PINAL COUNTY AREA DRAINAGE MASTER PLAN

RULES OF DEVELOPMENT:

Best Management Practices for Drainage Engineering in Pinal County

Pinal County Flood Control District
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Rules of Development
Overview

These Rules of Development were developed as part of the Pinal County Area Drainage Master Plan (ADMP). The Rules of Development are intended as guidelines to assist engineers, developers, and County reviewers identify flood hazards and implement cost-effective best management practices for drainage engineering in Pinal County. Adherence to these Rules of Development will facilitate the review process, minimize the need for expenditure of public funds to mitigate drainage problems, and help protect the health, safety and welfare of the citizens of Pinal County.

The Rules of Development presented in this document are organized by hazard and development type. The user should consult the individual watershed reports from the Pinal County ADMP as well as the ADMP Geographic Information System (GIS) for descriptions of hazards in each of the ADMP subareas in Pinal County. This document is organized as follows:

- Section 1: Introduction & Background
- Section 2: Rules for Development in Floodplains & Special Consideration Areas
- Section 3: Rules for Specific Types of Development
- Section 4: General Development Policies
- Section 5: Appendixes: Technical References & Supplemental Information

The table below is provided to guide the user to the appropriate rules of development for each hazard and development type. Hazards at specific land parcels can be identified by viewing the ADMP GIS or by meeting with Pinal County Flood Control District staff.

Pinal County Rules of Development			
Special Consideration Areas		**Types of Development**	
Riverine Floodplains	Section 2.2	Road Crossings	Section 3.2
Riverine Erosion Hazards	Section 2.3	Utility Crossings	Section 3.3
Distributary & Split Flow Areas	Section 2.4	Detention/Retention	Section 3.4
Alluvial Fans	Section 2.5	Dams	Section 3.5
Sheet Flow	Section 2.6	Levees & Embankments	Section 3.6
Ponding Areas	Section 2.7	Canals & Irrigation Structures	Section 3.7
Farmlands	Section 2.8	Storm Drains & Channels	Section 3.8
Hillside Slopes	Section 2.9	Sand & Gravel Mining	Section 3.9
Subsidence & Earth Fissures	Section 2.10		

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Rules of Development
Section 1. Introduction

Natural environmental hazards associated with drainage and storm water runoff exist in all watersheds. Development can adversely affect natural drainage and create flood and erosion hazards, unless adequate planning and management rules are applied. To protect private and public property, and the health and general welfare of the public, naturally occurring environmental hazards and potential hazards related to development need to be identified, and appropriate development standards applied to manage new development.

The Pinal County Area Drainage Master Plan (ADMP) identifies certain drainage and environmental hazards for watersheds in Pinal County. The ADMP also includes an inventory of existing drainage-related facilities, an HEC-1 hydrologic skeleton model, and a Geographical Information System (GIS) database. The rules of development outlined in this document are a non-structural component of the overall Pinal County comprehensive flood hazard management plan. Other flood mitigation strategies may be implemented by developers or agencies, such as flood warning systems, at-risk property acquisition, or structural flood control measures. The rules of development identify drainage issues, recommend development practices, identify required engineering analysis, and describe best management practices for floodplain management and drainage engineering.

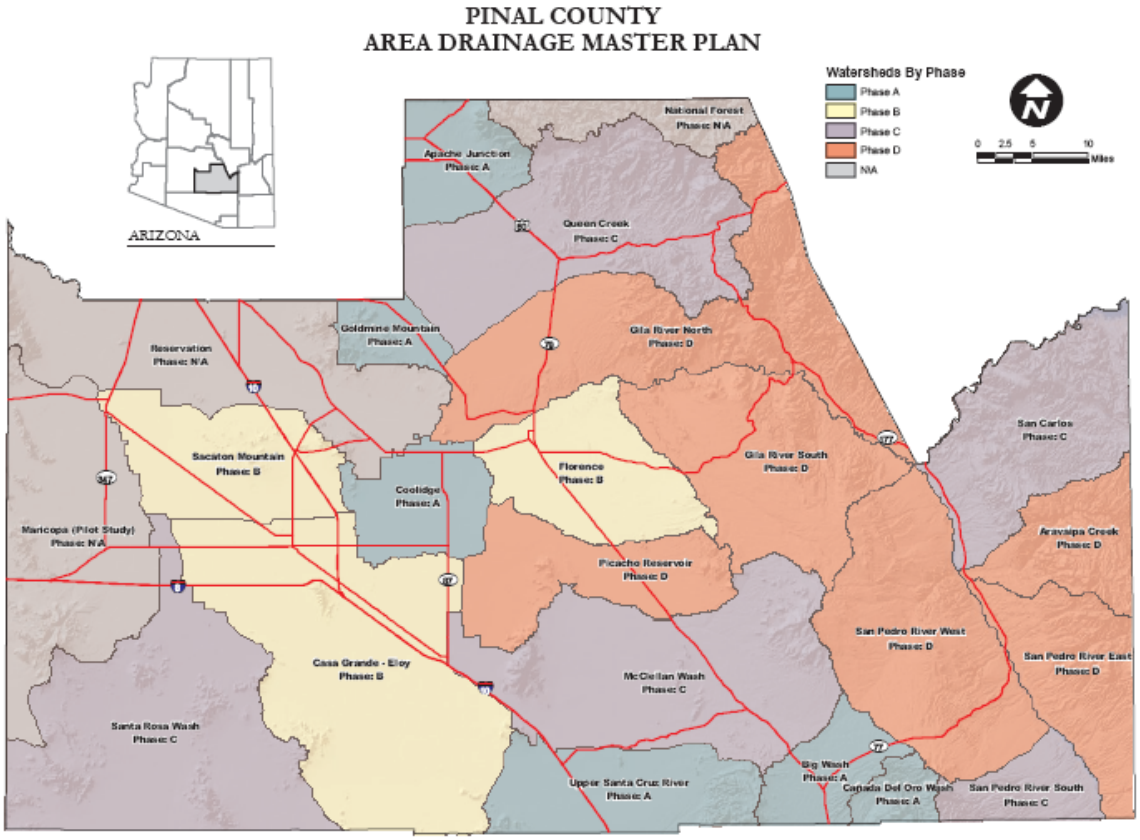

Figure 1-1. Pinal County ADMP watershed subareas.

Implementation of rules of development for drainage and environmental hazards has been shown to reduce public expenditures for structural flood control measures, decrease the level of maintenance needed for flood control facilities, and lessen the need for acquisition of public right-of-way for flood control. In addition, application of rules of development reduces the potential for flood damage to private and public property, and reduces the need for public funding for flood mitigation.

1.1. Background & Rationale

Historically, Arizona counties have developed floodplain management measures such as floodplain ordinances, drainage ordinances, and development standards intended to mitigate the flood impacts of urbanization. If these measures are not adequate or are not adequately enforced, the consequences may include flooding of homes and businesses, displacement of existing natural flood flows, increased flood depths, and flooding of lands previously not in a floodplain. The adverse impacts of urbanization on drainage often include the following:

- **More Frequent Flooding**. As the land area within a watershed is converted from natural rangeland to rooftops and pavement, less rainfall infiltrates into the ground and more rainfall becomes runoff. This results in more frequent runoff events and increased nuisance flooding.

- **Larger Flood Peaks**. The change from natural pervious land surfaces to urbanized impervious surfaces also causes the size of floods to increase, as more runoff leaves the watershed. Urbanized watersheds generate not only large flood peaks, but also larger flood volumes and floods of longer duration, both of which increase flood damages. As flood peaks increase with urbanization, existing drainage structures become inadequate and have a greater risk of failure.

