

*Draft*

**Erosion Hazard Zone  
Delineation and Development  
Guidelines**

May 2003



**Flood Control District of Maricopa County  
Regulatory Division  
2801 W. Durango St.  
Phoenix, AZ 85009**



Prepared by:  
JE Fuller/Hydrology & Geomorphology, Inc.  
6101 S. Rural Rd., Suite 110  
Tempe, AZ 85283

# **Table of Contents**

## **Section 1: Overview**

Problem Statement .....	p. 1-1
Applicability .....	p. 1-1
District Erosion Hazard Management Policies .....	p. 1-1
Purpose.....	p. 1-2
Authority .....	p. 1-2
Limitations .....	p. 1-3
Document Overview .....	p. 1-4

## **Section 2: Erosion Hazard Zone Delineation**

Types of Erosion Hazards .....	p. 2-1
Erosion Hazard Zone Delineation Methodology .....	p. 2-2
Level 1 .....	p. 2-3
Level 2 .....	p. 2-5
Level 3 .....	p. 2-9
Identifying Channel Banks .....	p. 2-12
Identifying Channel Avulsion Areas .....	p. 2-17

## **Section 3: Non-Structural Measures for Erosion Hazard Mitigation..... p. 3-1**

## **Section 4: Structural Measures for Erosion Hazard Mitigation**

Design Guidelines .....	p. 4-1
Definition of Low Impact Structural Alternatives .....	p. 4-1
Other Information .....	p. 4-2
Impact Analysis .....	p. 4-2

## **Section 5: District Review Procedures & Checklists**

Site Classification .....	p. 5-1
Review Criteria for Engineered Bank Protection .....	p. 5-4
Review Criteria for Scour Protection at Building Pads .....	p. 5-6
Review Criteria for Structural Measures in Avulsion Hazard Areas.....	p. 5-7
Erosion Hazard Assessment – Lateral Bank Erosion .....	p. 5-9
Erosion Hazard Assessment – Channel Avulsion.....	p. 5-11
Engineer’s Certification Form .....	p. 5-13

## **Section 6: References ..... p. 6-1**

## **Appendix**



## **Section 1:** **Overview**

### **Problem Statement**

One third of the nation's streams experience severe erosion problems, resulting in almost 450 million dollars in erosion-related damages per year (FEMA, 1999). In a study of riverine erosion hazards, the Federal Emergency Management Agency (FEMA, 1999) specifically noted that significant, well-documented erosion problems occur in Maricopa County. The FEMA report also states that lateral erosion in Arizona occurs to such a degree that areas outside of the designated 500-year floodplain have collapsed into the main channel due to lateral channel movement. Recent studies in Maricopa County have documented 100's to 1,000's of feet of channel bank erosion during single floods on some of the region's major watercourses (JEF, 1999; 2000; 2001; 2003). To address these unique erosion hazards, the Flood Control District of Maricopa County (District) regulates development in erosion prone areas.

### **Applicability**

The Flood Control District of Maricopa County regulates erosion hazards for all watercourses<sup>1</sup> with a 100-year discharge greater than 50 cfs. Erosion hazard zone regulations are separate and distinct from the 100-year floodway and floodplain regulations enforced by the District, and may be applicable to areas outside the regulatory floodplain.

### **District Erosion Hazard Management Policies**

The District has established the policies listed below to protect public health, safety, and welfare, to fulfill federal, state, and local mandates for floodplain management, to preserve floodplain functions and values, and to minimize the expenditure of public funds for construction and repair of infrastructure in the riverine environment. Mining operations located in the floodplain that meet the intent and criteria described in these policies will be viewed as consistent with the regulatory purpose of the District:

- 1.) New development should be located outside of the regulatory erosion hazard zone.
- 2.) Non-structural development measures are preferred over structural erosion control.
- 3.) Development within stream corridors and erosion hazard zones shall be consistent with the recommendations of any applicable watercourse master plan.
- 4.) If new development is located within a regulatory erosion hazard zone, then engineered structural erosion control measures shall be provided to protect the development.

---

<sup>1</sup> A watercourse includes any wash, arroyo, stream, creek, channel, river, or other topographic feature that conveys water.



- 5.) Development and erosion control structures shall have no adverse floodplain, erosion, or sedimentation impacts on any adjacent or off-site property.
- 6.) Channelization of natural watercourses should be avoided. A natural area buffer separating development from the main channel shall be provided.
- 7.) Technical information submitted by developers to support a floodplain use permit application shall be prepared and sealed by an Arizona-registered civil engineer with expertise in hydrology, hydraulics, sediment transport, river mechanics, fluvial geomorphology, and local stream systems.

The District has determined that watercourse erosion damages public infrastructure, private property, and public welfare. This determination is based on the District's experience gained from repair of flood damages, engineering studies, research, technical reports, historical documentation, and practical experience. Therefore, more detailed engineering analyses will be required to support any floodplain use permit application that does not meet the intent and criteria of the policies listed above.

### **Purpose**

The Flood Control District of Maricopa County has adopted the Erosion Hazard Zone Delineation and Development Guidelines for the following purposes:

- To protect the health, safety, and property of the citizens of Maricopa County.
- To minimize the expenditure of public funds for erosion hazard mitigation.
- To assure consistent floodplain management policies and review procedures.
- To inform the public of regulatory standards for development in erosion hazard zones.
- To provide guidelines for development and design to landowners, developers, and development engineers.
- To assure that development in stream corridors is consistent with the recommendations of watercourse master plans.

### **Authority**

Arizona Revised Statutes (ARS §48-3609) and the Code of Federal Regulations (44 CFR Ch.1) direct Maricopa County to promote and protect the health, peace, safety, comfort, convenience, and general welfare of its residents, to minimize public and private losses due to flood conditions in specific areas, and to enable Maricopa County and its residents to participate in the National Flood Insurance Program, receive Federal Disaster Assistance, obtain flood insurance and reduce the cost of flood insurance. To this end, the *Floodplain Regulations for Maricopa County* state:

*“This regulation includes methods and provisions for restricting or prohibiting uses which are dangerous to health, safety, and property due to water or erosion hazards, or which result in damaging increases in erosion.”* Article I, Section 104



The following portions of the *Floodplain Regulations for Maricopa County* also address erosion hazard management:

- Section 802 – “*For subdivision and master plan development, the developer shall delineate the 100-year floodplains and erosion setbacks per Arizona State Standards.*”
- Section 803 – “*Whenever the District determines ...that a flood related hazard existing due to such factors as high-velocity flow, erosion, sediment transport, deposition, unstable soil conditions or land subsidence, the Floodplain Administrator ...shall establish technical criteria and enforce rules and regulations for subsequent development...*”
- Section 902.7, Article X Section 1002, & Article XI, Section 1102 – “*Erosion setbacks shall meet Arizona State Standards or as determined by the Floodplain Administrator.*”
- Section 1401 – “*This article regulates uses located in flood hazard zones designated by the Floodplain Administrator ...including Erosion Control Zones, Watercourse Master Plans, Area Drainage Master Studies, Moveable Bed Watercourses and other special flood related designations determined...*”

State regulations also require that local communities enforce development standards in erosion hazard areas. Under the authority of Arizona Revised Statutes 48-3605(a), the Arizona Department of Water Resources (ADWR) developed standards for development near streams subject to lateral erosion. ADWR State Standard 5-96 “State Standard for Watercourse System Sediment Balance” (SS 5-96)<sup>2</sup> mandates use of a three-level procedure for determining erosion hazard setbacks to account for the natural lateral migration of Arizona watercourses.

Federal regulations for the National Flood Insurance Program (NFIP) require local communities to manage development in “flood-related erosion prone areas” in order to participate in the NFIP. 44 CFR Chapter 1, Part 60.5(a) establishes minimum standards for floodplain management of erosion-prone areas and requires that participating local communities do the following:

- (1) Require the issuance of a permit for all proposed construction, or other development in the area of flood-related erosion hazard, as it is known to the community;
- (2) Require review of each permit application to determine whether the proposed site alterations and improvements will be reasonably safe from flood-related erosion and will not cause flood-related erosion hazards or otherwise aggravate the existing flood-related erosion hazard; and
- (3) If a proposed improvement is found to be in the path of flood-related erosion or to increase the erosion hazard, require the improvement to be relocated or adequate protective measures to be taken which will not aggravate the existing erosion hazard.

---

<sup>2</sup> Arizona State Standards are available at: [www.adwr.state.az.us/publications](http://www.adwr.state.az.us/publications).



44 CFR Chapter 1, Part 60.24 further states that communities with flood-related erosion prone areas shall recognize the following:

- (a) The importance of directing future developments to areas not exposed to flood-related erosion; and
- (b) The possibility of reserving flood-related erosion-prone areas for open space purposes.

Therefore, to comply with federal, state, and local floodplain regulations, the District has adopted these guidelines for development in erosion hazard areas. For management and delineation of erosion hazard zones in Maricopa County, these guidelines replace ADWR State Standard 5-96.

## **Limitations**

Application of the methodologies and procedures outlined in this document are intended to promote safe development near erosion hazard zones. However, floods larger than the design standard can and will occur and may result in more severe flood and erosion hazards. In addition, because stream systems change with time, erosion hazard zone delineations should be updated periodically to reflect watershed and watercourse changes. This document does not specifically address erosion hazard development standards for active alluvial fans.

## **Document Overview**

In Maricopa County, the following two approaches are accepted for development in erosion hazard zones:

- Non-Structural Measures
- Structural Measures

Non-structural measures consist primarily of locating new development outside the erosion hazard zone. Structural measures consist of constructing structures to prevent erosion from impacting new and existing structures. These guidelines outline procedures for delineating erosion hazard zones so that non-structural approaches can be used, as well as procedures for evaluating structural erosion control measures. The following sections are included in these guidelines:

- ***Section 1: Overview.*** Section 1 describes the District's regulatory authority, management policies, purpose for regulation and management of erosion hazards, and a general discussion of erosion problems in Maricopa County.
- ***Section 2: Erosion Hazard Zone Delineation.*** Section 2 describes the recommended three-level methodology for delineating erosion hazard zones for watercourses where the District has not already approved an erosion hazard zone delineation. Section 2 also describes procedures for identifying channel bank locations.



- ***Section 3: Non-Structural Measures.*** Section 3 outlines the preferred non-structural approach, which consists of developing outside the erosion hazard zone.
- ***Section 4: Structural Measures.*** Section 4 outlines the criteria for designing and implementing structural approaches to erosion control, such as engineered bank protection or foundation design, to protect development built within the erosion hazard zone. Structural measures are required for all development located within the erosion hazard zone. To apply the structural approach, erosion control measures must not only prevent erosion damages, but they also must be designed to have no adverse impact on adjacent properties.
- ***Section 5: Review Procedures & Checklists.*** Section 5 consists of checklists to be used by District reviewers that indicate the types of information and analyses required with floodplain use permit applications for either non-structural or structural approaches.
- ***Section 6: References.*** Section 6 consists of technical references that discuss erosion hazard mechanics, prediction, delineation, and management.



## Section 2: **Erosion Hazard Zone Delineation**

### **2.1 Erosion Hazards**

Most of the erosion hazards that occur in Maricopa County, as illustrated in Figure 2.1, can be grouped into the following categories:

- Type A, or channel erosion, occurs within the main channel and the portions of the floodplain subject to high velocities, scour, and high rates of sediment transport.
- Type B, or avulsive channel movement, occurs within parts of the floodplain where flood depths and velocities are high enough to form new channels away from the main channel.
- Type C, or lateral bank erosion, occurs at sites located near enough to the main channel to be damaged if the channel erodes its banks or migrates within its historical channel corridor. Type C lateral erosion may also occur within the part of the Type B avulsion erosion area located near the channel bank.
- Type D erosion hazards occur within the portion of the floodplain not subject to avulsions or bank migration, where relatively low flood depths and velocities occur. Type D erosion hazards may be exacerbated where the natural shallow flooding flow paths are disturbed by development.

More than one type of erosion can affect a specific building site. Design of new structures shall consider the potential impacts from each of the four types of erosion hazard. Normally, the regulatory erosion hazard zone will include areas affected by Types A, B and C erosion hazards. Type D erosion hazards typically can be adequately addressed by elevating the structure, protecting the foundation or fill pad, and preventing concentration of floodwater conveyance through the property boundaries.

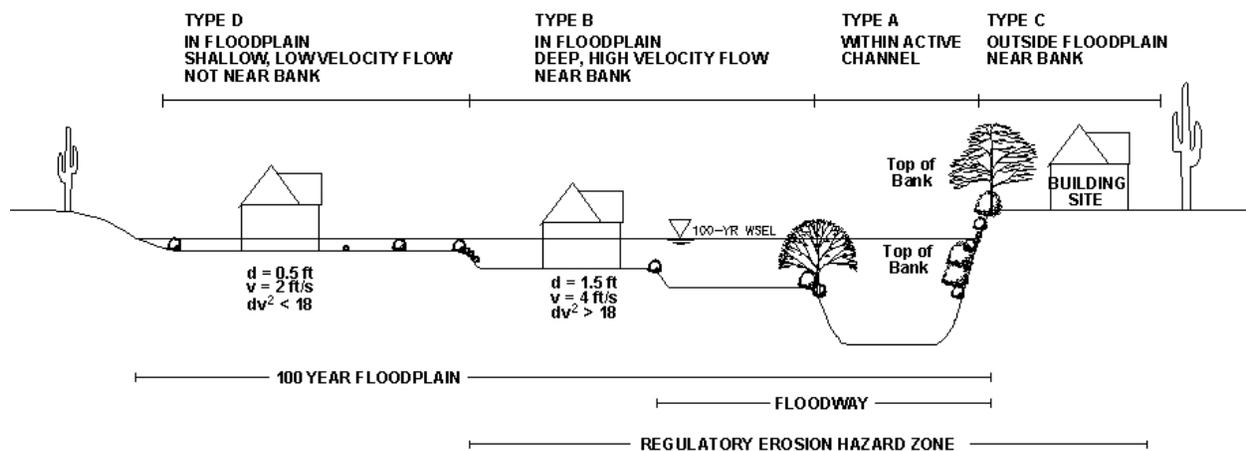


Figure 2.1. Illustration of the four principal types of erosion typically found within watercourses in Maricopa County. Note that erosion hazards may occur within or outside the regulatory floodplain.

## 2.2 Erosion Hazard Zone Delineation Methodology

If the District has not already adopted an erosion hazard zone for a specific watercourse, the erosion hazard zone limits shall be determined using the three-level methodology outlined below, in Table 2.1, and on the following pages.

- Level 1. The Level 1 methodology requires the lowest level of effort and generally results in a conservative erosion hazard zone delineation. The Level 1 methodology is typically applied only to small, single lot, or non-commercial developments, but can be applied to any type of development in watersheds less than 50 square miles.
- Level 2. The Level 2 methodology requires site information, basic hydraulic modeling, and a greater level of effort than the Level 1 methodology, but results in a site-specific erosion hazard zone more appropriate for the existing site conditions at the proposed development. The Level 2 methodology is typically applied only to small, single lot, or non-commercial developments, and may be difficult to apply over long stream reaches.
- Level 3. The Level 3 methodology consists of a detailed erosion hazard analysis, which requires special expertise in hydrology, hydraulics, sediment transport, river mechanics, fluvial geomorphology, and local stream system dynamics. A Level 3 analysis typically requires the greatest level of effort and cost. The Level 3 methodology is appropriate for multi-lot and commercial development, long stream reaches, and large watersheds.

Level	Drainage Area	Type of Development	Reach Length	Minimum Setback
1	< 50 sq. mi.	Any Type of Development	Any	Edge of floodplain + 50 ft.
2	< 500 sq. mi.	Single Lot Residential Small Commercial (< 5 acres)	< 1,000 ft.	2 x bank height (ft) or 15 ft.
3	Any drainage area	Any Type of Development	Any	2 x bank height (ft) or 15 ft. or geotechnical study

A Level 3 erosion hazard analysis is required to modify any erosion hazard zone delineation previously approved by the District as part of a watercourse master plan, area drainage master plan, floodplain delineation study, or erosion hazard study. *It is important to note that application of the Level 3 methodology does not necessarily result in a smaller setback than application of the Level 2 approach.* Therefore, in cases where the developer is intent on building close to the main channel banks or in areas likely to be in the erosion hazard zone regardless of the level of analysis, it may be more cost-effective and expedient to evaluate the feasibility of structural measures than to fund the detailed analyses required for a Level 3 erosion hazard analysis. Note that detailed engineering analyses of the proposed structural measures will also be required to demonstrate that no adverse impacts occur on adjacent properties.

Development is allowed within erosion hazard zones if the structures are adequately protected.



**2.2.1 - Level 1 Erosion Hazard Zone Delineation Analysis.** The Level 1 methodology defines the erosion hazard zone using a conservative erosion hazard setback formula. The Level 1 methodology may be used for any point along a watercourse where the watershed is smaller than 50 square miles and where no unusual conditions exist, as defined below. If no approved floodplain delineation and 100-year discharge estimate exist, floodplain data can be developed using District-approved methodologies<sup>3</sup> or the Level 1, 2 or 3 methodologies described in ADWR State Standard 2-96 (SS2-96).<sup>4</sup> The Level 1 erosion hazard setback is estimated using the equations shown in Table 2.2.

