North Peoria Area Drainage Master Plan

Attachment 3
Sedimentation Engineering & Geomorphic Evaluation

Book 1 of 2

January 2002

Prepared for the
Flood Control District
of Maricopa County

and the
City of Peoria

Project No. 82000146
Contract FCD 99-45

FCD 99-45

North Peoria Area Drainage Master Plan
Technical Data Notebook
Attachment 3

Sedimentation Engineering and Geomorphic Evaluation Technical Memorandums

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Chapter 1
Introduction

1-3-02

DATE: December 26, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E./Stantec

FROM: Jon Fuller, P.E.

RE: North Peoria ADMP
Sedimentation Engineering & Geomorphic Evaluation

Introduction

The North Peoria Area Drainage Master Plan (ADMP) is a flood control planning study of major watersheds draining to the Agua Fria River downstream of Lake Pleasant. The objectives of the ADMP are to identify current and anticipated drainage problems and to generate development guidelines to alleviate future flooding problems. A sedimentation engineering and geomorphic evaluation was included in the ADMP to identify existing erosion hazards and to provide a qualitative assessment of potential erosion and scour within the study area drainage network.

This analysis was performed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting Inc. (Stantec) under Tasks 2.4.2.3, 2.4.2.4.3, and 2.6 of contract FCD 99-45 with the Flood Control District of Maricopa County (District).

Study Area

The 73 square mile North Peoria study area is located in northern Maricopa County within portions of the City of Peoria and unincorporated Maricopa County. The study area includes the following watersheds that drain to the Agua Fria River downstream of Lake Pleasant:

- Morgan City Wash
- Unnamed Wash #1 (a.k.a. Bailey Tank Wash)
- Unnamed Wash #2
- Unnamed Wash #3
- Unnamed Wash #4
- Caterpillar Tank Wash
- Twin Buttes Wash and its tributaries

In addition, several small unnamed washes located east of the Agua Fria River between Lake Pleasant and Jomax Road are included in the study area, but were not included in the sediment engineering and geomorphic evaluation.

Scope of Services

The scope of services for the sedimentation engineering and geomorphic evaluation included the following tasks:

- Existing Condition Assessment (Task 2.6.2)
- Erosion Hazard Zone Delineation (Task 2.6.3)
- Sediment Yield Analysis (Task 2.6.4)
- Alternatives Analysis (Task 2.6.5)
    - Low-Impact Alternatives Analysis (Task 2.4.2.3)
    - Geomorphic Analysis of Detention Alternatives Analysis (Task 2.4.2.4.3)
- Development Guideline Recommendations (Task 2.6.6)
- Preparation of Final Report (Task 2.6.7)

Detailed description of each of the specific tasks is provided in the District's scope of services included in TDN Attachment 1 (Stantec, 2001).

Report Format

As required by the scope of services, this report is a series of technical memorandums prepared for each of the tasks listed above. The report is organized as follows:

- Chapter 1 – Introduction
- Chapter 2 – Existing Conditions Assessment
- Chapter 3 – Erosion Hazard Boundary Delineations
- Chapter 4 – Sediment Yield Assessment
- Chapter 5 – Alternatives Analysis
- Chapter 6 – Summary

Chapter 2
Existing Conditions Assessment

ARIZONA, U. S. A.

DATE: December 26, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E./Stantec

FROM: Jon Fuller, P.E.

RE: North Peoria ADMP
Sedimentation Engineering & Geomorphic Evaluation
Task 2.6.2 Existing Conditions Assessment

Introduction

The North Peoria Area Drainage Master Plan (ADMP) study area is currently undeveloped. An assessment of the existing conditions of the major watercourses in the study area was conducted to determine the system constraints for flood control planning with respect to sedimentation and fluvial geomorphology. The existing conditions assessment was based on field investigations, interpretation of aerial photographs, and review of available studies, and focused on the following:

- Identification of stream reaches that have experienced historical and/or recent long-term degradation or aggradation.
- Identification of stream reaches that have experienced historical and/or recent lateral instability or stability.
- Identification of stream reaches with existing sedimentation problems, such as at bridges, dip crossings, or existing hydraulic structures.
- Identification of historical and recent impacts of base level changes on the Agua Fria River on major tributaries in the study area.
- Identification of historical and recent stream responses to development in the watershed and along watercourses.
- Identification of points of natural grade control.
- Identification of existing sediment sources in the watershed.

For each of the major watercourses in the study area, the items listed above are discussed in detail in the erosion hazard analyses summarized in Chapter 3 of this report. An overview with respect to the entire study area is provided in this chapter.

This analysis was performed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting Inc. (Stantec) under Task 2.6.2 of contract FCD 99-45 with the Flood Control District of Maricopa County (District).

Evidence of Long-Term Degradation or Aggradation

No field evidence of significant historical long-term degradation was observed during the field investigations of any of the watercourses in the North Peoria ADMP study area, even downstream of the CAP culvert outlets where long-term scour might be expected. Field evidence of long-term scour typically includes undercut bank vegetation, leaning or fallen bank vegetation, high or multiple terraces, abundant cutbanks, headcutting, armoring, perched channels, and excessive erosion at structures. Bedrock exposed in the beds of Morgan City Wash and the four unnamed washes probably limits the potential for significant long-term degradation on those streams.

The conclusion that there is no significant field evidence of historical long-term scour is supported by comparing longitudinal profiles made using recent and older topographic mapping. A longitudinal profile is a plot of the channel elevation versus distance along the stream bed. Analysis of the longitudinal profile can be used to identify progressive changes in channel slope, slope irregularities, over-steepened or flattened reaches, headcuts, and areas of natural grade control. A longitudinal profile also provides some information on expected lateral stability. Reaches with lower slopes than adjacent reaches will tend to experience net deposition, and bank erosion associated with braiding and avulsions. Where longitudinal profiles from different time periods indicate that channel incision has occurred, bank erosion due to undercutting and bank collapse may be expected. The longitudinal profiles of each of the major watercourses examined in Chapter 3 of this report indicate that if any changes in bed elevation occurred since the date of the earliest topographic record, they are well within the margin of accuracy of the map data. That is, the available topographic data indicate that no measurable long-term degradation has occurred over the past several decades.

Some conclusions regarding degradation or aggradation within recent geologic time can be drawn from the overall shapes of the longitudinal profiles. A typical longitudinal profile for an equilibrium stream is concave up; that is, the slope decreases in the downstream direction. The longitudinal profiles of Twin Buttes Wash, Caterpillar Tank Wash, and unnamed washes #1, #2, and #3 are generally concave up in the reaches closest to the headwaters. However, the profiles of these streams are concave down and the slopes become significantly steeper about 1.5 miles upstream of their confluences with the Agua Fria River. This change in profile shape and channel slope is due to entrenchment of the Agua Fria River during the early Quaternary Period, more than 100,000 years ago. As the Agua Fria River became entrenched, it lowered the base level of its tributaries, causing them to become steeper. The effect of the entrenchment is also expressed in the height of the terraces along Twin Buttes Wash and Caterpillar Tank Wash, which become noticeably higher at the point of the change in concavity. Continued long-term degradation over future geologic time should be expected within the reaches where the longitudinal profile is concave down, although the natural rate of such slope adjustments will be extremely slow.

Summary: For existing conditions, long-term degradation or aggradation generally has not been significant on the major watercourses in the study area. More detailed

discussion of field evidence of long-term degradation and interpretation of longitudinal profiles for specific watercourses is provided in Chapter 3 of this report.

Evidence of Lateral Instability or Stability

Lateral stability assessments for each of the major watercourses in the North Peoria ADMP study area are presented in Chapter 3 of this report. In general, historical and field evidence suggest that the entire floodplain of the watercourses in the study area is subject to lateral erosion. The streams in the study area flow within shallow canyons comprised of Middle to Late Pleistocene-aged alluvium or bedrock, as illustrated in Figures 2-1 to 2-4. Within recent geologic time, the streams appear to have migrated over the entire canyon bottom, gradually widening the canyons through lateral erosion. The highest erosion hazards occur on these canyon bottoms and at the margins of the older surfaces that form the canyon walls. Three typical cross section types were observed along the stream corridors in the study area.

Single Channel Reach. The typical cross section (Figures 2-1 and 2-2) for most of the study reach consists of a well-defined, gravel-bedded single channel with one to five foot banks, and a low floodplain terrace of varying width. The canyon margins are formed by older alluvium (Figure 2-1) or bedrock (Figure 2-2). The low, moderately- to densely-vegetated floodplain surfaces usually occupy a greater percentage of the canyon bottom than the main channel. These low floodplains typically are composed of coarse gravels and sands, but may also have a fine-grained cap layer. The lowest floodplains appear to be regularly inundated by moderate to large floods, which leave a distinct bar and swale topography and affect the vegetative cover. Vegetation on the low floodplains is dominated by palo verde, ironwood, catclaw, and several brush and cacti species. In most places, small avulsive channels were observed on the low floodplain surfaces, often next to the canyon margin. Higher floodplain terraces were observed inset along the bedrock canyon walls in some locations. These higher terraces are not continuous on either side of the canyon, but are pinched out where the sinuous main channel intersects the canyon walls. Where the main channel intersects the canyon walls, there are typically steep or vertical cliffs, regardless of whether the canyon is composed of bedrock or alluvium. In some reaches, one or more strath terraces were observed at 10 to 20 feet above the channel floor. The lack of continuous high terraces in the study reach suggests that the wash periodically moves across the canyon bottom and erodes up to the canyon walls, removing the older terraces or preventing their development.

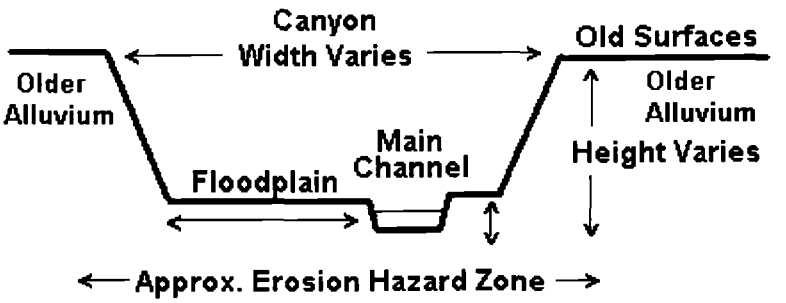


Figure 2-1. Typical cross section of single channel reach with floodplain in canyon formed of alluvial fill material.

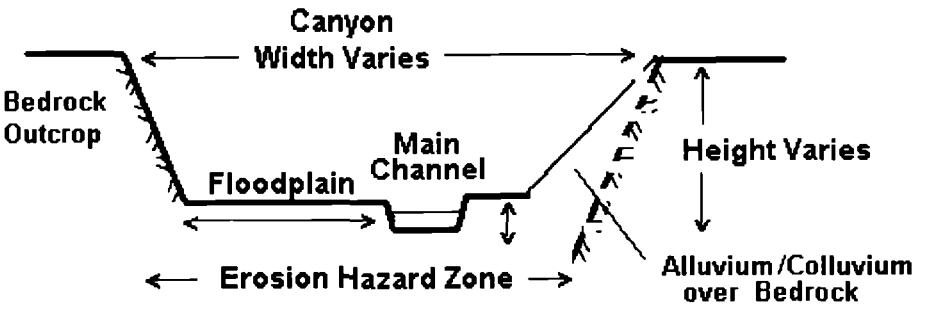


Figure 2-2. Typical cross section of single channel reach with floodplain in canyon formed of alluvial fill and bedrock.

Multiple Channel Reach. Multiple channel reaches (Figure 2-3) have the same basic characteristics as the single channel reaches, except that the main channel is divided into multiple flow paths. Multiple channel reaches exist where recent avulsions have occurred, creating islands out of the low floodplain surfaces. In some places, avulsive channel change has left large bedrock islands in the middle of the canyon bottom. The channel bed material or bank conditions in the multiple channel reaches are not significantly different from material and conditions in the single channel reaches.

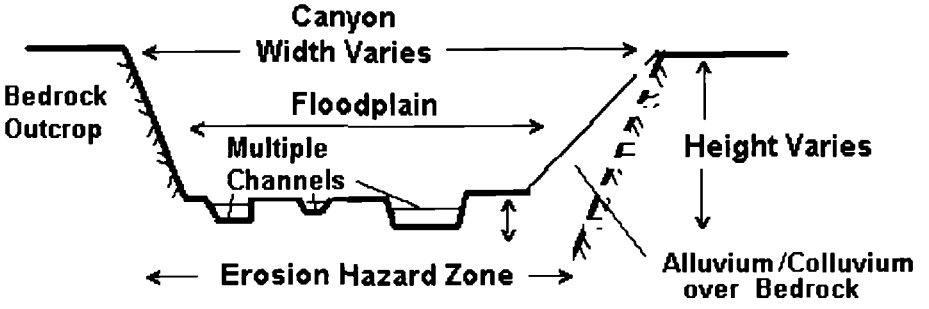


Figure 2-3. Typical cross section of multiple channel reach with floodplain in canyon formed of alluvial fill and bedrock.

Narrow Bedrock Canyon Reach. Narrow bedrock canyons (Figure 2-4) occur on Morgan City Wash, Twin Buttes and Caterpillar Tank Washes upstream of the CAP, White Peaks Wash near the confluence with the West Fork of White Peaks Wash, and all of the four unnamed washes. In the narrow canyon reaches, the typical cross section includes a gravel or boulder bed channel with shallow or exposed bedrock, a main channel that fills or nearly fills the entire canyon bottom, a narrow floodplain, and bedrock outcrops in both banks. Bedrock effectively limits lateral migration of the streams.

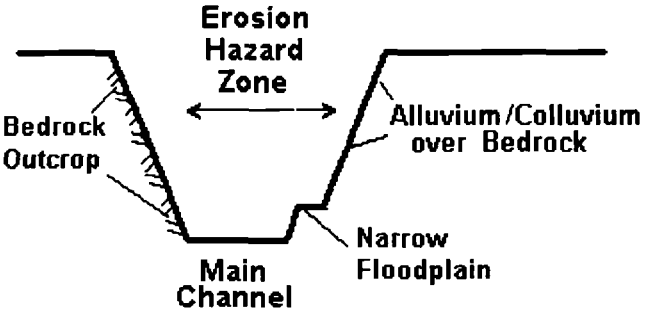


Figure 2-4. Typical cross section of channel in narrow bedrock canyon.

Summary. Historical and field evidence indicate that lateral erosion hazards extend across the entire canyon bottom of the typical cross section of the streams in the North Peoria ADMP study area. Lateral erosion of canyon walls is prevented only where the canyon is formed by bedrock. Lateral erosion hazards are discussed in more detail in Chapter 3 of this report.

Existing Sedimentation Problems at Existing Structures

Field observations and interpretation of aerial photographs indicate that the few existing structures in the North Peoria ADMP study area have few known sedimentation problems. Minor amounts of sediment have accumulated in the ponding areas upstream of drainages blocked by the CAP and Beardsley Canals. Small local scour holes were observed at several of the CAP culvert crossings, but none were large enough to require remedial measures.

Summary. No significant sedimentation problems were observed at existing structures in the North Peoria study area. Sedimentation problems at existing structures are discussed in more detail in Chapter 4 of this report. Field observation of structures on the major watercourses in the study area are described in Chapter 3 of this report.

Impacts of Base Level Changes on the Agua Fria River

Tributary channel responses to Early Quaternary incision of the Agua Fria River provide an analog for potential impacts of future base level lowering on the major watercourses in the North Peoria ADMP study area. The effect of Early Quaternary entrenchment of the Agua Fria River on the streams in the study area is expressed in the increased channel slope, as well as in the increased height of the Middle Pleistocene terraces that form the canyon walls and constrain the floodplains of Twin Buttes Wash and Caterpillar Tank Wash. Lowering of the Agua Fria River during the Early Quaternary resulted in slow incision of all of the tributaries that flow into it. The rate of tributary incision was extremely slow, and has progressed upstream less than two miles in about 1,000,000 years.

Historical topographic data collected for the Agua Fria Watercourse Master Plan Lateral Stability Assessment indicate that no progressive base level change has occurred on the Agua Fria River between Hatfield Road and the CAP siphon (JEF, 2001). Therefore, it is not surprising that no evidence of response to base level changes was observed along the major watercourses within the North Peoria ADMP study area. Future base level changes in the Agua Fria River, however, would probably result in long-term degradation on the tributaries to the Agua Fria River.

Summary. No evidence of geologically-recent responses to base level changes on the Agua Fria River was observed within the study area. Base-level impacts are also discussed in Chapter 3 of this report.

Stream Responses to Development in the Watershed

There has been very little development in the watersheds of the North Peoria ADMP study area. Historically, the area has been used only for cattle grazing, isolated mining, and recreation. During the course of this study no evidence was found that mining occurred with the floodplain of any major watercourse in the study area. Therefore, no responses to development have occurred. Know human impacts on the watersheds include the following:

- Construction of State Route 74 (SR74). In general, construction of SR 74 has had no significant impact on the stability of the major watercourses in the North Peoria ADMP study area. SR 74 traverses the northern part of the study area, crossing unnamed washes #1 and #2, as well as several of their tributaries. No evidence of significant aggradation or degradation was observed at the SR 74 culverts. Erosion protection has been constructed to prevent lateral erosion of the SR 74 roadway fill where the natural washes were displaced by road construction. The impacts of SR 74 are discussed in the erosion hazard assessments for unnamed washes #1 and #2 in Chapter 3 of this report.

- Construction of the Beardsley Canal. In general, construction of the Beardsley Canal has had only minor impacts on the overall stability of the major watercourses in the study area. The Beardsley Canal crosses Twin Buttes and Caterpillar Tank Wash in flumes, and unnamed wash #4 crosses under the canal in a box culvert. A number of smaller tributaries are completely blocked by the Beardsley Canal. At these smaller tributaries, sediment deposition and ponding occurs upstream of the canal. Known sedimentation impacts at the Beardsley Canal are discussed in Chapter 4 of this report.

- Construction of the Central Arizona Project (CAP) Canal. In general, construction of the CAP has had no significant impacts on the overall stability of the major watercourses in the study area. The CAP crosses West Fork of White Peaks Wash, White Peaks Wash, Twin Buttes Wash, East Garambullo Wash, West Garambullo Wash, Caterpillar Tank Wash, and unnamed wash #4 in culverts. A number of smaller tributaries are completely blocked by the CAP, resulting in upstream sediment deposition and ponding, and reduced runoff rates downstream. Sedimentation impacts at the CAP are discussed in Chapter 4 of this report.

- Construction of Homes. Several homes have been constructed in the floodplains of Twin Buttes Wash downstream of the Beardsley Canal. Several of these homes are located within the erosion hazard zone, with at least one home in the regulatory floodway. Despite the potential flood and erosion hazard to these homes, the presence of these homes has had no apparent impacts on the overall stability and morphology of Twin Buttes Wash. Typically, channel stability decreases in urbanized areas due to loss of bank vegetation and other disturbances of the channel and floodplain.

- Construction of Cattle Tanks. Two cattle tanks have been constructed on the major washes in the study area. Bailey Tank was constructed prior to 1950 on unnamed wash #1, and Caterpillar Tank was constructed on its namesake prior to 1964. The tanks trap sediment and alter the natural hydrology immediately downstream of the tanks. However, the presence of Bailey Tank appears to have had insignificant impacts on the overall stability of unnamed wash #1, except in the reach immediately upstream and downstream of the tank, probably due to the abundance of bedrock outcrops in the bed and banks of unnamed wash #1. Caterpillar Tank has had a more significant impact, with markedly decreased bank vegetation in the reach downstream of the tank. The potential impacts of cattle tanks on streams in the study area are discussed in Chapter 3 (erosion hazards) and Chapter 4 (sediment yield) of this report.

- Illegal Trash Dumping. Trash has been dumped in many of the washes located south of the CAP. Aside from aesthetic impacts, the presence of the trash does not appear to have significantly changed the overall morphology or stability of the watercourses. The impacts of illegal trash dumping are discussed in Chapter 3 of this report.

- Off-Road Vehicle Use. Many of the washes in the study area are used as ATV and 4-wheel drive roads. In some places where trails intersect the stream corridors bank vegetation has been destroyed by off-road vehicles. Where off-road vehicle use is limited to the non-vegetated portion of the channel bed, no significant impacts to overall channel stability or morphology were observed. The impacts of off-road vehicle use are discussed in Chapter 3 of this report.

- Cowtown Recreation Area. A paintball course has been constructed in the channel and floodplain of unnamed wash #1. Construction of obstacles and other structures related to the paintball course has removed bank vegetation and modified the natural channel morphology. However, these activities do not appear to have had any significant impact upstream or downstream of the site. The impacts of the Cowtown recreation area are discussed in Chapter 3 of this report.

- Lake Pleasant Access Roads. Paved roads leading to Lake Pleasant (and Castle Hot Springs) cross Morgan City Wash near its confluence with the Agua Fria River. While some evidence of local scour and deposition was observed near the culvert crossings of Morgan City Wash, the road crossings do not appear to have had any significant impacts on the overall stability or morphology of Morgan City Wash. The impacts of Lake Pleasant access roads are discussed in Chapter 3 of this report.

- Seepage Flow From Lake Pleasant to Morgan City Wash. Seepage of water from Lake Pleasant after construction of Waddell Dam in 1927 created springs which supply perennial flow to a portion of Morgan City Wash. Review of historical aerial photographs, discussed in Chapter 3 of this report, indicates that this seepage has drastically changed the natural character of the once-ephemeral Morgan City Wash.

Summary. The minimal human activities which have occurred in the North Peoria ADMP study area generally have had no significant impacts on channel stability and morphology. Human impacts on specific watercourses are discussed in more detail in Chapter 3 of this report.

Natural Grade Control

Natural grade control was observed on several of the streams in the North Peoria ADMP study area. Bedrock provides natural grade control for portions of Morgan City Wash, nearly all of the four unnamed washes, portions of Twin Buttes Wash and Caterpillar Tank Wash upstream of the CAP, and portions of White Peaks Wash upstream of the confluence with Twin Buttes Wash. Locations of bedrock outcrops are provided in the exhibits included with the erosion hazard delineations described in Chapter 3 of this report. Boulder sediments observed in riffles formed in the beds of most of major watercourses may provide some degree of natural grade control. 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. Finally, man-made grade control is provided at culverts under the CAP, Beardsley Canal, and SR 74.

Summary. Grade control is provided by bedrock, coarse sediment, and man-made structures at various points along the major watercourses in the North Peoria ADMP study area. More detailed discussion of natural grade control is provided in Chapter 3 of this report.

Existing Sediment Sources in the Watershed

An analysis of existing and future condition sediment yield is provided in Chapter 4 of this report. The primary sources of sediment supply are from upland erosion and erosion of channel banks. Fine-grained sediment is derived primarily from erosion of upland areas, and is deposited on floodplains or is transported out of the study area into the Agua Fria River. The coarse sediments observed in the main channels are derived primarily from erosion of channel banks, floodplain deposits, and older terrace materials. The coarse sediments are transported as bedload and remain in the main channels.

No natural sediment sinks occur in the watershed, with the exception of normal fine-grained sediment deposition on the floodplains. Man-made sediment sinks include Caterpillar and Bailey Tanks, and ponding areas upstream of the CAP, Beardsley Canal, and undersized roadway crossings. Future condition sediment supply rates will primarily depend on the type of retention and detention required for future development, as discussed in Chapter 4 of this report.

Summary. Sediment is derived from natural erosion of upland areas and bank erosion. Sediment sources and sediment yield are discussed in more detail in Chapter 4 of this report.

Summary

The existing conditions analysis indicates that there are few significant existing or historical sedimentation problems in the North Peoria ADMP study area. The limited degree of development that has occurred to date has not significantly impacted channel stability or induced sedimentation problems. 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.

References

JEF, 2001, *Agua Fria River Watercourse Master Plan Lateral Migration Report*. Report to Kimley Horn & Associates and the Flood Control District of Maricopa County.

Chapter 3
Erosion Hazard Boundaries

CONTENTS

- **Memorandum #1 – CAP Reaches**
  - **Caterpillar Tank Wash**
  - **Twin Buttes Wash**
  - **White Peak Wash**
  - **West Fork White Peak Wash**
  - **East Garambullo Wash**
  - **West Garambullo Wash**

- **Memorandum #2 – Unnamed Washes**

- **Memorandum #3 – Morgan City Wash**

- **Appendix 1 – Sample Field Form**
- **Appendix 2 – Typical Scope of Work for Level 3 Erosion Hazard Analysis**
- **Appendix 3 – State Standard 5-96 Information**

DATE: December 26, 2001

TO: Kelli Sertich./ FCDMC
Pat Ellison, P.E./ Stantec

FROM: Jon Fuller, P.E.

RE: North Peoria ADMS
Sedimentation Engineering & Geomorphic Evaluation
Task 2.6.3.1.2 – Erosion Hazard Analysis

Introduction

This memorandum describes the results of an evaluation of the erosion hazards for the following streams located within the North Peoria Area Drainage Master Plan (ADMP) study area:

- Caterpillar Tank Wash
- East Garambullo Wash
- West Garambullo Wash
- Twin Buttes Wash
- White Peaks Wash
- West Fork of White Peaks Wash

These six stream segments are generally located downstream of the Central Arizona Project Canal (CAP), and drain to the Agua Fria River. The study limits for the six streams are shown in Figure 3-1.

The primary objectives of this erosion hazard evaluation were to establish an erosion hazard zone for the six streams and to determine where more detailed erosion analyses should be required prior to development. The erosion hazard zone was established using the State Standard 5-96 (SSA 5-96) Level 1 Methodology, except where field and other data indicated a more conservative erosion hazard zone delineation was justified.

This evaluation was completed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting, Inc. (Stantec) under contract to the Flood Control District of Maricopa County (District). This memorandum and its attachments are the deliverables for Task 2.6.3.1.2 of Contract #FCD 99-45.

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 North Peoria 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. Estimates of the 100-year discharges were obtained from Floodplain Delineation Studies (FDS) performed by others, as described below. More recent hydrologic modeling performed by Len Erie & Associates (1999), which has not yet been approved by review agencies, has failed to duplicate the FDS modeling results and indicates that the FDS discharges may be underestimated. Gauged streamflow data for these streams would improve the accuracy of the erosion hazard evaluation.
- Hydraulic Modeling. HEC-2 models were prepared by others for the purpose of delineating the 100-year floodplain and floodway (AGK, 1991). As described below, floodway delineation procedures used for the FDS affect the SSA 5-96 Level 1 Methodology. Modification of the HEC-2 input code, which would improve the application of the SSA 5-96 methodology, was not part of the scope of services for this study.

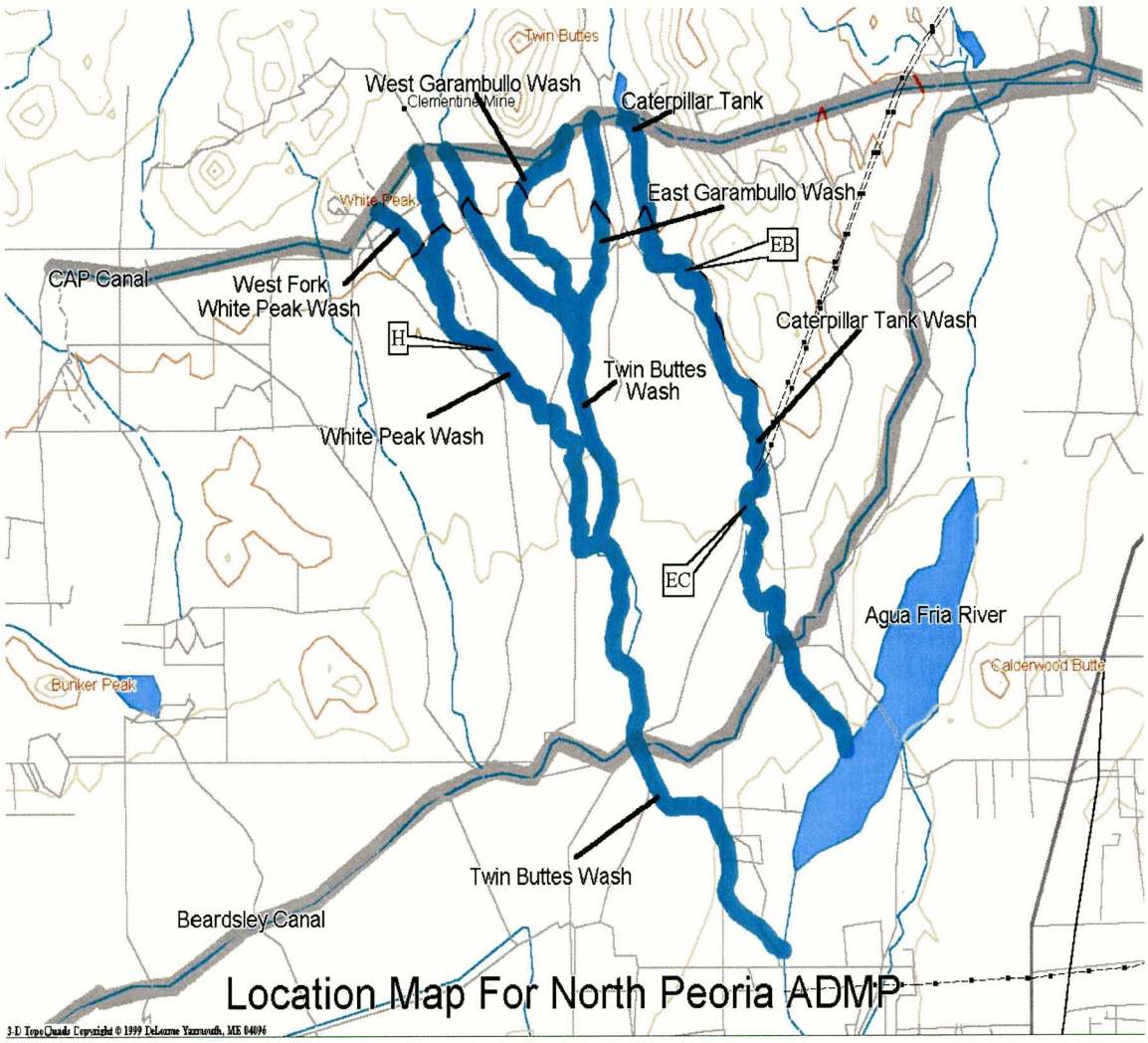


Figure 3-1. Study limits of the six streams located south of the CAP.

- 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.
- Level of Detail. The erosion hazard zones determined for this evaluation are based on the SSA 5-96 Level 1 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 six stream segments listed above.
- Scale of Analysis. The evaluation described in this technical memorandum considered approximately 17 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.

Other assumptions and limitations of this evaluation are discussed in the following paragraphs.

Methodology & Results

A variety of methodologies were used to evaluate the erosion hazard for the six watercourses in the study area. The project scope of work dictated that the SSA 5-96 Level 1 Methodology be used to establish the initial erosion hazard zone. In addition, the following types of information were considered:

- Field Observations
- Aerial Photographs
- Historical Channel Position
- Stream Longitudinal Profile
- Allowable Velocity Guidelines

The methodologies used to estimate the erosion hazard zone are described in more detail in the paragraphs below.

State Standard 5-96 Level 1 Methodology. State Standards for floodplain management have been adopted by the Arizona Department of Water Resources (ADWR) as the minimum required regulatory policy in the State of Arizona under authority of Arizona Revised Statutes 45-3605(a). SSA 5-96 (ADWR, 1996), adopted in 1996, describes a

methodology for estimating an erosion setback to account for the lateral instability of Arizona streams. The SSA 5-96 Level 1 Methodology is based on the following two equations:

$$SB = 1.0*(Q_{100})^{0.5} \qquad \text{Eq'n \#1}$$
$$SB = 2.5*(Q_{100})^{0.5} \qquad \text{Eq'n \#2}$$

Where SB = Erosion hazard setback distance (ft.)
Q_{100} = 100-year peak discharge (cfs)

According to SSA 5-96, equation #1 is intended for stream segments that are straight or have "minor curvature." Equation #2 is intended for stream segments with "obvious curvature." Obvious curvature is defined as a channel centerline with a radius of curvature less than five times the channel topwidth. Other guidelines and limitations for the SSA 5-96 Level 1 Methodology are summarized in Table 3-1. In general, the SSA 5-96 methodology is applicable to the streams in the study area.

Table 3-1. North Peoria ADMP Erosion Hazard Evaluation
SSA 5-96 Setback Guidelines and Limitation Study Area Condition

Guideline	Study Area Summary	Specific Streams					
		CTW	EGW	WGW	TBW	WPW	WFW
Drainage area < 30 mi.^{2}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Significant channel filling	Upstream CAP	No	No	No	No	No	No
Local mining	Ltd placer mining	Some	No	No	Some	No	No
Channel modifications	Dumping, grazing	Tank	Fence	Fence	Fence	Fence	Fence
Massive past channel shifting	Photos indicate minor recent shifting, but signif. within past 10,000 years.						
Channelization	CAP culverts cause ponding. Beardsley Canal has minimal impact.						

Notes: CTW = Caterpillar Tank Wash; EGW = East Garambullo Wash; WGW = West Garambullo Wash; TBW = Twin Buttes Wash; WPW = White Peaks Wash; WFW = West Fork White Peaks Wash

For the North Peoria ADMP study area, channel curvature was measured on plots of digital aerial photographs provided by Stantec. 100-year discharge estimates were obtained from the AGK (1991) Floodplain Delineation Study. The results of the SSA 5-96 Level 1 Methodology for the six streams in the study area are shown in Table 3-2.

The SSA 5-96 Level 1 setbacks were applied from the channel bank or the floodway, whichever was further from the channel centerline, as per the SSA 5-96 Level 1 Methodology. It is noted that for most of the stream segments in the study area, the FEMA floodway limit is coincident with the FEMA floodplain limit, presumably because of the way the bank stations were defined for the FDS.[1, 1] SSA 5-96 Level 1 setbacks for each of the six stream segments are shown on Exhibit 3-1 and Figure 3-1.

[1] The FDS by AGK (1991) defined the bank stations for many cross sections at the canyon boundaries, rather than at the main channel banks. HEC-2 floodway modeling subroutines will not allow floodway encroachment inside the bank stations. Therefore, the floodway limits are coincident with the floodplain limits, i.e., no encroachment was modeled in the floodway model for many of the reaches in the study area. Because the floodway stations were defined in this manner, the SSA 5-96 setbacks based on floodway stations are more conservative than may have been intended by the State Standards Workgroup.

Table 3-2. North Peoria ADMP Erosion Hazard Evaluation SSA 5-96 Setbacks			
Stream Name & Reach Limits for Q100 Value (AGK HEC-2 Cross Section #)	**Q100 (cfs)**	**Erosion Setback Distance (ft)**	
		Straight Chl	**Curved Chl**
Caterpillar Tank Wash			
Agua Fria River to Beardsley Canal (Xn #0.02-0.82)	1,315	36	91
Beardsley Canal to AGK "EC" (Xn #0.83-1.89)	1,375	37	93
AGK "EC" to AGK "EB" (Xn #1.99-3.69)	1,295	36	90
AGK "EB" to CAP (Xn #3.73-5.04)	970	31	78
Upstream of CAP - No HEC2	1,446	38	95
Twin Buttes Wash			
Agua Fria River to Beardsley Canal (Xn #0.19-1.91)	2,746	52	131
Beardsley Canal to White Peak Wash (Xn #1.92-3.50)	2,779	53	132
White Peak Wash to Garambullo Wash (Xn #3.60-4.73)	2,424	49	123
Garambullo Wash to CAP	2,163	47	116
Upstream of CAP - No HEC2	2,659	52	129
East Garambullo Wash			
CAP to confluence (entire reach)	259	20*	50*
West Garambullo Wash			
CAP to confluence (entire reach)	483	22	55
Garambullo Wash			
Garambullo Wash to W. Garambullo Wash (Xn #4.79-0.19)	651	26	64
White Peak Wash			
Twin Butte Wash to AGK "H" (Xn #0.09-1.42)	721	27	67
AGK "H" to West Fork (Xn #1.48-1.97)	599	24	61
West Fork to CAP (Xn #1.99-2.95)	395	20	50
West Fork White Peak Wash			
CAP to confluence (Xn #0.09-0.74)	294	20*	50*

Notes:
1. Source: HEC2 Output printouts in Hydraulics Report (AGK, 1991)
2. * indicates minimum SSA 5-96 setback used (20 ft., 50 ft., respectively)

Field Observations. Field visits were conducted to each of the six stream reaches in the study area. Field visits consisted of walking the entire study reach, photographing and mapping key features, and recording descriptions of existing channel conditions. Sample copies of the field data collection forms used during the visits are provided in Appendix 1. 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 stream responses to human impacts or structures
- Identify points of natural grade control

[1] Level 1 setbacks based solely on the top of bank identified on the aerial photographs and verified during the field reconnaissance are available digitally in AutoCAD format.

The most relevant data collected during the field visits were synthesized and are shown on Exhibit 3-1. Field data collected included the following:

- Locations of cut banks (active erosion)
- Locations of bedrock outcrop in the bed and channel banks
- Location of headcuts and slope breaks
- Location and extent of stream terraces and natural floodplains[1]
- Location of human impacts, structures, and road crossings
- Channel characteristics at representative cross sections

The following general conclusions are supported by the data collected during the field reconnaissance visits:

- Canyon Cross Section. The streams in the study area flow within shallow canyons comprised of geologically older (200,000 – 500,000 years before present) alluvium or bedrock, as illustrated in Figure 3-2. Within recent geologic time, the streams appear to have migrated over the entire canyon bottom, gradually widening the canyons through lateral erosion. The highest erosion hazards occur on these canyon bottoms and at the margins of the older surfaces that form the canyon walls. Figures 3-3 and 3-4 are photographs of typical canyon cross sections in the study area.

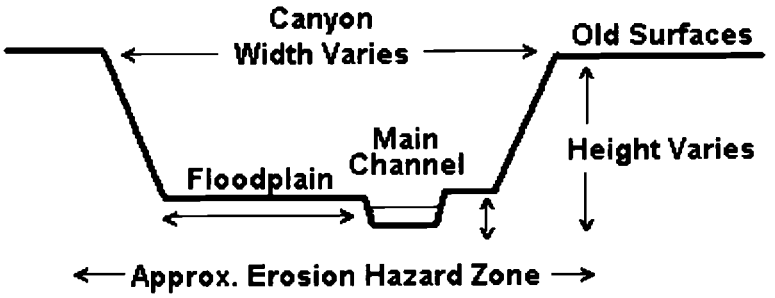


Figure 3-2. Typical Canyon Cross Section in Study Area

[1] Natural floodplains, which have physical expression in the landscape, are distinguished from the FEMA (100-year) floodplain, which is a regulatory concept and may not coincide with natural features observed in the field.

Figure 3-3. Canyon cross section on Twin Buttes Wash

Figure 3-4. Narrow canyon section on West Garambullo Wash

- Typical Cross Section. The typical cross section for all of the six streams evaluated in the study area consists of a well-defined main channel with one to five feet high, well-vegetated banks, and a natural floodplain terrace inset into the shallow canyon described above. The natural floodplain terrace may be present on one or both sides of the main channel, and ranges in width from several feet to several hundred feet. At some locations, up to three distinct terraces, in addition to the natural floodplain, were observed within the canyon bottom.

- Floodplain Dimensions. A natural floodplain of varying width is present along most channel reaches in the study area (Figure 3-5). In general, this natural floodplain is wider on stream segments with higher peak discharges, and increases in width in the downstream direction on individual streams. The height of the natural floodplain above the bed of the main channel varies from one to five feet. As the height of this natural floodplain above the main channel increases, the frequency of floodplain flow decreases, and the erosion potential of the main channel bank increases due to the relatively higher flow depths and velocities along the main channel bank, as illustrated in Figure 3-6. Where field evidence suggests more frequent floodplain flow, the potential for avulsive channel change increases.

Figure 3-5. High banks (foreground) and low bank (edge of natural floodplain) on Twin Buttes Wash

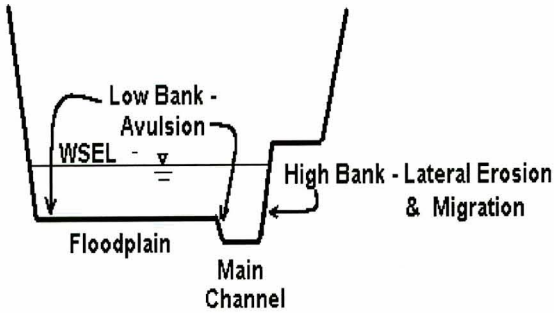


Figure 3-6. Sketch showing bank erosion type relative to bank height

- Floodplain Soils. The soil materials underlying the natural floodplains adjacent to the main channels appear to be comprised of highly erosive, unconsolidated sand and gravel.

- Caliche. Carbonate-rich soil layers (a.k.a. "caliche") occur throughout the study area, and are exposed in the walls of the shallow canyons, in cut banks, and on the channel bed in some locations (3- 7, 3-8, and 3-9). While the caliche layers themselves are more resistant to erosion than the non-carbonate-cemented soil layers, field data suggests that the carbonate layers have been eroded by recent and historical stream flows. The carbonate layers erode primarily by undercutting the non-cemented underlying layers (cantilever failures), but also by direct shear and impact forces on the carbonate layers themselves (Figure 3-10).

Figure 3-7. Exposed roots on eroded caliche-cemented bank.

Figure 3-8. Caliche-cemented bank subject to piping and cantilever failure.

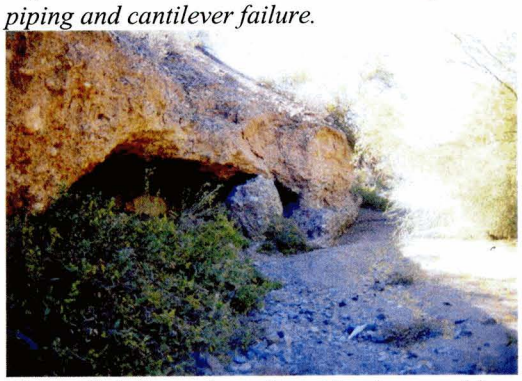


Figure 3-9. Severely undercut bank capped by carbonate layer - Twin Buttes Wash.

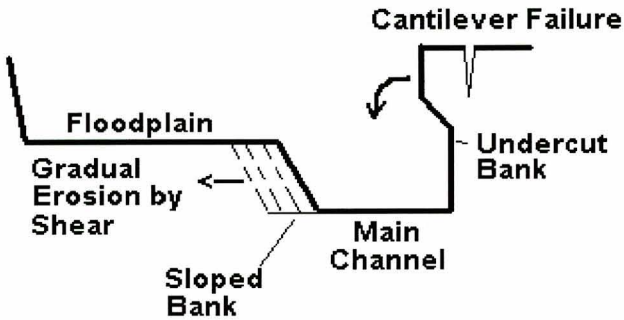


Figure 3-10. Illustration of cantilever failure and failure by shear.

- Bedrock. Bedrock crops out in several locations on Caterpillar Tank Wash, Twin Buttes Wash, and White Peaks Wash, but is probably present at shallow depths in many places within the study area (Figures 3-11 and 3-12). Bedrock outcrops observed in the field are plotted on Exhibit 3-1. Lateral erosion is prevented by bedrock.

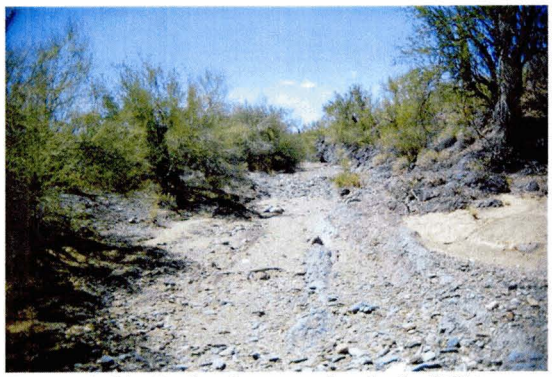


Figure 3-11. Bedrock exposed in bed of White Peaks Wash.

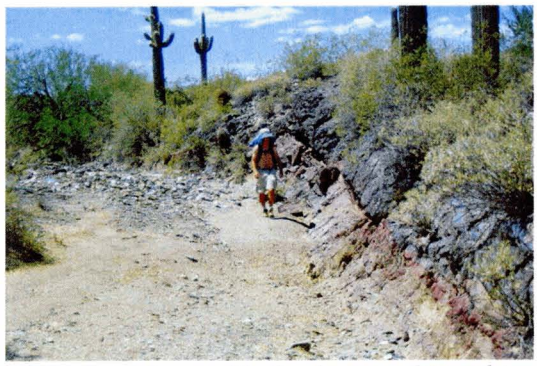


Figure 3-12. Layered bedrock exposed in right bank of White Peaks Wash.

- Long-term scour. No evidence of significant historical long-term degradation was observed in the field on any of the stream segments, even downstream of the CAP culverts where long-term scour is expected, except on Caterpillar Tank Wash immediately upstream of Caterpillar Tank (Figure 3-13). Field evidence of long-term scour typically 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 absence of significant long-term scour is supported by the comparison of longitudinal stream profiles from 1964 and 1990 discussed later in this memorandum.

  Within recent geologic time,[1] downcutting of the Agua Fria River has caused the channels of Caterpillar Tank Wash and Twin Buttes Wash to become more deeply incised at the margins of the Agua Fria River terraces. This incision is visible in the vicinity of the Beardsley Canal. No conclusive evidence of long-term scour due to more recent historical degradation of the Agua Fria River was observed in the field on Caterpillar Tank Wash or Twin Buttes Wash near their confluences with the Agua Fria River.

[1] Recent geologic time refers to the past 1,000 to 2,000,000 years.

Figure 3-13. Long-term scour downstream outlet of CAP culvert on Caterpillar Tank Wash.

- Local scour. Scour holes up to four feet deep were observed at some channel bends or where natural obstructions such as trees or boulders partially block the main channel, indicating that there is a high potential for severe local scour where favorable conditions exist (Figure 3-14).

Figure 3-14. Scour hole (3.5 ft.) on White Peak Wash at Twin Buttes Wash confluence.

- Structure impacts. Few structures exist within the study area for which structure impacts could be assessed. In general, the potential for lateral erosion increases near structures. The impacts from structures observed in the field are summarized below.
    - CAP Ponding Areas. At the ponding areas upstream of the CAP culverts, a significant increase in vegetation density and sediment deposition was observed only on Caterpillar Tank Wash (Figure 3-15). The increase in vegetation and sediment deposition in the ponding area was minimal on East Garambullo Wash, West Garambullo Wash, Twin Buttes Wash, and White Peaks Wash.

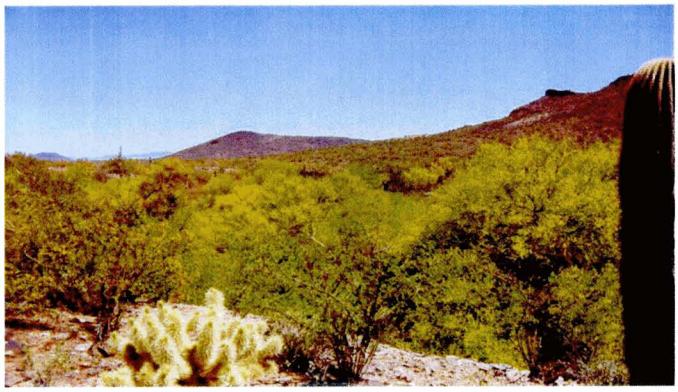


Figure 3-15. Dense vegetation caused by ponding upstream of CAP on Caterpillar Tank Wash.

- CAP Outlet Scour. Local scour was observed downstream of the CAP culverts on Caterpillar Tank Wash (Figure 3-16). Sediment deposition was observed at the outlets of the CAP culverts on East Garambullo Wash, West Garambullo Wash, and Twin Buttes Wash. Sediment was deposited above the elevation of the culvert crown on East and West Garambullo Washes (Figures 3-17 and 3-18).

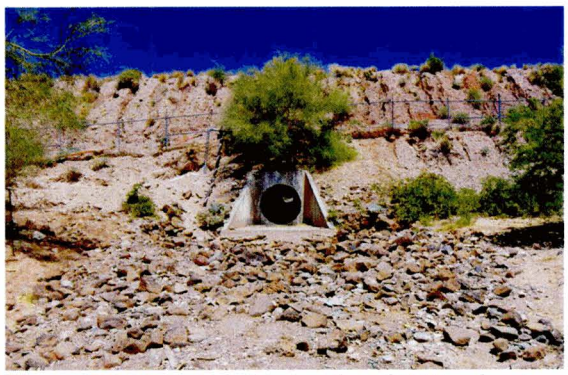


Figure 3-16. Scour hole at outlet of CAP culvert on Caterpillar Tank Wash

Figure 3-17. Gravel bar deposition CAP culvert outlet @ W. Garamubullo Wash

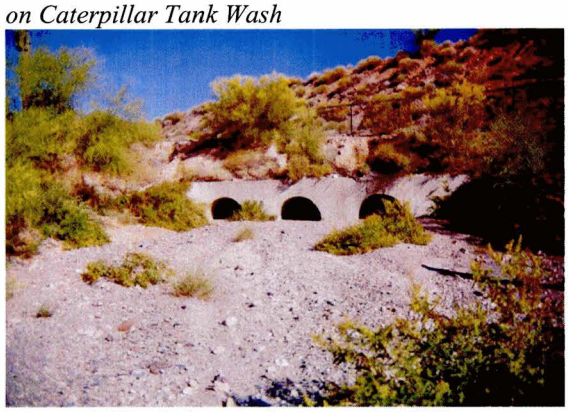


Figure 3-18. Sediment deposition at CAP culvert outlet on Twin Buttes Wash.

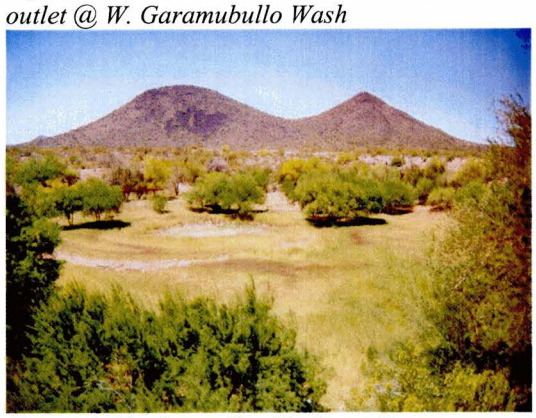


Figure 3-19. Caterpillar Tank ponding area looking downstream

- Caterpillar Tank. Upstream of Caterpillar Tank (Exhibit 3-1, Figure 3-1), the wash has incised through sediment deposited in the backwater created by the tank (Figure 3-13). The tank has no working low flow outlet and impounds all of the water and sediment delivered to it. Consequently, the bottom of the tank has been filled with fine-grained sediment (Figure 3-19). No evidence of recent overtopping of the tank was observed. Downstream of the tank, the wash has responded to the lack of natural runoff by decreasing the density of bank vegetation, and depositing fine grained sediment in the main channel from slope wash and local runoff.

  It is unlikely that Caterpillar Tank was designed and constructed by registered professional engineers; and therefore, it may be at risk of failure during future floods. Overtopping of the tank could result in significant erosion in the reaches adjacent to and downstream of the tank.

- Beardsley Canal. The Beardsley Canal crosses Caterpillar Tank Wash (Figure 3-20) and Twin Buttes Wash (Figure 3-21) in a conduit supported by piers. Due to the large amount of grading, dumping, and road construction near these crossings, the impacts from the structures themselves could not be distinguished in the field. The fact that structure impacts were not obvious may indicate that the Beardsley Canal crossing has no significant impacts on the overall morphology of the washes.

Figure 3-20. Beardsley Canal crossing of Caterpillar Tank Wash.

Figure 3-21. Beardsley Canal crossing of Twin Buttes Wash.

- Ranch Road Dip Crossings. At-grade crossing of the few dirt roads that cross the streams in the study area have minimal impact on the streams, aside from providing vehicle access for illegal dumping of trash (Figures 3-22 and 3-23).

Figure 3-22. At-grade crossing of dirt road on Twin Buttes Wash.

Figure 3-23. Abandoned car filled with flood debris in Caterpillar Tank Wash

- Fences. Fences have been built near the CAP culverts (Figure 3-24) and at the Beardsley Canal (Figures 3-20 and 3-21). In general, the fences increase local scour immediately surrounding the fence and trap flood debris, but have had no obvious impacts on the overall morphology of the streams in the study area.

Figure 3-24. Pipe rail and barbed wire fence on West Garambullo Wash.

- Cut banks. Cut banks observed in the field are plotted on Exhibit 3-1. Bank erosion occurs on most of the sharp channel bends, but also occurs in straight reaches where the main channel impinges on the margins of the older surfaces that comprise the shallow canyon walls. The banks apparently contain enough fine-grained sediment or carbonate to maintain vertical slopes over ten feet high (Figure 3-25), but obviously are not resistant to flowing water, particularly when they become saturated. The presence of cut banks indicates that active lateral erosion can occur within the stream systems in the study area regardless of bank vegetation, soil lithology, and soil composition (Figures 3-25 and 3-26).

Figure 3-25. Tall cut bank on Twin Buttes Wash.

Figure 3-26. Bank erosion by cantilever, shear and chemical process on Twin Buttes Wash.

The incidence of cut banks observed in the field was lowest on Caterpillar Tank Wash and Twin Buttes Wash, the largest streams in the study area, and was highest on the West Fork of White Peak Wash, the smallest stream segment considered. The estimates of percent of banks that were cut by recent erosion are summarized in Table 3-3. The data in Table 3-3 demonstrate that cut banks are not rare in the study area, and occur naturally despite minimal urbanization or disturbance of the watershed. No relationship explaining the variation of percent of cut banks could be developed based on the observed data.

Table 3-3. North Peoria ADMP Erosion Hazard Evaluation
Estimate of Percent Cut Banks

Stream Name	Stream Length (mi.)	Percent Cut Banks
Caterpillar Tank Wash	10.1	2.8
Twin Buttes Wash	12.8	6.0
White Peak Wash	5.9	10.2
West Fork White Peak Wash	1.5	20.9
East Garambullo Wash	2.9	13.8
West Garambullo Wash	3.4	13.0

- Bank vegetation. In most locations, the banks are well vegetated with mesquite, palo verde, and ironwood trees, and dense brush (Figure 3-27). The bank vegetation generally covers the entire bank slope from toe to top, and includes deep rooting riparian species which enhance bank stability.[1] Two aspects of the bank vegetation enhance bank stability: (1) root material which increases the cohesion of the soil material, and (2) leaves, branches, and debris which covers the soil and prevents floodwaters from flowing directly on the soils that comprise the bank. The presence of mature bank vegetation throughout much of the study area indicates that the average rate of lateral erosion has been slow in the past 50

[1] Bank vegetation enhances the stability of the bank materials, but does not preclude the possibility of bank erosion as indicated by the presence of cutbanks throughout the study area.

years. That is, the average rate of lateral erosion is less than the average growth rate of the vegetation on the banks.

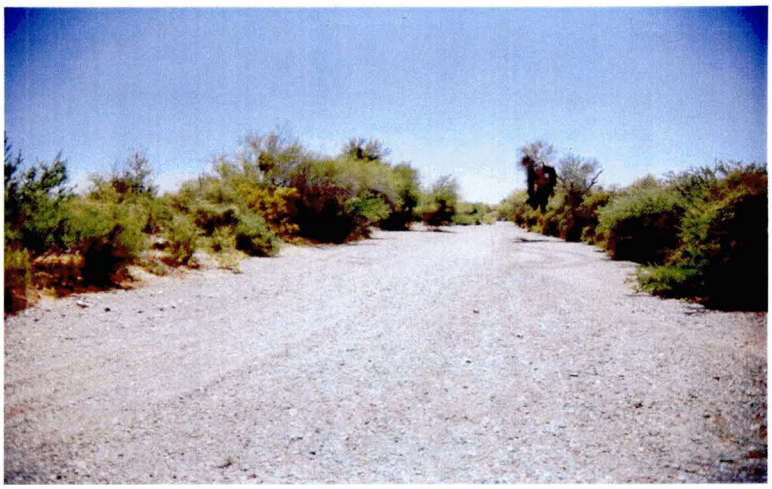


Figure 3-27. Dense bank vegetation on Twin Buttes Wash.

- Sediment Transport. The channel beds consist primarily of gravel and cobble sized sediment (Figure 3-28). The floodplains consist of finer sand and gravel deposits. The difference in composition between the floodplain and channel indicates that fine sediment are transported through the main channels without being deposited. The main channel sediments are moderately well sorted, indicating that they have been transported by recent flows, and are not primarily derived from slope processes acting on the banks and canyon slopes. Fine-grained sediment deposited in Caterpillar Tank also confirms that the streams do transport fine-grained material, but that it is normally conveyed through the system without deposition in the main channels. The coarse bed material normally found in the main channels, and the lack of fine-grained deposits in the channels indicates a high potential for sediment transport and for lateral erosion.

Figure 3-28. Coarse angular material on bed and bars in Twin Buttes Wash.

- Channel Pattern. The dominant channel pattern on the streams in the study area is a straight, single channel with a incipient pool and riffle pattern. In the bedrock confined reaches, the pool and riffle pattern is superimposed over a step-pool pattern formed by small waterfalls. At very low flows, the larger channels become weakly braided as flows work through the coarse bed sediments. Where

channel widening has induced sedimentation, the channels become strongly braided (Figure 3-29) and a significant volume of flow is diverted to the floodplain or into an anastomosing pattern which persists over a short distance before the channels recombine and the single channel pattern returns. Changes in channel pattern due to sediment deposition are one of the mechanisms of lateral instability and bank erosion in the study area.

Figure 3-29. Transition from single channel to multiple channel braided pattern on Twin Buttes Wash.

- Stream Capture. Geologically recent stream captures have occurred at several points on Twin Buttes Wash upstream of the CAP. Stream capture occurs when lateral erosion between two channels causes them to join, and flow is diverted into the steeper channel. Stream capture at some time in the future is predicted for White Peak Wash and the West Fork of White Peak Wash at the point where their floodplains are about 20 feet apart, several hundred feet upstream of their confluence. Capture is also predicted for Caterpillar Tank Wash where its floodplain nearly intersects a tributary which parallels it to the east. The stream and erosion corridor can be significantly widened following the occurrence of a stream capture.

- Avulsions. Where the natural floodplain is low enough relative to the main channel to convey frequent flows of sufficient volume and peak, the potential for these flows to erode a new channel exists (Figures 3-30 and 3-31). With time, these floodplain channels can capture the main channel and cause an avulsive shift of the main channel from one side of the floodplain to the other. Remnants of past avulsions or incipient avulsive channels were observed on the wider floodplain reaches of Caterpillar Tank Wash, Twin Buttes Wash, and White Peaks Wash.

Figure 3-30. Floodplain channels forming in left overbank of West Garambullo Wash.

Figure 3-31. Evidence of flow concentration in right floodplain of Twin Buttes Wash.

- Flood High Water Marks. Flotsam observed along the banks of the main channels indicates that at least one flood has recently filled the channels and inundated portions of the floodplain.

- Human Impacts. Impacts associated with human occupation of the study area are limited, but include the following:
    - Grazing (Figure 3-32)
    - Trash dumping (Figure 3-32)
    - Target shooting and hunting (Figure 3-32)
    - Off-road ATV use (Figure 3-32)
    - Construction of homes downstream of the Beardsley Canal (Figure 3-33)

  In general, human activities decrease bank stability by removing bank vegetation, causing flow obstructions, and changing natural runoff characteristics.

Figure 3-32. Human impacts by ATV use, dumping, and grazing on Caterpillar Tank Wash.

Figure 3-33. Home and chain link fence on right bank of Twin Buttes Wash.

Interpretation of Aerial Photographs. The lateral erosion hazard was also evaluated by interpreting characteristics of the geomorphic surfaces within the stream corridor that are visible on aerial photographs. The age of stream terraces adjacent to the main channels provides information on past stream bed elevations and positions that can be used to

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 Arizona Geological Survey (Huckleberry, 1995). Those characteristics included the following:

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

Individually, these age-indicating characteristics provide a relatively low degree of confidence in age estimates. Considered together, the characteristics provide a higher degree of confidence. The physical characteristics of a surface give clues as to its depositional history, stability, and its flood potential.

If the landform ceases to receive new deposits, its surface will begin to age. As it ages, the surface begins to develop distinctive physical and chemical characteristics indicative of its age. As the soil develops, its structure, color and content change. Clay and calcium carbonate accumulate in the soil, causing the soil to redden (clay) and become more cemented (carbonate) and resistant to erosion. Surfaces may also develop gravel lag coverings known as desert pavement as they age. 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 it takes thousands of years for many of these characteristics to develop, it can be concluded that surfaces that exhibit well developed soils, red color, significant carbonate development, desert pavements 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.

Recent color aerial photographs of the study area were used in conjunction with field observations to distinguish older, more stable surfaces from younger, more active surfaces near the stream channels. These data were used to estimate the potential for future lateral erosion.

Comparison of Historical Channel Position. The position of the main channel thalweg was digitized from historical aerial photographs and from the 7.5 minute USGS topographic quadrangles for the study area. A list of the historical aerial photographs

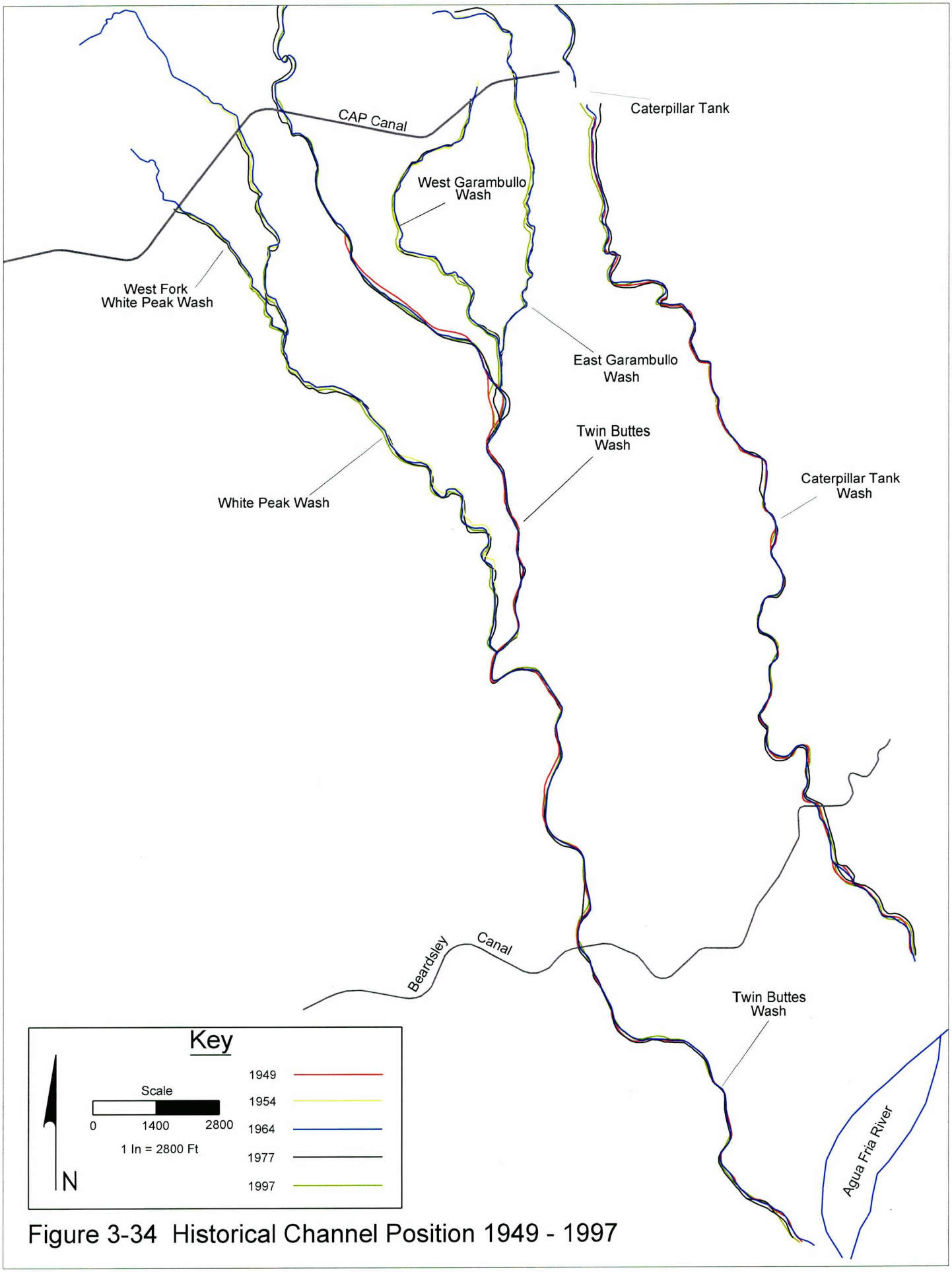


Figure 3-34 Historical Channel Position 1949 - 1997

used is shown in Table 3-4. The historical aerial photographs were scanned to create digital images which were then semi-rectified using AutoCAD 2000 software and the digital USGS quadrangles as the map base. A plot of the historical channel position is shown in Figure 3-34. In general, the channel position has not significantly changed during the 50 year period of record, although at least two avulsions and lateral channel movement up to 110 feet were recorded at specific locations.

Table 3-4. North Peoria ADMP Erosion Hazard Evaluation Historical Photographs and Maps

Year	Description	Scale
1949	Black & white aerial photo (2-14-49)	1:20,000
1977	Black & white aerial photo (12-5-77)	1:20,000
	7.5 Minute USGS topographic maps	
1981	Calderwood Butte, Arizona (1964 topo.)	1:24,000
1981	Baldy Mtn, Arizona (1964 topo.)	1:24,000
1997	Black & white aerial photo (4-30-97)	1:40,000

Evaluation of Stream Longitudinal Profile. The longitudinal profile is a plot of the channel elevation versus distance along the stream bed (Figures 3-35 to 3-40). Analysis of the longitudinal profile can be used to identify slope irregularities, over-steepened or flat reaches, headcuts, and areas of natural grade control. The longitudinal profile provides some information on expected lateral stability. Reaches with lower slopes than adjacent reaches will experience net deposition, and bank erosion associated with braiding and avulsions. Where longitudinal profiles from different time periods, as in Figures 3-35 to 3-40, indicate channel incision has occurred, bank erosion due to undercutting and bank collapse may be expected. Bank erosion occurs after channel incision because the channel material that had previously provided lateral support to the banks is removed, or because the banks are extended below the elevation of the rooting layer of the bank vegetation.

The following conclusions about lateral stability and erosion hazards can be drawn from the longitudinal profiles of the six streams segments in the study area shown in Figures 3-35 to 3-40:

- Caterpillar Tank Wash. The longitudinal profile for Caterpillar Tank Wash (3-35) indicates that some change in bed elevation may have occurred between 1964 and 1990, although the change is well within the margin of error of available topographic data. The irregular profile in the upper reaches is due to Caterpillar Tank and bedrock which creates small waterfalls upstream of the CAP. The profile has a weakly concave up shape in the upper reaches below the CAP, but is concave down near the Beardsley Canal due to entrenchment of the Agua Fria River during the early Quaternary Period. Long-term degradation should be expected near the reach where the profile transitions from concave up to concave down.

- Twin Buttes Wash. The longitudinal profile for Twin Buttes Wash (Figure 3-36) indicates that no discernable change in bed elevation occurred from 1964 to 1990.

The profile has a concave up shape in the upper reaches, but is concave down near the Beardsley Canal due to entrenchment of the Agua Fria River during the early Quaternary Period. Long-term degradation should be expected near the reach where the profile transitions from concave up to concave down.

- White Peak Wash. The longitudinal profile for White Peak Wash (Figure 3-37) indicates several feet of long-term scour may have occurred between 1964 and 1990 between the Twin Buttes Wash confluence and the bedrock controlled reach, although this conclusion cannot be supported by field evidence. The shape of the profile reflects the grade control provided by bedrock that crops out in the bed within the study reach.

- West Fork White Peak Wash. The changes in the longitudinal profiles (Figure 3-38) for the West Fork of White Peak Wash are due primarily to the scale and accuracy of the two sources of topographic information. The USGS 7.5 Quadrangles had a contour interval of 20 feet. The FCDMC FDS topographic mapping had a contour interval of 2 feet. The pronounced elevation change at the CAP may indicate that the CAP culvert was excavated below natural grade when it was constructed in the 1980's, and may explain the deposition observed in the field at the culvert outlet.

- West Garambullo Wash. The longitudinal profile for West Garambullo Wash (Figure 3-39) indicates that no discernable change in bed elevation occurred from 1964 to 1990 for most of the study reach. The pronounced elevation change at the CAP may indicate that the CAP culvert was excavated below natural grade when it was constructed in the 1980's, and may explain the deposition observed in the field at the culvert outlet.

- East Garambullo Wash. The longitudinal profile for East Garambullo Wash (Figure 3-40) indicates that no discernable change in bed elevation occurred from 1964 to 1990.