- **Scour and Erosion**. Because more land area is covered by homes, streets and landscaping as a watershed urbanizes, the natural sediment supply to streams is decreased, which causes floods to be more erosive. This erosion leads to loss of homes, property and farmland due to riverine bank erosion, scour damage to bridges, and adverse impacts to flood control facilities and natural river habitat.

- **Flow Diversion**. Unmanaged development can block natural flow paths, diverting runoff toward areas that were previously not flooded.

- **Flow Concentration**. Development in riverine or sheet flow floodplains blocks natural overland flow paths, concentrating runoff through narrower conveyance corridors. Flow concentration leads to higher flood peaks, higher flood velocities, and accelerated scour and erosion.

- **Expanded Floodplains**. Increased flood peaks and flow diversion increase flood water elevations and expand floodplain widths, inundating properties previously

safe from flooding and expanding the number of homes and business at risk for future flood damage.

- **Reduced Surface Storage**. Reducing surface storage area by grading individual lots to reduce ponding areas or soggy soils, by erecting structures within former ponding and flood-prone areas, increases both the peak flow and the volume of runoff generated by a given storm, and may also result in a loss of vegetation that further increases runoff rates.

- **Decreased Ground Water Recharge**. Increased impervious surface area in an urbanized watershed inhibits ground water recharge and reduces soil moisture, with adverse consequences to long-term water supply, subsidence, and vegetation.

- **Loss of Riparian Habitat**. Increased erosion due to increased flood peaks and reduced sediment supply leads to degraded habitat along river corridors, with adverse impacts to wildlife and public recreation.

Adherence to the rules of development will lessen the adverse impacts of urbanization and decrease the cost of flooding for the public.

1.2. Objectives

Communities develop drainage ordinances, policies, and standards with the intent to mitigate/minimize flooding impacts due to urbanization of a watershed. The overall objective of the ADMP rules of development is to minimize the occurrence of losses, hazards, and conditions adversely affecting the public health, safety, and general welfare.

The general objectives of the rules of development include the following:

- Enhance public safety by guiding development in the watershed to protect current and future residents from the effects of flooding.

- Reduce adverse drainage impacts due to development in the watershed by guiding activities of new construction.

- Guide future development in a manner consistent with the floodplain management objectives of Pinal County.

The following specific objectives were established to guide the development of criteria and the means of implementation:

- Develop rules of development that have been tested on the actual environmental and development conditions within the study area.

- Develop rules of development consistent and compatible with existing statutes, ordinances, and regulations.

- Limit the rules of development to solely those necessary to address watershed-specific problems not adequately covered by existing Floodplain and/or Drainage Regulations.

The proposed Rules of Development for the Pinal County ADMP are consistent with the general and specific objectives set forth above.

1.3. Authority

Authority to regulate development and flood hazard areas is provided to Pinal County by federal law, state law, and local ordinances.

National Flood Insurance Program

Under the National Flood Insurance Program (NFIP), federal laws require the State of Arizona and Pinal County to manage and regulate all development in flood and erosion hazard zones. The NFIP regulations are outlined in the Code of Federal Regulations (44 CFR Chapter 1).

Arizona Revised Statutes

Local governmental entities are limited in their powers to those expressly granted by the State, as codified in the Arizona Revised Statutes (ARS). ARS Title 11 addresses county authority to regulate drainage. ARS Title 48 addresses county authority to regulate floodplains. State statutes specifically pertaining to development guidelines or "rules of development" include the following:

- ARS 11-251.36. Subject to the prohibitions, restrictions and limitations as set forth in section 11-830, adopt and enforce standards for excavation, landfill and grading to prevent unnecessary loss from erosion, flooding and landslides.

- ARS 48-2664.D. Adopt equitable by-laws, rules and regulations and perform all acts necessary to carry out the purposes of this chapter.

- ARS 48-3609.B. Adopt and enforce regulations governing floodplains and floodplain management in its area of jurisdiction which shall include the following:
    - Regulations for all development of land, construction of residential, commercial or industrial structures or uses of any kind which may divert, retard or obstruct floodwater and threaten public health or safety or the general welfare.

- ARS 48-3609.01.A. If a district organized pursuant to this chapter has completed a watercourse master plan which includes one or more watercourses, and if the plan has been adopted by the board or by any other jurisdiction in that river or

drainage system, then the board and the governing body of each jurisdiction may adopt and shall enforce uniform rules for the river or drainage system within the jurisdiction using criteria that meet or exceed criteria adopted by the Director of Water Resources pursuant to section 48-3605, subsection A.

Pinal County Drainage Regulations

The Pinal County Drainage Regulations include the following language relating to the rules of development:

- Area Drainage Master Study – a study to develop storm water hydrology for a watershed, to define drainage systems, identify potential flood hazard areas, drainage problems and recommend solutions and standards for sound floodplain and storm water management. The ADMS identifies alternative solutions to a given flooding or drainage problem. An Area Drainage Master Plan (ADMP) identifies the preferred alternative. An ADMP, unique to the subject watershed provides minimum criteria and standards (for flood control and drainage) for land use and development.

- Area Drainage Master Study Adoption. Whenever an Area Drainage Master Study has been completed, such plan including uniform rules for development may be submitted to the Board of Supervisors for adoption as an Area Drainage Master Plan. If adopted by the Board of Supervisors, the County shall enforce the Area Drainage Master Plan under this Regulation.

Pinal County Floodplain Regulations

The Pinal County Board of Directors has adopted floodplain regulations as required by State Statute. In the current regulations further basis is found for development guidelines or "rules of development".

> Article XIV, Section 1402. Flood Hazard Development Standards.
> 1. Standards adopted for development contained in a Watercourse Master Plan, Area Drainage Master Plan or other hydrologically oriented master plan shall be consistent with sound floodplain management practices and this Regulation.
> 6. The standards, provisions, criteria and requirements for development in flood hazard zones imposed by an authorized master plan shall meet or exceed the requirements of this Regulation.

1.4. Report Organization

The ADMP Rules of Development report is organized by hazard and development type. The types of natural environmental hazards addressed in Section 2 include the following:

- Section 2.2: Riverine Floodplains
- Section 2.3: Riverine Erosion
- Section 2.4: Distributary and Split Flow Areas
- Section 2.5: Alluvial Fans
- Section 2.6: Sheet Flow
- Section 2.7: Ponding Areas
- Section 2.8: Farmlands
- Section 2.9: Hillside Areas
- Section 2.10: Subsidence & Earth Fissures

In addition, development guidelines are presented in Section 3 for the following specific types of development:

- Section 3.2: Road Crossings
- Section 3.3: Utility Crossings
- Section 3.4: Detention/Retention Basins
- Section 3.5: Dams
- Section 3.6: Levees & Embankments
- Section 3.7: Canals & Irrigation Structures
- Section 3.8: Storm Drains & Channels
- Section 3.9: Sand & Gravel Mining

The Rules of Development provide references to statutory guidelines and regulatory guidelines and identify basic criteria for Base Flood Elevations (BFE), Finished Floor Elevations (FFE), Erosion Setback Limits and Scour Protection to enhance public safety and flood protection in flood hazard areas.

Rules of Development

Section 2. Floodplains & Special Consideration Areas

2.1. General Considerations

Rules of development for the following types of natural hazards are presented in this chapter:

- Section 2.2: Riverine Floodplains
- Section 2.3: Riverine Erosion
- Section 2.4: Distributary and Split Flow Areas
- Section 2.5: Alluvial Fans
- Section 2.6: Sheet Flow
- Section 2.7: Ponding Areas
- Section 2.8: Farmlands
- Section 2.9: Hillside Areas
- Section 2.10: Subsidence & Earth Fissures

For each hazard type, a definition and example photographs are provided, several key technical references are provided, followed by the hazard specific rules of development.