<b>Table 2.2 Level 1 Erosion Hazard Setback</b>		
<b>Drainage Area</b>	<b>Setback Equations</b>	
	<b>Straight Channel</b>	<b>Outside of Bend</b>
< 50 sq. miles	$2 * Q100^{0.5}$	$4 * Q100^{0.5}$
> 50 sq. miles	Use Level 2 or Level 3 Methodology	
Minimum setback	Edge of floodplain + 50 ft.	

**Level 1 Application Notes:**

1. Level 1 erosion hazard setbacks are measured from the nearest bank of the main channel. Criteria for identifying channel banks are described in Section 2.3 of these guidelines.
2. The minimum Level 1 erosion hazard setback is 50 feet from the edge of the floodplain.
3. If no District-approved floodplain delineation exists, the floodplain and floodway shall be defined using the District modeling guidelines<sup>3</sup> or ADWR SS2-96.
4. If the ADWR SS2-96 Level 1 approach is used to delineate the floodplain, the minimum setback may be measured from the floodway rather than the floodplain.
5. The setback equation for the outside of a channel bend shall be used where a 20° change in the low flow channel direction occurs, as illustrated in Figure 2.4. Development on the inside of a channel bend shall use the straight channel equation.
6. Development is allowed within the erosion hazard setback if it is protected from erosion.

**Unusual Conditions.** If any of the following unusual conditions exist on a watercourse, the Level 2 or Level 3 methodologies shall be applied instead of the Level 1 methodology:

- Drainage area greater than 50 square miles
- History of significant lateral bank erosion or erosion damages on the watercourse
- In-stream sand and gravel mining activity located within one mile of the building site
- Evidence of significant long-term aggradation or degradation on the watercourse
- Channelization, main channel encroachment, or bank protection immediately upstream or on the opposite bank from the proposed building site

An illustration of the Level 1 setbacks for a straight reach is shown in Figure 2.2, and for a channel bend in Figure 2.3.

<sup>3</sup> Peak discharge estimates – Maricopa County Drainage Design Manual – Volume 1: Hydrology  
 Floodplain delineation – Maricopa County Drainage Design Manual – Volume 2: Hydraulics  
 See also: FCDMC Consultant Guideline for Consultant Services Contracts

<sup>4</sup> ADWR State Standards are available at <http://www.water.az.gov/adwr/Content/Publications>.



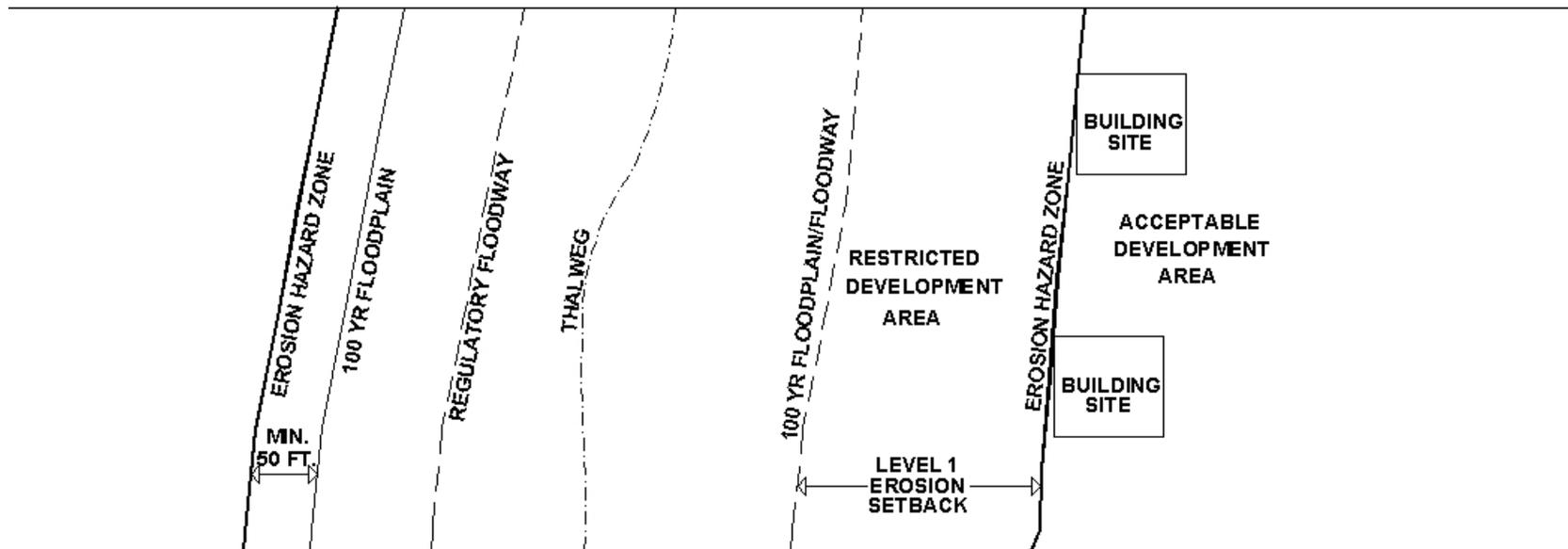
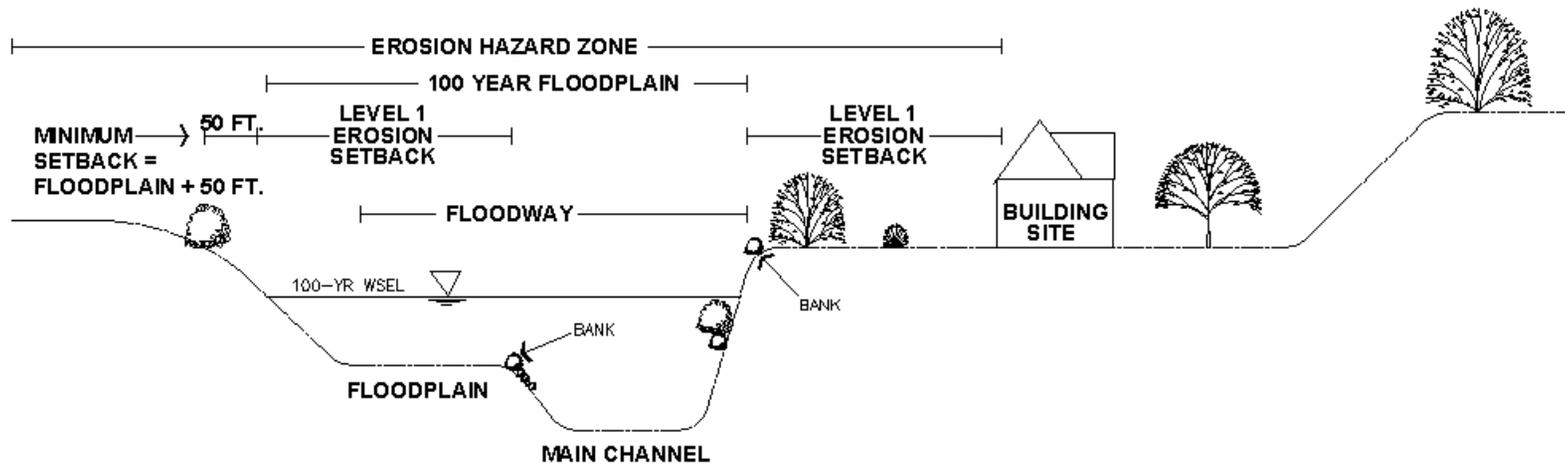


Figure 2.2. Illustration of Level 1 erosion hazard zone and building setback. Note the use of the minimum Level 1 setback on left side of the floodplain.

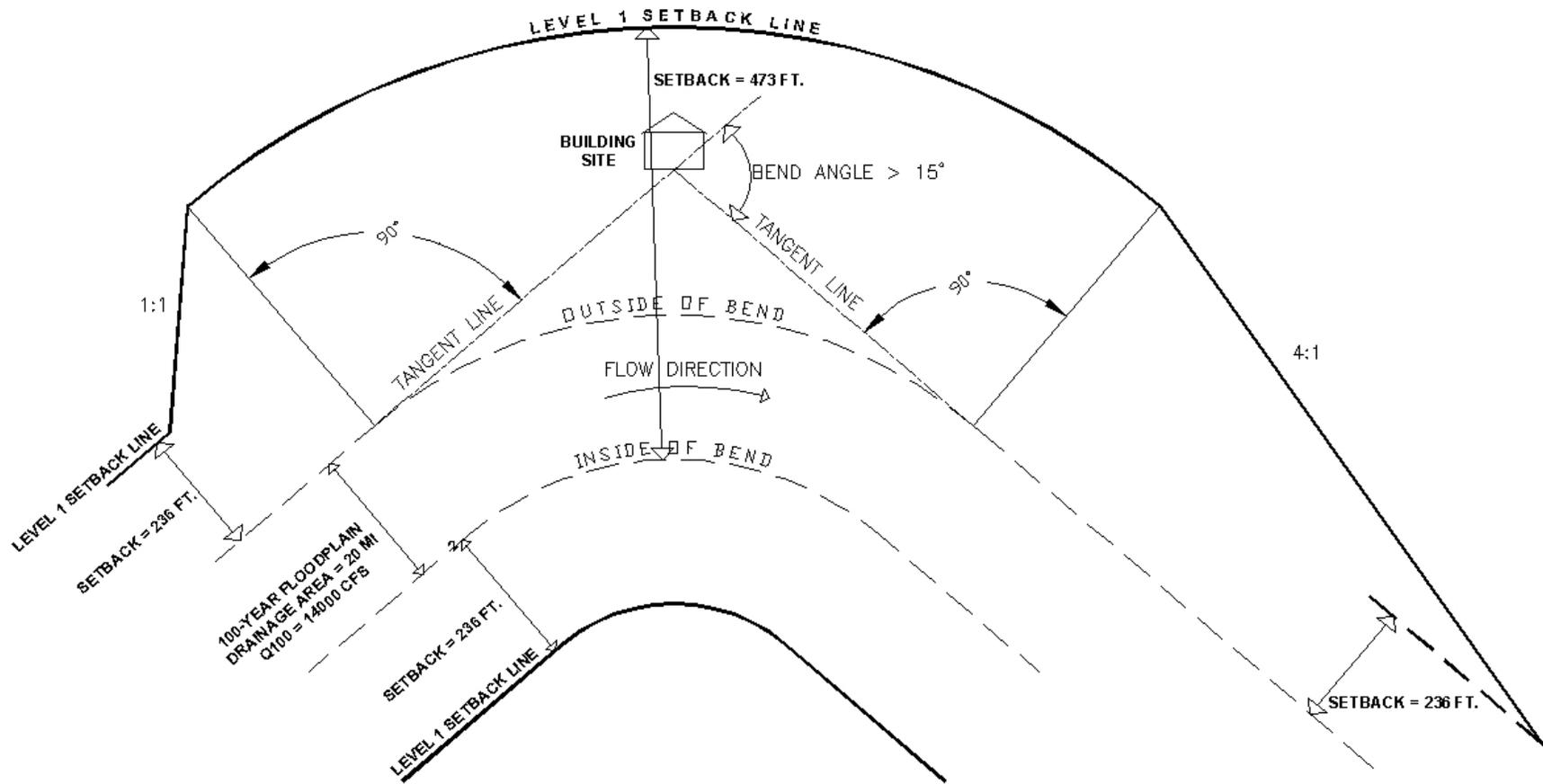


Figure 2.3. Illustration of the procedures for determining the channel bend angle and delineating the Level 1 or 2 erosion hazard zones transition from straight reaches to reaches with bends.

**2.2.2 - Level 2 Erosion Hazard Zone Delineation Analysis.** The Level 2 methodology defines the erosion hazard zone using an erosion hazard setback computed from site-specific information and field data collected from the stream reach near the proposed building site and from hydraulic data obtained from a floodplain delineation study. The Level 2 methodology may be applied on watercourses with watersheds less than 500 square miles where no unusual conditions exist, as defined in the Level 1 description (Section 2.2.1). Some hydraulic modeling, floodplain management, and field experience, as well as engineering judgment are required to apply the Level 2 methodology. The Level 2 methodology consists of the following steps:

- STEP ONE: Obtain Floodplain & Site Data (Office)
  - Existing floodplain/floodway delineation
  - Existing hydraulic model for watercourse
  - Aerial photograph of project reach<sup>5</sup>
  - Topographic mapping of channel and floodplain at project site
- STEP TWO: Obtain Hydrologic & Hydraulic Data from Existing or New Studies (Office)
  - Drainage area (< 500 sq. miles?)
  - 100-year discharge (Q100)<sup>6</sup>
  - Channel velocity ( $F_{VCH}$ )<sup>6</sup>
  - Overbank flow depth and velocity<sup>6</sup>
- STEP THREE: Obtain Map Data (Office)
  - Measure channel bend angle from aerial photograph ( $F_{\theta}$ )
  - Estimate degree and type of watershed development ( $F_W$ )
- STEP FOUR: Determine Bank Locations (See *Identifying Channel Banks – Section 2.3*)
  - Use aerial photographs, hydraulic model, and field data
  - Identify nearest main channel bank
  - Determine avulsion potential (See *Identifying Channel Avulsion Areas – Section 2.4*)
  - For avulsive areas, bank location is at margin of avulsive overbank area & setback is based on conditions at the margin of the avulsion area
- STEP FIVE: Collect Level 2 Adjustment Factor Data (Field)
  - Bankfull width/depth characteristics ( $F_{W/D}$ )
  - Bank material types ( $F_{BM}$ )
  - Bank material cementation ( $F_{C03}$ )
  - Bank vegetation density ( $F_{BVD}$ )
  - Bank vegetation type ( $F_{BVT}$ )
  - Bank condition – percent of cut banks ( $F_{CB}$ )
  - Flow condition – ephemeral vs. perennial/intermittent ( $F_Q$ )
  - Manmade channel disturbance ( $F_{MD}$ )
  - Vertical channel stability ( $F_{VERT}$ )
  - Other information - bedrock outcrops in banks, engineered bank protection
- STEP SIX: Estimate Adjustment Factors & Apply Setback Equation (Office)

<sup>5</sup> Aerials for Maricopa County can be obtained at [www.fcd.maricopa.gov/Resources/MapApplications.asp](http://www.fcd.maricopa.gov/Resources/MapApplications.asp).

<sup>6</sup> FEMA or District approved 100-year discharge values and hydraulic data should be used. If no approved values exist, new hydrologic and hydraulic data may be developed using District guidelines or ADWR State Standard 2-96. For the Level 2 erosion hazard zone delineation, use SS2-96 Level 2 or higher floodplain delineation methods.



The Level 2 erosion hazard setback can be estimated using the following basic equation:

$$\begin{aligned}\text{Setback} &= Q100^{0.5} * (\Sigma \text{ Adjustment Factors}) \\ &= Q100^{0.5} * (F_{\theta} + F_{VCH} + F_{W/D} + F_{BM} + F_{C03} + F_{BVD} + F_{BVT} + F_{CB} + F_Q + F_W + F_{MD} + F_{VERT})\end{aligned}$$

Where Q100 = 100-year peak discharge (cfs)

$F_{\theta}$  = Channel bend angle factor  
 $F_{VCH}$  = Channel velocity factor  
 $F_{W/D}$  = Bankfull width/depth ratio  
 $F_{BM}$  = Bank materials factor  
 $F_{C03}$  = Bank cementation factor  
 $F_{BVD}$  = Bank vegetation density factor  
 $F_{BVT}$  = Bank vegetation type factor  
 $F_{CB}$  = Bank conditions factor  
 $F_Q$  = Flow conditions factor  
 $F_W$  = Watershed development factor  
 $F_{MD}$  = Manmade channel disturbance factor  
 $F_{VERT}$  = Vertical channel stability factor

Adjustment factor values are listed in Table 2.6. Specific considerations for each of the adjustment factors and general Level 2 application guidelines are described in the following paragraphs.

**Channel Bend Angle Factor ( $F_{\theta}$ ).** Sinuous stream reaches and channels with sharp bends are subject to higher rates of lateral erosion and more frequent avulsions than straight channels.

- Determining Bend Angle. The bend angle may be determined using the guidelines illustrated in Figure 2.3. Where no straight reach exists upstream, the tangent line at a point upstream of the building site a distance equal to four times the channel width shall be used as the reference line from which to measure the bend angle.
- Geomorphic Feature. Channel bend angle shall be measured using either the centerline, thalweg, nearest bank, or flood channel alignment, whichever results in the most conservative setback.
- Adjacent Straight/Sinuous Reaches. On channel bends adjacent to straight reaches, the increased setback in the bend shall extend upstream from the point of curvature at 1:1 angle to meet the straight channel setback, and shall extend downstream at a 4:1 angle to the straight channel setback, as illustrated in Figure 2.3.
- Highly Sinuous Reaches. For highly sinuous reaches, setbacks for adjacent reaches immediately upstream and downstream shall be evaluated.