Figure 3-35. Caterpillar Tank Wash Longitudinal Profile

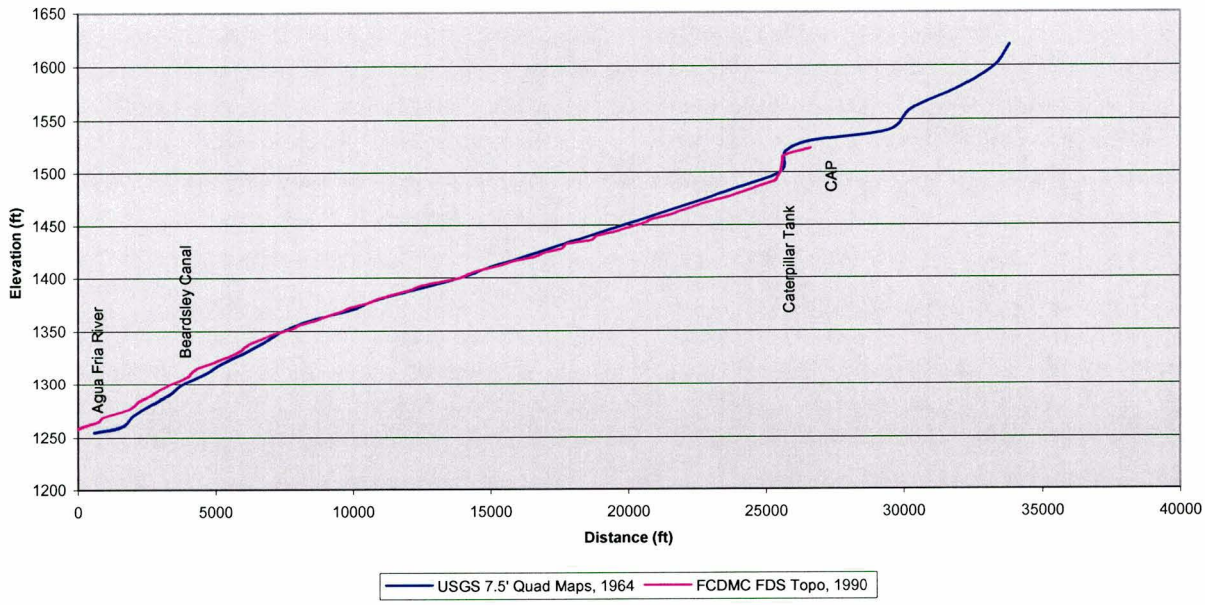


Figure 3-36. Twin Buttes Wash Longitudinal Profile

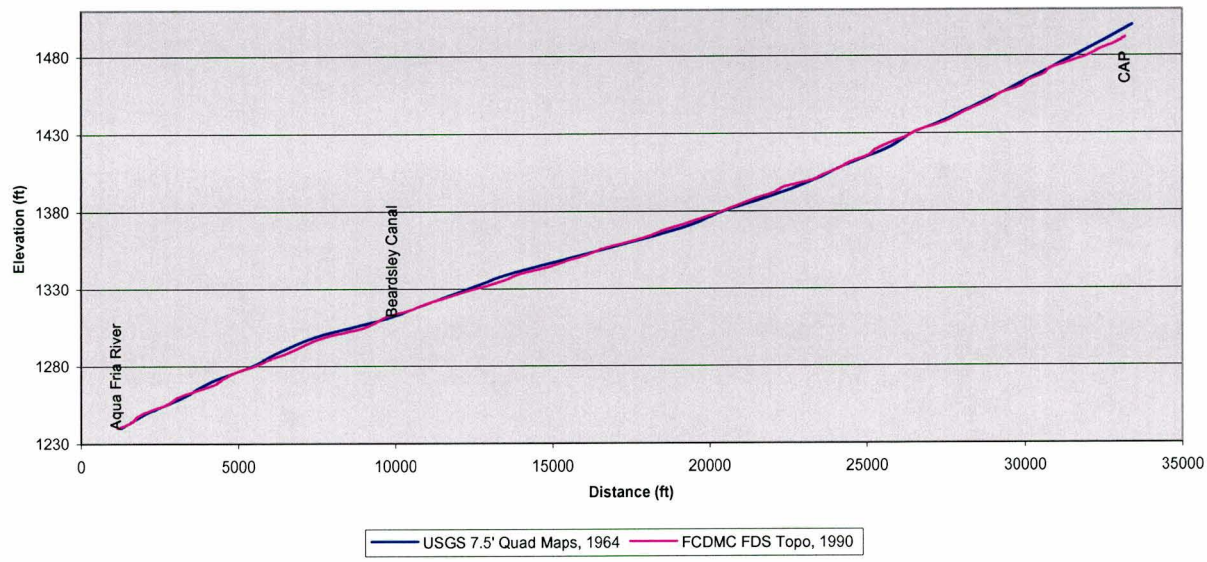


Figure 3-37. White Peak Wash Longitudinal Profile

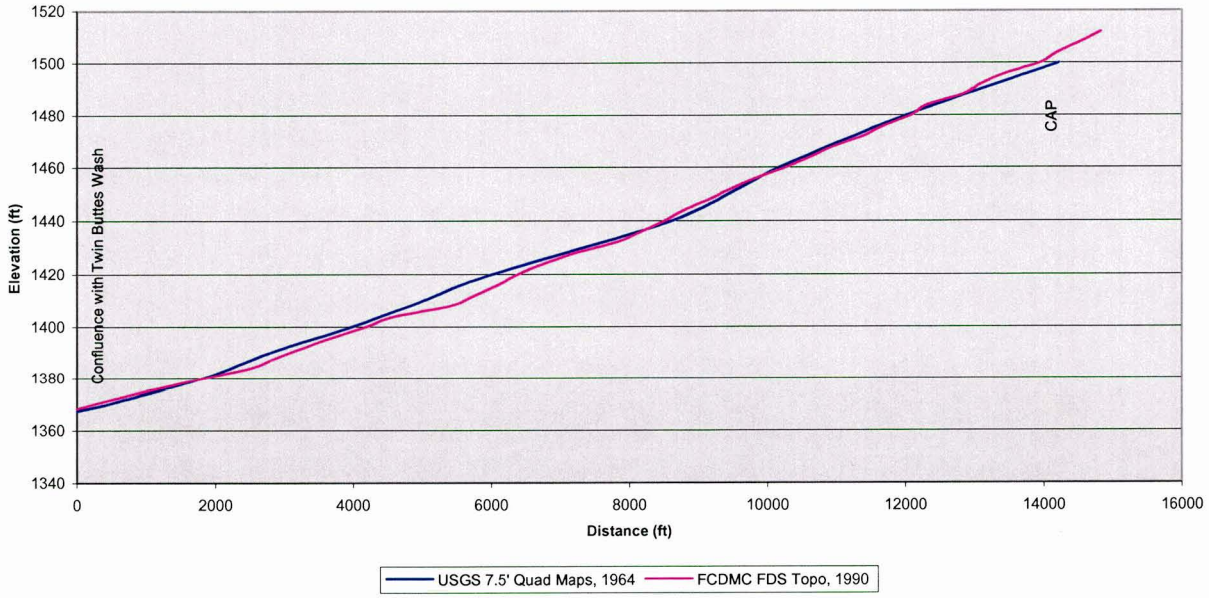


Figure 3-38. West Fork White Peak Wash Longitudinal Profile

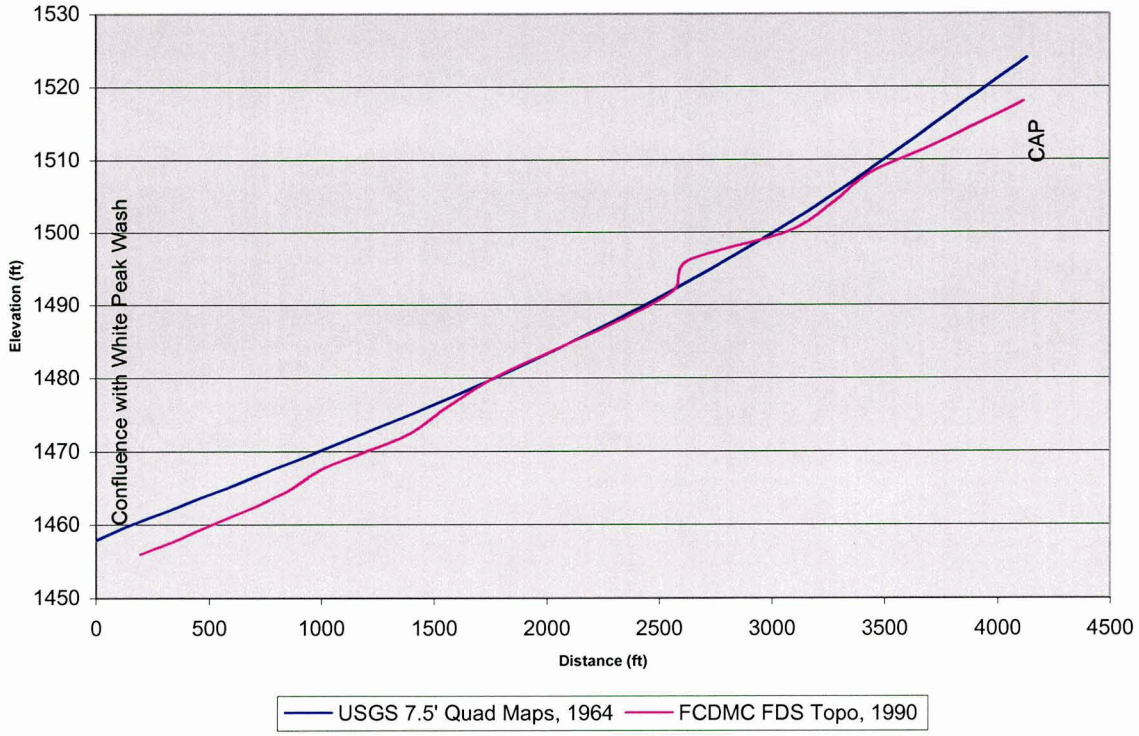


Figure 3-39 West Garambullo Wash Longitudinal Profile

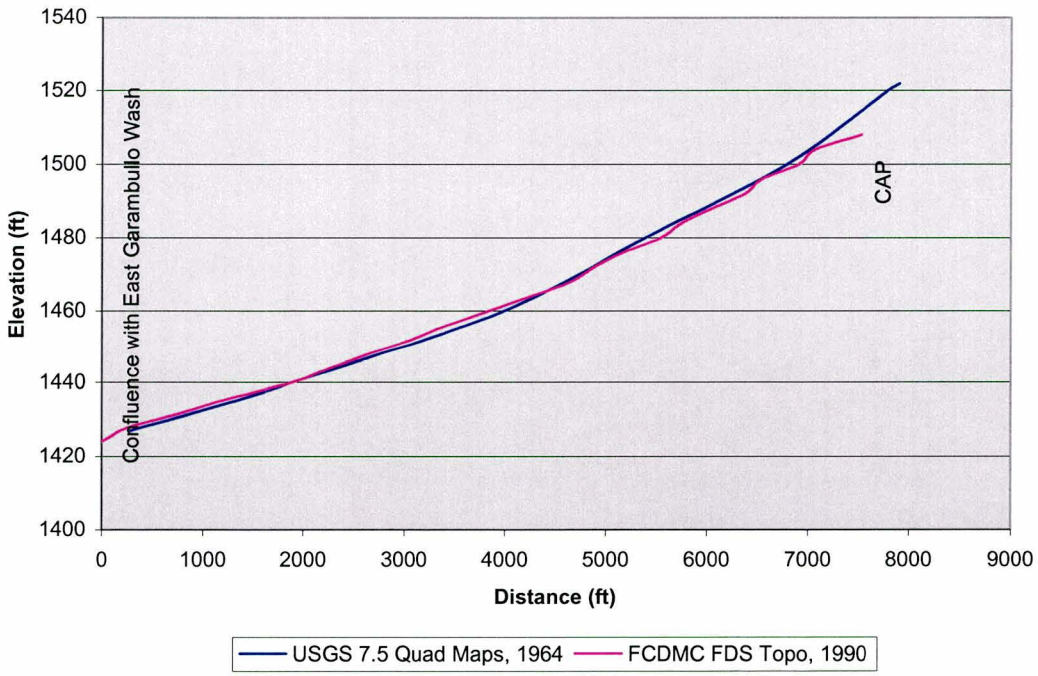
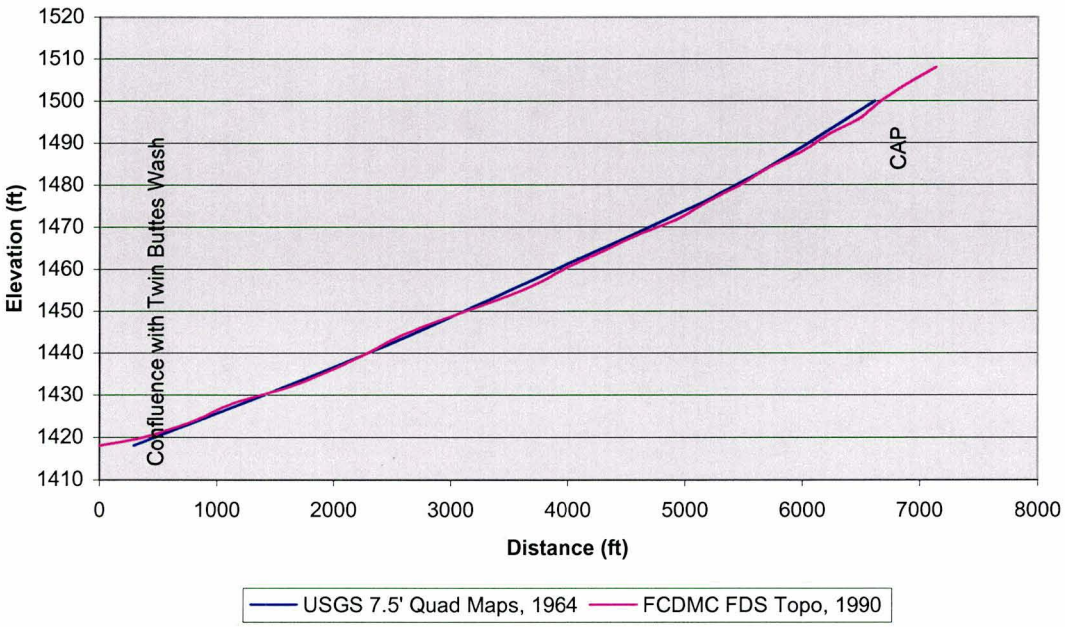


Figure 3-40. East Garambullo Wash Longitudinal Profile



Application of Allowable Velocity Guidelines. Allowable velocity criteria have long been used in channel design to estimate the velocity at which channel bed and bank sediments will begin to erode. A variety of allowable velocity data have been published by the Corps of Engineers (1970, 1990, 1995) and the Soil Conservation Service (1977), as well as by many other agencies.

The Corps of Engineers (1970; 1995) has established suggested maximum velocities for design of non-scouring flood control channels of various bank materials, as shown in Table 3-5. In general, the banks of the streams in the study area are composed of silty fine sand and are covered with brush and woody vegetation. Grass cover was not observed in the field. The average floodway velocities derived from the AGK (1991) HEC-2 modeling indicate that the erosive threshold for the bank material will be exceeded during the 100-year event, as shown in Table 3-6. In some cases, even the erosive threshold for weak sedimentary rock will be exceeded. No information on expected velocities for the 2-, 10- or other recurrence intervals was available, but should be included if more detailed erosion hazard evaluations are conducted. Bed sediments observed in the field indicated that up to cobble sized material is transported during bankfull events.

Table 3-5. North Peoria ADMP Erosion Hazard Evaluation
Suggested Maximum Permissible Mean Channel Velocities (USACOE, 1995)

Channel Material	Mean Velocity (ft/sec)
Fine Sand	2.0
Fine Gravel	6.0
Grass-Lined Banks (< 5% Slope, Sandy Silt, Bermuda Grass)	8.0
Poor Rock (Sedimentary)	10.0
Good Rock (Igneous or Metamorphic)	20.0

Table 3-6. North Peoria ADMP Erosion Hazard Analysis
FDS 100-Year Floodway Velocities

Stream Name	Average Velocity (ft/s)	Maximum Velocity (ft/s)
Twin Buttes Wash	6.6	10.9
White Peaks Wash	5.8	9.5
West Fork White Peaks Wash	6.2	7.9
West Garambullo Wash	6.2	9.2
East Garambullo Wash	5.1	7.7
Caterpillar Tank Wash	6.4	9.7

The allowable velocity information summarized above indicates that bank erosion should be expected during the 100-year event, particularly where the stabilizing bank vegetation is removed.

Conclusions

Based on the methodologies described above used to evaluate the erosion hazards, the following conclusions can be drawn:

- Cut banks, which are evidence of recent and ongoing bank erosion, occur throughout the study area as shown on Exhibit 3-1 and Table 3-3.
- Lateral erosion should be expected within the limits of the canyons that confine the main channels and their natural floodplain terraces as shown in Figure 3-2.
- 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.
- Floodplain soils appear to be composed of highly erosive materials.
- The streams in the study area have been subject to channel avulsions, stream capture, changes in channel pattern, local scour, and channel migration, all of which indicate a high erosion hazard.
- Historical data indicate that lateral channel movement of up to 110 feet and several channel avulsions have occurred within the past 50 years.
- Expected 100-year velocities exceed the erosive threshold for the soils that comprise the channel banks in the study area.
- The streams in the study area have a high sediment transport capacity, and could cause significant lateral erosion.
- Caliche or clay-rich soils do not prevent lateral erosion.
- Bedrock does prevent lateral erosion.
- Long-term scour has not occurred in the study area within the time scale of concern for this study, but could become a significant factor in lateral erosion with future changes in watershed conditions.
- Existing structures have had minimal impact on potential erosion hazards.

Based on the methodologies described above used to evaluate the erosion hazards, the following conclusions can be drawn with respect to specific streams in the study area:

Caterpillar Tank Wash. The occurrence of cut banks was lowest on Caterpillar Tank Wash (Table 3-2). Significant erosion hazards exist immediately downstream of Caterpillar Tank, due to the potential for failure of this non-engineered dam. At sharp channel bends, high velocities will erode any non-bedrock bank materials. Where the main channel bank heights are low relative to the floodplain elevation, the potential for channel avulsions exists, especially in more sinuous reaches.

Twin Buttes Wash. The highest risk of erosion on Twin Buttes Wash occurs where the canyon widens and where low floodplain elevations increase the risk of channel avulsions. The canyon is widest near the Garambullo Wash confluence and downstream of the Beardsley Canal.

White Peak Wash. Shallow bedrock which crops out in the bed and banks of White Peak Wash downstream of the confluence with the West Fork of White Peak Wash limits the potential for future lateral erosion. Significant lateral erosion hazards exist at sharp channel bends, especially where the main channel bank height is low relative to the floodplain. A narrow divide between White Peak Wash and the West Fork of White Peak Wash located about 600 feet upstream of their confluence has the potential to erode, and may lead to a stream capture, and accelerated lateral erosion downstream.

West Fork White Peak Wash. The potential for lateral erosion is somewhat limited on this wash compared to the other washes in the study area due to the low peak discharge caused by the small culvert under the CAP. However, ponding upstream of the small culvert under the CAP may lead to longer than natural flow durations. Long flow durations can cause higher rates of lateral erosion.

East Garambullo Wash. The potential for lateral erosion is somewhat limited on this stream compared to the other washes in the study area due to the low peak discharge caused by the small culvert under the CAP. However, ponding upstream of the small culvert under the CAP may lead to longer than natural flow durations. Long flow durations can cause higher rates of lateral erosion. The highest risk of erosion occurs in the reach immediately upstream of the Twin Buttes Wash confluence, where the bank heights are lower and a braided channel pattern is present.

West Garambullo Wash. The potential for lateral erosion is somewhat limited on this wash compared to the other washes in the study area due to the low peak discharge caused by the small culvert under the CAP. However, ponding upstream of the small culvert under the CAP may lead to longer than natural flow durations. Long flow durations can cause higher rates of lateral erosion.

Recommended Erosion Hazard Zone. The SSA 5-96 Level 1 Methodology erosion hazard setbacks are not conservative at many locations, according to the conclusions summarized above and the conditions observed in the field. Therefore, a recommended erosion hazard zone line for each of the six streams in the study area was established based on consideration of the following information:

- SSA 5-96 Setback
- Field Notes and Observations
- Historical Channel Changes
- Local Channel and Floodplain Topography
- 100-Year Floodplain Limits
- Bedrock Outcrop

- Caliche Outcrop
- Cut bank Locations
- Channel Bend Radius and Position
- Channel Pattern and Sinuosity
- Bank Vegetation Type, Density and Age
- Height of Natural Floodplain Terraces Above Main Channel Bed
- Avulsion Potential
- Stream Capture Potential
- 100-Year Discharge
- Flood Hydrograph Attenuation by CAP Ponding
- Future Development
- Longitudinal Profile
- Canyon Depth and Width
- Slope of Canyon Walls
- Location of Main Channel Within Canyon

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 outside (more conservative) than the setback based on the SSA 5-96 Level 1 Methodology, except in areas with bedrock outcrops or extensive well-indurated carbonate layers.

Differences between the erosion zone recommended by this study and the setback calculated from the SSA 5-96 Level methodology occur throughout the study area. These difference are primarily due to the higher level of analysis used for this study, and occur in the following areas:

- Downstream of Beardsley Canal. The greatest difference between the recommended erosion hazard zones and the SSA 5-96 Level 1 setbacks occur downstream of the Beardsley Canal. This difference in erosion hazard delineation is primarily due to the large width of the geologic floodplain of Twin Buttes Wash and Caterpillar Tank Wash in this area, the lack of resistant material in the banks, the low density of bank vegetation, and the potential for channel avulsions. It is possible (but not guaranteed), that with more detailed analysis of the floodplain soils and more detailed hydraulic modeling, as described in Appendix 2, the recommended erosion zone width could be reduced.

- Sharp Channel Bends. Where sharp channel bends occur leaving thin "peninsulas" between the erosion hazard zones, the recommend erosion zone was widened to eliminate the "peninsula" and to reflect the potential for these areas to be cut by erosion in the future.

- Wide Floodplains. The recommended erosion hazard zone envelopes the entire geologic floodplain to reflect the potential for channel avulsion, the fact that the floodplain soils are highly erodible, and the potential for erosion by flow moving across the floodplain during the design event. In many locations, the SSA 5-96 setback is arbitrarily located in the middle of the geologic floodplain regardless of local conditions.

- Bedrock Outcrop. The recommended erosion zone is set at the margins of bedrock outcrops. The SSA 5-96 setback frequently is much wider than the recommended erosion zone in these locations.

Discussion and Recommendations

Areas located within the recommended erosion hazard setback lines may be subject to increased risks that warrant specific development restrictions. Given the level of detail used to develop the recommended erosion hazard setback lines, the developer should be given the option of completing a more detailed erosion hazard zone analysis. A typical scope of work for such an analysis is provided in Appendix 2.

References Cited

ADWR, 1996, SSA 5-96: State Standard for Watercourse System Sediment Balance.

AGK, 1991, Flood Insurance Study for Caterpillar Tank and Twin Buttes Washes from Agua Fria River to C.A.P. Canal, Maricopa County, Arizona. Report and two Appendixes submitted to the Flood Control District of Maricopa County. June 1991.

Erie & Associates, 1999, Final Master Drainage Study Lakeland Village. Report submitted to the Flood Control District of Maricopa County. September 28, 1999.

Huckleberry, G., 1995, Surficial Geology of the Lower Agua Fria River, Lake Pleasant to Sun City, Maricopa County, Arizona. Arizona Geological Survey Open File Report 95-5.

JE Fuller/ Hydrology & Geomorphology, Inc., 2000, Upper Cave Creek/Apache Wash Watercourse Master Plan Report Volume XX: Lateral Stability Assessment. Draft Report submitted to the Flood Control District of Maricopa County. January 12, 2000.

U.S. Army Corps of Engineers, 1970, Hydraulic Design of Flood Control Channels, EM1110-2-1601.

U.S. Army Corps of Engineers, 1990, Stability of Flood Control Channels, Draft.

U.S. Army Corps of Engineers, 1995, Hydraulic Design of Flood Control Channels, EM1110-2-1601. ASCE Republication.

DATE: December 26, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E./ Stantec

FROM: Jon Fuller, P.E.

RE: North Peoria ADMP
Sedimentation Engineering & Geomorphic Evaluation
Task 2.6.3 – Erosion Hazard Analysis

Introduction

This memorandum describes the results of an evaluation of the erosion hazards for the three unnamed tributaries to the Agua Fria River in the North Peoria Area Drainage Master Plan (ADMP) study area. In addition, three tributaries to the unnamed washes were studied. In this report, the unnamed washes are referred to as Wash 1,[1] Wash 2, and Wash 3. The tributaries are referred to as Tributary #1 to Wash 1, Tributary #1 to Wash 2, and Tributary #2 to Wash 2. The primary objectives of the erosion hazard evaluation were to establish an erosion hazard zone for the unnamed washes and to determine where more detailed erosion analyses should be required prior to development.

This evaluation was completed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting, Inc. (Stantec) under contract to the Flood Control District of Maricopa County (District). This memorandum and its attachments are the deliverables for Task 2.6.3.2 of Contract #FCD 99-45.

Geologic Setting

The unnamed washes drain the Hieroglyphic Mountains, and are located west of the Agua Fria River and generally south of the Carefree Highway (Figure 3-41), in the transition zone between the Central Highland and Basin and Range Physiographic Provinces. The Hieroglyphic Mountains consist of normal-faulted Proterozoic granite and schist blocks unconformably overlain by Tertiary-aged volcanic and volcanoclastic units. The present landscape in the study area is a product of geological processes of upland erosion and basin filling during the past several millions years. During this period, highly variable sedimentary units were deposited and are now found plastered along the margins of the igneous units that form the mountainous areas (Huckleberry, 1995). The bedrock geology of the Hieroglyphic Mountains strongly controls the slope, pattern and extent of the three unnamed washes. Each of the washes flows within a narrow canyon with extensive bedrock exposures, small waterfalls, slot canyons, and narrow floodplains of limited extent.

[1] According to the records of the Arizona State Land Department, Wash 1 is actually named Bailey Tank Wash. For consistency with other project deliverables, Bailey Tank Wash is referred to as Wash 1 in this report.

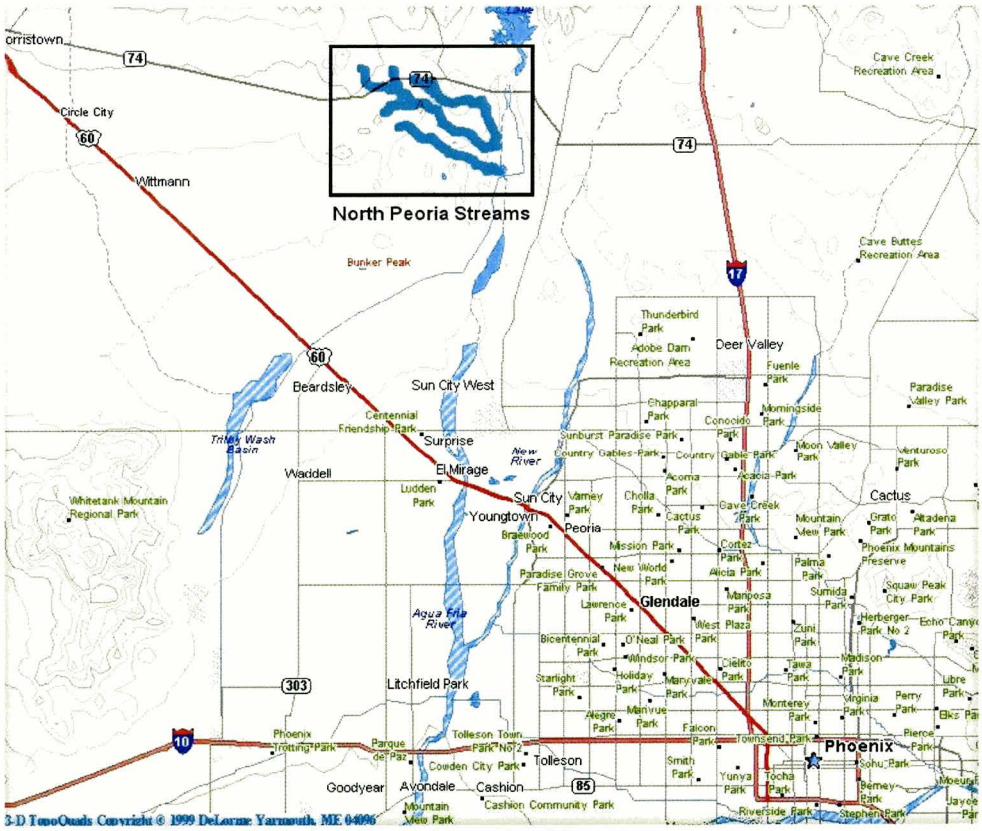


Figure 3-41. Unnamed Washes General Location Map

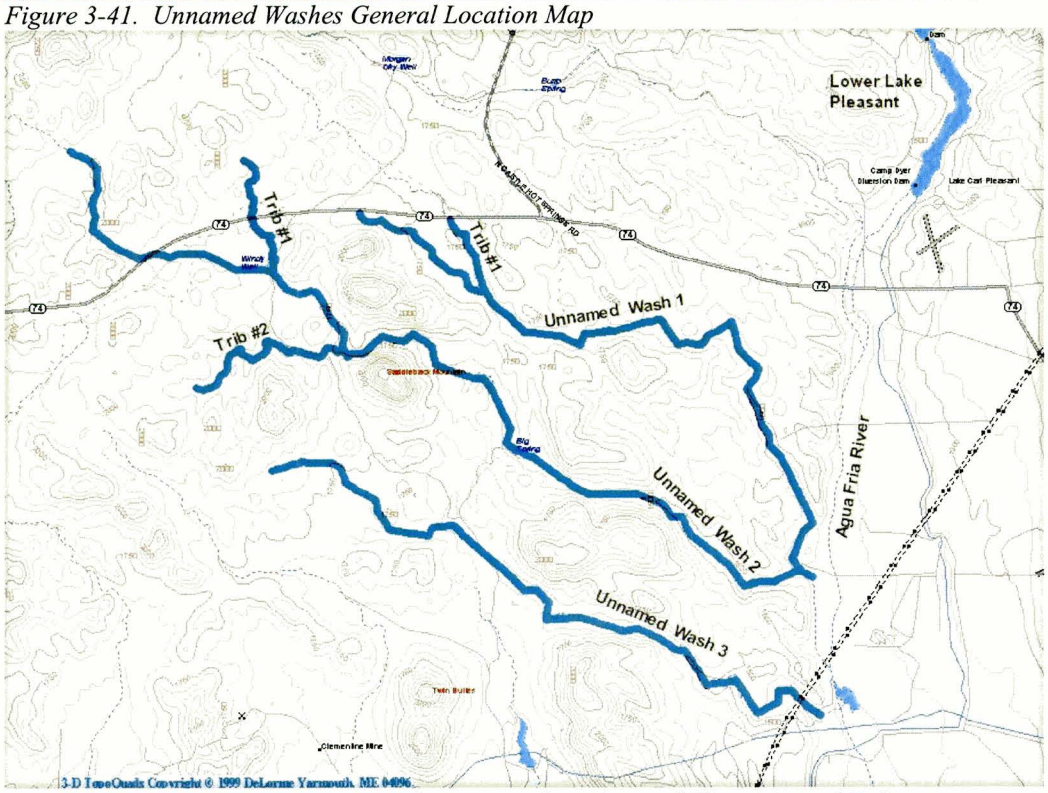


Figure 3-42. Detailed Location Map for Unnamed Washes and Their Mapped Tributaries.

Methodology & Results

A variety of methodologies were used to evaluate the erosion hazard for the unnamed washes. The project scope of work dictated that the SSA 5-96 Level 1 Methodology be used to establish an initial erosion hazard zone. In addition, the following types of information were considered:

- Field Observations
- Aerial Photographs
- Historical Channel Position
- Stream Longitudinal Profile
- Allowable Velocity Guidelines

The methodologies used to estimate the erosion hazard zone are described in more detail in the paragraphs below.

State Standard 5-96 Level 1 Methodology. Minimum required erosion hazard setbacks for watercourses in Arizona were established by the Arizona Department of Water Resources (ADWR) under authority of Arizona Revised Statutes 45-3605(a). SSA 5-96 (ADWR, 1996), adopted in 1996, describes a methodology for estimating an erosion setback to account for the lateral instability of Arizona streams. The SSA 5-96 Level 1 Methodology is based on the following two equations:

$$SB = 1.0 \cdot (Q_{100})^{0.5} \qquad \text{Eq'n \#1}$$
$$SB = 2.5 \cdot (Q_{100})^{0.5} \qquad \text{Eq'n \#2}$$

Where SB = Erosion hazard setback distance (ft.)
Q_{100} = 100-year peak discharge (cfs)

According to SSA 5-96, equation #1 is intended for stream segments that are straight or have "minor curvature." Equation #2 is intended for stream segments with "obvious curvature." Obvious curvature is defined as a channel centerline with a radius of curvature less than five times the channel topwidth. Other guidelines and limitations for the SSA 5-96 Level 1 Methodology are summarized in Table 3-7. According to the State Standard criteria, the SSA 5-96 methodology is applicable to the three unnamed washes in the North Peoria ADMP study area.

Channel curvature was measured on aerial photographs of the study area collected by Stantec for this project (Cooper, 2000) or on the digital aerial photography provided by the District. 100-year discharge estimates were obtained from the Stantec (2001) Floodplain Delineation Study. The results of the SSA 5-96 Level 1 Methodology for streams in the study area are shown in Table 3-8.

Table 3-7. Unnamed Wash Erosion Hazard Analysis SSA 5-96 Setback Guidelines and Limitation Study Area Condition		
SSA 5-96 Guideline/Limitation	**Characteristic for Unnamed Washes**	**SSA 5-96 Applicable?**
Drainage area < 30 mi.^{2}	Drainage area: Wash 1 = 5.1 mi.^{2}, Wash 2 = 7.7 mi.^{2}, & Wash 3 = 3.6 mi.^{2} at Agua Fria confluence	Yes
Significant channel filling	No – generally degradation observed	Yes
Local mining	None observed	Yes
Channel modifications	Minimal –culverts at Carefree Highway	Yes
Massive past channel shifting	Minor shifting – contained within bedrock canyon	Yes
Channelization	None observed except near culvert at Carefree Highway	Yes

Table 3-8. Unnamed Wash Erosion Hazard Analysis SSA 5-96 Setbacks for WASH				
Stream Name & Stantec HEC-1 Concentration Point	**Drainage Area (mi^2)**	**Q100 (cfs)**	**Erosion Setback Distance (ft)**	
			Straight Chl	**Curved Chl**
Wash #1				
S100	0.57	746	27	68
C102R	1.20	1185	34	86
C103R	2.95	2331	48	121
C104	4.11	2901	54	135
C105L	5.05	3202	57	141
Tributary #1 to Wash #1				
C102L	0.84	859	29	73
Wash #2				
S200	0.96	1379	37	93
C201	1.31	1669	41	102
C203R	1.81	1954	44	111
C204	3.17	2913	54	135
C205L	4.03	3345	58	145
C206	6.09	4325	66	166
C207R	6.74	4471	67	167
C105R	7.70	4567	68	169
Tributary #1 to Wash #2				
S204	0.95	1126	34	84
Tributary #2 to Wash #2				
S207	0.96	863	29	73
Wash #1 & Wash #2 Below Confluence				
C105	12.75	6847	83	207
Wash #3				
S301	0.99	1216	35	87
C301	2.07	1985	45	111
C302	2.78	2203	47	117
C303	3.60	2567	51	127
Note: Source of discharge data is Stantec HEC-1 model prepared for this study (Stantec, 2001).				

The SSA 5-96 Level 1 setbacks were applied from the channel bank or the floodway, whichever was further from the channel centerline, as per the SSA 5-96 Level 1 Methodology. For much of the study area, the FEMA floodway limit is coincident with the FEMA floodplain limit, because of the geometry, lack of floodplains, and limited area for encroachment within the narrow bedrock canyons. SSA 5-96 Level 1 setbacks for the

unnamed washes were provided digitally to the District, but are not recommended for adoption by the District, primarily due to the abundance of bedrock in the canyon walls and floor, as described in other sections of this memorandum. Instead, erosion hazard zones were defined using the techniques and information described in the remainder of this memorandum.

Field Observations. Field visits to the study area were conducted on several occasions. Field visits consisted of walking the entire study reach, 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 stream responses to human impacts or structures
- Identify points of natural grade control

The most relevant data collected during the field visits were synthesized and are shown on Exhibit 3-2. Field data collected included the following:

- Locations of cut banks (active erosion)
- Locations of bedrock outcrops in the bed and channel banks
- Location of headcuts and slope breaks
- Location and extent of stream terraces and natural floodplains[1]
- Location of human impacts, structures, and road crossings
- Channel characteristics at representative cross sections

The following general conclusions are supported by the data collected during the field reconnaissance visits:

- Canyon Cross Section. In most of the study area, the unnamed washes and their tributaries flow within confined bedrock canyons, as illustrated in Figures 3-42 and 3-43. The canyon walls generally consist of either bedrock outcrops or shallow colluvial material over bedrock (Figure 3-43). In much of the study area, the washes occupy the entire canyon bottom (Figure 3-44), although in some reaches a wider discontinuous floodplain was observed (Figure 3-43). The lateral erosion hazard is generally high across the entire canyon bottom and is limited only where bedrock crops out in the banks or canyon walls. Figures 3-45 to 3-48 are photographs of typical canyon cross sections in the study area.

[1] Natural floodplains, which have physical expression in the landscape, are distinguished from the FEMA (100-year) floodplain, which is a regulatory concept and may not coincide with natural features observed in the field.

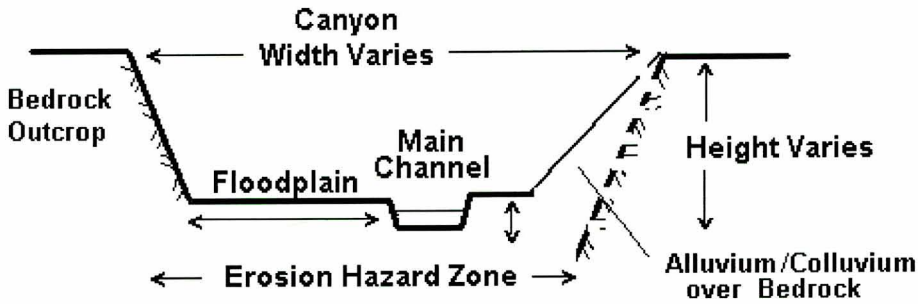


Figure 3-43. Typical Canyon Cross Section in Study Area

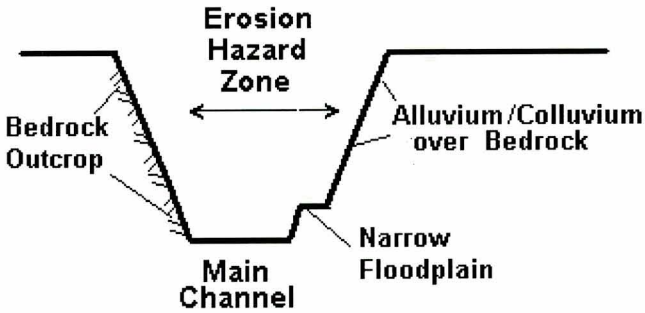


Figure 3-44. Typical Canyon Cross Section in Narrow Canyon Reaches

Figure 3-45. Typical cross section with narrow floodplain opposite bedrock canyon wall in Wash 1. Note lichens on bedrock above frequent flow line. Photo #UT3-11.

Figure 3-46. Bedrock exposed in bed and both banks in "V" shaped canyon section in Wash 1. Note steep slope of channel in bedrock chute. Photo #UT3-12.

Figure 3-47. Medium floodplain near tributary (foreground) with high terrace (back) within bedrock canyon on Wash 1. Photo #UT2-36.

Figure 3-48. Slope failure at cut bank in thin colluvium displacing varnish boulders on canyon wall along left bank of Wash 1. Photo #UT2-13.

- Slot Canyons. In several places on each of the three unnamed washes, bedrock confines the low flow channel within slot canyons as narrow as a few feet wide (Figures 3-49 to 3-52). The narrowest slot canyons are typically less than 100 feet in length and do not have capacity to convey large discharges. Field evidence suggests the narrowest slot canyon reaches are frequently overtopped, experience extremely high velocities, and have high rates of sediment transport. Areas of sediment deposition are typically located upstream and downstream of the constricted slot canyon sections. The erosion hazard boundaries at the slot canyon reaches were delineated assuming that the low capacity would force floods to overtop the slot sections and flow on the floodplain and terraces.

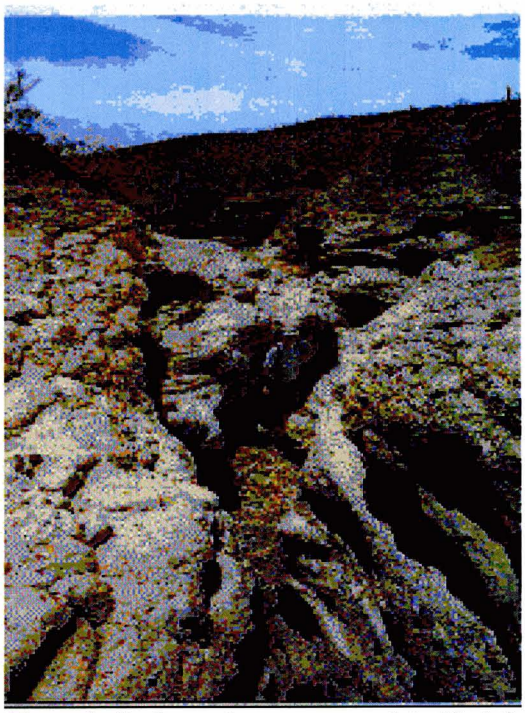


Figure 3-49. Long slot canyon reach in Wash 2. Photo #TM3-4.

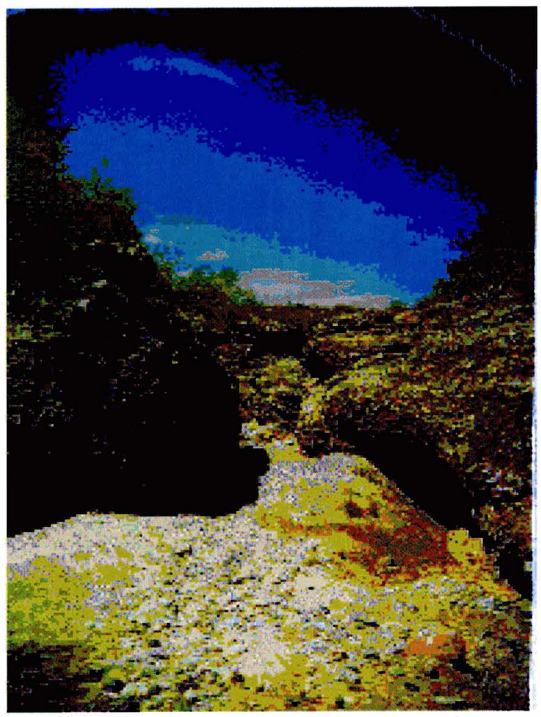


Figure 3-50. Slot Canyon with upstream deposition in Wash 3. Photo #PM 4-25.

Figure 3-51. Looking Upstream at a slot canyon on Wash 1. Floods overtop the slot canyon section and flow over as a waterfall. Photo #UT3-14.

Figure 3-52. Slot canyon reach on Wash 2. Note high areas scoured clean of sediment and downstream deposition. Photo #O-36.

- Typical Channel Section. The typical channel cross section for the unnamed washes is a single, well-defined channel with gravel and cobble bed material and well vegetated banks (Figures 3-53 to 3-55). Bank heights range from one foot to more than 20 feet at cut banks in canyon walls or high terraces. Observed channel widths were as low as about three feet in the smallest slot canyons, but averaged about 30 feet over the entire study area. In several isolated areas, avulsive braided or multiple channels were observed, particularly at or downstream of sharp bends or where the canyon was wider than adjacent reaches. Multiple channel reaches were observed where recent avulsions have occurred, creating islands out of the low floodplain surfaces. In a few places, avulsions have formed (or are forming) around bedrock islands in the canyon bottom. The channel bed material or bank conditions in the multiple channel reaches are not significantly different from the single channel reaches.

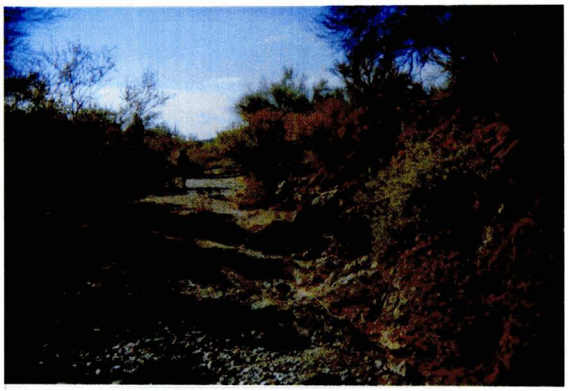


Figure 3-53. Typical channel section in shallow canyon reach of Wash 1. Channel dimensions reflect local bedrock geology. Note bedrock in right bank and low floodplain on left bank. Photo #UT1-25.

Figure 3-54. Typical channel section near headwaters of Wash 2. Note large angular bed material and overhanging vegetation. Photo #2-19.

Figure 3-55.Typical channel section in wide channel reach of Wash 3. Note cobble bed material and erosion of high terrace along right bank on channel bend. Photo #PM 2-6.

- Floodplain Characteristics. In most of the study area the floodplain is narrow, and is limited to the width of the canopy of the bank vegetation (Figures 3-57, 3-60, and 3-62) . In the few places where a wider floodplain occurs, two types of floodplain were observed (Figures 3-58, 3-59, and 3-63). The more common type of floodplain consisted of a wider, depositional surface composed of sand and gravel with sparse brushy vegetation and cacti. The less common type consisted of a low surface which appears to experience frequent inundation and active sediment transport, and is subject to avulsive channel movement. Floodplain characteristics are indicative of erosion hazard potential in the following manner. As the elevation of the floodplain above the channel bed increases, the frequency of flow on the floodplain surface decreases, and the erosion potential of the main channel bank increases due to the relatively higher flow depths and velocities along the main channel bank, as illustrated in Figure 3-56. Where the elevation of the floodplain is low, flow on the floodplain is more frequent, and the potential for avulsive channel change increases. The overall width of the 100-year floodplain (including the channel width; Figures 3-63 to 3-65) does not vary consistently in the downstream direction on any of the unnamed washes, and is probably controlled by the bedrock geology, as indicated by the increase in floodplain width in the upstream direction on Wash 3.

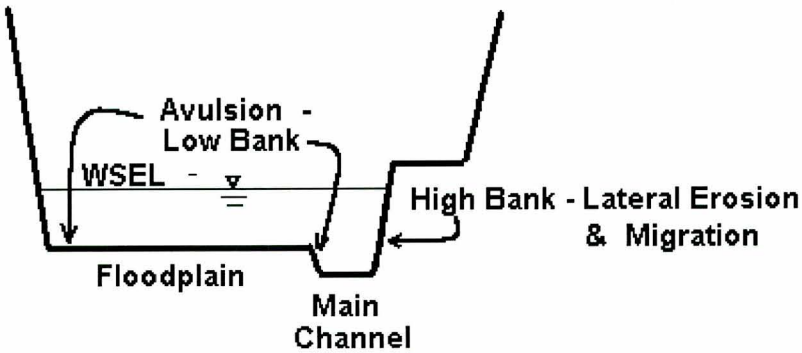


Figure 3-56. Sketch showing bank erosion type relative to bank height and floodplain elevation.

Figure 3-57. Narrow floodplain adjacent to main channel on Wash 1. Photo #UT2-8.

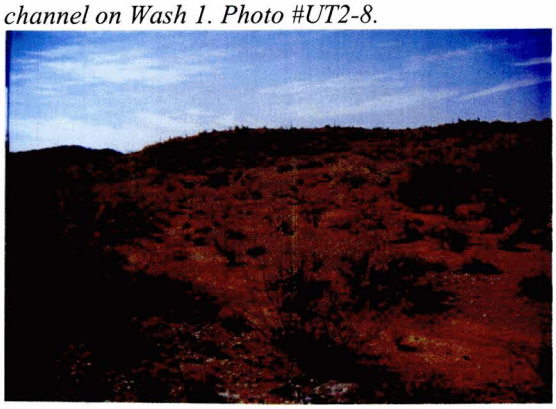


Figure 3-58. Wide depositional floodplain on Wash 1. Photo #UT2-10.

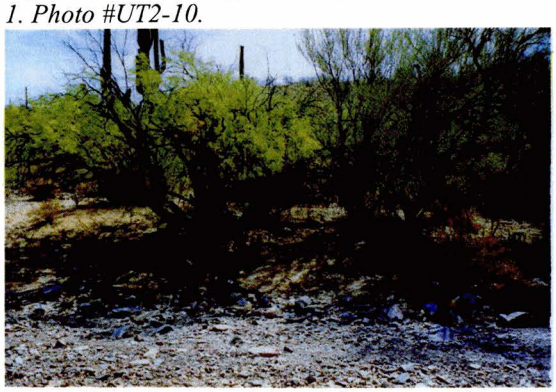


Figure 3-59. Low floodplain subject to avulsions, located on bend in Wash 2. Photo #TM2-24.

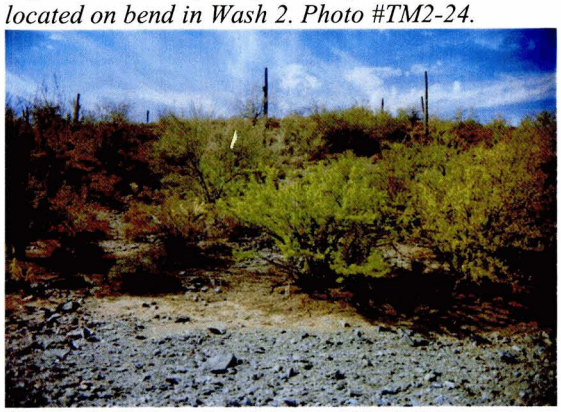


Figure 3-60. Low floodplain on Wash 3. note saguaros on high terrace. Photo #PM 1-20.

Figure 3-61. Exposed cross section of erodible floodplain soil on Wash 3. Photo #8.

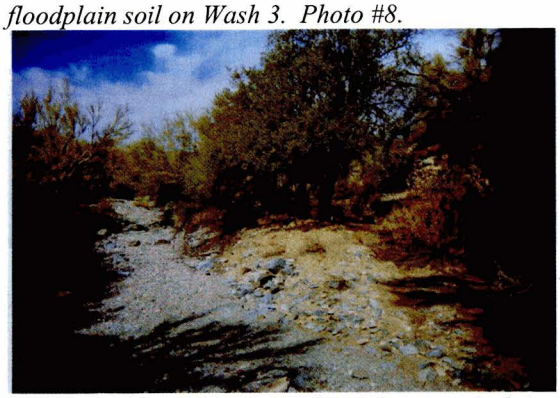


Figure 3-62. Small, narrow floodplain on Wash 3. Photo #PM2-11.

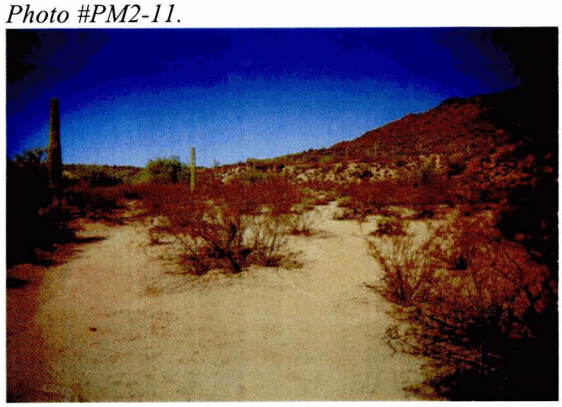


Figure 3-63. Wide depositional floodplain on Wash 3. Photo #11.

Figure 3-64. Wash #1 100-Year Floodplain Top Width

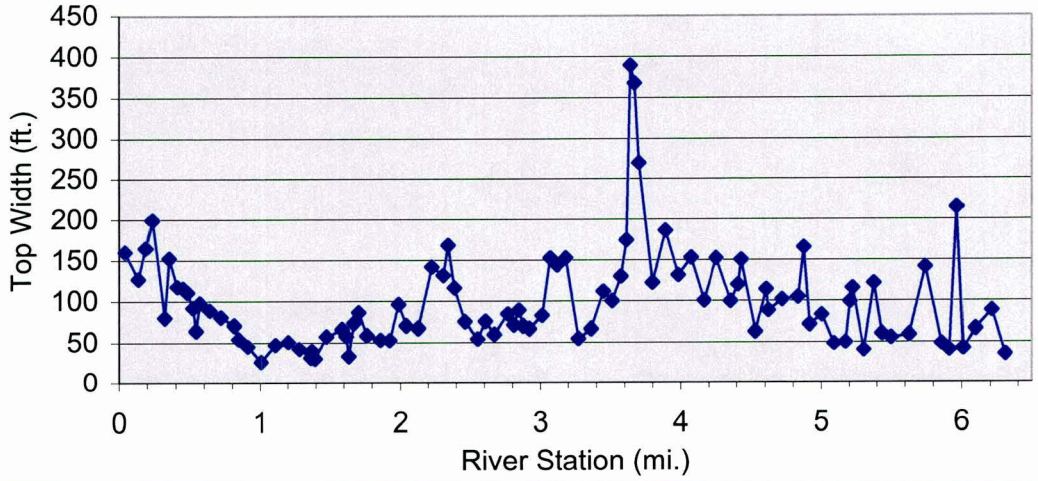


Figure 3-65. Wash #2 100-Year Floodplain Top Width

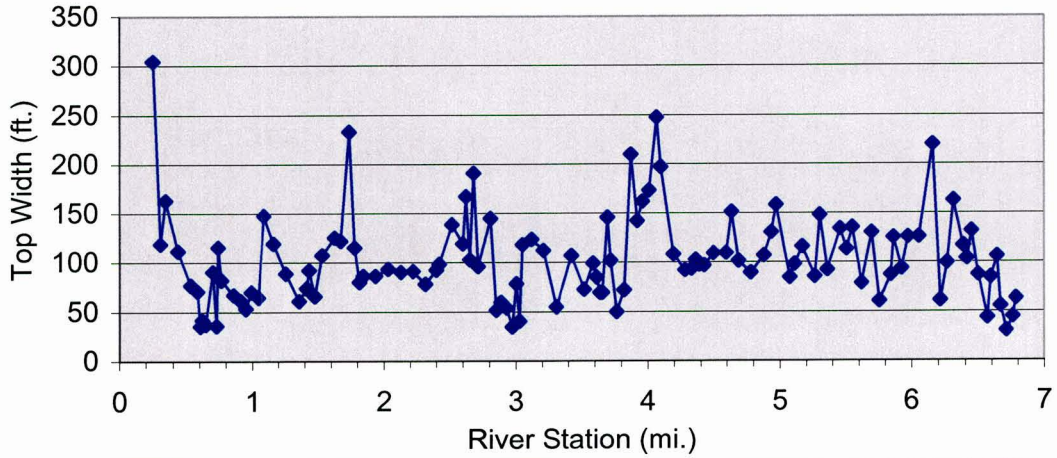
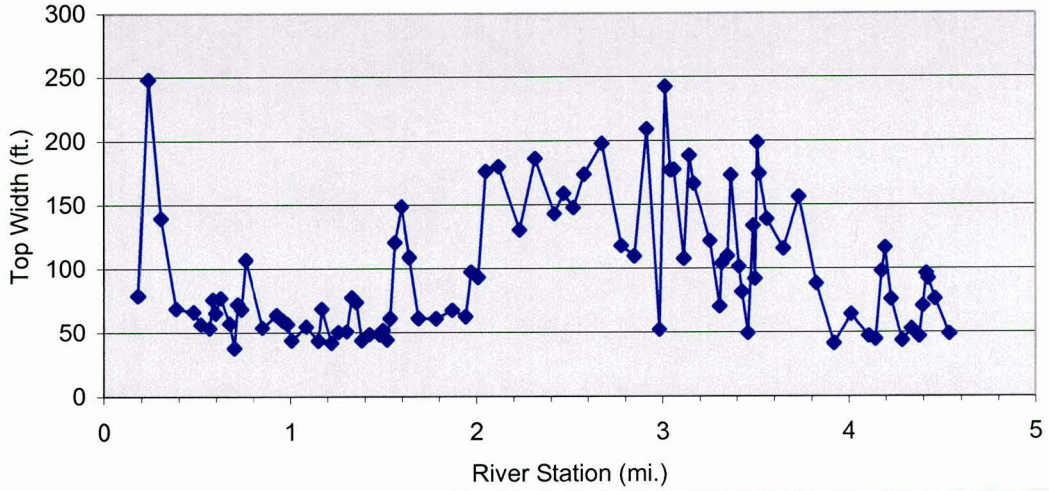


Figure 3-66. Wash #3 100-Year Floodplain Top Width



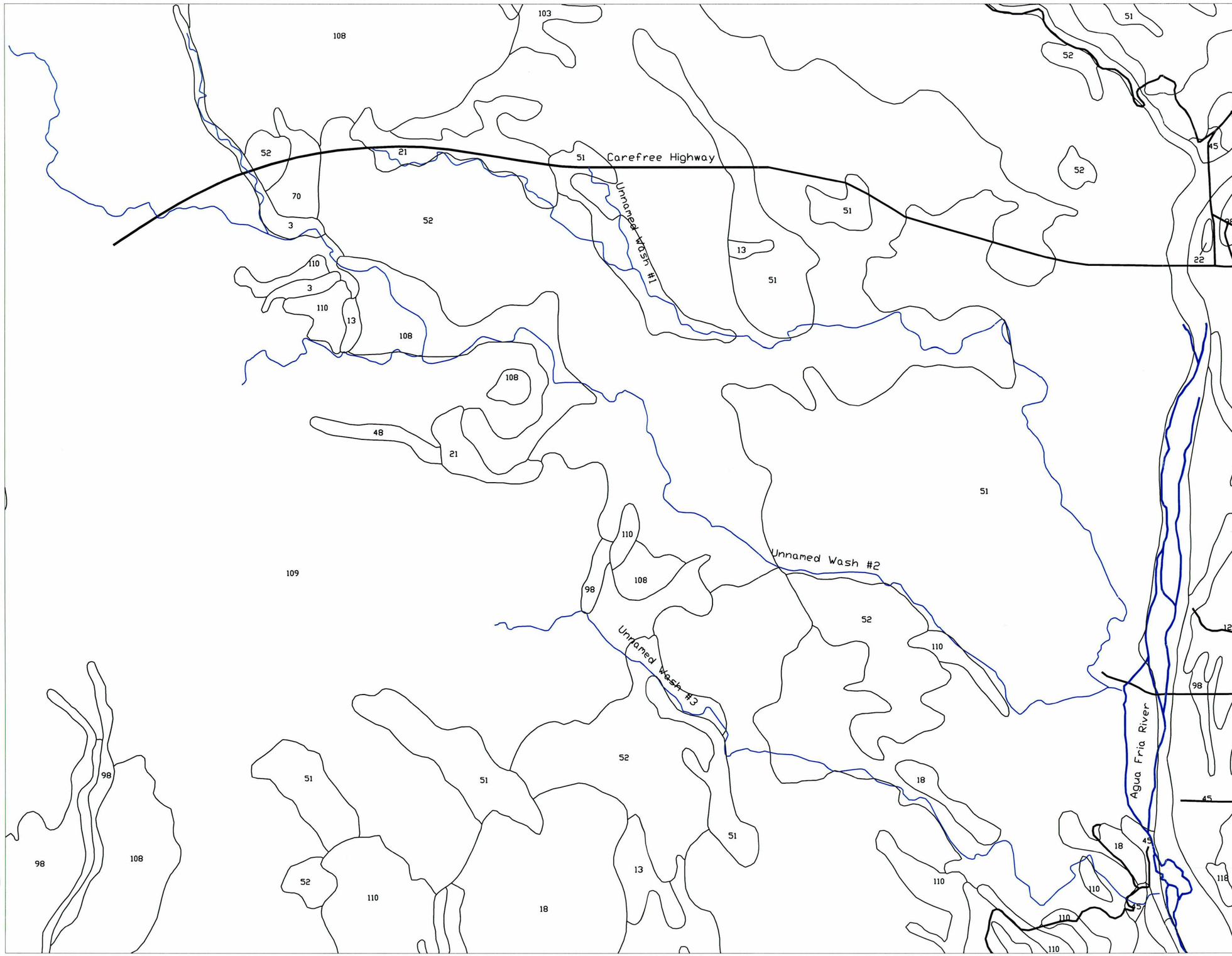


Figure 3-67
Soil Distribution -
Unnamed Washes

Symbol	Description
3	Antho-Carrizo Maripo complex
12	Carefree cobbly clay loam
13	Carefree-Beardsley complex
18	Cherioni-Rock outcrop complex
21	Cipriano very gravelly loam
22	Contine clay loam
45	Ebon very gravelly loam
51	Gachado-Lomitas complex
52	Gachado-Lomitas-Rock out. comp.
70	Gunsight-Rillito complex
98	Pinamt-Tremant complex
103	Rock outcrop-Gachado complex
108	Schenco-Rock outcrop complex
109	Schenco-Rock outcrop complex
110	Suncity-Cipriano complex
118	Tremant-Rillito complex

Thalweg - 2000

Unit Division

Roads

Scale

0 2400 4800

1 Inch = 2400 Feet

N

Overview

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Sheet 1 of 1

- Floodplain Soils. The soil materials underlying the floodplains adjacent to the main channels appear to be comprised of highly erosive, unconsolidated sand and gravel (Figure 3-61). Detailed soils mapping by the Soil Conservation Service (Camp, 1986) did not distinguish the soils along the unnamed washes from the soils of the surrounding uplands, except for a small area at the upstream end of the Wash #2 study reach (Table 3-9, Figure 3-67). In this area where floodplain soils were mapped (Unit 3, Antho-Carrizo Maripo Complex), they are reported to be subject to severe erosion hazards including active stream bank erosion, confirming the field observations made for this study. The area surrounding and including the most of the unnamed wash study area was mapped by the SCS as fan terraces, hill slopes, or mountain slopes. The decision of the SCS to map the canyon bottoms as the same soil units as the uplands probably reflects the lack of depositional soils along the canyon bottoms, the lack of significant floodplain surfaces, and the narrow width of the channels within the bedrock canyons.

Table 3-9. Unnamed Wash Erosion Hazard Analysis
Soil Conservation Service (Camp, 1986) Soils Map Units, Landform, and Erosion Potential

Unit	Name	Landform	Erosion Potential
3	Antho-Carrizo Maripo Complex	Floodplains & Drainageways	Severe & Stream Bank
21	Cipriano Very Gravelly Loam	Fan Terraces	Slight
45	Ebon Very Gravelly Loam	Fan Terraces	Slight
51	Gachado-Lomitas Complex	Hill Slopes	Slight
52	Gachado-Lomitas Rock Outcrop	Mountain Slopes	Moderate
70	Gunsight-Rillito Complex	Fan Terraces	Slight
98	Pinamt-Tremant Complex	Fan Terraces	Slight
108	Schenco Rock Outcrop Complex	Mountain and Hill Slopes	Slight
109	Schenco Rock Outcrop Complex	Mountain and Hill Slopes	Slight
110	Suncity Cipriano Complex	Fan Terraces	Slight

Note: Erosion potential refers to slope processes (e.g., rilling) unless specifically noted to be stream bank erosion.

- Caliche. Outcrops of carbonate-rich soil layers (a.k.a. "caliche") were observed in some cuts banks along the unnamed washes (Table 3-10). The low percentage of caliche outcrops observed in the field compared to the other streams examined in the North Peoria ADMP study area probably reflects the young geologic age of the floodplain surfaces within the canyon bottom and the extensive bedrock outcrops. Where caliche layers were observed in the channel banks, the caliche appeared to do little to protect the overlying surfaces from lateral erosion of the main channel (Figures 3-68 to 3-70). While the caliche layers themselves are more resistant to erosion than the non-carbonate-cemented soil layers, field data suggests the carbonate layers erode primarily by undercutting the non-cemented or poorly-consolidated underlying soil layers (cantilever failures; Figure 3-69). In other places, caliche layers had apparently failed by direct shear and impact forces on the caliche itself.

Figure 3-68. Erosion by undercutting of caliche-cemented bank on Tributary 1 to Wash 2. Note that material from bank collapse is actively removed by the stream. Photo #O-31.

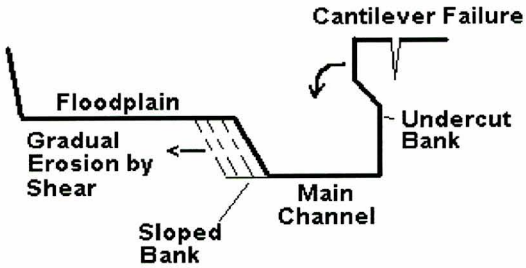


Figure 3-69. Illustration of tensional cantilever bank failure and lateral bank erosion by shear.

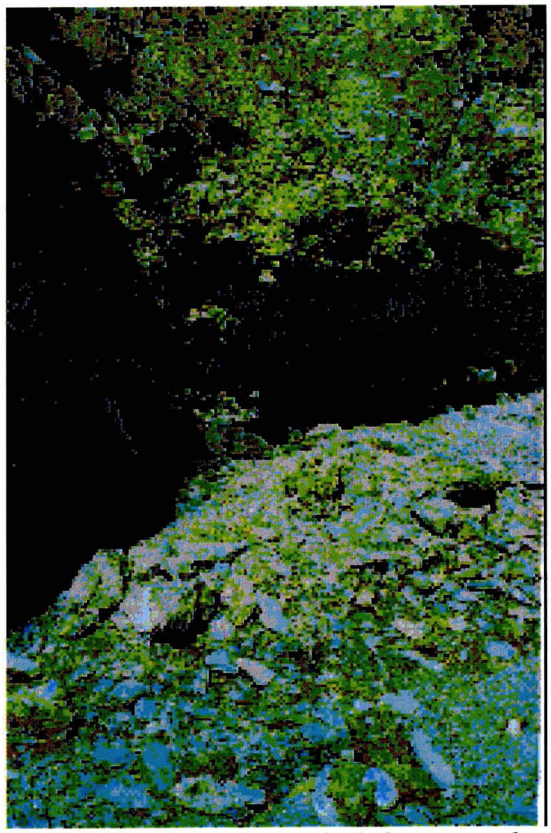


Figure 3-70. Undercutting of caliche-cemented cut bank on wash 2. Photo #2-17

- Bedrock. Bedrock crops out in the channel bed and banks of all the channels within the study area, and is probably present at shallow depths in most places where it does not crop out (Figures 3-71 to 3-73). The location of bedrock outcrops observed in the field are plotted on Exhibit 3-2. Lateral erosion is generally prevented by bedrock, although erosion of fine-grained volcanic units was observed in several places (Figure 3-73).

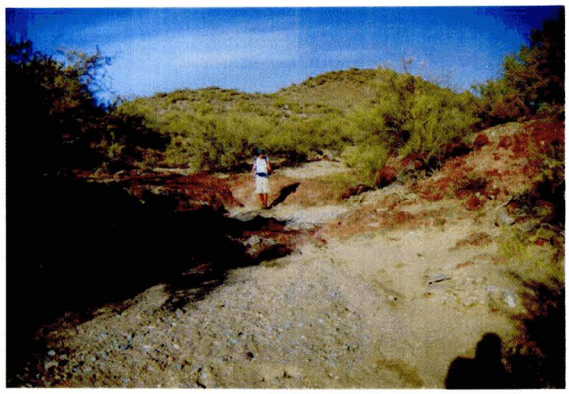


Figure 3-71. Bedrock sill exposed in the bed of Wash 1. Photo #UT1-19.

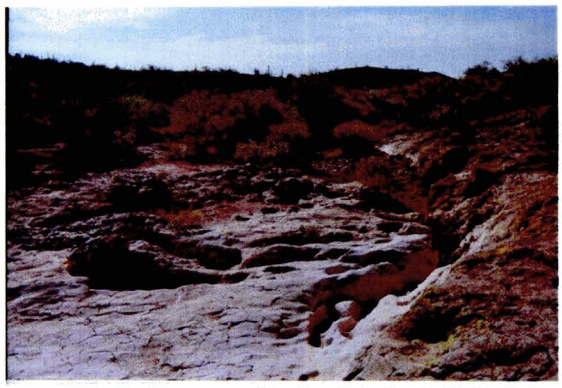


Figure 3-72. Erosion of bedrock in bed of Wash 1 ("fluting"). Photo #UT2-3.

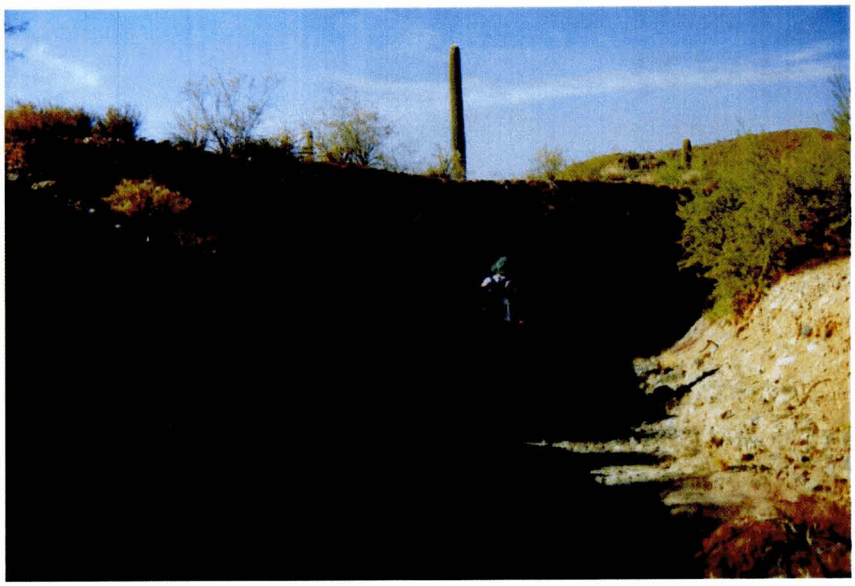


Figure 3-73. Erosion of weak volcanic rock (reddish unit) in left bank of Wash 1. Photo #UT1-23.

- Cut banks. Actively eroding cut banks were observed in many places on the unnamed washes. Cut banks were observed on channels cut into young and old geomorphic surfaces, poorly consolidated sedimentary rock units, and caliche-cemented alluvial material. Bank vegetation appeared to increase the stability of the bank soils, but did not prevent lateral erosion or the formation of cut banks. Undercut trees and brush with exposed roots were observed in a few places. Piles of alluvium which accumulate at the base of vertical cut banks provide basal control to the bank slopes. The absence of piles of collapsed soil material indicates that the stream is actively eroding and transporting the bank materials (Compare Figures 3-68 and 3-73). The presence of cut banks indicates that active lateral erosion can occur within the stream systems in the study area, regardless of bank vegetation, soil lithology, and soil composition (Figures 3-74 to 3-78). Cut banks observed in the field are plotted on Exhibit 3-2. The percentage of channel banks that were cut banks, as observed in the field, is summarized in Table 3-10.

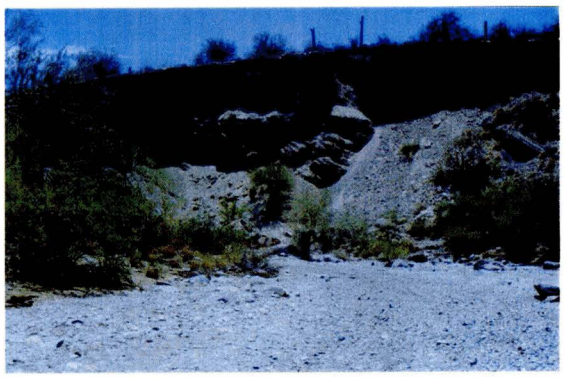


Figure 3-74. Canyon slope with basal control on Wash 2. Photo #2-10.