For any specific development parcel in Pinal County, general information regarding natural hazards impacting the site can be identified using the Pinal County ADMP GIS. The GIS provides comprehensive, but generalized hazard information. It is highly recommended that individuals developing property in Pinal County also contact qualified registered professional engineers, geologists, and/or hydrologists for more site-specific information regarding the hazards at specific development parcels.

In case of conflict between rules of development and other policy or regulatory guidelines, the following two guiding principles for development in Pinal County should be considered to apply universally:

- **No Adverse Impact**. All development shall have no adverse impact on the pre-development hazard level on any adjacent property.

- **Existing Regulations Enforced**. All development shall comply with all existing local, state and federal floodplain regulations.

As defined in the Pinal County Floodplain Ordinance, **development** means any man-made change to property, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations, or storage of materials or equipment.

2.2. Riverine Floodplains

2.2.1. Hazard Description

Riverine floodplains are found along watercourses in Pinal County and include both the river channel and areas adjacent to the channel that are periodically inundated by flood waters. For the purposes of these rules of development, a riverine floodplain occurs along a defined stream channel.

Figure 2-1. Aerial photograph of the Gila River floodplain near Florence, Arizona.

<u>Definitions</u>

- **Floodplain or Flood-Prone Area** means any land area susceptible to being inundated by water from any source. A riverine floodplain exists along a river or linear watercourse. Pinal County regulates all floodplains with 100-year discharges of 200 cfs or greater as noted in the Pinal County Floodplain Ordinance.

- **Flood Hazard Zone** means any land area located partially or wholly within a delineated floodplain susceptible to flood related damage as designated on the flood management maps. Such flood hazard zones may include but not be limited to areas highly susceptible to erosion, stream meander sensitivity, moveable bed, scour, wave action, and subsidence.

- **Regulatory Flood Elevation** means an elevation one foot above the base flood elevation for a watercourse for which the base flood elevation has been determined and shall be determined by the criteria developed by the Director of Water Resources for all other watercourses.

Types of Riverine Floodplains

- FEMA Floodplains. Certain riverine floodplains in Pinal County have been delineated on Flood Insurance Rate Maps or other flood hazard maps published by the Federal Emergency Management Agency (FEMA).
- ADMP Thalwegs. The Pinal County ADMP GIS includes a data layer called "thalwegs." The thalweg layer is a tool that identifies the approximate location of many significant watercourses. The thalwegs do not represent floodplain limits, although floodplains exist adjacent to each thalweg.
- Non-FEMA Floodplains. Some riverine floodplains in Pinal County have been delineated by agencies, developers, or other parties, but have not been submitted, reviewed, or approved by FEMA. Per NFIP regulations, these floodplains may be used by Pinal County as the best available information for floodplain management purposes. Pinal County regulates the floodplains of watercourses with 100-year discharges of 200 cfs or greater as noted in the Pinal County Floodplain Ordinance (August 2006).
- Non-Riverine Floodplains. Other types of floodplains including alluvial fan floodplains, sheet flow floodplains, and ponding area floodplains are described in the following sections of this document.

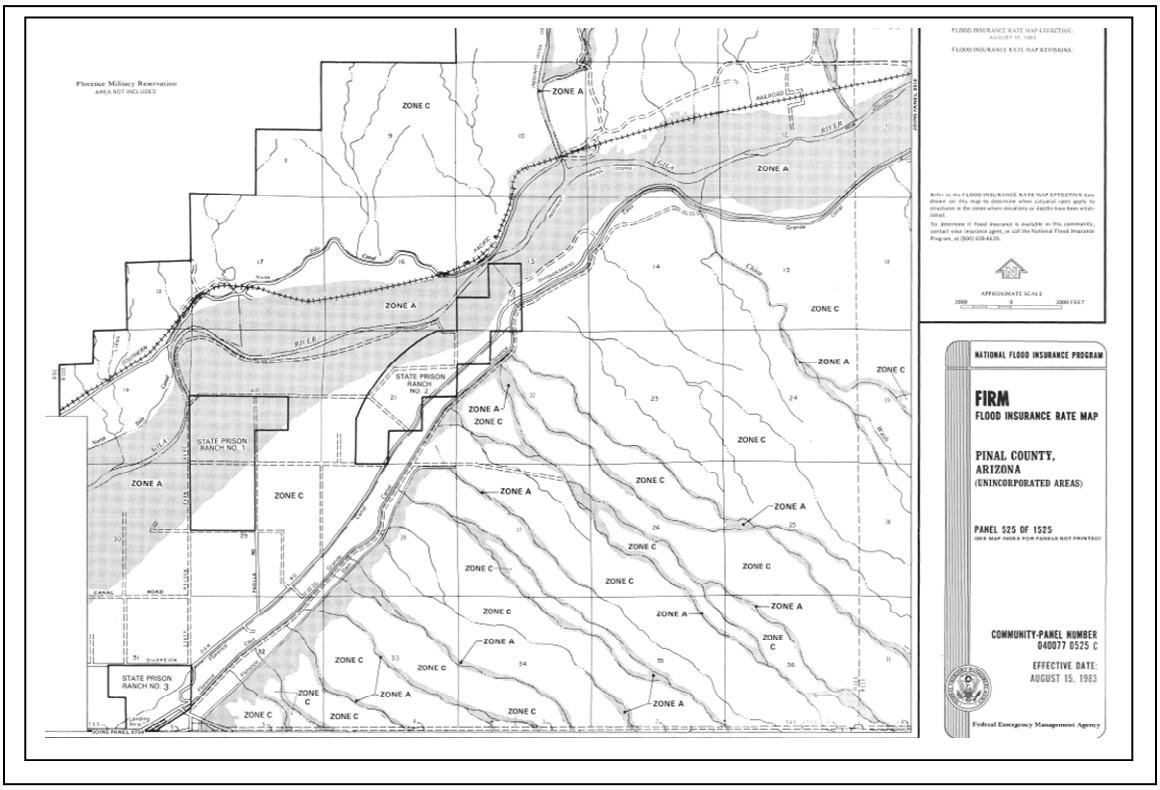

Figure 2-2. Gila River Zone A floodplain on a FEMA Flood Insurance Rate Panel #525.

2.2.2. Technical References:

Technical information regarding riverine floodplains can be found in the following resource documents.

- Federal Emergency Management Agency (FEMA), 2003, Guidelines and Specifications for Flood Hazard Mapping Partners – Report & Appendixes. Available at http://www.fema.gov/library.

- National Flood Insurance Program (NFIP) Regulations. Code of Federal Regulations (CFR) Title 44, Chapter 1. Available at: www.access.gpo.gov/nara/cfr/waisidx_02/44cfrv1_02.html.

- Arizona Department of Water Resources (ADWR). State Standards for Floodplain Management:[1]

    - (SS1-97) Requirement for Flood Study Technical Documentation
    - (SS2-96) Requirement for Riverine Floodplain And Floodway Delineation
    - (SS3-94) Standard for Supercritical Flow
    - (SS4-95) Standard for Development Within Sheet Flow Areas
    - (SS5-96) Standard for Watercourse System Sediment Balance
    - (SS6-96) Standard for Development of Lots Within Floodprone Areas
    - (SS7-98) Standard for Watercourse Bank Stabilization
    - (SS8-99) Standard for Stormwater Detention/Retention
    - (SS9-02) State Standard for Floodplain Hydraulic Modeling
    - (SS10-07) State Standard for Hydrologic Modeling Guidelines

- Pinal County Drainage Manual, Vol. 1 & 2 (2006). Available at: http://co.pinal.az.us/PubWorks

Additional technical references are listed in the bibliographies of the above-referenced documents.

