED BY						
APPROVED BY						
DATE	11-11-04					

ADOBE DAM/DESERT HILLS AREA DRAINAGE MASTER PLAN
EROSION HAZARD LINES

EXHIBIT 3-1

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.
8400 S. Kyrene Road, Suite 201
Tempe, AZ 85284
Phone (480) 752-2124
FAX (480) 839-2193
www.jefuller.com