**Channel Velocity Factor ( $F_{VCH}$ ).** Channels with high velocities are subject to higher rates of lateral erosion than channels with low velocities.

- Channel Velocity. The maximum channel velocity shall be used to estimate the channel velocity factor ( $F_{VCH}$ ), rather than an average velocity for a cross section that includes the overbank or floodplain areas. The hydraulic model used to estimate channel velocity shall, at



minimum, subdivide the cross section into a main channel, left floodplain, and right floodplain. Channel bank stations shall be defined using the guidelines in Section 2.3.

- Average Velocity Adjustment. If the channel velocity is obtained from a hydraulic model that averages the velocity over the entire main channel, and significant (>10%) variation in depth occurs over the main channel area, the average channel velocity shall be multiplied by a factor of 1.5 to obtain an estimate of the maximum velocity. Alternatively, the maximum channel velocity may be estimated using the HEC-RAS velocity distribution option (flow tube analysis).
- Avulsion Hazard. When assessing the risk of channel avulsions, the maximum overbank velocity shall be used. The maximum overbank velocity shall be estimated using the HEC-RAS velocity distribution option, or by subdividing the portion of the floodplain that is subject to avulsions.

**Bankfull Width/Depth Ratio ( $F_{W/D}$ ).** Streams with high width to depth ratios are subject to higher rates of lateral erosion than streams with low width to depth ratios.

- Bankfull Depth. Bankfull condition occurs at the point just before flow overtops the main channel and enters the floodplain. Bankfull depth is distance between the minimum channel elevation and the top of the main channel bank. For the purposes of erosion hazard analysis, the bankfull depth is estimated using the guidelines provided in Section 2.3 and main channel top of bank. Where the top of bank elevation differs significantly between the right and left banks, the lower top of bank elevation shall be used to define the bankfull depth.
- Bankfull Width. Bankfull width is the horizontal distance between the right and left top of bank stations.
- Incised Streams. For incised streams where the 100-year flow depth is significantly less than the top of bank elevation, the 100-year flow depth may be used to estimate the width/depth ratio.

**Bank Materials Factor ( $F_{BM}$ ).** Bank materials provide resistance to lateral erosion through a variety of properties such as cohesion, armoring (sediment material size), angle of repose, ability to transmit and store water, susceptibility to piping, stratigraphy, and the ability to promote or prevent root growth.

- Bank Characteristics. Only the bank characteristics on the side(s) of the channel for which development is proposed should be considered in determining the bank materials factor.
- Layered Bank Materials. If the bank consists of layered sediments, the bank material size and cementation shall be estimated using the least stable, most erosive layer located below the bankfull or 10-year water surface elevation, whichever is lower. Layers that are thinner than 5% of the bankfull depth may be ignored.
- Lateral Continuity. Alluvial sediments frequently consist of irregular, discontinuous layers that pinch out laterally. Therefore, where bank exposures indicate a high degree of lateral variability in sediment composition, the bank material factor shall be estimated using the exposure profile within the project reach that results in the most conservative setback. The project reach is defined as the portion of the stream within one channel width of the upstream and downstream property limits.



- Sediment Size Classification. Sediment size ranges are defined in Table 10.1 of the *Drainage Design Manual for Maricopa County - Hydraulics*.<sup>7</sup>
- Bank Material Exposures. Representative exposures of bank materials may be observed in cut banks, soil pits, or tributaries that cut the floodplain. Where such features are not present, and bank materials are not readily visible, bank material sizes may be estimated from detailed soil survey data published by the Natural Resource Conservation Agency.<sup>8</sup> Note that where banks are well vegetated and are uncut by lateral erosion or tributaries, the bank slope may be coated with fine-grained sediments not representative of the subsurface materials.
- Bedrock. The extent of bedrock outcrop shall be mapped in the field and submitted as an exhibit with the floodplain use permit application. Where bedrock has been adequately mapped and is extensive and competent enough to prevent erosion, the erosion setback can be reduced to the minimum allowable setback (i.e., 15 ft.).
- Bank Protection. If bank protection is present, and is certified by a registered engineer to prevent lateral erosion, the erosion setback can be reduced to the minimum setback (15 ft.).

**Bank Cementation Factor ( $F_{C03}$ ).** Accumulation of calcium carbonate ( $\text{CaCO}_3$ , a.k.a. “caliche”) in the bank materials can significantly increase resistance to bank erosion.

- Bank Characteristics. Only the bank characteristics on the side(s) of the channel for which development is proposed should be considered in determining the bank cementation factor.
- Carbonate Stage. Descriptions of carbonate ( $\text{CaCO}_3$ ) stage are provided in Birkeland et. al. (1991) and are summarized in Table 2.6.
- Non-Carbonate Cementation. Other types of soil cementation besides carbonate may also occur in Arizona soils. The effect of non-carbonate cementation can be addressed as part of a Level 3 erosion hazard analysis, or may be used in a Level 2 analysis if sufficient supporting documentation is provided by a registered geotechnical engineer or soils scientist.
- Layered Bank Materials. If the bank material consists of layered sediments, the bank cementation factor shall be estimated using the least cemented, most erosive layer located below the bankfull or 10-year water surface elevation, whichever is lower. Layers that are thinner than 5% of the bankfull depth may be ignored. Alternatively, the bank cementation factor for each layer can be determined and weighted by the percent of the soil column it occupies relative to the bankfull depth. However, if greater than 20% of the soil column is composed of Stage 0 or I cemented materials (See Table 2.3), then 0.20 shall be added to the weighted bank cementation factor, up to the maximum value of 0.80.

<sup>7</sup> Available at: <http://www.fcd.maricopa.gov/Resources/Publications.pdf>.

<sup>8</sup> Formerly known as the USDA Soil Conservation Service (SCS).



<b>Stage</b>	<b>Gravelly Soils</b>	<b>Non-Gravelly Soils</b>	<b>Physical Characteristics</b>
0	No coatings or filaments Brown or tan matrix color	No coatings or filaments Brown or tan color	Loose, cohesionless soil No reaction to acid (HCL)
I	Thin discontinuous clast coatings Some CaCO <sub>3</sub> filaments About 4% CaCO <sub>3</sub>	Few CaCO <sub>3</sub> filaments Few coatings on sand grains Less than 10% CaCO <sub>3</sub>	Soil matrix easily broken apart by hand Weak reaction to acid
II	Continuous clast coatings Local cementation of clasts Somewhat whitened matrix	Few to common CaCO <sub>3</sub> nodules Slightly whitened matrix 10-15% CaCO <sub>3</sub>	Soil matrix can be broken with moderate difficulty Moderate reaction to acid
III	Continuous CaCO <sub>3</sub> medium Mostly white matrix color 20-25% CaCO <sub>3</sub>	Many CaCO <sub>3</sub> nodules Over 90% of matrix is white 20% CaCO <sub>3</sub>	Hard to break off clasts Need hammer to break apart Strong reaction to acid
IV	Upper layer of pure cemented CaCO <sub>3</sub> Matrix plugged with CaCO <sub>3</sub> > 50% CaCO <sub>3</sub>		Rings when hit by hammer Strong reaction to acid

**Bank Vegetation Density Factor ( $F_{BVD}$ ).** Bank vegetation can reduce the rate of lateral erosion by increasing the hydraulic roughness (lower velocity), anchoring soil material, and decreasing the amount of soil to water contact.

- Bank Characteristics. Only the bank characteristics on the side(s) of the channel for which development is proposed should be considered in determining the bank vegetation density factor.
- Density Measurement. Vegetation density can be estimated from the percent of bank soils obscured from sight when looking directly at the bank from the channel bottom. Photo documentation shall be provided to support the visual estimate of bank vegetation density.
- Seasonal Variation. Bank vegetation density shall be estimated for the season during which most floods occur on the watershed. The dominant flood season can be determined by examining USGS gauge records<sup>9</sup> for nearby watershed or by examining local precipitation records.<sup>10</sup>
- Variable Bank Cover. The density of bank vegetation typically varies over a stream reach. If the bank cover density is variable, an average cover density value shall be used. If large patches of un-vegetated banks occur in the project reach, the minimum (not average) cover density value shall be used.

**Bank Vegetation Type Factor ( $F_{BVT}$ ).** Different plant species provide different levels of bank stability and resistance to erosion.

- Bank Characteristics. Only the bank characteristics on the side(s) of the channel for which development is proposed should be considered in determining the bank vegetation type factor.
- Vegetation Condition. Three conditions of bank vegetation cover are defined in Table 2.4. To assign the appropriate  $F_{BVT}$  value, determine which of the three conditions best describes the bank vegetation near the project reach and select the corresponding value.

<sup>9</sup> USGS streamflow records can be obtained at <http://waterdata.usgs.gov/nwis>.

<sup>10</sup> Arizona climate data can be obtained at <http://ag.arizona.edu/agnet/dbaseapps/>.



- **Vegetation Types.** For the purposes of these guidelines, woody species are those that consist of a well-defined trunk and leafy canopy. Shrubs consist of a narrow stem, are generally less than six feet high, and include plants that tend to bend downstream when submerged in flowing water. Grasses are annual species that grow low to the ground, lack a trunk, and tend to lie flat when submerged by flowing water.
- **Perched Vegetation.** Bank vegetation is ineffective at preventing erosion if the root mass is exposed by bank erosion or the roots do not extend below water surface elevation of the most frequent floods. Therefore, bank vegetation growing at the top of a bank should not be considered in the bank vegetation type factor if the root mass does not reach below the channel bed.

<b>Table 2.4. Bank Vegetation Type Factor Conditions</b>		
<b>Condition #</b>	<b>F<sub>BVT</sub> Value</b>	<b>Description</b>
1	0.20	Deep rooting woody species <ul style="list-style-type: none"> <li>• No woody plants or isolated emergent woody plants</li> <li>• Woody plants perched above channel bottom</li> </ul> Shrub and grass cover <ul style="list-style-type: none"> <li>• Sparse (&lt; 25% cover) cover, bare ground between plants</li> </ul>
2	0.10	Deep rooting woody species <ul style="list-style-type: none"> <li>• Isolated woody plants separated by greater than one canopy width</li> <li>• Small diameter emergent woody species</li> <li>• Some roots of large plants near bank exposed by erosion</li> </ul> Shrub and grass cover <ul style="list-style-type: none"> <li>• Moderate cover (25-50%), bare ground between plants</li> </ul>
3	0.00	Deep rooting woody species <ul style="list-style-type: none"> <li>• Root mass extends below channel invert</li> <li>• Trunk diameter of most woody plants &gt; 4 inches</li> <li>• No roots exposed by bank erosion</li> <li>• Close spacing: interlocking root masses and continuous canopy</li> </ul> Shrub and grass cover <ul style="list-style-type: none"> <li>• Bank slope has greater than 50% cover</li> </ul>

**Bank Conditions Factor ( $F_{CB}$ ).** The physical condition of the stream banks provides evidence of whether the stream has been subject to recent lateral erosion and may be subject to future bank erosion.

- **Bank Characteristics.** Only the bank characteristics on the side(s) of the channel for which development is proposed should be considered in determining the bank conditions factor.
- **Bank Conditions Factor ( $F_{CB}$ ) Value.**  $F_{CB}$  is estimated from the sum of the following variables using the values listed in Table 2.5:
  - a. **Percent of Cutbanks.** If a high percentage of the project reach has cutbanks, a high rate of future lateral erosion should be expected.
  - b. **Freshness of Cutbanks.** In arid regions like Arizona, cutbanks may persist for long periods after they form due to infrequency of channel forming flows, resistant bank materials, and/or slow rates of slope processes and vegetative growth. Newly formed (fresh) cutbanks are most diagnostic of significant erosion hazard.
  - c. **Thalweg Proximity.** The banks closest to the thalweg, or lowest part of the active channel, are most likely to experience lateral erosion.



- **Cutbank Definition.** A cutbank is defined as a vertical or near vertical, unstable, unvegetated stream bank that has been recently eroded or trimmed by lateral erosion. If a stream does not continue to erode the bank to a vertical face, slope processes will work to flatten the bank slope to its angle of repose (typically, about a 2:1 slope). The rate at which slope processes act on a stream bank is a function of the resistance of the bank slope material, the climate, interference by stream processes, and other hydrologic and geologic factors.
- **Bank Resistance.** The resistance of the bank sediments is not a component of the bank conditions factor. Bank material resistance is accounted for in the bank materials factor ( $F_{BM}$ ) and bank cementation factor ( $F_{CO3}$ ). Therefore, a bank shall be identified as a cutbank if it meets the defining criteria outlined above, regardless of the type of alluvium that forms the bank.
- **Basal Endpoint Control.** Basal endpoint control occurs when material eroded from the vertical bank is not removed by stream flow and begins to form a sloped bank at the base of the vertical slope.

<b>Variable</b>	<b>Characteristic</b>	<b><math>F_{CB}</math> Component Value</b>
Percent of Cutbanks	0-5% of banks in reach are cutbanks	0.00
	5-25% of banks in reach are cutbanks	0.15
	> 25% of banks in reach are cutbanks	0.30
Freshness of Cutbanks	Steep banks, vegetated, basal control, and resistant materials	0.00
	Vertical cutbanks with some vegetation, basal control, or resistance	0.15
	Vertical cutbanks in loose alluvium, no basal control, recent erosion	0.30
Thalweg Proximity	Thalweg abuts opposite bank	0.00
	Thalweg is located mid-channel	0.05
	Thalweg abuts toe of bank	0.10

**Flow Conditions Factor ( $F_Q$ ).** Ephemeral streams tend to be poorly vegetated, subject to erosive flash floods, experience slow recovery from flood damage, and are more likely to be braided or exist in a state of non-equilibrium. Perennial and intermittent streams tends to be better vegetated, have more stable stream patterns, and be more resistant to lateral erosion than ephemeral streams.

**Watershed Development Factor ( $F_W$ ).** Urbanization often causes changes in the natural hydrology of a watershed that result in erosive channel changes such as long-term degradation, increased flooding, or depletion of sediment supply.

- **Floodplain Management.** If an approved Area Drainage Master Plan (ADMP) that addresses flooding and sedimentation exists for the watershed and retention/detention is enforced in the watershed, a value of  $F_W = 0.00$  may be used.
- **Definitions.**
  - a. Development means any type of residential, commercial, industrial, or agriculture land use except rangeland.
  - b. Natural Watershed. Natural watersheds include those that are located within a National Forest or managed public rangeland not located adjacent to major urban centers. Public lands, except designated wilderness areas, national parks, and national



- monuments, adjacent to major urban centers shall be considered as undeveloped watersheds.
- c. Undeveloped Watershed. An undeveloped watershed consists of private or public land that has not yet been subject to development.
  - d. Partially Developed Watershed. A partially developed watershed consists of less than 50% developed lands.
  - e. Urbanized Watershed. An urbanized watershed consists of more than 50% developed lands.
- Data Sources. Estimates of existing and potential urbanization can be made from field inspections, regional land planning documents, and aerial photographs.

***Manmade Channel Disturbance Factor ( $F_{MD}$ )***. Manmade disturbances of the natural channel such as floodplain encroachment, in-stream sand and gravel mining, highway encroachments, construction of bank protection or channelization often leads to accelerated rates of lateral erosion in adjacent reaches.

- Floodplain Management. If an approved Watercourse Master Plan (WMP) or other floodplain policy that prevents or mitigates manmade channel disturbances is enforced for the watercourse, a value of  $F_{MD} = 0.00$  may be used.
- Reach Length. The estimate of the degree of disturbance shall be based on the following stream reach lengths:
  - a. Drainage area  $< 10 \text{ mi}^2$ : one mile upstream and downstream.
  - b. Drainage area  $10\text{-}50 \text{ mi}^2$ : two miles upstream and downstream
  - c. Drainage area  $> 50 \text{ mi}^2$ : five miles upstream and downstream
- Definitions.
  - a. Natural Floodplain. A natural floodplain has less than 10% of the pre-development floodplain altered by construction, grading, fill placement, roads, or development (including the development for proposed project).
  - b. Moderately Disturbed Floodplain. A moderately disturbed floodplain has between 10 and 50% of the floodplain altered by construction, grading, fill placement, roads, or development, but none of the specific conditions listed for Disturbed Floodplains.
  - c. Disturbed Floodplain. A disturbed floodplain has greater than 50% of the pre-development floodplain altered by construction, grading, fill placement, roads, or development, or has any of the following conditions within the reach length, as defined above:
    - i. Bank protection constructed on the opposite bank
    - ii. Bank protection or any form of channelization located immediately upstream from the proposed project
    - iii. In-stream sand and gravel mining
- Data Sources. Estimates of manmade channel disturbance are best made using field observations and comparisons of recent and historical aerial photographs.<sup>11</sup>

---

<sup>11</sup> Recent aerial photographs can be obtained at [www.fcd.maricopa.gov/Resources/MapApplications.asp#](http://www.fcd.maricopa.gov/Resources/MapApplications.asp#).



**Vertical Channel Stability Factor ( $F_{VERT}$ ).** Channel degradation is closely linked to increased lateral erosion of the incised channel. Conversely, long-term aggradation leads to channel widening and/or avulsive channel change.