2.2.3. Rules of Development for Riverine Floodplains

Policy FP(1): No Adverse Impact. Activities on a property that affect drainage may not result in adverse impacts on adjacent properties. At a minimum, such drainage activities, including wash relocations and the concentration of sheet flows or braided washes, shall not adversely change water surface elevation and flow characteristics. Such activities shall require an engineering report that substantiates there are no adverse impacts.

Policy FP(2): Floodplain Delineation Required. All development is required to delineate floodplain and floodway zones for areas not covered by delineation conducted

[1] http://www.azwater.gov/AzDWR/SurfaceWater/FloodManagement/StateStandards.htm

by FEMA or Pinal County. According to ARS 48-3609A and under the authority outlined in ARS 48-3605A floodplain delineations shall be conducted on all watercourses with drainage areas more than ¼ of a square mile or having a 100-year estimated peak flow rate of more than 200 cfs, or the rate currently listed in the Pinal County Floodplain Ordinance. Floodplain delineations shall be conducted in conformance with State Standard 2-96 guidelines, as presented in Pinal County Drainage Manual. Such floodplain delineations will be developed only for the purpose of local floodplain management and need not be submitted to or approved by FEMA.

Policy FP(3): Use of ADMP GIS Thalwegs. The ADMP GIS thalweg delineation indicates the presence of a floodplain, but does not depict the lateral extent of the floodplain. The ADMP GIS thalwegs are not intended for use in drainage or design reports prepared by engineers, except as order-of-magnitude preliminary planning estimates. Single lot development parcels near a GIS thalweg line may use the GIS upper hazard classification discharge limit (e.g. for the 500-999 cfs classification, use 999 cfs for the 100-year discharge) as the 100-year peak discharge, if no official discharge approved by Pinal County is available for that watercourse. The GIS thalweg hazard classifications may not be used for subdivisions or large commercial developments. The location of the ADMP GIS thalwegs may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. In all cases, if more detailed hydrologic modeling results are available and have been approved by the County, the more detailed flow rates should be used rather than the GIS thalweg discharge values.

Policy FP(4): Development in FEMA Floodplains. Development in FEMA-approved floodplains is governed by the most recent NFIP Regulations, ADWR State Standard for Floodplain Management, and the Pinal County Floodplain Ordinance. Any development that alters a FEMA floodplain limit or base flood elevation is required by NFIP regulations to submit a Letter of Map Revision for review and approval by FEMA.

Policy FP(5): Floodplain Development Discouraged. In general, development in, or modification of, the floodplain is discouraged. Development should be located outside the 100-year floodplain wherever possible. If site characteristics require that some development occur within the floodplain, the floodplain modifications should be the minimum possible disruption of the natural water and sediment transport capacity of the floodplain.

Policy FP(6): Maintenance of Natural Drainage Patterns. Changes to natural drainage patterns should be avoided within individual development parcels whenever possible. Under no circumstances may the point(s) where drainage enters and exits a parcel be altered without the express written consent of all affected property owners or an engineering study demonstrating no adverse impacts to adjacent land parcels is submitted to and approved by the County Engineer.

Figure 2-3. Example of ADMP thalweg map showing flow lines and structure locations.

<u>Policy FP(7): Finished Floor Elevations</u>. All finished floors of all habitable structures shall be elevated no less than one (1) foot above the natural adjacent grade, even those located outside delineated floodplains. Natural adjacent grade is defined as the highest pre-construction/pre-grading ground elevation within the structure footprint and a 25-foot buffer area surrounding all sides of the structure. For development within a floodplain, the minimum finished floor of all habitable structures shall be set one (1) foot above the regulatory flood elevation. The Regulatory Flood Elevation is defined within the Floodplain Regulations as "The elevation which is one foot above the base flood elevation for a watercourse." Where a floodway has been delineated, the base flood elevation is the higher of either the natural or encroached water surface elevation of the 100-year flow.

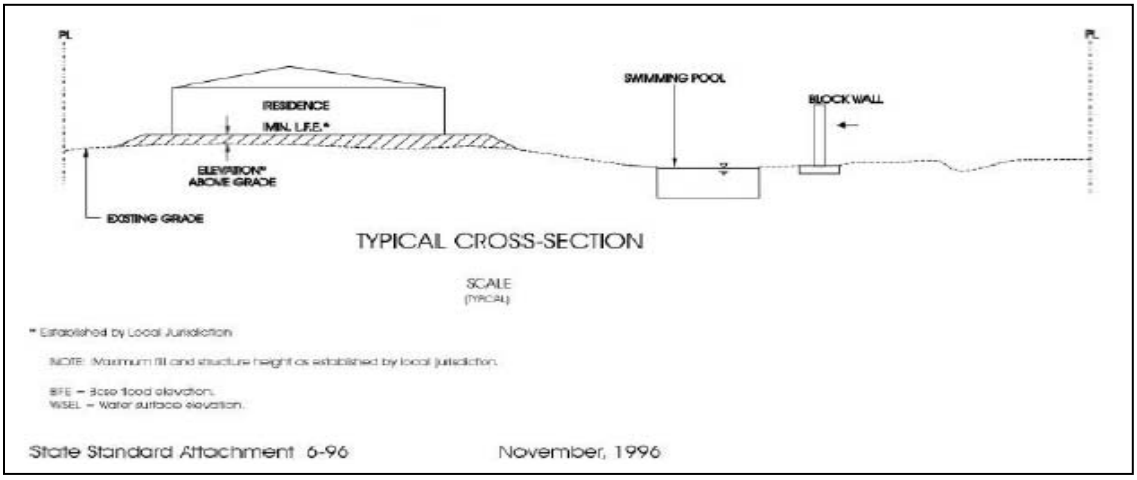

Figure 2-4. Illustration of finished floor elevation above natural ground surfaces.

Policy FP(8): Floodplain Encroachment. Floodplain encroachment should be avoided except where it meets the low-impact criteria defined in Appendix 5.2. Encroachment means the advance or infringement of uses, plant growth, fill, excavation, buildings, permanent structures or development into a floodplain, which may impede or alter the flow capacity of a floodplain. Encroachment that does not meet the low-impact criteria outlined in Appendix 5.2 is allowed only where it can be demonstrated by an engineering analysis that no long-term or short-term off-site impacts are expected to occur, that the encroachment is adequately protected from erosion and flooding, and a long-term maintenance and inspection program is adopted by the property owner.

Policy FP(9): Floodplain Modification. Modification of the regulatory floodplain should be avoided except at sites where the low impact criteria can be met or on a case-by-case basis approved by the County Engineer. Low impact criteria are defined in Appendix 5.2.

Policy FP(10): Fences & Walls. Construction of fences and walls should be avoided in riverine floodplains. If fences or walls are necessary in a single lot development, they must be elevated at least 0.5 feet above the natural grade within the regulatory floodplain limits. Fences and walls that cross natural washes, channels, or flow paths should be elevated to pass bank-full flows without obstruction, and should provide openings to convey the 100-year flood with no adverse impact to adjacent properties. Perimeter block walls should be set back from property lines to provide flow conveyance between lots or should be designed to pass drainage accounting for blockage by vegetation or debris and scour and should demonstrate that no adverse impact on neighboring properties results from the construction of the proposed fence, wall, or berm.