Figure 3-75. Bedrock "cutbank" on Wash 2. Photo #1-18.

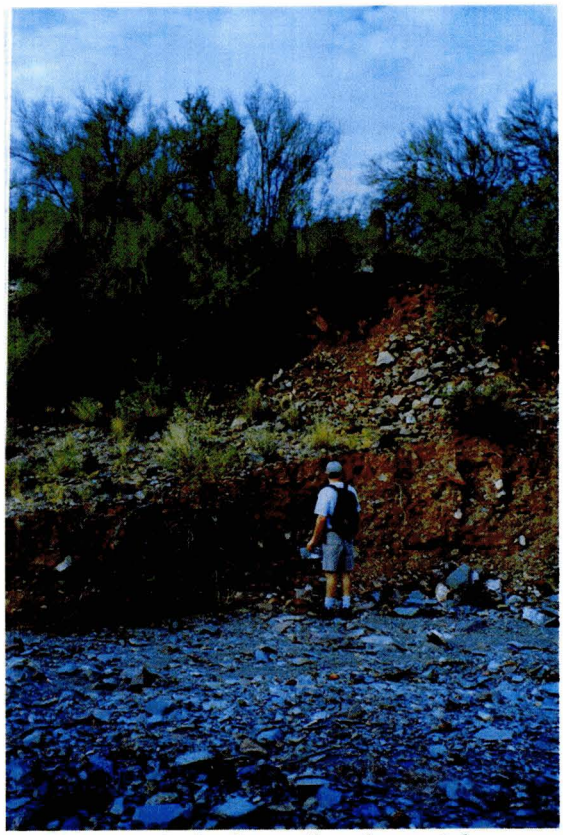


Figure 3-76. Cutbank in colluvial material on Wash 2. Photo #1-7.

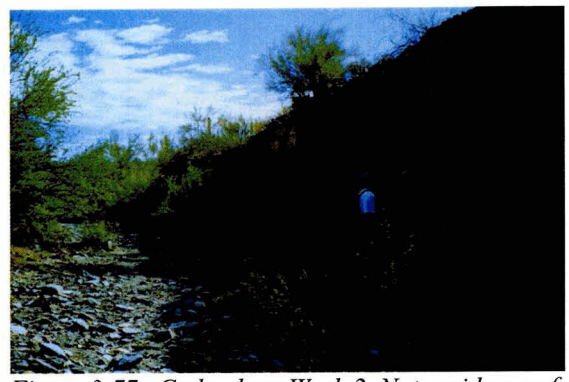


Figure 3-77. Cutbank on Wash 2. Note evidence of soil development and stratigraphy in soil column. Photo #2-5.

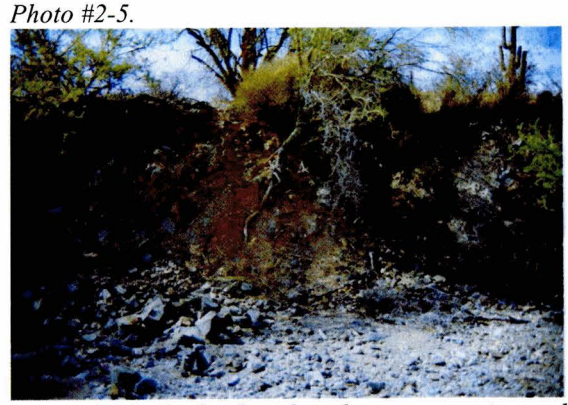


Figure 3-78. Cut bank with undercut vegetation and exposed roots on Wash 3. Photo #PM 2-5.

Table 3-10. Unnamed Wash Erosion Hazard Analysis Observed Bank Conditions

Wash #	Stream Length	Cut Banks	Bedrock Outcrop	Caliche ($CaCO_3$)
Wash 1	6.0 mi.	0.4%	30 %	0 %
Wash 2	7.8 mi.	5 %	45 %	0.2 %
Wash 3	5.5 mi.	11 %	28 %	0 %
Tributary 1 to Wash 1	0.6 mi.	0 %	39 %	0 %
Tributary 1 to Wash 2	0.8 mi.	18 %	15 %	0 %
Tributary 2 to Wash 2	1.3 mi.	7 %	55 %	0 %

The percentages of banks cut by recent erosion estimated from field notes are summarized in Table 3-10. The data in Table 3-10 demonstrate that cut banks are not rare in the study area, and occur naturally, despite minimal urbanization or disturbance of the watershed. No relationship explaining the variation of percent of cut banks could be developed based on the observed data. Field observations of the percent of bank composed of bedrock and caliche-cemented alluvium are also shown in Table 3-10.

- Stream capture. In several places the divides between adjacent canyons are less than 50 feet wide (Figure 3-79). Where these narrow divides are subject to lateral

erosion, such as along the outside of channel and canyon bends, the potential for stream capture exists. However, given that most of these narrow divides are at least in part composed of bedrock, the rate of lateral erosion will be slow, and the capture is not likely to occur in the near future. Furthermore, all of the narrow divides are located near the confluences of the canyon streams separated by the divides. Stream capture near the existing confluence, therefore, would not significantly impact stream morphology.

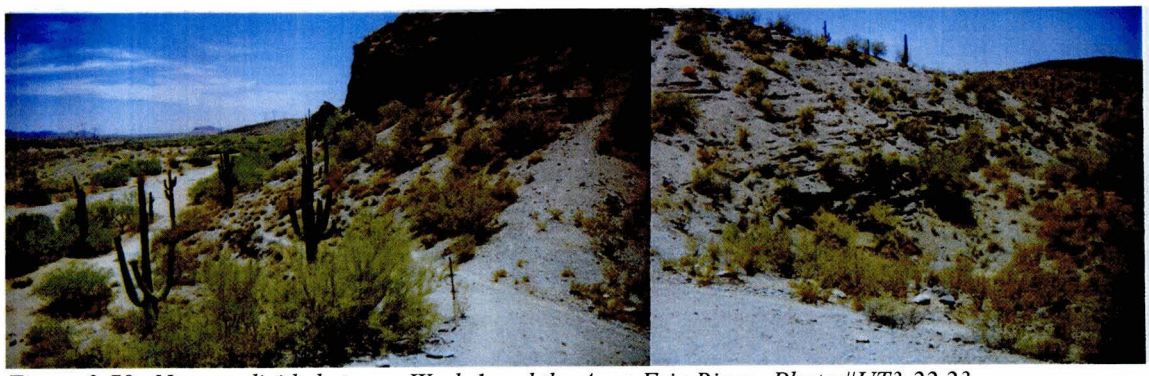


Figure 3-79. Narrow divide between Wash 1 and the Agua Fria River. Photo #UT3-22,23.

- Bank vegetation. In most locations, the banks of the main channel are well vegetated with palo verde, mesquite, ironwood, and dense brush (Figure 3-80). The bank vegetation generally covers the entire bank slope from toe to top, and includes deep rooting riparian species which enhance bank stability. The following aspects of the bank vegetation enhance bank stability: (1) root material which increases the cohesion of the soil material, and (2) leaves, branches, and debris which lower local flow velocities, cover the soil matrix, and prevent floodwaters from flowing directly on the soils that comprise the bank. The relatively young bank vegetation throughout much of the study area indicates that bank vegetation is periodically removed by erosion and flooding.

Figure 3-80. Typical bank vegetation consisting of palo verde, mesquite, ironwood, and various brush species (Wash 2). Photo #2-22.

- Sediment Transport. The beds of the main channels in the study area are primarily composed of gravel, sand and cobbles (Figures 3-81 and 3-82), with coarser sediment near the headwaters (Figure 3-54). The floodplains typically consist of finer sand and gravel deposits, with some coarse lenses of sediment. The difference in composition between the floodplain and channel materials indicates that fine-grained sediments are transported through the main channels without being deposited. The main channel sediments are moderately well sorted, indicating that they have been transported by recent flows, and are not primarily derived from slope processes acting on the banks and canyon slopes. Materials from bank collapse, soil failure and undercut banks are rapidly removed by channel processes.

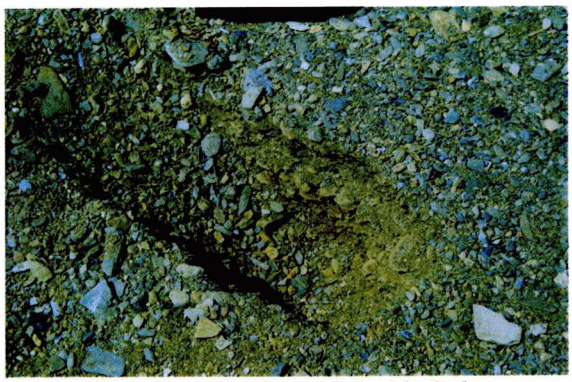


Figure 3-81. Gravel bed material with slight armoring on Wash 2. Note slight reddening under active bed layer. Photo #2-25.

Figure 3-82. Coarse bed material in riffle. Note clay layer under active bed layer in Wash 2. Photo #1-24.

- Channel Pattern. The dominant channel pattern of all the streams in the study reach is a slightly sinuous, single channel with a poorly- to well-developed pool and riffle pattern. In some reaches, recent avulsions have left a multiple channel pattern. Bedrock constrictions interrupt the channel pattern, particularly where bedrock sills create small waterfalls or grade control. The bedrock canyons themselves have a meandering character which is forced on the channels that flow within the canyons.

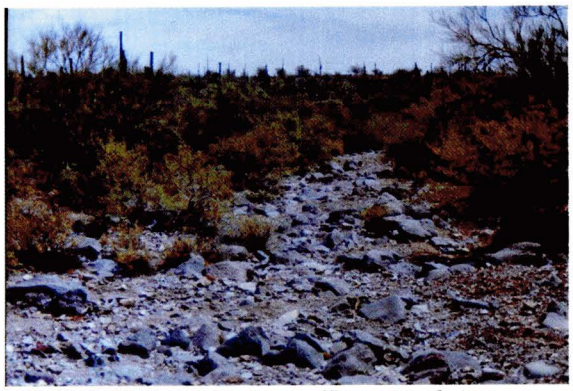


Figure 3-83. Long boulder riffle on Wash 1. Photo #UT2-25.

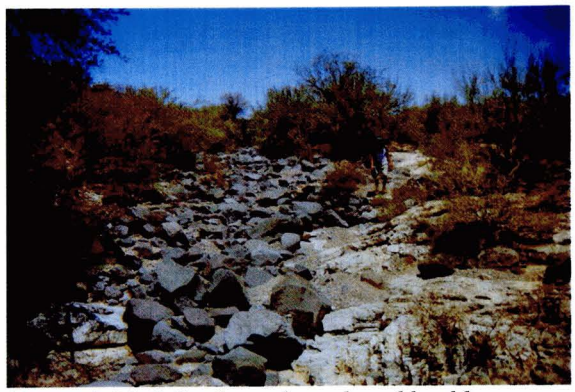


Figure 3-84. Split channel reach and boulder riffle on Wash 1. Photo #UT3-3.

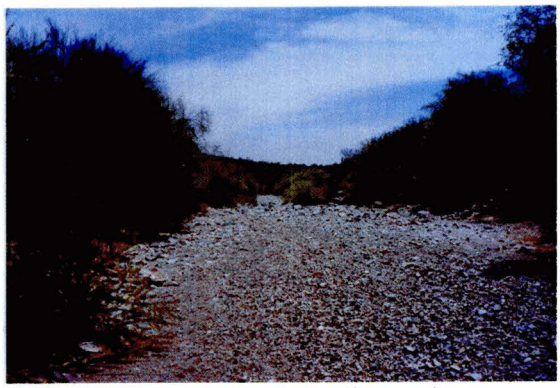


Figure 3-85. Pool and riffle (in distance) on Wash 2. Photo #TM3-13.

Figure 3-86. Split channel around low vegetated island on Wash 2. Photo #O-19.

Figure 3-87. Sediment deposition in channel expansion area ("splay") on Wash 2. Photo #BP2-14.

- Avulsions. Where the floodplain elevation is low relative to the main channel, avulsive channel change can occur (Figure 3-56). However, only in rare instances where low divides separate tributaries would avulsions create a channel outside the existing 100-year floodplain, which is generally bounded by the canyon walls. With time, new avulsive channels formed on the floodplain can capture the main channel and cause an avulsive shift of the main channel from one side of the floodplain to the other. Remnants of past avulsions or incipient avulsive channels were observed in several places on the unnamed washes (Figure 3-88).

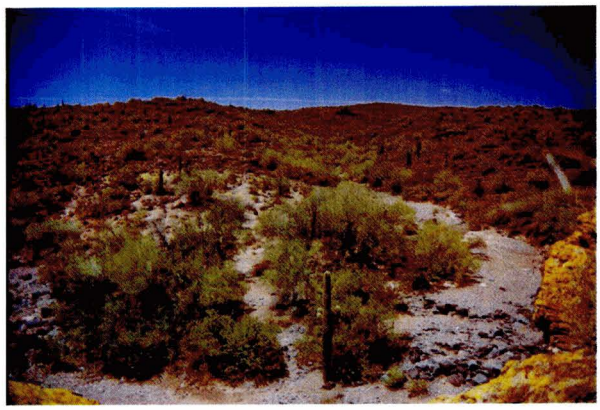


Figure 3-88. Small floodplain and cutoff channel at sharp bend on Wash 1. Photo #UT2-35.

- Flood High Water Marks. Flotsam observed along the banks of the main channels indicates that at least one flood has recently exceeded the banks, inundated the floodplain, and actively moved bed sediments within the study reach.

- Long-term scour. No evidence of significant historical long-term degradation was observed in the field on any of the unnamed washes or their tributaries. The single headcut observed on Wash 2 was a local feature which may be related to grading practices, and is not likely to advance any significant distance upstream. Bedrock exposed in the bed of the channel throughout the study reach limits the potential for significant long-term degradation. The absence of progressive long-term scour is supported by the comparison of longitudinal stream profiles from 1964 and 1990 discussed later in this memorandum.

- Local scour. Scour holes up to three feet deep were observed at some channel bends or where natural obstructions such as trees or boulders partially block the main channel, indicating that there is potential for local scour where favorable conditions exist (Figure 3-89 to 3-92). The depth of local scour is probably limited by shallow bedrock in most places within the study reach.

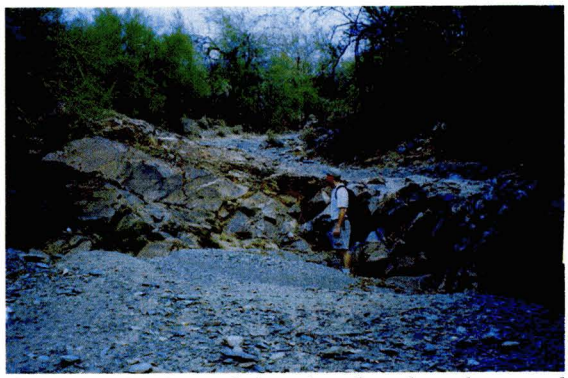


Figure 3-89. Natural slope break and grade control on Wash 2. Photo #1-16.

Figure 3-90. Tributary joining Wash 2 at grade. Photo #BP 1-8.

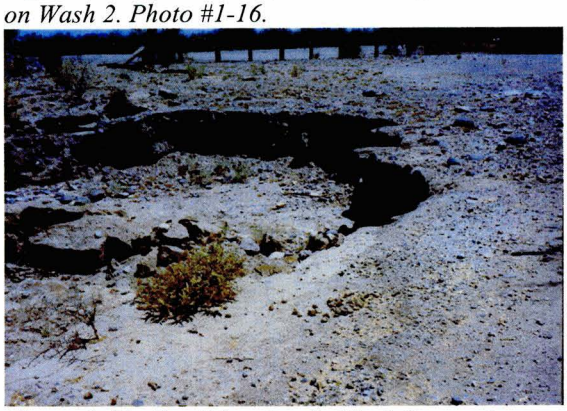


Figure 3-91. Small headcut in Wash 2 near Agua Fria River confluence. Photo #TM4-18.

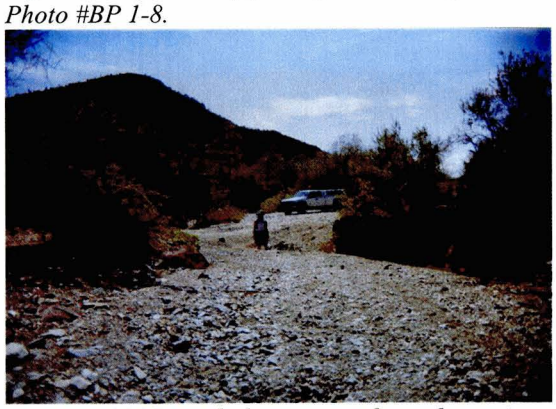


Figure 3-92. Scour hole near ranch road crossing on Wash 3. Photo #PM3-3.

- Structure impacts. Few structures exist within the study reaches for which impacts could be assessed. In general, the potential for lateral erosion increases near structures due to flow acceleration through constrictions or over concrete surfaces, disruption of sediment continuity, and/or removal of bank vegetation and placement of fill material. The impacts from structures observed in the field are summarized below.

    - Improved Road Crossings. State Route 74 (SR 74, a.k.a. Carefree Highway) is the only existing improved road within the study limits. SR 74 crosses Wash 1 and Wash 2, and is the upstream study limit for Tributary #1 to Wash 1, and Tributary #1 to Wash 2. Observed impacts of these structures on channel morphology outside the culvert section were minimal (Figures 3-93-3-99). Some deposition occurs upstream of culvert inlets (Figure 3-96), although no increase in vegetative density was observed in the headwater pool area. No scour holes were observed at any of the culvert outlets.

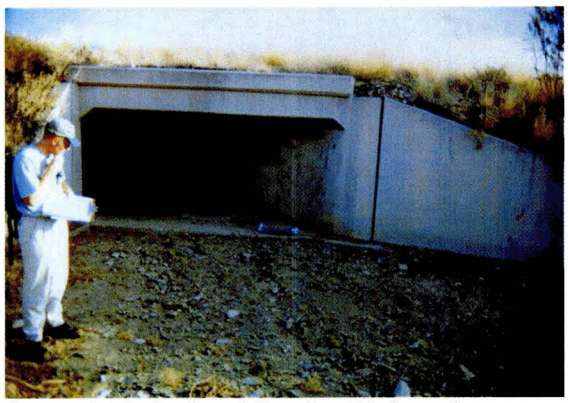


Figure 3-93. Outlet of Carefree Highway box culvert at Wash 1. Note lack of scour hole at outlet. Photo #UT1-15.

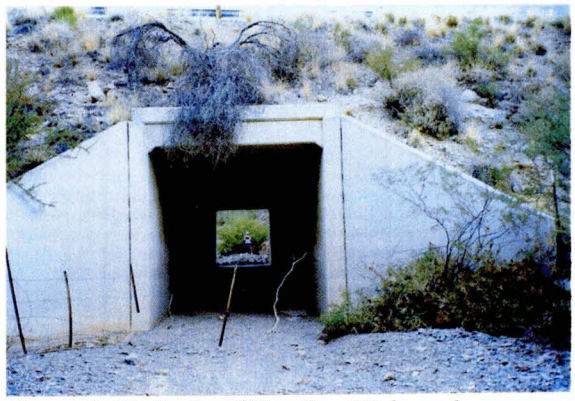


Figure 3-95. Outlet of Carefree Highway box culvert on Wash 2. Note lack of scour hole at culvert outlet. Photo #1-3.

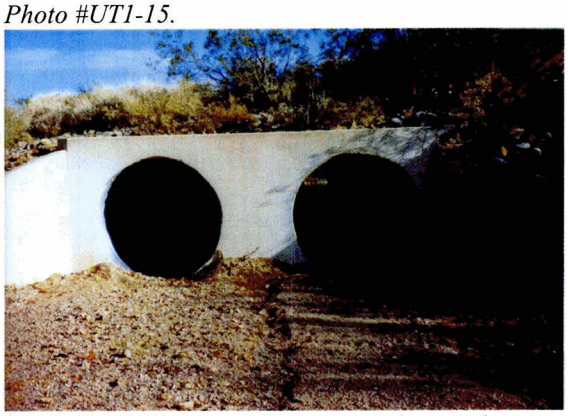


Figure 3-94. Downstream face Carefree Highway CMP culvert at Tributary #1 to Wash 1. Note lack of scour hole at outlet. Photo #TM-9.

Figure 3-96. Inlet of Carefree Highway box culvert at Tributary #1 to Wash 2 showing some upstream sediment deposition. Photo #0-27.

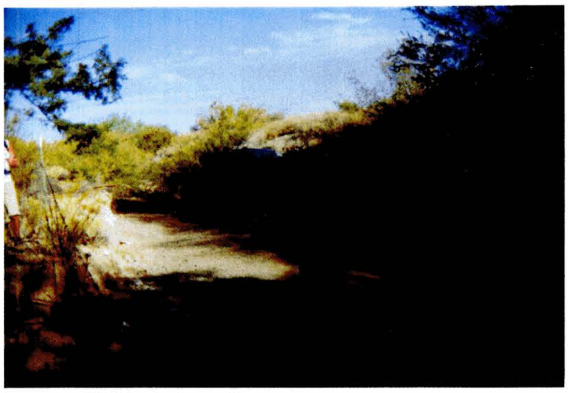


Figure 3-97. Hanging culvert under Carefree Highway entering Wash 1. Photo #UT1-20.

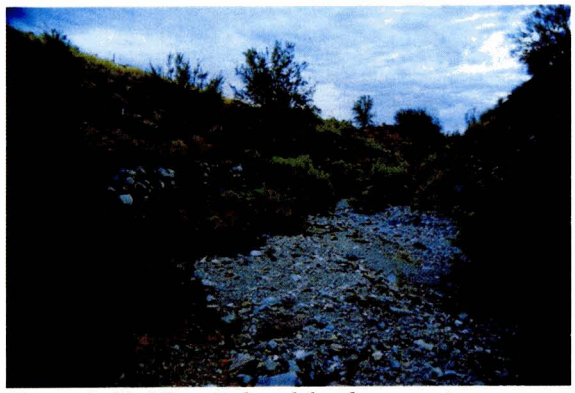


Figure 3-99. Wire-tied rock bank protection near Carefree Highway on Wash 2. Photo #O-14.

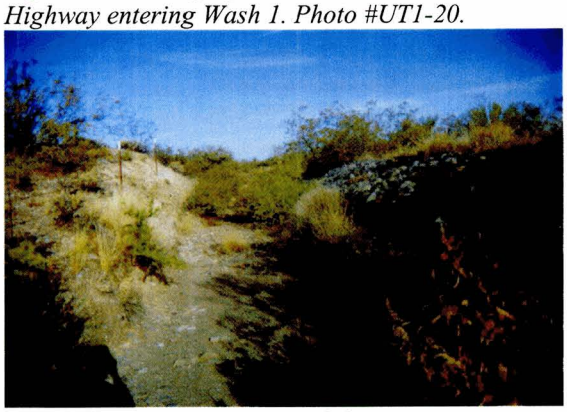


Figure 3-98. Rip rap bank stabilization near Carefree Highway on Wash 1. Photo #UT1-16.

Rip rap or wire-tied rock bank stabilization has been placed along the SR74 embankment in the reaches where the washes were displaced or realigned by highway construction (Figures 3-98 and 3-99).

- Ranch Road Crossings. At-grade crossing of the few unimproved dirt roads and four-wheel drive trails that cross the streams in the study area have minimal impact on the streams, aside from providing vehicle access for illegal dumping of trash (Figures 3-100 and 3-101).

Figure 3-100. Ranch Road at-grade crossing with minimal impact on Wash 2. Photo #0-33.

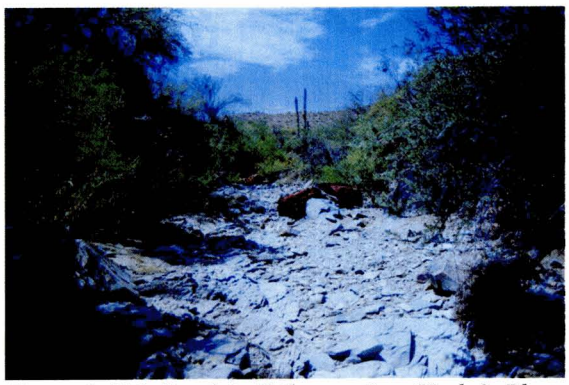


Figure 3-101. Trash in Tributary 2 to Wash 2. Photo #BP1-14.

- Recreation. Paint ball war game obstacles have been built in the floodplain of Wash 1 near the Agua Fria River confluence (Figure 3-103). These structures are likely to be destroyed during moderate sized floods, and are unlikely to significantly affect erosion hazards.

- Bailey Tank. A stock tank, built in the 1940's on Wash 1, impounds nearly all of the water and sediment delivered to it from upstream. Only if the dam or spillway is overtopped will sediment be passed downstream. The stock tank impacts stream stability by causing upstream deposition (Figure 3-102), widening the floodplain and erosion hazard limits at the dam (Exhibit 3-2), and increasing the risk of an erosive dam break event.

Figure 3-102. Backwater and sediment deposition area in Wash 1 upstream of Bailey Tank. Photo #UT2-15.

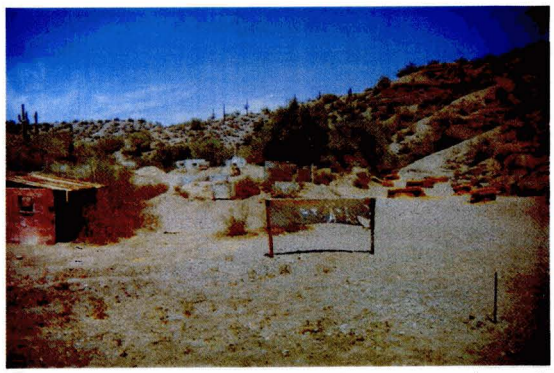


Figure 3-103. Paintball obstacles in main channel and floodplain of Wash 1 near the Agua Fria River confluence. Photo #UT 3-25.

- Corrals. Historic horse corrals and cattle pens were observed in several places on shallow floodplains (Figure 3-104). These features do not significantly impact stream stability, except where overgrazing near the pens has reduced bank vegetative cover.

Figure 3-104. Corral in low floodplain of Wash 2. Photo #O-21.

- Human Impacts. Impacts associated with human occupation of the study area are limited, but include the following:
    - Historic grazing
    - Trash dumping
    - Target shooting and hunting
    - Off-road ATV use

  In general, human activities decrease bank stability by removing bank vegetation, causing flow obstructions, and changing natural runoff characteristics.

Interpretation of Aerial Photographs. The lateral erosion hazard was also evaluated by interpreting characteristics of the geomorphic surfaces visible on aerial photographs and observed in the field. The age of stream terraces adjacent to the main channels provides information on past stream bed elevations and positions that can be used to 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 Arizona Geological Survey (Huckleberry, 1995). Those characteristics included the following:

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

Individually, these age-indicating characteristics provide a relatively low degree of confidence in age estimates. Considered together, the characteristics provide a higher degree of confidence. The physical characteristics of a surface give clues as to its depositional history, stability, and flood potential.

If a land surface ceases to receive new deposits, it will begin to age. As it ages, the surface begins to develop distinctive physical and chemical characteristics indicative of its age. As the 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 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 for to develop, it can be concluded that surfaces that exhibit well developed soils, red color, significant carbonate development, desert pavements 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.

Recent color aerial photographs of the study area were used in conjunction with field observations to distinguish older, more stable surfaces from younger, more active surfaces near the stream channels. These data were used to estimate the potential for future lateral erosion.

For the study reach, the AZGS mapping (Figure 3-105; Huckleberry, 1995) does not distinguish Holocene or Late Pleistocene terraces along any of the unnamed washes or their tributaries. The canyon bottom area, which includes the main channels and floodplains, is mapped as a modern stream channel unit (Ya2). In two places, the AZGS distinguished a Middle Pleistocene age surface inset within the bedrock canyons. This surface corresponds to the highest terrace observed in the field. The high terrace are outside the recommended erosion hazard boundary delineated for this study. The AZGS maps the areas above the canyon bottom as middle to late Tertiary age sedimentary rock units (Tsm) or undifferentiated bedrock (b).

Comparison of Historical Channel Position. The position of the main channel thalweg was digitized from historical aerial photographs and from the 7.5 minute USGS topographic quadrangles for the study area. A list of the historical aerial photographs and maps used is shown in Table 3-11. The historical aerial photographs were scanned to create digital images which were then semi-rectified using AutoCAD 2000 software and the digital USGS quadrangles as the map base. A plot of the historical channel position is shown in Figure 3-106. In general, the channel position has not significantly changed during the 50 year period of record. Channel movement has been limited to the canyon bottoms.

Table 3-11. Unnamed Wash Erosion Hazard Analysis
Available Historical Aerial Photographs

Year	Date	Scale	Number	Description
1949	2-14	1:20,000	DHP-4F-151	B/W, No stereo
1954	1-24	1:20,000	DHP-4N-30,31	B/W, Stereo
1977	12-5	1:12,000	19-22,23	B/W, Stereo
1992	9-6	1:24,000	5236-158,159	B/W, Stereo
1997	4-30	1:24,000	9870-254,255	B/W, Stereo

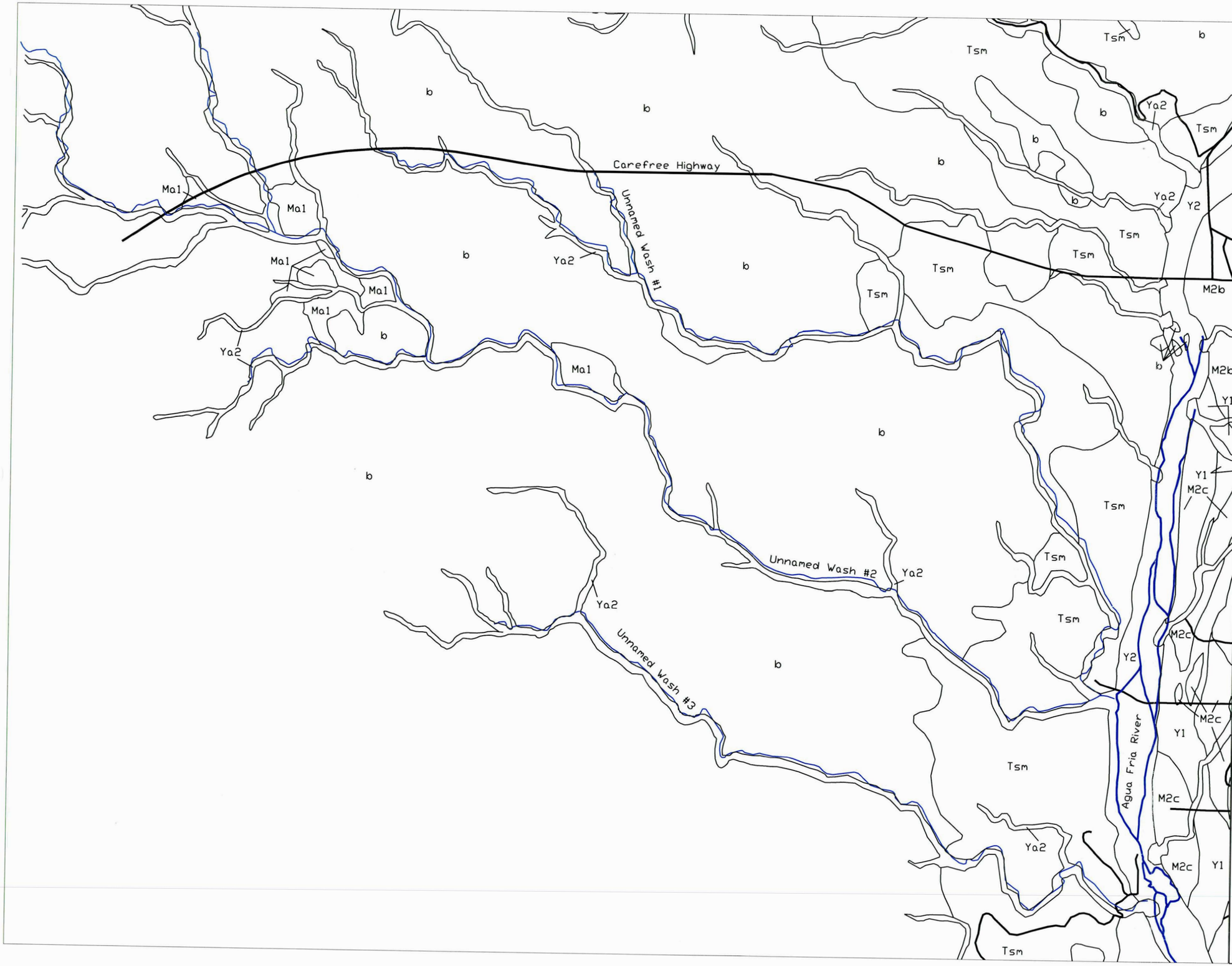


Figure 3-105
Surficial Geology - Unnamed Washes

Symbol	Description
b	bedrock
Ma1	indurated soils & moderate to steep slopes 200-500 kya
M2b	pleistocene terrace east of Agua Fria River
M2c	pleistocene terrace east & west of Agua Fria River
Tsm	mid-late tertiary sandstones & conglomerates
Ya2	modern stream channels
Y1	holocene alluvium
Y2	modern Agua Fria stream channels
———	Thalweg - 2000
———	Unit Division
▬▬	Roads

Scale

0 2400 4800

1 Inch = 2400 Feet

N

Overview

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

Sheet 1 of 1

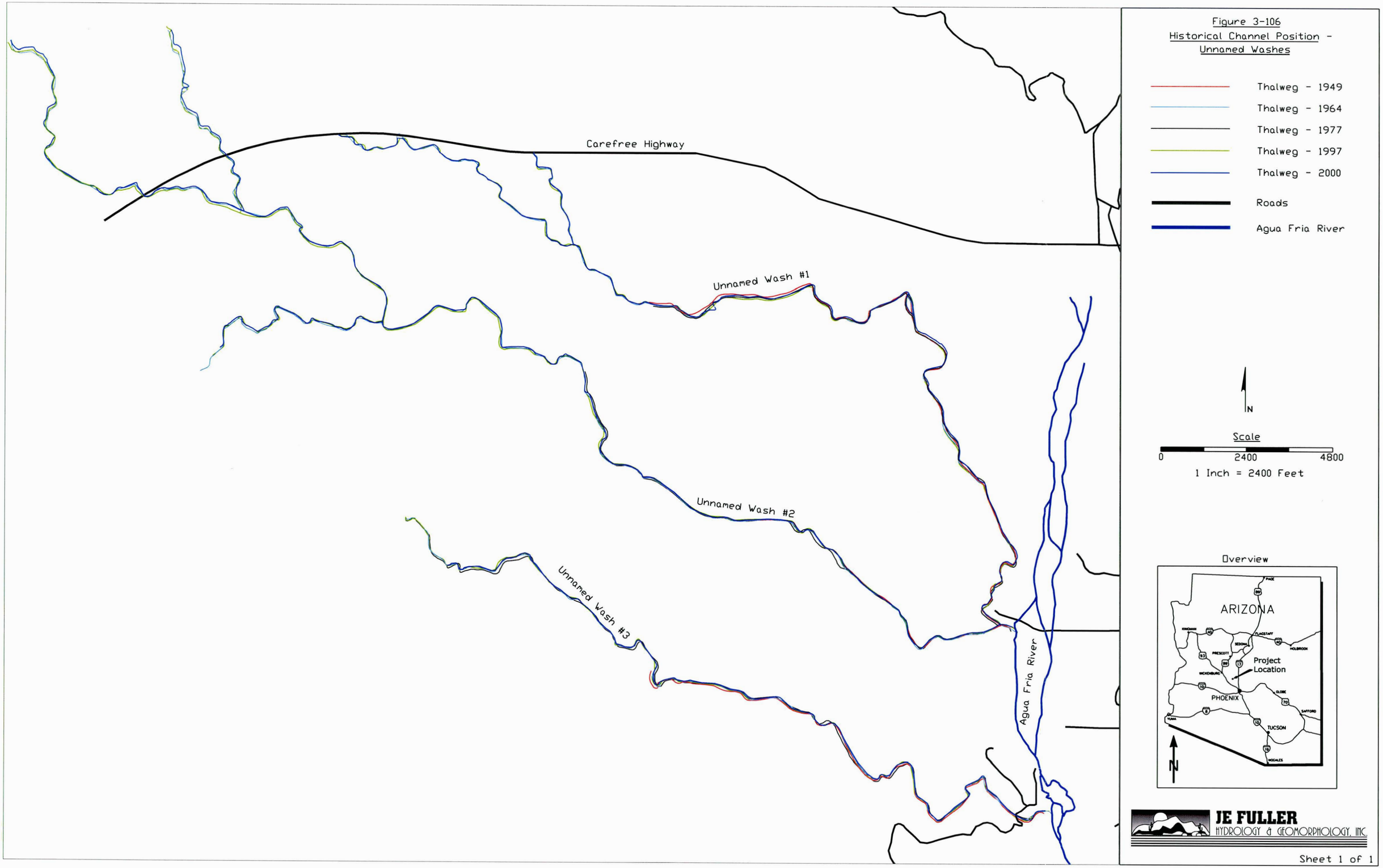


Figure 3-106
Historical Channel Position - Unnamed Washes

Evaluation of Stream Longitudinal Profile. The longitudinal profile is a plot of the channel elevation versus distance along the stream bed (Figures 3-107 to 3-109). Analysis of the longitudinal profile can be used to identify slope irregularities, over-steepened or flat reaches, headcuts, and areas of natural grade control. The longitudinal profile also provides some information on expected lateral stability. Reaches with lower slopes than adjacent reaches will experience net deposition, and bank erosion associated with braiding and avulsions. Where longitudinal profiles from different time periods indicate channel incision has occurred, bank erosion due to undercutting and bank collapse may be expected. Bank erosion occurs after channel incision because the channel material that had previously provided lateral support to the banks is removed, or because the banks are extended below the elevation of the rooting layer of the bank vegetation.

The following conclusions about lateral stability and erosion hazards can be drawn from the longitudinal profile of three unnamed washes shown in Figures 3-107 to 3-109:

- Profile Shape. Each of the profiles of the three unnamed washes have an irregular shape. They are neither concave up or down, but instead steepen and flatten along their length. The irregular profile reflects the local bedrock control. The steep slope reach located near the Agua Fria River confluence on all three washes probably reflects an incomplete adjustment to the Late Pleistocene entrenchment of the Agua Fria River, indicating that the unnamed washes are resistant to slope adjustments and not subject to significant long-term scour.
- Knickpoints. The profiles based on the detailed topography collected by Stantec show numerous vertical or near-vertical knickpoints. These knickpoints are bedrock waterfalls, not headcuts.
- Historical Elevation Change. The difference in bed elevation between the 1962 and 2000 profiles is well within the margin of accuracy of the topographic mapping. The offsets in the profiles for Wash 2 and Wash 3 are caused by scale differences which could not be resolved in the topographic data sets.
- Bedrock. Numerous outcrops and shallow bedrock under the stream bed will limit long-term slope adjustments. There are no significant differences in channel slope between reaches of obvious and assumed bedrock control. The 1962 and 2000 profiles are closest in the reaches where bedrock outcrops were observed in the bed of the channel.

In general, the longitudinal profile indicates that the three unnamed washes have experienced long-term vertical stability during recent geologic time.

Figure 3-107. Unnamed Wash #1 Longitudinal Profile

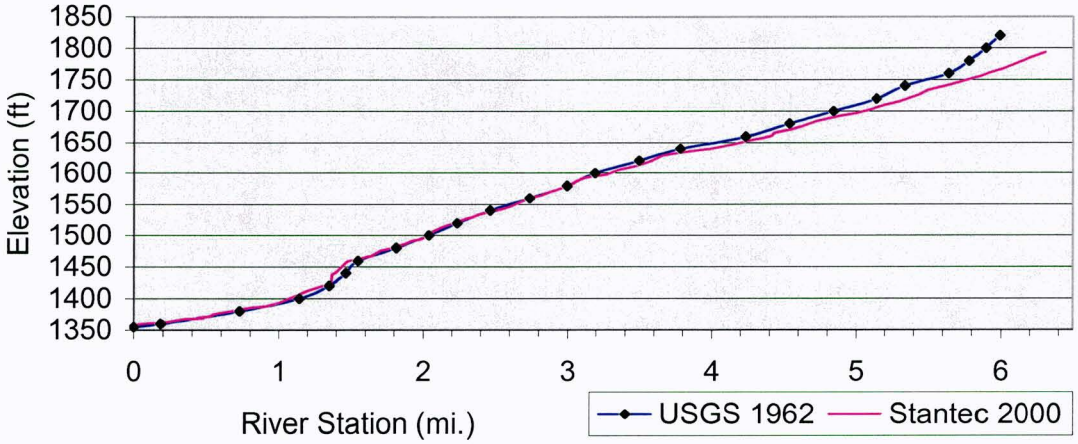


Figure 3-108. Unnamed Wash #2 Longitudinal Profile

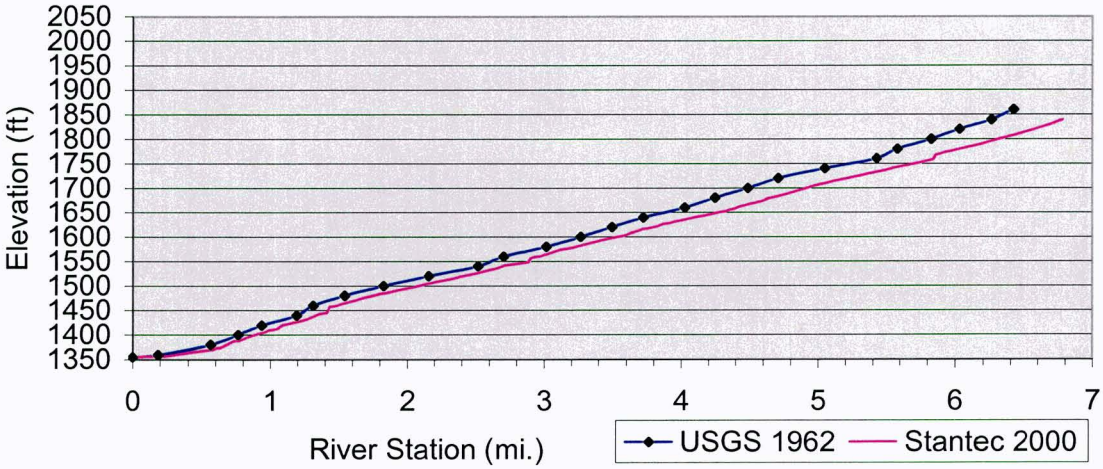
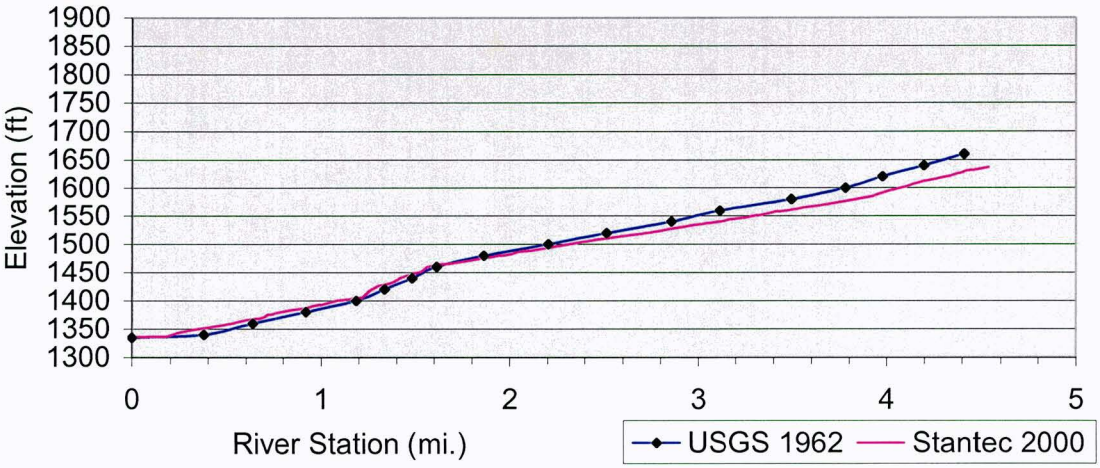


Figure 3-109. Unnamed Wash #3 Longitudinal Profile



Application of Allowable Velocity Guidelines. Allowable velocity criteria have long been used in channel design to estimate the velocity at which channel bed and bank sediments will begin to erode. A variety of allowable velocity data have been published by the US Army Corps of Engineers (1970, 1990, 1995) and the USDA Soil Conservation Service (1977), as well as by many other agencies.

The Corps of Engineers (1970; 1995) has established suggested maximum velocities for design of non-scouring flood control channels of various bank materials, as shown in Table 3-12. In general, the few alluvial banks of the unnamed washes are composed of sand, gravel and cobbles and are moderately well covered by brush and woody vegetation. No significant grass cover was observed in the field. Less than 20 percent of the observed banks are actively eroding with no effective vegetative cover (Table 3-10), and 15 to 55 percent of the banks are composed of bedrock. The average 100 year flood channel velocities derived from the Stantec (2001) HEC-RAS modeling indicate that the erosive threshold for the bank material will be exceeded during the 100-year event, as shown in Table 3-13. In some cases, even the erosive threshold for weak sedimentary rock is exceeded. Evidence of erosion of soft sedimentary rocks was observed during the field work (Figure 3-103). No information on expected velocities for the 2-, 10- or other recurrence intervals was available, but should be included if more detailed erosion hazard evaluations are conducted. Bed sediments observed in the field indicated that up to boulder-sized material is transported during floods.

Table 3-12. Unnamed Wash Erosion Hazard Analysis
Suggested Maximum Permissible Mean Channel Velocities (USACOE, 1995)

Channel Material	Mean Velocity (ft/sec)
Fine Sand	2.0
Fine Gravel	6.0
Grass-Lined Banks (< 5% Slope, Sandy Silt, Bermuda Grass)	8.0
Poor Rock (Sedimentary)	10.0
Good Rock (Igneous or Metamorphic)	20.0

Table 3-13. Unnamed Wash Erosion Hazard Analysis
FDS 100-Year Flood Velocities

Channel Segment	Average Velocity (ft/s)			Maximum Velocity (ft/s)		
	Main Channel	Overbanks		Main Channel	Overbanks	
		Left	Right		Left	Right
Wash 1	8.7	2.6	2.4	15.2	8.7	6.0
Wash 2	11.1	2.7	2.4	16.5	8.3	7.3
Wash 3	9.0	2.3	2.2	13.3	7.6	8.3
Source: Stantec HEC-RAS models for Floodplain Delineation Study						

Plots of channel and overbank velocities shown in Figures 3-110 to 3-115, show a slight but insignificant increase in velocity with increasing discharge. In general, channel velocities are erosive and overbank velocities are less erosive.

Figure 3-110. Wash #1 100-Year Channel Velocity

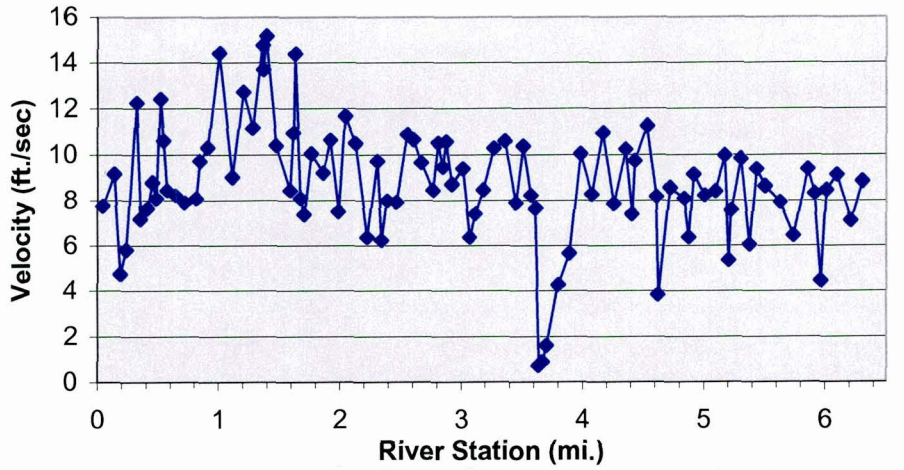


Figure 3-111. Wash #2 100-Year Channel Velocity

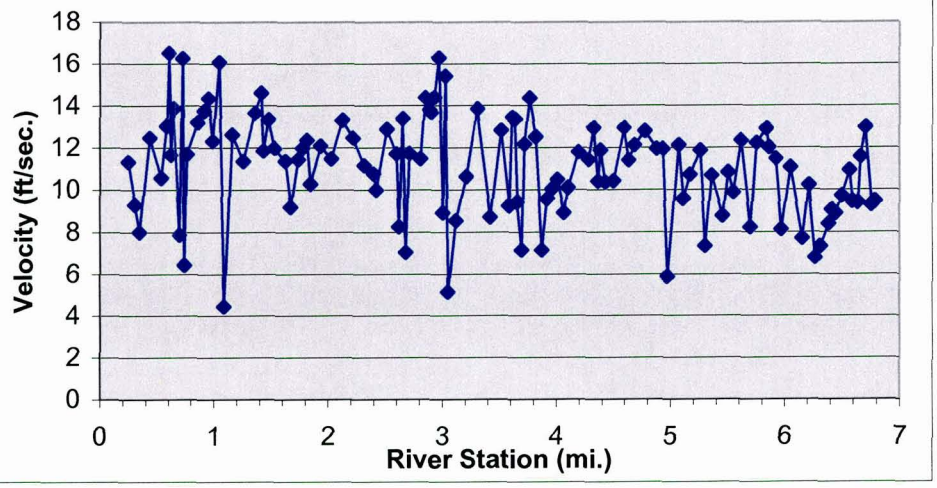


Figure 3-112. Wash #3 100-Year Channel Velocity

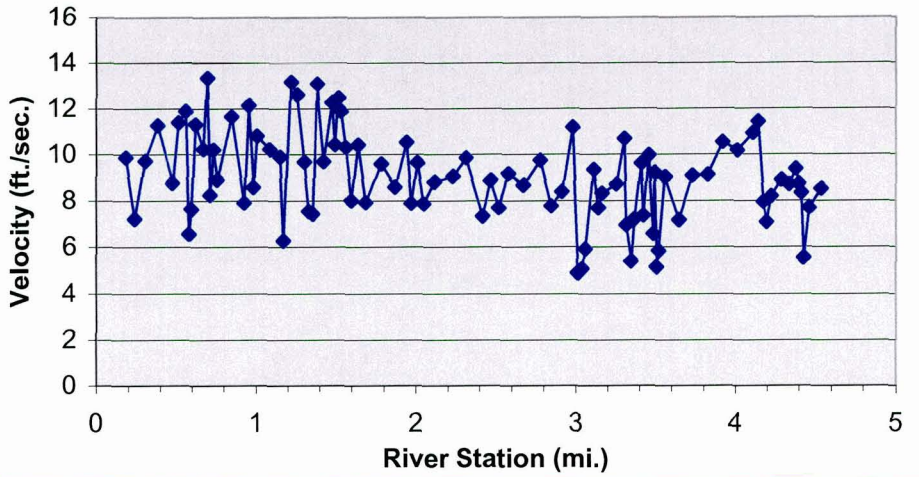


Figure 3-113. Wash #1 100-Year Left & Right Overbank Velocities

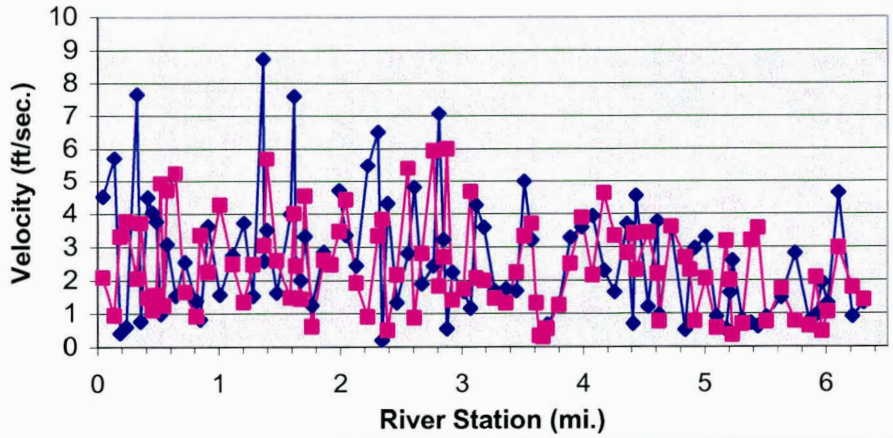


Figure 3-114. Wash #2 100-Year Left & Right Overbank Velocities

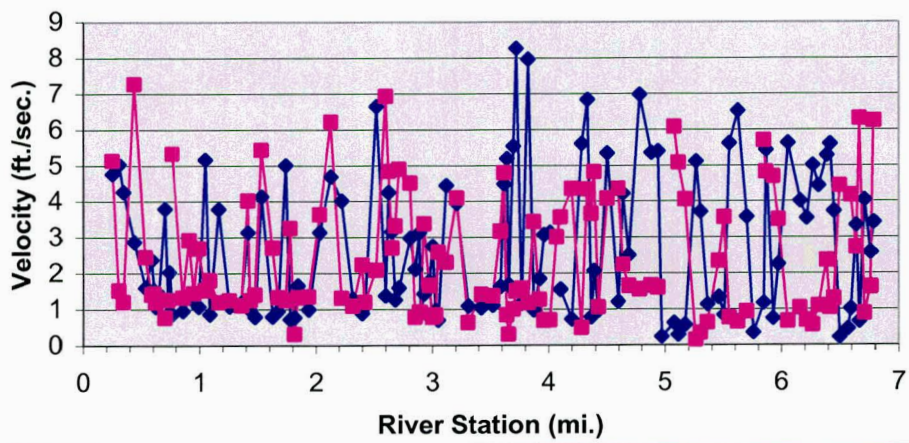
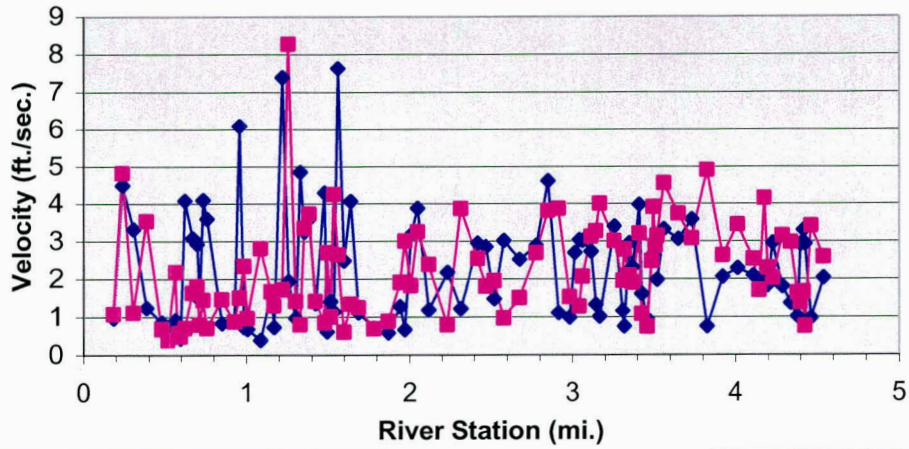


Figure 3-115. Wash #3 100-Year Left & Right Overbank Velocities



The allowable velocity information summarized above indicates that bank erosion should be expected during the 100-year event, particularly where the stabilizing bank vegetation is removed.

Conclusions

Based on the methodologies described above used to evaluate the erosion hazards, the following conclusions can be drawn:

- Cut banks, which are evidence of recent and ongoing bank erosion, occur throughout the study area as shown on Exhibit 3-2 and Table 3-10.
- Lateral erosion should be expected within the limits of the bedrock canyon that confines the main channels and its low floodplain terrace, as shown in Exhibit 3-2.
- Lateral erosion will occur in response to the following 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 a series of smaller floods. The effects of numerous small floods combine to produce significant amounts of cumulative erosion over time periods equivalent to the design life of most engineered structures.
- Floodplain soils appear to be composed of highly erosive materials and will generally not prevent lateral erosion over the long term.
- Historical data indicate that lateral channel movement is confined within the bedrock canyon.
- Expected 100-year velocities exceed the erosive threshold for the soils that comprise the channel banks in the study area.
- The streams in the study area have a high sediment transport capacity, and could cause significant lateral erosion.
- Caliche-cemented soils do not prevent lateral erosion.
- Bedrock does prevent lateral channel movement, except where the local sedimentary units are weakly indurated.
- Significant long-term scour has not occurred in the study area within the time scale of concern for this study.
- Existing structures have had minimal impact on potential erosion hazards.

The recommended erosion hazard for the unnamed washes and their tributaries includes the canyon bottom and a portion of the canyon walls. In general, the recommended erosion hazard boundary is located outside the 100-year floodplain.

Recommended Erosion Hazard Zone. The SSA 5-96 Level 1 Methodology erosion hazard setbacks are not conservative at many locations and are overly conservative at other locations, according to the conclusions summarized above and the conditions observed in the field. Therefore, a recommended erosion hazard zone line for each of the three unnamed washes and the three unnamed tributaries to the unnamed washes in the study area was established based on consideration of the following information:

- Field Notes and Observations
- Historical Channel Changes
- Local Channel and Floodplain Topography
- 100-Year Floodplain Limits
- Bedrock Outcrop
- Caliche Outcrop
- Cut bank Locations
- Channel Bend Radius and Position
- Channel Pattern and Sinuosity
- Bank Vegetation Type, Density and Age
- Height of Natural Floodplain Terraces Above Main Channel Bed
- Avulsion Potential
- 100-Year Discharge
- Future Development
- Longitudinal Profile
- Bedrock Canyon Width
- Location of Main Channel Within Canyon

The recommended erosion hazard zone lines shown on Exhibit 3-2 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.

Differences between the erosion zone recommended by this study and the setback calculated from the SSA 5-96 Level methodology occur throughout the study area. These differences are primarily due to the higher level of analysis used for this study. In general, the SSA 5-96 methodology did not appropriately consider the stabilizing effect of bedrock in the canyon walls.

Discussion and Recommendations

Areas located within the recommended erosion hazard zone lines may be subject to increased risks that warrant specific development restrictions. Given the level of detail used to delineate the recommended erosion hazard zone lines, the developer should be

given the option of completing a more detailed erosion hazard zone analysis. A typical scope of work for such an analysis is provided in Appendix 2.

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 North Peoria ADMP erosion hazard assessment, the following general limitations apply:

- Hydrologic Data. No stream flow gauging data were available for the study reach. Estimates of the 100-year discharges were obtained from Floodplain Delineation Studies (FDS) performed by others, as described below. Availability of gauged stream flow data for the unnamed washes and their tributaries might improve the accuracy of the erosion hazard evaluation.
- Hydraulic Modeling. HEC-RAS models were prepared by others for the purpose of delineating the 100-year floodplain and floodway (Stantec, 2001). No additional modeling of more frequent flood events was part of this analysis. Modeling of other return period events would improve the understanding of channel behavior during more frequent, small floods.
- Geotechnical Data. No geotechnical data were available for the study area. Predictions of the existing lateral erosion hazards could be refined in some reaches if extensive geotechnical investigations of bank and floodplain stability were completed along the stream corridors.
- Level of Detail. The erosion hazard zones determined for this evaluation are based on observations made during field reconnaissance, interpretation of aerial photographs and topographic maps, consideration of data and mapping from previously published reports, and application of the SSA 5-96 Level 1 Methodology. It is possible that the recommended erosion hazard zones could be refined by applying more detailed methodologies, such as those used in the District's Watercourse Master Plan studies (JEF, 2000). The erosion hazard delineations recommended by this study of the unnamed washes are based on techniques that are equivalent to a SSA5-96 Level 3 Analysis.
- Quality of Aerial Photographs. The aerial photography used as the base map for erosion hazard boundary delineations outside of the reaches where detailed floodplain delineations were performed was not fully rectified to the topographic mapping or to State Plane Coordinates. Consequently, while the erosion hazard boundaries fit the aerial photograph base maps, the boundaries may not be positioned in real world coordinates. Also, the black and white digital photography used as the base map was dark in some places, making it difficult to distinguish channel features, bedrock outcrops, shadows, and dense vegetation. Where the erosion hazard boundaries shown on Exhibit 3-2 are difficult to interpret due to the quality of the base map, the boundaries should be verified in the field.
- Additional Erosion Hazards. Riverine erosion and flood hazards exist along the entire watercourses. 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 main stems of the unnamed washes.

- Scale of Analysis. The evaluation described in this technical memorandum considered approximately 26.2 miles of river corridor. It is possible that more detailed evaluation of shorter reaches or specific sites would result in a refined prediction of future channel behavior in those reaches.

References Cited

ADWR, 1996, SSA 5-96: State Standard for Watercourse System Sediment Balance.

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

Huckleberry, G., 1995, Surficial Geology of the Lower Agua Fria River, Lake Pleasant to Sun City, Maricopa County, Arizona. Arizona Geological Survey Open File Report 95-5.

JE Fuller/ Hydrology & Geomorphology, Inc., 2000, Upper Cave Creek/Apache Wash Watercourse Master Plan Report Volume XX: Lateral Stability Assessment. Draft Report submitted to the Flood Control District of Maricopa County. January 12, 2000.

Soil Conservation Service (USDA-SCS), 1977, Design of Open Channels – Technical Release 25.

Stantec, 2001, Flood Insurance Study for Unnamed Washes Tributary to the Agua Fria River, Maricopa County, Arizona. Report submitted to the Flood Control District of Maricopa County. Not yet completed.

U.S. Army Corps of Engineers, 1970, Hydraulic Design of Flood Control Channels, EM1110-2-1601.

U.S. Army Corps of Engineers, 1990, Stability of Flood Control Channels, Draft.

U.S. Army Corps of Engineers, 1995, Hydraulic Design of Flood Control Channels, EM1110-2-1601. ASCE Republication.

DATE: December 27, 2001

TO: Kelli Sertich/ FCDMC
Pat Ellison, P.E./ Stantec

FROM: Jon Fuller, P.E.

RE: North Peoria ADMS – Optional Task 2.6.3.1.1
Morgan City Wash Erosion Hazard Analysis

Introduction

This memorandum describes the results of an evaluation of the erosion hazards for Morgan City Wash. Morgan City Wash, a tributary to the Agua Fria River, is located west of Lake Pleasant (Figure 3-116), within the North Peoria Area Drainage Master Plan (ADMP) study area. The primary objectives of the erosion hazard evaluation were to establish an erosion hazard zone for Morgan City Wash and to determine where more detailed erosion analyses should be required prior to development.

This evaluation was completed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting, Inc. (Stantec) under contract to the Flood Control District of Maricopa County (District). This memorandum and its attachments are the deliverables for Task 2.6.3.1.1 of Contract #FCD 99-45.

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 North Peoria ADMP erosion hazard assessment, the following general limitations apply:

- Hydrologic Data. No stream flow gauging data were available for the study reach. Estimates of the 100-year discharges were obtained from Floodplain Delineation Studies (FDS) performed by others, as described below. Availability of long-term gauged stream flow data for Morgan City Wash and its tributaries might improve the accuracy of the erosion hazard evaluation.
- Hydraulic Modeling. HEC-2 models were prepared by others for the purpose of delineating the 100-year floodplain and floodway (Baker, 1990).[1] No additional modeling of more frequent flood events was part of this analysis. Modeling of other return period events would improve the understanding of channel behavior during more frequent, small floods.

[1] Michael Baker, Jr. Consulting Engineers, 1990, Technical Documentation Notebook and Work Maps for Morgan City Wash Floodplain Delineation Study, FCD #89-xx.

- Geotechnical Data. No geotechnical data were available for the study area. Predictions of the existing lateral erosion hazards could be refined if extensive geotechnical investigations of bank and floodplain stability were completed along the stream corridor.
- Level of Detail. The erosion hazard zones determined for this evaluation are based on observations made during field reconnaissance, interpretation of aerial photographs and topographic maps, consideration of data and mapping from previously published reports, and application of the SSA 5-96 Level 1 Methodology. It is possible that the recommended erosion hazard zones could be refined by applying more detailed methodologies, such as those used in the District's Watercourse Master Plan studies (e.g., JEF, 2000).[1] The erosion hazard delineations recommended by this study of Morgan City Wash are based on techniques that are equivalent to a SSA5-96 Level 3 Analysis.
- Additional Erosion Hazards. Riverine erosion and flood hazards exist along the entire length of the Morgan City Wash study reach. In addition, erosion from slope processes will occur on the steep slopes adjacent to the wash and its canyon. This study is limited to evaluation of riverine erosion hazards on the main stem of Morgan City Wash.
- Scale of Analysis. The evaluation described in this technical memorandum considered approximately 12.0 miles of river corridor. It is possible that more detailed evaluation of shorter reaches or specific sites would result in a refined prediction of future channel behavior in those reaches.

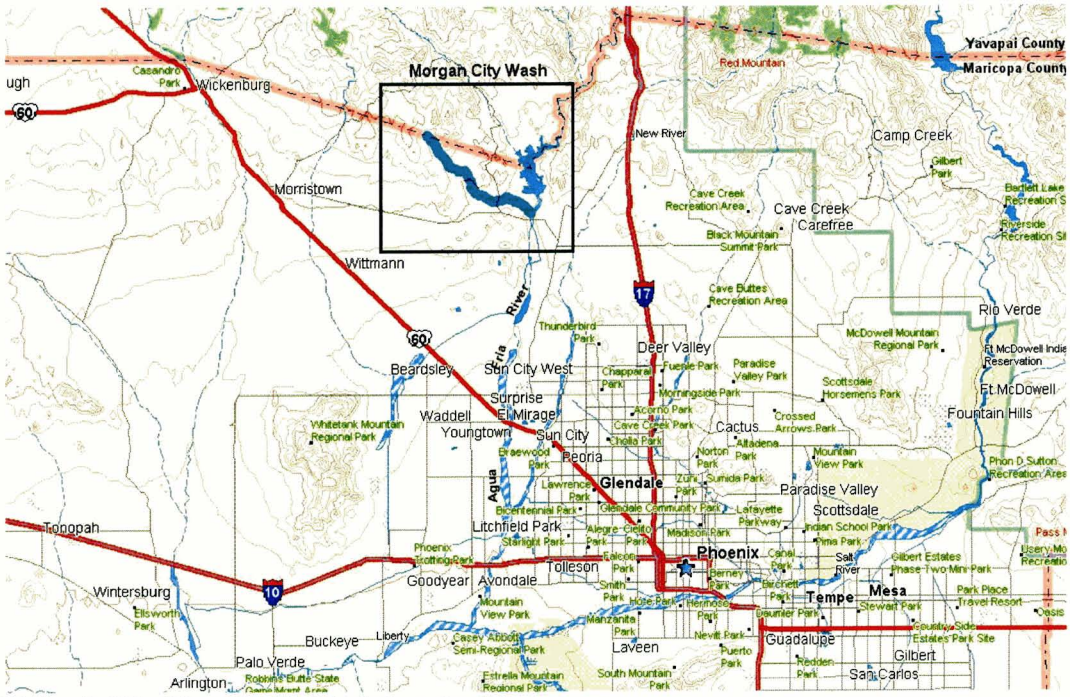


Figure 3-116. Morgan City Wash Location Map

[1] JE Fuller/ Hydrology & Geomorphology, Inc., 2000, Cave Creek/Apache Wash Watercourse Master Plan Report – Lateral Stability Analysis. Report to the Flood Control District of Maricopa County.

Methodology & Results

A variety of methodologies were used to evaluate the erosion hazard for Morgan City Wash. The project scope of work dictated that the SSA 5-96 Level 1 Methodology be used to establish an initial erosion hazard zone. In addition, the following types of information were considered:

- Field Observations
- Aerial Photographs
- Historical Channel Position
- Stream Longitudinal Profile
- Allowable Velocity Guidelines

The methodologies used to estimate the erosion hazard zone are described in more detail in the paragraphs below.

State Standard 5-96 Level 1 Methodology. State Standards for floodplain management have been adopted for the State of Arizona by the Arizona Department of Water Resources (ADWR) as the minimum required regulatory policy under authority of Arizona Revised Statutes 45-3605(a). SSA 5-96 (ADWR, 1996), adopted in 1996, describes a methodology for estimating an erosion setback to account for the lateral instability of Arizona streams. The SSA 5-96 Level 1 Methodology is based on the following two equations:

$$SB = 1.0 \cdot (Q_{100})^{0.5} \qquad \text{Eq'n \#1}$$
$$SB = 2.5 \cdot (Q_{100})^{0.5} \qquad \text{Eq'n \#2}$$

Where SB = Erosion hazard setback distance (ft.)
Q_{100} = 100-year peak discharge (cfs)

According to SSA 5-96, equation #1 is intended for stream segments that are straight or have "minor curvature." Equation #2 is intended for stream segments with "obvious curvature." Obvious curvature is defined as a channel centerline with a radius of curvature less than five times the channel topwidth. Other guidelines and limitations for the SSA 5-96 Level 1 Methodology are summarized in Table 3-14. According to the State Standard criteria, the SSA 5-96 methodology is applicable to Morgan City Wash.

Table 3-14. Morgan City Wash Erosion Hazard Analysis
SSA 5-96 Setback Guidelines and Limitation Study Area Condition

SSA 5-96 Guideline/Limitation	Morgan City Wash Characteristic	SSA 5-96 Applicable?
Drainage area < 30 mi.^{2}	Drainage area = 22.9 mi.^{2} at Agua Fria confluence	Yes
Significant channel filling	Not observed – local aggradation & degradation	Yes
Local mining	Not observed – small excavations on stream terraces	Yes
Channel modifications	Minimal – two culvert crossings near Lake Pleasant	Yes
Massive past channel shifting	Minor shifting - contained within bedrock canyon	Yes
Channelization	None observed except in culvert sections	Yes

Channel curvature for Morgan City Wash was measured on topographic maps provided by the District. 100-year discharge estimates were obtained from the Baker (1990) Floodplain Delineation Study. The results of the SSA 5-96 Level 1 Methodology for Morgan City Wash are shown in Table 3-15.

The SSA 5-96 Level 1 setbacks were applied from the channel bank or the floodway, whichever was further from the channel centerline, as per the SSA 5-96 Level 1 Methodology. For most of the Morgan City Wash study reach, the FEMA floodway limit is coincident with the FEMA floodplain limit, because of the way the bank stations were defined for the FDS and because of the extent of the main channel and its braids within the bedrock canyon.[1] SSA 5-96 Level 1 setbacks for Morgan City Wash are not recommended for management, but are shown on Exhibit 3-3 for comparison with the recommended erosion hazard boundaries.