- Definitions.
  - a. Degradation. Progressive lowering of the channel bed elevation with time.
  - b. Aggradation. Progressive increase in the channel bed elevation with time.
- Data Sources. Qualitative and quantitative evidence of changes in channel elevations can be made from field observations. Quantitative evidence of channel bed elevation changes can also be made by comparing recent and older topographic maps, comparison of channel elevations shown on as-built design drawings with existing channel conditions, or interpretation of historical aerial photograph stereo pairs.

***General Level 2 Methodology Application Notes.***

1. Minimum Setback. The minimum allowable Level 2 erosion setback is 15 feet or two times the bank height, whichever is greater. The bank height is the maximum elevation difference between the toe and top of the bank at any point within the property limits in the stream reach adjacent to the project.
2. Setback Reference Point. The Level 2 erosion setback is measured from one of the following reference points:
  - a. The top of the bank of the main channel, except in overbank areas subject to avulsions. Procedures for identifying the top of bank and avulsive overbank areas are described in Section 2.4.
  - b. For avulsion areas, the Level 2 setback is measured from the outside margin of the area subject to avulsions.
  - c. For braided channels, the Level 2 setback is measured from the bank of the outermost braid on each side of the floodplain.
3. Bank Conditions. Only the bank and floodplain characteristics the side(s) of the channel for which development is proposed should be considered in determining the setback factors.
4. Avulsion (Type B) Erosion Hazards. The setback adjustment factors for an avulsion area are determined using the characteristics of the avulsion area bank, unless the main channel bank characteristics result in a more conservative setback. To identify avulsion erosion hazards, it may be necessary to evaluate reaches upstream of the property or project boundaries to identify the point where flow leaves the main channel.
5. Setback from a Floodplain Terrace. The setback adjustment factors for determining an erosion setback from a floodplain terrace shall be based on the physical characteristics of the overbank flow impacting the terrace margin, rather than on the main channel characteristics.
6. Non-Riverine Floodplains. The Level 2 methodology is not directly applicable to channels located within areas designated as active alluvial fans, but may be applied to the more riverine and inactive portions of piedmont surface, distributary flow areas, or sheet flow areas. Refer to the District's Piedmont Flood Hazard Assessment Manual for information on identifying active alluvial fans and other piedmont landforms.
7. No Data Available. If no information is available from which to estimate any individual adjustment factor, the largest factor for that site characteristic listed in Table 2.6 shall be used.



8. Erosion Zone Delineation. Level 2 erosion setback distances may vary within a project site. Therefore, the final erosion hazard zone delineation shall be smoothed such that the line envelops the maximum individual setback distances determined for the project site. Setback distances shall not be averaged for a project site.
9. Development. Development is permitted within a Level 2 erosion hazard zone if it is adequately protected from erosion by structural measures.
10. Documentation. Field photographs shall be provided to document and support the determination of each adjustment factor.

<b>Site Characteristic</b>	<b>Adjustment Factor</b>	<b>Explanation</b>
Channel Bend Angle Factor, $F_{\theta}$ Sites on outside of bends Bend angle < 5° Bend angle = 5° - 15° Bend angle = 15° - 30° Bend angle > 30° Sites on inside of bends	0.00 0.05 0.20 0.30 0.00	The bend angle is measured along the tangents of straight reaches upstream and downstream of the bend. (See Figure 2.2)
Channel Velocity Factor, (Q100) $F_{VCH}$ Velocity < 3 ft/sec Velocity = 3-5 ft/sec Velocity = 5-7 ft/sec Velocity = 7-10 ft/sec Velocity > 10 ft/sec	0.00 0.10 0.30 0.50 0.60	Use overbank velocity (velocity against bank) for erosion of non-channel floodplain areas.
Bankfull Width/Depth Ratio Factor, $F_{W/D}$ W/D < 10 W/D = 10-40 W/D > 40	0.00 0.02 0.05	Bankfull conditions identified using bank definition described in Section 2.3.
Bank Materials Factor, $F_{BM}$ Clay Loam Silt Sand Gravel Cobbles Boulders Bedrock Bank Protection	0.05 0.10 0.25 0.30 0.20 0.10 0.00 See Notes See Notes	Silt/clay < 0.062 mm Sand/gravel = 0.062-64 mm Cobbles > 64 mm  Must be competent, extensive Requires PE certification
Bank Cementation Factor, $F_{CO3}$ Loose, unconsolidated, no Carbonate Stage I-II Carbonate Stage III Carbonate Stage IV+ Carbonate	0.80 0.60 0.20 0.00	Use weakest layer in bank  Small flecks of $CaCO_3$ Thick rinds & $CaCO_3$ matrix Laminar, cemented $CaCO_3$
Bank Vegetation Density Factor, $F_{BVD}$ Bare (no vegetation) Sparse vegetation Moderate vegetation Dense vegetation	0.30 0.25 0.15 0.00	Recent erosion or grading > 75% bank soils exposed 25-75% of bank soils exposed < 25% bank soils exposed
Bank Vegetation Type Factor, $F_{BVT}$ Condition #1: Least Stable	0.20	See Table 2.4



<b>Table 2.6.</b>		
<b>Level 2 Erosion Hazard Methodology Adjustment Factors</b>		
<b>Site Characteristic</b>	<b>Adjustment Factor</b>	<b>Explanation</b>
Condition #2: Intermediate	0.10	
Condition #3: Most Stable	0.00	
Bank Conditions Factor, $F_{CB}$ = Sum of: Percent Cutbanks Fresh Cutbanks Proximity of Bank to Channel Invert	0.00-0.30 0.00-0.30 0.00-0.10	See Table 2.5
Flow Conditions Factor, $F_Q$ Ephemeral Stream Perennial/Intermittent Stream	0.05 0.00	Normally dry streambed Normally or seasonally flowing
Watershed Development Factor, $F_W$ Natural watershed Undeveloped watershed Partially urbanized or developing Urbanized watershed (>50%)	0.00 0.05 0.08 0.10	See description in text. Base estimates on field inspection, regional studies, or aerial photographs
Manmade Channel Disturbance Factor, $F_{MD}$ No disturbance of natural floodplain Moderate floodplain disturbance Intense channel & floodplain activity	0.00 0.15 0.30	Base estimates on field inspection, regional studies, or aerial photographs
Vertical Channel Stability Factor, $F_{VERT}$ No degradation/aggradation expected Long-term degradation & scour Aggradation & deposition	0.00 0.15 0.30	Base estimates on field inspection or regional studies
No Information Available	Use largest value for factor in category	
Minimum Setback	15 ft. or 2 x bank height, whichever is greater	



**2.2.3 - Level 3 Erosion Hazard Delineation Analysis.** A Level 3 erosion hazard delineation is an in-depth evaluation of the potential for lateral erosion that considers historical information regarding past channel behavior, past changes in the watercourse outside the project reach, the local geology and geomorphology of the river corridor, hydraulic modeling of the channel and floodplain, and interpretation of field observations. The exact scope of analyses required to complete a Level 3 analysis is a function of the specific site characteristics, the type of development proposed, the level of precision required, and the location of the proposed development relative to the active channel and floodplain. In general, the closer the proposed development to the main channel and active floodplain of a watercourse, the more complex and extensive the required level of analysis. The following flow chart depicts the process of determining an appropriate scope of work for a Level 3 analysis:

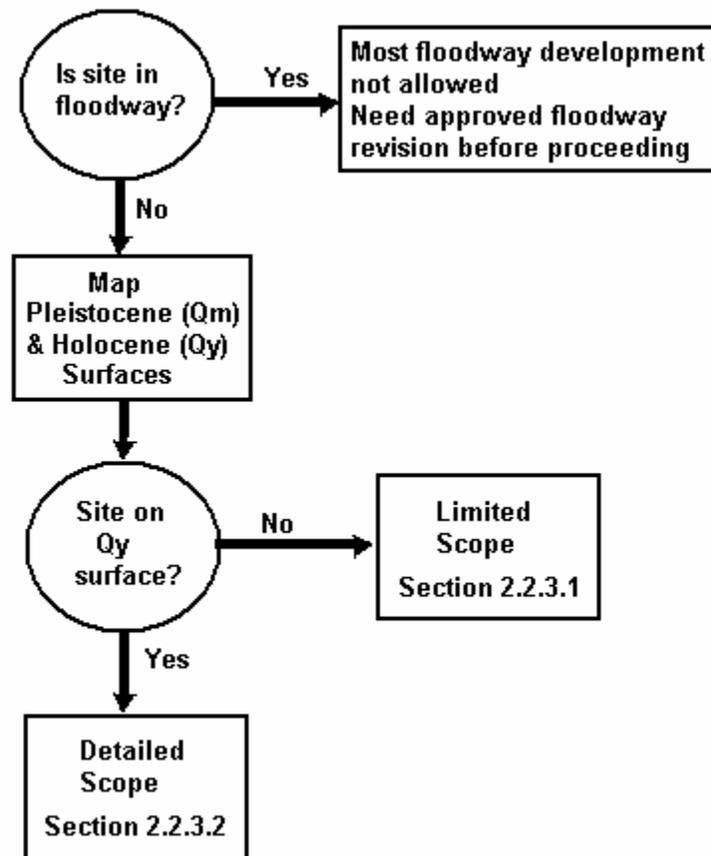


Figure 2.4. Flow chart for identifying Level 3 scope items. References describing methods of mapping geomorphic surfaces are provided in Section 6.

A Level 3 erosion hazard analysis is always required under the following conditions:

- The drainage area at the project site is greater than 500 square miles
- An existing District-approved erosion hazard zone is to be revised
- Unusual conditions exist, as defined in Section 2.2.1 of these guidelines or as designated by the floodplain administrator



When delineating a Level 3 erosion hazard zone, it is critical to understand that the erosion hazard zone is not based solely on the expected channel change during the 100-year design flood. The regulatory erosion hazard zone consists of the channel margin area likely to be eroded by a “typical” series of floods over a sixty-year period, in addition to the lateral erosion that would be caused by a 100-year flood. The erosion hazard zone also includes natural channel movement due to geomorphic processes such as meander migration or channel avulsion, as well as the expected channel responses to human impacts on the watershed and the watercourse.

The minimum Level 3 setback from the nearest bank is 15 feet or two times the bank height, whichever is greater, unless bedrock crops out at all points between the development and the channel, or a slope stability analysis sealed by a registered geotechnical engineer or geologist is provided that justifies a reduced setback.

2.2.3.1 Limited Scope Level 3 Analysis. If the proposed development will be located outside the Holocene floodplain, or the modern geologic floodplain, the risk of lateral erosion is generally less than if the development is located within the Holocene floodplain. For development outside the Holocene floodplain a less detailed erosion hazard evaluation consisting of the following elements is required to characterize the erosion hazard:

- **Geomorphic and Geologic Mapping.** Mapping of Holocene ( $Q_y$ , < 10,000 years before present) and Pleistocene landforms and geomorphic surfaces ( $Q_m$ , > 10,000 years before present), as well as mapping of the locations of bedrock outcrops, is required. Geomorphic mapping shall extend upstream and downstream of the proposed development a distance of at least four times the regulatory floodplain width. Photographic documentation and written descriptions of field and soils characteristics used to differentiate Holocene and Pleistocene surfaces are required to support the geomorphic mapping. The extent and lithology of bedrock shall be clearly described and delineated. Surficial geologic mapping for many parts of Arizona is available from the Arizona Geological Survey ([www.azgs.us.az](http://www.azgs.us.az)). Detailed soils mapping may be available in published soil surveys by the Soil Conservation Service or U.S. Forest Service.<sup>12</sup> References to publications describing procedures for mapping geomorphic surfaces are provided in Section 6.
- **Field Investigation.** Documentation of each of the Level 2 site characteristics is required. Field data shall be succinctly summarized and the investigator shall provide a clear conclusion regarding the relevance of the field data for determining stream stability and erosion hazard.
- **$Q_m$  Surface Lateral Erosion Rate.** Estimation of the rate of lateral erosion of the  $Q_m$  surfaces based on field data, historical documentation of long-term channel movement, interpretation of hydraulic modeling results, and/or geotechnical analysis of erosion potential is required, especially where the main channel abuts the  $Q_m$  terrace.
- **Floodplain/Floodway Delineation.** If no regulatory floodplain exists, the 100-year floodplain and floodway shall be delineated within the project limits using, at minimum, the procedures described in Section 2.2.2. Hydraulic data from the floodplain delineation shall be used to support the geomorphic mapping and estimate of the  $Q_m$  surface lateral erosion rate.

---

<sup>12</sup> SCS soils mapping coverage is at: [http://data4.ftw.nrcs.usda.gov/website/archived\\_ssurgo/viewer.htm](http://data4.ftw.nrcs.usda.gov/website/archived_ssurgo/viewer.htm).



- Delineate Erosion Hazard Zone. Based on the analyses described above, an erosion hazard zone for the study area shall be delineated.
- Report. A brief report shall be prepared summarizing the methodologies used to support the erosion hazard delineation, the assumptions and limitations of those methodologies, and the results of the analysis. The report shall include photographic and other documentation supporting the analyses and conclusions. An engineer's certification form (Section 5) shall be provided with the erosion hazard analysis report.

2.2.3.2 Detailed Scope Level 3 Analysis. If a proposed development is located within the Holocene floodplain, the risk of lateral erosion may be significant and detailed analyses are warranted. In general, the District will assume that all areas within the Holocene floodplain are subject to lateral erosion hazards unless it can be clearly demonstrated otherwise. Where detailed Level 3 erosion hazard analyses are required, the developer should meet with District staff prior to beginning the analyses to determine the most appropriate elements of the Level 3 evaluation. A typical scope for a Level 3 erosion hazard analysis is outlined below.

A detailed Level 3 erosion hazard analysis must answer the following basic questions:

- Has the proposed development site been subject to lateral erosion in the past?
- Will the proposed development site be subject to lateral erosion in the future?

The question of past erosion is addressed by analysis of historical information such as aerial photographs and maps, as well as by geomorphic mapping, which is essentially a long-term record of historical channel behavior. The answer to the first question also provides a means of calibrating and verifying the answer to the second question regarding future erosion. The second question is typically addressed by engineering and empirical analyses that use hydraulic modeling, sediment transport and scour equations, and other stream geometry relationships to evaluate the erosion hazard, as well as by analysis of historical data from adjacent stream reaches. For assessing lateral erosion hazards, historical data are more reliably predictive of future channel movement than any existing engineering or empirical methods. Therefore, if the results of engineering-based erosion hazard predictions conflict with measured historical rates and amounts of channel change, erosion hazard zone delineations should be based primarily on the interpretation of the historical record.

A detailed Level 3 erosion hazard analysis may consist of any or all the following elements:

1. Historical Analyses
  - a. Historical analysis of horizontal channel change
    - i. Quantify maximum long-term channel movement by comparing channel position on rectified historical (oldest available) and modern (most recent) aerial photographs and/or historical survey data.
    - ii. Quantify maximum single event channel movement by comparing channel position on a sequence of rectified historical and modern aerial photographs and/or historical survey data.



- iii. Identify trends of channel movement (direction, scale, and type) related to the current or historical channel pattern that may affect future channel movement.
  - iv. Identify changes in channel pattern during the period of historical record. Determine whether channel pattern changes are cyclical or evolutionary, and relate pattern changes to the potential future channel movement.
  - v. For streams with limited historical data, expand the study reach to adjacent stream reaches or adjacent watercourses (spatial data substitutes for temporal data) to identify regional rates of historical channel movement. Where regional rates of channel movement are significantly different from historical channel movement in the project reach, the regional rates should be used to estimate future erosion potential, or a physical reason for the differences is required.
  - vi. Identify land use changes and human impacts to watercourse, as well as the historical channel response to those changes. Relate the potential for future land use changes and human impacts to future channel changes.
  - vii. Catalogue the record of past floods by magnitude and relate the observed historical channel changes to the flood series. Where no flood records exist, examine rainfall records or flood series from adjacent watercourses to identify periods of likely flooding or drought.
  - viii. Relate the observed historical scale of channel change to the magnitude and frequency of historical floods, as well as to a potential future flood series that might occur during the design life of the proposed development.
- b. Historical analysis of vertical channel change
- i. Quantify past bed elevation changes by comparing historical and modern topographic mapping, field observations, and channel elevations shown on structure as-built plans.
  - ii. Identify long-term degradation or aggradation trends in the project reach indicated by the historical record.
  - iii. Relate observed changes in elevation to historical watershed changes, natural riverine processes, and manmade changes to the river system.
  - iv. Predict future channel elevation changes and the anticipated channel response given past trends and likely future watercourse and watershed changes.

## 2. Geomorphic and Geologic Mapping & Analyses

- a. Delineate Holocene and Pleistocene surfaces and landforms. Surficial geologic mapping for many parts of Arizona is available from the Arizona Geological Survey ([www.azgs.us.az](http://www.azgs.us.az)). Detailed soils mapping may be available in published soil surveys by the Soil Conservation Service or U.S. Forest Service. References to publications describing procedures for mapping geomorphic surfaces are provided in Section 6.
- b. Subdivide Holocene surfaces by age, topography, and surficial characteristics to constrain long-term rate of lateral movement in modern geologic time. Map the extent and describe the physical characteristics of each Holocene surface.
- c. Conduct subsurface investigations using test pits or borings to quantify physical differences between Holocene surfaces such as resistance to erosion, clay content, degree of carbonate cementation, induration, sediment size, bedding, degree of soil development, color, provenance, or other characteristics.