Policy FP(11): Scour Protection. The foundations of buildings constructed in the floodplain should be protected against scour. Where floodplain or overbank flow is concentrated by development, the post-construction (full build out) condition 100-year hydraulic data should be used to establish the scour protection design.

Policy FP(12): Site Grading. Building sites should be graded to direct nuisance runoff away from the building pad and building interior.

Policy FP(13): Structure Alignment. Buildings constructed in riverine floodplains should be aligned parallel to the primary flow direction to limit flow obstruction and to allow for flow path continuity.

Additional policies for specific types of development in floodplains are provided in Section 3 of this document. In addition, the rules of development for riverine floodplains also apply to other natural flood hazard areas described in later sections of this report, as shown in Table 2-1.

Table 2-1. Riverine Floodplain Rules of Development Applicable to Other Flood Hazard Areas

Rule	Erosion Hazard Zones	Distributary & Split Flow Areas	Alluvial Fans	Sheet Flow Areas	Ponding Areas	Farmlands
No Adverse Impact	X	X	X	X	X	X
Floodplain Delineation Required	X	X	X	X	X	X
Development in FEMA Floodplains	X	X	X	X	X	X
Use of ADMP GIS		X	X	X	X	X
Floodplain Development Discouraged	X	X	X	X	X	X
Maintain Natural Drainage Patterns	X	X	X	X	X	
Finished Floor Elevations	X	X	X	X	X	X
Encroachment Limits	X	X	X	X	X	X
Floodplain Modification		X	X	X	X	
Fences & Walls		X	X	X	X	X
Scour Protection	X	X	X	X		
Site Grading	X	X	X	X	X	X
Structure Alignment		X	X	X		

2.3. Riverine Erosion

2.3.1. Hazard Description

Rivers are dynamic features that change position and shape with time. River channel change occurs through erosion of the banks. Development should be set back from the banks of streams to prevent damage from erosion.

Figure 2-5. Examples of damage from riverine erosion.

<u>Definitions</u>

Erosion Hazard Zone means a land area adjoining a body of water or adjacent to or located partially or wholly within a floodplain which due to the soil instability, is likely to suffer flood-related erosion damage.

Erosion Setback means the minimum horizontal distance between a structure and a channel bank necessary to protect the structure from flood related erosion damage.

Flood-Related Erosion means the collapse or subsidence of land along the shore of a lake or other body of water as a result of undermining caused by waves or currents of water exceeding anticipated cyclical levels or suddenly caused by an unusually high water level in a natural body of water, accompanied by a severe storm, or by an unanticipated force of nature, such as a flash flood or an abnormal tidal surge, or by some similarly unusual and unforeseeable event which results in flooding.

Types of Riverine Erosion

The riverine erosion hazards that occur in Pinal County, as illustrated in Figure 2.6, can be grouped into the following categories:

- Type A: 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: 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: 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. Lateral erosion may also occur within the avulsion erosion area near the channel bank.

- Type D: Shallow flooding erosion hazards occur within the portion of the floodplain not subject to avulsions or bank migration, where relatively low flood depths and velocities occur. This type of erosion 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 channel erosion, lateral bank erosion and avulsion hazards. Shallow flooding 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.

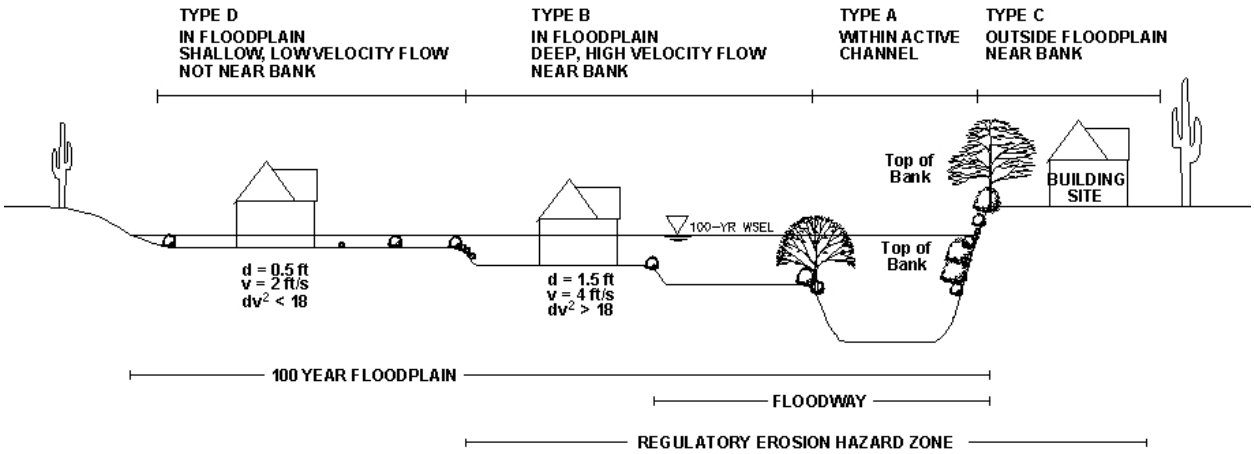

Figure 2-6. Illustration of the four principal types of erosion typically found within watercourses in Pinal County. Note that erosion hazards may occur within or outside the regulatory floodplain.

2.3.2. Technical References:

- National Flood Insurance Program (NFIP) Regulations. Code of Federal Regulations (CFR) Title 44, Chapter 1. Refer to Parts 60.5 and 60.24. Available at: www.access.gpo.gov/nara/cfr/waisidx_02/44cfrv1_02.html.

- Arizona Department of Water Resources (ADWR). State Standards for Floodplain Management: http://www.azwater.gov/dwr/Content/Publications/default.htm

    - (SS5-96) Standard for Watercourse System Sediment Balance
    - (SS7-98) Standard for Watercourse Bank Stabilization

- FEMA, 1999, Riverine Erosion Hazard Area Feasibility Study. Available at: http://www.fema.gov/plan/prevent/fhm/ft_reha.shtm.

- Pima County Floodplain and Erosion Hazard Management Ordinance. Refer to Part 16.28. Available at: http://www.pima.gov/cob/code/c16.html

- 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. Refer to Chapter 7. Available at: http://tdotmaps.transview.org/mandr/Download/

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

2.3.3. Rules of Development for Riverine Erosion Hazard Zones

Policy EHZ-1: Erosion Hazard Zone Delineation Required. All new development adjacent to watercourses with a 100-year discharge greater than 200 cfs must determine an erosion hazard setback. For individual single lot residential development applications,

100-year discharge rates for many watercourses may be obtained from the ADMP GIS. All habitable structures must be located outside the erosion hazard zone setback or provide for engineered bank protection measures. Erosion hazard setbacks will be determined using the following methodologies:

- Drainage Area < 30 square miles:
  - ADWR State Standard 5-96 methodologies.
  - City of Tucson Erosion Hazard Setback Equations
- Drainage Area > 30 square miles.
  - ADWR State Standard 5-96 Level III methodology.