Table 3-15. Morgan City Wash Erosion Hazard Analysis
SSA 5-96 Setbacks for Morgan City Wash

Stream Name & Reach Limits for Q100 Value (River Mile = Baker HEC-2 Cross Section #)	Q100 (cfs)	Erosion Setback Distance (ft)	
		Straight Chl	Curved Chl
Agua Fria River to River Mile 2.724	14,400	120	300
River Mile 2.724 to River Mile 3.714	14,200	119	298
River Mile 3.714 to River Mile 5.853	13,900	118	295
River Mile 5.853 to River Mile 6.688	12,300	111	277
River Mile 6.688 to River Mile 8.878	12,000	110	274
River Mile 8.878 to River Mile 10.355	8,130	90	225
River Mile 10.355 to River Mile 12.018, Maricopa Co. Line	4,820	69	174

Note: Source of discharge data is work map cover sheet (Baker, 1990).

Field Observations. Field visits were conducted to the study reach on several occasions. Field visits consisted of walking and driving the entire study reach, photographing and mapping key features, and recording descriptions of existing channel conditions. Sample copies of the field data collection forms used during the visits are provided in Appendix 1. 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 stream responses to human impacts or structures
- Identify points of natural grade control

[1] The FDS by Baker (1990) defined the bank stations for many cross sections at the canyon boundaries, rather than at the main channel banks. HEC-2 floodway modeling subroutines will not allow floodway encroachment inside the bank stations. Therefore, the floodway limits are coincident with the floodplain limits, i.e., no encroachment was computed in the floodway model for most reaches in the study area. In some places, the FDS indicates that the Morgan City Wash floodway extends up small tributaries beyond the canyon walls (e.g., left bank tributary downstream of HEC-2 section 2.882). Because the floodway stations were defined in this manner, the SSA 5-96 setbacks based on floodway stations are more conservative than may have been intended by the State Standard.

The most relevant data collected during the field visits were synthesized and are shown on work maps used to support the recommend erosion zones. Field data collected included the following:

- Locations of cut banks (active erosion)
- Locations of bedrock outcrop in the bed and channel banks
- Location of headcuts and slope breaks
- Location and extent of stream terraces and natural floodplains[1]
- Location of human impacts, structures, and road crossings
- Channel characteristics at representative cross sections

The following general conclusions are supported by the data collected during the field reconnaissance visits:

- Canyon Cross Section. Morgan City Wash flows within a bedrock canyon, as illustrated in Figure 3-117. Within recent geologic time, field evidence indicates that the main channel has migrated over the entire canyon bottom in most of the study reach, except in a few places where small remnants of Late Pleistocene alluvial terraces are present. The lateral erosion hazard is generally high across the entire canyon bottom. Figures 3-118 and 3-119 are photographs of typical canyon cross sections in the study area.

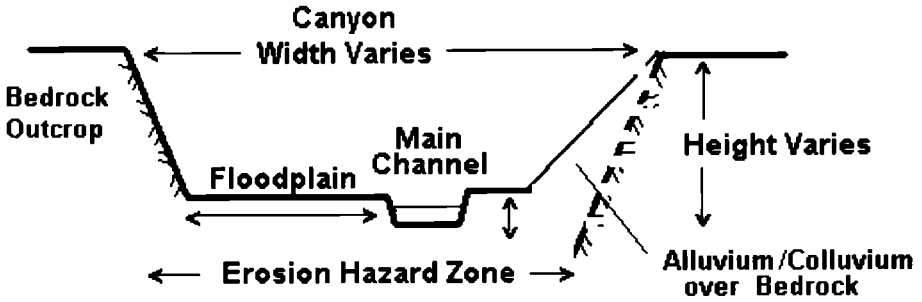


Figure 3-117. Typical Canyon Cross Section in Study Area

[1] Natural floodplains, which have physical expression in the landscape, are distinguished from the FEMA (100-year) floodplain, which is a regulatory concept and may not coincide with natural features observed in the field.

Figure 3-118. Narrow bedrock canyon reach looking upstream at sharp bend in canyon. Photo #JF 3-3. River mile (RM) 2.577.

Figure 3-119. Canyon cross section showing main channel, low floodplain with cut bank, and steep canyon slope. Photo #MC 1-16. RM 11.352.

- Typical Cross Section. Within the study reach, Morgan City Wash has the following three typical cross sections:
    - Narrow Bedrock Canyon Reach. The bedrock canyon is narrowest near the upstream and downstream limits of the study reach, suggesting that the channel morphology is strongly controlled by the local geology. In the narrow canyon reaches, the typical cross section includes a gravel bed channel with shallow or exposed bedrock, a main channel that fills or nearly fills the entire canyon bottom, and bedrock outcrops in both banks.
    - Single Channel Reach. The typical cross section for most of the study reach consists of a well-defined, gravel-bedded single channel with one to five foot banks, and a low floodplain terrace of varying width. The low, densely-vegetated floodplain surfaces usually occupy a greater percentage of the canyon bottom than the main channel. These low floodplains typically are composed of coarse gravels and sands, but may also have a fine-grained cap layer. These low floodplains appear to be regularly inundated by moderate to large floods, which leave a distinct bar and swale topography and affect the vegetative cover. Vegetation on the low floodplains is dominated by palo verde, ironwood, catclaw, and several brush and cacti species. In most places, small avulsive channels were observed on the low floodplain surfaces, often next to the canyon margin. In a few places, higher terraces were observed inset along the bedrock canyon walls. These higher terraces are not continuous on either side of the canyon, but are pinched out where the sinuous main channel intersects the canyon walls. Where the main channel intersects the canyon walls, there are typically steep or vertical cliffs regardless whether the canyon is composed of bedrock or alluvium. In some reaches, one or more strath terraces were observed at 10 to 20 feet above the channel floor. The lack of continuous high terraces in the study reach suggests that the wash periodically moves across the canyon bottom and erodes up to the canyon walls, removing the older terraces or preventing their development.
    - Multiple Channel Reach. Multiple channel reaches exist where recent avulsions have occurred, creating islands out of the low floodplain

surfaces. In some places, avulsive channel change has left large bedrock islands in middle of the canyon bottom. The channel bed material or bank conditions in the multiple channel reaches are not significantly different from the single channel reaches.

- Floodplain Dimensions. A floodplain of varying width is present in most of the study area (Figures 3-118 to 3-120). On most streams in Maricopa County, the floodplain width increases as the discharge increases. However, for Morgan City Wash, the width of the 100-year floodplain (Figure 3-120) estimated from the Baker (1990) FDS HEC-RAS model shows that local geologic control is more important than discharge in determining floodplain width. The local geology does not appear to control the elevation of the floodplain. Floodplain elevation, which ranges from one to five feet above the bed of the main channel, does affect the type of erosion. As the elevation of the floodplain above the channel bed increases, the frequency of flow on the floodplain surface decreases, and the erosion potential of the main channel bank increases due to the relatively higher flow depths and velocities along the main channel bank (Figure 3-121). Where the floodplain elevation is low, flow on the floodplain is more frequent, and the potential for avulsions increase.

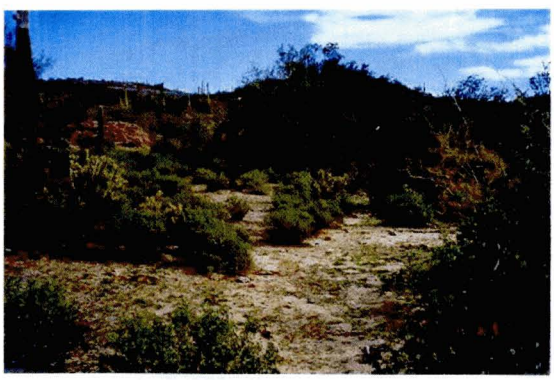


Figure 3-120. Typical floodplain. Photo #JF 2-11.

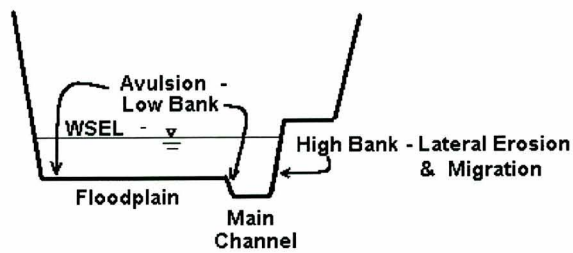
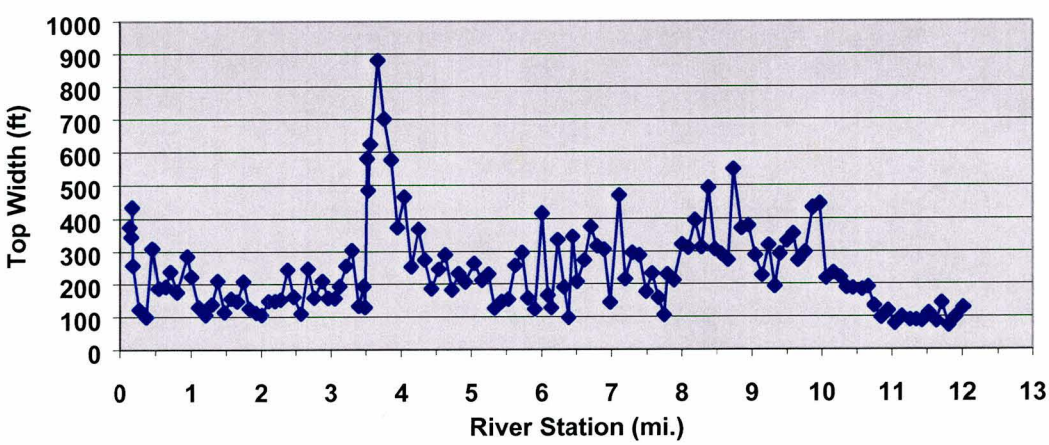


Figure 3-121. Sketch showing bank erosion type relative to bank height.

Figure 3-122. Morgan City Wash 100-Year Floodplain Top Width



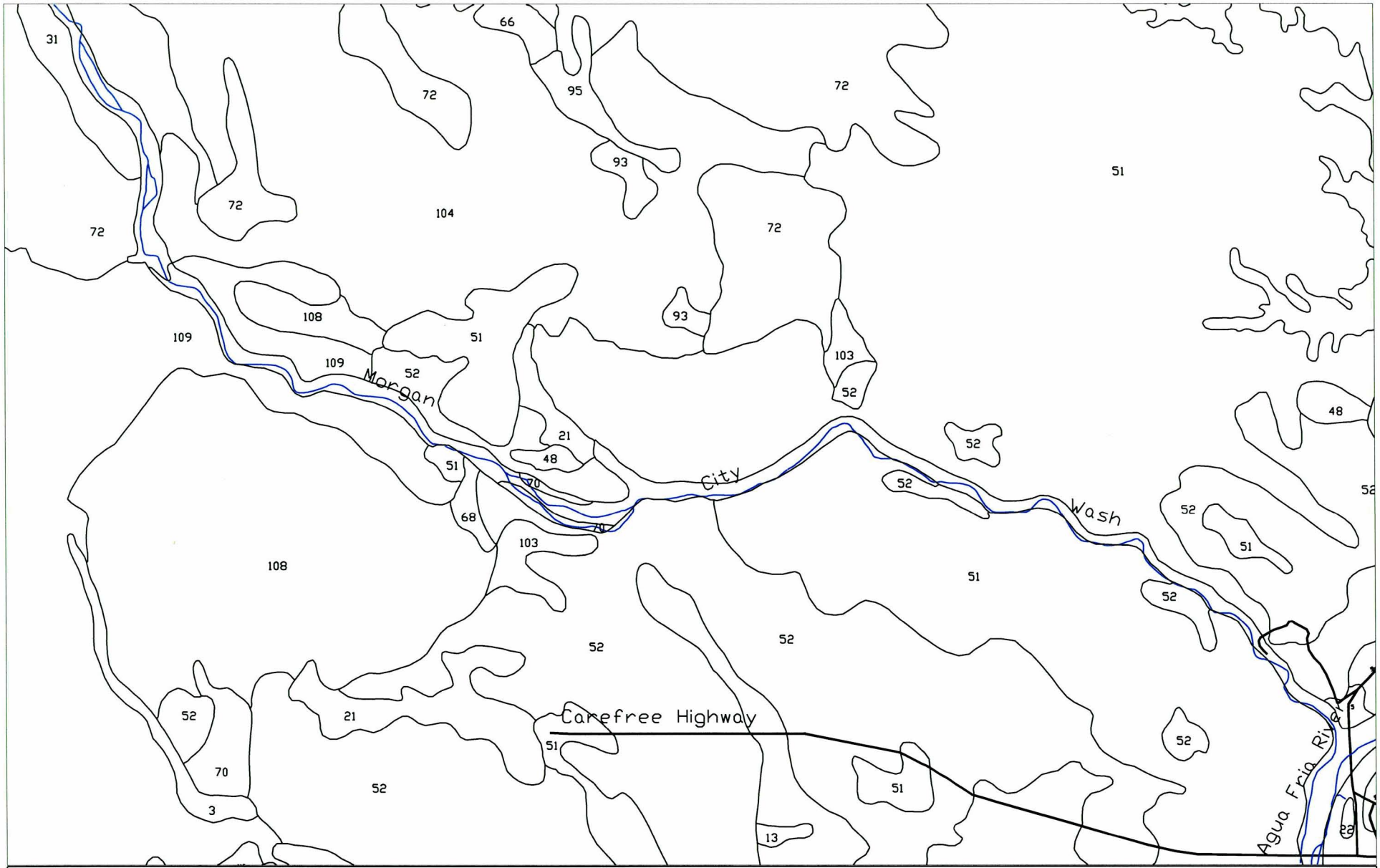


Figure 3-123 Soil Distribution - Morgan City Wash

3 -Antho-Carrizo-Maripo complex
13 -Carefree-Beardsley complex
21 -Cipriano very gravelly loam
22 -Contine clay loam
31 -Dixaleta-Rock outcrop complex
48 -Ebon-Pinamt complex
51 -Gachado-Lomitas complex
52 -Gachado-Lomitas-Rock outcrop complex
66 -Greyeagle-Suncity Variant complex
68 -Gunsight-Cipriano complex
70 -Gunsight-Rillito complex
72 -Lehmans-Rock outcrop complex
93 -Nickel-Cave complex
95 -Ohaco gravelly loam
103 -Rock outcrop-Gachado complex
108 -Schenco-Rock outcrop complex

66 - soil unit
unit division
1964 thalweg

Scale
0 2800 5600
1 Inch = 2800 Feet

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC

- Floodplain Soils. The soil materials underlying the natural floodplains adjacent to the main channels appear to be comprised of highly erosive, unconsolidated sands and gravel. Detailed soils mapping by the Soil Conservation Service (Camp, 1986),[1] does not distinguish between channel and floodplain deposits lying within the canyon bottom (Table 3-16, Figure 3-123). Several small areas adjacent to the study reach mapped by the SCS as fan terraces correspond to the high terraces described above.

Figure 3-124. Typical depositional floodplain with fine-grained cap unit, and brushy vegetative cover, located at canyon margin. Photo #JF 2-11. RM 1.477.

Table 3-16. Morgan City Wash Erosion Hazard Analysis
Soil Conservation Service (Camp, 1986) Soils Map Units, Landform, and Erosion Potential

Unit	Name	Landform	Erosion Potential
8	Arizo Cobbly Sand Loam	Floodplains	Severe & Stream Bank
10	Brios-Carrizo Complex	Floodplains & Drainageways	Severe & Stream Bank
31	Dixeleta Rock Outcrop	Mountain & Hill Slopes	Moderate
33	Denure-Momoli-Carrizo Complex	Fan Terraces	Slight
41	Eba-Pinaleno Complex	Fan Terraces	Moderate
51	Gachado-Lomitas Complex	Hill Slopes	Slight
52	Gachado-Lomitas Rock Outcrop	Mountain Slopes	Moderate
70	Gunsight-Rillito Complex	Fan Terraces	Slight
72	Lehmans Rock Outcrop	Hill and Mountain Slopes	Moderate
109	Schenco Rock Outcrop	Mountain and Hill Slopes	Slight

Note: Erosion potential refers slope processes (rilling, sheet flow) unless specifically noted to be stream bank erosion.

- Caliche. Few outcrops of carbonate-rich soil layers (a.k.a. "caliche") were observed in the channel banks and floodplain margins within the Morgan City

[1] Camp, P.D., 1986, Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona. USDA Soil Conservation Service

Wash study area (Table 3-17), probably due to the young geologic age of the floodplain units within the canyon bottom and the extensive bedrock outcrops forming the canyon walls. Where caliche layers were observed in the channel banks, the caliche appeared to do little to protect the overlying surfaces from lateral erosion of the main channel (Figures 3-125 to 3-127). While the caliche layers themselves are more resistant to erosion than the uncemented soil layers, field data suggests the carbonate layers erode primarily by undercutting the non-cemented or poorly-consolidated underlying soil or bedrock layers (cantilever failures). In other places, caliches layers had apparently failed by direct shear and impact forces on the caliche itself (Figure 3-127).

Figure 3-125. Erosion resistant carbonate-rich layer over erodible bedrock unit. Photo #MC 5-5. RM 4.149.

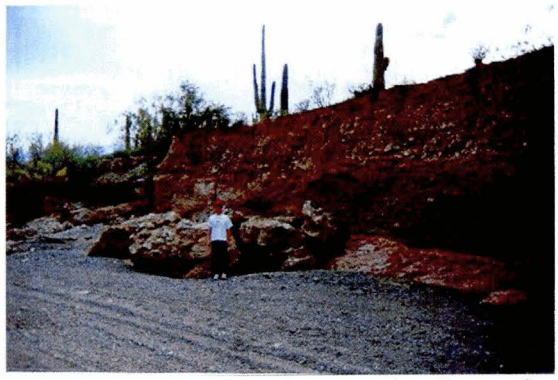


Figure 3-126. Tensional failure and collapse of carbonate-rich layer by undercutting; downstream of Figure 3-125. Photo # MC 5-7. RM 4.149.

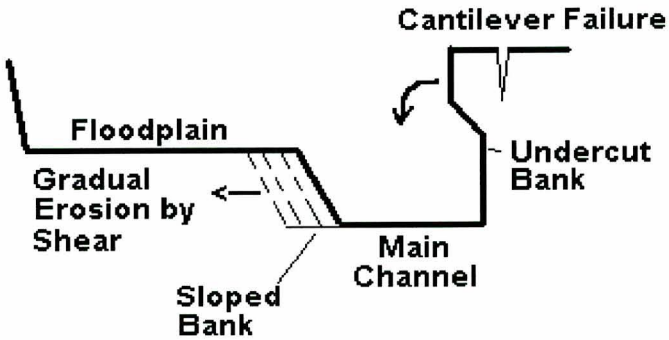


Figure 3-127. Illustration of tensional cantilever bank failure and lateral bank erosion by shear.

- Bedrock. Bedrock crops out in the bed and banks throughout the Morgan City Wash study reach, and is probably present at shallow depths in most places where it does not crop out (Figures 3-128 to 3-131). The locations of bedrock outcrops observed in the field are plotted on work maps used in the erosion hazard analysis. Lateral erosion is generally prevented by bedrock, although erosion of fine-grained volcanic units was observed in several places (Figure 3-125).

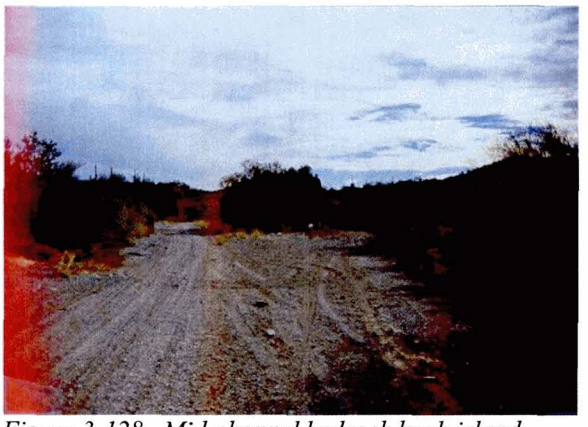


Figure 3-128. Mid-channel bedrock knob island. Photo #MC 5-1. RM 4.634.

Figure 3-129. Bedrock-alluvial contact in canyon wall. Photo #MC 4-12. RM 5.808.

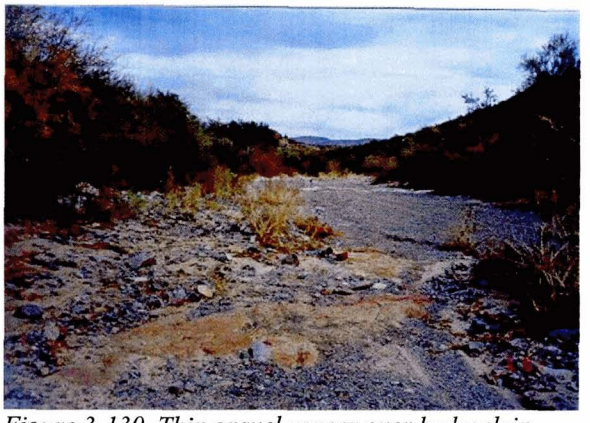


Figure 3-130. Thin gravel veneer over bedrock in channel bed. Photo #JF 3-10. RM 3.219.

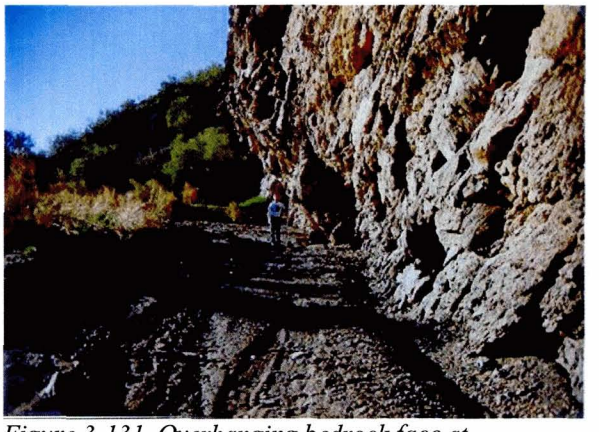


Figure 3-131. Overhanging bedrock face at channel bank & canyon wall. Photo #MC 3-2. RM 2.476.

- Cut banks. Actively eroding cut banks were observed throughout the Morgan City Wash study reach. Cut banks were observed on channel banks cut into young and old geomorphic surfaces, poorly consolidated sedimentary rock units, and caliche-cemented alluvial material. Bank vegetation appeared to increase the stability of the bank soils, but did not prevent lateral erosion or the formation of cut banks. Undercut trees, saguaro cacti, and brush with exposed roots were observed in many places. Piles of alluvium which accumulate at the base of vertical cut banks provide basal control to the bank slopes. Where such piles of collapsed soil material are absent, it implies that the stream is actively eroding and transporting the bank materials. The presence of cut banks indicates that active lateral erosion can occur within the stream systems in the study area regardless of bank vegetation, soil lithology, and soil composition (Figures 3-132 to 3-137).

Figure 3-132. Looking upstream at cutbank on channel bend. Photo #JF 2-24. RM 2.287.

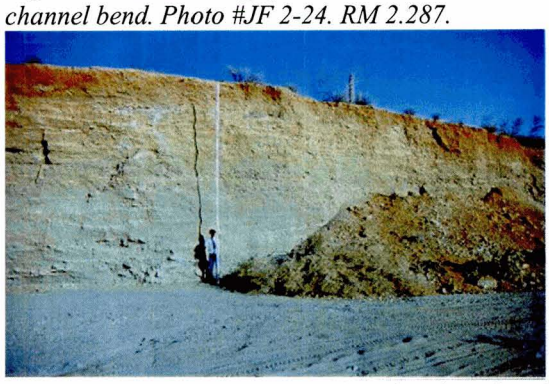


Figure 3-133. Tall cutbank with and without basal endpoint control. Photo #MC 2-22. RM 0.010.

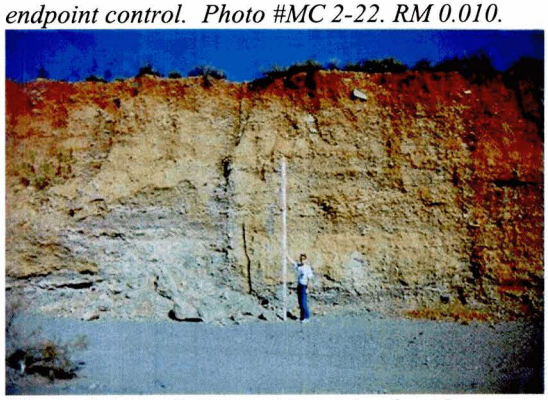


Figure 3-134. Tall unstable cut bank with recent collapse. Photo #MC 2-3. RM 0.010.

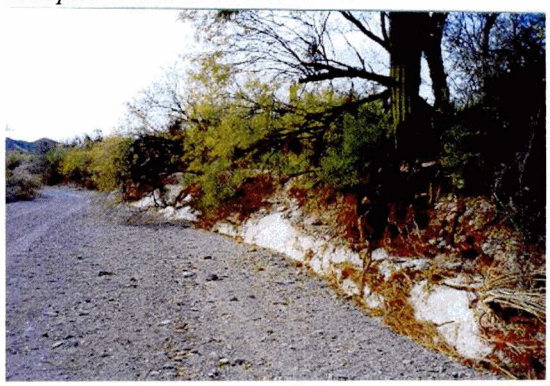


Figure 3-135. Saguaro and tree roots exposed by bank erosion. Photo #JF 3-17. RM 3.303.

Figure 3-136. Large tree with roots exposed by bank erosion. Photo #MC 3-16. RM 6.901.

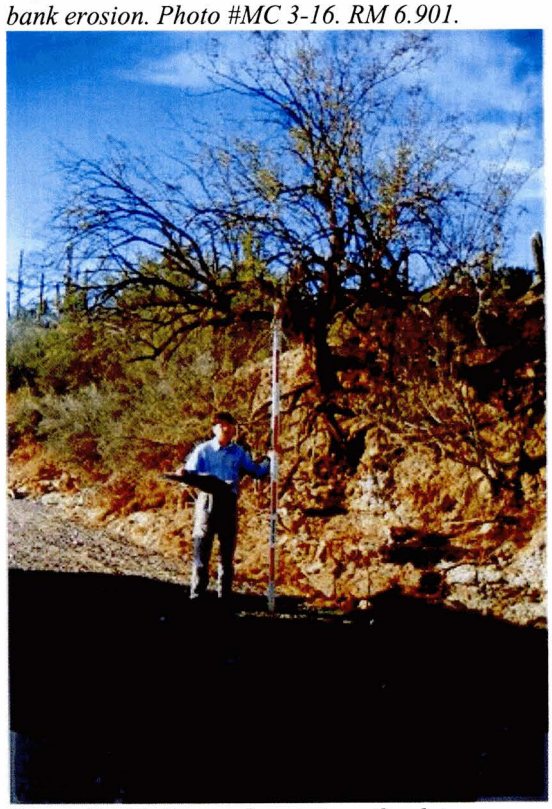


Figure 3-137. Exposed roots in cutbank in moderately old terrace. Photo #MC 3-12. RM 6.987.

Table 3-17. Morgan City Wash Observed Bank Conditions

Stream Length	Cut Banks	Bedrock Outcrop	Caliche ($CaCO_3$)
12 mi.	14 %	46 %	0.3 %

The field estimate of percent of banks cut by recent erosion are summarized in Table 3-17. The data in Table 3-17 demonstrate that cut banks are not rare in the study area, and occur naturally despite minimal urbanization or disturbance of the watershed. No relationship explaining the distribution of cut banks could be developed based on the observed data, although cuts banks are more prevalent on the outside of channel bends. Field observations of the percent of bank composed of bedrock and caliche-cemented alluvium are also shown in Table 3-17.

- Bank vegetation. In most locations, the banks of the main channel are well vegetated with mesquite, palo verde, ironwood, and dense brush (Figure 3-138). The bank vegetation generally covers the entire bank slope from toe to top, and includes deep rooting riparian species which enhance bank stability.[1] Two aspects of bank vegetation enhance bank stability: (1) root material which increases the cohesion of the soil material, and (2) leaves, branches, and debris which lower local velocities, cover the soil matrix, and prevent floodwaters from flowing directly on the soils that comprise the bank. The relatively young bank vegetation throughout much of the study area indicates that the average rate of lateral erosion has been moderately rapid in the recent past. That is, the average rate of lateral erosion is only slightly less than the average growth rate of the bank vegetation. Where very old trees were observed, they were typically protected by bedrock, had exposed roots on cutbanks, or were located on wider floodplains away from active cutbanks or avulsive overbank channels.

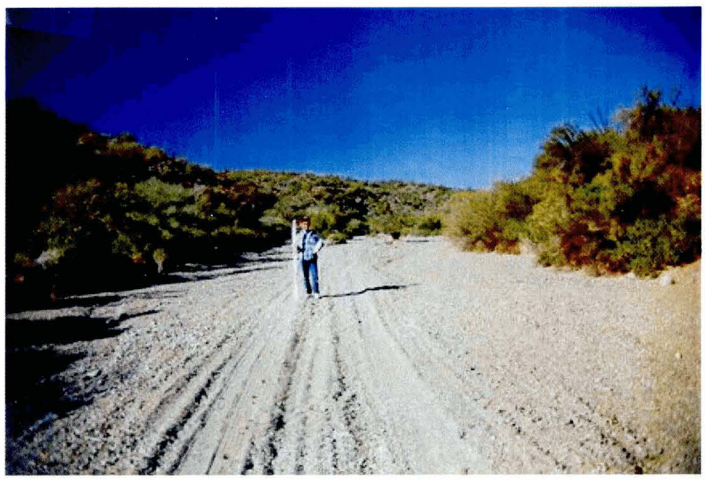


Figure 3-138. Typical dense bank vegetation in Morgan City Wash. Photo #MC 1-8. RM 10.752.

[1] Bank vegetation enhances the stability of the bank materials, but does not preclude the possibility of bank erosion as indicated by the presence of cutbanks throughout the study area where vegetation was perched or undercut. In some cases, bank vegetation accelerates bank erosion by creating eddies, increasing hydrostatic forces, and increasing flow stage in the main channel

- Sediment Transport. The bed of Morgan City Wash is composed primarily of gravel-sized sediment, with some cobbles and sand (Figure 3-139 to 3-140). The floodplains typically consist of sand and gravel deposits, with cobble bars. Some slackwater deposits and higher terraces are composed of more uniform sand, silt, and gravel. The difference in composition between the floodplain and channel materials indicates that fine-grained sediment is transported through the main channels, but is not deposited unless it is transported over the floodplain. The main channel sediments are moderately well sorted, indicating that they have been transported by recent flows, and are not primarily derived from slope processes acting on the banks and canyon slopes.

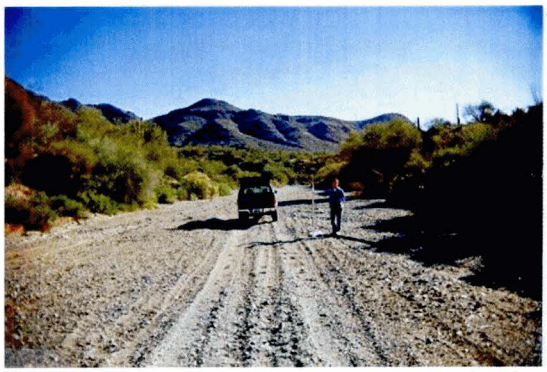


Figure 3-139. Typical gravelly bed material. Photo #MC 1-9. RM 11.636.

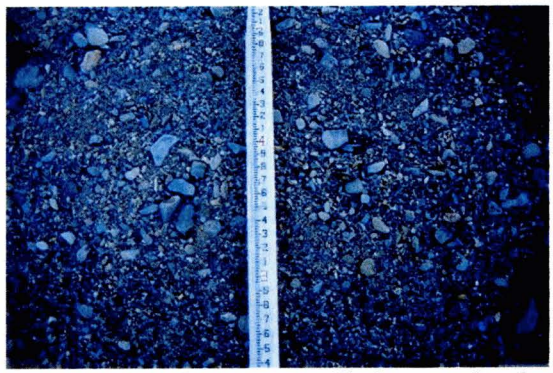


Figure 3-140. Close up view of bed material with scale. Photo #MC 3-5. RM 7.396.

- Channel Pattern. Although the Morgan City Wash canyon has an entrenched meandering pattern in some reaches, the dominant channel pattern of Morgan City Wash itself is a slightly sinuous to sinuous, single channel with a weakly braided or anastomosing pattern created by recent avulsions. In the perennial reach, dense vegetation obscures the natural channel pattern and confines the low flow channel to a narrow cross section. In the narrow bedrock canyon reaches, a step-pool pattern formed by small waterfalls, slope breaks, and fallen trees was observed. At low discharges, flow in the main channel is braided as it reworks the gravel bed material. At slightly higher discharges, the braided pattern is drowned out and a single channel pattern dominates. When discharges are high enough to inundate the floodplain, where avulsions have occurred, or mid-channel vegetative growth induces sedimentation, flow become more strongly braided (Figure 3-141), especially on the floodplain. Braided reaches generally persist over a short distance before flow is forced into a single channel by geologic control, bends in the bedrock canyon, or narrowing of the canyon walls. Changes in channel pattern due to sediment deposition is one of the mechanisms of lateral instability and bank erosion in the study area. The channel pattern also indicates that sediment is actively transported on most floodplains, as well as in the main channel.

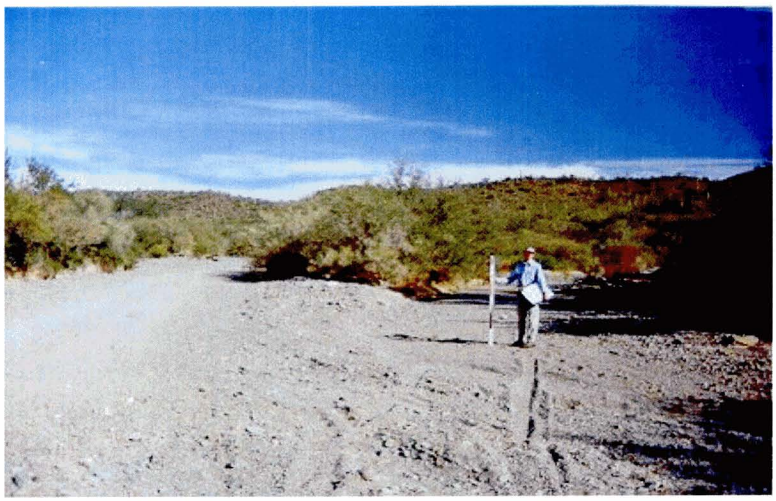


Figure 3-141. Channel split showing differing bed elevations in braids, gravel material in bar, and mid-channel vegetation. Photo #MC4-6. RM 6.143.

- Avulsions. Because of the low floodplain elevation relative to the main channel, there is a high potential for avulsive channel change along the Morgan City Wash. However, only in rare instances would avulsions create a channel outside the 100-year floodplain (e.g. RM 8.283). Where the natural floodplain is low enough to convey frequent flows of sufficient volume and peak, the potential for these flows to erode a new channel exists (Figure 3-141). With time, these new floodplain channels can capture the main channel and cause an avulsive shift of the main channel from one side of the floodplain to the other. Remnants of past avulsions or incipient avulsive channels were observed throughout the Morgan City Wash study reach, especially downstream of sharp bedrock controlled bends.

- Flood High Water Marks. Flotsam observed along the banks of the main channels indicates that at least one recent flood has exceeded the channel banks and inundated the floodplain. The stage recorded by flotsam in the perennial reach exceeded 8 feet in some places (Figure 3-142) and transported significant volumes of sediment. Slackwater sediments observed at several points in the study reach are suitable for paleoflood reconstruction of the stream's flood history.

Figure 3-142. Flotsam highwater marks in the Morgan City Wash perennial reach. White arrow points to highest flotsam from recent flood. Red arrows point to boulders perched in trees from recent high flow. Note trees bent over from flood forces. Photo #JF 2-5. RM 1.110.

- Long-term scour. No evidence of significant historical long-term degradation was observed in the field on Morgan City Wash. Bedrock exposed in the bed of the channel at the downstream and upstream ends of the study area probably limits the potential for significant long-term degradation. Field evidence from the middle reaches of the study area that scour has lowered the bed elevation by up to several feet was interpreted as cyclical scour (and fill) in response to watershed impacts, sediment removal by several recent large floods, or macro-scale sediment waves moving through the canyon. Field evidence of bed lowering included small headcuts and slope breaks, floodplain characteristics that appear perched, and lack of evidence of aggradation despite the braided channel pattern. The absence of progressive long-term scour is supported by the comparison of longitudinal stream profiles from 1964 and 1990 discussed below.

- Local scour. Scour holes up to four feet deep were observed at some channel bends or where natural obstructions such as trees or boulders partially block the main channel, indicating that there is a high potential for significant local scour where favorable conditions exist (Figure 3-143 to 3-145). The depth of local scour is probably limited by shallow bedrock in most places within the study reach.

Figure 3-143. Scour at downstream lip of culvert under Lake Pleasant access road. Note rock hammer for scale. Photo #JF 3-19. RM 3.492.

Figure 3-144. Small headcut on overflow channel parallel to, and lower elevation than, main channel. Photo #JF 1-12. RM 0.278.

Figure 3-145. Local scour hole at bedrock protrusion and channel bend. Arrow points at rock hammer for scale. Photo #JF 2-17. RM 1.831.

- Structure impacts. Few structures exist within the Morgan City Wash study reach for which structure impacts could be assessed. In general, the potential for lateral erosion increases near structures due to flow acceleration through constrictions or over concrete surfaces, disruption of sediment continuity, and/or removal of bank vegetation and placement of fill material. The impacts from structures observed in the field are summarized below.

    - Improved Road Crossings. Small local scour holes were observed at the outlets of the culverts under the two paved Lake Pleasant access roads. Some deposition was also observed upstream of these culverts, probably due to backwater deposition in the culvert headwater pool. Observed impacts of these structures on channel morphology outside the culvert sections were minimal (Figures 3-143, 3-146, and 3-147).

    - Ranch Road Crossings. At-grade crossings of the few unimproved dirt roads and four-wheel drive trails that cross Morgan City Wash have minimal impact on the stream morphology, aside from providing vehicle access for illegal dumping of trash (Figures 3-148 and 3-149). Morgan City Wash itself serves a road and may be the legal access for a few homesteads in the area.

Figure 3-146. Culvert outlet at dam maintenance road. Photo #JF 1-10. RM 0.141.

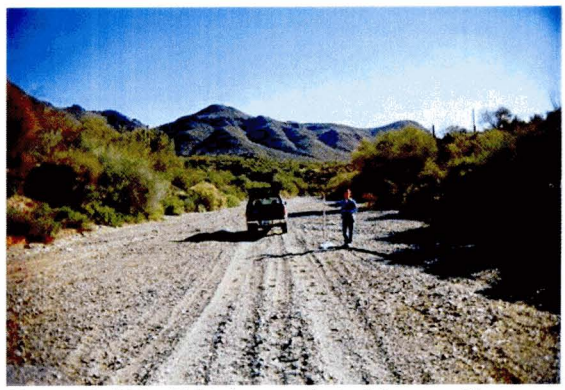


Figure 3-148. Vehicles tracks in Morgan City Wash. Photo #MC 1-9. RM 1.527.

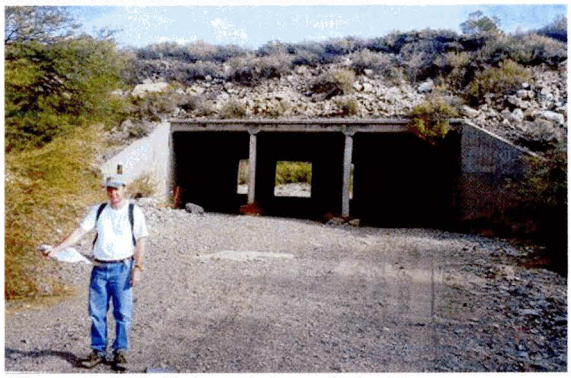


Figure 3-147. Culvert inlet at Lake Pleasant access road. Photo #JF 3-22. RM 3.520.

Figure 3-149. Abandoned vehicle buried in bed of wash. Photo #MC 3-12. RM 6.901.

Figure 3-150. Trash and debris near ranch road access to Morgan City Wash. Includes naughty boudoir photo of Jason "George Castanza" Alexander. Photo #MC 5-3. RM 4.344.

- Human Impacts. Impacts associated with human occupation of the study area are limited, but include the following:
    - Grazing
    - Trash dumping (Figure 3-149 & 3-150)
    - Target shooting and hunting (Figure 3-150)
    - Off-road ATV use
    - Perennial flow near Lake Pleasant (discussed below)

  Typically, human activities tend to decrease bank stability by removing bank vegetation, causing flow obstructions, and changing natural runoff characteristics. However, in the case of Morgan City Wash, moderately heavy use of the wash as a transportation and recreation corridor appears to have had minimal impacts on lateral stability.

- Perennial Flow Reach & Riparian Area. The perennial flow and the dense riparian habitat present downstream of RM 1.110 are not natural elements of Morgan City Wash (Figures 3-151, 3-152, and 3-154). Historical aerial photographs from 1949 and 1954 (Table 3-18, Figure 3-153) indicate that Morgan City Wash was ephemeral with no significant riparian habitat or evidence of perennial flow. By 1977, dense vegetation had sprung up between RM 0.41 and RM 1.06. By 1997, the dense vegetation area extended from the Agua Fria River confluence to RM 1.06. Based on field observations and the chronology summarized in Table 3-18, the following hypotheses are offered:
    - Perennial flow in Morgan City Wash is the result of human activities associated with impoundment of water at Lake Pleasant after construction of Waddell Dam in 1923.
    - The perennial reach begins at an elevation of approximately 1482 feet. The spillway elevation of Waddell Dam was 1567 feet, indicating that the perennial reach was down gradient of the maximum lake level.
    - Growth of the dense riparian habitat in Morgan City Wash downstream of RM 1.110 is the result of perennial flow caused by groundwater seepage from Lake Pleasant through the surrounding bedrock.
    - Perennial flow and the dense riparian reach occurred prior to the construction of New Waddell Dam, but after construction of Waddell Dam.
    - Raising of the lake level by construction of New Waddell Dam could cause analogous seepage into Morgan City Wash upstream of the existing inflow points. Such seepage could expand the perennial flow reach and dense riparian growth upstream at some time in the future. Perennial flow did not appear in Morgan City Wash until about 50 years after construction of Waddell Dam. Therefore, if new seepage inflow to the wash occurs, it may take 50 or more years from the completion of New Waddell Dam, and may be a function of lake level and operating rules.

Table 3-18. Morgan City Wash Erosion Hazard Analysis
Available Historical Aerial Photographs

Year	Date	Scale	Number	Description	Riparian Habitat
1949	2-14	1:20,000	DHP-4F-151	B/W, No stereo	None
1954	1-24	1:20,000	DHP-4N-30,31	B/W, Stereo	None Lake level higher than 1977
1977	12-5	1:12,000	19-22,23	B/W, Stereo	Moderate from RM 0.41-1.06 Minimal growth in tributaries
1985	3-21		F-21	B/W, No stereo	Dense from RM 0.41-1.06 Moderate from RM 0.16-0.32 Dense in tributary @ RM 0.78 Lake level higher than 1954
1992	9-6	1:24,000	5236-158,159	B/W, Stereo	Dense from RM 0.16-1.06 New dam under construction
1997	4-30	1:24,000	9870-254,255	B/W, Stereo	Dense from RM 0.16-1.06 New dam completed & filled Highest lake level observed

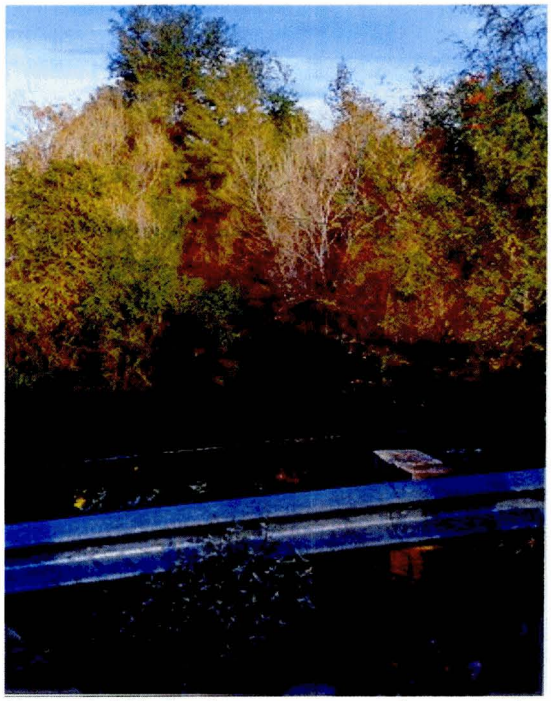


Figure 3-151. Looking upstream at dense riparian area above Lake Pleasant maintenance access road. Photo #JF 1-1. RM 0.161.

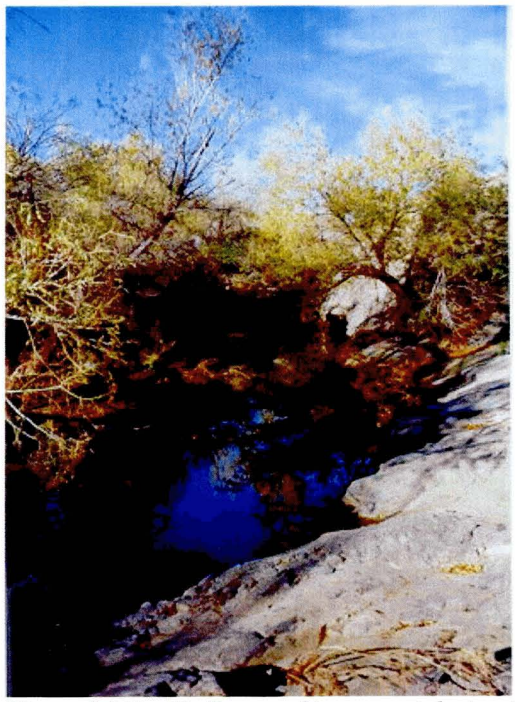
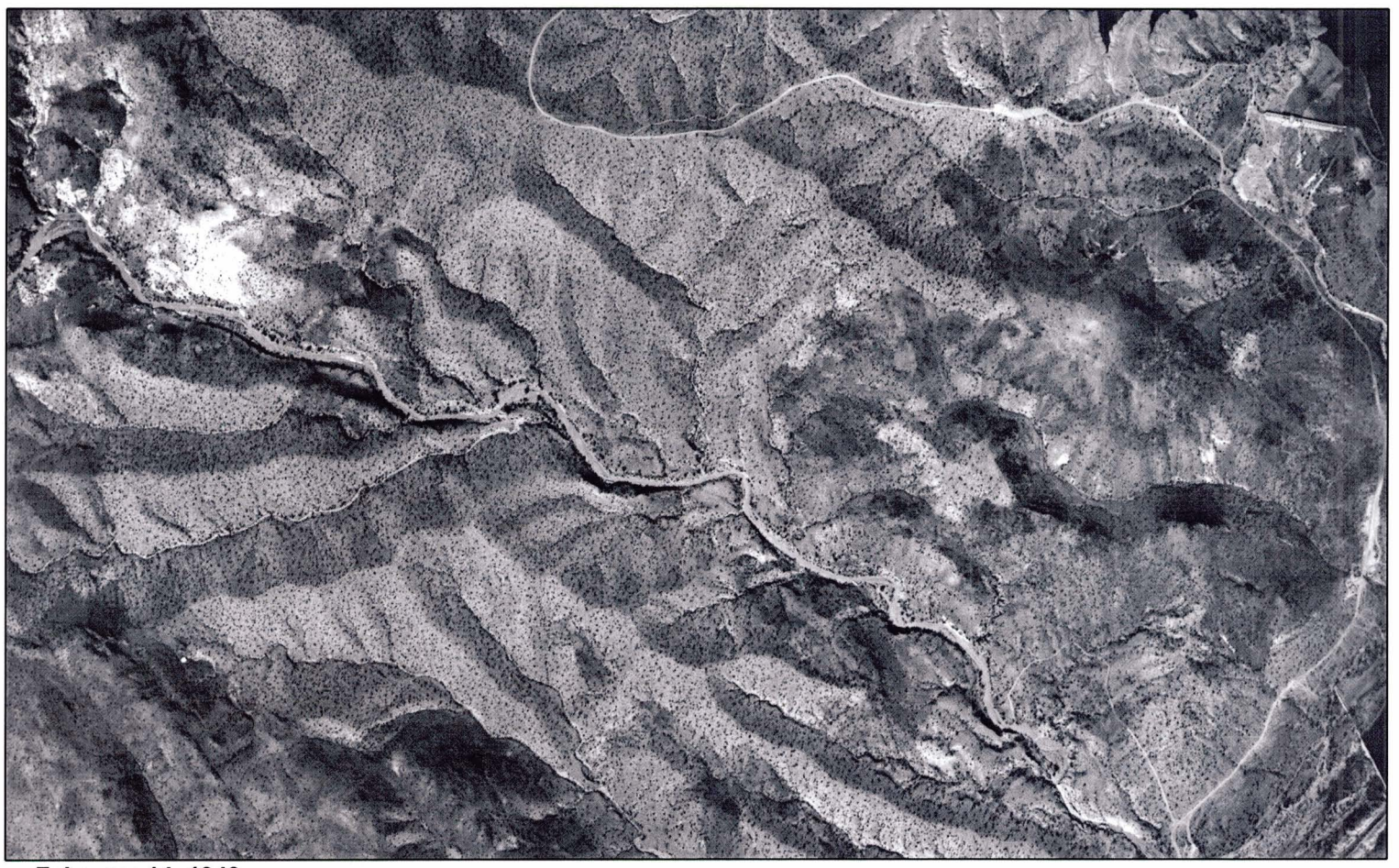
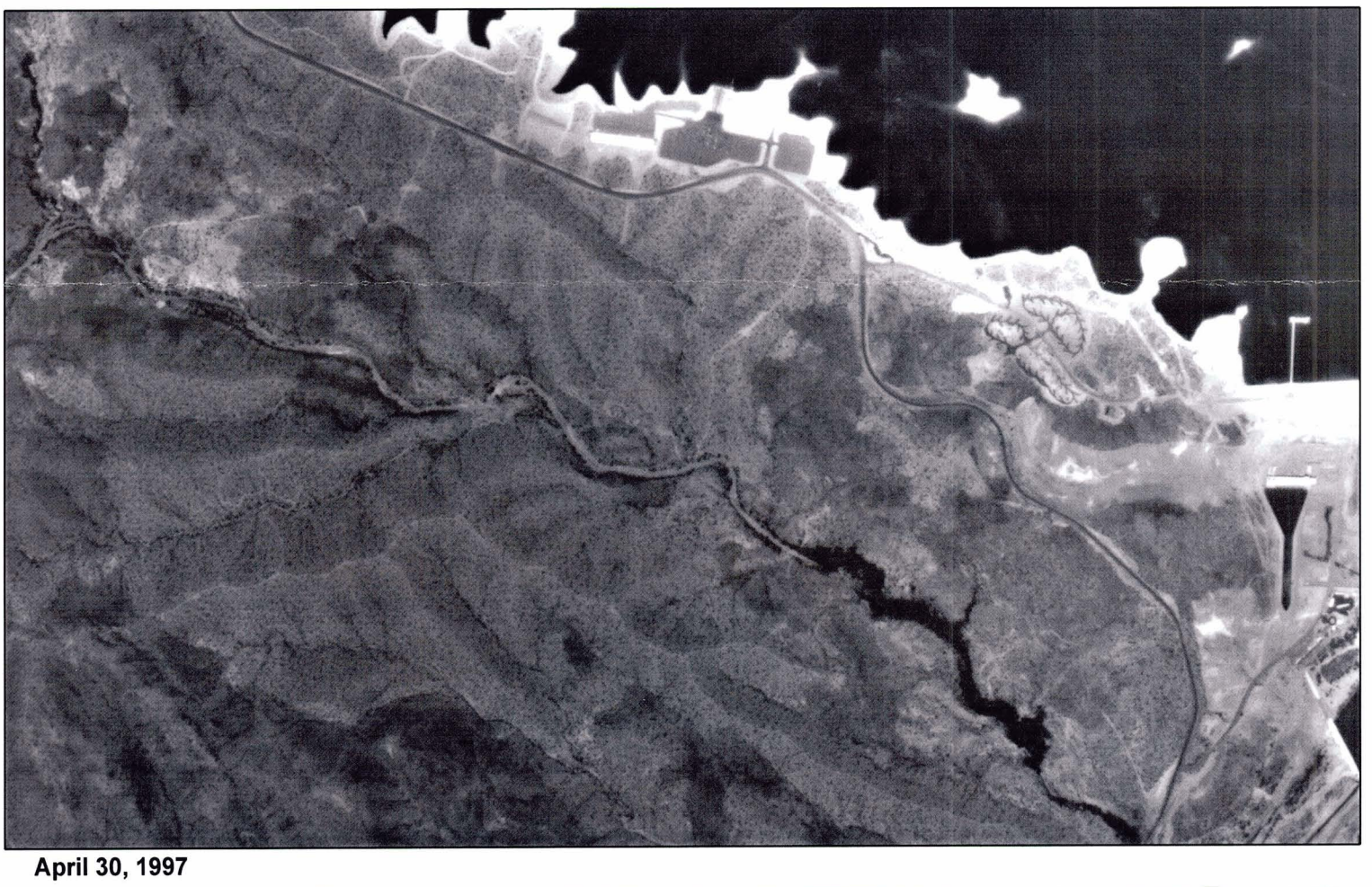


Figure 3-152. Shallow pool in perennial, riparian reach and narrow slot canyon. Photo #JF 1-14. RM 0.278.



February 14, 1949

December 5, 1977



April 30, 1997

Figure 3-153 Riparian Growth in Morgan City Wash

Scale = 1:20000

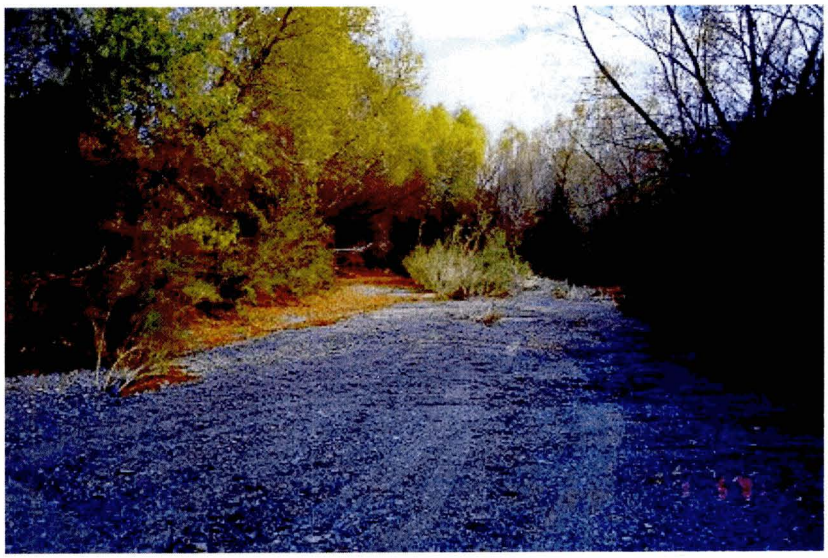


Figure 3-154. Upstream end of dense riparian growth. Perennial flow begins a short distance downstream. Photo #JF 2-7. RM 1.110.

The hypotheses listed above, while supported by the available data, should be considered preliminary until more detailed investigations are completed. With respect to the lateral stability of Morgan City Wash, the presence of the dense riparian vegetation increases the potential for fine-grained sediment deposition during small to moderate floods, but increases the likelihood of avulsive channel change during large floods. Trees and vegetation displaced by flood erosion could also significantly decrease structure capacity at the downstream culverts.

Interpretation of Aerial Photographs. The lateral erosion hazard was also evaluated by interpreting geomorphic surface characteristics visible on aerial photographs. The age of stream terraces adjacent to the main channels provides information on past stream bed elevations and positions that can be used to 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 Arizona Geological Survey (Huckleberry, 1995). Those characteristics included the following:

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

Individually, these age-indicating characteristics provide a relatively low degree of confidence in age estimates. Considered together, the characteristics provide a higher degree of confidence. The physical characteristics of a surface give clues as to its depositional history, stability, and its flood potential.

If the landform ceases to receive new deposits, its surface will begin to age. As it ages, the surface begins to develop distinctive physical and chemical characteristics indicative of its age. As the soil develops, its structure, color and content change. Clay and calcium carbonate accumulate in the soil, causing the soil to redden (clay) and become more cemented (carbonate) and 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 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 it takes thousands of years for many of these characteristics to develop, it can be concluded that surfaces that exhibit well developed soils, red color, significant carbonate development, desert pavements 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.

Recent color aerial photographs of the study area were used in conjunction with field observations to distinguish older, more stable surfaces from younger, more active surfaces near the stream channels. These data were used to estimate the potential for future lateral erosion, in conjunction with surficial mapping prepared by others. For the study reach, AZGS mapping (Huckleberry, 1995)[1] does not distinguish Holocene or Late Pleistocene terraces along most of Morgan City Wash. The canyon bottom area is mapped modern stream channels (Ya2). In only one reach, between RM 4.437 and 5.529, the AZGS distinguished a Holocene age alluvial surface which alternates between the left and right side of the canyon. This surface corresponds to the high terrace described in the field observations above, which is generally out of the recommended erosion hazard boundary. The AZGS maps the areas above the canyon bottom as middle to late Tertiary age sedimentary rock units (Tsm).

Comparison of Historical Channel Position. The position of the main channel thalweg was digitized from historical aerial photographs and from the 7.5 minute USGS topographic quadrangles for the study area. A list of the historical aerial photographs used is shown in Table 3-19. The historical aerial photographs were scanned to create digital images which were then semi-rectified using AutoCAD 2000 software and the digital USGS quadrangles as the map base. A plot of the historical channel position is shown in Figure 3-155. The position of the Morgan City Wash main channel has not significantly changed during the 50 year period of record. Channel movement has been limited to the canyon bottom.

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[1] Huckleberry, G., 1995, Surficial Geology of the Lower Agua Fria River, Lake Pleasant to Sun City, Maricopa County, Arizona. Arizona Geological Survey Open-File Report 95-5.

Figure 3-155
Historical Channel Position 1949-1997
Morgan City Wash

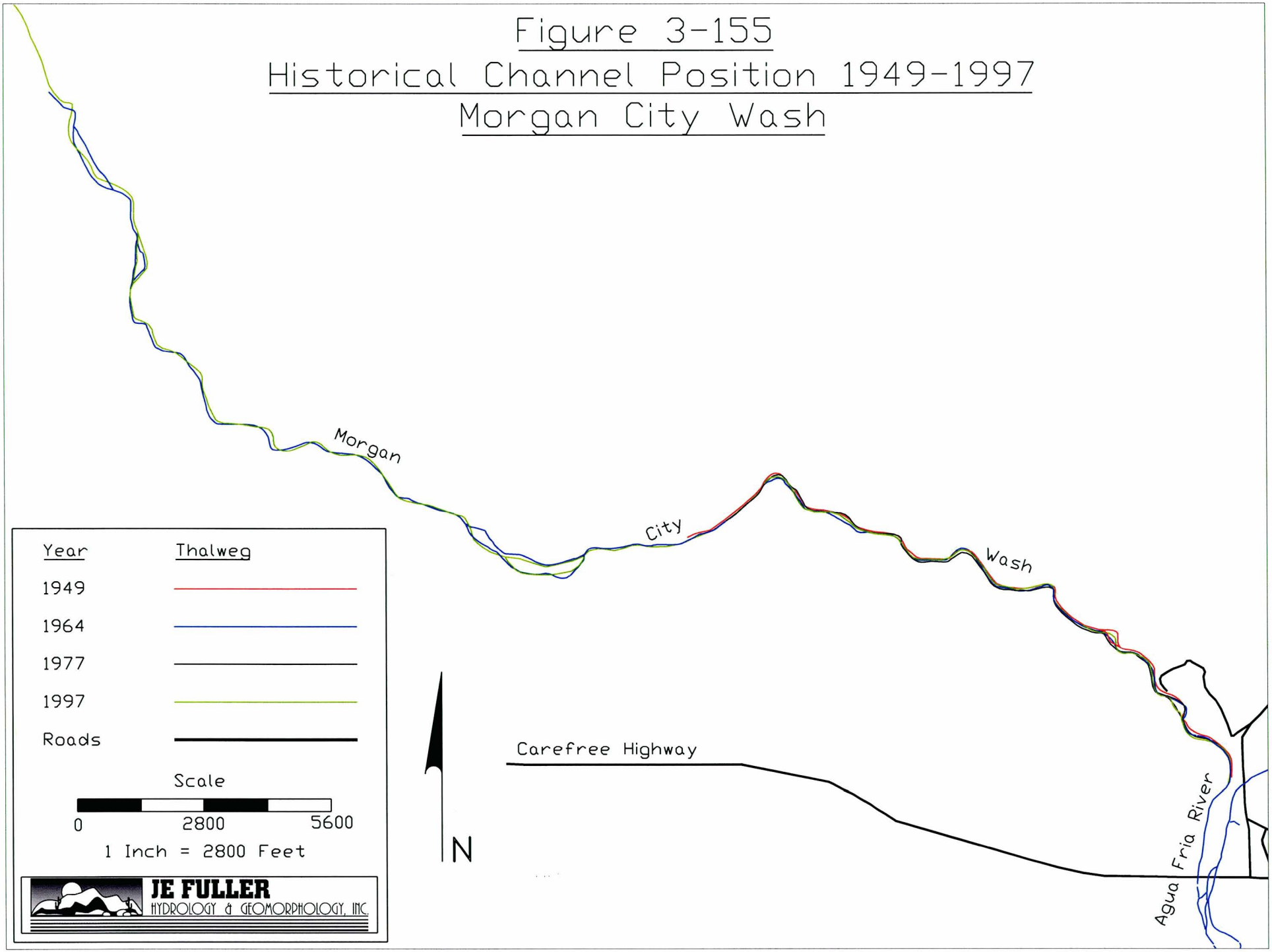
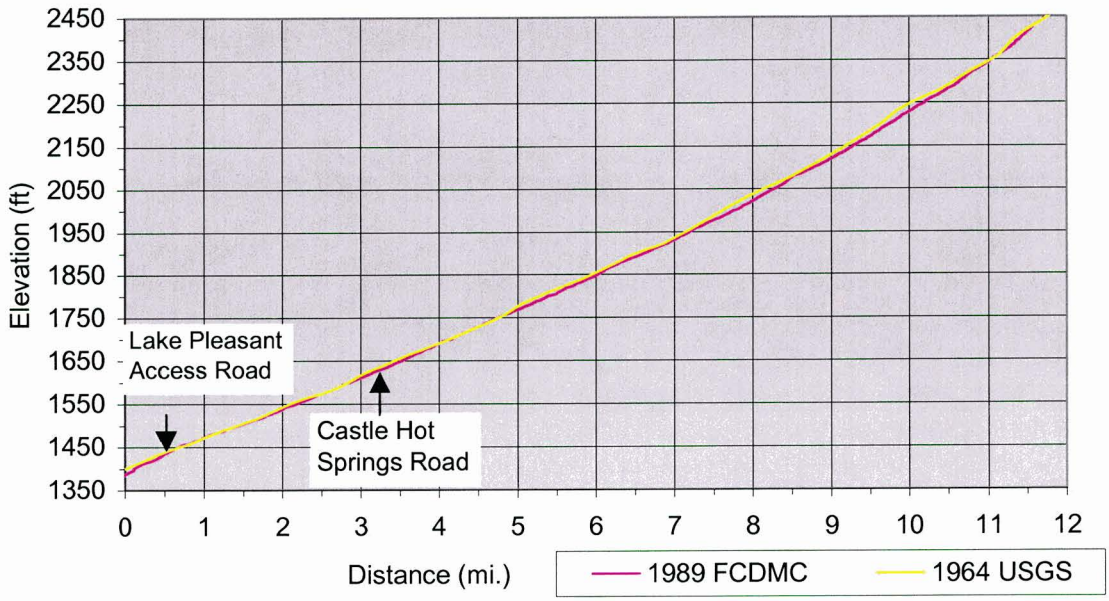


Table 3-19. Morgan City Wash Erosion Hazard Analysis Historical Photographs and Maps		
Year	**Description**	**Scale**
1949	Black & white aerial photo (2-14-49)	1:20,000
	7.5 Minute USGS topographic maps	
1981	Calderwood Butte, Arizona (1964 topo.)	1:24,000
1981	Baldy Mtn, Arizona (1964 topo.)	1:24,000
1997	Black & white aerial photo (4-30-97)	1:40,000
2000	Color aerial photos (2-2-00)	1:12,000

Evaluation of Stream Longitudinal Profile. A longitudinal profile is a plot of the channel elevation versus distance along the stream bed (Figure 3-156). Analysis of the longitudinal profile can be used to identify slope irregularities, over-steepened or flattened reaches, headcuts, and areas of natural grade control. The longitudinal profile also provides some information on expected lateral stability. Reaches with lower slopes than the adjacent reaches will experience net deposition, and bank erosion associated with braiding and avulsions. Where longitudinal profiles from different time periods indicate channel incision has occurred, bank erosion due to undercutting and bank collapse may be expected. Bank erosion occurs after channel incision because the channel material that had previously provided lateral support to the banks is removed, or because the banks are extended below the elevation of the rooting layer of the bank vegetation.

Figure 3-156. Longitudinal Profile of Morgan City Wash



The following conclusions about lateral stability and erosion hazards can be drawn from the longitudinal profile of Morgan City Wash, as shown in Figure 3-156:

- Uniform Profile. There are no abrupt slope changes, nickpoints, or significant irregularities in the longitudinal profile of Morgan City Wash. Therefore, the slope is probably close to the equilibrium slope, and no major changes in the bed elevation should be expected unless major changes in the watershed occur.
- Bedrock. Numerous outcrops and shallow bedrock under the stream bed will limit long-term slope adjustments. There are no significant differences in channel slope between reaches of obvious and assumed bedrock control. The 1964 and 1989 profiles are closest in the reaches where bedrock outcrops were observed in the bed of the channel.
- Historical Elevation Change. The difference in bed elevation between the 1964 and 1989 profiles is well within the margin of accuracy of the topographic mapping. However, the fact that the 1989 profile plots below the 1964 profile from RM 5.0 to 10.5 supports field observations that up to several feet of scour may have occurred during recent floods.

In general, the longitudinal profile indicates that Morgan City Wash has experienced long-term vertical stability.

Application of Allowable Velocity Guidelines. Allowable velocity criteria have long been used in channel design to estimate the velocity at which channel bed and bank sediments will begin to erode. A variety of allowable velocity data have been published by the Corps of Engineers (1970, 1990, 1995)[1] and the USDA Soil Conservation Service (1977).[2]

The Corps of Engineers (1970; 1995) has established suggested maximum velocities for design of non-scouring flood control channels of various bank materials, as shown in Table 3-20. In general, the banks of the streams in the study area are composed of sand, gravel and cobbles and are covered with brush and woody vegetation. No significant grass cover was observed in the field. Approximately 14 percent of the banks are actively eroding with no effective vegetative cover (Table 3-17). The average 100-year flood channel velocities derived from the Baker (1990) HEC-2 modeling (Figures 3-157 and 3-158) indicate that the erosive threshold for the bank material will be exceeded during the 100-year event, as shown in Table 3-21. In some cases, even the erosive threshold for weak sedimentary rock is exceeded, a condition which was observed during the field work. No information on expected velocities for the 2-, 10- or other recurrence intervals was available, but should be included if more detailed erosion hazard evaluations are conducted. Bed sediments observed in the field indicated that up to cobble-sized material is transported during floods.