- d. Use geomorphic mapping to calibrate the minimum long-term rate of lateral movement within the stream corridor, and maximum magnitude of channel movement within different time periods represented by the Holocene surfaces.
- e. Identify and map the extent and lithology of bedrock outcrops. Identify physical barriers to lateral channel movement.
- f. Describe modern geomorphic setting relative to local historical geology and channel evolution to determine trends of expected future channel change.
- g. Examine a longitudinal profile of the stream to identify knickpoints, convexities, or other slope irregularities relative to the position of the proposed development. Predict changes in channel profile and discuss the implications of profile changes on potential lateral and vertical erosion.

### 3. Field Investigation

- a. Describe and document channel and bank conditions in reach, at minimum using the Level 2 site characteristics, or other appropriate field data collection methodologies.
- b. Identify and document stream characteristics indicative of active or recent lateral erosion. Provide photographs of diagnostic features.
- c. Identify and document stream characteristics indicative of resistance to lateral erosion. Provide photographs of diagnostic features.
- d. Identify and document stream and floodplain characteristics indicative of potential, historical, or active channel avulsions (See Section 2.4). Provide photographs of diagnostic features.
- e. Conduct stream classification analysis to identify the scale of erosion potential by analogy to similar stream types.
- f. Apply bank stability indexes based on field parameters. A variety of bank stability indexes have been published. See Section 6 for references.
- g. Identify local bank failure mechanisms. Relate observed bank failure mechanisms to flow hydraulics & sediment transport analysis results.
- h. Identify evidence of long-term degradation or aggradation near the proposed development site or in adjacent stream reaches.
- i. Identify evidence of bed sediment movement, armoring, imbrication, and scour for use in verifying the results of sediment transport and scour analyses.
- j. Identify archaeological evidence to help identify the age of geomorphic surfaces.

### 4. Hydraulic Modeling

- a. Perform inundation mapping using HEC-RAS or other hydraulic models to determine the relative magnitude and frequency (recurrence interval) of floodplain inundation and inundation of Holocene geomorphic surfaces. Relate the inundation frequency to avulsion potential and definition of channel bank stations.
- b. Determine channel and floodplain hydraulic data, such as velocity, depth, and stream power, for a range of flood frequencies to determine thresholds of channel and floodplain erosion, and for use in sediment transport analyses. Plot changes in channel velocity and other hydraulic variables versus stream distance to identify trends and discontinuities, and to identify channel choke points and flow expansion areas that may impact the lateral erosion potential.



- c. Map overbank flow patterns at various flow frequencies, and identify overbank flow concentration areas to identify possible avulsive flow paths.
  - d. Determine bankfull discharge for use in applying regime and hydraulic geometry equations.
5. Sediment Transport & Engineering Analysis
- a. Estimate sediment transport competence and size range of transported material at various flow frequencies. Relate transport competence to bed material gradations observed in the streambed and banks.
  - b. Estimate local scour at a range of flow frequencies and rates and predict the impact of such scour on bank stability and lateral erosion.
  - c. Estimate armoring potential to whether vertical scour limit exists in channel at a range of flow frequencies. If armoring is likely, revise scour estimates accordingly and estimate the potential impacts of armoring on the potential for lateral erosion.
  - d. Apply equilibrium and stable slope equations to estimate long-term degradation or aggradation potential. Relate equilibrium slope predictions to the observed longitudinal profile and potential armoring. Predict long-term scour by comparing the estimated equilibrium slope and the existing channel slope, considering natural or man-made grade control features that may serve as hinge points for channel slope adjustments.
  - e. Apply bank resistance methodologies such as allowable velocity, tractive force, and tractive shear to determine susceptibility of banks and surfaces to lateral erosion or avulsion.
  - f. Apply regime and hydraulic geometry equations to determine direction or potential for future channel adjustments in the main channel width and depth.
  - g. Perform sediment continuity analysis to identify localize sediment deficits or surplus and relate to areas of expected erosion and deposition. Consider potential changes in predicted sediment deficit and surplus due to channel pattern migration and lateral erosion.
  - h. Consolidate results of engineering and sediment transport analyses to identify stable and unstable stream reaches and the expected direction and magnitude of future channel changes.
6. Computer Modeling of Lateral Erosion
- a. Computer models have not advanced to the point of being able to accurately predict single event or long-term lateral channel movement. Therefore, computer modeling shall not be included in the scope of analysis for a Level 3 erosion hazard analysis without prior approval by the District. Sediment transport computer models have some utility for identifying reaches of sediment deficit or sediment surplus, comparing relative differences between management alternatives, or predicting the expected direction of vertical channel changes.
7. Delineate Erosion Hazard Zone
- a. An erosion hazard zone shall be delineated that is based on the results of the methodologies and analyses outlined above.



## 8. Report

- a. An engineering report shall be prepared summarizing the methodologies used to support the erosion hazard delineation, the assumptions and limitations of those methodologies, the results of the analysis, and the applicable time frame for the erosion hazard zone delineation. The report shall include photographic and other documentation supporting the analyses and conclusions. An engineer's certification form (Section 5) shall be provided with the erosion hazard analysis report.

### 2.3 Identifying Channel Banks

Identification of the channel banks is required for application of the Level 2 and 3 erosion hazard methodologies. Channel bank stations can be identified using the following procedures, as illustrated in Figures 2-4 to 2-8:

- Ordinary High-Water Mark
- Flood Frequency
- Hydraulic Criteria

Examples of bank definition for various channel configurations are provided below.

***Ordinary High-Water Mark.*** The U.S. Army Corps of Engineers' (USACE) criteria for identifying the ordinary high-water mark can be used to identify bank stations. The USACE recommends identifying the ordinary high-water mark using a combination of the following three basic physical characteristics:

- **Vegetation.** The ordinary high-water mark is located at the point where vegetation along the stream corridor changes from terrestrial to aquatic species, or the point where permanent, terrestrial vegetation begins.
- **Soils.** The ordinary high-water mark is located at the point where soil characteristics change from undifferentiated, poorly-developed, layered, fluvial deposits subject to scour and deposition to more well-developed soils with distinct soil, or where coarse-grained channel deposits transition to fine-grained floodplain deposits. The change in soil characteristics is caused by channel processes that prevent soil formation from occurring in the portions of the stream corridor subject to erosion and deposition.
- **Topography.** The ordinary high-water mark is located at a break in slope or at the point where the top of the channel bank transitions to the more planar floodplain.

The ordinary high-water mark, as defined by the Corps of Engineers, is analogous to a geomorphic definition of the top of the channel bank. Therefore, the Corps' definition can be applied to help define the channel bank location. However, the following modifications are required to apply these definitions to streams in Arizona:



- Vegetation. On ephemeral and intermittent streams, vegetation in the channels may not be significantly different from vegetation growing in or above the floodplain. However, the following guidelines for identifying a change in vegetative characteristics are suggested:
  1. Scoured vegetation. The areas of highest velocity occur in the main channel, and will be periodically swept clear of vegetation during high flows. Therefore, the channel will either lack vegetation, or will be populated with very young, fast growing vegetation. An inspection of the stream's flood history, either from gauge records or field evidence, should be made to determine whether high flows have occurred in the recent past. If no large flows have occurred in the recent past, terrestrial vegetation may have encroached into the main channel and obscured the bank location.
  2. Vegetation density. A swath of dense vegetation often lines the banks of ephemeral and intermittent channels. In southern and central Arizona, this vegetation generally consists of mesquite, palo verde, ironwood, and brushy plants, but may also include cactus species. This bank vegetation zone is usually distinguished by a change in species and/or density relative to channel bottom vegetation and floodplain or upland vegetation.
  3. Vegetation age. The relative age of the bank vegetation can be used to assess the frequency and/or the age of the most recent channel changes. Mature bank vegetation indicates infrequent channel movement in the past, and a stable bank. Immature vegetation may indicate the bank of an erodible terrace, rather than the primary channel bank from which erosion hazards should be measured.
  4. Avulsions. If the main channel is subject to avulsive movement, as defined in Section 2.4, the bank stations required for the erosion hazard assessment may be well outside the area defined by bank vegetation. Definition of channel bank stations in reaches subject to avulsive changes is complex. In general, the bank location shall be defined for the main channel, with consideration of potential overbank flow paths when defining n values and partitioning the floodplain.
  
- Soils. Soil characteristics can be used to distinguish the main channel from less frequently inundated floodplain surfaces. The channel bank location must lie between the main channel and floodplain. The following soil characteristics can be used to help identify the correct bank location:
  1. Sediment size. Overbank floodplains primarily are subject to deposition, and thus generally are composed of accretive layers of fine-grained sediment, or have a mantle of more recently deposited fine-grained materials. Coarser sediments typically underlie areas subject to channel processes. The point of transition between fine- and coarse-grained sediment often occurs at the channel banks.
  2. Imbrication. Channel sediments are often imbricated, or aligned, in the direction of flow. Caution should be used in areas of recent entrenchment where imbricated sediments are found in areas perched above the main channel. Imbricated sediments are generally found within the area between the channel banks.
  3. Soil profile development. Sediments located outside the active channel generally have been undisturbed for periods of time long enough to develop soil horizons or other soil development features such as desert varnish, desert pavement, clay accumulation and reddening. The area between the channel banks should generally not include areas with significant soil profile or surficial feature development.



- **Topography.** Most large stream systems consist of compound channels with one or more terraces that reflect different levels of flooding and inundation. Inundation of these terraces corresponds to different flow frequencies – larger floods are required to inundate the highest terraces. Therefore, to some degree, definition of the main channel depends on the frequency of the flow event under consideration. For the purposes of applying the erosion hazard methodology, the area between the channel banks should be able to contain at least a 5- to 10-year event.

**Flood Frequency.** Defining channel bank stations using a predetermined recurrence interval is not recommended. For the purposes of erosion hazard analysis, the banks impacted by a 5- to 100-year event are of more concern than the banks or channel formed by an average-annual type flow event. The following bank definition criteria relating to flood frequency information should be considered:

1. Bankfull discharge. Definitions of bankfull discharge that refer to a 1.5-year or more frequent recurrence interval are not relevant for the type of erosion hazard assessment discussed in these guidelines, and undervalue the role of floods on shaping channels, causing lateral movement, and initiating bank erosion.
2. Sediment transport. The flow rate required to reach the bank stations should be sufficient to transport the bed material observed in the channel. If the channel is armored, and the banks are resistant to lateral erosion, it is unlikely that the channel forming discharge is a frequent event (Q2 or less). In these cases, the flood channel geometry probably is the result of the larger flows (Q25 or greater).
3. Bank station. The flood frequency of the bankfull discharge defined by the bank stations should be high enough to achieve erosive velocities ( $> 3\text{-}5$  ft/sec), and high enough to flow against the banks.

**Hydraulic Criteria.** In the rare instances in which no physical features can be identified from which to define the bank stations, the bank stations will be defined as the outermost point in the floodplain where the 100-year flow depth equals three feet,<sup>13</sup> or the product of the flow depth (d) and the square of the velocity (v) equals 18 ( $dv^2 = 18$ ), whichever is more conservative. Where bank stations are not easily identified, comparison with upstream and downstream reaches may provide useful information on bank station position.

**Examples of Bank Definition for Specific Channel Types.** Figures 2-4 to 2-8 illustrate the recommended bank station locations from which to measure erosion hazard setbacks for a variety of stream types.

---

<sup>13</sup> ADWR Arizona State Standard 3-94, p. 4.



## Single Channels

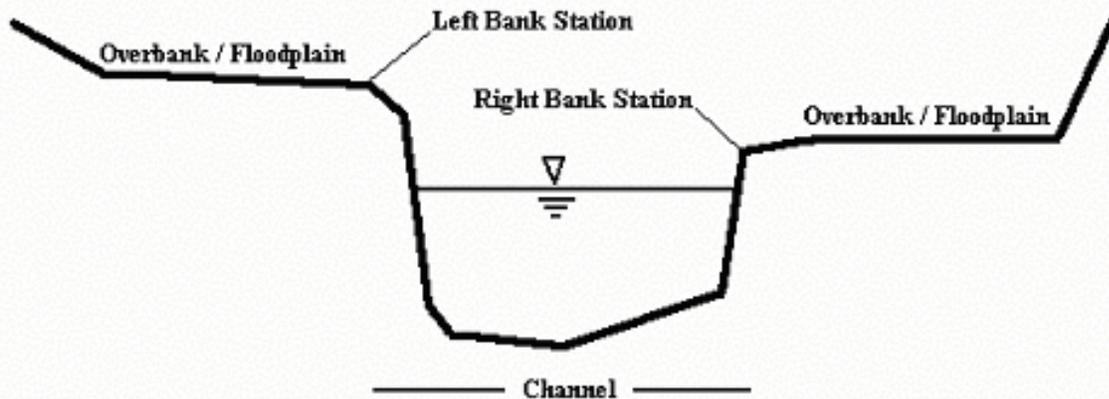


Figure 2-4. Recommended bank stations for a single channel cross section. Bank stations are located at the top of the bank at the slope break between the bank and the floodplain.

## Multiple Channels

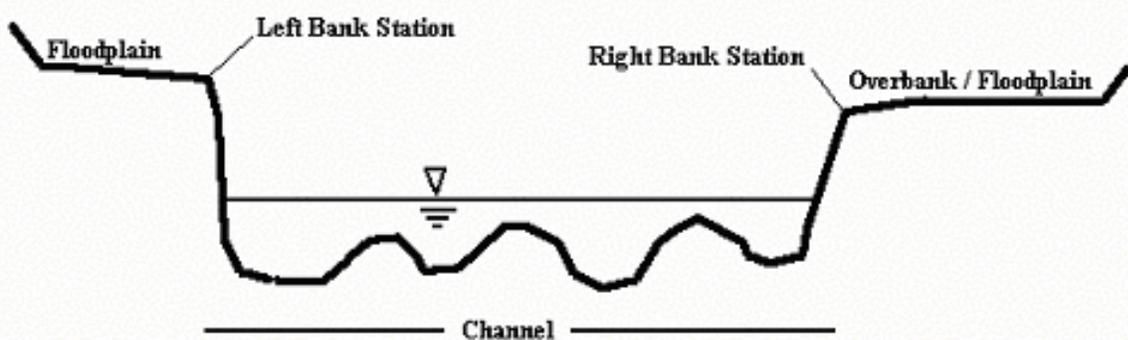


Figure 2-5. Recommended bank stations for a multiple channel with shallow islands or bars inundated by the 100-year flood. Low islands are subject to frequent erosion, deposition and channel processes. Bank stations are located at the top of bank at the slope break between the bank and the floodplain.

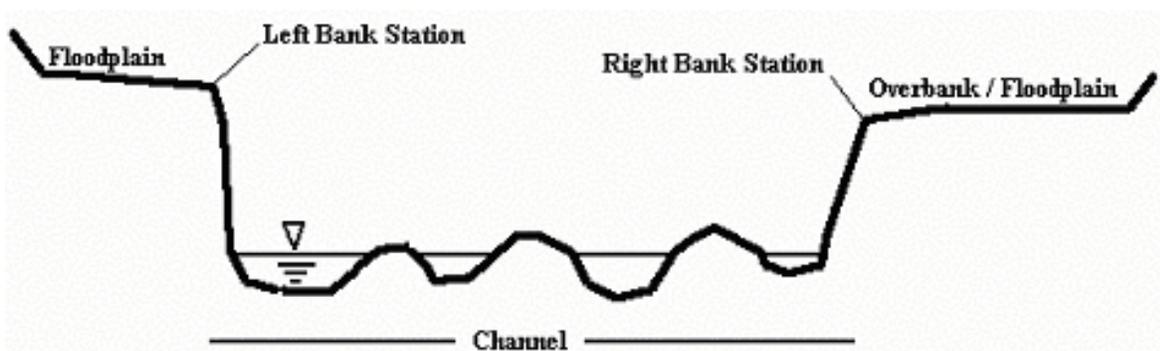


Figure 2-6. Recommended bank stations for braided or multiple channels with shallow, insignificant or small islands near the 100-year water surface elevation, but not inundated by the 100-year flood. Low, small islands between active braids are subject to avulsive channel movement or frequent erosion by floods and should be considered part of the erosion hazard area. Bank stations are located at the top of the bank that separates the outermost braided channel from the floodplain or unflooded area. Islands must be of significant size and permanence to justify delineation of distinct bank stations.