The following notes apply to erosion hazard zone determinations in Pinal County:

- Minimum Erosion Hazard Setback. In no case shall the erosion hazard setback be less than 15 feet without the approval of the County Engineer.
- Level 1 Setback. Caution should be used in interpreting and applying the results of a Level I evaluation. Watercourses characterized with wide geologic floodplains, multiple or braided channels, highly erosive banks, poorly vegetated banks, and potential for channel avulsion should be evaluated at Level III.
- Setback Reduction. A Level 1 erosion hazard setback may be reduced if a Level III analysis demonstrates that a lesser setback is warranted. Any erosion hazard setback may be reduced if engineered erosion protection is constructed. Erosion protection must meet the no adverse impact standard.
- Level III Analysis. An example scope of services for a Level III erosion hazard analysis is provided in Appendix 5.3.
- Bank Location. In general, erosion hazard setbacks are to be measured from the top of the main channel bank. Guidelines for identifying the top of bank location are provided in Appendix 5.4.
- Avulsion Hazards. Potential avulsion hazard areas can be difficult to identify. Some guidelines for identifying avulsion hazard zones are provided in Appendix 5.5.

Policy EHZ(1): Analysis of Sedimentation Impacts. All new development shall take into account the effect of aggradation and degradation on drainage facilities (such as detention/retention, off-line/in-line facilities). Drainage facilities constructed in the watercourses shall strive to maintain the watercourses sediment continuity, throughout the system.

Policy EHZ(2): Maintenance of Bank Vegetation. Natural bank vegetation on and adjacent to the channel banks should be preserved or enhanced whenever possible, to help maintain the stability of existing channel banks and minimize the potential for lateral channel migration. Restoration of bank vegetation disturbed by grading may require irrigation and maintenance.

Policy EHZ(3): Engineered Erosion Protection Design Criteria. Where structural measures are proposed to provide erosion protection, the engineered erosion protection shall meet the following criteria:

- Design sealed by an Arizona-registered professional engineer.
- Demonstrate no adverse impacts to adjacent properties.
- Designed to protect against damage during the 100-year flood.
- Designed to withstand undermining by long-term scour (degradation) and single 100-year event local scour.
- Designed to withstand damage by flanking and lateral channel movement.
- Design life at least equal to the structures protected.
- Design to function with minimal maintenance, or have maintenance requirements clearly denoted.

Additional policies for specific types of development in riverine erosion hazard areas are provided in Section 3 of this document. In addition, the rules of development for riverine floodplains also apply to riverine erosion hazard areas, as shown in Table 2-2.

Table 2-2. Riverine Floodplain Rules of Development Applicable to Other Flood Hazard Areas

Rule	Policy	Erosion Hazard Zones
No Adverse Impact	FP(1)	X
Floodplain Delineation Required	FP(2)	X
Development in FEMA Floodplains	FP(4)	X
Use of ADMP GIS	FP(3)	
Floodplain Development Discouraged	FP(5)	X
Maintain Natural Drainage Patterns	FP(6)	X
Finished Floor Elevations	FP(7)	X
Encroachment Limits	FP(8)	X
Floodplain Modification	FP(9)	X
Fences & Walls	FP(10)	
Scour Protection	FP(11)	X
Site Grading	FP(12)	X
Structure Alignment	FP(13)	

2.4. Distributary & Split Flow Areas

2.4.1. Hazard Description

Distributary and split flow areas are unique flood hazards that occur throughout Pinal County, and which create difficulties for engineering design and floodplain management due to the uncertainty created by diverging flow paths.

Figure 2-7. Aerial photograph of distributary flow area. Flow is toward bottom of photo.

Split and distributary areas are identified in the Pinal County ADMP. Development in split flow areas can cause changes to flow distributions and result in adverse impacts to downstream properties.

<u>Definitions</u>

Split Flow. A split flow is a physical condition where runoff divides and continues along hydraulically-separate flow paths. This can occur in areas where a wash or channels capacity is limited due to vegetation or debris blockage. Split flows also occur at drainage facilities such as detention/retention basins, at culverts that are overtopped or roadways that block or divert flows. Split flows may rejoin or remain separated permanently. A split flow is defined and identified by hydraulic analysis.

Distributary Flow. Distributary flow is a specific drainage pattern in which defined channels divide, such that the number channels increase in the downstream direction. Distributary flow areas have channels which split and rejoin in a complex pattern. The number of channel forks commonly exceeds the number of channel confluences, creating a *dis*tributary, rather than tributary drainage pattern. The separate channels downstream of a channel fork may have terraces independent of other channels within the distributary flow system. A distributary channel is a stream branch flowing away from the main stream and not rejoining it. Identifying characteristics of distributary flow areas include the following:

- Low, but distinguishable topographic relief perpendicular to the primary flow direction.
- Topographic relief sufficient to create isolated islands during flood conditions within the overall floodplain.
- Channels which divide in the downstream direction so that the number of flow paths conveying floodwaters increases in the downstream direction.
- An increase in vegetative density along flow lines, with more uniform upland vegetation types found between flow lines, extending laterally over an expansive area.
- Soils units mapped by the Soil Conservation Service as alluvial fan terraces, inactive alluvial fans, or alluvial fans.
- During large floods, the distribution of flow between various existing distributary flow paths may not be predictable. However, flow lines themselves are relatively stable, especially during smaller floods.
- Large floods may cause isolated or widespread bank erosion, or sediment deposition within the channel which changes channel capacity or may change overbank conveyance.

Alluvial Fans. Distributary flow areas are frequently found on alluvial fans, but distributary flow can occur on a variety of landforms that are not alluvial fans. Alluvial fan flood hazards are described in Section 2.5 below.

Sheet Flow. Some, but not all, distributary flow areas convey significant components of flooding by sheet flooding. Sheet flow areas are described in Section 2.6 below.

2.4.2. Technical References:

- Federal Emergency Management Agency (FEMA), 2003, Guidelines and Specifications for Flood Hazard Mapping Partners –Appendix E: Guidance for Shallow Flooding Analyses and Mapping. Available at www.fema.gov/mit/tsd/dl_cgs.htm.

- Arizona Department of Water Resources (ADWR). State Standards for Floodplain Management: http://www.azwater.gov/dwr/Content/Publications/default.htm

    - (SS4-95) Standard for Development Within Sheet Flow Areas

- Flood Control District of Maricopa County, 2003, Piedmont Flood Hazard Assessment for Floodplain Management for Maricopa County, Arizona – User's Manual. Available from the Flood Control District of Maricopa County.

- Hjalmarson, H.W., and S.P. Kemna. "Flood Hazards of Distributary-Flow Areas in Southwestern Arizona." USGS Water-Resources Investigation. 1991. 91-4171.

2.4.3. Rules of Development for Distributary & Split Flow Areas

Policy DFA(1): Flow Concentration. Development in distributary or split flow areas should not concentrate flow or eliminate flow paths that change the flow rate or distribution on adjacent parcels.

Policy DFA(2): Drainage Master Plan. A drainage master plan is required for any subdivision located in distributary or split flow areas. The drainage master plan should demonstrate that the roadway network that serves the property has acceptable impact to drainage patterns and runoff concentration. Subdivision drainage design in the distributary/ split flow areas shall focus on limiting the concentration of flows. Where flows are concentrated, appropriate scour protection shall be applied to the channel reach. Concentrated flows shall return to the natural distributary flow condition prior to exiting the property.

Policy DFA(3): Finished Floor Elevation. Policy FP(7) applies to distributary and split flow areas. In addition, the finish floor elevation for new construction may be estimated using the procedures cited in State Standard 4-95.

Policy DFA(4): Minimum Flow Split Discharge. If a hydraulic rating is used to determine flow distributary at a flow split, no less than 50% of the 100-year discharge upstream of the bifurcation should be used on any single channel downstream, unless a publicly maintained engineered structure controls the flow distribution. If no hydraulic modeling is provided, the full 100-year discharge upstream of the split should be used on all downstream channels for drainage design.

Policy DFA(5): Engineering Analysis Methods. The engineering guidelines for estimating flow rates, designing flood control facilities, setting finished floor elevations, and other floodplain management tasks provided in Appendix 5.7 shall be used.