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[1] U.S. Army Corps of Engineers, 1970, Hydraulic Design of Flood Control Channels, EM1110-2-1601.
U.S. Army Corps of Engineers, 1990, Stability of Flood Control Channels, Draft.
U.S. Army Corps of Engineers, 1995, Hydraulic Design of Flood Control Channels, EM1110-2-1601. ASCE Re-publication.
[2] Soil Conservation Service (USDA-SCS), 1977, *Design of Open Channels – Technical Release 25.*

Table 3-20. Morgan City Wash Erosion Hazard Analysis Suggested Maximum Permissible Mean Channel Velocities (USACOE, 1995)	
Channel Material	**Mean Velocity (ft/sec)**
Fine Sand	2.0
Fine Gravel	6.0
Grass-Lined Banks (< 5% Slope, Sandy Silt, Bermuda Grass)	8.0
Poor Rock (Sedimentary)	10.0
Good Rock (Igneous or Metamorphic)	20.0

Table 3-21. Morgan City Wash Erosion Hazard Analysis FDS 100-Year Flood Velocities		
Channel Segment	**Average Velocity (ft/s)**	**Maximum Velocity (ft/s)**
Main Channel	13.0	20.5
Left Overbank	5.4	11.6
Right Overbank	5.3	15.4

Figure 3-157. Morgan City Wash Channel Velocity

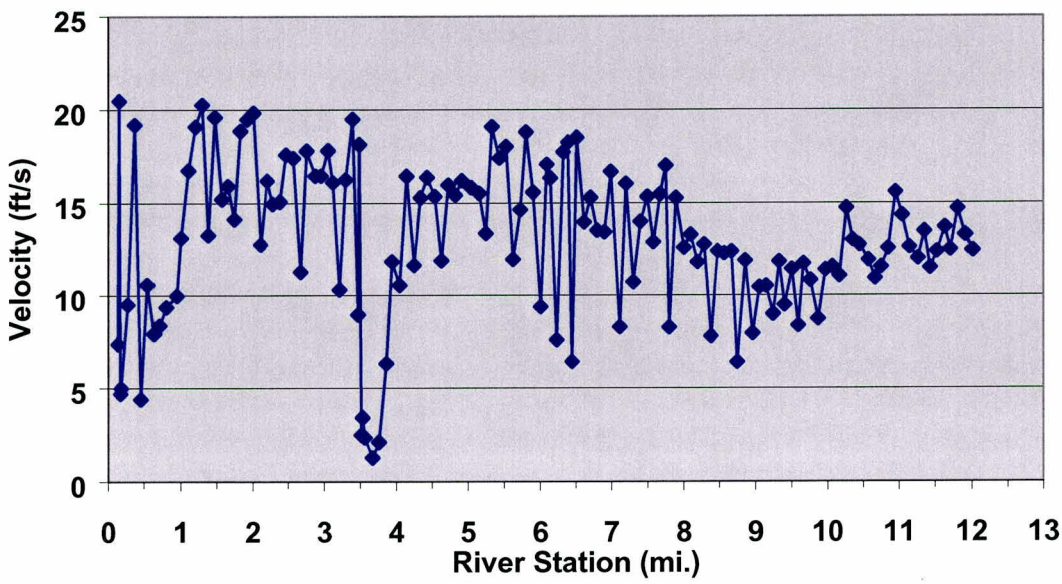
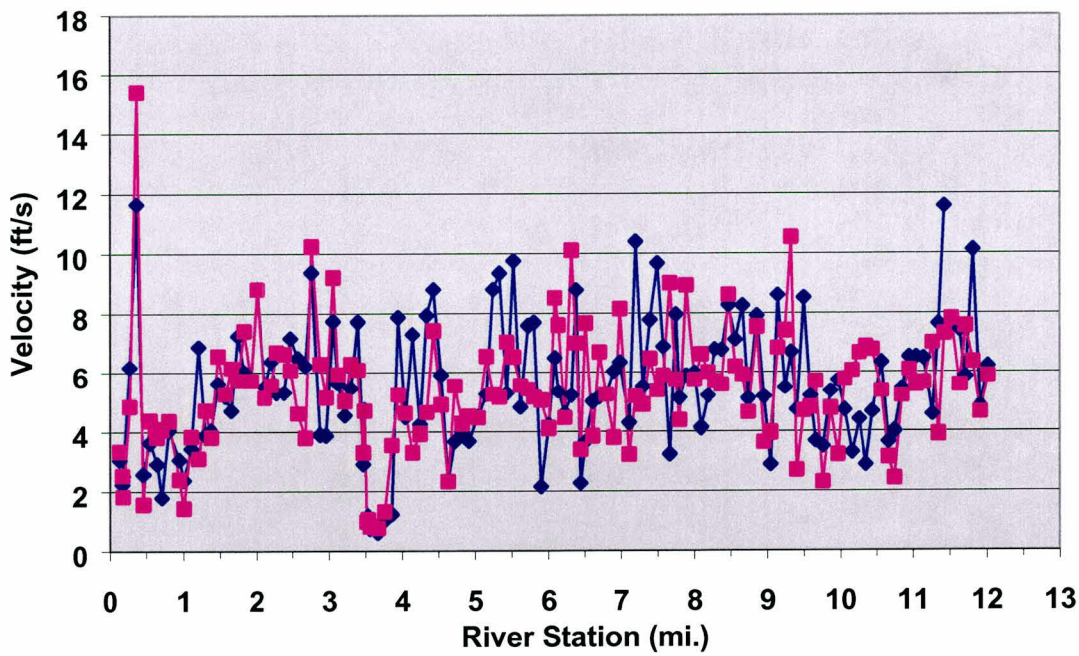


Figure 3-158. Morgan City Wash Overbank Velocities



The allowable velocity information summarized above indicates that bank erosion should be expected during the 100-year event, particularly where the stabilizing bank vegetation is removed.

Conclusions

Based on the methodologies described above used to evaluate the erosion hazards, the following conclusions can be drawn:

- Lateral erosion should be expected within the limits of the bedrock canyon that confines the main channels and its low floodplain terrace, as shown in Figure 3-117.
- Cut banks, which are evidence of recent and ongoing bank erosion, occur throughout the study area (Table 3-17).
- 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.
- Floodplain soils appear to be composed of highly erosive materials.

- The streams in the study area have been subject to channel avulsions, changes in channel pattern, local scour, and channel migration, all of which indicate a high erosion hazard.
- Historical data indicate that lateral channel movement is confined within the bedrock canyon.
- Expected 100-year velocities exceed the erosive threshold for the soils that comprise the channel banks in the study area.
- The streams in the study area have a high sediment transport capacity, and could cause significant lateral erosion.
- Caliche-cemented soils occur infrequently in Morgan City Wash and do not prevent lateral erosion.
- Bedrock does prevent lateral channel movement, except where the local sedimentary units are weakly indurated and subject to erosion.
- Significant long-term scour has not occurred in the study area within the time scale of concern for this study.
- Existing structures have had minimal impact on potential erosion hazards.

The recommended erosion hazard for Morgan City Wash includes the canyon bottom and a portion of the canyon walls. In general, the recommended erosion hazard boundary includes the 100-year floodway and floodplain, alluvial terraces above the 100-year floodplain, but within the bedrock canyon, and portions of the canyon walls where lateral channel movement would cause slope failures.

Recommended Erosion Hazard Zone. The SSA 5-96 Level 1 Methodology erosion hazard setbacks are too conservative at many locations, according to the conclusions summarized above and the conditions observed in the field, especially where bedrock crops out in the canyon walls. Therefore, a recommended erosion hazard zone for the study reach was established based on consideration of the following information:

- Field Notes and Observations
- Historical Channel Changes
- Local Channel and Floodplain Topography
- 100-Year Floodplain Limits
- Bedrock and Caliche Outcrop
- Cut bank Locations
- Channel Bend Radius and Position
- Channel Pattern and Sinuosity
- Bank Vegetation Type, Density and Age
- Height of Natural Floodplain Terraces Above Main Channel Bed
- Avulsion Potential
- 100-Year Discharge
- Stable Longitudinal Profile
- Bedrock Canyon Width
- Location of Main Channel Within Canyon

The recommended erosion hazard zones on Exhibit 3-3 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.

Differences between the erosion zone recommended by this study and the setback calculated from the SSA 5-96 Level methodology occur throughout the study area. These difference are primarily due to the higher level of analysis used for this study. In general, the SSA 5-96 methodology did not appropriately consider the stabilizing affect of bedrock in the canyon walls, and was therefore more conservative than the erosion zone established by this study.

Discussion and Recommendations

Areas located within the recommended erosion hazard zones may be subject to increased risks that warrant specific development restrictions. Given the level of detail used to develop the recommended erosion hazard zones, the developer should be given the option of completing a more detailed erosion hazard zone analysis. A typical scope of work for such an analysis is provided in Appendix 2. However, it is our professional opinion that any technically correct, more detailed study would reach similar conclusions to those presented in this report.

References Cited

ADWR, 1996, SSA 5-96: State Standard for Watercourse System Sediment Balance.

Baker, 1990, Flood Insurance Study for Morgan City Wash, Maricopa County, Arizona. Report submitted to the Flood Control District of Maricopa County. July 1990.

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

Huckleberry, G., 1995, Surficial Geology of the Lower Agua Fria River, Lake Pleasant to Sun City, Maricopa County, Arizona. Arizona Geological Survey Open File Report 95-5.

JE Fuller/ Hydrology & Geomorphology, Inc., 2000, Upper Cave Creek/Apache Wash Watercourse Master Plan Report Volume XX: Lateral Stability Assessment. Draft Report submitted to the Flood Control District of Maricopa County. January 12, 2000.

Soil Conservation Service (USDA-SCS), 1977, Design of Open Channels – Technical Release 25.

U.S. Army Corps of Engineers, 1970, Hydraulic Design of Flood Control Channels, EM1110-2-1601.

U.S. Army Corps of Engineers, 1990, Stability of Flood Control Channels, Draft.

U.S. Army Corps of Engineers, 1995, Hydraulic Design of Flood Control Channels, EM1110-2-1601. ASCE Republication.

Appendix 1: Sample Field Form

FIELD CHECK LIST – CHANNEL CHARACTERISTICS

STREAM NAME:	DATE:	FIELD CREW:
DESCRIPTION OF SECTION LOCATION:		☐ GPS LOCATION

1. PHOTO-DOCUMENTATION (RECORD PHOTO # & TIME)

NOTES: 1. INCLUDE SCALE IN PHOTOGRAPHS 2. PLOT PHOTO LOCATION & ASPECT ON AERIAL

PHOTO #	DESCRIPTION	PHOTO #	DESCRIPTION

2. INFORMATION TO PLOT ON AERIALS

☐ POOL/RIFFLE BOUNDARY	☐ MISC. CHANNEL CHARACTERISTICS
☐ CUTBANKS	☐ HEADCUTS/ SLOPE BREAKS
☐ BEDROCK OUTCROP	☐ CALICHE/ CARBONATE OUTCROP
☐ HUMAN IMPACTS	☐ STRUCTURES
☐ ACTIVE FLOODPLAIN LIMIT	☐ TERRACE BOUNDARIES
☐ TRIBUTARIES	☐ OVERBANK CHANNELS

3. CHANNEL STABILITY INFORMATION

	LEFT	RIGHT
☐ BANK HEIGHT		
☐ BANK MATERIAL		
☐ BANK VEGETATION		
☐ BANKS ERODIBLE?		
☐ RECENT EROSION ?		
☐ FAILURE MECHANISM		
☐ SCOUR OR DEPOSITION?		

☐ BED MATERIAL D10_____ D50_____ D90_____ (BY EYE)
UPSTREAM LAMINATION _____ ARMORING? _____ VEGETATION _____

4. DESCRIPTION OF UNIQUE CHANNEL & REACH CHARACTERISTICS

☐ CHANNEL CROSS SECTION	☐ CHANNEL PLANFORM

FIELD CHECK LIST – STRUCTURE IMPACT REPORT

STREAM NAME:	DATE:	FIELD CREW:	STRUCTURE TYPE:
DESCRIPTION OF STRUCTURE LOCATION:			☐ GPS LOCATION

1. PHOTO-DOCUMENTATION **(RECORD PHOTO # & TIME)**

NOTES: 1. INCLUDE SCALE IN PHOTOGRAPHS **2. PLOT PHOTO LOCATION & ASPECT ON AERIAL**

PHOTO #	DESCRIPTION	PHOTO #	DESCRIPTION

2. INFORMATION TO PLOT ON AERIALS

☐ STRUCTURE FEATURES & EXTENT	☐ STRUCTURE IMPACTS
☐ AREAS OF ACTIVE EROSION	☐ LIMITS OF ACTIVE DEPOSITION
☐ AREAS OF EXPECTED EROSION	☐ LIMITS OF EXPECTED DEPOSITION

3. STRUCTURE STABILITY INFORMATION

☐ UPSTREAM IMPACTS	
☐ DOWNSTREAM IMPACTS	
☐ DIFFERENCES FROM ADJACENT REACHES	
☐ ROADWAY APPROACH CONDITION	
☐ VEGETATIVE CHARACTERISTICS	

7. DESCRIPTION OF UNIQUE CHANNEL & REACH CHARACTERISTICS

☐ STRUCTURE CROSS SECTION	☐ STRUCTURE PLAN VIEW

Appendix 2. Typical Level 3 Erosion Hazard Analysis Scope of Work

Typical Scope of Services for Detailed Erosion Hazard Analysis

Channel stability, or the potential for lateral migration, will be evaluated using the following types of analyses:

- Interpretation of Geologic Surfaces
- Historical Analyses
- Field Analyses
- Geomorphic Analyses
- Hydraulic and Empirical Analyses
- Sediment Transport Modeling
- Sediment Yield Analysis
- Sediment Gradation Analysis

Specific tasks likely to be conducted with each of these analyses are outlined below.

Technical Analysis Work Plan

Task 1 – Hydraulics Analysis

Hydraulic Data – HEC-RAS Models. Hydraulic data will be obtained from modeling prepared for the effective FEMA Flood Insurance Studies or new modeling prepared for this study. Specific tasks include the following:

- Convert HEC-2 to HEC-RAS format. In addition to simple translation of the file format from line-based HEC-2 input to window-based HEC-RAS input, the input files will be screened for consistent channel bank stationing, extraneous GR points, and ineffective flow areas.
- Plot Cross Sections. Cross section plots showing existing condition 2-, 10-, and 100-year water surface elevations will be prepared. If the future conditions flow rates change significantly from existing condition flow rates, then water surface elevations and channel geometry will also be plotted for future conditions. Ineffective flow areas in cross sections will also be documented.
- Prepare Plots of Hydraulic Data from HEC-RAS. Plots of top width, hydraulic depth, flow cross section area, maximum flow depth, mean channel velocity, and other data, as needed, will be prepared. At minimum, data from the 100-year event will be plotted. Additional plots for the 10-year event may be made to estimate conditions for the dominant discharge.
- Define Channel Subreaches. Plots of HEC-RAS data will be used to define characteristic hydraulic reaches based on uniform flow sections, erosion prone sections (narrow width, high velocity), choke sections (short, constricted reaches), backwater sections upstream of choke sections, longitudinal profile, and potential grade controls. To eliminate potential data scatter between cross sections that may mask trends, running averages of hydraulic data will also be examined to help define reaches. Reach definition will be coordinated with results of geomorphic analyses described below.

Sediment Gradations. Sediment data for the channel bed and banks will be collected for use in hydraulic and geomorphic analyses. Specific tasks include the following:

- Sediment Sampling. Samples of bed sediments from representative locations at approximately one mile increments throughout the study reach will be obtained for sieve analysis. In addition, surficial sediment size data will be estimated using pebble counts. Bank sediment data will be collected from detailed descriptions and photographic records. These supplemental bed and bank sediment data will be collected at cross sections spaced approximately 1,000 feet apart throughout the study reach. All sampling locations will be noted on a detailed exhibit.
- Sediment Analysis. Sediment gradations showing D90, D84.1, D50, D15.9, and D10 will be prepared for each sediment sample. Sediment gradations will be reviewed to verify that reach definitions are supported, and to quantify reach-averaged sediment gradation data. Bed and bank and overbank sediment characteristics will be compared and quantified. Armored reaches will be identified. Size gradation for HEC-6 model input will be quantified for each subreach. Ranges of size gradation will be defined so that various scenarios of sediment transport analyses can be constructed to identify zones of potential aggradation or degradation, for use in sensitivity analyses of HEC-6 modeling.

Sediment Yield. Sediment supply to the study reach will be evaluated to quantify sediment sources outside the study limits. Specific tasks include the following:

- Regional Sediment Yield Estimates. Sediment yield information will be compiled and analyzed from published reports, regional data, and site specific analysis. Regionalized estimates of sediment yield will be made for the 2-, 10- and 100-year events. Rough estimates of sediment yield will made using pre- and post-development conditions.
- HEC-6 Modeling. Sediment yield estimates will be used as HEC-6 inflow boundary conditions, and will also be used to assess long-term impacts due to sediment accumulations in ponding areas or other backwater areas.

HEC-6 Modeling. HEC-6 models of existing and future (alternative) conditions will be prepared to estimate trends in scour and deposition in the study reach. The primary goal of the HEC-6 modeling is single event simulation of general sedimentation trends of aggradation or degradation, as reflected in a net sediment deficit or surplus. The HEC-6 model will be used to assess sediment transport and related channel stability for the 10-year, dominant channel forming discharge, 100-year flood discharge, and possibly an extreme catastrophic discharge event. Specific tasks include the following:

- Base Condition Modeling. HEC-6 models for existing conditions will be prepared, defined as the conditions indicated by the District's topographic mapping.
- Alternatives Modeling. Base condition HEC-6 models will be modified, as appropriate, as alternatives are evaluated and as floodplain encroachment alternatives are considered.

Model development will be based on hydraulic geometry, with appropriate adjustments, from the HEC-RAS models, sediment yield estimates, and size gradations as previously discussed, and on the inflow hydrographs. Initial model development and verification will be prepared for a test reach. Upon satisfactory verification of the proposed modeling technique, HEC-6 models will be developed in a similar manner for the other study reaches.

Task 2 – Lateral Stability Assessment

Interpretation of Geologic Surfaces. Geologic data will be used to identify and map recent geomorphic surfaces near the stream. The age and position of these surfaces will be used to constrain the rate of lateral and vertical movement over recent geologic time. Specific tasks include the following:

- Interpret aerial photographs
- Select soil test pit locations
- Describe soil profiles in soil test pits
- Describe surficial soil characteristics
- Inspect surfaces in field
- Prepare geomorphic mapping

Historical Analyses. Historical data will be used to identify historical patterns of channel behavior, historical impacts on the stream by humans, and past rates of lateral and vertical channel change. Historical data will be used to set the context for interpretation of existing conditions and prediction of future channel response. Specific tasks include the following:

- Collect historical maps and topography
- Collect historical aerial and ground photographs
- Digitize historical channel position
- Determine rates and types of channel change from digitized channel plots
- Measure historical channel characteristics (width, sinuosity, etc.)
- Plot and compare historical longitudinal profiles
- Catalogue types of human impacts, plot locations
- Prepare time line of watershed and channel changes

Field Analyses. Field data will be collected to identify areas of channel instability, quantify channel and bank characteristics, and document existing channel conditions. Specific tasks include the following:

- Select index cross section spacing and locations
- Measure channel characteristics at index cross sections
- Measure bank characteristics at index cross sections
- Document existing conditions with photographs and notes

- Perform boulder counts for channel bed sediments
- Describe soil pits excavated in the channel bottom
- Collect sediment samples from the channel bottom for sieve analysis

Geomorphic Analysis. A geomorphic description of the stream characteristics will be prepared to identify appropriate types of hydraulic and empirical analyses, identify existing channel processes, and to predict trends in future channel behavior. Specific tasks include the following:

- Describe regional geologic history
- Collect hydrologic data - peak discharge rates, flow duration curve, mean and monthly flow rates, annual flood series, flood history, climatic data, etc.
- Measure channel planform characteristics – channel pattern, meander features, pool & riffle spacing, width, slope, periodicity of narrow and wide reaches
- Identify evidence of paleofloods
- Identify stream analogs on adjacent watersheds
- Evaluate tributary characteristics – drainage area, slope, sediment type, sediment yield, flow rates, location of confluence
- Assess impacts of tributaries and tributary sediment load on main channel morphology
- Apply applicable methodologies from *FCDMC Piedmont Flood Hazard Assessment Manual* to identify surface ages and stability
- Perform stream classification
- Define stream reaches

Hydraulic and Empirical Analyses. Engineering analyses based on hydraulic data obtained from a HEC-RAS model of the study reach will be performed to assess the potential for bank erosion and scour. These analyses will be used to determine whether a stream is stable, whether it is likely to experience bank erosion and/or scour, and what amount of lateral erosion is likely to occur. Where hydraulic data are required, the computations will be based on 2-, 10-, and 100-year reach-averaged hydraulic data. Specific tasks include the following:

- Revision of HEC-RAS model as described above
- Define stream reaches using hydraulic data and physical stream characteristics
- Determine reach-averaged hydraulic data
- Compute allowable velocity
- Compute scour depths (general, local, and long-term)
- Compute armoring potential & depth to armor
- Compute equilibrium slope
- Compute reach sediment continuity relationships
- Apply Lane Relation to stream reaches
- Apply regime equations to stream reaches
- Apply hydraulic geometry relationships to stream reaches
- Apply empirical channel geometry relationships to stream reaches

- Apply appropriate regional lateral stability prediction methodologies – these may include the AMAFCA Prudent Line, ADWR State Standard 5-96, King County (WA) methodology, Rosgen bank assessment techniques, etc.

Impacts Analysis. The proposed development will be modeled to assess the potential downstream and upstream impacts, using the same procedures and methodologies listed above.

Final Product

The final product for these tasks will include a map showing the recommended erosion hazard zone boundaries and a final report. The final report will include the following:

- Discussion of assumptions and limitations of methodologies
- Discussion of how the results of the various analyses were combined with the sediment transport modeling results, sand & gravel mining impact assessment analysis, and were translated into the erosion hazard zone(s)
- Recommendation for future updates of hazard zone boundaries
- Recommendation for long-term monitoring
- Recommendations for how to modify the erosion hazard boundaries and/or under what conditions development can occur within the boundaries

Appendix 3: State Standard 5-96

Review of SSA 5-96 Level 1 Erosion Hazard Setback Methodology

State Standards for floodplain management have been adopted by the Arizona Department of Water Resources as the minimum required regulatory policy in the State of Arizona. State Standard 5-96 (ADWR, 1996), which was adopted in 1996, describes a methodology for estimating an erosion setback to account for lateral instability.

Limitations. The Level 1 erosion setback methodology has the following limitations:

1. Drainage area. The Level 1 methodology is not intended to be used for streams with drainage areas larger than 30 square miles. Most streams with significant erosion hazards have drainage areas greater than 30 square miles.
2. Historic channel movement. The Level 1 methodology is not to be used for streams where "massive shifting" has been observed in the past. No definition of "massive shifting" is provided in the State Standard. If the historical data are available from which to determine that "massive" shifting has or has not occurred, then it is not clear why the erosion hazard would need to be established by the SSA 5-96 regression equations. A better estimate of setback could be developed from the historical data.
3. Human impacts. The Level 1 methodology is not to be used for streams where local mining, channelization or other modifications could alter the anticipated flow direction. In general, streams for which erosion hazards are a concern have been modified by human impacts. In addition, almost all streams in Arizona have been impacted by historical or modern grazing, land use changes, or water diversions.
4. Top of bank. No definition of the "top of bank" or description of how to identify the top of bank is provided in the State Standard. It is assumed that the top of bank refers to the primary bank of the main channel, rather than to the bank associated with the margin of the 100-year floodplain.
5. Setback from floodway. For streams where a regulatory floodway has been delineated, the setback is to be measured from the edge of the floodway, rather than the top of bank. This means that for streams where more detailed hydraulic and hydrologic data are available, the setback is greater than for identical streams where no floodway has been delineated. Therefore, the Level 1 setback is less conservative for streams where little or no hydraulic data are available.
6. Curvature. The setback for reaches of obvious curvature is applied only to property on the outside of channel bend. In some very sharp "S" bends, the setback should be applied throughout the bend along both banks.
7. Aggradation. The methodology is not recommended for reaches undergoing a significant degree of channel filling (aggradation). No guidelines are provided on how to determine whether this condition exists. A similar restriction should be applied for streams undergoing significant degradation, with guidelines on how to recognize this condition.
8. Obvious curvature. The methodology does not clearly define how the limits of reaches with obvious curvature are defined. For example, is just the bend included or reaches (of what length) between bends?

9. Future conditions. The setback regression equations are based on the existing condition, rather than on future condition, 100-year discharges. Reliance on existing condition hydrology sets up a scenario where the setbacks will be inadequate in the future.
10. Setback distance. Field experience indicates that in many cases, the Level 1 setbacks are not conservative, contrary to the stated policy of Level 1 approaches for other State Standards, indicating the Level 1 methodology should be revised to generate more conservative estimates.
11. Unique site conditions. The results of the Level 1 methodology do not consider unique soil conditions or other geomorphic features, and hence could significantly underestimate or overestimate the actual erosion hazard.
12. Documentation. No supporting documentation, technical support, or useful literature citations for the recommended Level 1 equations are provided in the State Standard. There is no reason to suggest that the equations produce technically meaningful results for streams in central Arizona.

The main weakness of the Level 2 methodology for State Standard 5-96 is that it does not include a procedure for estimating an erosion setback. Other limitations include the following:

1. Bank materials. Instructions for considering stratified bank materials are lacking, rendering the methodology ineffective in most real-world applications.
2. Cohesive and vegetated bank materials. Instructions for assessing the stability of cohesive materials or well-vegetated channel banks are lacking, rendering the methodology ineffective in most real-world applications.

The Level 3 methodology is not defined, nor are useful references provided from which the reader could identify such methodologies.

Chapter 4
Sediment Yield Assessment

DATE: December 27, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E., Stantec Consulting

FROM: Jon Fuller, P.E.

RE: North Peoria Area Drainage Master Plan
Task 2.6.4 - Sediment Yield Analysis

Introduction

This memorandum describes the sediment yield analysis for the North Peoria Area Drainage Master Plan (ADMP). This analysis was performed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting Inc. (Stantec) under Task 2.6.4 of contract FCD 99-45 with the Flood Control District of Maricopa County (District). The primary objective of the sediment yield analysis is to estimate the existing and future sediment yield, with emphasis on sediment deposition and maintenance requirements upstream of the Central Arizona Project (CAP) Canal drainage crossings, and sediment storage for future regional retention/detention facilities.

Sediment yield is the amount of solid material transported past a given point in a stream system, or alternately, the amount of material deposited in an enclosed basin. Sediment yield includes particles small enough to be carried in suspension by the flowing water (suspended load) and particles moved along the bottom of a channel by rolling, sliding, or bouncing (bedload). When flow velocities are reduced, sediment carried by a stream is deposited. Flow velocities can be reduced by natural or manmade changes in channel slope or channel geometry, or by impoundment in flood control basins. Sediment yield is a major concern for public officials in charge of maintaining the effectiveness of flood control structures, because sedimentation behind dams or in floodways reduces the volume of water that can be stored or transported through the system. A reduction in effective storage volume increases the likelihood of a spillover in larger runoff events, increasing the chances of injuries, damage to the structure itself, property damage downstream, and loss of human life.

This memorandum consists of the following elements:

- Description of Data Sources
- Existing Condition Sediment Yield Analysis
- Future Condition Sediment Yield Analysis
- Application of Sediment Yield Results for Flood Control Planning

Each of the elements listed above are described in the following sections of this report.

Description of Data Sources

Data required to perform the sediment yield analysis were obtained from a variety of sources, and included the following types of information:

- Geology
- Soils
- Topographic Mapping
- Land Use
- Hydrology

Geologic mapping of the North Peoria ADMP study area was prepared by the Arizona Geological Survey and is shown in Figure 4-1 (Reynolds 1997). Map units shown in Figure 4-1 are listed in Table 4-1. As shown in Figure 4-1, the geology of the study area is highly variable. Therefore, sediment production and yield will vary significantly with the local geology.

Table 4-1. North Peoria ADMP Geologic Units in Study Area (See Figure 4-1)

Map Symbol	Unit Name/Description	Age
Qyc	[Qyc] Young alluvium in modern stream channels (Pan-608)	Holocene
Qt	[Qt] Talus (Pan-127)	Holocene and Late Pleistocene
Q	[Q] Alluvium and talus, undifferentiated (Pan-Warm Gray 1)	Holocene and Pleistocene
Qm2	[Qm2] Younger middle alluvium (Pan-461)	Late - Middle Pleistocene
Qm1	[Qm1] Older middle alluvium (Pan-100)	Middle Pleistocene
Qmo	[Qmo] Middle and older alluvium, undifferentiated (Pan-106)	Middle – Early Pleistocene
Qo	[Qo] Older alluvium (Pan-113)	Middle - Early Pleistocene
Tsy	[Tsy] Younger sedimentary rocks; conglomerate, sandstone, and lacustrine rocks	Pliocene
Tbu	[Tbu] Upper basalt (Pan-495)	Miocene
Tbs	[Tbs] Lower basalt, basaltic andesite, and sedimentary rocks, including arkosic sandstone and conglomerate	Miocene or Oligocene
Ti	[Ti] Intrusive and hypabyssal rocks (Pan-165)	Miocene or Oligocene
Tsm	[Tsm] Sedimentary rocks; conglomerate, sedimentary breccia, sandstone, and siltstone	Miocene or Oligocene
Tsv	[Tsv] Sedimentary rocks related to Tertiary volcanism; locally includes breccia, tuff, and other volcanic rocks	Miocene or Oligocene
Tt	[Tt] Tuff and associated sedimentary rocks (Pan-4655)	Miocene or Oligocene
Xa	[Xa] Meta-andesitic flows, tuffs, associated clastic rocks, and ferruginous quartzite	Lower Proterozoic
Xg	[Xg] Granitoid rocks; commonly foliated (Pan-463)	Lower Proterozoic
Xm	[Xm] Metamorphic rocks, undifferentiated (Pan-456)	Lower Proterozoic
Xms	[Xms] Metasedimentary rocks, including schist, phyllite, quartzite, and rare thin marble	Lower Proterozoic
Xmv	[Xmv] Metavolcanic rocks, undifferentiated; metamorphosed mafic to felsic flows, tuff, and sedimentary rock	Lower Proterozoic
Xr	[Xr] Metarhyolite, rhyodacite, and dacite (Pan-480)	Lower Proterozoic

Soils mapping of the North Peoria study area was prepared by the Soil Conservation Service and is shown in Figure 4-2 (Camp 1986 and Hartman 1977). Soil unit descriptions are provided in Table 4-2. Stantec provided soil unit distribution data for individual sub-basins as part of the HEC-1 model. As shown in Table 4-2, several of the more prominent soil units (#18, 45, 52, 109; highlighted in Table 4-2) are "highly susceptible to erosion" when cut. Therefore, as future development occurs on these soils, sediment yields may increase significantly where cuts are not stabilized. Given the topographic relief in the study area, it is likely that cuts will be required to accommodate future development of roads, infrastructure, homes, and commercial buildings.

Topographic mapping for the North Peoria ADMP study was taken from USGS Digital Elevation Models of the 7.5' maps and, where necessary, the original paper copies of the USGS topographic maps. The 7.5' USGS topographic maps that cover the North Peoria ADMP study area include Governor's Peak, Garfais Mountains, Baldy Mountain, Hieroglyphic Mountains Southwest, and Calderwood Butte quadrangles. Digital topographic mapping obtained by Stantec for the floodplain delineation tasks of several watercourses was also used where more detailed topographic information was required.

Land use information was provided by Stantec and was based on existing development as well as on the City of Peoria and Maricopa County master plan. Stantec provided land use distribution data for individual sub-basins as part of the existing and future conditions HEC-1 models. A future condition land use map is provided in Figure 4-11 in a later section of this memorandum.

Hydrologic modeling of the North Peoria ADMP study area was provided by Stantec. HEC-1 models of existing and future conditions were developed for the 2-, 10-, and 100-year 24-hour events as well as the 2-, 10-, and 100-year 6-hour events. HEC-1 modeling is discussed in detailed in *North Peoria Area Drainage Master Plan Technical Data Notebook Attachment 2 - Hydrology and Hydraulics* (Stantec, 2001).

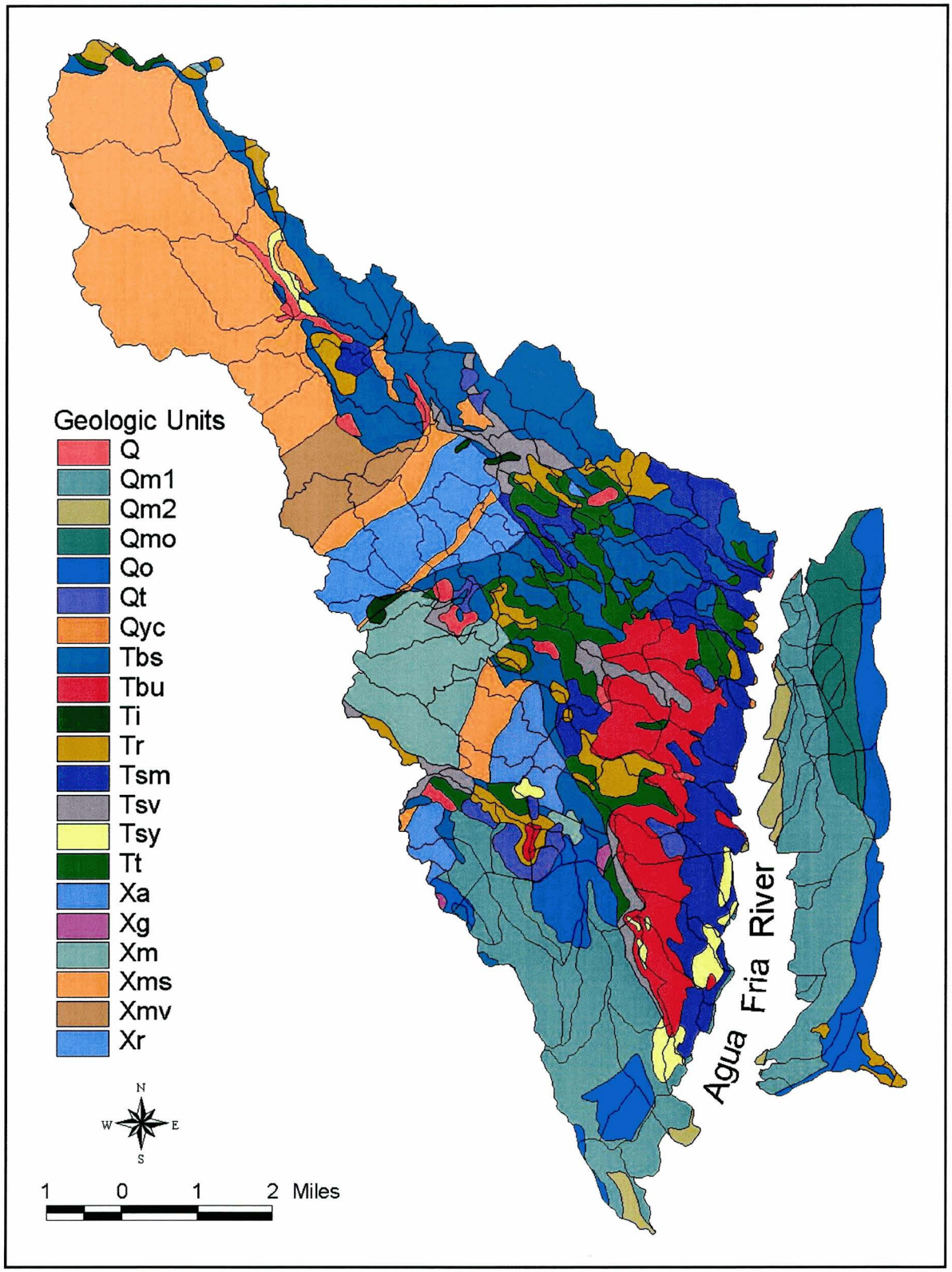


Figure 4-1. Geologic map of the North Peoria ADMP study area with watershed and subbasin boundaries. See Table 4-1 for map unit names.

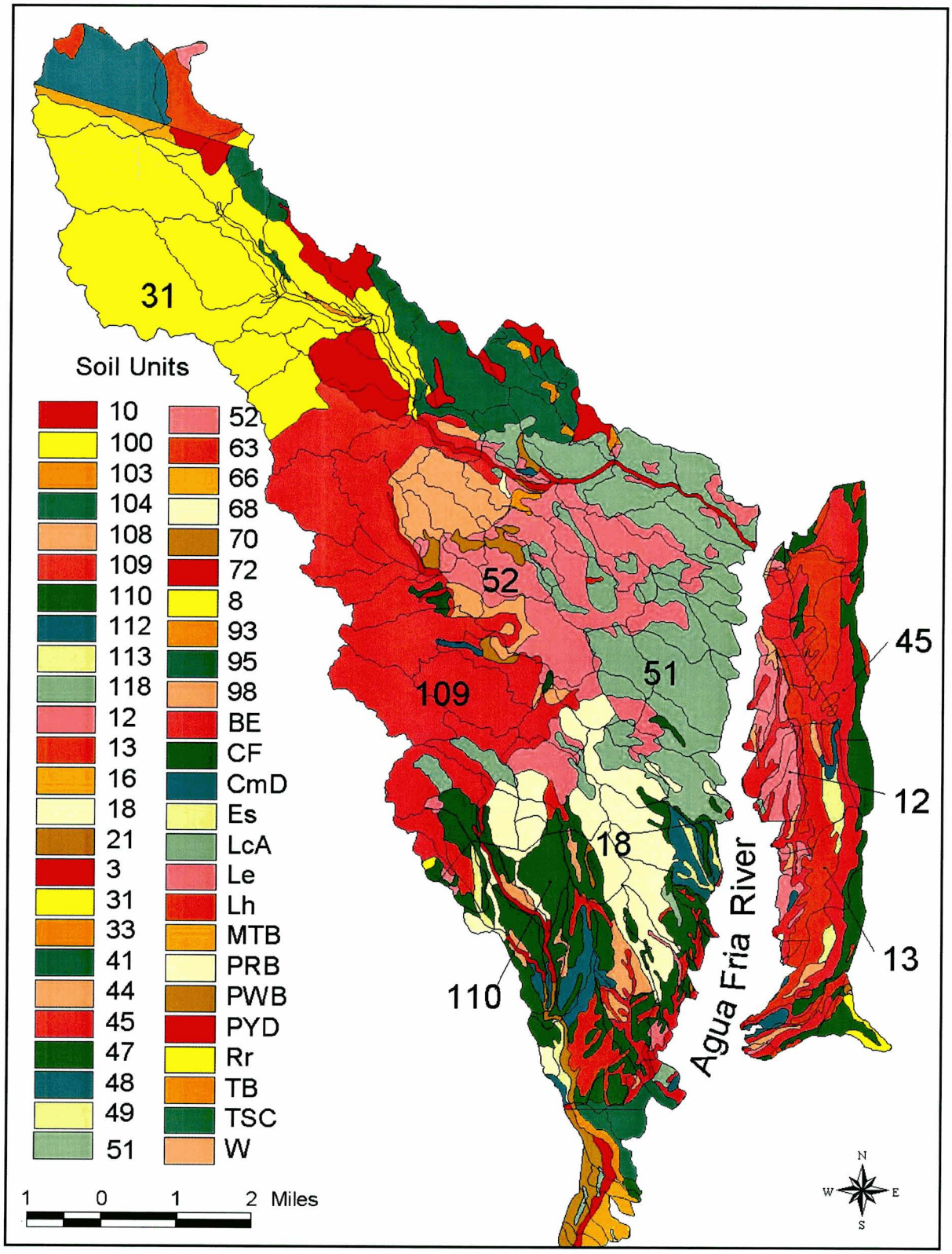


Figure 4-2. Soils map for the North Peoria ADMP study area with watershed and subbasin boundaries. See Table 4-2 for soil unit descriptions.

Table 4-2. North Peoria ADMP
Soils Map Unit Descriptions (See Figure 4-2)

Map Unit	Unit Name	Primary Soils Series	Locations	Physiographic Setting	Erosion Related Characteristics
31	Dixaleta-Rock outcrop complex, 25-65% slopes	Dixaleta extremely channery sandy loam	Upper Morgan City Wash	Mountain and hill slopes	Derived from alluvial and colluvial schist. Runoff medium to rapid, water erosion hazard moderate, 35% rock outcrops
109	Schenco-Rock outcrop complex, 25-65% slopes	Schenco extremely channery loam	Upper Unnamed Washes	Mountain and hill slopes	Shallow. Runoff medium to rapid, water erosion hazard slight, cuts and fills highly susceptible to erosion, 35% rock outcrops
52	Gachado-Lomitas-Rock outcrop complex, 7-55% slopes	Gachado very gravelly loam, Lomitas very gravelly sandy loam	Middle Unnamed Washes	Mountain and hill slopes	Runoff medium to rapid, water erosion hazard moderate, cuts and fills highly susceptible to erosion, 20% rock outcrop
51	Gachado-Lomitas complex, 8-25% slopes	Gachado very gravelly sandy loam, Lomitas extremely gravelly sandy loam	Lower Unnamed and Morgan City Washes	Hill slopes	Shallow, derived from alluvium and colluvium from volcanic breccia and tuff, runoff medium, water erosion hazard slight
110	Sun City-Cipriano complex, 1-7% slopes	Sun City gravelly loam, Cipriano very gravelly loam	Middle Twin Buttes and Caterpillar Tank Washes	Fan terraces	Very shallow, runoff slow to medium, water erosion hazard slight, hardpan
18	Cherioni-Rock outcrop complex, 5-60% slopes	Cherioni extremely stony loam	Basalt hills Twin Buttes and Caterpillar Tank Washes	Hills and mountain slopes	Shallow. Runoff medium to rapid, water erosion hazard moderate, cuts and fills highly susceptible to erosion
45	Ebon very gravelly loam, 8-20% slopes	Ebon very gravelly loam	East Agua Fria terraces	Fan/River terrace	Runoff medium, water erosion hazard slight, cuts and fills highly susceptible to erosion
13	Carefree-Beardsley complex	Carefree cobbly clay, Beardsley cobbly clay loam	East Agua Fria terraces	River terrace	Runoff slow, water erosion hazard slight for both
12	Carefree cobbly clay loam, 1-8% slopes	Carefree cobbly clay loam	East Agua Fria terraces	River terrace	Reddish color, runoff slow to medium, water erosion hazard slight

Existing Condition Sediment Yield Analysis

The following predictive methods were utilized to estimate the existing conditions sediment yield for the North Peoria ADMP study area:

- Renard Equation (1972, 1975)
- Dendy-Bolton Equation (1976)
- Flaxman Equation (1972, revised 1974)
- Pacific Southwest Inter-Agency Committee Method (PSIAC) (1968, revised 1991)
- Modified Universal Soil Loss Equation (MUSLE)

A detailed description of the equation or procedure used in each method is presented in the following paragraphs.

Renard Equation. Renard (1972) and Renard and Laursen (1975) developed an equation for predicting sediment yield from semiarid rangeland in the southwestern United States. The Renard equation was developed by simulating individual hydrographs from semiarid watersheds and computing sediment transport for the simulated hydraulic conditions. The resulting equation relating average annual sediment yield to drainage area is:

$$Y = 0.001846\ A_a^{-0.1187} \qquad (1)$$

where Y = average annual sediment yield in acre-feet/acre/year
A_a = drainage area in acres.

The Renard equation is applicable to the North Peoria ADMP study area since it was calibrated using data from the Southwest. However, it should be noted that sediment yield predicted by the Renard equation compared against measured sediment yield values in the Walnut Gulch Experimental Watershed near Tombstone, Arizona indicated that the Renard Equation over-predicts sediment yield (Renard and Stone, 1981).

For the North Peoria ADMP study area, the Renard Equation predicted a range of average annual sediment yields from 0.49 to 0.70 acre-feet/square mile/year (AF/mi^2/yr), with an average of 0.58 AF/mi^2/yr, and a standard deviation of 0.04 AF/mi^2/yr.

Dendy-Bolton Equation. The Dendy and Bolton (1976) equation for average annual sediment yield is based on regression equations developed from sedimentation data collected from over 800 reservoirs in the United States. The equation relates drainage area and average annual runoff to sediment yield in the following equation:

$$S = 1280\ Q^{0.46}\ (1.43 - 0.26 \log A) \qquad (2)$$

where S = sediment yield in tons/square mile/year
Q = annual runoff in inches
A = watershed area in square miles.

Because none of the streams in the North Peoria ADMP study area are gauged, the average annual runoff rate (Q) was estimated using an equation developed by Renard (1977) from data collected at the Walnut Gulch Experimental Watershed located near Tombstone, Arizona. Watershed conditions at the Walnut Gulch Experimental Watershed can be considered analogous to Sonoran Desert conditions in the North Peoria study area. The Renard equation for average annual runoff is:

$$Q = 0.4501\ A^{-0.1449} \qquad (3)$$

where Q = annual runoff in inches
A = watershed area in square miles.

By substituting Renard's average annual runoff equation into the Dendy-Bolton Equation, the Dendy-Bolton Equation can be simplified to the following equation with only one independent variable:

$$S = 887\ A^{-0.0667}(1.43 - 0.26 \log A) \qquad (4)$$

For the North Peoria ADMP study area, the Dendy-Bolton Equation predicted a range of average annual sediment yields from 0.46 to 0.70 AF/mi^2/yr, with an average of 0.57 AF/mi^2/yr and a standard deviation of 0.05 AF/mi^2/yr.

Flaxman Method. Flaxman (1972) developed a regression equation relating sediment yield to the following four factors: (1) the ratio of average annual precipitation to average annual temperature, (2) the average watershed slope, (3) the percent of soil particles greater than 1.0 mm, and (4) a soil aggregation index. The data set for Flaxman's regression equation included 27 watersheds in the western United States which ranged in size from 12 to 54 square miles. Flaxman (1974) later added a fifth factor to the regression equation that represented the 50% chance (2-year) peak discharge. Both Flaxman equations were developed using data from the semiarid and arid west, so the Flaxman method should be generally applicable to the North Peoria ADMP study area. However, it should be noted that while the subbasin size in the North Peoria study area averages 0.67 square miles, smaller than the drainage areas used to calibrate the Flaxman equations, they are comparable in area to those in the Walnut Gulch Experimental Watershed where the 1974 Flaxman Equation was compared to measured sediment yields (Renard and Stone, 1981). In the comparisons at the Walnut Gulch Experimental Watershed, the 1974 Flaxman equation predicted sediment yields that were closer to the measured yields than those predicted the 1972 equation.

The 1972 Flaxman equation is:

$$\log(Y+100) = 6.21301 - 2.19113 \log(X_1+100) + 0.06034 \log(X_2+100) - 0.01644 \log(X_3+100) + 0.04250\,(X_4+100) \qquad (5)$$

where Y = sediment yield in acre-feet per square mile per year
X_1 = the ratio of average annual precipitation (inches) to average annual temperature (^{o}F)

X_2 = the average watershed slope (%)
X_3 = soil particles greater than 1 mm in diameter (%)
X_4 = a measure of soil aggregation based on the percent clay and soil pH.

Flaxman (1974) modified the regression equation to reflect the 2-year peak discharge in cubic feet per second per square mile (csm). The revised equation is:

$$\log(Y+100) = 524.37321 - 270.65625 \log(X_1+100) + 6.41730 \log(X_2+100) - 1.70177 \log(X_3+100) + 4.03317 (X_4+100) + 0.99248 (X_5+100) \quad (6)$$

where $Y, X_1 - X_4$ = same as 1972 equation
X_5 = 2-year peak discharge (csm).

Estimates of the five factors used in the Flaxman sediment yield equations are described below.

Precipition:Temperature Ratio (X_1). Climate records from weathers stations located near the North Peoria ADMP study area indicate an average annual precipitation of 8.75 inches. Average annual temperature was reported as 69.4 degrees Fahrenheit, for a ratio of 0.126.

Watershed Slope (X_2). The average watershed slope for each subbasin was estimated from watershed statistics generated by AutoCAD Land Development software and the digital terrain model provided by Stantec.

Percent Soil Particles Greater than 1 mm (X_3). Soil data were obtained from the *Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona* (Camp, 1986). Estimates of the percent of particles greater than 1 mm (X_3) weighted by soil unit distribution were derived from the "Percentage Passing Sieve Number 10" column in Table 13 (Engineering Index Properties) of the Soil Survey Report (Camp, 1986). A Number 10 sieve has openings of 1.1 mm, which is approximately equal to the 1 mm characteristic used in the Flaxman equation.

Aggregation Factor (X_4). The aggregation factor is a percent value based on the percent clay in the soil modified by the soil pH. For the aggregation factor (X_4) percent clay and pH were taken from Table 14 (Physical and Chemical Properties of Soils) in the *Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona* (Camp, 1986). Soil data values from the top horizon of the soil profile were used for soil units with variable properties within the soil column. If the pH is less than 7.0, the aggregation factor is assigned a negative value. If the pH is greater than 7.0, a positive value is assigned. However, if the percent of coarse particles in the soil (i.e. greater than 1.0 mm) exceeds 25%, then the aggregation factor is assigned a value of zero. For all soils in the North Peoria ADMP study area, the aggregation factor is zero due to the abundance of coarse sediment sizes.

2-Year Peak Discharge (X_5). The 2-year peak discharge was not available from the Stantec HEC-1 models at the time the sediment yield analysis was initially completed. Therefore, the 2-year peak discharge was estimated using the ratio of the 2-year to 100-year peak discharge implied by the USGS Region 12 area regression equation (Thomas et al., 1997), and the 100-year discharge from the Stantec existing conditions HEC-1 model. Later, Stantec provided a 2-year existing

condition HEC-1 model. The Flaxman equation was applied using both the ratio-derived 2-year peak discharges and the HEC-1 2-year peak discharge. The HEC-1 2-year peak discharge estimates are higher than the ratio-derived 2-year peak discharge for all sub-basins.

Flaxman Equation Results. The 1974 Flaxman equation, using the ratio-derived 2-year peak discharges, predicted a range of average annual sediment yields from 0.04 to 0.37 AF/mi^2/yr, with an average yield of 0.13 AF/mi^2/yr, and a standard deviation of 0.06 AF/mi^2/yr. The 1974 Flaxman Equation, using the HEC-1 2-year peak discharges, predicted a range of average annual sediment yields from 0.08 to 1.04 AF/mi^2/yr, with an average yield of 0.30 AF/mi^2/yr and a standard deviation of 0.17 AF/mi^2/yr.

Pacific Southwest Inter Agency Committee (PSIAC) Method. The PSIAC (1968; ADWR 1985) procedure was developed for planning level analyses of sedimentation in the southwest United States. The PSIAC method is recommended for planning level sedimentation studies of drainage areas approximately 10 square miles in area. In tests conducted by Renard and Stone (1981) at the Walnut Gulch Experimental Watershed, the PSIAC method generally agreed most closely with measured sediment yield when compared to the Flaxman, Renard, Dendy-Bolton and MUSLE methods. The PSIAC procedure quantifies watershed characteristics by assigning a sediment yield rating number to each characteristic, and calculates sediment yield based on the assigned ratings. The following watershed characteristics are utilized by the PSIAC method for estimating sediment yield:

- Surface Geology
- Soils
- Climate
- Runoff
- Topography
- Effective Ground Cover
- Land Type and Management Quality
- Upland Erosion
- Channel Erosion and Sediment Transport

Surface Geology. The PSIAC surface geology factor takes into account the nature of exposed bedrock. The State of Utah update (Interagency Team, 1991) to the PSIAC sediment yield estimation method assigns a factor of between 0 (low sediment yields) and 5 (high sediment yields) to surficial geology. If the surface is made up of alluvial or colluvial deposits, the rating assigned is zero. Guidelines for the assigning of a surface geology rating factor are presented in Figure 4-3. Evaluation of the surface geology based on existing geologic maps and field observation resulted in weighted rating factors for the sub-basins ranging between 0 and 2.2 for areas of exposed bedrock.

PSIAC Sediment Yield Factor Rating Sheet 1991 Rev.

Watershed:_____ State:_____ Condition: Present, FWOP, FWP, Fire

Geomorphic Unit_____ Names:_____ Date:_____

Map_____ Location: T____R_____, S____, ____1/4____1/4____1/4

(a) Surface Geology Geologist	(b) Soils Soil Scientist	(c) Climate Local Knowledge	(d) Runoff Hydrologist	(e) Topography Map & Field
(5) a. Marine shales and related mudstones and siltstones	(10) a. Fine textured; easily dispersed; saline-alkaline; high shrink-swell characteristics b. Single grain silt and fine sands	(10) a. Storms of several days' duration with short periods of intense rainfall b. Frequent intense convective storms c. Freeze-thaw occurrences	(10) a. High peak flows per unit area b. Large volume of flow per unit area	(20) a. Steep upland slopes (in excess of 30%) b. High relief; little or no floodplain development
(3) a. Rocks of medium hardness b. Moderately weathered c. Moderately fractured	(5) a. Medium textured soil b. Occasional rock fragments c. Caliche layers	(5) a. Storms of moderate duration and intensity b. Infrequent convective storms	(5) a. Moderate peak flows per unit area b. Moderate volume of flow per unit area	(10) a. Moderate upland slopes (less than 20%) b. Moderate fan or floodplain development
(0) a. Massive, hard formations	(0) a. High percentage of rock fragments b. Aggregated clays c. High in organic matter	(0) a. Humid climate with rainfall of low intensity b. Precipitation in form of snow c. Arid climate, low intensity storms d. Arid climate; rare convective storms	(0) a. Low peak flows per unit area b. Low volume of runoff per unit area c. Rare runoff events	(0) a. Gentle upland slopes (less than 5%) b. Extensive alluvial plains % Slope %Area = _____ x _____ = _____ _____ x _____ = _____ _____ x _____ = _____ _____ x _____ = _____ _____ x _____ = _____ Weighted Slope %_____ Rating Chart (e) on back
Factor Value				

(f) Effective Ground Cover Land Use Planner Range Conservationist	(g) Land Type and Management Quality Land Planner	(h) Upland Erosion Geologist	(i) Channel Erosion and Sediment Transport Geologist
(10) Ground cover does not exceed 20% a. Vegetation sparse; little or no litter b. No rock in surface soil cover	(10) a. Almost all of area overgrazed or historic overgrazing impacts still active b. All of area recently burned c. Roads in need of O & M or improved design d. Almost all of area is badlands with minimal armor	(25) a. More than 50% of the area characterized by concentrated flow erosion with increasing gully development	(25) a. Eroding banks, continuously or at frequent intervals, with deep flows of long duration. b. Active headcuts and degradation in tributary channels
(0) Cover not exceeding 40% a. Noticeable litter b. If trees present, understory not well developed	(0) a. <50% of area overgrazed or with historic overgrazing impacts still active b. <50 % area recently logged c. Ordinary road and other construction d. Almost all of area is badlands with 50% of area covered with armor	(10) a. About 25 % of the area characterized by concentrated flow erosion with increasing gully development	(10) a. Moderate flow depths, medium flow duration with occasionally eroding banks or bed
(-10) a. Area completely protected by vegetation, rock fragments, litter b. Little opportunity for rainfall to reach erodible material	(-10) a. No recent logging b. Good grazing management or historic overgrazing impact under control c. Badland are totally armored	(0) a. No apparent signs of erosion Rating Chart (h) on back	(0) a. Wide shallow channels with flat gradients and short flow duration b. Channels in massive rock, large boulders, or well vegetated c. Artificially controlled channels
Rating Chart (f) on back Veg.____% Litter____% Rock___% Total Cover_____%			
Factor Value			

	Subtotal (a) - (g)	Subtotal (h) - (i)	Total Rating____ = _____ ac.ft./sq.mi./yr.

(instructions on reverse side)

(AcFt/mi ^{2}) X (3) Conversion Factor = Tons/acre

Figure 4-3. PSIAC Sediment Yield Factor Rating Sheet (Interagency Report 1991)

Soil Rating Factor Analysis. The PSIAC method accounts for the effect of soil characteristics on sediment yield by assigning a rating number to the soil based on its texture, clay aggregation, shrink-swell potential, rockiness, and organic matter. Rating factors for these soil characteristics are presented in Figure 4-3. The PSIAC soil rating factor can range from 0 (lowest sediment yield) to 10 (highest sediment yield). Soil data required for the PSIAC method were obtained from the *Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona* (Camp, 1986), and were weighted by percent coverage of each soil unit in each subbasin. Final PSIAC soil factors for the study area ranged from 1.1 to 4.8.

Climate. The PSIAC method accounts for the effect of climate on sediment yield, by evaluating the frequency and intensity of storms. The PSIAC climate rating factor can range from 0 (lowest sediment yield) to 10 (highest sediment yield). Rating factors for the climate rating are presented in Figure 4-3. The North Peoria ADMP study area is in an arid climate, which places it in the low rating category (rating = 0). However, due to the annual occurrence of short, but intense thunderstorms during the monsoon season, a slight increase in the rating factor was warranted. Therefore, the PSIAC climate factor was increased to two, and was applied to all subbasins.

Runoff Rating. The PSIAC method accounts for effect of storm runoff on sediment yield by using the characteristics of an "average" storm. The PSIAC runoff rating factor ranges from 0 (lowest sediment yield) to 10 (highest sediment yield). Figure 4-3 lists the criteria for classifying the storm runoff and selecting the corresponding rating values. The North Peoria ADMP study area experiences low volume of runoff per unit area (low rating), but has high peak flows per unit area (high rating) due to the occurrence of flash floods. Therefore, a moderate rating of five was assigned to all of the subbasins in the study area.

Topography. The PSIAC method accounts for the effects of topography on sediment yield by using the watershed slopes. Slopes less than 5% are assigned a rating of 0 (lowest sediment yield) and slopes greater than 30% are assigned a rating of 20 (highest sediment yield). Slopes between 5% and 30% are assigned a rating of 10 (medium sediment yield). Guidelines for selecting the PSIAC topographic factor are presented in Figure 4-3. Slope categories for each sub-basin were calculated by processing the Stantec digital elevation model, AutoCAD Land Development software, and the watershed boundaries delineated in ArcView GIS. A weighted average slope factor was computed for each sub-basin using the area within each slope category and the appropriate rating factor. Final PSIAC topography rating factors for the study area ranged from 0.1 to 13.6.

Effective Ground Cover. The PSIAC method accounts for the effect of various types of ground cover on sediment yield. If effective ground cover is widespread, the PSIAC rating factor is negative, thus reducing the sediment yield. Groundcover includes vegetation, vegetative litter, and rock fragements on soil surface. Guidelines for selecting the PSIAC ground cover factor are presented in Figure 4-3. Estimates of ground cover were obtained based on land use values used in the Stantec HEC-1 model (Figure 4-11), percent rock fragments listed in the *Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona* (Camp, 1986), and field

observations. The effective ground cover values for the study area ranged from 48% to 93%, with corresponding PSIAC rating factors of –1.6 to –8.6, respectively.

Land Type and Management Quality. The PSIAC method accounts for the effect of land use and land management practices, as outlined in Figure 4-3. Land type data were estimated from field observations and interpretation of aerial photographs of the study area. Because the watershed is relatively undeveloped, a PSIAC land type factor of –2 was used.

Upland Erosion. The PSIAC method accounts for the contribution of upland erosion to sediment yield through gully development processes, as described in Figure 4-3. Field observations revealed that very little gullying has occurred in upland portions of the study area, even on the steeper slopes. Therefore, an upland erosion factor of zero was used for the study area.

Channel Erosion and Sediment Transport. The PSIAC method accounts for the effect of channel erosion processes in sediment yield, as described in Figure 4-3. Field inspection of the sub-basins in the North Peoria ADMP study area, combined with knowledge of the probable flow regime, suggested that the channel erosion rating factor should be low. Flow durations in the study area are relatively short. However, evidence of bank erosion in alluvial reaches was noted in some reaches of the large stream systems in the study area. Therefore, a rating factor of 5 was assigned to most sub-basins in the study area. Well-vegetated reaches, such as the perennial reach of Morgan City Wash, were assigned a rating factor of one.

Results. The PSIAC method predicted a range of average annual sediment yield from 0.13 to 0.17 AF/mi^2/yr, with an average of 0.15 AF/mi^2/yr and a standard deviation of 0.01 AF/mi^2/yr.

Modified Universal Soil Loss Equation (MUSLE). The Modified Universal Soil Loss Equation (MUSLE) was developed by the U.S. Soil Conservation Service to predict sediment yield, and is commonly used to predict sediment yield in the semiarid Southwest (Renard and Stone, 1981; ADWR, 1985). MUSLE can be used to estimate sediment supplied from individual design storms as well as for average annual sediment production. The MUSLE equation is:

$$Y_S = R_W \, K \, LS \, C \, P \qquad (7)$$

where
Y_S = sediment yield in tons for the storm event,
R_W = storm runoff energy factor,
K = soil erodibility factor,
LS = slope length and gradient factor,
C = cover and management factor,
P = erosion control.

Guidelines for using MUSLE are presented in Appendix B of the *Design Manual for Engineering Analysis of Fluvial Systems* (ADWR, 1985). The sediment yields calculated with MUSLE for a range of storm events were then probability weighted and averaged to determine average annual sediment yield in tons. A density of 110 lbs/cubic foot (1.77 g/cm^3) estimated from data presented in the *Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona* (Camp,1986) was used to convert tons to acre-feet.

Storm Runoff Energy Factor (R_W). The storm runoff energy factor is determined by the equation:

$$R_W = \alpha\,(Vq_p)^{\beta} \qquad (8)$$

where R_W = storm runoff energy factor,
α, β = coefficients,
V = storm event runoff volume in acre-feet,
q_p = storm event peak flow in cfs.

Arizona Department of Water Resources (ADWR, 1985) recommends values for α and β of 95 and 0.56, respectively. Stantec provided peak discharges for the 100-year 24-hour event for each sub-basin. The 2-, 5-, 10-, 25-, and 50-year events were determined by applying a calculated Q_T:Q100 ratio for each basin. The ratios were based on the ratio of discharges estimated using the USGS Region 12 area regression equations (Thomas et al., 1997).

Subsequently, Stantec provided additional HEC-1 models for the 2- and 10-year events. Rating curves incorporating the HEC-1 derived 2-, 10-, and 100-year peaks were used to estimate 5-, 25-, and 50-year peaks. Thus, the MUSLE method was applied once using the ratio-derived 2-year peak discharges and a second time using the 2-year peak discharge from the HEC-1 model. The HEC-1 models indicated higher 2- and 10-year discharges than those indicated by the ratio method. Both the ratio-derived and rating curve-derived discharges were used to generate sediment yield values using the MUSLE.

Soil Erodibility Factor (K). The soil erodibility factor (K) for each soil type present in the North Peoria ADMP study area was obtained directly from Table 13 in the *Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona* (Camp, 1986). A weighted K factor for each subbasin was computed using the percent coverage of each soil unit and the percent of each K factor in each soil unit.

Slope Length and Gradient Factor (LS). The MUSLE slope length and gradient factor describes the topography of a basin. The MUSLE equation relating the slope length and gradient to factor is:

$$LS = (\lambda / 72.6)^{n}\,(0.065 + 0.0454\,S + 0.0065\,S^{2}) \qquad (9)$$

where LS = slope/length factor
λ = slope length
S = percent slope
n = exponent based on slope (0.3 for slope < 3%; 0.4 for slope = 4%; 0.5 for slope > 5%).

The slope length is defined in the MUSLE guidelines as the distance from the beginning of overland flow to the point where either slope decreases to the extent that deposition occurs or the runoff enters a channel. Slope lengths were estimated for each sub-basin based on crenulations

in the contours on USGS topographic maps and aerial photograph interpretation. The adjusted slopes (converted to percent slopes) for each sub-basin provided in the Stantec HEC-1 model were used to determine the LS factor.

Cover and Management Practice (C). The MUSLE cover and management practice factor is the product of three factors:

$$C = C_I \times C_{II} \times C_{III} \qquad (10)$$

where C_I = canopy cover
C_{II} = mulch cover
C_{III} = root cover.

Values for these three factors were estimated using the percent vegetation for varying land uses provided in the Stantec HEC-1 model, field observation, and engineering judgment. The percent vegetation cover factor is divided into percent canopy and percent mulch. Canopy cover includes leaves and branches that do not directly touch the ground. Mulch cover includes plants that are low to the ground such as grasses, as well as litter and in some cases, rock (e.g., xeriscape landscaping). Based on field observations, desert areas were assumed to have 80% of the vegetation cover in the form of canopy and 20% as mulch. The entire study area was classified as desert for the purpose of existing conditions land use. Figures B.2., B.3., and B.4. in Appendix B of *Design Manual for Engineering Analysis of Fluvial Systems* (ADWR, 1985) were used to assign the C_I, C_{II}, and C_{III} factors. The results are presented in Table 4-3.

Table 4-3. North Peoria ADMP
Land Use – Vegetation Cover and Associated MUSLE C Factors

Land Use Classification	% Veg. Cover	% Canopy	Canopy Factor C_I	% Mulch	Mulch Factor C_{II}	% Rooting	Root Factor C_{III}	C Factor
Sonoran Desert	25	20	0.85	5	0.90	25	0.42	0.32

Erosion Control Practice Factor (P). The MUSLE erosion control practice factor accounts for conservation practices such as contouring and terracing. In desert and open areas like the study area it can be reasonably assumed that no such activities have taken place, and the factor can be assigned a value of 1.0.

MUSLE Results. The MUSLE methodology using the ratio-derived discharges predicts average annual sediment yields ranging from 0.07 to 1.25 AF/mi^2/yr, with an average of 0.27 AF/mi^2/yr and a standard deviation of 0.20 AF/mi^2/yr. The MUSLE methodology using the HEC-1 rating curve discharges predicts a range of average annual sediment yields from 0.12 to 2.26 AF/mi^2/yr, with an average of 0.61 AF/mi^2/yr and a standard deviation of 0.39 AF/mi^2/yr.

Results. The results of the five sediment yield methodologies applied to each subbasin and HEC-1 concentration point are presented in Table 4-4. The Renard, Dendy-Bolton, and MUSLE (HEC-1 discharges) sediment yield results are more than 2.5 times higher than the sediment yield estimate made using the Flaxman (ratio-derived discharges) and PSIAC methods. The Flaxman (HEC-1 discharges) and MUSLE (ratio-derived discharges) results are about half of the Renard, Dendy-Bolton, and MUSLE (HEC-1 discharges) sediment yield results.

Table 4-4. Existing Conditions Sediment Yield Estimates - North Peoria ADMP Study Area

	Sub-basin ID	Renard (ac-ft/mi^2/yr)	Dendy-Bolton (ac-ft/mi^2/yr)	Flaxman (1974) --ratio-- (ac-ft/mi^2/yr)	Flaxman (1974) --model-- (ac-ft/mi^2/yr)	MUSLE --ratio-- (ac-ft/mi^2/yr)	MUSLE --model-- (ac-ft/mi^2/yr)	PSIAC (ac-ft/mi^2/yr)	Average (ac-ft/mi^2/yr)
Unnamed Wash #1	S100	0.59	0.57	0.09	0.20	0.18	0.45	0.15	0.21
	S101	0.58	0.57	0.16	0.33	0.41	0.89	0.15	0.39
	S102	0.60	0.59	0.09	0.21	0.14	0.35	0.16	0.19
	S103	0.61	0.60	0.07	0.17	0.14	0.31	0.14	0.17
	C102	0.50	0.48	0.08	0.16	0.16	0.40	0.15	0.19
	S104	0.56	0.54	0.09	0.19	0.14	0.33	0.14	0.18
	S105	0.58	0.57	0.08	0.17	0.11	0.26	0.14	0.15
	C103	0.47	0.44	0.08	0.12	0.13	0.30	0.15	0.16
	S106	0.59	0.57	0.11	0.20	0.14	0.28	0.15	0.18
	C104	0.46	0.43	0.08	0.12	0.12	0.27	0.15	0.15
	S107	0.55	0.53	0.11	0.17	0.08	0.16	0.15	0.13
	C105L	0.45	0.41	0.08	0.11	0.11	0.22	0.15	0.13
Average for sub-basins:		0.58	0.57	0.10	0.21	0.17	0.38	0.15	0.20
Unnamed Wash #2	S200	0.55	0.53	0.15	0.36	0.25	0.66	0.16	0.32
	S201	0.62	0.61	0.15	0.38	0.26	0.62	0.16	0.31
	C201	0.53	0.51	0.13	0.32	0.22	0.61	0.16	0.29
	S202	0.70	0.70	0.15	0.38	0.24	0.47	0.15	0.28
	S203	0.62	0.61	0.09	0.20	0.14	0.34	0.15	0.18
	S204	0.55	0.53	0.10	0.24	0.17	0.45	0.16	0.22
	C203	0.49	0.46	0.10	0.22	0.16	0.46	0.16	0.22
	S205	0.61	0.60	0.10	0.20	0.24	0.53	0.15	0.24
	C204	0.48	0.45	0.10	0.21	0.17	0.47	0.16	0.22
	S206	0.56	0.54	0.08	0.20	0.16	0.43	0.15	0.21
	S207	0.55	0.53	0.10	0.25	0.16	0.45	0.16	0.22
	C205	0.45	0.42	0.09	0.19	0.17	0.44	0.16	0.21
	S208	0.54	0.52	0.15	0.35	0.27	0.73	0.16	0.33
	C206	0.44	0.40	0.10	0.19	0.18	0.46	0.16	0.22
	S209	0.58	0.56	0.19	0.38	0.44	0.99	0.16	0.43
	S210	0.60	0.59	0.14	0.24	0.15	0.28	0.15	0.19
	C207	0.43	0.39	0.10	0.19	0.18	0.43	0.16	0.21
	S211	0.60	0.59	0.18	0.32	0.25	0.50	0.16	0.28
	C105R	0.43	0.39	0.10	0.18	0.17	0.41	0.16	0.21
Average for sub-basins:		0.59	0.58	0.13	0.29	0.23	0.54	0.16	0.27
Unnamed Wash #1 & #2	**C105**	0.41	0.36	0.09	0.15	0.15	0.31	0.15	0.17
Average for sub-basins:		0.59	0.57	0.11	0.25	0.20	0.46	0.15	0.23
Unnamed Wash #3	S300	0.58	0.57	0.10	0.22	0.21	0.52	0.15	0.24
	S301	0.55	0.53	0.08	0.20	0.13	0.35	0.15	0.18
	C300	0.52	0.49	0.08	0.18	0.14	0.39	0.15	0.19
	S302	0.60	0.59	0.12	0.28	0.31	0.73	0.15	0.32
	C301	0.50	0.48	0.08	0.18	0.16	0.42	0.15	0.20
	S303	0.57	0.56	0.21	0.36	0.59	1.20	0.16	0.50
	C302	0.49	0.45	0.10	0.18	0.21	0.52	0.15	0.23
	S304	0.56	0.54	0.11	0.19	0.14	0.27	0.15	0.17
	C303	0.47	0.44	0.10	0.16	0.17	0.41	0.15	0.20
Average for sub-basins:		0.57	0.56	0.12	0.25	0.28	0.61	0.15	0.28
Caterpillar Tank Wash	S400	0.55	0.53	0.09	0.21	0.26	0.64	0.14	0.27
	S401	0.58	0.56	0.11	0.21	0.37	0.76	0.15	0.32
	C401	0.52	0.49	0.08	0.15	0.20	0.52	0.15	0.22
	S402	0.57	0.55	0.12	0.21	0.37	0.72	0.15	0.32
	C402	0.49	0.46	0.09	0.13	0.20	0.46	0.15	0.21
	S403	0.59	0.58	0.08	0.20	0.19	0.47	0.14	0.22
	C403	0.48	0.45	0.08	0.11	0.19	0.40	0.15	0.19
	S404	0.64	0.64	0.16	0.41	0.59	1.20	0.14	0.50
	C404	0.48	0.44	0.08	0.11	0.18	0.38	0.15	0.18
Average for sub-basins:		0.58	0.57	0.11	0.25	0.36	0.76	0.14	0.32

Table 4-4. Existing Conditions Sediment Yield Estimates - North Peoria ADMP Study Area (continued)

	Sub-basin ID	Renard (ac-ft/mi²/yr)	Dendy-Bolton (ac-ft/mi²/yr)	Flaxman (1974) --ratio-- (ac-ft/mi²/yr)	Flaxman (1974) --model-- (ac-ft/mi²/yr)	MUSLE --ratio-- (ac-ft/mi²/yr)	MUSLE --model-- (ac-ft/mi²/yr)	PSIAC (ac-ft/mi²/yr)	Average (ac-ft/mi²/yr)
Twin Buttes Wash	S500	0.55	0.53	0.09	0.22	0.13	0.37	0.16	0.19
	S501	0.58	0.57	0.09	0.20	0.14	0.34	0.15	0.18
	C501	0.52	0.49	0.08	0.19	0.11	0.30	0.15	0.16
	S502	0.61	0.60	0.19	0.35	0.73	1.48	0.15	0.58
	S503	0.55	0.53	0.09	0.20	0.18	0.45	0.15	0.21
	C502I	0.48	0.45	0.08	0.16	0.15	0.37	0.17	0.18
	S504	0.63	0.62	0.04	0.08	0.07	0.12	0.13	0.09
	S505	0.69	0.70	0.28	0.63	1.25	2.26	0.14	0.91
	S506	0.69	0.69	0.22	0.42	0.90	1.46	0.14	0.63
	S507	0.58	0.56	0.06	0.11	0.16	0.28	0.13	0.15
	C505	0.46	0.42	0.07	0.11	0.15	0.35	0.15	0.17
	S509	0.68	0.68	0.13	0.38	0.47	0.93	0.14	0.41
	S510	0.70	0.70	0.06	0.13	0.47	0.77	0.13	0.31
	S511	0.62	0.61	0.11	0.31	0.11	0.25	0.15	0.19
	S512	0.66	0.66	0.07	0.15	0.63	1.17	0.13	0.43
	C508	0.56	0.54	0.06	0.17	0.16	0.50	0.14	0.21
	S513	0.57	0.55	0.05	0.13	0.07	0.15	0.13	0.11
	S508	0.64	0.63	0.17	0.24	0.18	0.29	0.15	0.21
	C509	0.44	0.40	0.07	0.09	0.14	0.28	0.14	0.14
	S514	0.58	0.56	0.10	0.23	0.26	0.62	0.14	0.27
	C510	0.44	0.39	0.07	0.09	0.14	0.29	0.14	0.15
	S515	0.54	0.52	0.07	0.20	0.17	0.45	0.14	0.21
	C511	0.43	0.38	0.07	0.09	0.14	0.29	0.14	0.15
	S516	0.59	0.58	0.09	0.61	0.16	0.46	0.14	0.29
	C512	0.42	0.38	0.07	0.08	0.14	0.27	0.14	0.14
	Average for sub-basins:	0.61	0.61	0.11	0.27	0.36	0.70	0.14	0.32
Morgan City Wash	S600	0.50	0.48	0.35	0.59	0.22	0.49	0.17	0.36
	S601	0.56	0.54	0.37	1.04	0.31	0.93	0.16	0.56
	C601	0.48	0.45	0.34	0.62	0.24	0.56	0.17	0.39
	S602	0.51	0.48	0.13	0.29	0.19	0.54	0.16	0.26
	S603	0.58	0.56	0.27	0.92	0.49	1.44	0.17	0.66
	C602	0.45	0.41	0.22	0.41	0.24	0.57	0.17	0.32
	S604	0.49	0.46	0.14	0.30	0.19	0.55	0.17	0.27
	S605	0.54	0.52	0.09	0.22	0.14	0.39	0.15	0.20
	S606	0.58	0.56	0.15	0.36	0.29	0.74	0.16	0.34
	C603	0.42	0.37	0.16	0.31	0.21	0.50	0.16	0.27
	S607	0.56	0.54	0.07	0.18	0.11	0.30	0.14	0.16
	S609	0.59	0.58	0.11	0.21	0.15	0.37	0.15	0.20
	C604	0.41	0.36	0.15	0.27	0.19	0.44	0.16	0.24
	S608	0.59	0.58	0.11	0.36	0.22	0.60	0.15	0.29
	C605	0.41	0.36	0.14	0.26	0.19	0.43	0.16	0.24
	S610	0.58	0.57	0.13	0.34	0.24	0.66	0.16	0.31
	S612	0.56	0.55	0.12	0.29	0.21	0.58	0.16	0.27
	C606	0.40	0.36	0.14	0.25	0.18	0.43	0.16	0.23
	S611	0.59	0.57	0.16	0.44	0.23	0.62	0.16	0.32
	S613	0.51	0.49	0.11	0.28	0.16	0.49	0.16	0.24
	C608	0.40	0.35	0.13	0.24	0.18	0.43	0.16	0.23
	S614	0.54	0.52	0.11	0.28	0.18	0.50	0.16	0.25
	C609	0.39	0.34	0.13	0.24	0.18	0.42	0.16	0.23
	S615	0.55	0.53	0.16	0.51	0.30	1.01	0.17	0.43
	S616	0.60	0.58	0.10	0.25	0.15	0.40	0.15	0.21
	S617	0.57	0.56	0.11	0.25	0.22	0.54	0.15	0.26
	C611	0.39	0.33	0.12	0.23	0.18	0.42	0.16	0.22
	S618	0.55	0.53	0.20	0.40	0.12	0.30	0.16	0.24
	S619	0.56	0.54	0.18	0.54	0.50	1.49	0.16	0.57
	S620	0.60	0.60	0.22	0.55	0.39	1.05	0.15	0.47
	C613	0.38	0.33	0.13	0.23	0.18	0.42	0.16	0.22
	S621	0.55	0.54	0.14	0.24	0.16	0.30	0.14	0.20
	C614	0.38	0.33	0.13	0.22	0.17	0.39	0.16	0.21
	S622	0.56	0.54	0.12	0.21	0.12	0.25	0.14	0.17
	C615	0.38	0.32	0.12	0.21	0.17	0.37	0.16	0.21
	Average for sub-basins:	0.56	0.54	0.16	0.39	0.23	0.63	0.16	0.31
	Sub-basin Average	0.58	0.57	0.13	0.30	0.27	0.61	0.15	0.29
	Sub-basin Maximum	0.70	0.70	0.37	1.04	1.25	2.26	0.17	0.91
	Sub-basin Minimum	0.49	0.46	0.04	0.08	0.07	0.12	0.13	0.09
	Standard Deviation	0.04	0.05	0.06	0.17	0.20	0.39	0.01	0.15

Verification of Sediment Yield Estimates. Given the range of existing condition sediment yield estimates summarized in Table 4-4, field verification of the results was attempted to refine the estimate of sediment yield to be used for planning purposes in the North Peoria ADMP. The procedures used to estimate sediment yield at Bailey Tank on Bailey Draw (a.k.a., unnamed wash #1), are described in the following paragraphs.