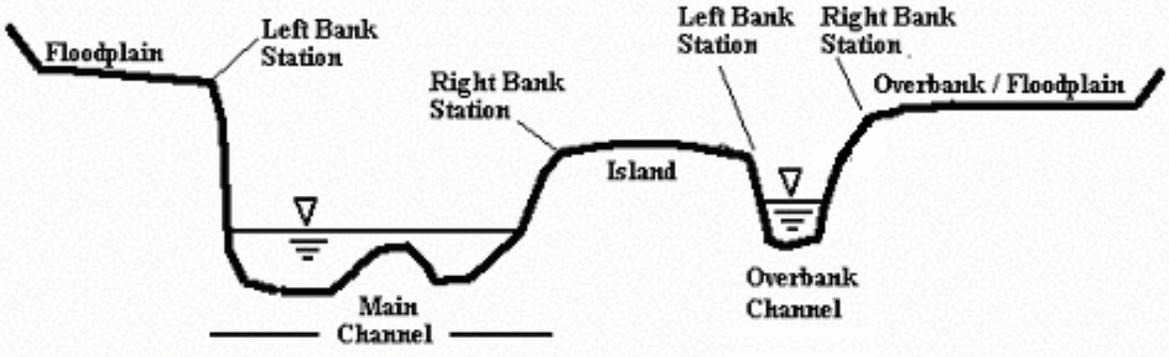


Figure 2-7. Recommended bank stations for multiple channels with large, significant islands or for perched channels hydraulically and topographically separated from the main channel. Two sets of bank stations are defined, each with its own erosion hazard area. Where the erosion hazard zones overlap, the islands are not of sufficient size to justify distinction from the main channel. Perched channels are typically overbank conveyance corridors that are hydraulically and topographically separated from the main channel.

Channels With No Defined Banks.

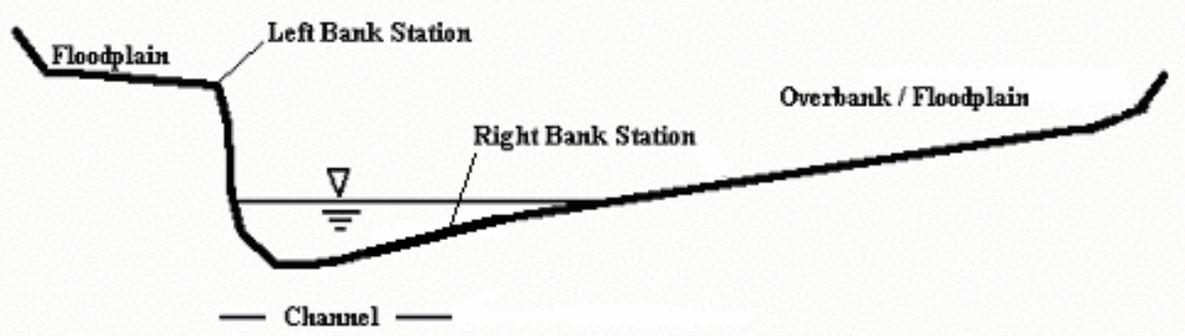


Figure 2-8. Recommended bank stations for channels with no defined banks. For this example, the left bank station is defined using the single channel guidelines and the right bank channel is defined using hydraulic criteria at the point where the 100-year flow depth is three feet, or the 100-year depth x velocity<sup>2</sup> = 18. In some cases, bank stations in reaches with poorly defined banks can be identified by comparison with upstream and downstream bank locations.



## 2.4 Identifying Channel Avulsion Areas

Channel avulsions are responsible for some of the largest magnitudes of known lateral channel movement in Arizona. An avulsion occurs when a new channel forms in an area that was formerly part of the floodplain, leaving an island of relatively high ground between the former and current channel locations. The potential for avulsive channel change increases as the frequency of inundation, depth of inundation, and duration of inundation increases. In order for an avulsion to occur, the floodplain must be subject to inundation for a long enough duration for erosion of a new channel to occur. Therefore, to be avulsive, a floodplain must be flooded at great enough depth, velocity and frequency to cause channel formation.

Floodplain and channel characteristics that are often indicative of avulsive conditions on many Arizona stream systems are listed below. No single characteristic should be considered solely diagnostic of avulsive conditions. Where several of the avulsive characteristics listed below are observed, the stream corridor should be considered subject to avulsions. As with other aspects of predicting river behavior, historical data are the most reliable indicator of the potential for future avulsions. The following characteristics are indicative of avulsion potential:

1. The 100-year maximum (not average) flow depth in the floodplain is greater than two feet.
2. The 100-year maximum velocity in the floodplain is greater than four feet per second, or the product of 100-year floodplain depth and velocity squared is greater than 18 ( $dv^2 > 18$ ).
3. The 10-year flood is not contained in main channel.
4. Lack of, or minimal, topographic relief between main channel invert and floodplain elevation
5. Evidence of frequent overbank flooding such as flood damage records and high water marks.
6. Perched channels and swales observed in the overbanks and floodplain created by concentration of floodplain flow, tributary inflow to the floodplain, or physical modification of the floodplain.
7. Meander cutoff channels present in stream reaches located upstream or downstream.
8. The overbank topography indicates continuous flow paths have formed in the floodplain (floodplain contours bend in the upstream direction).
9. Lack of upland or mature vegetation in the floodplain.
10. Lack of bank vegetation along the main channel and/or minimal differences between the channel, channel bank, and floodplain vegetation.
11. Hummocky bar and swale terrain in the floodplain caused by sculpting of floodplain surface by flooding, sediment transport, and scour.
12. Fresh gravel and coarse sand deposits in continuous swales located within the floodplain or in overbank channels.
13. Alignments of large trees (living or dead) in the floodplain of similar species to bank vegetation that identify former or forming avulsive flow paths.
14. Islands of older geomorphic surfaces of low relief inset within younger floodplain deposits that indicate former incision of the floodplain.
15. Tributary channels that flow parallel to the main channel across the floodplain that may become conduits for future avulsive flows.
16. Rapid and significant changes in main channel geometry and capacity, particularly alternating single and highly braided reaches.



**Section 3:**

**Non-Structural Measures for Erosion Hazard Management**

The recommended non-structural erosion hazard management approach consists of limiting development to areas outside the erosion hazard zone, as shown in Figures 2.1 and 2.2. While it is preferable to locate the entire development outside the erosion hazard zone, in some cases it may be possible to locate certain land uses within erosion hazard zones, as shown in Table 3.1, and still achieve non-structural flood control for the overall development. In no case shall permanent, habitable structures be located in an erosion hazard area without structural erosion control and engineered erosion protection measures.

<b>Table 3.1 Acceptable Development Near Erosion Hazard Areas</b>	
<b>Within Erosion Hazard Zone</b>	<b>Outside Erosion Hazard Zone</b>
Permitted Uses With No Structural Measures: Agricultural, open space, park, passive recreation, limited parking, trails, unimproved roads Uses Not Permitted Without Structural Measures: Permanent buildings or habitable structures, parallel roadways and utilities, and road crossings.	Any development or improvements conforming to local zoning and drainage regulations.
Notes: 1. Other development and zoning restrictions or design guidelines may apply to roads, utilities, and structures. 2. Any development within an erosion hazard zone may be subject to damage during floods, including the permitted uses listed above, and is undertaken at the sole risk of the developer. 3. The developer of property in an erosion zone shall demonstrate that no adverse impacts to adjacent properties occur as a result of the proposed development.	

Erosion hazard zones have been delineated and approved by the District for a number of watercourses in Maricopa County. A list of watercourses with District-approved erosion hazard delineations is provided in the Appendix. The most current list of watercourses with approved erosion hazard delineations can be obtained from the District’s Regulatory Division. If no erosion hazard zone has been delineated for the watercourse, one shall be determined using the procedures outlined in Section 2 of this manual.



## **Section 4:** **Structural Erosion Hazard Management**

Structural measures remove the natural erosion hazard via a constructed barrier designed to withstand, deflect, or prevent erosion.

### **4.1 Design Guidelines**

Detailed design guidelines for structural erosion control measures are provided in the District's *Drainage Design Manual for Maricopa County, Arizona - Hydraulics*. The following three basic types of structural erosion control are typically used: (1) erosion barriers such as engineering bank protection (rip rap, concrete, etc.), (2) channel control features such as dikes, jetties, groins, or energy dissipaters, and (3) construction techniques that allow development to withstand erosion such as building on anchored piers or walls. The following design guidelines apply to any erosion control structures proposed for development in an erosion hazard zone:

- Structural measures must be designed to have no short-term or long-term adverse impact on adjacent properties. Low impact criteria are given below.
- Structural measures must be designed to withstand at least the 100-year event.
- Structural measures must have a design life equal to the design life of the structures to be protected from erosion.
- Maintenance and inspection requirements should be clearly identified.
- Piecemeal bank protection should be avoided. Piecemeal bank protection consists of bank stabilization measures or designs that are not continuous along a watercourse.
- Erosion protection constructed anywhere within the erosion hazard zone shall be toed-down below local and long-term scour depth of the main channel.
- Erosion protection shall be tied in upstream and downstream to a stable area outside the erosion hazard zone. The requirement for upstream and downstream tie-in may preclude use of structure measures on some small lot developments in erosion hazard zones.
- Flexible bank protection (e.g., rip rap) is preferred over rigid bank protection (e.g. concrete).
- Grade control may be required where potential for long-term degradation exists.
- Bank protection should be buried and revegetated wherever possible.
- Bioengineering techniques are acceptable if they meet the other criteria listed above.

Additional design concepts appropriate for single lot developments are provided in ADWR State Standard 7-98.

### **4.2 Definition of Low Impact Structural Alternatives**

The District requires that structural erosion control measures not negatively impact flood and erosion hazards on adjacent properties and stream reaches. The District also requires that an engineering assessment of erosion control structures impacts be reviewed and approved prior to development. To facilitate review of proposed structural measures, the District has defined criteria that, if met, indicate minimal impacts will occur.



Low impact structural measures should be implemented wherever possible. The best way to minimize impacts on stream corridors is to maintain the form and function of the natural stream system to the greatest degree possible. The following definition of low impact criteria is intended to achieve the District's goals of minimum disturbance of the natural system:

- Minimal velocity increase.
  - The average 10-year velocity in the channel or overbank should not change ( $\pm 0.0$  fps).
  - The average 100-year velocity in the channel or overbank should not change (increase or decrease) by more than 10 percent or 1 foot per second (fps), whichever is less.
- Minimal water surface elevation increase.
  - The 10-year water surface elevation or energy grade line should not change ( $\pm 0.0$  ft.).
  - The 100-year water surface elevation or energy grade line should not increase or decrease by more than 0.1 foot.
- Minimal change in floodplain width
  - The 10-year floodplain width should not change ( $\pm 0.0$  ft.).
- Minimal disturbance of the main channel.
  - The natural 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.
- Minimal disturbance of the 10-year floodplain
  - Alteration of the natural vegetation and ground elevations within the 10-year floodplain should be minimized, except for purposes of restoration of disturbed areas to natural conditions.
- No offsite impacts.
  - No erosion, sedimentation, or flood impacts to adjacent properties shall occur without the written permission of all affected property owners.
- Preservation of natural landscape character and habitat within the floodplain.

In general, the less the natural channels and floodplains are disturbed, the less sedimentation, erosion and flood problems will occur.

### **4.3 Impact Analysis**

If a proposed development in an erosion hazard zone does not meet the Low Impact Criteria defined above, an analysis of the potential impacts of the development on adjacent properties and the watercourse system sediment balance is required. Note that, in general, the District assumes that any channelization or other forms of structural erosion control will impact adjacent parcels and will have negative cumulative impacts on the watercourse that will require mitigation. It is the developer's responsibility to demonstrate that any such impacts are minimal, justified, and consistent with the District's regulatory objectives. An engineering analysis of stream impacts typically consists of the following elements:



1. Regulatory Floodplain/Floodway Impacts. Hydraulic modeling of the pre- and post-project channel and floodplain conditions must be submitted and approved by the District to document the following:
  - a. Floodplain.
    - i. Changes in the 100-year water surface elevation must be less than one foot within the property limits.
    - ii. No changes in the 100-year water surface elevation may occur on adjacent properties.
  - b. Floodway.
    - i. No changes in the regulatory floodway elevation are permitted, either within or adjacent to the proposed project limits.
2. Stream Stability and Sedimentation Impacts. Engineering analyses must be submitted to document that no adverse impacts occur on adjacent properties due to the proposed structural measures. It is recommended that the applicant's engineer meet with District staff prior beginning any analyses to discuss and review the engineering methodologies to be used to evaluate sedimentation impacts.
  - a. Sedimentation impacts from floodplain encroachment or channelization. The engineering analysis must address each of the following types of sedimentation impacts:
    - i. Deflection scour. Deflection scour occurs on a stream bank when the channel or floodplain alignment is modified causing changes in flow direction, or where only one bank is protected, thus limiting the available sources of sediment in the reach. The following conditions can lead to reflective scour:
      1. Change in the main channel alignment
      2. Change in the overbank flow path alignment
      3. Concentration of overbank flow
      4. Increase in percentage of flow carried in the main channel due to overbank encroachment or deflection
      5. Protection of only one channel bank
      6. Severe contraction of the channel or floodplainThe evaluation of potential deflection scour should account for development of adverse channel alignment caused by exposure of proposed flood control structures following long-term channel movement. Channelization or structural measures located within the EHZ should be designed with smooth transitions.
    - ii. Contraction scour. Floodplain encroachment increases flow velocity and depth, which results in increased channel bed erosion and sediment transport capacity. Hydraulic data from the pre- and post-project hydraulic models should be used in conjunction with an approved sediment transport function to demonstrate that the proposed mining plan does not increase scour, erosion, or deposition on any adjacent property.
    - iii. Upstream scour and degradation. Upstream scour occurs when floodwater enters an excavated channel reach that is below the grade of the surrounding floodplain or channel. Upstream scour consists of two primary elements: (1) a headcut that migrates upstream as floodwater falls over a steep face into the



excavation, and (2) long-term degradation as the watercourse adjusts to a new base level provided by the bottom of the excavation. Headcut modeling guidelines are given in Section 6.5 of the District's *Sand and Gravel Mining Floodplain Use Permit Application Guidelines*. Long-term and single headcut migration should be limited to the property owned by the applicant. Long-term degradation can be assessed using the methods outlined in Section 2.2.3.2.

- iv. Downstream degradation. Downstream degradation is caused when sediment is trapped or depleted in a reach, and sediment-deprived water flows downstream. Downstream degradation potential can be estimated using procedures outlined in Section 2.2.3.2.
  - b. Cumulative impacts analyses. The District will consider the effect on the river system, adjacent properties, and public infrastructure if all landowners along the watercourse were allowed the same degree of impact on the river system as the permit applicant. On streams lacking a watercourse master plan, the District may require a cumulative impacts analysis as part of the floodplain use permit application engineering report.
  - c. Guidelines for Use of Computer Sediment Transport Modeling. Guidelines for use of computer sediment transport models are provided in the District's *Sand and Gravel Mining Floodplain Use Permit Application Guidelines*. To facilitate the permitting process and to prevent any wasted effort and funds by permit applicants, engineers are strongly advised to coordinate any computer modeling efforts with District staff prior to undertaking the modeling effort and prior to submittal of results.
3. Statement of Findings.
- a. An engineering report shall be prepared summarizing the methodologies used to support the impact analysis, the assumptions and limitations of those methodologies, and the results of the analysis. The report shall include all computations and other documentation supporting the analyses and conclusions. An engineer's certification form (Section 5) shall be provided with the impact analysis report.

#### **4.4 Other Information**

It is the developer's responsibility to obtain any permits required by any government agency, such as U.S. Army Corps of Engineers Section 404 Permit, Arizona Department of Environmental Quality 401 Certification, and National Pollutant Discharge Elimination System (NPDES/AZPDES) prior to construction of structural erosion control measures.



## **Section 5:** **Review Procedures & Checklists**

Review checklists have been developed to facilitate the District's floodplain use permit review process. In some cases, more than one review checklist is required. Each review checklist identifies the types of analyses, documentation, and information to be submitted with the floodplain use permit application.

### **Checklist #1: General Site Information - Erosion Hazard Assessment**

- Basic site information such as watershed size, type(s) of erosion hazards present, and proposed mitigation measures is required.

### **Checklist #2: Level 1 Erosion Hazard Assessment**

- A Level 1 erosion hazard assessment is applicable for locations with watersheds smaller than 50 square miles and any type of development.

### **Checklist #3: Level 2 Erosion Hazard Assessment**

- A Level 2 erosion hazard assessment is applicable for locations with watersheds smaller than 500 square miles and is typically used for non-commercial development on stream reaches shorter than 1,000 feet.

### **Checklist #4: Level 3 Erosion Hazard Assessment**

- A Level 3 erosion hazard assessment is applicable for any locations or type of development, and consists of detailed analyses of the watercourse.

### **Checklist #5: Structural Erosion Control Measures**

- Building sites located within the delineated erosion hazard zone require engineering design of structural measures and analyses to determine impacts to adjacent properties.



**Checklist #1: General Site Information – Erosion Hazard Assessment**

Checklist #1 is required for all floodplain use permit applications.