Policy DFA(6): Use of ADMP GIS Data. The ADMP GIS delineates area subject to upstream split flows. Rules of development for distributary and split flow areas shall be used for any parcel(s) shown within split flow areas in the ADMP GIS. The location of the ADMP GIS split flow zones may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. It is possible that some split flow zones were not identified in the ADMP. In the course of due diligence and site analyses, site developers and their engineers should evaluate the watershed to see if the project site is subject to distributary or split flow conditions.

Policy DFA(7): Rules of Development for Riverine Floodplains. Distributary and split flow areas are subject to floodplain hazards. Therefore, all of the riverine floodplain rules of development indicated in Table 2-3 also apply to areas subject to distributary and split flow conditions.

Table 2-3. Riverine Floodplain Rules of Development Applicable to Distributary & Split Flow Ares

Rule	Policy	Distributary & Split Flow Areas
No Adverse Impact	FP(1)	X
Floodplain Delineation Required	FP(2)	X
Development in FEMA Floodplains	FP(4)	X
Use of ADMP GIS	FP(3)	X
Floodplain Development Discouraged	FP(5)	X
Maintain Natural Drainage Patterns	FP(6)	X
Finished Floor Elevations	FP(7)	X
Encroachment Limits	FP(8)	X
Floodplain Modification	FP(9)	X
Fences & Walls	FP(10)	X
Scour Protection	FP(11)	X
Site Grading	FP(12)	X
Structure Alignment	FP(13)	X

2.5. Alluvial Fans

2.5.1. Hazard Description

Alluvial fans are gently sloped, fan-shaped landforms created by the deposition of sediment eroded from an upstream watershed. Active alluvial fans are unique flood hazards in that they experience not only flash flooding and erosion common to all arid region streams, but they can also experience dramatic shifts in channel location that make floodplain management and flood hazard mitigation challenging.

Figure 2-8. Alluvial fan with distributary flow pattern and extensive sheet flow areas.

Definitions

- **Alluvial Fan** means a sedimentary deposit located at a topographic break, or sudden loss of lateral confinement, such as the base of a mountain, escarpment, or valley side, is composed of streamflow and/or debris flow sediments, and that has the shape of a fan either fully or partially extended. Alluvial fans may be active or inactive. The rules of development described in below apply primarily to active alluvial fans.

- **Alluvial Fan Flooding** occurs only on alluvial fans and is characterized by flow path uncertainty so great that this uncertainty cannot be set aside in realistic assessments of flood risk or in the reliable mitigation of the hazard. The presence of alluvial fan flooding is indicated by three key criteria:
    - Flow path uncertainty below the hydrographic apex
    - Abrupt deposition and ensuing erosion of sediment as a stream or debris flow loses its competence to carry material eroded from a steeper, upstream source
    - An environment where the combination of sediment availability, slope and topography creates an ultra hazardous condition for which elevation on fill will not reliably mitigate the risk.

- **Apex** means a point on an alluvial fan below which the flow of the major stream that formed the fan becomes unpredictable and alluvial fan flooding may occur.

Types of Alluvial Fans

A variety of terms are commonly used to describe alluvial fans. The terms are not synonyms, as each type of fan is subject different types of flood hazards. More detailed information on these can be found in the references listed below.

Active Alluvial Fan. Those locations where flooding, erosion, and/or deposition have occurred on the landform such as an alluvial fan in relatively recent time (the historic period), and probably will continue to occur on that part of the landform.

Alluvial Plain. A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or an alluvial fan.

Bajada. A broad, continuous alluvial slope or gently inclined detritus surface, extending along and from the base of a mountain range out into and around an inland basin, formed by the lateral coalescence of a series of separate but confluent alluvial fans, and having an undulating character due to the convexities of the component fans. A bajada is a surface of deposition, as contrasted with a pediment (a surface of erosion that resembles a bajada in surface form), and its top often merges with a pediment.

Inactive Fan. Those locations where flooding, erosion, and/or deposition have not occurred on a landform such as an alluvial fan in relatively recent time, and probably will

not occur on that part of the landform. On inactive alluvial fans flood water typically is conveyed along incised channels and adjacent stable land.

Pediment A broad, flat or gently sloping, rock-floored erosion surface or plain of low relief, typically developed by sub aerial agents (including running water) in an arid or semiarid region at the base of an abrupt and receding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but more often partly mantled with a thin and discontinuous veneer of alluvium derived from the upland masses and in transit across the surface. The longitudinal profile of a pediment is normally slightly concave upward, and its outward form may resemble a bajada (which continues the forward inclination of a pediment).

Piedmont. Lying or formed at the base of a mountain or mountain range; e.g. a piedmont terrace or a piedmont pediment. (n.) An area, plain, slope, glacier, or other feature at the base of a mountain; e.g. a foothill or a bajada.

2.5.2. Technical References:

- Federal Emergency Management Agency (FEMA), 2003, Guidelines and Specifications for Flood Hazard Mapping Partners –Appendix G: Guidance for Alluvial Fan Flooding Analyses and Mapping. Available at www.fema.gov/mit/tsd/dl_cgs.htm.

- National Research Council, 1996, Alluvial Fan Flooding, National Academy Press, Washington, D.C. Available for purchase at: http://www.nap.edu/

- Arizona Department of Water Resources (ADWR). State Standards for Floodplain Management: http://www.azwater.gov/AzDWR/SurfaceWater/FloodManagement/StateStandards.htm

    - (SS4-95) Standard for Development Within Sheet Flow Areas

- Flood Control District of Maricopa County, 2003, Piedmont Flood Hazard Assessment for Floodplain Management for Maricopa County, Arizona – User's Manual (PFHAM). Available from: Flood Control District of Maricopa County.

2.5.3. Rules of Development for Alluvial Fans

Policy AF(1): Floodplain Delineation Required. A floodplain delineation must be completed to Pinal County and FEMA standards for all development within alluvial fan flooding areas. For subdivisions, the alluvial fan floodplain delineation must extend from a point above the apex where no flow path uncertainty exists downstream to the piedmont axial stream. In most cases, the floodplain delineation must be submitted to and approved by FEMA prior to the issuance of building permits. For single lot residential development, the floodplain delineation may be limited to the building envelope and does not need to be submitted to FEMA. For all delineations, lateral tie-in upstream and

downstream to effective (approved) floodplain delineations and to CLOMR/LOMR delineations that reflect structural flood control measures. Floodplain delineations on alluvial fans shall be completed using the procedures described in FEMA Guidelines and the Flood Control District of Maricopa County's Piedmont Flood Hazard Assessment Manual.

Policy AF(2): Whole Fan Solution Preferred. Identification of active alluvial fans, control of their apex, and conveyance of flow through the entire fan will be necessary for development within active alluvial fan areas. Pinal County has a strong preference of whole fan solutions that control the apex of the active alluvial fans, provides for flood conveyance through the entire fan (a regional solution), and outfalls into a regional drainageway sized to convey the 100-year discharge. In some cases, developments on active alluvial fans where the apex and alluvial fan flooding are not controlled may be designed to withstand the full apex discharge (plus tributary inflows above the project) as well as potential sedimentation and scour.

Policy AF(3): Alluvial Fan Floodways. Active areas on alluvial fans are considered administrative floodways. The standard riverine floodway regulations for development and land use apply within the alluvial fan administrative floodways.

Policy AF(4): Non-Structural Flood Control. Special consideration should be given to avoiding development within flood prone areas on active alluvial fans, accommodating the unstable and indeterminate flow associated with the alluvial fans, and maintaining existing sediment transport conditions. Consideration should be given to protect the major conveyance channels, and associated banks and vegetation.