Drainage Area. The drainage area contributing water and sediment to Bailey Tank was digitized on USGS 7.5 minute digital raster graphics (DRG) maps. The total area was computed as 2.34 square miles (Figure 4-4).

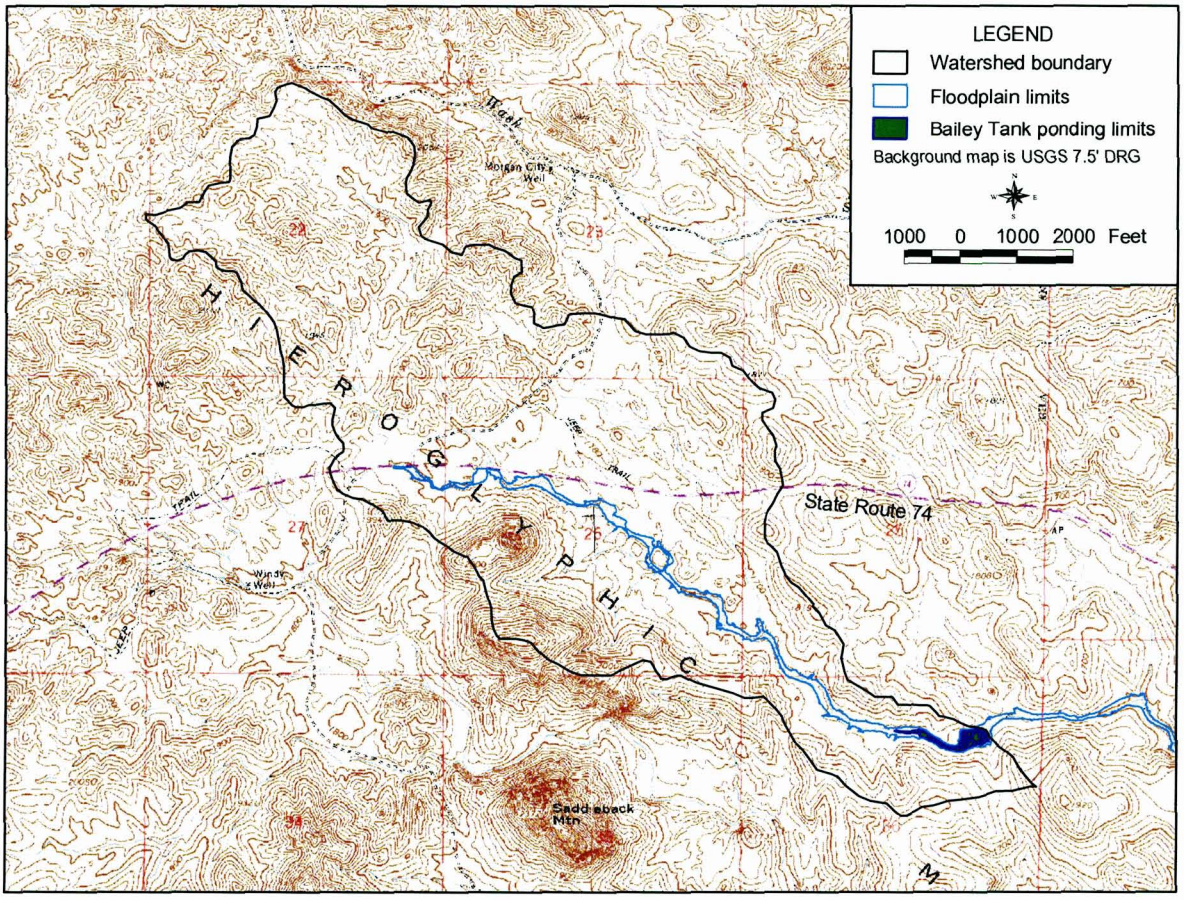


Figure 4-4. Bailey Tank watershed (unnamed wash #1). Light blue lines indicate the 100-year floodplain limits. Dark blue lines indicate the Bailey Tank ponding area. Watershed limits for the tank are shown in black.

Area of Deposition. The planimetric area of sediment deposition in the Bailey Tank ponding area was estimated from two-foot contour mapping, orthographic aerial photographs, and field observations (Figure 4-5). Polygons were digitized from the contour mapping and aerial photographs at each contour line upstream of the dam up to an elevation of 1640 feet, the elevation at which the original and current stream profiles intersect (i.e. the upstream limit of sediment deposition) as shown in Figure 4-6. The area of sediment deposition in square feet was computed using ArcView GIS 3.2 from the digitized polygons. The areas for each polygon are listed in Table 4-5.

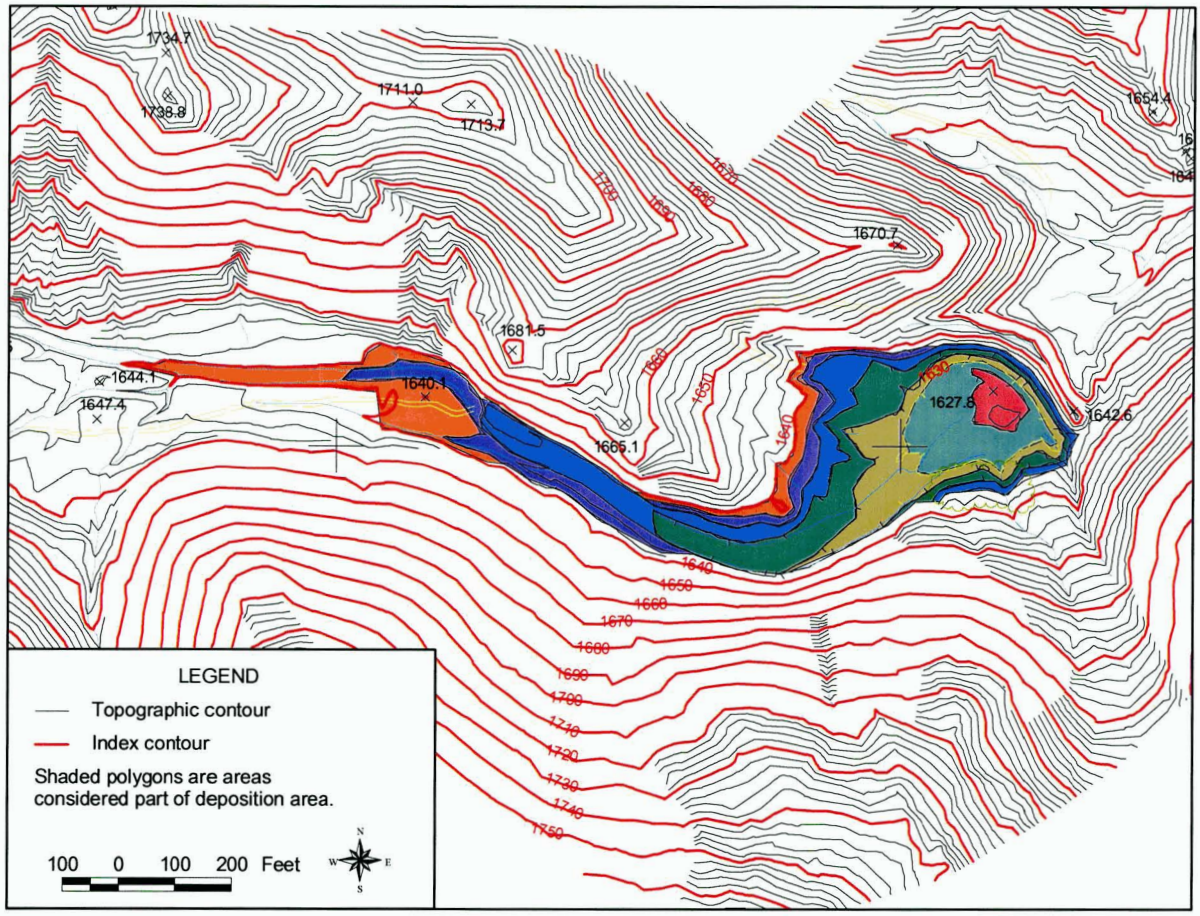


Figure 4-5. Areas of sediment deposition in the Bailey Tank ponding area.

Sediment Depths. A longitudinal profile was constructed from the two-foot contour mapping (Cooper Aerial, 2000) for unnamed wash #1 (Figure 4-6). The profile extended from about 2,900 feet upstream of Bailey Tank dam, through the impoundment area, to about 1,700 feet downstream of the dam. The post-deposition profile (existing stream bed elevation) shows a distinct decrease in slope of the wash entering the impoundment area of the tank. The native stream slope upstream from the area of lower slope was projected downstream past the dam to generate a pre-tank, pre-deposition channel slope. The area between the projected (pre-tank) slope and the existing bed slope shown on the two foot contour mapping represents the accumulated sediment behind the tank. Depths of sediment deposition were measured at contours as the distance between the current and original stream profiles. The estimated depths are listed in Table 4-5.

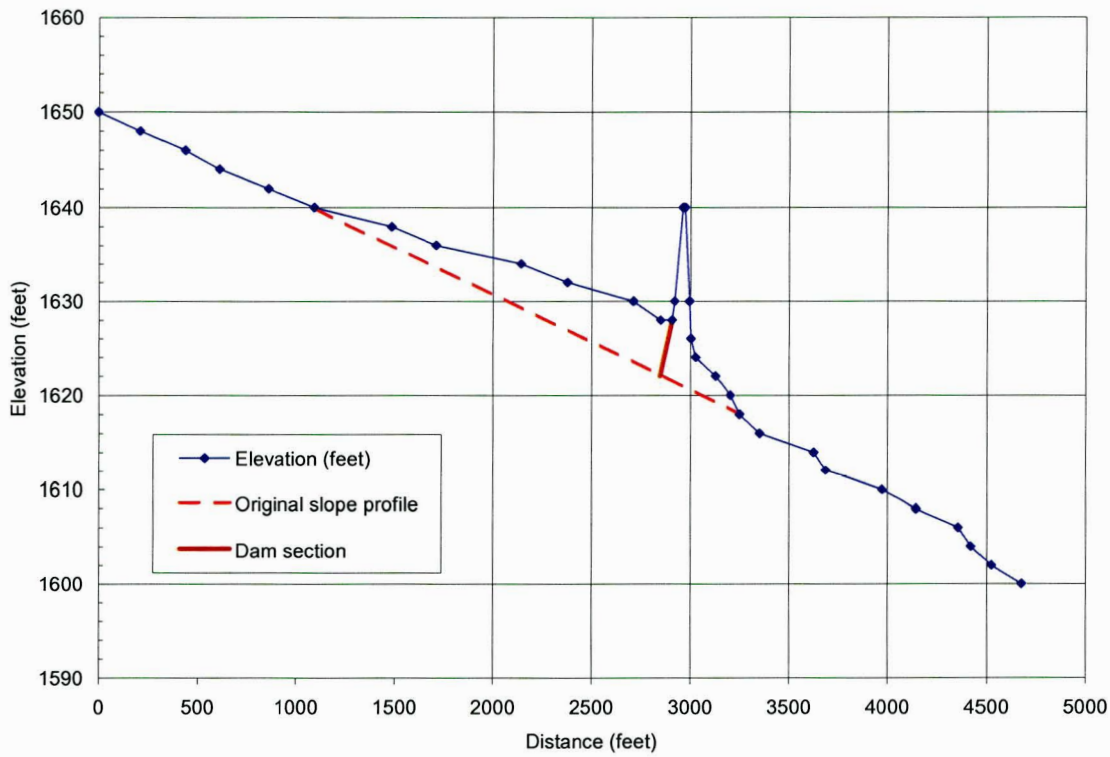


Figure 4-6. Channel profile through Bailey Tank on unnamed wash #1(Bailey Draw).

Deposited Sediment Volume. The volume of deposited sediment was computed as the product of the polygon areas and the average depth of sediment at the contour uphill and downhill limits of the polygon between contours. An assumption of this procedure is that the sediment depth at the stream centerline is the same across the polygon, which is likely a conservative estimate of sediment depth because the average sediment depth across the polygon is likely less than the depth along the stream centerline. The computed sediment volumes for the polygon areas were summed to arrive at a total sediment volume deposited behind Bailey Tank. The computed sediment volumes are listed in Table 4-5.

Figure 4-7. View upstream of Bailey Tank dam.

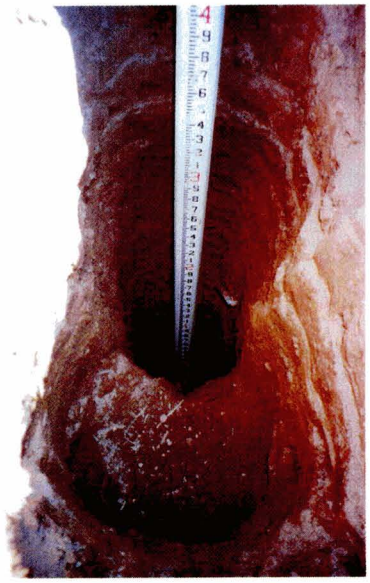


Figure 4-8. View of sediments deposited behind Bailey Tank and observation in soil pit excavated in the impoundment area.

Time. The time period for accumulation of the sediment deposited in Bailey Tank was estimated as between 1949 to 2000, or 51 years. Arizona Department of Water Resources (ADWR) and Arizona State Land Department (ASLD) indicate that Bailey Tank was completed on December 31, 1951. However, examination of historical aerial photographs indicates that the tank was substantially in place as early as February 1949. Therefore, 1949 was taken as the minimum start date for accumulation of sediment behind Bailey Tank.

Average Annual Sediment Yield. The average annual sediment yield for Bailey Draw at Bailey Tank for the period 1949 to 2000 is estimated as 0.18 ac-ft/mi^2/yr (Table 4-5). While the average depths computed in this analysis may be conservative, as described above, the sediment yield estimate is considered a minimum rate based on the following considerations:

- Overflow. Some floods overtop the dam, carrying a portion of the (suspended) sediment load downstream.
- Breach. It is possible that the dam has breached and been repaired in the past. During a breach some of the accumulated sediment, as well as the sediment delivered in the breaching event could be transported downstream.
- Dam Construction Practices. ASLD Drainage Engineering staff have reported that ranchers often build up the dam during its life by excavating material from the impoundment area and placing it on the dam embankment.

While the balance between the conservative estimate of sediment depth and the trapping efficiency is not known, the average annual sediment yield estimate at Bailey Tank is well within the lower range of sediment yield estimates made using analytical methods.

Table 4-5. North Peoria ADMP Sediment Yield Estimate at Bailey Tank				
POLYGON up to contour	**AREA (sq. ft.)**	**Depth (feet)**	**Sediment Volume (cubic feet)**	**Sediment Volume (ac-ft)**
1628	7295	6.2	45059	1.0
1630	29299	6.8	189580	4.4
1632	32153	5.3	193864	4.5
1634	44437	4.7	222186	5.1
1636	43237	2.6	158961	3.6
1638	32270	2.1	75928	1.7
1640	42696	0.0	43951	1.1
		Total	929531	21.3
Time: 1949-2000 (years)				51
Drainage Area (square miles):				2.34
Average Annual Sediment Yield (ac-ft/sq. mi../yr):				**0.18**

Results from the observed sediment yield at Bailey Tank can be compared to the results of the predictive equations for the corresponding sub-basins (S100-S104 in Table 4-4) to determine the accuracy of the predictive equations. The observed average annual sediment yield at Bailey Tank was 0.18 acre-feet/square mile/year. Comparison to predictive results for sub-basins S100 through S104 supports the following conclusions.

- Renard Equation. The Renard equation predicted about three times the measured sediment yield at Bailey Tank.
- Dendy-Bolton Equation. The Dendy-Bolton equation predicted about three times the measured sediment yield at Bailey Tank.
- Flaxman Equation (ratio-derived discharges). The Flaxman equation predicted about half the measured sediment yield at Bailey Tank.
- Flaxman Equation (HEC-1 discharges). The Flaxman equation using HEC-1 discharges predicted about the same sediment yield as was measured at Bailey Tank.
- MUSLE Method (ratio-derived discharges). The MUSLE method predicted about the same sediment yield as was measured at Bailey Tank.
- MUSLE Method (HEC-1 discharges). The MUSLE method using HEC-1 discharges predicted about twice the sediment yield as was measured at Bailey Tank.
- PSIAC Method. The PSIAC method predicted about the same sediment yield as was measured at Bailey Tank.

Given the range of sediment yield results, the measured minimum sediment yield estimate, and the planning objectives of the North Peoria ADMP, it is recommended that the average sediment yield be used for planning purposes, but that the extremes of the range of sediment yield estimates also be considered for design studies.

Future Conditions Sediment Yield Analysis

For the purposes of this study, future conditions were defined as full development of the watershed according to densities and land use types specified in the City of Peoria's and Maricopa County's current land use master plans. Major changes to the watersheds in the future condition involve the construction of residential and commercial buildings and their associated infrastructure. The increase in impermeable surface area in developed areas increases the total volume and peak flow rate of runoff and decreases the amount of sediment available for delivery to the stream system. Increased runoff rates tend to increase sediment yield due to increased erosive capability. Conversely, increased impermeable surface area in developed areas tends to reduce sediment yield due to decreased available sediment. Often, the combination of increased water supply and decreased sediment supply leads to increased rates of channel erosion.

The future conditions sediment yield analysis included two scenarios. The first scenario was a developed condition that included no retention, which represents the maximum level of watershed impact and maximum increase in sediment yield. The second scenario was a developed condition that included consideration of the effect of implementation of Maricopa County's retention requirement on future conditions discharges. The future condition without retention scenario is discussed this section of this memorandum. The effects of in-line and side-weir detention and retention alternatives on watershed sediment yield is discussed qualitatively in the following section of this memorandum as well as in the Alternatives Analysis Memorandum presented in Chapter 5 of *North Peoria Area Drainage Master Plan Technical Data Notebook Attachment 3 - Sedimentation Engineering and Geomorphic Evaluation Technical Memorandums*.

The future conditions sediment yield analysis used the same methods and the same types of watershed data described above for the existing conditions sediment yield analysis, with the following exceptions:

- Renard/Dendy-Bolton Methods. The Renard and Dendy-Bolton equations were not applied for future conditions, because they predict yield based on drainage basin area alone. There were no changes in drainage basin area for future conditions.
- Hydrology. Future conditions HEC-1 models were provided by Stantec, as described in Technical Data Notebook Attachment 2 – Hydrology & Hydraulics (Stantec, 2001). In general, peak discharges and runoff volumes increased for the future conditions, no retention models. Percent change in peak discharge and runoff volume due to future development for each subbasin is shown in Figures 4-9 and 4-10, respectively. Future conditions land use and estimated percent imperviousness are shown in Figure 4-11.
- Additional Variables. Certain watershed parameters, such as vegetative cover, land use, and impervious area were adjusted in the Flaxman, PSIAC, and MUSLE methods, as described below.

Flaxman (1974). The five variables used to determine sediment yield in the Flaxman (1974) equation include a precipitation-temperature ratio, the watershed slope, the percent of particles greater than 1 mm, an aggregation index, and the 50% chance (Q2) peak discharge. For the future conditions analysis, the 50% chance peak discharge is the only variable used in the

Figure 4-9. Percent Changes in Peak Discharges - Existing vs. Future Conditions Without Retention

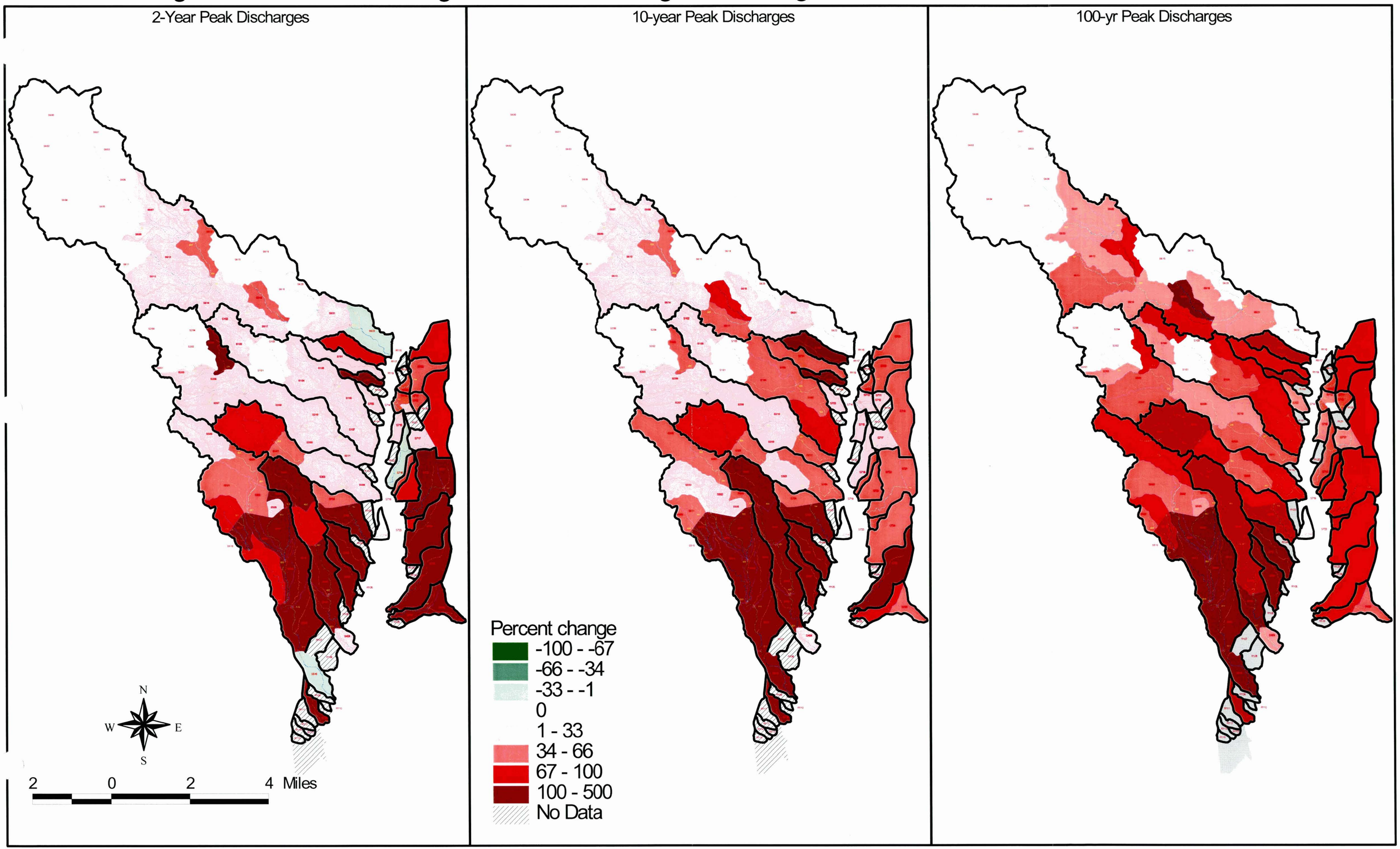


Figure 4-10. Percent Changes in Runoff Volume - Existing vs. Future Conditions Without Retention

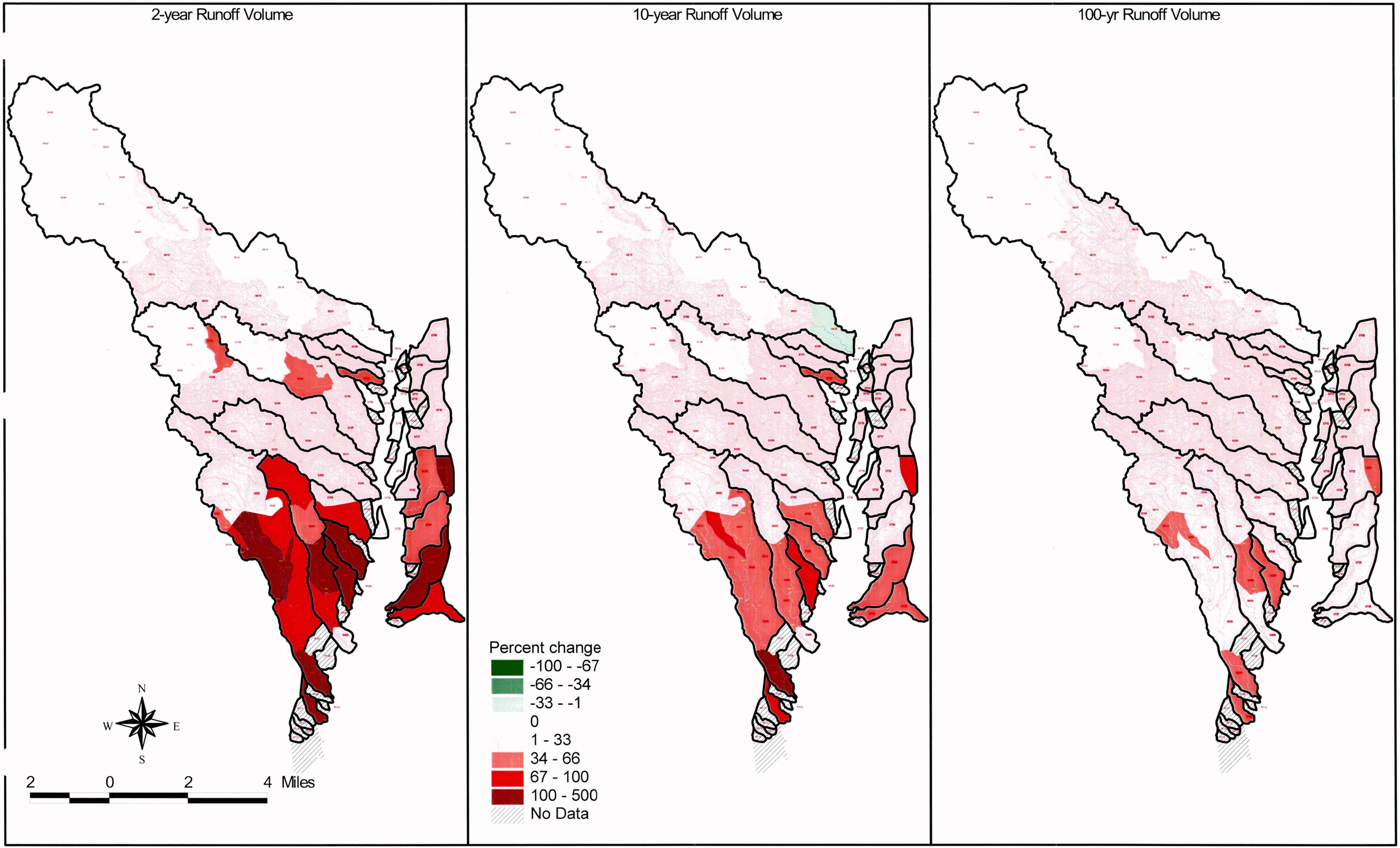
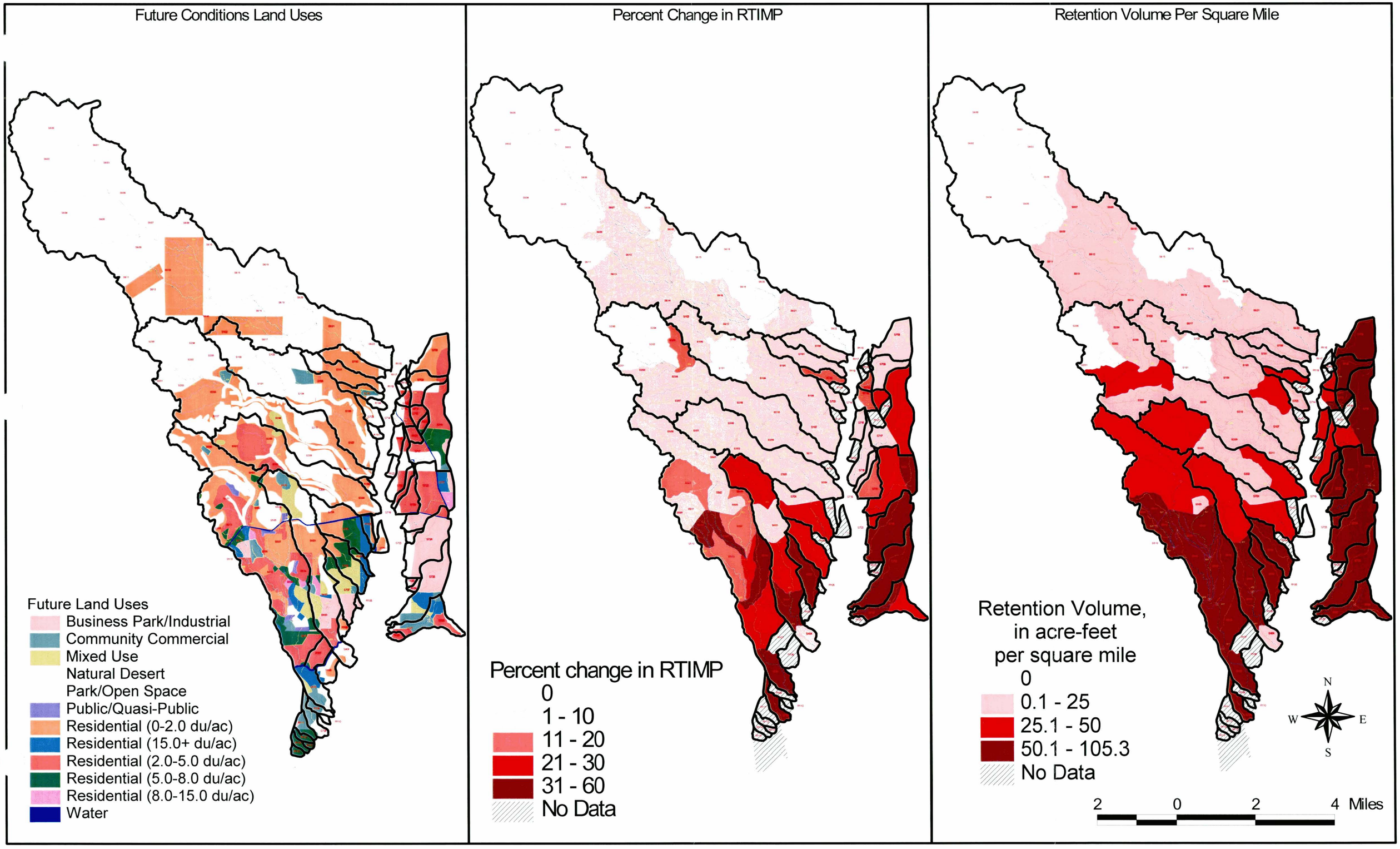


Figure 4-11. Future Development, Changes in Effective Impervious Area (RTIMP), and Retention Volumes



Flaxman equation to have changed. The 2-year discharge values increased due to development in the sub-basins. Discharge values derived from both the HEC-1 model and the Region 12 equation ratios were used to complete the Flaxman calculations. Consistent with the existing conditions, the HEC-1 discharge values were higher than the Region 12 ratio-derived discharges.

The values inserted in the Flaxman equation for particles greater than 1 mm and the aggregation index are generated from soil characteristics reported in the soil survey. While it is known that the area of soil exposed to erosion will ultimately decrease with development, the inherent nature of the soil does not. Thus, the soil-related values did not change. This insensitivity to land use is a disadvantage for applying the Flaxman equation when attempting to compare present and future scenarios, especially those involving development.

The Flaxman equation, using the ratio-derived 2-year peak discharges, predicted future condition average annual sediment yields ranging from 0.06 to 0.37 AF/mi^2/yr, with an average 0.14 AF/mi^2/yr and a standard deviation of 0.06 AF/mi^2/yr. Using the HEC-1 discharges, the 1974 Flaxman equation predicts future condition average annual sediment yield ranging from 0.17 to 1.04 AF/mi^2/yr, with an average of 0.39 AF/mi^2/yr and a standard deviation of 0.19 AF/mi^2/yr.

PSIAC. Of the nine factors used in the PSIAC method discussed in the existing conditions analysis summary, the following two factors were considered to have changed for the future conditions analysis: (1) runoff, and (2) effective ground cover. Changes in the estimated PSIAC runoff and effective ground cover factors have opposite effects on sediment yield. The runoff factor is a qualitative assessment of the volume and peaks associated with runoff events. The future HEC-1 model indicates that flood peaks and volumes will increase in future watershed conditions. The increase in discharge requires an increase in the value assigned to the runoff factor. Adjustments to the PSIAC runoff factor were made using the percentage increase in the 100-year peak discharges computed by the HEC-1 models.

Effective ground cover approximates the amount of impermeable surface. Impermeable surfaces cannot contribute sediment to the sediment yield, which results in a decrease in the predicted sediment supply. The amount of surface area developed in the individual sub-basins ranges between 0 and 100 percent. The average amount of development in the sub-basins, excluding those where no development is proposed, is about 60 percent. Adjustments to the effective ground cover factor were based on the percent of developed area in each sub-basin.

The PSIAC method predicts future conditions average annual sediment yield ranging from 0.11 to 0.17 AF/mi^2/yr, with an average of 0.15 AF/mi^2/yr and a standard deviation of 0.02 AF/mi^2/yr. The PSIAC results indicate that changes from the existing condition were negligible and predominantly in the negative direction. Therefore, according to the PSIAC results, the reduction in sediment yield created by increased impervious surface cover outweighed the effects of the increase in discharge.

MUSLE. Future condition sediment yield based on the MUSLE method differed from the existing conditions sediment yield analysis due to changes in two of the five MUSLE factors. Development of the basin will cause both the hydrology (R_w factor) and land use (C factor) to change.

RW Factor. The R_w factor changed based on the future condition HEC-1 modeling. Peak discharge and runoff volume increased in sub-basins affected by development for every return period modeled by Stantec. Event discharges calculated by the application of the ratios derived from the Region 12 equation to the 100-year discharge also increased, but not to the degree indicated by the HEC-1 model. As described above, increased runoff results in increased sediment yield.

Cover Factor. Increases in effective ground cover are expected to decrease the sediment yield. The MUSLE method models in ground cover by adjusting the cover factors. The cover factors for the future conditions in North Peoria study area were modified from the existing conditions based on the land use parameters established in the Stantec HEC–1 model. For desert areas, it was estimated that 80% of the vegetation cover was in the form of canopy and 20% in the form of mulch based on field observations, as described for the existing conditions sediment yield analysis. It was estimated that residential areas would have slightly higher proportions of mulch due to the increased probability of grass and rock lawns. Thus 66.7% and 33.3% percent of the vegetation cover was assigned to canopy and mulch, respectively, in proposed residential areas. For industrial, commercial, and park areas it was estimated that mulch would be more prominent than canopy cover. Thus 33.3% and 66.7% percent of the vegetation cover was assigned to canopy and mulch, respectively. For the root factor it was assumed that rooting percentages would equal vegetation cover percentages. Figures B.2., B.3., and B.4. in Appendix B of the *Design Manual for Engineering Analysis of Fluvial Systems* (ADWR, 1985) were used to assign factor values. The results are presented in Table 4-6.

Table 4-6. North Peoria ADMP
MUSLE Cover Factors - Future Conditions

Land Use	% Veg. Cover	% Canopy	Canopy Factor C_I	% Mulch	Mulch Factor C_{II}	% Rooting	Root Factor C_{III}	C Factor
Sonoran Desert	25	20	0.85	5	0.90	25	0.42	0.32
Open	25	20	0.85	5	0.90	25	0.42	0.32
Very Low Density Residential	30	20	0.85	10	0.76	30	0.40	0.26
Low Density Residential	50	33	0.78	17	0.63	50	0.37	0.18
Medium Density Residential	50	33	0.78	17	0.63	50	0.20	0.10
Multi-Family Residential	50	33	0.78	17	0.63	50	0.20	0.10
Industrial	60	20	0.85	40	0.39	60	0.17	0.06
Commercial	75	25	0.82	30	0.31	75	0.12	0.03
Park	90	30	0.78	60	0.25	90	0.10	0.02

Stantec provided land use divisions for each sub-basin used in the HEC-1 model. The divisions were presented as percentages of the total sub-basin area. These percentages were used to develop a weighted average C factor for future conditions.

Results. Future conditions MUSLE sediment yield results calculated using the Region 12 ratio discharges generally decreased slightly from existing conditions. These results are due to the effective ground cover increasing such that the slight increases in discharge were unable to increase sediment yields. The MUSLE method predicted future condition average annual sediment yields ranging from 0.07 to 1.29 AF/mi^2/yr, with an average of 0.25 AF/mi^2/yr and a standard deviation of 0.19 AF/mi^2/yr.

In contrast, the sediment yield results using the event discharges from the HEC-1 models show an increase from existing conditions, primarily due to the higher computed runoff rates. The MUSLE method based on the HEC-1 discharges predicts average annual sediment yields ranging from 0.18 to 2.43 AF/mi^2/yr, with an average of 0.64 AF/mi^2/yr and a standard deviation of 0.40 AF/mi^2/yr.

Results. The results of the five future conditions sediment yield methods for each sub-basin and concentration point are presented in Table 4-7. In general, the sediment yield methods applied for this analysis indicate that the average changes to sediment yield for the entire watershed will be minimal if the watershed develops as currently proposed. Note that in the more intensely developed watersheds, such as a C508 (Twin Buttes Wash; compare Table 4-4 and 4-7), the average annual sediment yield is predicted to more than double due to development. Implications of the existing and future conditions sediment yield analyses on flood control are discussed in the following section of this memorandum.

Table 4-7. Existing Conditions Sediment Yield - North Peoria ADMP, No Retention

	Sub-basin ID	Flaxman (1974) --ratio-- (ac-ft/mi²/yr)	Flaxman (1974) --model-- (ac-ft/mi²/yr)	MUSLE --ratio-- (ac-ft/mi²/yr)	MUSLE --model-- (ac-ft/mi²/yr)	PSIAC (ac-ft/mi²/yr)	Average* (ac-ft/mi²/yr)
Unnamed Wash #1	S100	0.086	0.207	0.18	0.44	0.15	0.21
	S101	0.164	0.329	0.41	0.89	0.15	0.39
	S102	0.094	0.258	0.15	0.37	0.15	0.20
	S103	0.074	0.173	0.14	0.31	0.14	0.17
	C102	0.087	0.166	0.17	0.43	0.15	0.20
	S104	0.094	0.238	0.15	0.37	0.14	0.20
	S105	0.082	0.187	0.11	0.27	0.14	0.16
	C103	0.079	0.142	0.13	0.33	0.15	0.17
	S106	0.117	0.234	0.14	0.30	0.14	0.19
	C104	0.079	0.136	0.12	0.30	0.15	0.16
	S107	0.118	0.184	0.09	0.18	0.15	0.15
	C105L	0.082	0.128	0.11	0.25	0.15	0.14
	Average for sub-basins:	0.104	0.226	0.17	0.39	0.15	0.21
Unnamed Wash #2	S200	0.145	0.360	0.25	0.66	0.16	0.32
	S201	0.148	0.378	0.26	0.62	0.16	0.31
	C201	0.133	0.323	0.22	0.61	0.16	0.29
	S202	0.146	0.378	0.24	0.47	0.15	0.28
	S203	0.092	0.226	0.14	0.34	0.14	0.19
	S204	0.099	0.236	0.17	0.45	0.15	0.22
	C203	0.101	0.226	0.16	0.45	0.16	0.22
	S205	0.111	0.358	0.25	0.66	0.15	0.31
	C204	0.097	0.217	0.17	0.47	0.16	0.22
	S206	0.088	0.210	0.16	0.41	0.14	0.20
	S207	0.104	0.258	0.16	0.46	0.15	0.23
	C205	0.092	0.198	0.17	0.44	0.15	0.21
	S208	0.153	0.379	0.25	0.71	0.16	0.33
	C206	0.098	0.204	0.18	0.46	0.15	0.22
	S209	0.196	0.394	0.47	1.06	0.16	0.46
	S210	0.149	0.278	0.15	0.30	0.14	0.20
	C207	0.101	0.196	0.17	0.44	0.15	0.21
	S211	0.191	0.356	0.26	0.54	0.16	0.30
	C105R	0.103	0.193	0.17	0.42	0.15	0.21
	Average for sub-basins:	0.135	0.318	0.23	0.56	0.15	0.28
Unnamed Wash #1 & #2	**C105**	0.093	0.158	0.15	0.33	0.15	0.18
	Average for sub-basins:	0.120	0.272	0.20	0.47	0.15	0.24
Unnamed Wash #3	S300	0.116	0.357	0.22	0.61	0.14	0.29
	S301	0.090	0.345	0.12	0.38	0.15	0.22
	C300	0.089	0.295	0.14	0.43	0.14	0.22
	S302	0.134	0.394	0.31	0.80	0.15	0.36
	C301	0.089	0.268	0.15	0.47	0.15	0.23
	S303	0.213	0.369	0.55	1.14	0.15	0.48
	C302	0.105	0.256	0.20	0.59	0.15	0.26
	S304	0.118	0.194	0.15	0.31	0.15	0.18
	C303	0.101	0.216	0.17	0.47	0.15	0.22
	Average for sub-basins:	0.134	0.332	0.27	0.65	0.15	0.31
Caterpillar Wash	S400	0.107	0.412	0.25	0.80	0.14	0.34
	S401	0.133	0.336	0.44	1.05	0.13	0.42
	C401	0.086	0.256	0.19	0.62	0.13	0.26
	S402	0.148	0.591	0.31	0.96	0.13	0.43
	C402	0.090	0.207	0.19	0.56	0.13	0.23
	S403	0.109	0.624	0.13	0.45	0.12	0.29
	C403	0.084	0.191	0.15	0.49	0.13	0.21
	S404	0.160	0.516	0.60	1.33	0.14	0.55
	C404	0.084	0.187	0.16	0.51	0.13	0.21
	Average for sub-basins:	0.131	0.496	0.35	0.92	0.13	0.41

Table 4-7. Existing Conditions Sediment Yield - North Peoria ADMP, No Retention

	Sub-basin ID	Flaxman (1974) --ratio-- (ac-ft/mi^2/yr)	Flaxman (1974) --model-- (ac-ft/mi^2/yr)	MUSLE --ratio-- (ac-ft/mi^2/yr)	MUSLE --model-- (ac-ft/mi^2/yr)	PSIAC (ac-ft/mi^2/yr)	Average* (ac-ft/mi^2/yr)
Twin Buttes Wash	S500	0.093	0.239	0.13	0.38	0.15	0.20
	S501	0.101	0.283	0.15	0.37	0.14	0.21
	C501	0.084	0.205	0.12	0.33	0.15	0.18
	S502	0.199	0.493	0.69	1.58	0.14	0.62
	S503	0.089	0.245	0.15	0.41	0.13	0.21
	C502I	0.086	0.189	0.15	0.41	0.16	0.20
	S504	0.058	0.189	0.07	0.18	0.12	0.12
	S505	0.283	0.775	1.29	2.43	0.14	0.98
	S506	0.245	0.818	0.76	1.66	0.15	0.73
	S507	0.075	0.248	0.17	0.44	0.11	0.21
	C505	0.072	0.158	0.14	0.42	0.14	0.18
	S509	0.153	0.676	0.38	0.93	0.13	0.45
	S510	0.088	0.442	0.26	0.65	0.11	0.31
	S511	0.131	0.526	0.09	0.25	0.12	0.22
	S512	0.101	0.550	0.27	0.76	0.11	0.36
	C508	0.067	0.318	0.12	0.47	0.12	0.22
	S513	0.070	0.202	0.08	0.19	0.12	0.13
	S508	0.219	0.765	0.16	0.41	0.13	0.34
	C509	0.068	0.133	0.12	0.34	0.13	0.16
	S514	0.134	0.621	0.20	0.66	0.13	0.35
	C510	0.069	0.131	0.12	0.34	0.13	0.16
	S515	0.087	0.515	0.12	0.44	0.12	0.26
	C511	0.066	0.127	0.11	0.32	0.13	0.15
	S516	0.119	0.507	0.14	0.46	0.13	0.27
	C512	0.066	0.131	0.10	0.32	0.13	0.15
	Average for sub-basins:	0.132	0.476	0.30	0.72	0.13	0.35
Morgan City Wash	S600	0.354	0.588	0.22	0.49	0.17	0.36
	S601	0.374	1.040	0.31	0.93	0.16	0.56
	C601	0.338	0.618	0.24	0.56	0.17	0.39
	S602	0.129	0.291	0.19	0.54	0.16	0.26
	S603	0.273	0.921	0.49	1.44	0.17	0.66
	C602	0.217	0.413	0.24	0.57	0.17	0.32
	S604	0.136	0.303	0.19	0.55	0.17	0.27
	S605	0.092	0.223	0.14	0.39	0.15	0.20
	S606	0.152	0.360	0.29	0.74	0.16	0.34
	C603	0.162	0.309	0.21	0.50	0.16	0.27
	S607	0.070	0.179	0.11	0.30	0.14	0.16
	S609	0.112	0.219	0.16	0.37	0.15	0.20
	C604	0.147	0.271	0.19	0.44	0.16	0.24
	S608	0.116	0.409	0.23	0.62	0.15	0.30
	C605	0.142	0.262	0.18	0.43	0.16	0.24
	S610	0.146	0.422	0.26	0.72	0.16	0.34
	S612	0.128	0.339	0.20	0.58	0.15	0.28
	C606	0.136	0.249	0.18	0.42	0.16	0.23
	S611	0.161	0.444	0.23	0.62	0.16	0.32
	S613	0.115	0.296	0.16	0.49	0.15	0.24
	C608	0.130	0.241	0.18	0.42	0.16	0.23
	S614	0.116	0.288	0.18	0.50	0.16	0.25
	C609	0.128	0.235	0.17	0.41	0.16	0.22
	S615	0.162	0.512	0.30	1.01	0.17	0.43
	S616	0.129	0.305	0.22	0.53	0.16	0.27
	S617	0.118	0.305	0.24	0.61	0.15	0.28
	C611	0.124	0.225	0.17	0.41	0.16	0.22
	S618	0.197	0.400	0.12	0.40	0.16	0.26
	S619	0.176	0.536	0.50	1.49	0.16	0.57
	S620	0.216	0.554	0.39	1.05	0.15	0.47
	C613	0.126	0.225	0.17	0.41	0.16	0.22
	S621	0.151	0.244	0.16	0.31	0.13	0.20
	C614	0.125	0.218	0.16	0.38	0.16	0.21
	S622	0.120	0.210	0.12	0.24	0.13	0.16
	C615	0.124	0.211	0.16	0.36	0.16	0.20
	Average for sub-basins:	0.163	0.408	0.24	0.65	0.16	0.32
	Sub-basin Average	0.140	0.389	0.25	0.64	0.15	0.31
	Sub-basin Maximum	0.374	1.040	1.29	2.43	0.17	0.98
	Sub-basin Minimum	0.058	0.173	0.07	0.18	0.11	0.12
	Standard Deviation	0.061	0.185	0.19	0.40	0.02	0.15

Application of Sediment Yield Results for Flood Control Planning

The results of the sediment yield analyses provide important information for flood control planning. Changes in sediment yield due to development have been linked to increased channel instability, failure of flood control structures, damage to roadway drainage crossings, and increased channel and structure maintenance costs. Estimates of sediment yield are also important for determining maintenance schedules and storage requirements for flood control basins. The sediment yield results were applied to the North Peoria ADMP study area in the following ways:

- Comparison of Existing vs. Future Condition Sediment Yield
- Impact of 100-Year 2-Hour Retention on Sediment Yield
- Impact of In-Line Detention on Sediment Yield
- Impact of Side Weir Detention on Sediment Yield
- Sediment Yield Impacts at the CAP and Beardsley Canals

Existing vs. Future Condition Sediment Yield. The sediment yield results summarized in Tables 4-4 and 4-7 indicate that the methodologies used predict a slight overall increase in the sediment yield generated from the North Peoria study area when the area develops. The future increase in sediment yield is due mainly to the increased runoff generated by developed portions of the sub-basin. In most cases the degree of development is not sufficient to significantly reduce the amount of sediment removed from the land surface. The average annual sediment yield changes for all of the subbasins in each of the major watersheds in the study area are presented in Table 4-8.

Table 4-8. North Peoria ADMP
Existing vs. Future Condition Sediment Yield for Significant Watercourses
Average of Individual Subbasins

Wash	Existing (ac-ft/mi2/yr)	Future (ac-ft/mi2/yr)	Percent Change
Unnamed Wash #1	0.20	0.21	+ 5.0
Unnamed Wash #2	0.27	0.28	+ 3.7
Unnamed Wash #3	0.28	0.31	+ 10.7
Caterpillar Tank Wash	0.32	0.41	+ 28.1
Twin Buttes Wash	0.32	0.35	+ 9.4
Morgan City Wash	0.31	0.32	+ 3.2

Changes between the existing and future conditions average annual sediment yield at the mouths of the major washes is presented in Table 4-9. The sediment yield values at the mouths of the washes are lower than the averages of the individual subbasins within the watershed due to the cumulative effects of basin storage. In general, the future condition average annual sediment yield increases at the Agua Fria confluences, except for unnamed wash #2 and Morgan City Wash.

Table 4-9. North Peoria ADMP Existing vs. Future Condition Sediment Yield Significant Watercourses at Agua Fria River Confluence			
Wash	**Existing (ac-ft/mi2/yr)**	**Future (ac-ft/mi2/yr)**	**Percent Change**
Unnamed Wash #1	0.13	0.14	+ 7.7
Unnamed Wash #2	0.21	0.21	0
Unnamed Wash #1 & #2	0.17	0.18	+ 5.9
Unnamed Wash #3	0.20	0.22	+ 10.0
Caterpillar Tank Wash	0.18	0.21	+ 16.7
Twin Buttes Wash	0.14	0.15	+ 7.1
Morgan City Wash	0.21	0.20	- 4.8

The potential impacts of increased sediment yield in the future for the North Peoria study area include the following:

- Decreased storage capacity in flood control basins. Sediment storage should be computed using the future condition sediment yield values.
- Aggradation in stream channels. Excess sediment from upland areas will tend to deposit in stream channels, resulting in slight aggradation of fine-grained sediment during periods between large floods. Field evidence suggests that the streams are sediment supply-limited. Therefore, floods which exceed bankfull will tend to remove fine-grained sediments and transport the material to the Agua Fria River.

Note that the future conditions summarized above do not consider the potential effects of future condition storm water retention, or direct impacts on channel morphology by future development and infrastructure.

Impact of 100-Year 2-Hour Retention on Sediment Yield. Maricopa County and the City of Peoria currently require that new development provide on-site retention of the 100-year 2-hour storm volume. On-site storage of this volume significantly alters the natural runoff pattern of the watershed in several ways. First, the percent of rainfall that becomes runoff generally increases due to the extent of impervious area in developed watersheds. For the areas that do not drain to retention basins, there is a increase in the frequency and volume of water supplied to the stream system. That is, due to the increased impervious cover, rainfall which would have infiltrated or been intercepted on a natural surface becomes runoff. Second, small rainfall-runoff events which previously would have delivered water and sediment to the neighboring stream systems are captured by the retention basins, thus reducing the sediment (and water) yield to downstream channels. Third, for larger rainfall events which exceed the retention volume, much of the bedload supply, as well as a significant portion of the suspended load, is trapped in the retention basins, particularly if they are in-line facilities (see discussion of in-line facilities below). Because of the changes in hydrology and sediment supply due to retention, the sediment yield is likely to decrease in watersheds where retention requirements are enforced. Figures 4-12 and 4-13 show the estimated future condition changes in peak discharge and volume for watersheds in the study area if the retention standards are enforced.

Figure 4-12. Percent Changes in Peak Discharges - Future With 100-yr 2-hr Retention

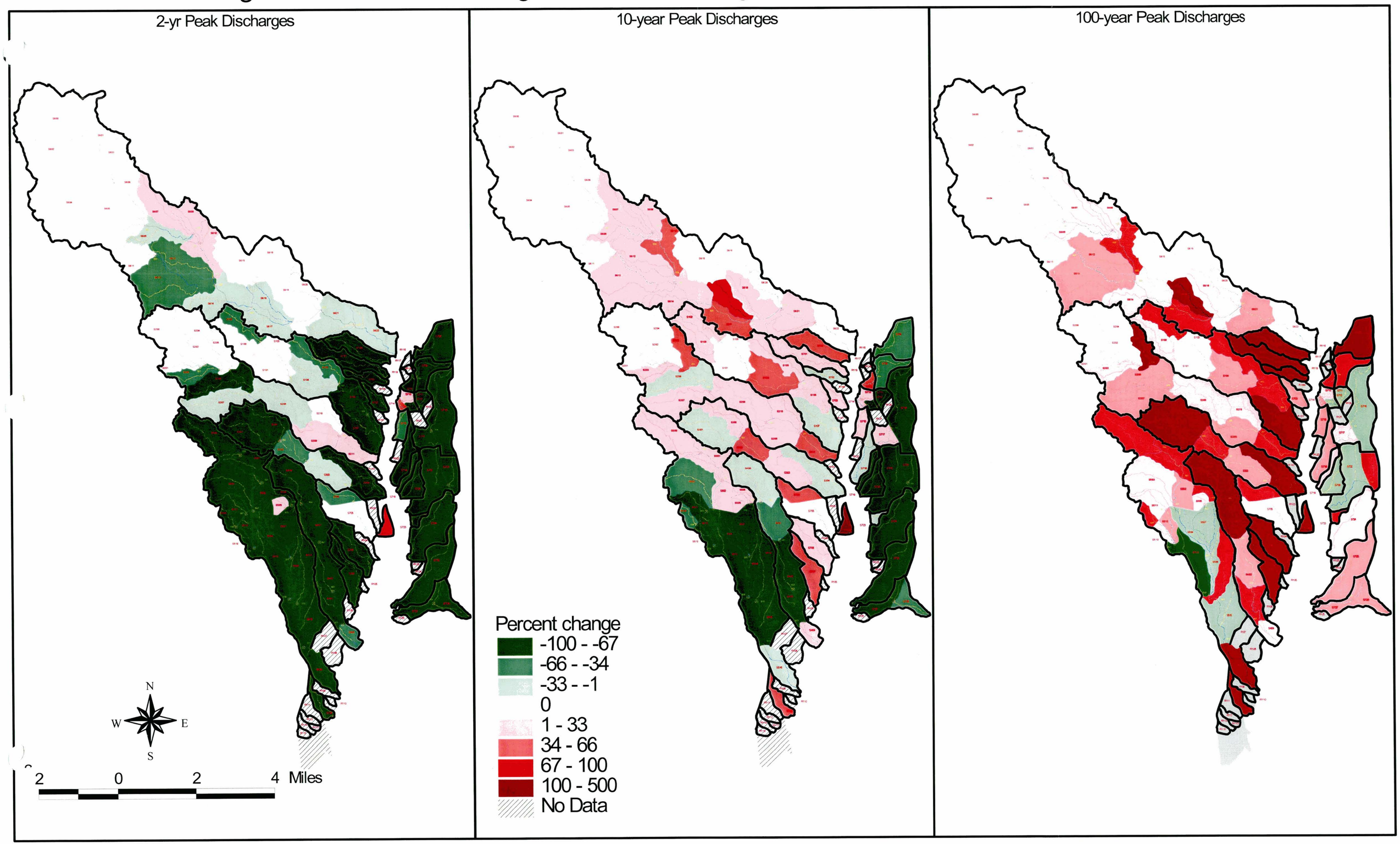
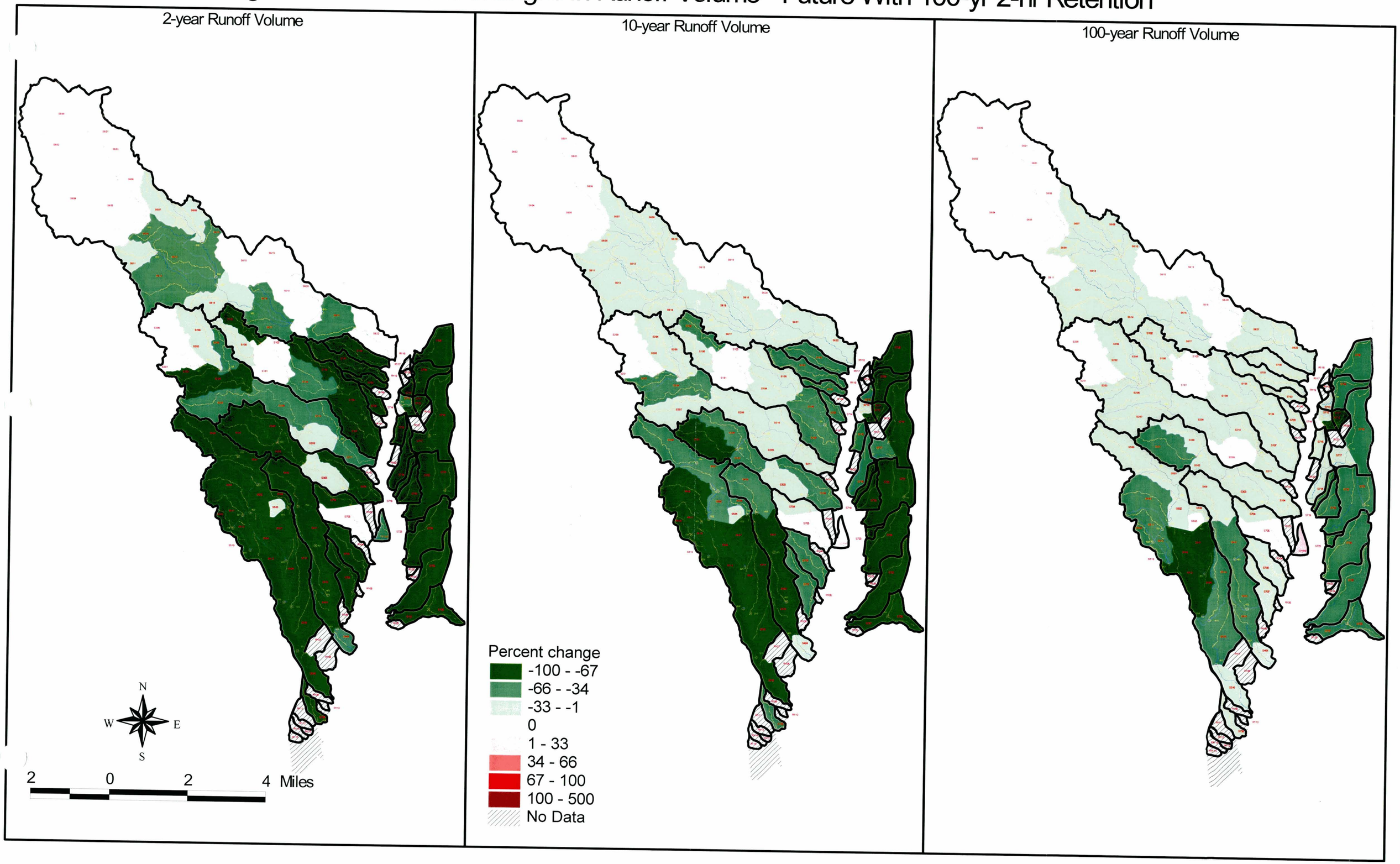


Figure 4-13. Percent Changes in Runoff Volume - Future With 100-yr 2-hr Retention



In general, the data summarized in Figures 4-12 and 4-13 indicate that water (and thus, sediment) supply will decrease if retention requirements are enforced in the study area. The greatest decreases will occur in the areas with the most dense development. Changes in estimated future condition average annual sediment yield and sediment yield during the 2- and 100-year events for various retention scenarios applied to each subbasin in the study area are shown in Figures 4-14 to 4-16.

Impacts of In-Line Detention on Sediment Yield. Several storm water detention alternatives have been proposed to offset projected increases in runoff due to future development. In-line detention is defined as construction of a flood control basin directly on the main channel of a watercourse. In-line detention designed to impede or retain the natural flow of flood water will also cause the sediment transported by the water to be deposited in the detention basin.

The MUSLE method was used to examine the impacts of in-line detention. Evaluation of the sediment deposited in Bailey Tank indicated that about 67% of the sediment is suspended load and 33% is bedload. From these values estimates of suspended sediment concentration for the various magnitude events were determined by dividing the volume of sediment, less the bedload percentage, into the volume of water. The volume of retention for each sub-basin was compared to the volume of each event (including the 2-, 5-, 10-, 25-, 50-, and 100-year events). In events where the retention volume exceeded the runoff volume, 100 percent of the sediment was considered trapped. When the runoff volume exceeded the retention volume, the excess runoff volume was assumed to have the sediment concentration implied by the Bailey Tank sediment deposits. For runoff that passed the detention basin, it was assumed that at least 33% of the total sediment yield (100% of the bedload) would be trapped in the detention basin due to the decrease in velocity, and that 90% of the suspended sediment would be trapped behind the detention structure using an assumed trapping efficiency of 90%.

The total sediment retained in each developed subbasin was then compared to the existing condition sediment yield estimate to determine the percent change. Percent changes from the existing conditions to future conditions with inline detention are presented in Figures 4-14 to 4-16. The data shown in Figures 4-14 to 4-16 indicate that significant decreases in sediment yield will occur if the in-line detention alternative is implemented. The impacts of such decreases in sediment yield on flood control and downstream channel stability include the following:

- Long-Term Channel Degradation. Decreased sediment supply with no decrease or an increase in water supply will result in scour and/or armoring of downstream stream reaches.
- Bank Erosion and Lateral Channel Movement. Bank erosion will increase downstream of in-line detention basins due to long-term degradation and clear water scour of the channel banks.
- Excess Sediment Storage in Basins. Because about 90% of the upstream sediment yield will be deposited in the in-line basins, frequent maintenance will be required to assure that the intended flood storage volumes are preserved.

In general, the sediment yield analyses indicate that in-line detention will decrease channel stability and lead to increased costs for bank protection, grade control and channel maintenance.