1. **Site Location Information:**

- SITE LEGAL DESCRIPTION: \_\_\_\_\_
- WATERCOURSE NAME(S): \_\_\_\_\_

2. Existing Watercourse Information. List Source, Author, & Date for each available study.

- FLOODPLAIN: \_\_\_\_\_
- FLOODWAY: \_\_\_\_\_
- EROSION HAZARD ZONE: \_\_\_\_\_
- WATERCOURSE MASTER PLAN: \_\_\_\_\_
- AREA DRAINAGE MASTER PLAN: \_\_\_\_\_

**NOTE:** A FLOODPLAIN, FLOODWAY, AND EROSION HAZARD ZONE DELINEATION IS ALWAYS REQUIRED. IF NONE EXISTS, THEY MUST BE DELINEATED AS PART OF THE FLOODPLAIN USE PERMIT.

3. **New or Revised Floodplain, Floodway, and Erosion Hazard Zone Delineations.**

- PROPOSED BUILDING SITE IS WITHIN:  FLOODPLAIN  FLOODWAY  EROSION HAZARD ZONE
- FLOODPLAIN DELINEATION METHOD: \_\_\_\_\_
- FLOODWAY DELINEATION METHOD: \_\_\_\_\_
- TYPE OF EROSION HAZARDS PRESENT:  A  B  C  D
- EROSION SETBACK METHOD:  LEVEL 1  LEVEL 2  LEVEL 3
- MINIMUM SETBACK:  FLOODPLAIN + 50 FT.  2\*BANK HT OR 15 FT.  15 FT.
- EROSION SETBACK DISTANCE: \_\_\_\_\_ FT.  \_\_\_\_\_ FT.  \_\_\_\_\_ FT.  
 USE CHECKLIST #2  USE CHECKLIST #3  CHECKLIST #4
- DISTANCE FROM STRUCTURE TO NEAREST BANK: \_\_\_\_\_ (FT)
- HEIGHT OF NEAREST BANK: \_\_\_\_\_ (FT)
- SEALED ENGINEERING REPORT SUBMITTED?  NO  YES
- FLOODPLAIN DELINEATION ENGINEER OF RECORD: \_\_\_\_\_  
 (NAME) (AZ REGISTRATION #)
- EROSION ANALYSIS ENGINEER OF RECORD: \_\_\_\_\_  
 (NAME) (AZ REGISTRATION #)

4. **Structural Erosion Protection Information:**

- STRUCTURAL EROSION PROTECTION PROPOSED:  NO  YES USE CHECKLIST #5
- TYPE OF STRUCTURAL PROTECTION PROPOSED: \_\_\_\_\_
- STRUCTURAL PROTECTION MEETS LOW IMPACT CRITERIA?  NO  YES
- IMPACT ANALYSIS SUBMITTED?  NO  YES
- SEALED ENGINEERING REPORT SUBMITTED?  NO  YES
- IMPACT ANALYSIS ENGINEER OF RECORD: \_\_\_\_\_  
 (NAME) (AZ REGISTRATION #)

5. **Engineer’s Certification Form Submitted?**

- NO  YES



**Checklist #2: Level 1 Erosion Hazard Assessment**

Checklist #2 is required if the Level 1 erosion hazard methodology is used.

- DRAINAGE AREA: \_\_\_\_\_ SQ. MI. (IF > 50 SQ. MI., USE LEVEL 2 OR 3)
- UNUSUAL CONDITIONS PRESENT: (IF YES, USE LEVEL 2 OR 3)
  - HISTORY OF SIGNIFICANT LATERAL EROSION:  NO  YES
  - IN-STREAM MINING WITHIN ONE MILE OF BUILDING SITE:  NO  YES
  - SIGNIFICANT LONG-TERM DEGRADATION OR AGGRADATION:  NO  YES
  - CHANNELIZATION, ENCROACHMENT, OR BANK PROTECTION:  NO  YES
- 100-YEAR DISCHARGE (Q100): \_\_\_\_\_ CFS (Q100)<sup>0.5</sup> = \_\_\_\_\_
- SOURCE OF 100-YEAR DISCHARGE ESTIMATE: \_\_\_\_\_
- SITE IS LOCATED ON OUTSIDE OF CHANNEL BEND:  NO  YES
- CHANNEL BEND ANGLE: \_\_\_\_\_ DEGREES
- DOCUMENTATION OF BEND ANGLE SUBMITTED:  NO  YES
- COMPUTED LEVEL 1 EROSION HAZARD SETBACK: \_\_\_\_\_ FT.
- BANK LOCATION PLOTTED ON MAP:  NO  YES
- BUILDING SITE LOCATION PLOTTED ON MAP:  NO  YES
- FLOODPLAIN LIMIT PLOTTED ON MAP:  NO  YES
- MINIMUM EROSION SETBACK DETERMINED BY:  SETBACK EQUATION  FLOODPLAIN + 50 FT.
- BUILDING SITE LOCATED WITHIN LEVEL 1 EROSION HAZARD ZONE:  NO  YES  
IF YES, SUBMIT CHECKLIST #5

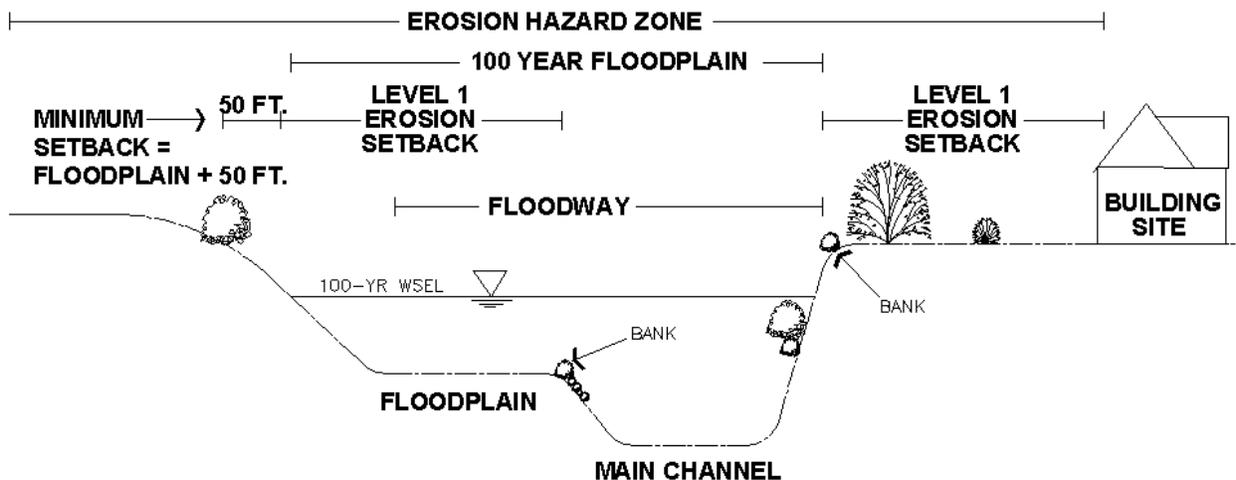


Figure 5-1. Illustration of Level 1 erosion hazard setback.



**Checklist #3: Level 2 Erosion Hazard Assessment**

Checklist #3 is required if the Level 2 erosion hazard methodology is used.

- DRAINAGE AREA: \_\_\_\_\_ SQ. MI. (IF > 500 SQ. MI., USE LEVEL 3)
- REACH LENGTH: \_\_\_\_\_ FT. (IF > 1,000 FT, RECOMMENDED LEVEL 1 OR 3)
- 100-YEAR DISCHARGE (Q100): \_\_\_\_\_ CFS (Q100)<sup>0.5</sup> = \_\_\_\_\_
- SOURCE OF 100-YEAR DISCHARGE ESTIMATE: \_\_\_\_\_
- SOURCE OF HYDRAULIC DATA: \_\_\_\_\_
- HYDRAULIC MODEL USED: \_\_\_\_\_ (SUBMIT DOCUMENTATION)
  - CHANNEL VELOCITY = \_\_\_\_\_ FT/S OVERBANK VELOCITY (MAX) = \_\_\_\_\_ FT/S
  - CHANNEL DEPTH = \_\_\_\_\_ FT OVERBANK DEPTH (MAX) = \_\_\_\_\_ FT
  - SOURCE OF TOPOGRAPHIC MAPPING: \_\_\_\_\_
- AVULSION HAZARD PRESENT?  NO  YES (SUBMIT DOCUMENTATION)
  - DEPTH X VELOCITY<sup>2</sup> = \_\_\_\_\_
  - BANK CHARACTERISTICS & HYDRAULIC DATA BASED ON AVULSION HAZARD?  NO  YES
- SETBACK ADJUSTMENT FACTORS (DOCUMENTATION?) **FACTOR VALUE**

	<input type="checkbox"/> Y <input type="checkbox"/> N	
<input type="checkbox"/> CHANNEL BEND ANGLE:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> CHECK UPSTREAM/DOWNSTREAM BENDS</li> <li><input type="checkbox"/> SHOW CHANNEL FEATURE &amp; TANGENT LINES USED ON MAP</li> </ul>		
<input type="checkbox"/> CHANNEL VELOCITY:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> USE MAXIMUM VELOCITY OR 1.5* AVERAGE VELOCITY</li> <li><input type="checkbox"/> PARTITIONED CHANNEL OR FLOODPLAIN MODEL REQUIRED?</li> </ul>		
<input type="checkbox"/> BANKFULL WIDTH/DEPTH RATIO:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> LOWEST BANK HEIGHT = _____ FT</li> <li><input type="checkbox"/> CHANNEL WIDTH = _____ FT. WIDTH/DEPTH RATIO = _____</li> </ul>		
<input type="checkbox"/> BANK MATERIALS:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> CHECK FOR LAYERED BANK MATERIALS</li> <li><input type="checkbox"/> MAP BEDROCK OUTCROP, DESCRIBE LITHOLOGY</li> </ul>		
<input type="checkbox"/> BANK CEMENTATION:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> CHECK FOR LAYERED BANK MATERIALS</li> </ul>		
<input type="checkbox"/> BANK VEGETATION DENSITY:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> SEASONAL DENSITY VARIATION EXPECTED?</li> </ul>		
<input type="checkbox"/> BANK VEGETATION TYPE:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> BANK VEGETATION PERCHED?</li> </ul>		
<input type="checkbox"/> BANK CONDITIONS:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> PERCENT CUTBANK ESTIMATE = _____ %</li> <li><input type="checkbox"/> BASAL ENDPOINT CONTROL PRESENT?</li> </ul>		
<input type="checkbox"/> FLOW CONDITIONS:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<input type="checkbox"/> WATERSHED DEVELOPMENT:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> WMP OR ADMP APPROVED &amp; ENFORCED?</li> </ul>		
<input type="checkbox"/> MANMADE CHANNEL DISTURBANCE:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> WMP APPROVED &amp; ENFORCED</li> <li><input type="checkbox"/> CHECK REACH LENGTH</li> </ul>		
<input type="checkbox"/> VERTICAL CHANNEL STABILITY:	<input type="checkbox"/> Y <input type="checkbox"/> N	
<ul style="list-style-type: none"> <li><input type="checkbox"/> AGGRADATION OR DEGRADATION EXPECTED?</li> </ul>		

**SUM OF ADJUSTMENT FACTORS:** \_\_\_\_\_



**Level 3 Checklist (continued)**

- BANK HEIGHT NEAREST BUILDING SITE = \_\_\_\_\_ FT
- BANK LOCATION PLOTTED ON MAP?  NO  YES
- BUILDING SITE LOCATION PLOTTED ON MAP?  NO  YES
- REDUCED SETBACK DUE TO BEDROCK OR BANK PROTECTION?  NO  YES
  - ENGINEER'S CERTIFICATION OF BANK PROTECTION?  NO  YES
  
- COMPUTED LEVEL 2 EROSION HAZARD SETBACK:** \_\_\_\_\_ **FT.**
- EROSION SETBACK DETERMINED BY:  SETBACK EQUATION  15 FT. OR 2\*BANK HEIGHT
  
- ENGINEER'S CERTIFICATION FORM SUBMITTED?  NO  YES
  
- BUILDING SITE LOCATED WITHIN LEVEL 2 EROSION HAZARD ZONE:  NO  YES  
 IF YES, SUBMIT CHECKLIST #5



### **Checklist #4: Level 3 Erosion Hazard Assessment**

Checklist #4 is required if the Level 3 erosion hazard methodology is used.

- SITE LOCATION IN HOLOCENE FLOODPLAIN?
  - YES: USE LIMITED DETAIL SCOPE OF ANALYSIS (SECTION 2.2.3.1)
  - NO: USE DETAILED SCOPE OF ANALYSIS (SECTION 2.2.3.2)
  - SOURCE OF HOLOCENE/PLEISTOCENE DELINEATION: \_\_\_\_\_
  
- LIMITED DETAIL LEVEL 3 EROSION HAZARD ASSESSMENT (SEE SECTION 2.2.3.1 FOR TASK LIST)
  - FLOODPLAIN/FLOODWAY DELINEATION
  - GEOMORPHIC/GEOLOGIC MAPPING
  - FIELD INVESTIGATION
  - QM SURFACE EROSION RATE
  - REPORT SEALED BY ENGINEER OR GEOLOGIST
  
- DETAILED LEVEL 3 EROSION HAZARD ASSESSMENT (SEE SECTION 2.2.3.2 FOR TASK LIST)
  - HISTORICAL ANALYSIS OF HORIZONTAL CHANNEL CHANGE
    - LIST OF HISTORICAL RESOURCES USED
    - PERIOD OF RECORD OF HISTORICAL DATA
  - HISTORICAL ANALYSIS OF VERTICAL CHANNEL CHANGE
    - LIST OF HISTORICAL RESOURCES USED
    - PERIOD OF RECORD OF HISTORICAL DATA
  - GEOMORPHIC/GEOLOGIC MAPPING
    - SOURCE OF GEOMORPHIC MAPPING
    - MAPS OF HOLOCENE SURFACES & BEDROCK OUTCROPS
  - FIELD INVESTIGATION
    - DOCUMENT LEVEL 2 FIELD PARAMETERS
    - DOCUMENT ALTERNATIVE FIELD PROCEDURES, IF USED
    - PROVIDE PHOTOGRAPHIC DOCUMENTATION
    - MAP OF OBSERVED FEATURES
  - HYDRAULIC MODELING
    - SOURCE OF HYDROLOGIC DATA: PEAKS & HYDROGRAPHS
    - ANALYSIS OF AVULSION POTENTIAL
    - SOURCE OF HYDRAULIC DATA
    - DOCUMENTATION & MODELS PROVIDED?
  - SEDIMENT TRANSPORT & ENGINEERING ANALYSIS
    - INTEGRATE RESULTS WITH FIELD & HISTORICAL DATA
    - DOCUMENTATION OF METHODS, ASSUMPTIONS, & RESULTS
  - COMPUTER MODELING USED?
    - VERIFICATION & CALIBRATION PROVIDED?
  - REPORT
    - ENGINEER'S CERTIFICATION PROVIDED?
    - LONG-TERM CHANNEL BEHAVIOR PREDICTED?
    - CONCISE SUMMARY OF RESULTS?
  
- DEVELOPMENT IN EROSION HAZARD ZONE?
  - IF YES, USE CHECKLIST #5



**Checklist #5: Structural Erosion Control Measures**

Checklist #5 is required if development is proposed within an erosion hazard zone. Such development must be protected from erosion damage.

- DESCRIPTION OF PROPOSED STRUCTURAL MEASURE(S): \_\_\_\_\_
- SOURCE OF HYDRAULIC MODELING: \_\_\_\_\_
- MEETS LOW-IMPACT CRITERIA?
 

	10-YEAR	100-YEAR
○ VELOCITY	_____	_____
○ WATER SURFACE ELEVATION:	_____	_____
○ FLOODPLAIN WIDTH:	_____	_____
○ MAIN CHANNEL DISTURBED?		
○ 10-YEAR FLOODPLAIN DISTURBED?		
○ BANK VEGETATION REPLACED?		
○ NO OFF-SITE IMPACTS?		
- IMPACT ANALYSIS
 

	ON-SITE	OFF-SITE
○ WATER SURFACE ELEVATION CHANGE	_____	_____
○ FLOODWAY CHANGE	_____	_____
○ SEDIMENTATION IMPACTS – COMPARE PRE-PROJECT & POST-PROJECT CONDITIONS <ul style="list-style-type: none"> <li>▪ CHANNEL REALIGNMENT</li> <li>▪ UPSTREAM SCOUR</li> <li>▪ DOWNSTREAM SCOUR</li> <li>▪ TRANSPORT CAPACITY</li> <li>▪ PROVIDE DESCRIPTION OF METHODS</li> <li>▪ PROVIDE DOCUMENTATION &amp; CALCULATIONS</li> </ul>		
○ CUMULATIVE IMPACTS ANALYSIS		
○ STATEMENT OF FINDINGS		
○ REPORT SEALED BY ENGINEER		
- STRUCTURE DESIGN ELEMENTS
  - MEETS *DRAINAGE DESIGN MANUAL – HYDRAULICS* STANDARDS
  - NO PIECEMEAL BANK STABILIZATION
  - TOE DOWN BELOW MAIN CHANNEL SCOUR + LONG-TERM SCOUR DEPTH
  - GRADE CONTROL REQUIRED?
  - LATERAL TIE-IN UPSTREAM & DOWNSTREAM
  - MATERIAL RESISTS DESIGN EVENT SCOUR & EROSION
  - LONG-TERM
- AGENCY PERMITS OBTAINED PRIOR TO CONSTRUCTION
- REPORT
  - ENGINEERS CERTIFICATION FORM
  - DESIGN & CONSTRUCTION DRAWINGS



**Engineer's Certification**

This is to certify that I am a duly qualified registered professional engineer licensed to practice in the State of Arizona, with expertise in hydrology, hydraulics, sedimentation transport, fluvial geomorphology, river mechanics, and local stream systems in Maricopa County. I also certify that the attached technical data supports the fact that the proposed development located at \_\_\_\_\_ (LOCATION) will be safe from all erosion hazards associated with \_\_\_\_\_ (WATERCOURSE NAMES) up to and including the base (100-year) flood and long-term channel movement over a period of at least 100 years.