Figure 4-15. Percent Changes in 2-Year Sediment Yield

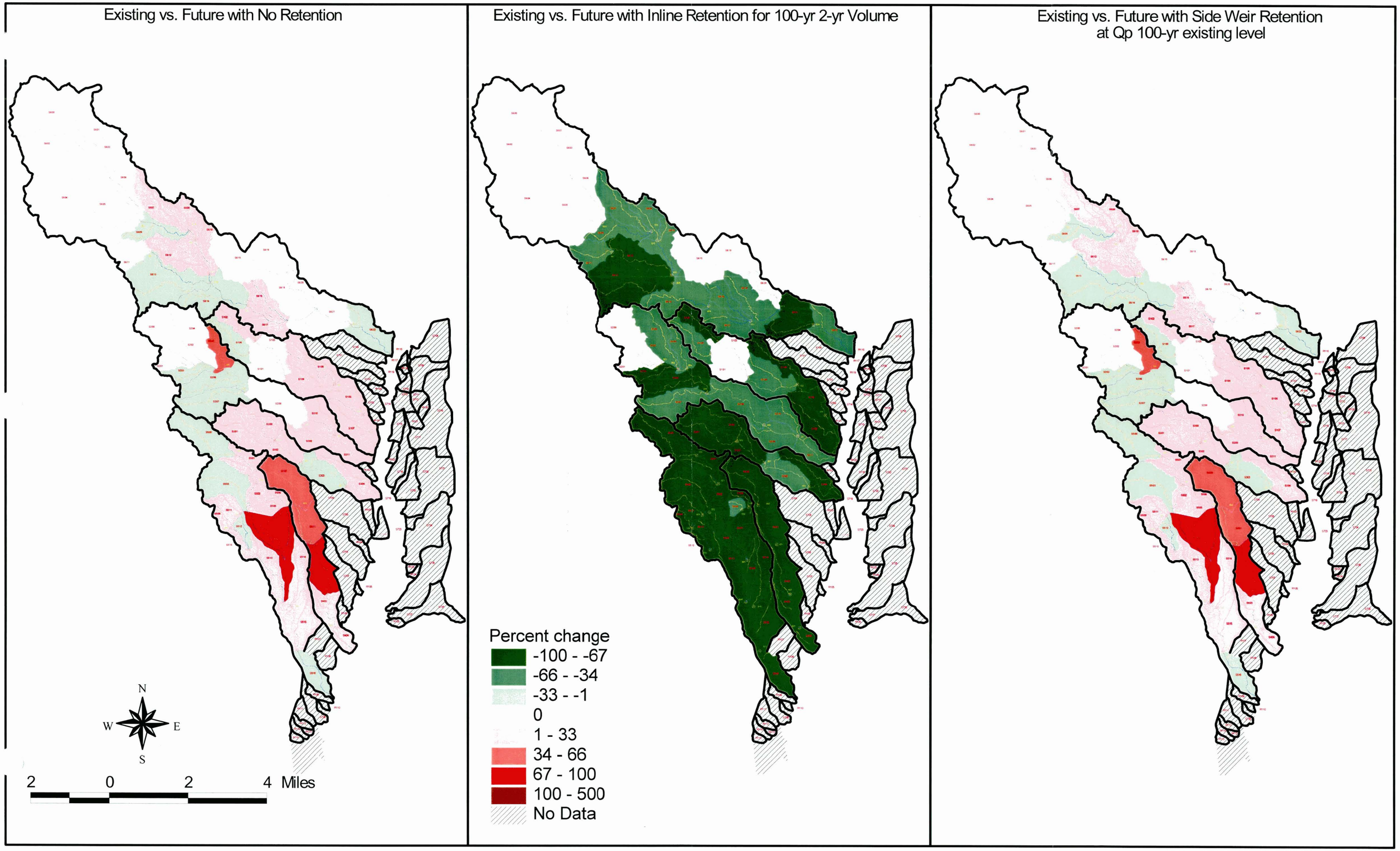


Figure 4-16. Percent Changes in 100-Year Sediment Yield

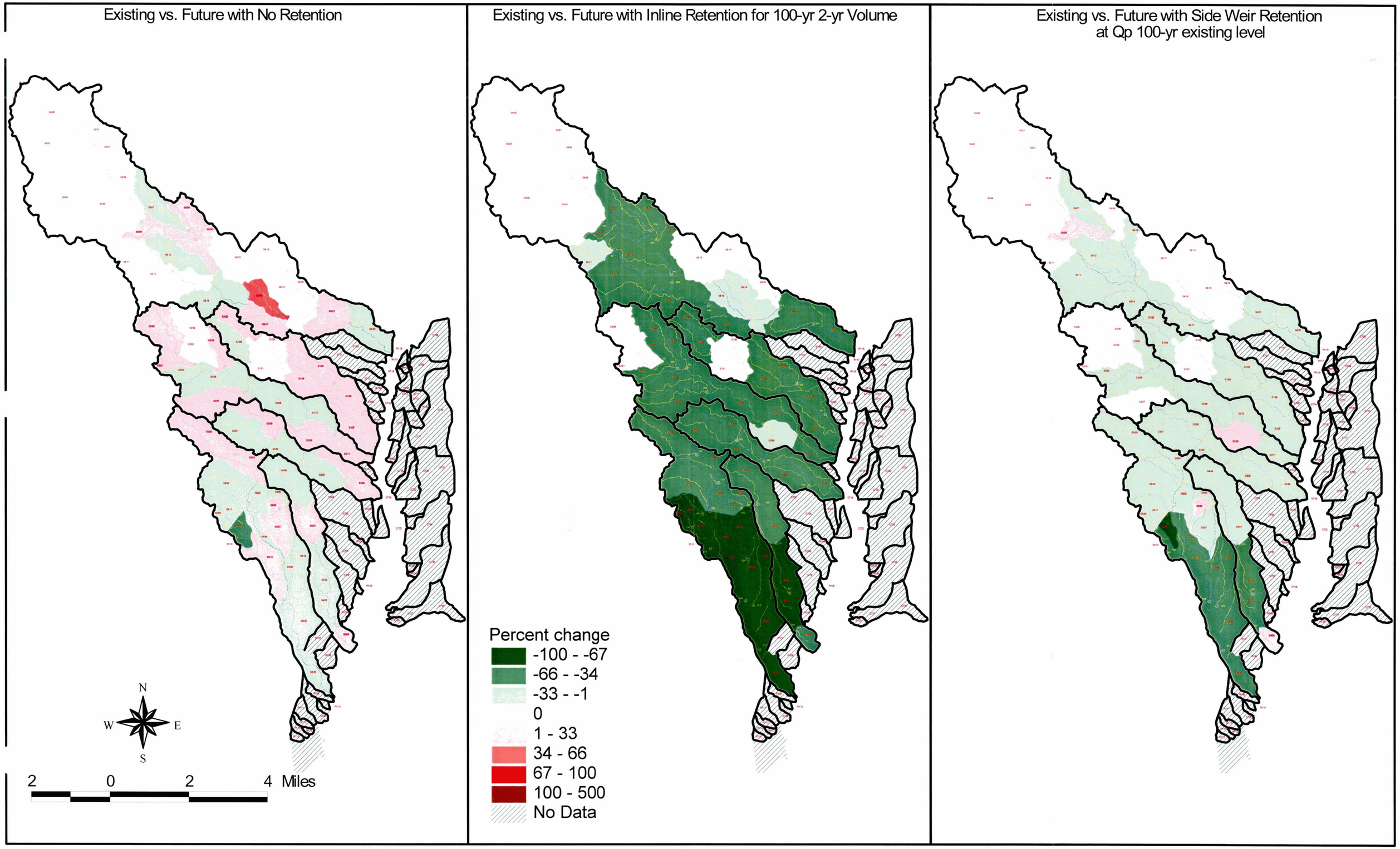
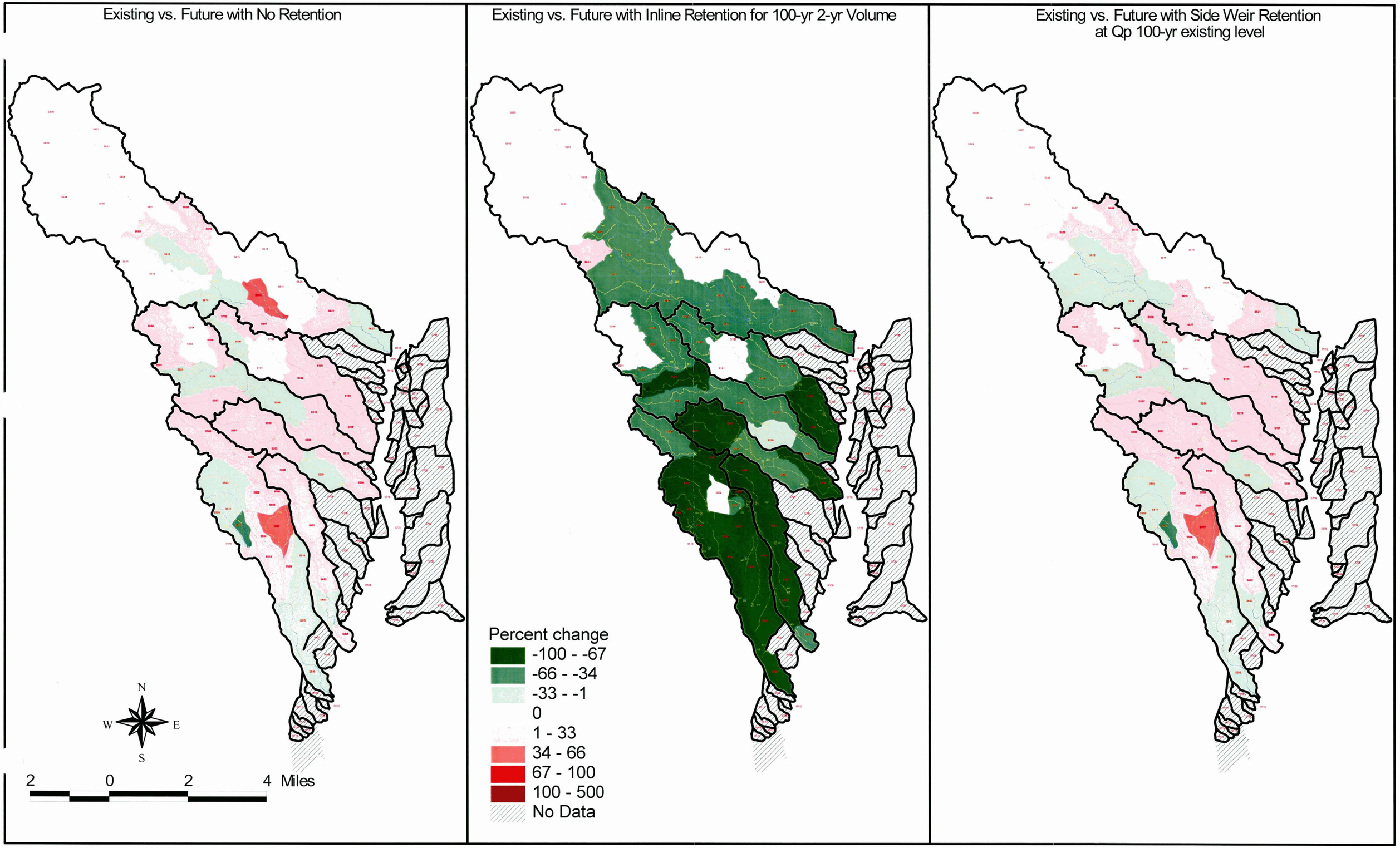


Figure 4-14. Percent Changes in Average Annual Sediment Yield



Impacts of Side-Weir Detention on Sediment Yield. Use of side-weir, or off-line, detention basins is another alternative for offsetting projected increases in peak discharge and runoff volume caused by urbanization. A side-weir detention basin allows the majority of the water and sediment to pass through the stream system, and captures only the peak a flood hydrograph. The bedload, which has been estimated at about 33% of the total sediment yield, would therefore bypass the side-weir detention basin and remain in the stream system. Conceptually, the suspended load in the portion of the hydrograph not captured by the side weir would also remain in the natural stream system. The only sediment that would be captured by a side-weir detention basin would be the suspended load entrained in water that flows over the side weir into the detention basin. The volume in excess of the existing 100-year volume is detained behind the side weir, allowing the suspended sediment to settle out of the water.

To determine the amount of sediment trapped in a side-weir basin, the detention volume was multiplied by the suspended sediment concentration. The total sediment retained in each sub-basin was then compared to the total sediment yield to determine a percent change. Percent changes from the existing conditions to future conditions with side weir detention are presented in Figures 4-14 to 4-16. The data summarized in Figures 4-14 to 4-16 indicate that the side-weir detention alternative has similar impacts to the "no-retention" alternative, with minimal impacts on channel stability and flood control directly related to the side weir basins. Impacts on channel stability for the side-weir detention alternative are related to the increase, if any, in the frequency of low flows that are too small to be captured by the side weir (Figure 4-15). Other concerns related to side-weir detention are discussed in Chapter 5 of the *North Peoria Area Drainage Master Plan Technical Data Notebook Attachment 3 - Sedimentation Engineering and Geomorphic Evaluation Technical Memorandums.*

In general, the sediment yield analyses indicate that the side-weir detention alternative will have less significant impacts on channel stability, flood control, and facility maintenance than the in-line detention alternative.

Sediment Yield Impacts at the CAP and Beardsley Canals. The Central Arizona Project (CAP) canal, constructed in 1978, and the Beardsley Canal, constructed in 1927, traverse the North Peoria ADMP study area.[1] Where these canals cross natural watercourses, historical and recent sediment impacts observed in the field can be assessed to evaluate the range of potential channel responses to floodplain activities such as in-line or side-weir detention. The following impacts were considered:

- Upstream Impacts. The CAP and Beardsley Canals completely block or detain runoff from most of the upstream drainage basins. If passageways beneath or over these canals are small relative to the runoff rate, water will be impounded and sediment will be deposited upstream of the crossing. Excessive vegetative growth was observed at a number of the undersized drainage crossings, presumably due to frequent ponding and deposition of fertile fine-grained sediment. Storage of water and sediment upstream of the canals may eventually lead to overtopping of the canals if sediment and vegetation is not removed from the ponding area.

[1] A map of CAP and Beardsley Canal cross drainage facilities is provided on Plate 8 in the North Peoria TDN Attachment 1.

- Downstream Impacts. Where a significant portion of the watershed sediment supply is deposited upstream of the canal, clear water discharge on the downstream side of the canal may lead to long-term degradation or scour in the channels downstream. Local scour near culvert outlets also commonly occurs downstream of culverts.

Figure 4-17. Culvert inlet at West Garambullo Wash at CAP.

Figure 4-18. Beardsley Canal flume over Caterpillar Tank Wash

Evaluation of Specific Drainage Crossings. Field observations were made at the following drainage crossings under the CAP canal:

- West Fork White Peak Wash. Runoff from a relatively small upstream watershed is conveyed under the CAP through a 30-inch reinforced concrete pipe (RCP). No evidence of significant ponding, sediment deposition, or vegetative growth was observed upstream of the culvert inlet (Figure 4-19). Deposition of about two feet of sandy sediment was observed at the outlet (i.e., no outlet scour).
- East Fork White Peak Wash. Runoff from a relatively small upstream watershed is conveyed under the CAP through a 30-inch RCP. No evidence of significant ponding, sediment deposition, or vegetative growth was observed upstream of the culvert inlet (Figure 4-19). A shallow scour hole about 0.5 feet deep was observed at the outlet.
- West Garambullo Wash. Runoff from a very small upstream watershed is conveyed under the CAP through a 24-inch RCP. No evidence of significant ponding, sediment deposition, or vegetative growth was observed upstream of the culvert inlet (Figure 4-17). Deposition of a large sandy bar was observed just downstream of the outlet (i.e., no outlet scour), which may be due to rill erosion of the CAP levee (Figure 4-20).
- East Garambullo Wash. Runoff from a small upstream watershed is conveyed under the CAP through a 24-inch RCP. No evidence of significant ponding, sediment deposition, or vegetative growth was observed upstream of the culvert inlet. Deposition of a sand was observed at the outlet (i.e., no outlet scour).
- Twin Buttes Wash. Runoff from a moderately large watershed is conveyed under the CAP through four 66-inch RCP. Small gravel bar deposits were observed in the ponding area upstream of the crossing, but no evidence of a large ponding area with fine-grained deposition was observed (Figure 4-21). Sediment has been deposited at the downstream end

of the culvert, and blocks about 30% of the culvert capacity (Figure 4-22). The downstream sediment, probably caused by the change in slope from the culverts to the downstream channel, extend back into the culverts over about half their length.

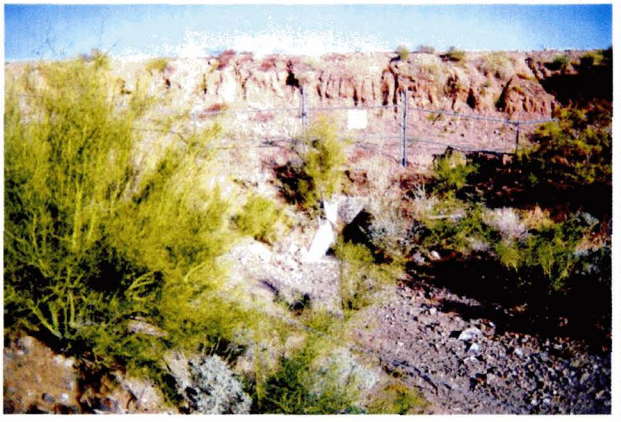


Figure 4-19. Culvert inlet, West Fork White Peak Wash at CAP.

Figure 4-20. Culvert outlet West Garambullo Wash at CAP.

Figure 4-21. Aerial photograph of Twin Buttes Wash at CAP.

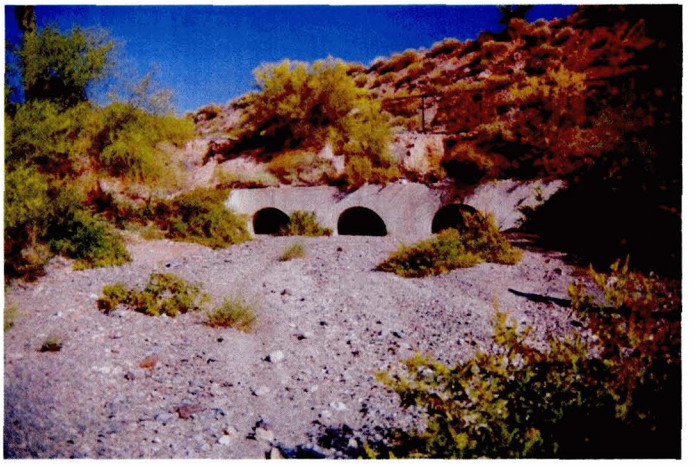


Figure 4-22. Deposition on downstream side of CAP crossing of Twin Buttes Wash.

- Caterpillar Tank Wash. Despite a small watershed draining to the CAP, significant sediment impacts were observed upstream of the CAP crossing of Caterpillar Tank Wash. A large ponding area with extensive fine-grained sediment deposition and growth of a dense mesquite bosque was observed upstream of the CAP (Figure 4-23). At the time of the field visit, the inlet to the 6-foot RCP was not clogged by sediment or debris, although there was evidence of recent maintenance activities. A partially attached hog-wire fence blocks the outlet of the RCP. A small scour hole and channel armoring (or dumped rock) were observed at the outlet of the RCP (Figure 4-24). Immediately downstream of the CAP crossing, Caterpillar Tank Wash enters the impoundment area of Caterpillar Tank. Backwater from

the dam at Caterpillar Tank may be responsible for the degree of ponding and sediment deposition upstream of the CAP.

Figure 4-23. Aerial photograph of Caterpillar Tank Wash at the CAP.

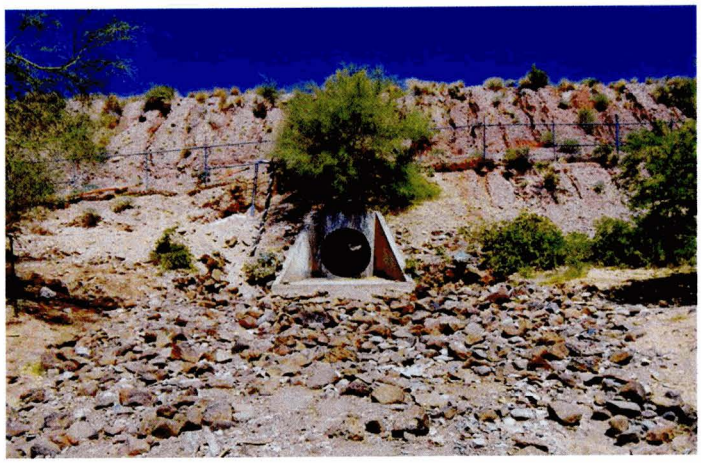


Figure 4-24. View of scour at outlet of Caterpillar Tank Wash at CAP.

- Unnamed Wash #4. Unnamed wash #4 crosses under the CAP in a 36-inch RCP. The 36-inch RCP outlets into a steep concrete flume with a energy dissipater (Figure 4-25). No sedimentation problems were noted at this CAP crossing.

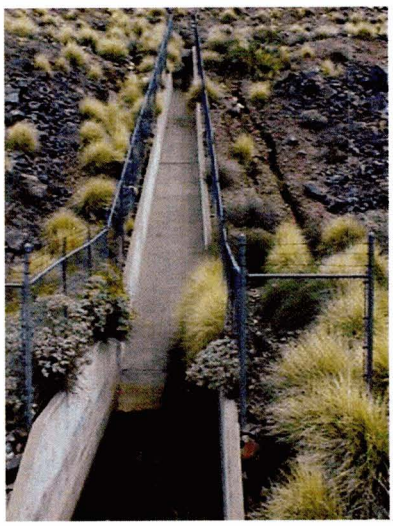


Figure 4-25. View of outlet of CAP crossing of Unnamed Wash #4.

Figure 4-26. Culverts inlet at Beardsley Canal on unnamed wash #4.

In general, the drainage crossings along the CAP appear to be functioning without significant sediment impacts, or at least with whatever maintenance schedule currently in use by CAP

personnel. The sediment deposition observed at Caterpillar Tank Wash may be more related to ponding at Caterpillar Tank than at the CAP itself. The lack of significant sediment deposition at the CAP culvert inlets suggests that existing condition upstream sediment yield rates are low, or that significant floods have not occurred in the watersheds since construction of the CAP. Overtopping of the CAP canal due to sediment deposition at the culvert inlets has a low probability of occurrence. Culvert capacities, upstream storage volumes, and peak discharge data are provided in Table 4-9.

Field observations were also made at the following drainage crossings of the Beardsley Canal west of the Agua Fria River:

- Twin Buttes Wash, Caterpillar Tank Wash, and the unnamed wash in subbasin S707 all cross the Beardsley Canal in flumes which span the high Pleistocene terraces with no significant obstruction of the floodplain. While there may sediment concerns related to pier scour or erosion of the abutment, no impacts to sediment yield are expected at these crossings.
- Unnamed Wash #4. Field evidence suggests that fine-grained sediment deposition has occurred in the ponding area upstream of the two cell 5'x5' reinforced concrete box culvert (RCBC), but that no significant impacts to structure capacity have occurred since its construction in 1927. (Alternatively, sediment maintenance by the canal operators may have occurred.)
- Structure 64. A large ponding area at the upstream side of structure 64 that appears to have accumulated significant sediment and vegetation is visible on aerial photographs (Figures 4-27 and 4-28).

Figure 4-27. View of structure 64 outlet (C706)at the Beardsley Canal.

Figure 4-28. Aerial photograph of ponding area upstream of Beardsley Canal at C706.

Table 4-9. North Peoria ADMP
Discharge Frequency, Culvert Capacity, and Storage Volumes – Structures Along CAP and Beardsley Canals

Location	Q2	Q5	Q10	Q25	Q50	Q100	V100	Culvert Q[1]	Storage Vol.[2]	Storage Vol. @ Top of Lining[3]
At CAP Canal										
Caterpillar Tank Wash (S401)	26	125	247	489	787	1212	105	500[4]	41	190
E. Garambullo Wash (S506)	11	51	102	213	233	318	15	93	7	36
W. Garambullo Wash (S505)	14	63	125	262	282	382	13	97	7	9
Twin Buttes Wash (C502)	43	211	416	797	1428	2246	276	1982	22	338
E. Fork White Peaks Wash (S511)	21	97	191	390	529	777	41	98	28	51
W. Fork White Peak Wash (S509)	14	65	128	269	304	420	18	93	10	13
At Beardsley Canal										
Unnamed Wash #4 (C705)	30	144	285	562	917	1418	108	689	39	55
Unnamed Wash (S706)	18	90	178	356	543	825	67			

Notes:
[1] Culvert capacity at 100-yr head elevation according to stage-storage-discharge curves in AGK, 1991 as modeled by Stantec, 2001 for CAP locations.
[2] Maximum storage for 100-yr hydrograph per Stantec, 2001 HEC-1 models.
[3] Top of lining elevations calculated as 3 feet below embankment elevations seen on topographic maps in AGK, 1991 for CAP locations. Overtopping elevation from Stantec, 2001 reported for Beardsley Canal.
[4] Storage routing at C400O assumes Caterpillar Tank is not hydraulically effective (i.e. CAP culvert controls hydraulic performance).

Summary

This technical memorandum describes estimation of existing and future sediment yield in the North Peoria Area Drainage Master Plan study area. Results from qualitative and quantitative evaluations of potential sediment yield are provided. The results indicate that expected sediment yields from the study area are relatively low, and future development will impact sediment yield, with potentially significant consequences for channel stability and flood control planning. For planning purposes the future condition sediment yield of 0.3 acre-feet/square mile/year is recommended. Side-weir detention was determined to have less impact on sediment yield and channel stability than in-line or no detention/retention. Historical sediment impacts have been minimal or have been adequately maintained in the past at the CAP and Beardsley Canal drainage crossings.

References Cited

Arizona Department of Water Resources (ADWR), 1985, *Design Manual for Engineering Analysis of Fluvial Systems*. Phoenix, AZ.

Camp, P.D. 1986. *Soil Survey of Aguila Carefree Area, Parts of Maricopa and Pinal Counties, Arizona*. Soil Conservation Service, USDA.

Cooper Aerial Mapping Co., 2000, *Digital Topographic Mapping for the North Peoria ADMP Floodplain Delineation Studies*. Prepared for Stantec and the Flood Control District of Maricopa County.

Dendy, F.E. and G.C. Bolton, 1976, Sediment yield-runoff drainage area relationships in the United States. *Journal of Soil and Water Conservation*, ser. 31, v. 6, p. 264-266.

Flaxman, E.M., 1972, Predicting sediment yield in western United States. *Journal of the Hydraulics Division, American Society of Civil Engineers*, v. 98, p. 2073-2085.

Flaxman, E.M., 1974, *Progress Report on Development of Sediment Yield Predictive Equations. Soil Conservation Service*, TSC Advisory ENG-PO-32. Portland, Oregon. 14 p.

Hartman, G.W. 1977. *Soil Survey of Maricopa County, Arizona, Central Part*. Soil Conservation Service, USDA.

Interagency Report, 1991, *Upper Colorado River Basin Rangeland Salinity Control Project: West Water Canyon Sub-Basin*.

Pacific Southwest Inter-Agency Committee (PSIAC), 1968, *Factors Affecting Sediment Yield And Measures For The Reduction Of Erosion And Sediment Yield*, 13 p.

Renard, K.G. 1972. Sediment Problems In The Arid And Semiarid Southwest. *Proceedings, 27th Annual Meeting, Soil Conservation Society of America*. Portland, Oregon. p. 225-232.

Renard, K.G. and E.M. Laursen, 1975, A Dynamic Behavior Model Of An Ephemeral Stream. *Journal of the Hydraulics Division, American Society of Civil Engineers*, v. 101, p. 511-528.

Renard, K.G. and J.J. Stone, 1981, Sediment Yield From Small Semiarid Rangeland Watersheds. *Proceedings of the Workshop on Estimating Erosion and Sediment Yield on Rangelands*. Tucson, Arizona. p. 129-144.

Renard, K.G. et al., 1997, *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. Agriculture Handbook 703. USDA, Agricultural Research Service.

Reynolds, S.J., et al. 1997. *Digital Representation of the Geological Map of the Phoenix North 30' x 60' Quadrangle, Central Arizona.* Digital Information Series, DI-4, version 1.1. Arizona Geological Survey: Tucson, Arizona.

Stantec, 2001, *North Peoria Area Drainage Master Plan Technical Data Notebook: Attachment 1 - Field Survey Report.* Report to the Flood Control District of Maricopa County.

Stantec, 2001, *North Peoria Area Drainage Master Plan Technical Data Notebook: Attachment 2 - Hydrology and Hydraulics.* Report to the Flood Control District of Maricopa County.

Thomas, B.E., Hjalmarson, H.W., and Waltemeyer, S.D., 1997, *Methods for Estimating Magnitude and Frequency of Floods in the Southwest United States*: U.S. Geological Survey, Water Supply Paper 2433, 195 p.

Chapter 5
Alternatives Analysis

CONTENTS

- Memorandum #1 – Channel Stability Impacts
- Memorandum #2 – Low-Impact Structural Alternatives
- Memorandum #3 – Geomorphic Impacts of Detention Alternatives
- Memorandum #4 – Development Guidelines

1-302

DATE: December 27, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E., Stantec Consulting

FROM: Jon Fuller, P.E.

RE: North Peoria Area Drainage Master Plan
Task 2.6.5 Channel Stability Impacts of Development Scenarios

Introduction

This memorandum describes the sedimentation and geomorphic impacts on channel stability of development scenarios likely to occur in North Peoria Area Drainage Master Plan (ADMP) study area. The following development scenarios were considered:

- Sand and Gravel Mining in the Agua Fria River
- Floodplain Encroachment
- Channelization
- Roadway Crossings
- Utility Crossings

In addition, typical structural flood control designs to address sedimentation concerns are discussed.

This analysis was performed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting, Inc. (Stantec) under Task 2.6.5 of contract FCD 99-45 with the Flood Control District of Maricopa County (District). The primary objective of the analysis is to describe qualitatively the likely impacts on stream stability of various types of development.

Sand and Gravel Mining in the Agua Fria River

In-stream sand and gravel mining lowers a stream's local base level. The Agua Fria River provides the local base level for the major watercourses in the North Peoria ADMP study area. The expected channel response to base level lowering is long-term degradation and accelerated bank erosion due to undercutting. Therefore, if in-stream sand and gravel mining occurs on the Agua Fria River near the confluence with one of its major tributaries in the study area, long-term degradation should be expected on that tributary. However, as discussed in Chapter 2 of this report, no evidence of recent or historical base level lowering on the streams in the study area due to sand and gravel mining on the Agua Fria River was identified during the course of this study.

Future channel responses to sand and gravel mining in the Agua Fria River depend on the management strategy adopted by the District and other regulatory agencies. The District's Watercourse Master Plan for the Agua Fria River is currently nearing completion (KHA, 2001).

The draft Agua Fria River Watercourse Master Plan proposes to limit new sand and gravel mining to areas outside the Lateral Migration Erosion Hazard Zone, or to limit in-channel excavations to a depth equal to the 1986 thalweg elevation. In-channel excavations will be required to provide engineered flood control structures to prevent capture of the main channel by lateral erosion, upstream headcut migration, and downstream degradation. If the Agua Fria River Watercourse Master Plan recommendations are implemented, future mining in the Agua Fria River floodplain will have no significant impacts on channel stability in the North Peoria ADMP study area.

If the Agua Fria River Watercourse Master Plan draft recommendations are not implemented, new in-stream sand and gravel mines are highly likely to be constructed near the confluences with the major tributaries in the North Peoria ADMP study area. If no engineered structures are provided to prevent headcutting or capture of the pit by the main channel of either the Agua Fria River or the major tributaries in the study area, long-term degradation and accelerated bank erosion will occur on the tributaries. The following specific impacts to channel stability and unique conditions apply to the major streams in the study area:

- Twin Buttes Wash. Of the streams in the North Peoria ADMP study area, Twin Buttes Wash is the most vulnerable to long-term degradation and accelerated erosion due to sand and gravel mining in the Agua Fria River. Twin Buttes Wash is located closest to existing and proposed in-stream sand and gravel mines and does not have natural grade control such as shallow bedrock. Furthermore, the type of existing development and zoning along the downstream reaches of Twin Buttes Wash makes it more likely that public funds would be the only realistic means to provide channel stabilization if unacceptable rates of channel erosion were to occur.
- Caterpillar Tank Wash. A large recharge facility is currently under construction in the Agua Fria River floodplain near the mouth of Caterpillar Tank Wash. While the recharge facility itself will do little to prevent headcutting or erosion caused by in-stream sand and gravel mines, the presence of the recharge facility will at least prevent sand and gravel mines from being located directly at the mouth of Caterpillar Tank Wash. Caterpillar Tank Wash has no natural grade control that would limit headcutting initiated by in-stream sand and gravel mining in the Agua Fria River.
- Unnamed Washes #1 , #2, and #3. Shallow bedrock exposed in the beds of unnamed washes #1, #2, and #3 would limit the impacts of headcutting from sand and gravel mining to a relatively short reach near the Agua Fria River confluence.
- Unnamed Wash #4. It is likely that shallow bedrock exists below unnamed wash #4, but no outcrops were observed during the field reconnaissance. Regardless, the culvert under the Beardsley Canal provides grade control and would isolate the wash from impacts of sand and gravel mining in the Agua Fria River.
- Morgan City Wash. The confluence of Morgan City Wash with the Agua Fria River is located immediately downstream of New Waddell Dam and immediately upstream of the State Route 74 (SR 74) bridge. Bedrock crops out in the bed of the Agua Fria River at several places between SR 74 and New Waddell Dam. Therefore, it is unlikely that sand and gravel mining would be either economically feasible, permitted by regulatory agencies, or deep enough to cause any significant upstream impacts.

Recommendation. Sand and gravel mining on the Agua Fria River should be regulated to prevent impacts to the streams in the North Peoria study area. The draft recommendations for sand and gravel mining in the Agua Fria River Watercourse Master Plan should be implemented. Specifically, new and existing mines should be required to have engineered flood control structures that prevent upstream headcutting and capture of the pits by lateral migration. New mines should be located outside the Lateral Migration Erosion Hazard Zone of the Agua Fria River and outside the erosion hazard zones delineated for the major watercourses in the North Peoria ADMP study area.

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. Velocity is exponentially related to sediment transport rate and erosion potential. A quantitative analysis of the effect of increased velocity on sediment transport and erosion is provided in the Low Impact Alternative Analysis presented in the next section of this chapter.
- 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 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 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 most reaches of the major watercourses in the North Peoria ADMP study area, the floodplain and floodway are coincident due to the channel and floodplain geometry in the deep, narrow canyons, and 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 floodplain encroachment will occur. Floodplain delineations are shown in Technical Documentation Notebook Attachment 2 – Hydrology and Hydraulics (Stantec, 2001). The majority of the wider floodway fringe areas in the study area occur on Caterpillar Tank Wash, Twin Buttes Wash, and the Twin Buttes Wash tributaries.

Recommendation. Where floodway fringe areas exist in the North Peoria ADMP study area, floodplain encroachment should be avoided except where it meets the low-impact criteria

defined later in this chapter. 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 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. 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. A quantitative analysis of the effect of increased velocity on sediment transport and erosion is provided in the Low Impact Alternative Analysis presented later in this chapter.
- 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. 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 development alternative in the North Peoria 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 occur, that

downstream reaches are adequately protected from erosion and flooding, and a long-term maintenance and inspection program is adopted.

Roadway Crossings

Roadway crossings of drainageways can be constructed at-grade (dip sections), or with culverts or bridges. The impacts of each crossing type on channel stability are discussed in the following paragraphs.

At-Grade Crossings. 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 can cause erosion of the pavement and subgrade, deposition of sediment in the road section, and disruption of 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 and increased turbulence as flow transitions back at the natural channel bed. In most cases, formation of a scour hole doesn't 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.

Culverts. The impact of culvert crossings is primarily a function of their size. Large culverts pass the more frequent floods without impacting the natural flow conditions. Undersized culverts and culverts that create headwater ponding have impacts similar to in-line detention basins, as discussed in Chapter 4 (Sediment Yield) and in the third part of this chapter (Geomorphic Impacts of Detention Alternatives). The impacts of undersized 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 culvert inlet. 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.
- Floodplain Encroachment. A culvert is a form of floodplain encroachment, with the same types of encroachment impacts described in the floodplain encroachment discussion above.
- Scour Hole. A scour hole may form at the culvert outlet due to accelerated velocity through the culvert, discharge of sediment-deprived water, 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.

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. Bridges with narrow openings are functionally like a culvert, 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 North Peoria ADMP study area:

- Bridges are preferable to culverts. Bridges typically have less impact on channel stability than culverts due to the wider opening and decreased likelihood of headwater ponding.
- 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.
- In-line detention facilities at roadway crossings are not recommended because of the expected increase in channel instability in adjacent stream reaches.
- 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.
- To prevent formation of scour holes or ponding areas, erosion protection should be provided where roadway runoff directly enters the stream channel

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 general scour depth in the main channel plus the long-term scour depth. 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 utility should not be located within the floodplain or erosion hazard zone. Where the length of the span requires that support structures be constructed in

erosion hazard zone, the structures should be designed using the 100-year general scour plus long-term scour in the main channel burial depth. No structures should be placed in the main channel.

Typical Structural Flood Control Designs

Design standards for typical structural flood control structures that address sedimentation concerns are provided in the *Maricopa County Drainage Design Manual Volume II – Hydraulics* (District, 1991) and are, therefore, not repeated here. Typical flood control structures that address sedimentation concerns include the following:

- Engineered Bank Protection
- Sedimentation Basins
- Sediment Traps
- Grade Control Structures
- Cutoff Walls

The types of materials typically used for full structural flood control measures include concrete, soil cement, and various forms of large diameter rock products.

Conclusions

Floodplain development will negatively impact the stability of the major watercourses in the North Peoria ADMP study area. Negative impacts will include increased lateral erosion rates, long-term degradation and scour, increased downstream flood peaks and sedimentation, and loss of floodplain function and habitat. For the North Peoria ADMP, non-structural and low-impact structural measures were found to be more appropriate than traditional full structural measures. Low impact structural alternatives are discussed in more detail in the next section of this chapter.

References

Flood Control District of Maricopa County, 1991, *Maricopa County Drainage Design Manual Volume II – Hydraulics.*

KHA, 2001 (in press), *Agua Fria River Watercourse Master Plan*, Report to the Flood Control District of Maricopa County.

DATE: December 27, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E./Stantec

FROM: Jon Fuller, P.E.

RE: North Peoria ADMP
Sedimentation Engineering & Geomorphic Evaluation
Task 2.4.2.3 Low-Impact Structural Alternative

Introduction

This memorandum describes low-impact alternatives for development within the erosion hazard zones delineated for the major watercourses in the North Peoria Area Drainage Master Plan (ADMP) study area. Erosion hazard boundaries (Chapter 3) and 100-year floodplains (TDN Attachment 2; Stantec, 2001) have been delineated for the following washes in the North Peoria ADMP study area:

- Morgan City Wash
- Unnamed Wash #1
- Unnamed Wash #2
- Unnamed Wash #3
- Unnamed Wash #4
- Caterpillar Tank Wash
- Twin Buttes Wash
- East Garambullo Wash
- West Garambullo Wash
- White Peak Wash
- West Fork of White Peak Wash

The non-structural alternatives for flood and erosion hazard management of the North Peoria ADMP study area recommend that no new development be permitted within the delineated erosion hazard zones. Low-impact structural alternatives have been suggested as a means to modify the erosion hazard zone boundaries to facilitate development, while still achieving the overall goals of preserving the natural form and function of the watercourses, minimizing impacts to adjacent properties, and protecting public health, safety and welfare.

This memorandum was prepared by JE Fuller/Hydrology & Geomorphology, Inc. (JEF) for Stantec Consulting, Inc. (Stantec) under contract FCD 99-45 with the Flood Control District of Maricopa County (District).

Definition of Low Impact

For the purposes of the North Peoria ADMP, a "low-impact" development alternative is defined as any activity within the erosion hazard zone that does not significantly alter the natural form and function of the watercourse. The following standards are proposed to quantify the definition of "low impact:"

- 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 should not change (± 0.0 ft.).
  - The 100-year water surface elevation should not increase or decrease by more than 0.1 foot.
- Minimal disturbance of the main channel.
  - No decrease in the bankfull width of the main channel.
  - No excavation or deepening of the streambed in the main channel.
  - No removal of bank vegetation. Where bank vegetation is temporarily disturbed by construction, it should be replaced, monitored for health, and irrigated if required to assure its survival.
  - No relocation of the low-flow channel within the floodplain.
- No offsite impacts.
  - No erosion, sedimentation, or flood impacts to adjacent properties without written permission of affected property owners.
  - Engineering and geomorphic analysis required to demonstrate no long-term, short-term, or 100-year offsite impacts.
- Preservation of natural landscape character and habitat within the floodplain.

Alternatives that exceed the standards listed above are not considered low-impact alternatives. Such alternatives may be acceptable methods of mitigating flood and erosion hazards, if properly engineered, but are outside the scope of this analysis.

Technical Justification for Low-Impact Standards

The low-impact standards outlined above were defined based on local field experience, observations of the channel and floodplain conditions made during field reconnaissance trips to the North Peoria ADMP study area, results of detailed geomorphic analyses of other stream systems in central Arizona, engineering judgment, floodplain development criteria enforced elsewhere in Arizona and the Southwest, and the stated goals and objectives of the North Peoria ADMP.

Velocity. The impacts of increased channel velocity and depth on sediment transport capacity and erosion potential were considered to provide technical justification for the low-impact criteria. Erosion potential is a function of sediment transport capacity, which is exponentially related to channel velocity. Therefore, changes in channel or overbank velocity due to development will have a significant impact on sediment transport rates. The Zeller-Fullerton sediment transport function (ADWR, 1985) was used to compute total sediment transport capacity to illustrate the impact of changes in velocity, as well as other hydraulic variables, as shown in Table 5-1.

The data shown in Table 5-1 indicate that for a channel with a velocity of 4 feet per second, depth of 5 feet, topwidth of 50 feet, D_{50} of 7 millimeters, and gradation coefficient of 3, a 1 foot per second increase in velocity results in *about a 160 percent increase in the sediment transport rate*. Such an increase in sediment transport rate would nearly triple the rate of bank erosion if the sediment deficit were made up by bank erosion alone. For the same channel conditions described above, a 10 percent increase in channel velocity (+ 0.4 ft./sec.) results in about a 50 percent increase in sediment transport capacity, almost doubling the rate of erosion. Increased channel velocity also impacts channel stability by increasing scour depths, increasing the potential for bank failure by undercutting bank vegetation, increasing shear and hydrodynamic forces on the channel banks, and depleting fine-grained sediment in the bed and banks.

Depth. Sediment transport capacity is inversely related to the average flow depth, as shown in Table 5-1, if all other variables remain unchanged. It is noted that velocity typically increases with depth in natural channels, which would lead to increased sediment transport rates as described above. Other unacceptable impacts of increased flow depths include inundation of land previously outside the floodplain, increased potential for avulsion due to increased depth and frequency of flow on the floodplain, and increased potential for channel widening to preserve a stable width/depth ratio.

Main Channel. Because the main channel conveys flow far more frequently than the floodplain, and because overbank flow velocities are often too low to transport sediment, most of the sediment transport, erosion, and geomorphic work occurs within the main channel. Consequently, alternatives which leave the main channel untouched will have less impact on channel morphology than alternatives which modify the main channel. Therefore, the low impact alternative was defined as one that includes no modification of the main channel. Similarly, if the 10-year floodplain is not modified, and the 100-year changes are limited as defined above, the impact on channel morphology will be minimal. Regional stream gauge data from ephemeral watersheds in central Arizona indicate that more than 99 percent of the annual runoff volume in the North Peoria ADMP study area will occur at flow rates well below the 10-year peak discharge. Therefore, if the low-impact criteria are enforced, the channel would be subject to non-natural sedimentation and geomorphic impacts less than one percent of the time, only during the peaks of the largest, most rare floods.

Table 5-1. North Peoria ADMP
Sediment Transport Sensitivity Analysis Using the Zeller-Fullerton Equation

% Change in Variable	N Chl	Vel chl (ft/s)	Grad Coef.	Hyd. D (ft)	D50 (mm)	TW (ft)	Qs (cfs)	% Increase in Qs
% Change in Channel Velocity (1 ft/s increments)								
	0.035	4	3	5	7	50	0.10	0%
25%	0.035	5	3	5	7	50	0.27	162%
50%	0.035	6	3	5	7	50	0.60	476%
75%	0.035	7	3	5	7	50	1.17	1022%
100%	0.035	8	3	5	7	50	2.08	1897%
125%	0.035	9	3	5	7	50	3.47	3222%
150%	0.035	10	3	5	7	50	5.47	5137%
% Change in Channel Velocity								
	0.035	4.00	3	5	7	50	0.10	0%
1%	0.035	4.04	3	5	7	50	0.11	4%
5%	0.035	4.20	3	5	7	50	0.13	23%
10%	0.035	4.40	3	5	7	50	0.16	51%
15%	0.035	4.60	3	5	7	50	0.19	83%
20%	0.035	4.80	3	5	7	50	0.23	120%
% Change in Hydraulic Depth								
	0.035	10	3	5.00	7	50	5.47	0%
2%	0.035	10	3	5.10	7	50	5.43	-1%
5%	0.035	10	3	5.25	7	50	5.39	-1%
10%	0.035	10	3	5.50	7	50	5.31	-3%
20%	0.035	10	3	6.00	7	50	5.17	-5%
% Change in Channel N Value								
	0.0350	10	3	5	7	50	5.47	0%
1%	0.0354	10	3	5	7	50	5.56	2%
10%	0.0385	10	3	5	7	50	6.47	18%
20%	0.0420	10	3	5	7	50	7.55	38%
% Change in D50, Median Bed Sediment Diameter								
	0.035	10	3	5	7.00	50	5.47	0%
1%	0.035	10	3	5	7.07	50	5.43	-1%
10%	0.035	10	3	5	7.70	50	5.16	-6%
20%	0.035	10	3	5	8.40	50	4.89	-11%
% Change in Channel Top Width								
	0.035	10	3	5	7	50.0	5.47	0%
1%	0.035	10	3	5	7	50.5	5.52	1%
10%	0.035	10	3	5	7	55.0	6.01	10%
20%	0.035	10	3	5	7	60.0	6.56	20%
% Change in G, Gradation Coefficient								
	0.035	10	1.0	5	7	50	3.33	0%
100%	0.035	10	2.0	5	7	50	4.55	37%
200%	0.035	10	3.0	5	7	50	5.47	64%

Code to Abbreviations:
N Chl = Manning's N value for channel
Vel Chl = Mean channel velocity
Grad Coef = Gradation coefficient of sediment
Hyd D = Hydraulic depth of channel
TW = Channel topwidth
Qs = Sediment discharge
D50 = Median bed sediment diameter
Highlight field is changed variable

Offsite Impacts. The current Maricopa County Floodplain Regulations require that floodplain activities not impact adjacent stream reaches. The low-impact alternative definition is consistent with current County regulations.

Erosion Protection Alternatives

A large variety of alternative designs and materials are available for use as erosion protection. Although it is beyond the scope of this analysis to provide information on all of the available alternatives, information on the following approaches to erosion protection is provided as background to the discussion of low-impact alternatives:

- Bank Protection. Bank protection is any method of erosion protection that is constructed directly on the existing channel bank (Figure 5-1).

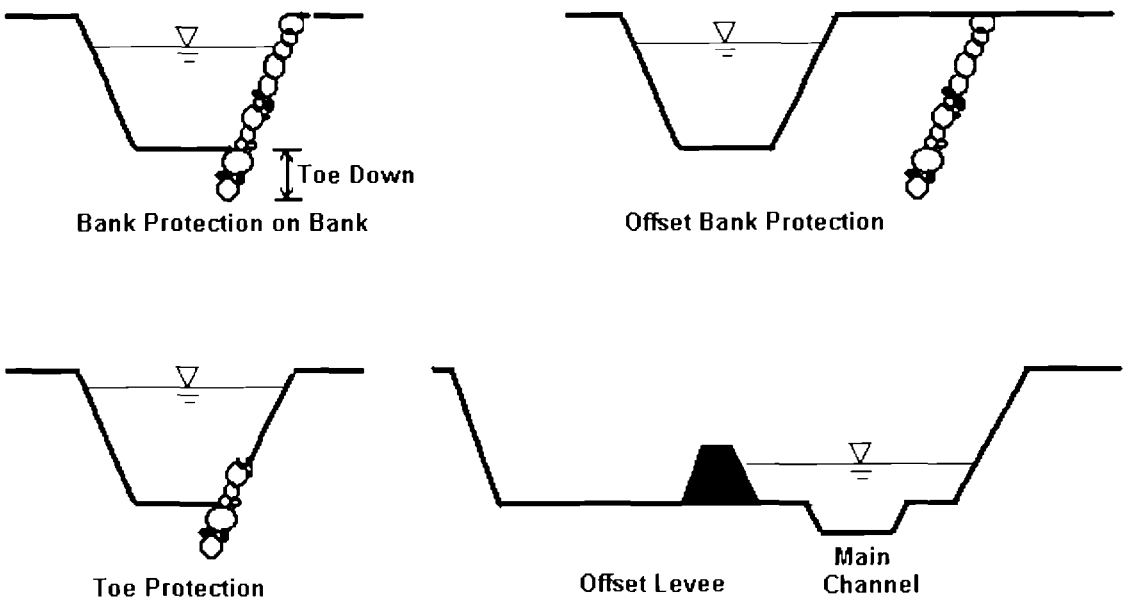


Figure 5-1. Illustration of alternative forms of erosion protection.

- Offset Bank Protection. Offset bank protection is any method of erosion protection that is constructed outside the existing channel bank, leaving the natural channel bank undisturbed (Figure 5-1). Offset bank protection becomes exposed if future erosion occurs.

- Toe Protection. Toe protection is a form of bank stabilization where only the toe of the bank is protected from erosion (Figure 5-1). At many sites in the study area, the primary mechanism of bank failure is erosion of the bank toe. Stabilization of the toe prevents rotational, tensional, and cantilevered failures of the upper portions of the bank.

- Toe Down. Toe down is the portion of the erosion protection that extends below the bed of the existing channel (Figure 5-1). Toe down is required to prevent failure of the erosion protection by undercutting caused by general, local, or long-term scour.

- Offset Levee. An offset levee leaves the main channel of a watercourse and a portion of the floodplain undisturbed (Figure 5-1), with a flood control levee in the floodplain.

- Lateral Extent. Erosion protection must be extended upstream and downstream of the problem area to prevent failure by flanking. The upstream and downstream ends of erosion protection should be tied into a stable, non-eroding surface.

- Revegetation. Vegetation may be effective at providing erosion protection where velocities are low and no significant long-term scour is expected. On ephemeral streams like those in the North Peoria ADMP study area, irrigation may be required to achieve survival rates and growth densities required for effective erosion control.

- Engineered Materials. Engineering materials typically used for erosion protection in Maricopa County include the following:
    - Rip rap
    - Gabions
    - Reno Mattresses
    - Articulated Concrete Block Mattresses
    - Wire-Tied Rock
    - Soil Cement
    - Concrete
    - Gunite
    - Geotextiles
    - Sheet Piling
    - Bioengineering (vegetation, natural materials)

The following references provide more information or citations to design guidelines for various traditional and non-traditional alternatives for structural erosion protection measures:

- FCDMC, 1991, *Drainage Design Manual for Maricopa County, Arizona – Volume II Hydraulics*.
- Federal Interagency Stream Restoration Working Group, 1998, *Stream Corridor Restoration – Principles, Processes, and Practices*.
- Simons, Li & Associates, 1983, *Engineering Analysis of Fluvial Systems*, Ft. Collins, Colorado.
- Federal Highway Administration, 1990, *Highways in the Riverine Environment*, Publication No. FHWA-HI-90-016.

In general, for low-impact alternatives, engineered erosion protection that uses flexible and permeable materials that can be vegetated is preferred to rigid, brittle, impermeable materials that cannot support vegetation.

Development Scenarios

The major watercourses in the North Peoria ADMP study area generally are well-defined streams that flow within shallow canyons (Figure 5-2). The low-flow channels of these watercourses meander across the canyon bottoms. The remainder of the canyon bottom outside the main channel is comprised of alluvial floodplains of variable widths and elevations. The erosion hazard zones generally extend across the entire canyon bottom, and include portions of the upland areas where the canyon walls are composed of erodible material.

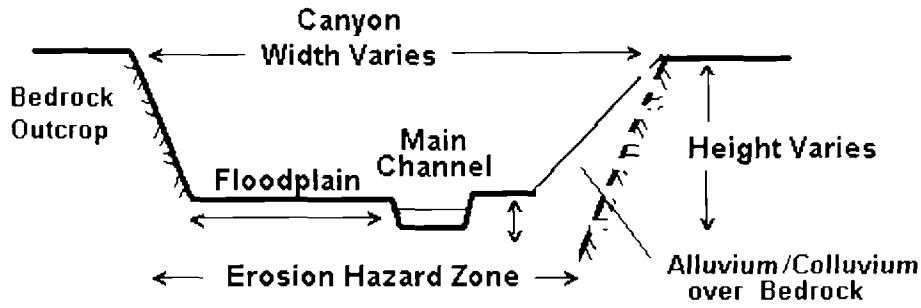
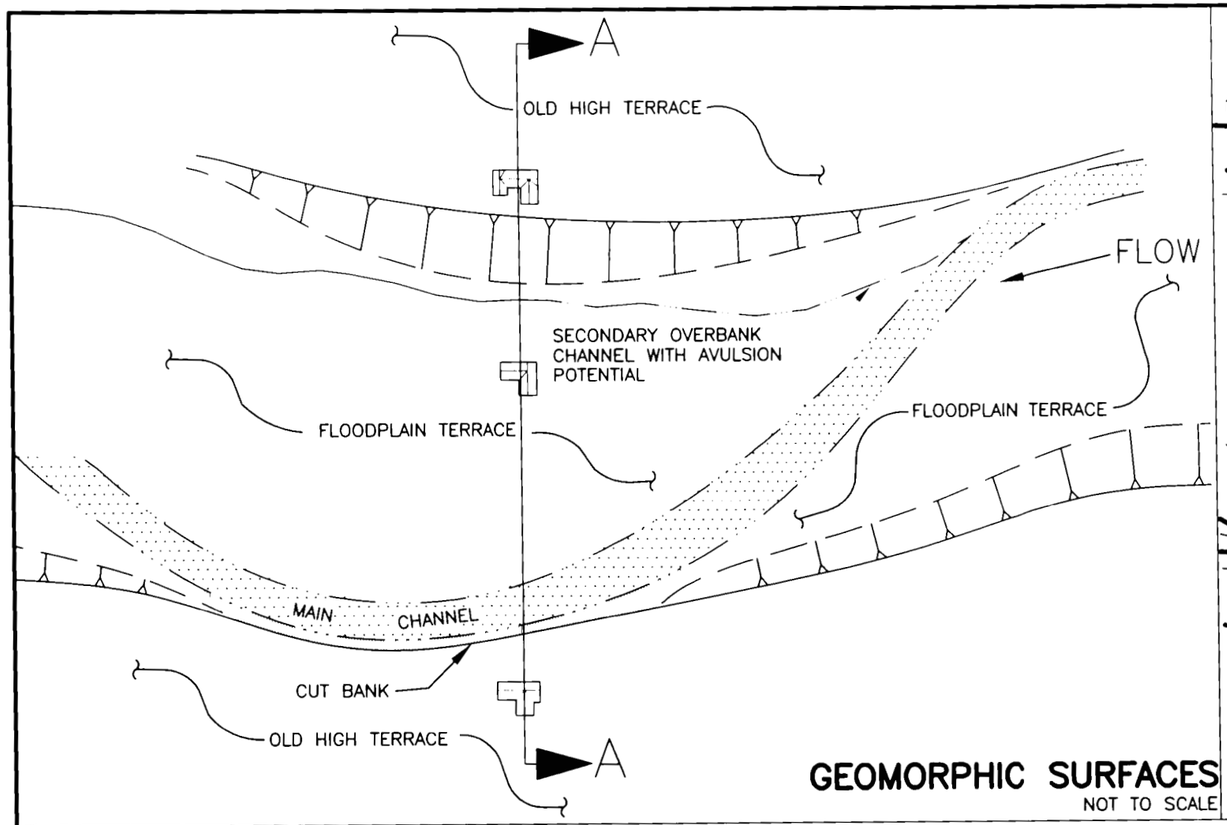


Figure 5-2. Typical canyon cross section for the major watercourses in the study area.

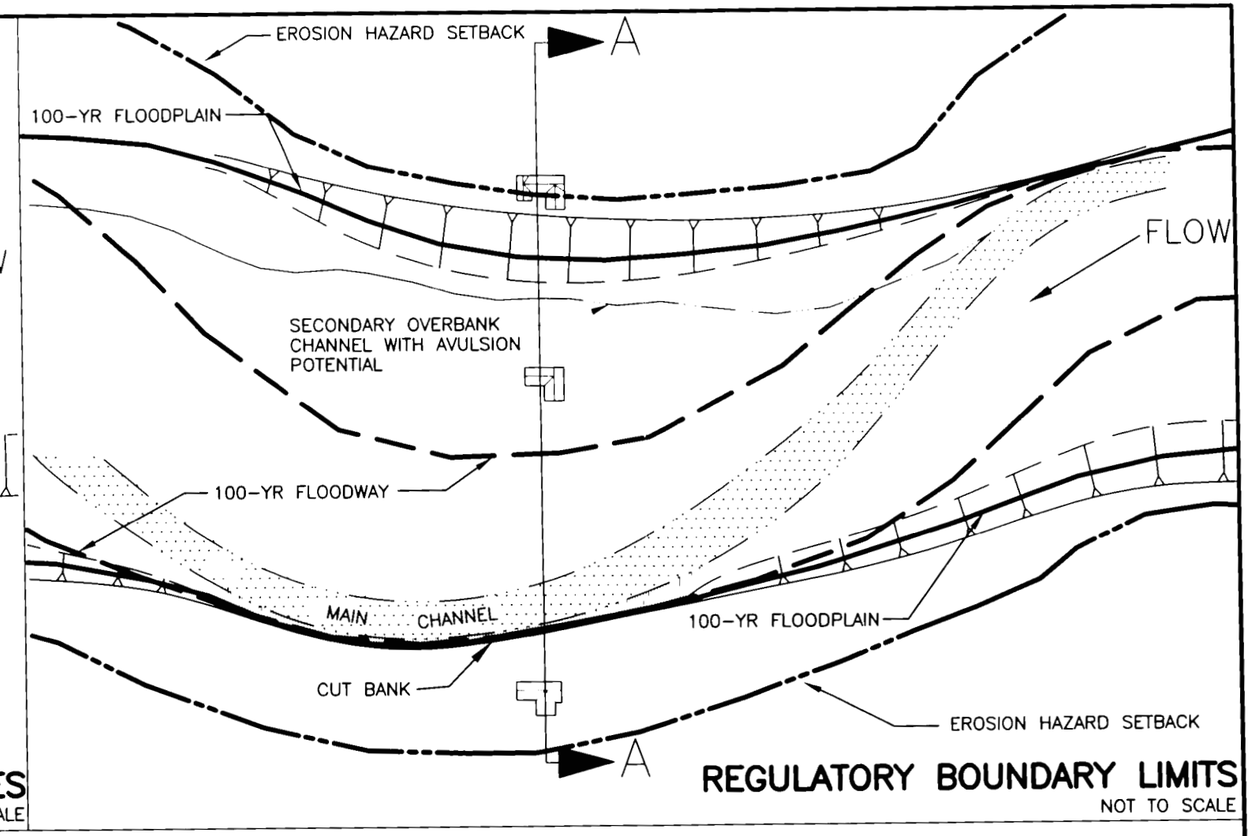
In locations where the erosion hazard zones extend well beyond the terrace or canyon margin, or where flow on the floodplain is shallow and infrequent, it may be possible to implement a low-impact structural alternative within the erosion hazard zone. The following three basic low-impact development scenarios were identified for the North Peoria ADMP study area:

- Scenario 1. Development is within the 100-year floodplain and erosion hazard zone (Figures 5-3 and 5-4).
- Scenario 2. Development is outside the 100-year floodplain, but within the erosion hazard zone and is adjacent to an actively eroding bank or canyon wall (Figures 5-3 and 5-5).
- Scenario 3. Development is outside the 100-year floodplain, but within the erosion hazard zone and is not adjacent to an actively eroding bank or canyon wall (Figures 5-3 and 5-6).

Unique low impact alternatives are described below for each of the three most common development scenarios.

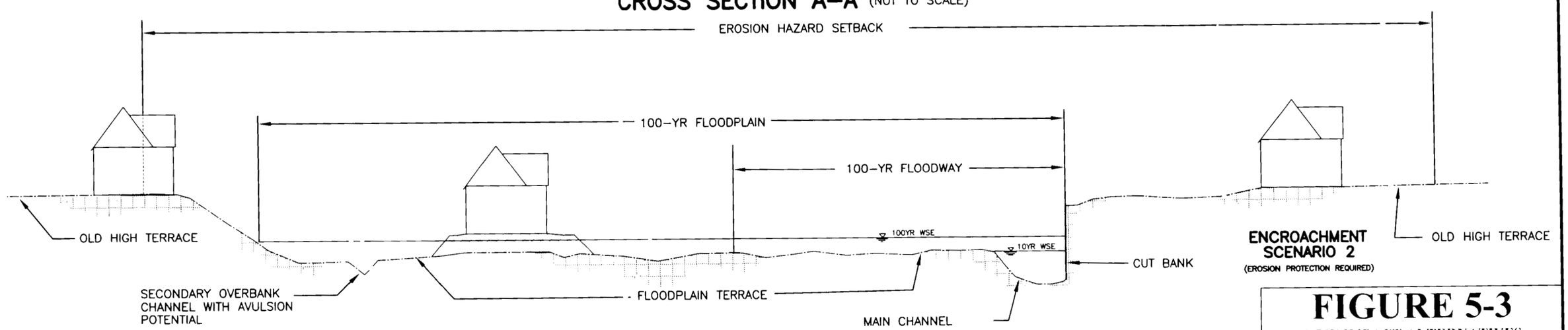


GEOMORPHIC SURFACES
NOT TO SCALE



REGULATORY BOUNDARY LIMITS
NOT TO SCALE

CROSS SECTION A–A (NOT TO SCALE)



ENCROACHMENT SCENARIO 3
(EROSION PROTECTION REQUIRED)

ENCROACHMENT SCENARIO 1
(EROSION PROTECTION REQUIRED)

ENCROACHMENT SCENARIO 2
(EROSION PROTECTION REQUIRED)

FIGURE 5-3
LOW IMPACT ALTERNATIVES
TYPICAL PLAN AND CROSS SECTION

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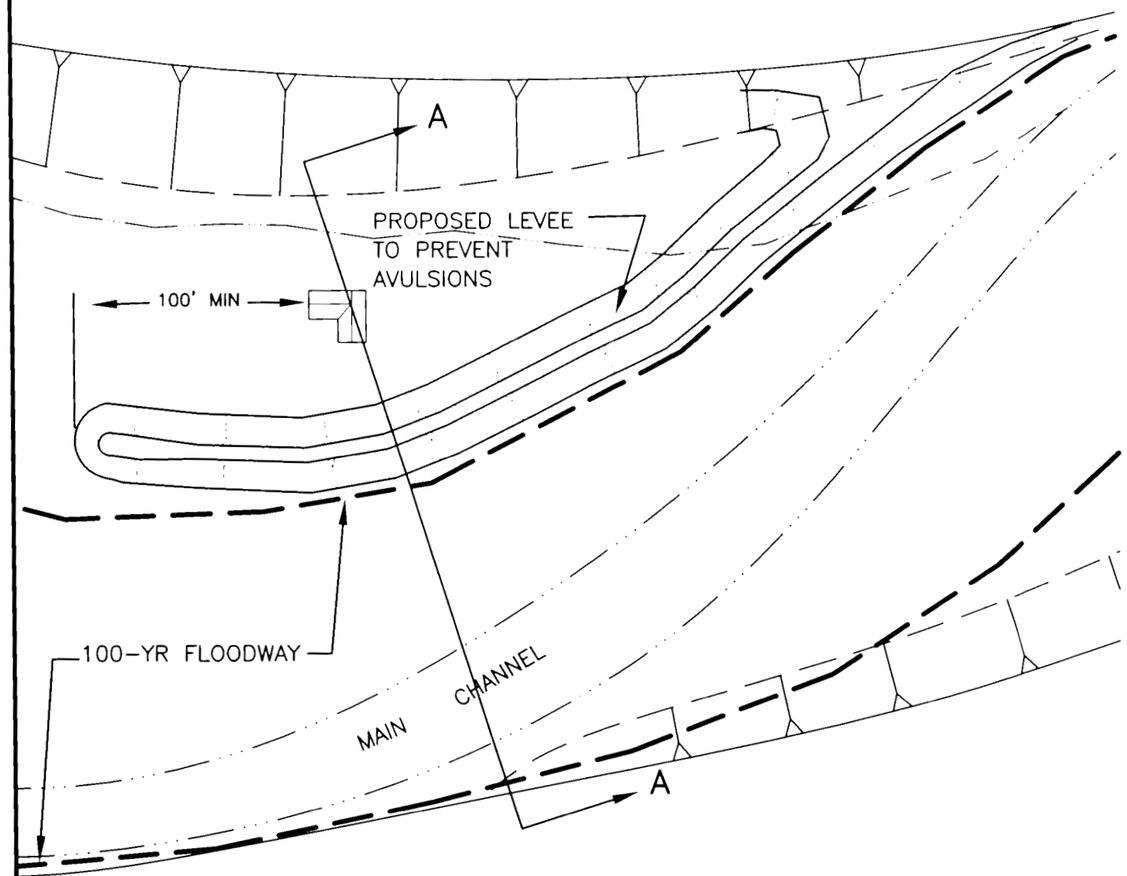
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY
FCD CONTRACT NO. 99-45

SCENARIO 1, OPTION B – PLAN VIEW

NOT TO SCALE



DESIGN NOTES:

- Q100 OVERBANK DEPTH X VELOCITY ^{2} < 18 SF/S
- NO DISTURBANCE OF MAIN CHANNEL
- BURY RIP RAP AND REVEGETATE
- IRRIGATION REQUIRED TO MAINTAIN VEGETATION
- SIZE RIP RAP BASED ON MAIN CHANNEL HYDRAULICS
- EXTEND LEVEE A MINIMUM OF 100 FT DOWNSTREAM OF STRUCTURE
- TIE IN LEVEE TO STABLE SURFACE
- TOE DOWN DEPTH BASED ON SCOUR DEPTH IN MAIN CHANNEL
- DESIGN OF ALL DRAINAGE IMPROVEMENTS AND EROSION PROTECTION SHALL COMPLY WITH THE CRITERIA SET FORTH IN THE 1996 "DRAINAGE DESIGN MANUAL FOR MARICOPA COUNTY, VOLUME II, HYDRAULICS."

CONCEPTUAL–NOT FOR CONSTRUCTION

SCENARIO 1, OPTION B – SECTION A–A

NOT TO SCALE

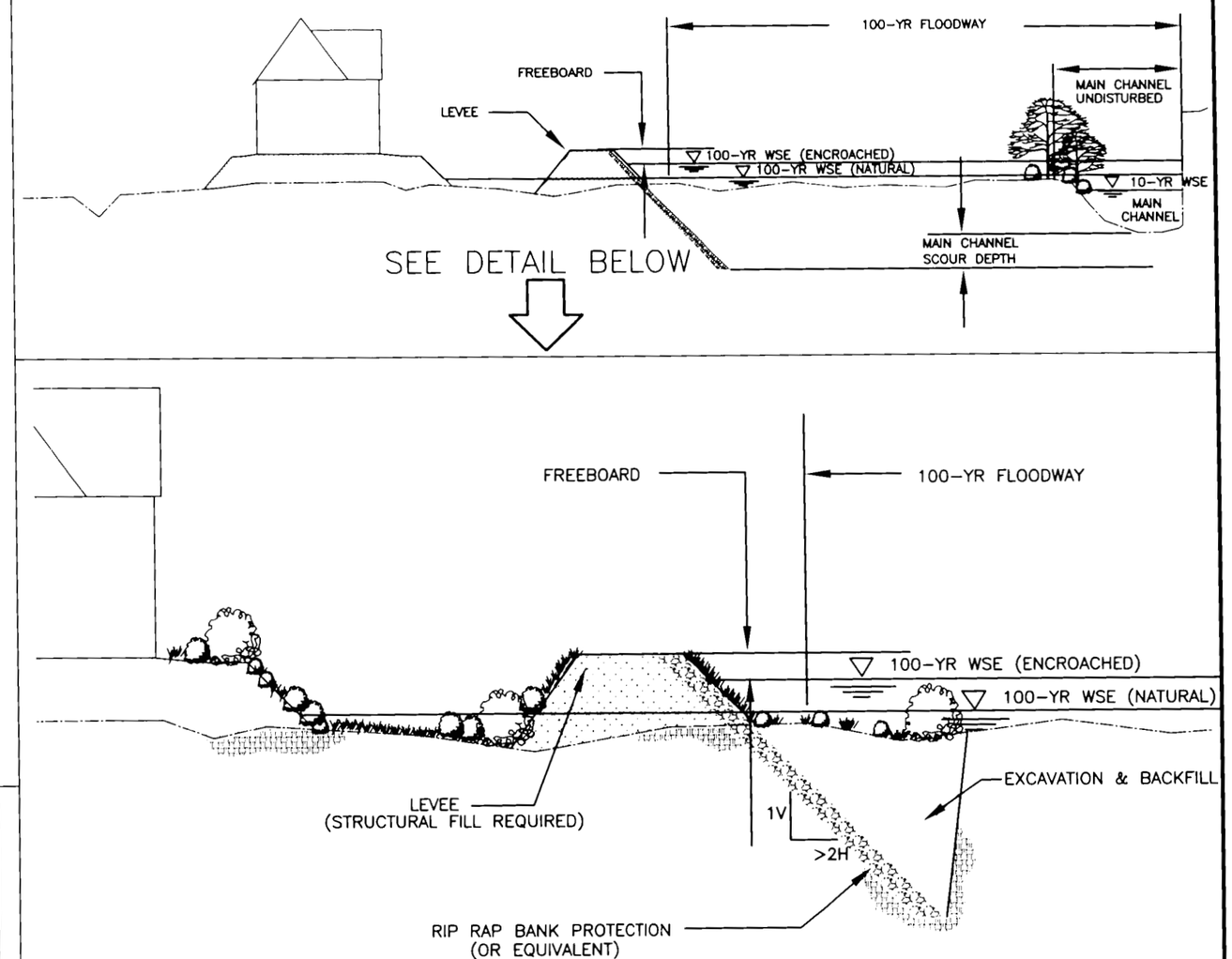


FIGURE 5-4

LOW IMPACT ALTERNATIVES
SCENARIO I OPTIONS

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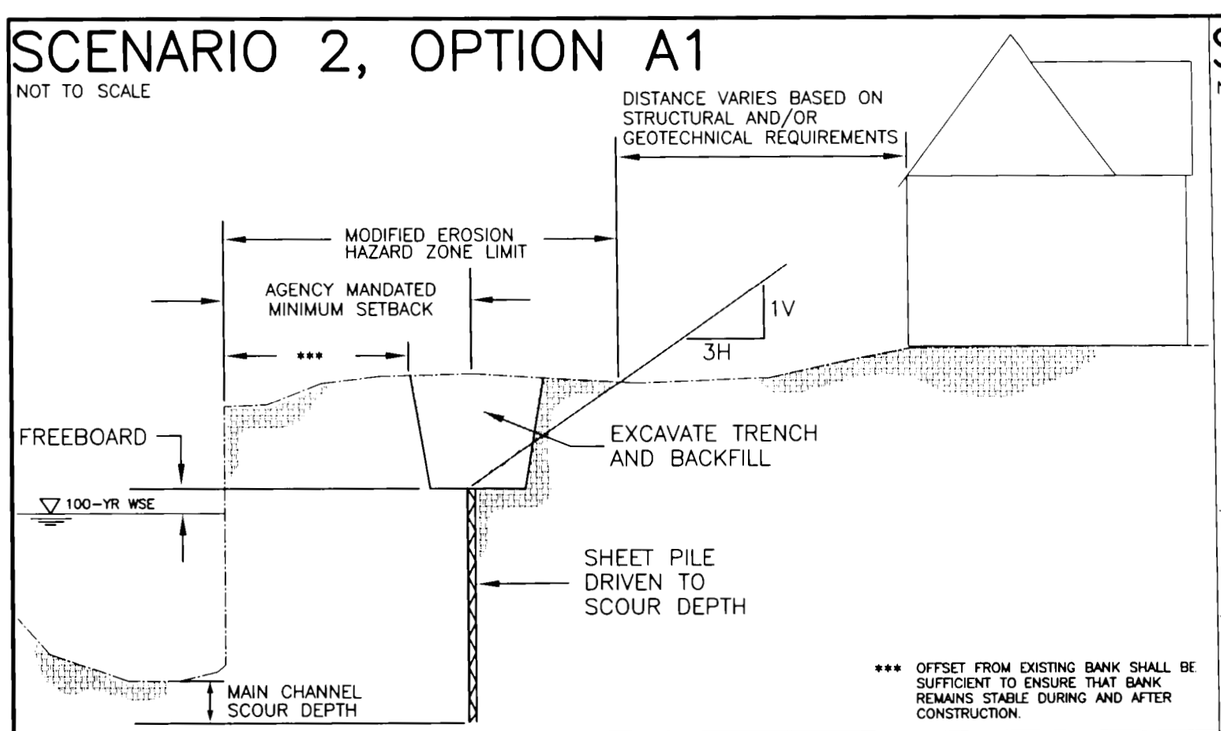

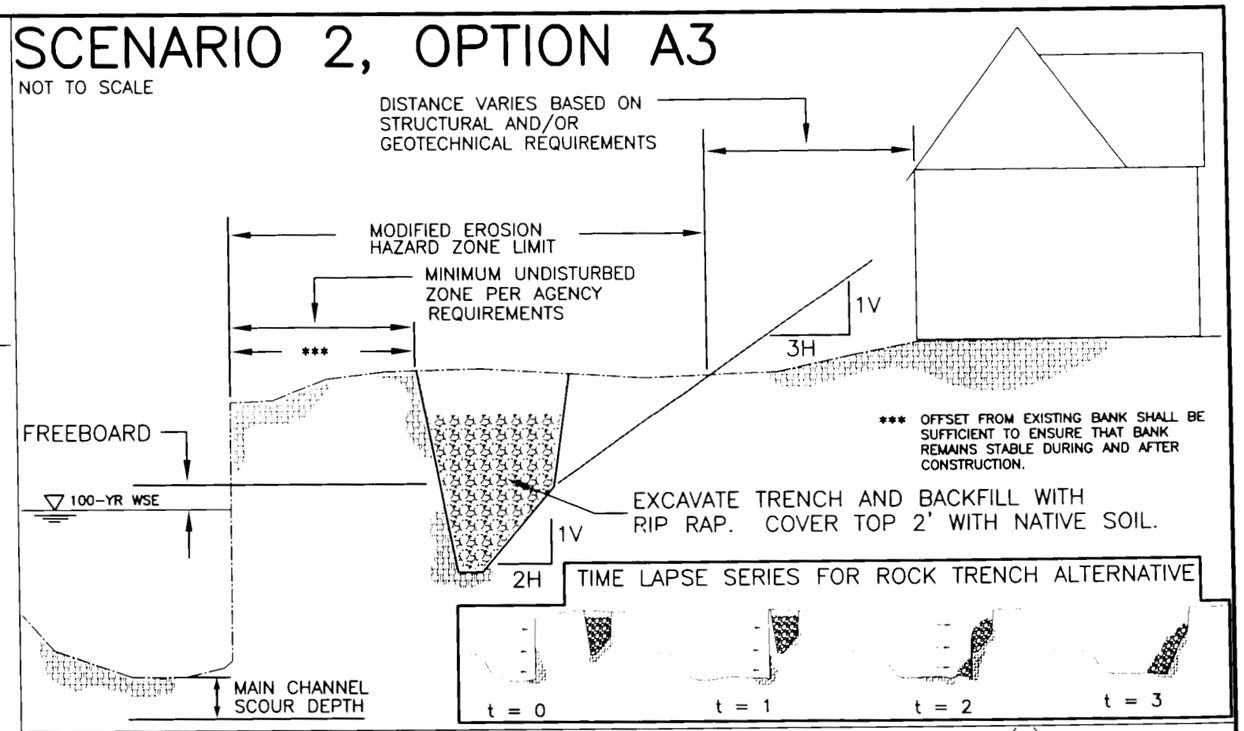

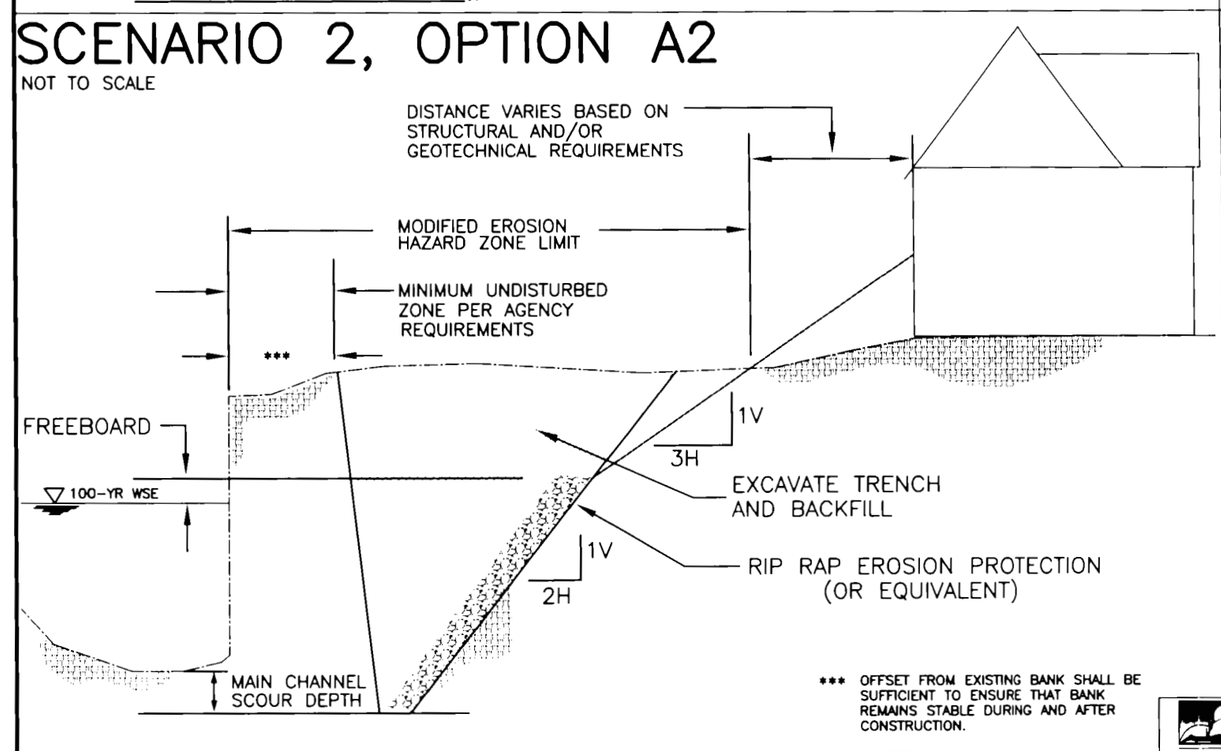

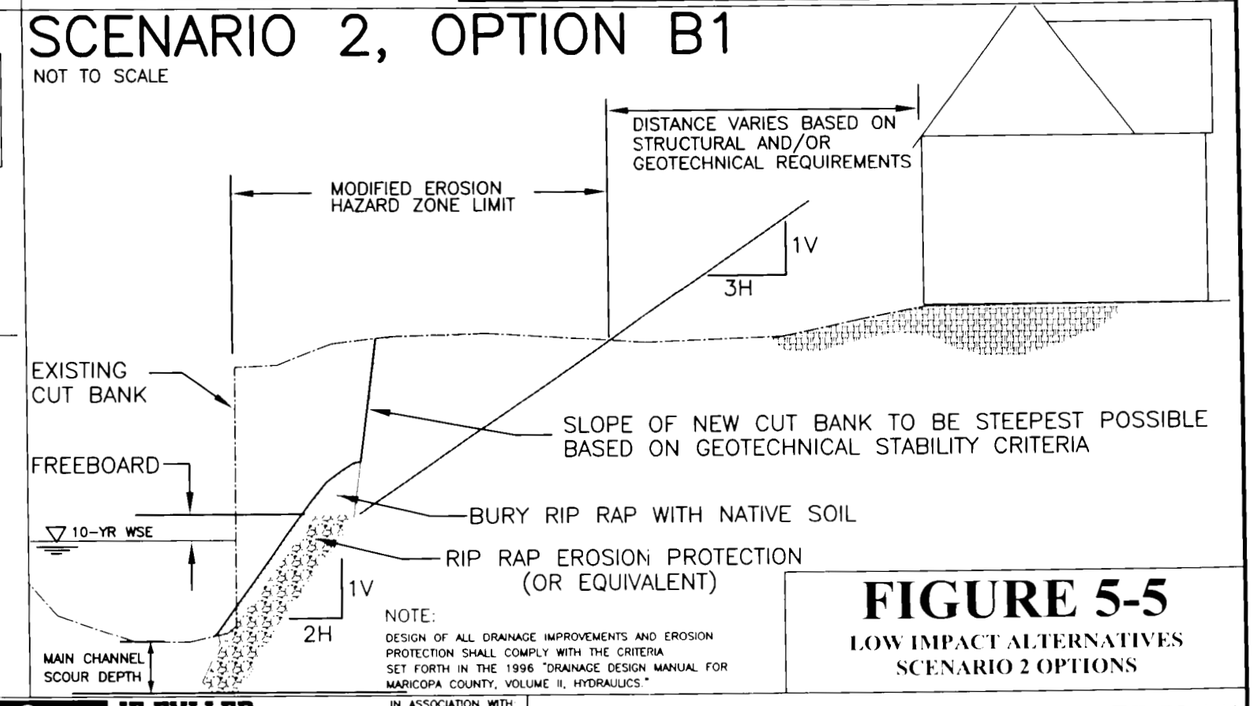

NOTE:
DESIGN OF ALL DRAINAGE IMPROVEMENTS AND EROSION PROTECTION SHALL COMPLY WITH THE CRITERIA SET FORTH IN THE 1996 "DRAINAGE DESIGN MANUAL FOR MARICOPA COUNTY, VOLUME II, HYDRAULICS."

FIGURE 5-5

LOW IMPACT ALTERNATIVES
SCENARIO 2 OPTIONS

CONCEPTUAL—NOT FOR CONSTRUCTION

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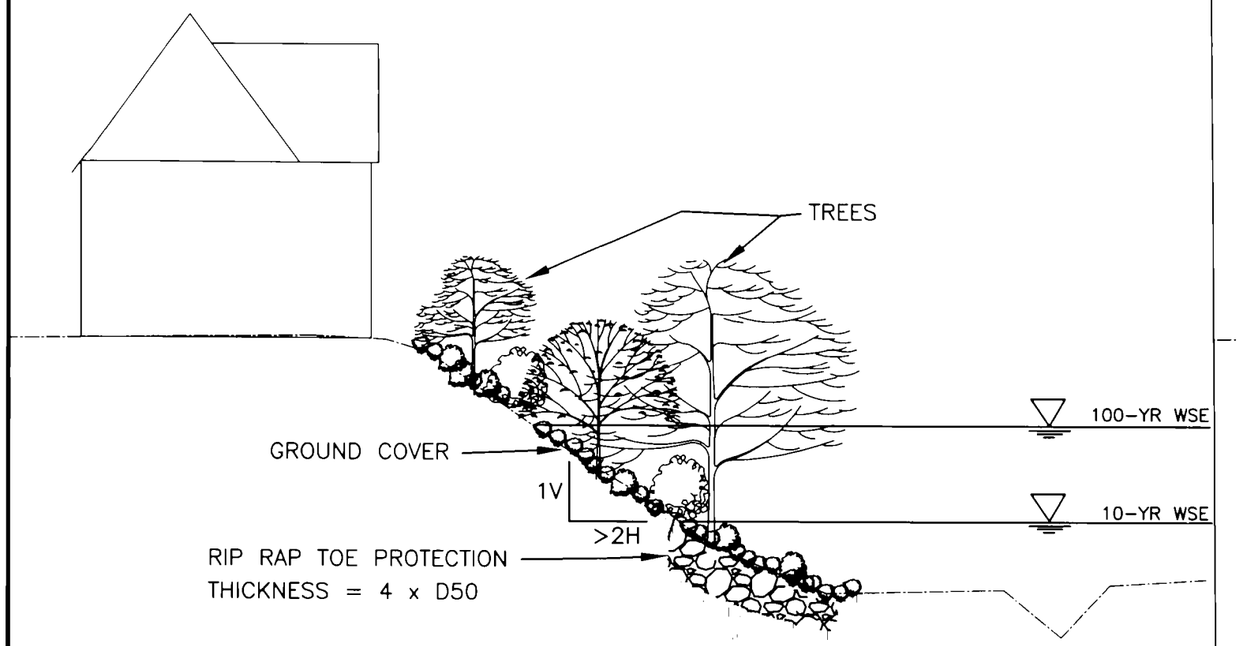
NOT TO SCALE

SCENARIO 3, OPTION A

LOW OVERBANK VELOCITY & DEPTH;
LOW POTENTIAL FOR AVULSIONS



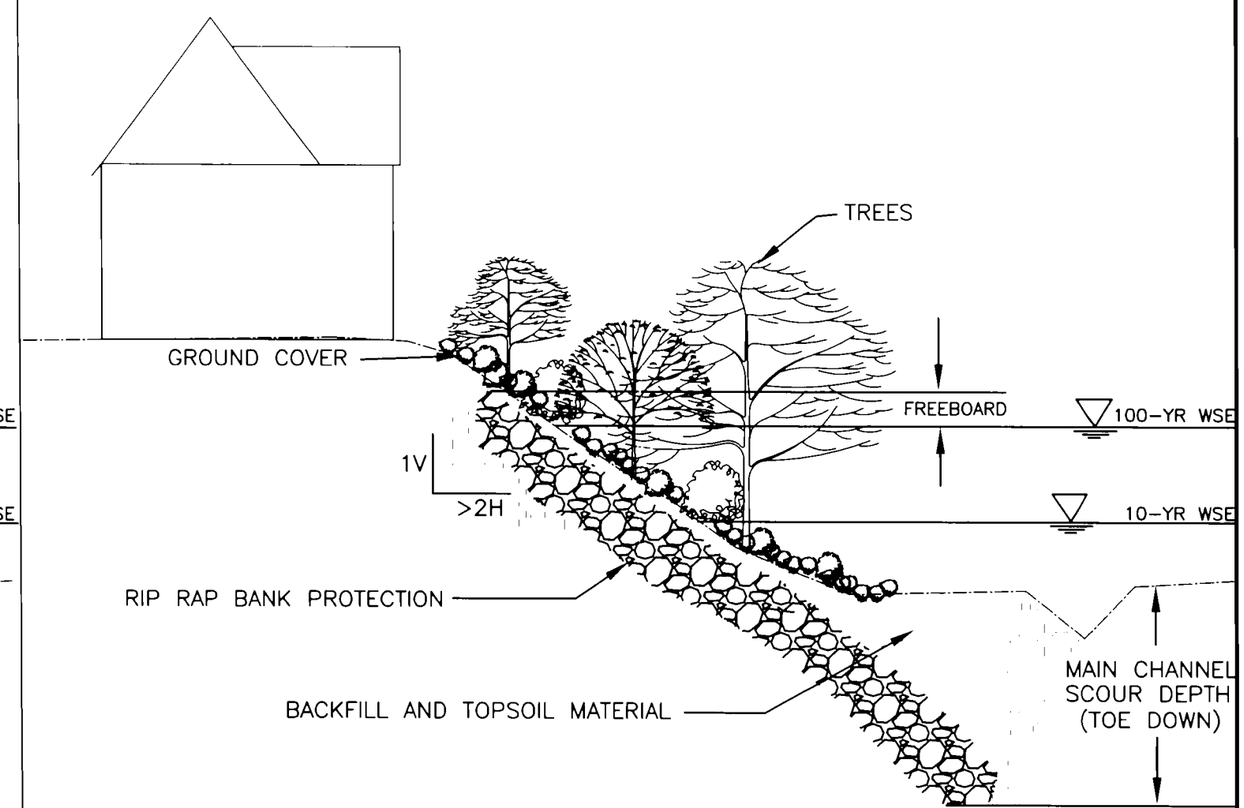
DESIGN NOTES:

- Q100 OVERBANK VELOCITY < 5 FPS
- LOW AVULSION POTENTIAL
- BURY RIP RAP AND REVEGETATE
- IRRIGATION REQUIRED TO MAINTAIN VEGETATION
- SIZE RIP RAP BASED ON LOW FLOW CHANNEL HYDRAULICS
- EXTEND PROTECTION A MINIMUM OF 100 FT UPSTREAM AND DOWNSTREAM OF STRUCTURE AND TIE INTO STABLE SURFACE
- DESIGN OF ALL DRAINAGE IMPROVEMENTS AND EROSION PROTECTION SHALL COMPLY WITH THE CRITERIA SET FORTH IN THE 1996 "DRAINAGE DESIGN MANUAL FOR MARICOPA COUNTY, VOLUME II, HYDRAULICS."

NOT TO SCALE

SCENARIO 3, OPTION B

MODERATE TO HIGH OVERBANK VELOCITY & DEPTH;
POTENTIAL FOR AVULSIONS



DESIGN NOTES:

- Q100 OVERBANK VELOCITY > 5 FPS
- HIGH AVULSION POTENTIAL
- BURY RIP RAP AND REVEGETATE
- IRRIGATION REQUIRED TO MAINTAIN VEGETATION
- SIZE RIP RAP BASED ON LOW FLOW CHANNEL HYDRAULICS
- EXTEND PROTECTION A MINIMUM OF 100 FT UPSTREAM AND DOWNSTREAM OF STRUCTURE AND TIE INTO STABLE SURFACE
- DESIGN OF ALL DRAINAGE IMPROVEMENTS AND EROSION PROTECTION SHALL COMPLY WITH THE CRITERIA SET FORTH IN THE 1996 "DRAINAGE DESIGN MANUAL FOR MARICOPA COUNTY, VOLUME II, HYDRAULICS."

FIGURE 5-6

LOW IMPACT ALTERNATIVES
SCENARIO 3 OPTIONS

CONCEPTUAL—NOT FOR CONSTRUCTION

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FLOOD CONTROL DISTRICT OF MARICOPA COUNTY
FCD CONTRACT NO. 99-45

Scenario 1 – Development Within Floodplain and Erosion Zone

With the exception of the narrow bedrock canyon reaches, the main channels in the study area generally occupy only a small fraction of the floodplain formed within the canyon bottoms. In some cases, the floodway and floodplain are coincident, limiting the potential for future development of the floodplain. Elsewhere, there are wide areas of floodway fringe that could be developed according to current FEMA regulations. However, development of the floodway fringe results in floodplain encroachment, which often increases flood and erosion hazards in adjacent reaches. Low impact alternatives for development of the floodway fringe are discussed below. Issues for development in the floodplain and erosion hazard zone under Scenario 1 include the following:

- Floodway. Development must be outside the regulatory floodway. Given the standard floodway delineation techniques usually employed in Maricopa County, there is often little developable land left between the floodway and the canyon walls, making development of the floodway fringe economically infeasible.
- Low-Impact Definition. Given the "low impact" criteria defined for this study, there is little land that could be recovered from the floodway fringe without using more intensive structural flood control measures. In some areas, the 10-year floodplain extends the width of the canyon bottom, making the low-impact standard of no disturbance of the 10-year floodplain difficult to achieve using low-impact alternatives.
- Avulsions. In many parts of the North Peoria ADMP study area, the floodplains are subject to channel avulsions. Therefore, low-impact alternatives must prevent formation of avulsive channels within the floodplain.

Scenario 1: Option A – Low Avulsion Potential. The potential for future avulsions is considered low where all of the following conditions are met:

- Infrequent Inundation. If the floodplain is rarely flooded; i.e. it is not inundated by the 10-year flood, the potential for avulsions is low.
- Low Floodplain Velocity. Where 100-year velocities in the floodplain are non-erosive, the potential for avulsion is low.
- Evidence of Deposition. Where physical evidence suggests that the floodplain is primarily subject to fine-grained sediment deposition, rather than sediment transport and erosion, the potential for avulsion is generally low.
- Topographic Uniformity. Where no evidence of formation of small overbank channels in the floodplain exists, and the floodplain surface is relatively uniform, the potential for avulsions is generally low.
- Adjacent Reaches. Where no channel splays, split channels, or channel fans are observed in adjacent reaches, the potential for avulsions is generally low.

For reaches where there is low potential for avulsions, the recommended low impact alternative is development on compacted fill or development protected by an offset levee.

Development on Compacted Fill. Development on fill is most appropriate for large lot or single lot development. The development on fill must also meet the following criteria:

- Low impact criteria defined for this study must be satisfied, e.g., no impact on 10-year flow conditions.
- Existing District regulations for floodplain development must be satisfied, e.g., 100-year flow depth must be less than two feet.
- Fill pad must be compacted and protected from erosion.
- FEMA criteria for development on fill must be satisfied.
- Visual and habitat impacts should be mitigated.

Development Protected by an Offset Levee. Protection of floodplain development by an offset levee is most appropriate for planned communities and subdivisions where the cost of the levee can be justified by the high density of housing. Design criteria for an offset levee are similar to those described below under Scenario 1 Option B. The design of the offset levee must also meet the following criteria:

- Erosion protection is required on the levee face.
- Levee erosion protection should be toed down below the depth of expected scour in the main channel.
- Low impact criteria defined for this study must be satisfied, e.g., no impact on 10-year flow conditions.
- District and FEMA other regulations for levees and floodplain development must be satisfied.

Scenario 1: Option B – Avulsion Potential. Where the potential for avulsions exists, low impact alternatives for development are generally not feasible, primarily because the 10-year flood fills the entire floodplain or flows within overbank channels that traverse most of the floodplain. In the rare cases where an avulsion hazard exists, but development could occur without significantly impacting the 10- and 100-year water surface elevations or velocities, the low impact alternative consists of construction of an offset levee to prevent overbank flow concentration that could lead to formation of an avulsive channel in the floodplain. Conceptual design of an offset levee is shown in Figure 5-4. Design criteria for the offset levee include the following:

- Erosion protection is required on the levee face, and should be designed using velocities and depths computed for the main channel.
- Levee erosion protection should be toed down below the depth of expected scour in the main channel.
- Levee erosion protection should be buried and revegetated to mitigate visual impacts and replace lost habitat. Irrigation may be required to assure the survival of vegetation on the levee face.
- Low impact criteria defined for this study must be satisfied, e.g., no impact on 10-year flow conditions or on the main channel bed and banks.
- The levee should be tied in to stable surfaces to prevent failure by flanking.
- The levee should extend at least 100 feet downstream of any structure it protects.
- District and FEMA regulations for levees and floodplain development must be satisfied.

Scenario 2 – Development Outside Floodplain, Adjacent to Actively Eroding Bank

Actively eroding cut banks were observed on reaches of all the major watercourses in the North Peoria ADMP study area, as described in Chapter 3 of this report. In many cases, the tops of the cut banks were higher than the 100-year water surface elevation. Therefore, the terrace above the cut bank is mapped as outside the 100-year floodplain, despite the potential for future lateral erosion to make those areas part of the main channel. The erosion hazard zone boundaries, described in Chapter 3 of this report, were widened adjacent to actively eroding channels to account for the potential for future lateral erosion. Within the North Peoria study area, lateral channel movement of more than 100 feet in the past 40 years was measured by comparing channel positions on historical and recent aerial photographs. Because of the potential for future channel erosion, no development should be allowed within the delineated erosion hazard boundaries unless erosion protection or more detailed erosion hazard analyses are provided. Low impact alternatives that would provide engineered erosion protection and allow development in recovered portions of the erosion hazard zone are described below.

Some of the issues associated with implementation of low-impact alternatives along stream reaches with actively eroding banks include the following:

- Habitat. Some cliffs along channel margins provide habitat for certain animal species. Alternatives which would immediately or ultimately remove cliffs should be evaluated by appropriate environmental scientists for potential impacts on those species.
- Landscape Character. Loss of naturally formed cut banks and cliffs would alter the visual character in some reaches of the study area.
- Sediment Supply. Erosion of cut banks can be an important source of sediment for some watercourses. Depletion of the sediment supply increases the potential for long-term degradation and lateral migration in adjacent reaches.
- Environmental Permitting. Direct modification of channel banks requires review and clearance by environmental permitting agencies.
- Cost. Cost of effective erosion protection may be more than the value of the land recovered from the erosion hazard zone.

Two low-impact erosion protection alternatives are proposed for development adjacent to cut banks.

Scenario 2: Option A – Offset Erosion Protection. Offset erosion protection is any form of erosion protection that is set back from the existing channel bank, and leaves the main channel bank undisturbed (Figure 5-5). Design and implementation issues for offset erosion protection include the following:

- Minimal Permitting. Since the erosion protection is not constructed within the U.S. Army Corps of Engineers jurisdictional limits (outside the ordinary high watermark), Section 404 and floodplain use permits are generally not required.

- Eventual Exposure of Erosion Protection. As lateral migration occurs, the offset erosion protection will eventually be exposed. The exposed erosion protection could mar the natural landscape character, unless mitigation measures are made after the material is exposed. The cost of mitigation would be borne by homeowner's associations or public agencies.
- Cost. The construction cost of offset erosion protection can be significant and may exceed the value of the land recovered from the erosion hazard zone. Economic analyses are recommended prior to implementation of an offset erosion protection alternative.
- Sediment Supply. In the short-term, offset erosion protection does not disrupt the sediment supply derived from bank erosion because the offset erosion protection leaves the main channel banks in their natural condition. However, over the long term, once the erosion protection is exposed, the portion of the sediment load derived from bank erosion will no longer be available, and the stream will tend to seek its supply by increasing erosion from other parts of the floodplain. If the remainder of the erosion hazard corridor is preserved (i.e., no floodplain encroachment or channelization) loss of the sediment source at the offset erosion protection boundary should not significantly impact overall channel stability in adjacent reaches. That is, future adjustments will occur within the corridor defined by the erosion hazard boundary and the offset erosion protection.

Offset erosion protection alternatives considered included the following types of materials and construction methods, as depicted in Figure 5-5:

- Buried Rock Trench
- Buried CSA
- Buried Gabions
- Buried Rip Rap
- Buried Sheet Pile

The types of material selected for the offset erosion protection were not evaluated in detail for this analysis, but were merely identified to develop order-of-magnitude costs for comparison of non-structural, structural and low-impact alternatives. Other materials or construction techniques that meet the low-impact criteria defined above and the other objectives of the North Peoria ADMP could also be selected.

Design guidelines for offset erosion protection include the following:

- Offset Distance. The offset distance, or the area above the top of bank to be left undisturbed should be established by a geotechnical investigation, as shown in Figure 5-5. Alternatively, a minimum setback distance that exceeds the geotechnical requirements may be defined by zoning or the appropriate regulatory agency. The geotechnical investigation should establish the setback distance required to destabilizing the existing channel bank during construction.
- Minimum Erosion Zone. Development should be located no closer than three times the difference in height between the ground surface and the top of the offset

erosion protection (Figure 5-5), unless a geotechnical investigation certifies that a lesser distance is safe.

- Toe Down. The depth of offset erosion protection should be equal to elevation of the 100-year general scour depth plus the long-term scour in the main channel.
- Height of Erosion Protection. The offset erosion protection should extend to the 100-year water surface elevation plus freeboard.
- Revegetation. Surfaces disturbed by construction of the offset erosion protection should be revegetated using appropriate native plants.

Scenario 2: Option B – Toe Protection. The primary failure mechanism for the types of bank erosion observed in the study area is erosion of the toe of the bank. Toe erosion is the primary bank failure mechanism for the following reasons:

- Flow Frequency. The vast majority of flows are small events with shallow depths that only reach the toe of the bank. Even for the largest floods, most of the flood hydrograph occurs at stages well below the peak stage. For example, the 100-year design hydrographs used in the North Peoria ADMP only exceed the 2- and 10-year peak discharge rates for about 5 and 3 hours, respectively. That is, more than 60 percent of the 100-year flood occurs at rates below the 10-year peak discharge.
- Flow Duration. Flow duration data from gauged ephemeral streams in central Arizona indicate that more than 99 percent of the annual runoff volume occurs during flows which peak at less than the 2-year flood. Since bank erosion is more strongly related to flow duration than to flow peak, flows rates with longer durations are more effective agents of erosion than those with shorter duration.
- Critical Threshold of Movement. The smallest flows probably do not have sufficient velocities and depths to significantly alter the channel morphology or erode the banks. Therefore, a combination of at least moderate flooding and long flow duration is required to cause significant channel change and bank erosion.
- Saturation. Bank erosion occurs at faster rates when the banks are saturated than when they are not. The lower, more frequently inundated part of the bank is far more likely to be inundated than the top of the bank.
- Basal Endpoint Control. As the toe of a bank is eroded, material from the top of the bank collapses into the channel and forms a talus pile at the base of the bank slope. If the talus materials are not swept away by subsequent flow, they buttress the rest of the bank slope, and are said to provide "basal endpoint control" that prevents further failures of the bank by undercutting. Fine materials in the talus slope are typically removed by future flows, while any large, immovable materials form a natural toe protection.

Therefore, if adequate toe protection is provided, the risk of future lateral movement is significantly decreased. Some of the advantages of toe protection compared to traditional 100-year bank protection include the following:

- Cost. The construction cost of providing toe protection is significantly less than the cost of providing offset erosion protection or bank protection up to the 100-

year water surface elevation, because less protection material (rip rap, soil cement, etc.) and earthwork are required for construction.

- Visual Impacts. Toe protection has a smaller construction footprint and requires less disturbance of the natural bank slopes than offset erosion protection, and thus has fewer visual impacts.
- Less Habitat Impact. Toe protection disturbs less of the natural bank slopes and thus has fewer impacts on native habitat than traditional bank protection.
- Kinder, Gentler Approach. Use of toe protection is consistent with the "kinder, gentler" approach to flood control advocated by the District and the overall goals of the North Peoria ADMP.
- Technically Sound. Toe protection addresses the primary erosion mechanism that causes bank failures. Engineered material installed above the 10-year water surface elevation provides insignificant amounts of actual protection from erosion. Where minor erosion occurs during rare floods that exceed the 10-year peak, it can be repaired after the event.
- Permitting Issues. Use of toe protection in conjunction with revegetation is a common stream restoration technique. Use of restoration technology, in conjunction with low visual and habitat impacts, may facilitate environmental permitting.

Design and implementation issues related to use of toe protection as a low impact alternative include the following:

- Soil Material. Use of toe protection is not appropriate if banks above the erosion protection consist of highly erosive or fine-grained materials. Fine-grained erosive soils are vulnerable to lateral or vertical flanking during events that overtop the toe protection. Toe protection is appropriate where native soils consist of resistant bouldery and/or carbonate-rich materials.
- Flanking. Toe protection should tie into stable surfaces to limit the potential for lateral flanking.
- Local Runoff. Local runoff should be prevented from flowing over the unprotected bank slope, particularly where the source of runoff is from urbanized watersheds. Flow over the top of an unprotected bank can lead to headcut or rill erosion.
- Low-Impact Standards. Construction of toe protection should not alter the geometry or hydraulic performance of the main channel or 10-year floodplain, in keeping with the low-impact standards defined for this analysis.
- Slope Failures. Natural slope processes may cause gradual slumping of the upper banks above the toe protection, until the natural angle of repose is achieved. Development should be set back a minimum of three times the difference in height between the top of bank (development elevation) and the top of the toe protection.
- Construction Materials. For this analysis, rock rip rap material was assumed to be used for the toe protection. A variety of engineered materials are possible, but the toe protection will perform better if it is flexible enough to withstand settling, permeable to allow vegetative growth, and stable enough to resist erosion.

- Design standard. The specific design criteria for toe protection depend on the local hydrology, hydraulic conditions, and bank soil characteristics. The conceptual design used for this analysis assumed the following:
    - Toe protection extends to the 10-year water surface elevation or the top of the opposite (non-cut) bank, whichever is higher.
    - Toe protection is toed down to the 100-year scour depth.
    - Toe protection material is specified to be stable at the 100-year channel velocity and depth.
- Revegetation. Revegetation of toe protection may require irrigation, inspection and maintenance to assure survival.
- Aesthetic Concerns. At minimum, toe protection should be buried to minimize visual impacts of the engineered elements.

Scenario 3 - Outside Floodplain, Not Adjacent to Actively Eroding Bank

The erosion hazard analyses described in Chapter 3 demonstrate that the main channels have actively migrated across the canyon bottoms of the major watercourses in the study area. Therefore, even though a channel bank or sloping canyon wall may be well-vegetated and appear stable today, it is highly likely to be subject to active erosion at some time in the future. Areas that are not actively eroding were identified using the following characteristics:

- Side Slope. If the canyon (or bank) side slope is greater than 2:1, it has probably been subject to recent channel erosion, or at minimum, to slope erosion processes.
- Vegetation. Canyon (or bank) slopes that are well vegetated, especially with woody, slow-growing vegetation have not been subject to active lateral erosion.
- Soil Material. The presence of carbonate (caliche), large cobbles and boulders was considered evidence of slow rates of lateral erosion.

To account for potential future erosion of these areas due to shifting of the main channel within the floodplain, the erosion hazard boundaries were generally located a short distance from the tops of the canyon slopes and terrace margins. The defined erosion hazard zone width varied depending on the following factors:

- Floodplain Flow Depth
- Floodplain Velocity
- Avulsion Potential
- Long-Term Degradation in Main Channel
- Terrace Soil Characteristics

The applicability of the low-impact alternatives outlined below depends on the factors listed above.

Scenario 3A – Low Floodplain Velocity and Low Avulsion Potential. Where floodplain velocities are low and there is little chance of an avulsion that could cause the main channel to impact the canyon slope, a lower level of erosion protection is recommended (Figure 5-6). Low floodplain velocity is defined as a computed 100-year velocity that is

less than five feet per second (5 fps). The erosion protection should include the following characteristics:

- Toe Protection.
  - Install engineered bank protection up to the 10-year water surface elevation. Rip rap should be installed at a thickness that is four times the mean rock size (D_{50}) to allow for some toe scour. Mattress applications shall be toed down at a maximum 2H to 1V slope and to a depth below natural grade that is equivalent to the 10-year depth of flow.
  - Size bank protection for channel velocity, not floodplain velocity.
  - Design bank protection to prevent flanking; e.g., extend laterally.
- Revegetation.
  - See revegetation guidelines below.
  - May require irrigation and maintenance to assure survival.
- Monitoring and Inspection.
  - Require annual inspection of revegetation to assure health.
  - Require seasonal inspection of channel position or evidence of avulsion formation.

For reaches where 100-year floodplain velocities and depths are extremely low (< 2 fps and < 1 ft., respectively) and no avulsion potential exists, no engineered erosion protection is required if the canyon slope vegetation is maintained and floodplain conditions are regularly monitored.

Scenario 3B – High Floodplain Velocity or High Avulsion Potential. Where floodplain velocities are high, floodplain depths are high, or where a significant avulsion potential exists, erosion protection with the following characteristics is recommended (Figure 5-6):

- Bank Protection.
  - Install engineered bank protection up to the 100-year water surface elevation plus freeboard.
  - Bank protection should be toed-down below the long-term and general scour elevation of the main channel.
  - Size bank protection for channel velocity, not floodplain velocity.
  - Design bank protection to prevent flanking; e.g., extend at least 100 feet laterally upstream and downstream of the nearest structure.
- Revegetation.
  - See revegetation guidelines below.
  - Bank protection should be buried and revegetated.
  - May require irrigation to assure survival.
- Monitoring and Inspection.
  - Require annual inspection of revegetation to assure health.
  - Require seasonal inspection of channel position or evidence of avulsion formation.

Vegetation Guidelines

DATE: December 27, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E., Stantec Consulting

FROM: Jon Fuller, P.E.

RE: North Peoria Area Drainage Master Plan
Sedimentation Engineering & Geomorphic Evaluation
Task 2.4.2.4.3 – Geomorphic Impacts of Detention Alternatives

Introduction

This memorandum describes the results of a qualitative geomorphic analysis of retention/ detention alternatives considered as part of the North Peoria Area Drainage Master Plan (ADMP). The primary objective of this analysis was to describe qualitatively the probable geomorphic impacts of the retention/detention alternatives on the washes in the study area. The following retention/detention alternatives were analyzed:

- No Retention
- In-Line Retention/Detention
- Side-Weir Retention/Detention

This analysis was performed by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting, Inc. (Stantec) under Task 2.4.2.4.3 of contract FCD 99-45 with the Flood Control District of Maricopa County (District).

Urbanization Impacts on Storm Water Hydrology

Urbanization generally results in significant changes to the hydrologic response of a watershed. Typically, the change in land uses from natural rangeland to urban development results in increased magnitude and frequency of runoff due to the addition of impervious surfaces such as rooftops and streets. Both maximum instantaneous discharges and total runoff volumes are increased by urbanization. Urban watersheds also tend to collect runoff more efficiently and more quickly than natural basins. The decrease in travel time for runoff through the basin results in increased peak discharges. These types of changes to the hydrologic system due to urbanization may have adverse effects on the geomorphic system.

Figures 5-7 to 5-9 show examples of the effects of urbanization on runoff hydrographs and flood frequency relationships from the North Peoria study area.

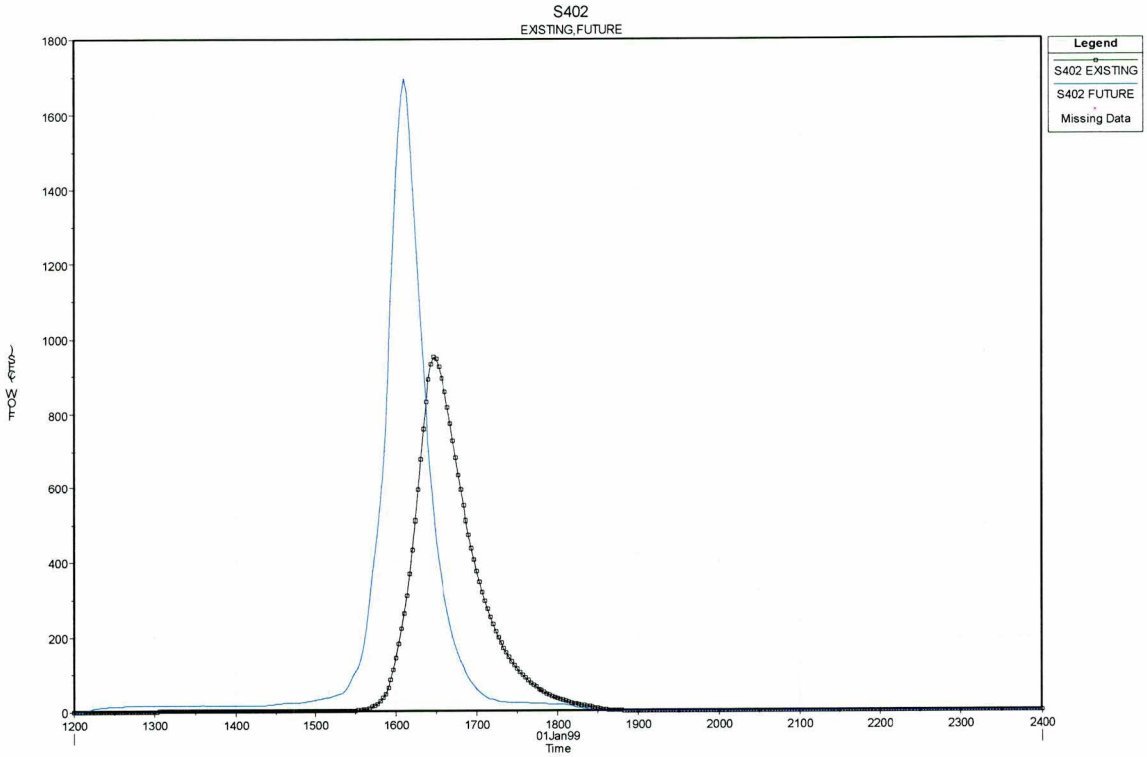

Figure 5-7 - Example of natural vs. urbanized hydrographs. Black line represents the natural condition hydrograph. Blue line indicates the urbanized condition hydrograph. Hydrograph is from Caterpillar Tank Wash.

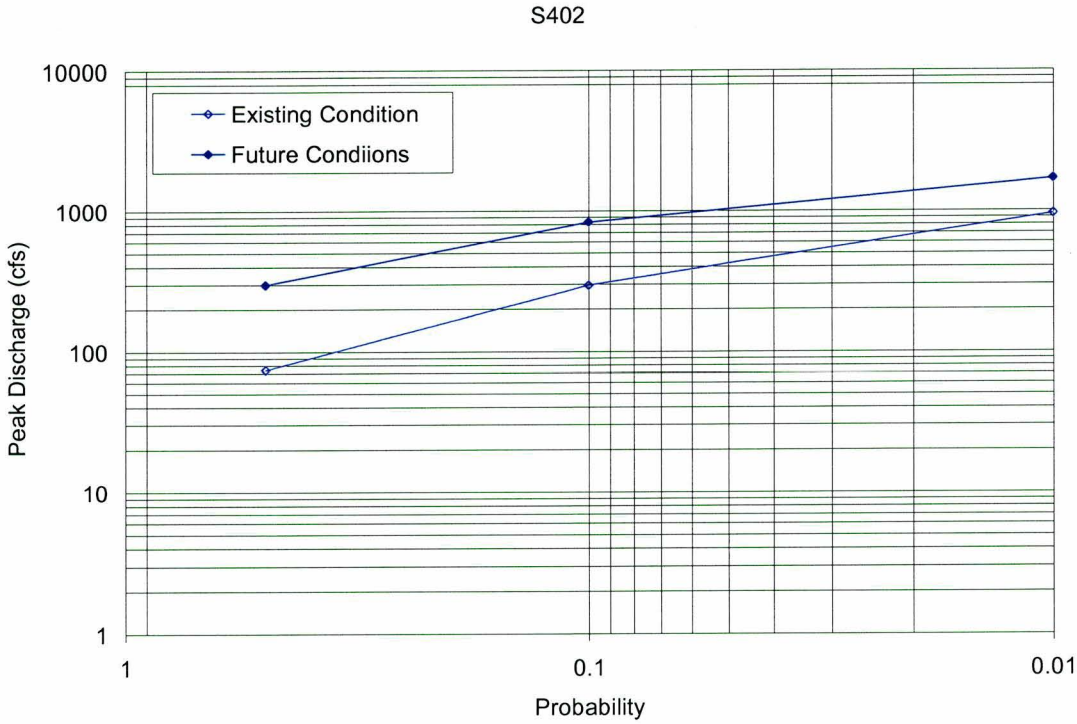

Figure 5-8. Comparison of a typical existing vs. future (urbanized) condition flood frequency curve from the North Peoria ADMP study area showing the increase in flood frequency and magnitude.

Land use managers have attempted to counteract the adverse hydrologic impacts of urbanization by implementation of storm water retention and detention policies. Retention is the storage of surface runoff where no runoff exits the collection system. Storm water runoff is "retained" by a flood control facility, usually a below ground retention basin, and drains by infiltration and/or evaporation. Retention systems primarily mitigate the increase in storm water volume due to urbanization. Detention refers to drainage systems that temporarily hold back or "detain" runoff before returning it to a channel or stream. Detention systems are typically designed to reduce the peak discharge due to the storage effect of the detention basin as the runoff passes through the facility. Detention systems primarily mitigate the increase in storm water peaks due to urbanization.

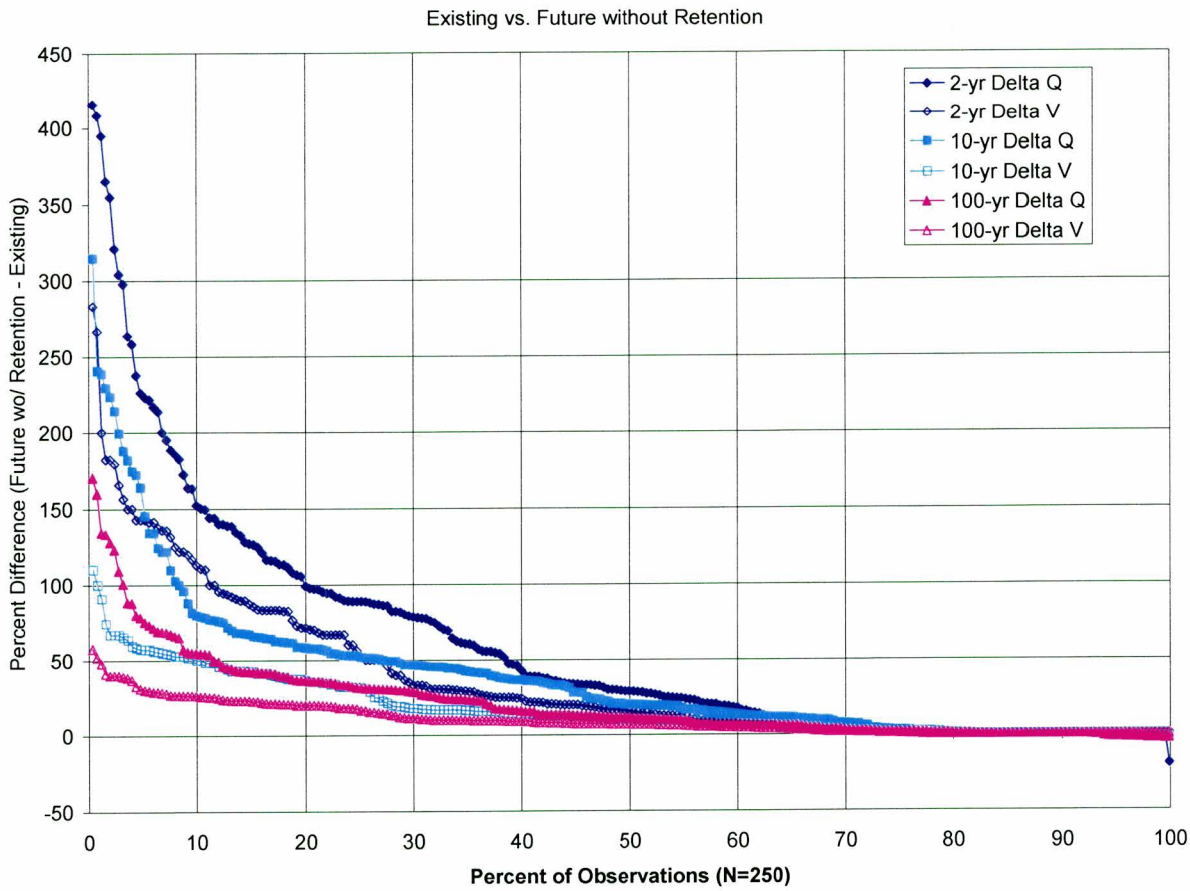

Figure 5-9. Existing vs. future peak discharge and runoff volume for 2-yr, 10-yr, and 100-yr floods in the North Peoria ADMP study area with no retention considered.

Summary. The geomorphic impacts to the stream systems in the North Peoria ADMP study of requiring no retention or detention include the following:

- The volume and frequency of flooding increases (Figure 5-9).
- More rainfall events become runoff.
- Increased flooding results in more geomorphic work.
- Increased geomorphic work results in more lateral and vertical erosion.
- Increased erosion may result in loss of bank vegetation.
- Loss of bank vegetation will result in increased rates of bank erosion.

Increased flooding and erosion in the North Peoria ADMP study area will result in increased sediment deposition in the Agua Fria River, increased flood damages in the study area, and increased infrastructure and maintenance costs for public agencies.

Geomorphic Impacts of Retention

A retention approach to moderating the effects of urbanization addresses the increased volume of runoff. Retention also alters runoff frequency if the retention facility is located so all local runoff flows into the facility. Realistically, retention facilities rarely capture all the local runoff. In particular, streets that run adjacent to or cross a stream will likely create runoff that is not collected by a retention facility. Also, runoff in excess of the retention facility storage volume will continue to flow out of the basin, often with little impact on the magnitude of peak discharge. In some cases, depending on the retention facility design, some flood peak attenuation may occur. Overall, enforcing retention policies has the following hydrologic effects:

- Small Events. The frequency and magnitude of the most frequent runoff events would be increased due to urbanized areas flows that are not captured by retention basins.
- Moderate Events. The frequency and magnitude of peak discharges and volumes for events would be decreased for events up to the retention facility volume.
- Large Events. The largest events that exceed the retention facility volume would experience little or no effect on the peak discharge, but would have a decrease in volume.

Small Events. The geomorphic effect of urbanization with retention reflects the hydrologic changes to the flood flow frequency regime. More frequent, small rainfall events that would otherwise infiltrate or be intercepted will become runoff due to increased imperviousness, and will enter the channel system and cause localized erosion near the outfalls. Because of their small contributing drainage areas, these frequent runoff events will not likely be capable of significant geomorphic work within the main channel. The primary effect of these small, frequent events include the following:

- Formation of small scour holes at outfall locations
- Intermittent ponding in scour holes
- Increased vegetation growth near ponding and runoff areas

Of the three effects listed above, the increased vegetation growth probably has the most important geomorphic effect on the main channels. Vegetation increases hydraulic roughness, which decreases flow velocity and increases flow depth. Therefore, when larger floods occur, the vegetation stands may result in increased flow depths and increased areas of inundation (wider, deeper floodplains) as compared to the natural condition. Additionally, deposition of sediments created by the reduction in flow velocity could also lead to reduced flow area and therefore even greater flow depths and areas of inundation.

Moderate Events. Decreases in flood frequency and magnitude for the intermediate runoff events (i.e. up to the retention facility volume) means that less geomorphic work (i.e. sediment transport) will be done in the channel. In other words, for the intermediate events, rainfall that

would have caused runoff in the stream is now impounded in a retention basin. If channel slopes are insufficient or discharges are drastically reduced, the result may be deposition in the channel. Deposition occurs because tributary drainages without retention provide sediment to the channel which cannot be transported by the (now smaller) intermediate floods. Deposition decreases cross sectional area, increasing flow depth.

For example, Twin Buttes Wash, while it has slopes of about 1.3 percent, has future development planned for almost the entire watershed. Consequently, the future condition (with retention) 2-year peak discharges result in an average channel velocity of only 2.3 feet per second (fps) and a discharge of about 35 cfs throughout much of the system. The future condition discharge without retention for Twin Buttes Wash ranges from about 200 to 500 cfs. Typical median particle sizes based on field observations are about 15 mm. Incipient motion analysis indicates that, on average, these particles may be just barely transported. The average, however, is the result of oscillations between pool and riffle sections where the riffles are competent to initiate sediment transport, while the pool sections are not. Therefore, increased deposition in pool reaches may be expected. Alternatively, Unnamed Wash #2, which has a slope of about 1.5 percent, has an average channel velocity of 5.6 ft/s for the 2-year discharge in the future condition with retention. Field observations indicate that the median particle size in Unnamed Wash #2 is about 10 mm. Incipient motion analysis shows that, on average, the 2-year discharge in Unnamed Wash #2, even after development with retention, is capable of transporting particles smaller than about 60 mm, which represent nearly 90 percent of the channel sediments.

Reductions in discharges for the intermediate events may also have an effect on the survival of riparian vegetation along the channel banks. Bank vegetation enhances channel stability and reduces lateral migration rates. If a large percentage of the natural runoff volume is retained and not released into the stream system, vegetation which relies on the surface runoff will eventually die. A reduction in bank vegetation density, particularly for the woody, deep rooting species, would result in increased rates of bank erosion during large floods.

The overall impact of retention on the small and intermediate events would be less overall bank vegetation, with isolated clusters of dense vegetation dependent on low quality pavement drainage that collects at scour holes near urban drainage outfalls. Sediment from un-retained tributaries will accumulate at confluences with the main stem streams, resulting in general aggradation and loss of channel capacity. Into this modified setting, the large floods will still occur as described below.

Large Events. Large, infrequent floods in excess of the retention facility volume will result in significant geomorphic work due to the changes in the small and moderate event hydrographs. The hydrologic analyses conducted by Stantec (2001) and shown on Figure 4-12 in Chapter 4 of this report, show that peak discharges increase for the 10- and 100-yr events in much of the study area, despite implementation of retention policies, in the urbanized portions of the watershed. The increased peak discharges from urbanization will be capable of more lateral and vertical erosion compared to the natural condition due to increased stages (deposition) and loss of bank vegetation. The runoff volume, however, will be reduced for all flow events up to at least the 100-year event (see Figure 4-13). Runoff volumes decrease for larger floods, according to the Stantec HEC-1 modeling.

Decreases in vegetation and aggradation resulting from decreased runoff volumes coupled with increased peak discharges for infrequent floods could lead to excessive lateral and avulsive channel changes. Moreover, the recovery time for the channel from the pronounced erosive effects of the large floods will be extremely long due to the lack of runoff during more frequent storms. In addition to the impacts discussed above, retention basins will trap sediment eroded from developed watersheds. This reduction in sediment delivery to the channel system downstream of retention basins may result in channel degradation and increased bank erosion in watersheds without undeveloped natural areas which can supply sediment to the system. In partially developed watersheds, the decreased sediment delivery from the developed areas may offset the local aggradation created by deposition in the channel from the undeveloped areas. Monitoring of sensitive areas and management of the erosion hazard zones is described in more detail in Chapter 3 of this report.

Geomorphic Impacts of Detention

The detention approach to managing the hydrologic effects of urbanization addresses the increased magnitudes of peak discharges from urbanized watersheds. Detention may also alter runoff frequency depending on the hydraulic design of the facility. Ideally, a detention facility would replicate the natural, pre-development flood frequency relationship as closely as possible. Therefore, the hydrologic effect of urbanization using the detention approach will vary depending on the facilities' design and the ability of the design to mimic natural runoff hydrographs. Also, the number and location of detention facilities will influence the geographic distribution of the hydrologic impacts of urbanization.

The geomorphic impact of detention depends on the magnitude of the outflows from the detention facility, which is a function of the size and design of the detention facility outlet structure. Detention reduces the peak discharge, but does not appreciably change the runoff volume. Therefore, detention will result in increased quantities and frequencies of runoff to the channels, while the magnitude of the peak flow rates will be a function of the facility hydraulic design. As with the retention approach, it is not practical to expect that all runoff will enter the detention facilities. Therefore, more frequent runoff to the channels is expected locally, potentially increasing vegetation growth in the channel, as described above. Moreover, the extended duration of detention outflow relative to the shorter duration natural hydrograph may cause more vegetative growth over longer reaches of the channel, in addition to vegetative growth caused by small flows which bypass the facility. Therefore, increased vegetative growth is more likely for the detention scheme as compared to retention. Increased vegetative growth in the channel and floodplain could result in increased deposition, which would decrease cross sectional area in the channel and expand the inundation area for any given discharge.

Detention basins which alter the natural flood frequency regime for the channel will have effects similar to those of any dam – namely, deposition upstream and degradation downstream. The magnitude of the impacts on the channel is a function of the magnitude of the alteration from the natural condition. Some reaches within the North Peoria study area have channels dominated by bedrock (see Chapters 1, 2, and 3). These channels are not susceptible to degradation. Elsewhere, outflows greater than the threshold discharge for sediment movement have the

potential to cause significant long-term degradation (vertical erosion). Increased lateral erosion occurs if degradation occurs and no grade control is provided.

Detention basins that do not alter the natural flood frequency relationships for a watershed may still cause some adverse geomorphic impacts on channels in urbanized watersheds. Even though the shapes of the natural flood hydrographs are mimicked by a well-designed detention basin, the total runoff volume increases (Figure 5-10). Increased runoff volume with no change in peak discharge means longer durations of flow. Longer flow durations mean more geomorphic work will occur. The result will be increased vertical and lateral erosion, unless channels are formed in bedrock canyons. Increased work applied to a channel could be especially dramatic in ephemeral washes unaccustomed to frequent flow.

An unintended consequence of storm water detention in an urban watershed is change in the timing of peak discharges from various subwatersheds. Development does not necessarily happen concurrently throughout the watershed and does not always occur according to the current zoning. Consequently, changes in peak discharge timing, even reduced peak discharges, can result in increased peak discharges elsewhere in the watershed. Geomorphic impacts associated with increased peak discharges include increased vertical and lateral channel erosion.

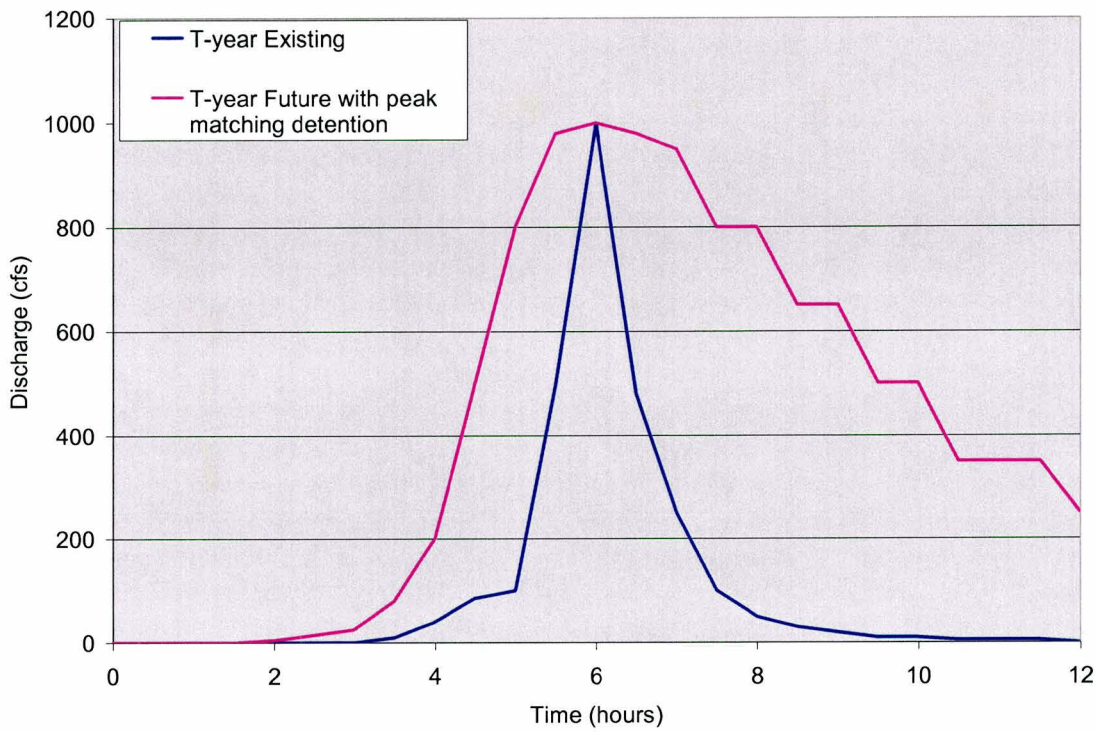

Figure 5-10. Comparison of hypothetical hydrographs for natural vs. urbanized watershed with a detention basin designed to match peak discharges for a particular frequency.

Detention can be accomplished by flood control facilities that are constructed directly on a stream system (in-line detention) or by facilities that capture a portion of runoff diverted from the stream system (side-weir detention).

Geomorphic Impacts of In-Line Retention/Detention Basins

Conceptual designs and hydrologic modeling of in-weir detention basins have been prepared by Stantec (2001). The geomorphic impacts of in-weir detention facilities are a subset of the types of impacts for retention and detention facilities described above. Impacts of in-line detention on sediment yield and channel stability were also discussed in Chapter 4 of this report. In-line detention basins have similar impacts to dams. The following items summarized the expected effects of in-line detention basins:

- Basin Design. Hydrologic effects of individual basins depend on the design of the outfall structure. Basins with large outlets and less frequent ponding have less significant impact on channel stability.
- Retention Element. If all runoff is effectively retained for the 100-year, 2-hour rainfall per County regulation, peak discharges and volumes generally decrease (Figure 5-9).
- Dam Impacts. In-line detention basins cause dam-like effects with long-term degradation occurring downstream and aggradation occurring upstream. A rule of thumb for upstream aggradation is a 50% of reduction of the original slope, as demonstrated in the discussion of sedimentation in Bailey Tank in Chapter 4 of this report.
- Maintenance and Inspection. Channel and basin maintenance and inspection are required to manage sediment deposition and vegetation growth, and to assure continued performance of the basin.
- Habitat Impacts. In-line basins cause a major disturbance of the wash corridor with high impacts on wildlife movement and vegetation.
- Hard Point. Detention basins, like any constructed facility in a wash, introduce a hard point which prevents the natural horizontal and vertical adjustments by the fluvial system.
- Channel Stability. Use of in-line detention basins will result in increased rates of lateral and vertical erosion during large floods.

Geomorphic Impacts of Side-Weir Detention Basins

Conceptual designs and hydrologic modeling of side-weir detention basins have been prepared by Stantec (2001). The geomorphic impacts of side-weir facilities are similar to those related to increases in storm water volume, as described above. While side weirs do not interrupt the natural (or post-urbanization) sediment supply, neither do they mitigate the impacts of increased discharge for events that are smaller than the design frequency of the side weir. That is, side weirs typically provide no detention for most of the floods that occur in an urbanizing watershed.

Side weir retention/detention was modeled as described in Chapter 4 and in TDN Attachment 2 (Stantec, 2001) with the flows in excess of the existing condition 100-year peak discharge diverted for each subbasin.

- Weir Design Frequency. In the future developed condition models prepared by Stantec, only flows in excess of the existing condition 100-year discharge are affected. In other words, flood peaks and volumes increase similarly to the no retention alternative, except for the most infrequent floods.
- Weir Channel Section. If channel bed elevation is not stabilized, there will be significant uncertainty about the exact discharge (and volume) diverted over the side weir. For example,

long-term degradation of the channel at the weir location would lead to increases in peak discharges downstream in the future. Therefore, a fixed channel section would be required to ensure design performance. A fixed channel section could induce local scour downstream of the grade control.

- Natural Channel Approach. Construction of a stabilized channel section to assure constant weir hydraulics defeats the ADMP goal of minimizing channel disturbance. If avoiding channel disturbance is a goal, side weir basins may not be preferred.
- Low Flow Channel Geometry. If only the 100-year peak is affected by side weir detention, and the smaller floods increase in frequency, peak and volume, then a larger low-flow channel will develop to accommodate the increased flow.
- Erosion Impacts. Increased flood magnitudes and volumes below the 100-year event will result in increased rates and magnitudes of lateral and vertical erosion.
- Reflective Scour. Near fixed channel sections adjacent to the side weir, the potential for reflective scour exists.
- Downstream Impacts. Increased flood magnitudes and volumes will cause locally enhanced deposition near the confluence of North Peoria ADMP study area washes with the Agua Fria River. However, deposition is already happening at these confluences. Significant increases in sediment delivery could result in deflection of flows within the Agua Fria channel away from the area of deposition, thus increasing erosion hazards on the other side of the Agua Fria channel from the confluences.

Summary

Retention and detention are flood control methods used to mitigate the adverse hydrologic effects of urbanization. Urbanization impacts the natural hydrologic response of a watershed, which in turn impacts the stability of the stream system. Retention and detention mitigate some of the impacts of flooding, but have additional consequences for channel stability. In general, the long-term expected response to any retention/detention alternative is increased rates of lateral and vertical erosion. Of the retention/detention alternatives considered, side-weir off-line detention will have the least impact on channel stability for the streams in the North Peoria ADMP study area.

References

Stantec, 2001, North Peoria Area Drainage Master Plan Technical Documentation Notebook Attachment 2 – Hydrology & Hydraulics. Report to the Flood Control District of Maricopa County.

DATE: December 27, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E., Stantec Consulting

FROM: Jon Fuller, P.E.

RE: North Peoria Area Drainage Master Plan
Sedimentation Engineering & Geomorphic Evaluation
Task 2.6.6 – Best Management Practices

Introduction

This memorandum lists proposed best management practices for management of sediment and scour at drainage crossings and other structural features. The best management practice recommendations are intended for use by the City of Peoria 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 North Peoria Area Drainage Master Plan (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

This memorandum was prepared by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF) on behalf of Stantec Consulting Inc. (Stantec) under Task 2.4.2.4.3 of contract FCD 99-45 with the Flood Control District of Maricopa County (District).

Erosion Hazard Zones

Erosion hazard zones were defined for each of the major watercourses in the North Peoria ADMP study area and for several of the larger tributaries. The recommended best management practice for areas within the erosion hazard zones is to prohibit construction of permanent or habitable structures. Alternatives to the recommended best management practice for erosion include the following:

- Detailed Analyses. In some cases, the erosion hazard zones delineated for the North Peoria ADMP sedimentation engineering and geomorphic analysis may be

refined by a more detailed analysis. The analysis should be completed by a registered professional engineer and qualified fluvial geomorphologist. A sample scope of work for a more detailed erosion hazard analysis is provided in Appendix 2 of Chapter 3.

- Low Impact Alternatives. Low impact alternatives for development within the erosion hazard zones were provided in the second memorandum in Chapter 5 of this report. Low impact alternatives consist of methods of constructing erosion protection that have minimal impacts on channel morphology.

Erosion hazards also exist on small watercourses in the North Peoria ADMP study area. New development should be set back a safe distance from any watercourse.

Maintenance of Bank Vegetation
Maintenance of Riparian Corridors

Bank vegetation and riparian corridors provide habitat, erosion protection, aesthetic benefits, water quality, and other vital functions for the North Peoria 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 elsewhere in Chapter 5 of this report 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. Elsewhere in Arizona, homeowners frequently cut or thin bank vegetation to gain better views of the stream bank, thus initiating or accelerating bank erosion.
    - Open space and common areas that include watercourses should be at least wide enough to encompass bank vegetation and a 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.
    - Where in-line retention is used, irrigation of bank vegetation should be required.

- Riparian Corridors. Riparian vegetation should be preserved or replaced where disturbed by floodplain development. The recommended low impact alternatives described elsewhere in Chapter 5 of this report assume that any disturbance of the

riparian corridor will be mitigated, and that additional vegetation will be planted within the stream corridor.

In general, the erosion hazard zones delineated for the major watercourses 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.

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 North Peoria ADMP study area:

- Bridges are preferable to culverts. Bridges typically have less impact on channel stability than culverts due to the wider opening and decreased likelihood of headwater ponding.
- At-grade crossings are preferable to undersized culverts. Undersized culverts are those that do not meet the recommended span and rise criteria defined below.
- 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 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.
- To prevent formation of scour holes or ponding areas, erosion protection should be provided where roadway runoff directly enters the stream channel.

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 should not change (± 0.0 ft.).
  - The 100-year water surface elevation should not increase or decrease by more than 0.1 foot.
- 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 without written permission of 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.

Erosion Hazard Evaluation

A scope of services for future detailed erosion hazard evaluations was provided in Appendix 2 of Chapter 3. Erosion hazard zones should not be modified without technical justification provided by the types of detailed analyses described in that scope of work.

Downstream Impact Assessment

The scope of services for future detailed erosion hazard evaluations provided in Appendix 2 of Chapter 3 can also be used to evaluate potential downstream impacts. 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 defined elsewhere in Chapter 5 are implemented, downstream impacts will be negligible.

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.
- Bank Slope. Use of ground cover species is encouraged from the toe of slope to the 100-year water surface elevation.
- Top of Slope. Use of drought-tolerant desert species is recommended above the 100-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.
- 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 view sheds 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.*

Chapter 6
Summary

DATE: December 27, 2001

TO: Kelli Sertich/FCDMC
Pat Ellison, P.E./Stantec

FROM: Jon Fuller, P.E.

RE: North Peoria ADMP
Sedimentation Engineering & Geomorphic Evaluation

Summary

A sedimentation engineering and geomorphic evaluation was completed as part of the North Peoria Area Drainage Master Plan (ADMP), a flood control planning study of major watersheds draining to the Agua Fria River downstream of Lake Pleasant. The objectives of the ADMP are to identify current and anticipated drainage problems and to generate development guidelines to alleviate future flooding problems.

The sedimentation and geomorphic evaluation consisted of the following elements:

- Existing Conditions Assessment
- Erosion Hazard Analyses
- Sediment Yield Analysis
- Alternatives Analysis

Existing Conditions Assessment. The existing conditions analysis indicated that there are few significant existing or historical sedimentation problems in the North Peoria ADMP study area. The limited degree of development that has occurred to date has not significantly impacted channel stability or induced sedimentation problems. 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.

Erosion Hazard Analyses. Erosion hazard analyses were completed for the following major watercourses in the North Peoria ADMP study area and several of the larger tributaries:

- Caterpillar Tank Wash
- East Garambullo Wash
- West Garambullo Wash
- Twin Buttes Wash
- White Peaks Wash
- West Fork of White Peaks Wash
- Unnamed Wash #1
- Unnamed Wash #2

- Unnamed Wash #3
- Unnamed Wash #4
- Morgan City Wash

Erosion hazard zones were delineated for each of the washes listed above. Areas located within the recommended erosion hazard setback lines are subject to increased flood and erosion risks that warrant specific development restrictions. Given the level of detail used to develop the recommended erosion hazard setback lines, the study recommends that future developers be given the option of completing a more detailed erosion hazard zone analysis. However, it is our professional opinion that any technically correct, more detailed study would reach similar conclusions to those presented in this report.

Sediment Yield Analysis. Existing and future sediment yield in the North Peoria Area Drainage Master Plan study area was evaluated using regional methods, engineering analytical tools, regional regression equations, and field data. Results from qualitative and quantitative evaluations of potential sediment yield indicate that expected sediment yields from the study area are relatively low. Future development will impact sediment yield, with potentially significant consequences for channel stability and flood control planning. For planning purposes the future condition sediment yield of 0.3 acre-feet/square mile/year is recommended. Side-weir detention was determined to have less impact on sediment yield and channel stability than in-line or no detention/retention. Historical sediment impacts have been minimal or have been adequately maintained in the past at the CAP and Beardsley Canal drainage crossings.

Alternatives Analysis. The alternatives analyzed for the North Peoria ADMP study area included consideration of the sedimentation and geomorphic impacts on channel stability of likely development scenarios such as sand and gravel mining in the Agua Fria River, floodplain encroachment, channelization, roadway crossings, and utility crossings. All types of floodplain development were found to negatively impact the stability of the major watercourses in the North Peoria ADMP study area. Negative impacts include increased lateral erosion rates, long-term degradation and scour, increased downstream flood peaks and sedimentation, and loss of floodplain function and habitat. For the North Peoria ADMP, non-structural and low-impact structural measures were found to be more appropriate than traditional full structural measures.

Low-impact alternatives were described for new development within the erosion hazard zones delineated for the major watercourses in the North Peoria ADMP study area. A working definition of low-impacts was developed and applied to typical scenarios of developable areas along the major watercourses in the study area. Low impact alternatives such as offset erosion protection, toe protection, and fill were found to be viable means of developing portions of erosion prone lands while still providing safe building envelopes for future structures.

Retention and detention alternatives for mitigating the adverse hydrologic effects of urbanization were evaluated for potential impacts on channel stability. Retention and detention mitigate some of the impacts of flooding, but have additional consequences for

channel stability. In general, the long-term expected response to any retention/detention alternative is increased rates of lateral and vertical erosion. Of the retention/detention alternatives considered, side-weir off-line detention will have the least impact on channel stability for the streams in the North Peoria ADMP study area.

Finally, best management practices intended to minimize sedimentation and channel impacts of future development were proposed for inclusion in the North Peoria Area Drainage Master Plan.