Attached are the following documents and technical information that support my findings:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

\_\_\_\_\_  
Name/Title

\_\_\_\_\_  
Date

\_\_\_\_\_  
Registration Number

Affix Seal:



## **Section 6:** **References**

### **General References**

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

Arizona Department of Water Resources (ADWR), 1996, *State Standard 5-96, State Standard for Watercourse System Sediment Balance*.

Arizona Department of Water Resources (ADWR), 1998, *State Standard 7-98, State Standard for Watercourse Bank Stabilization*.

Bachman, and Machette, M.N., 1977, Calcic Soils and Calcretes in the Southwestern United States, USGS Open File Report 77-74, 163 pgs.

Birkeland, P. W., Machette, M. N., and Haller, K. M., 1991, *Soils as a tool for applied Quaternary geology*: Utah Geological and Mineral Survey Miscellaneous Publication 91-3, 63 p.

City of Tucson, 1989, *Standards Manual for Drainage Design and Floodplain Management*. Manual Prepared by Simons Li and Associates.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, "Morphological and Genetic Sequences of Carbonate Accumulation in Desert Soils," *Soil Science*, Vol. 101, p. 347-360.

Leopold, L.B., and Maddock, T.M., 1953, *The Hydraulic Geometry of Stream Channels and Some Physiographic Implications*, USGS Professional Paper 252, Washington, D.C.

Leopold, L.B., Wolman, M.G., and Miller, 1964, *Fluvial Processes in Geomorphology*. Freeman Company. San Francisco.

Pemberton, E.L., and Lara, J.M., 1984, *Computing Degradation and Local Scour, Technical Guideline for Bureau of Reclamation*. Denver, Colorado. January.

Pope, G.L., Rigas, P.D., and Smith, C.F., 1998, *Statistical Summaries of Streamflow Data and Characteristics of Drainage Basins for Selected Streamflow-Gaging Stations in Arizona Through Water Year 1996*, USGS Water-Resources Investigations Report 98-4225.

RCE, Resource Consultants & Engineers, Inc., 1994, *Sediment and Erosion Design Guide*, Manual prepared for the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA).

Rosgen, D., 1996, *Applied River Morphology*, Wildland Hydrology, Pagosa Springs, Colorado.



Thorne, C.R., 1998, *Stream Reconnaissance Handbook*, John Wiley & Sons, New York.

U.S. Army Corps of Engineers, 1989, *Sedimentation Investigation of Rivers and Reservoirs*, EM1110-2-4000.

### **Technical References for Erosion Hazard Delineation**

ADWR, 1996, State Standard 5-96: State Standard for Watercourse System Sediment Balance. Report by the Arizona Dept. of Water Resources State Standards Work Group.

FHWA, 1990, Highways In The River Environment, Publication # FHWA-HI-90-016. Report by the US Dept. of Transportation - Federal Highways Administration.

FHWA, 1985, Streambank Stabilization Measures For Highway Engineers, Publication #PB86-187986. Report by Sutron Corp. for US Dept. of Transportation - Federal Highways Administration.

FHWA, 1991, Hydraulic Engineering Circular No. 20: Stream Stability At Highway Structures, Publication No. FHWA-IP-90-014. Report by US Dept. of Transportation - Federal Highways Administration.

JE Fuller/ Hydrology & Geomorphology, Inc, 2001, Skunk Creek/Sonoran Wash Lateral Migration Report, Appendix to the Skunk Creek/Sonoran Wash Watercourse Master Plan. Report prepared for the Flood Control District of Maricopa County.

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

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

USACOE, 1989, Sedimentation Investigation Of River And Reservoirs, Engineering Manual EM 1110-2-4000. Report by the US Army Corps of Engineers.

USACOE, 1994, Channel Stability Assessment For Flood Control Projects: Engineering Manual EM 1110-2-1418. Report by the US Army Corps of Engineers. Also available as ASCE Technical Engineering and Design Guide #20 (1997).

USDA, 1984, National Engineering Handbook Section 3: Sedimentation. Report by the US Dept. of Agriculture Soil Conservation Service.



## **Technical References for Designing Structural Erosion Protection**

ADOT, 1989, Sizing Riprap for the Protection of Approach Embankments and Spur Dikes and Limiting the Depth of Scour at Bridge Piers and Abutments - Two Volumes. Report for the Arizona Dept. of Transportation. Report #FHWA-AZ89-260.

City of Tucson, 1989, Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona. Report prepared for the City of Tucson Dept. of Transportation.

FCDMC, 1991, Drainage Design Manual for Maricopa County, Arizona - Volume II: Hydraulics. Report by NBS Lowry for the Flood Control District of Maricopa County.

FHWA, 1985, Design of Spur-Type Streambank Stabilization Structures. Report by Sutron Corp for the US Dept. of Transportation Federal Highway Administration.

FHWA, 1985, Streambank Stabilization Measures for Highway Engineers. Report by Sutron Corp for the US Dept. of Transportation Federal Highway Administration.

PCFCD, 1984, Drainage and Channel Design Standards for Local Drainage for Floodplain Management Within Pima County, Arizona. Report prepared by the Pima County Dept. of Transportation and Flood Control District.

PCFCD, 1985, Soil Cement Applications and Use in Pima County for Flood Control Projects. Report by the Pima County Dept. of Transportation and Flood Control District.

Rosgen, D., 1996, Applied River Morphology, Wildland Hydrology Books, Pagosa Springs, Colorado.

USACOE, 1988, Hydraulic Design Criteria. Report by US Army Corps of Engineers Waterway Experiment Station, Vicksburg, Mississippi.

USACOE, 1991, Hydraulic Design of Flood Control Channels: Engineering Manual EM 1110-2-1601. Report by the US Army Corps of Engineers. Also available as ASCE Technical Engineering and Design Guide #10 (1995).

USACOE, 1978, Design and Construction of Levees: Engineering Manual EM 1110-2-1913. Report by the US Army Corps of Engineers.

USDA, 1977, Technical Release No. 25: Design of Open Channels. Report by the US Dept. of Agriculture Soil Conservation Service.



## Technical References for Geomorphic & Geologic Mapping

Bachman, and Machette, M.N., 1977, Calcic Soils and Calcretes in the Southwestern United States, USGS Open File Report 77-74, 163 pgs.

Birkeland, P. W., Machette, M. N., and Haller, K. M., 1991, Soils as a tool for applied Quaternary geology: Utah Geological and Mineral Survey Miscellaneous Publication 91-3, 63 p.

Field, J.J., and Pearthree, P.A., 1992, Geologic Mapping of Flood Hazards in Arizona: An Example From the White Tank Mountains Area, Maricopa County, OFR91-10, 16 p., scale 1:24,000, 4 sheets.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, "Morphological and Genetic Sequences of Carbonate Accumulation in Desert Soils," Soil Science, Vol. 101, p. 347-360.

Spencer, E.W., 1993, Geologic Maps: A Practical Guide to the Interpretation and Preparation of Geologic Maps: For Geologists, Geographers, Engineers, and Planners, Prentice Hall.

Spencer, E.W., 1999, Geologic Maps: A Practical Guide to the Preparation and Interpretation of Geologic Maps (2nd Edition),  
Prentice Hall.

See also: Arizona Geological Survey @ <http://www.azgs.az.gov/publications.htm>.



## **Appendix A: Erosion Hazard Assessment**

The following guidelines to help identify erosion hazards along streams and watercourses in Arizona. Stream channel erosion can increase local flood hazards by causing bank failures or undermining structures. Channel erosion can occur on all stream types, including perennial streams, ephemeral washes, man-made channels, or in areas of sheet flow. The following guidelines are intended to help identify watercourses that could be subject to erosion.

### **Identifying Characteristics for Stream Channel Erosion**

Streams that have experienced erosion exhibit certain characteristics that can be readily identified in the field. The lists of characteristics shown below are divided into those that can be observed along natural reaches (no structures present), and those that can be observed where structures have been built in the channel. In addition, the following general rules apply to streams in Arizona:

- Streams that have experienced erosion problems in the past will experience erosion problems in the future.
- Undisturbed natural streams are less likely to experience erosion than streams that have been altered or that flow through urban areas.
- As a stream and its watershed become more disturbed, the stream is more likely to experience channel erosion.
- The most effective way to avoid erosion damages is to avoid construction or other development activities in the floodplain.
- Bank erosion occurs more rapidly on the outside of bends (meanders) than on the inside of bends.
- Vertical bank slopes are the most readily identified sign of high potential for channel erosion.

### **Natural Features**

The following list of natural channel features are evidence that stream erosion has occurred in the recent past, or is likely to occur in the future. However, erosion can occur on any streams, regardless of its current appearance.

**Cut or undercut stream banks.** Cut banks occur where erosion has left stream banks steeper than the natural angle of repose of the soil material. Signs of cut banks include lack of bank vegetation, loose soil material (slides when touched), tension cracks in the



soils adjacent to the banks, piles of soil at the base of the bank slope, and bank vegetation leaning into the stream corridor.

**Vertical banks.** Vertical banks are the most easily identified evidence of bank erosion. Except where the vertical banks are composed of solid bedrock, vertical banks are never stable, and indicate recent channel erosion.

**Bank vegetation leaning into channel.** Trees and other bank vegetation will fall into the channel as the soil around the roots is removed by erosion. Once the bank vegetation fails, bank erosion occurs more rapidly.

**Roots of bank vegetation exposed.** Exposed roots of bank vegetation indicate that soil material has been removed from the banks and that erosion is beginning to occur.

**Lack of bank vegetation.** Where no vegetation is present along the banks, especially on perennial or intermittent streams, it has either been artificially removed or eroded away by the stream. Where a stream's bank vegetation is discontinuous compared to upstream and downstream reaches, the stream is more likely to erode its banks.

**Mid-channel bars higher than floodplain elevation.** Where the elevation of the top of the mid-channel bars is close to or higher than the floodplain elevation, rapid bank erosion and channel avulsions are more likely.

**Gully formation in the watershed.** Gully formation in a watershed indicates excess runoff and a sediment deficit, which may cause bank erosion on main stem streams.

**Irregular channel geometry.** Natural channels generally have gradual changes in the channel width and depth over short reaches. Where channel width and depth change rapidly without a recognizable pattern, it is likely that the channel is unstable and subject to erosion.

**Piping of bank soils.** Piping, or formation of zones of high hydraulic conductivity in a stream bank, can destabilize the banks and lead to more rapid erosion.

**Perched tributaries.** Tributaries normally join the main stream at an elevation equal to the bed elevation of the main channel. Where the elevation of the tributary mouth is significantly higher than the main stem, it is likely that accelerated bank erosion of the main stem will occur.

### **Man-Made Features**

Man-made structures, since they are generally not designed to move, offer a reference point from which to assess the magnitude of channel change since their construction date. Some types of structures that can be used to identify erosion include the following:



**Failed bank protection.** Failures of bank protection, such as slumped riprap or cracked concrete, may indicate long term degradation of the channel or channel movement.

**Footings of structures.** Footings are typically designed below the elevation of the stream bed. If exposed or undercut, it can be assumed that the stream channel has degraded or moved.

**Activities That Can Increase the Potential for Stream Erosion:**

The following human activities can increase the potential for river erosion:

- Removing vegetation from channel banks or the channel bed.
- Excavating sand and gravel material from the channel bed.
- Lining only one bank with permanent bank protection such as riprap.
- Changing the natural channel geometry by channelization or grading.
- Straightening a naturally sinuous channel.
- Increasing the frequency of runoff by discharging urban runoff into a stream.
- Developing within the floodplain.
- Constructing an on-line detention basin or dam upstream.
- Removing a large number of trees from a forested watershed.
- Removing of watershed vegetation by overgrazing.

Erosion hazards should be considered in the design of structures along any watercourse that exhibits any of the features described above.



<b>List of Watercourses With Erosion Hazard Delineations</b>				
<b>Watercourse Name</b>	<b>Delineation Limits</b>	<b>Reference</b>		<b>Agency</b>
Agua Fria River	New Waddell Dam to Gila River	Agua Fria Watercourse Master Plan	Approved	FCDMC
Apache Wash	Carefree Highway to Cave Creek	Upper Cave Creek/Apache Wash Watercourse Master Plan	Approved	FCDMC
	Headwaters to Carefree Highway	Adobe Area Drainage Master Plan	In progress	FCDMC
Buchanan Wash	Headwaters to Skunk Creek	Adobe Area Drainage Master Plan	In progress	FCDMC
CAP Tributaries	Headwaters to CAP, Buchanan Wash area	Adobe Area Drainage Master Plan	In progress	FCDMC
Caterpillar Tank Wash	Headwaters to Agua Fria River	North Peoria Area Drainage Master Plan	Approved	FCDMC
Cave Creek	Carefree Highway to Cave Buttes Dam	Upper Cave Creek/Apache Wash Watercourse Master Plan	Approved	FCDMC
Cline Creek	Headwaters to Skunk Creek	Adobe Area Drainage Master Plan	In progress	FCDMC
	Cline Creek Tributaries	Adobe Area Drainage Master Plan	In progress	FCDMC
Desert Hills Wash	City of Phoenix Boundary to Apache Wash	Upper Cave Creek/Apache Wash Watercourse Master Plan	Approved	FCDMC
	Carefree Highway to Headwaters	Adobe Area Drainage Master Plan	In progress	FCDMC
	Desert Hills Tributaries 1-6	Adobe Area Drainage Master Plan	In progress	FCDMC
East Garambullo Wash	CAP to Twin Buttes Wash	North Peoria Area Drainage Master Plan	Approved	FCDMC
Gila River	Agua Fria River to SR85	El Rio Watercourse Master Plan	In progress	FCDMC
Jonathan Wash (Desert Lake Wash)	Desert Hills to Headwaters	Adobe Area Drainage Master Plan	In progress	FCDMC
	Jonathan Wash Tributaries	Adobe Area Drainage Master Plan	In progress	FCDMC
King's Well Wash	Headwaters to Skunk Creek	Adobe Area Drainage Master Plan	In progress	FCDMC
Morgan City Wash	Headwaters to Agua Fria River	North Peoria Area Drainage Master Plan	Approved	FCDMC
Paradise Wash	Carefree Highway to Apache Wash	Upper Cave Creek/Apache Wash Watercourse Master Plan	Approved	FCDMC
	Headwaters to Carefree Highway	Adobe Area Drainage Master Plan	In progress	FCDMC
Ranieri Tank Wash	Headwaters to Paradise Wash	Adobe Area Drainage Master Plan	In progress	FCDMC
Rodger Creek	Headwaters to Skunk Creek	Rodger Creek Erosion Hazard Study	Approved	FCDMC
Skunk Creek	Adobe Dam to CAP	Adobe Area Drainage Master Plan	In progress	FCDMC
	New River Road to CAP	Skunk Creek Watercourse Master Plan	Approved	FCDMC
	Headwaters to New River Road	Adobe Area Drainage Master Plan	In progress	FCDMC
Skunk Creek Tributaries	Headwaters to Skunk Creek	Adobe Area Drainage Master Plan	In progress	FCDMC
Skunk Tank Wash	Headwaters to Skunk Creek	Skunk Tank Wash Erosion Hazard Study	Approved	FCDMC
Sonoran Wash	7 <sup>th</sup> Street Alignment to CAP	Skunk Creek Watercourse Master Plan	Approved	FCDMC
Twin Buttes Wash	Headwaters to Agua Fria River	North Peoria Area Drainage Master Plan	Approved	FCDMC
Unnamed Wash #1 (Bailey Tank Wash)	Headwaters to Agua Fria River	North Peoria Area Drainage Master Plan	Approved	FCDMC
Unnamed Wash #2	Headwaters to Agua Fria River	North Peoria Area Drainage Master Plan	Approved	FCDMC

<b>List of Watercourses With Erosion Hazard Delineations</b>				
<b>Watercourse Name</b>	<b>Delineation Limits</b>	<b>Reference</b>		<b>Agency</b>
Unnamed Wash #3	Headwaters to Agua Fria River	North Peoria Area Drainage Master Plan	Approved	FCDMC
Unnamed Wash #4	Headwaters to Agua Fria River	North Peoria Area Drainage Master Plan	Approved	FCDMC
West Garambullo Wash	CAP to Twin Buttes Wash	North Peoria Area Drainage Master Plan	Approved	FCDMC
White Peaks Wash	CAP to Twin Buttes Wash	North Peoria Area Drainage Master Plan	Approved	FCDMC