Policy AF(5): Assessing Development Impacts on Alluvial Fans. Guidelines for performing engineering analysis on alluvial fans, and identifying pre- and post-development impacts are provided in Appendix 5.8. Additional technical guidance is provided in the technical references listed above.

Policy AF(6): Use of ADMP GIS Data. The ADMP GIS delineates some alluvial fans in the subarea watersheds of Pinal County. Rules of development for alluvial fans shall be used for any parcel(s) shown within alluvial fan areas in the ADMP GIS. Note that the location of the ADMP GIS alluvial fan zones may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. It is possible that some alluvial fan zones were not identified in the ADMP. In the course of due diligence and site analyses, site developers and their engineers should evaluate the watershed to see if the project site is subject to alluvial fan flooding.

Policy AF(7): Rules of Development for Riverine Floodplains. Portions of all alluvial fans are subject to floodplain hazards. Therefore, all of the riverine floodplain rules of development indicated in Table 2-4 also apply to alluvial fan areas.

Table 2-4. Riverine Floodplain Rules of Development Applicable to Alluvial Fans		
Rule	**Policy**	**Alluvial Fans**
No Adverse Impact	FP(1)	X
Floodplain Delineation Required	FP(2)	X
Development in FEMA Floodplains	FP(4)	X
Use of ADMP GIS	FP(3)	X
Floodplain Development Discouraged	FP(5)	X
Maintain Natural Drainage Patterns	FP(6)	X
Finished Floor Elevations	FP(7)	X
Encroachment Limits	FP(8)	X
Floodplain Modification	FP(9)	X
Fences & Walls	FP(10)	X
Scour Protection	FP(11)	X
Site Grading	FP(12)	X
Structure Alignment	FP(13)	X

2.6. Sheet Flow

2.6.1. Hazard Description

Sheet flooding is a type of surface water runoff that occurs on broad, unconfined floodplains with low lateral relief. Sheet flooding can occur in urban, rural, and natural areas. Because sheet flooding often occurs in areas that lack defined stream channels, identification of sheet flood areas can be difficult.

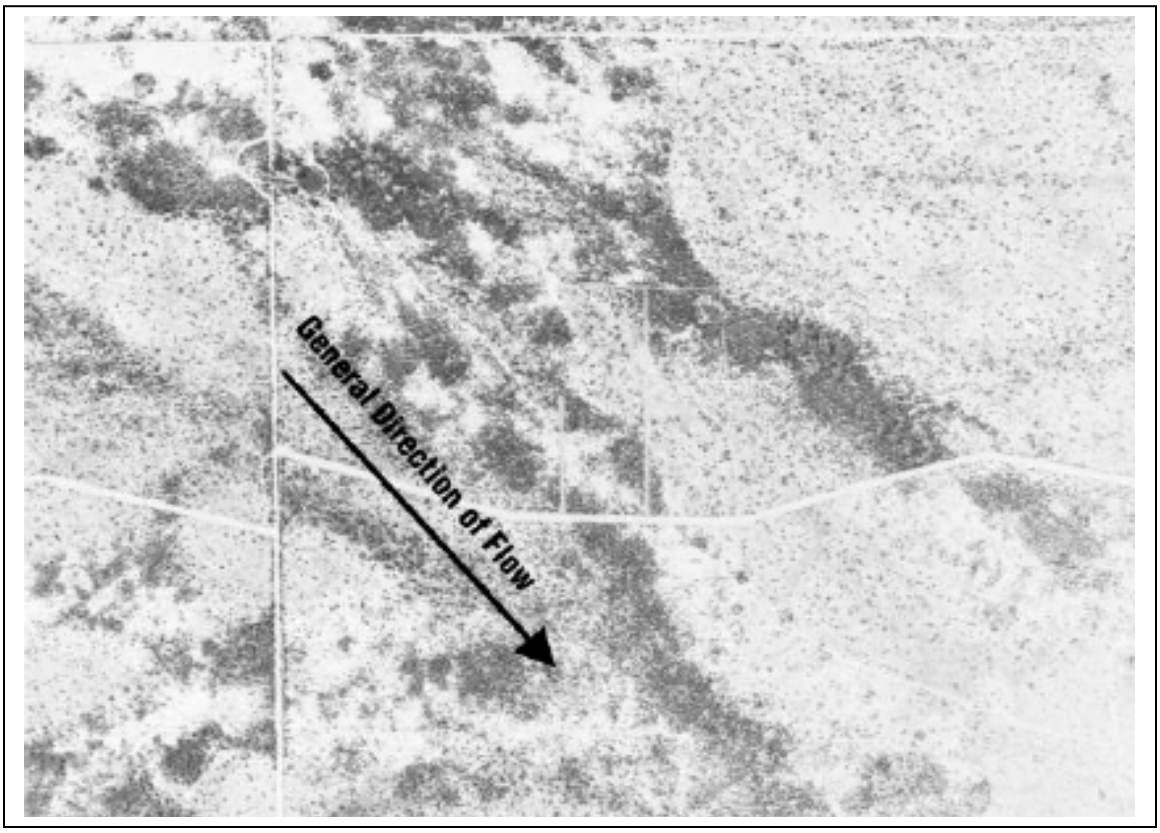

Figure 2-9. Aerial photograph of sheet flow area with poorly defined drainage channels.

<u>Definitions</u>

Sheet flow is a loosely defined term. In general, the term "sheet flow" may refer to any form of unconfined runoff that occurs over a broad, expansive area. This broad definition of sheet flow incorporates several more narrowly defined flow types, including natural (classic) sheet flow, urban sheet flow, agricultural sheet flow, overland flow, perched flow, anastomosing flow, and distributary flow. The variety of terms used for sheet flow probably reflects the variety of flow types that occur within specific geographic regions of the state. For this study, the term "sheet flow" will be used generically, to include all types of sheet flow that occur in Pinal County.

In general, sheet flooding in Pinal County has the following characteristics:

- The primary identifying characteristic of sheet flow is that a significant part of flood water is not conveyed in a single, well-defined channel. Flood flow is conveyed over the unchannelized land surface.

- Water moving over a smooth stable surface does not move as a uniform film. If the surface is broad, the sheet differentiates into parallel streams of greater depth and relatively rapid flow, separated by shallower bands of relatively sluggish flow; and at the same time, both streams and intervening bands differentiate into series of transverse waves which move forward more rapidly than the body of the undifferentiated sheet.

- Sheet flow over poorly vegetated surfaces often has the ability to transport large sediment particles relatively large distances over low slopes without significant reduction in sediment diameter, angularity, or degree of sorting, such as may be considered typical of most well defined streams.

- Sheet flooding has markedly different hydraulic characteristics for sediment laden and sediment deprived flows. Sheet flooding may not have gradually varied or steady flow, and may have a strong two-dimensional character.

- Significant loss of flow volume may occur during sheet flooding due to infiltration and other abstractions.

- Sheet flow often enters a larger channel or drainage system that intersects its flow, but occasionally dissipates due to infiltration or other loss mechanisms before ever reaching a channel.

Types of Sheet Flow

The following types of sheet flow are recognized in ADWR State Standard 4-95:

- Natural sheet flow occurs in undeveloped areas, and consists of flowing water characterized by a tendency to spread widely in relatively shallow sheets over gently sloping areas with low topographic relief which lack defined drainage systems.

- Urban sheet flow occurs where development has obscured natural drainage patterns or where urban drainage facilities are severely undersized. Urban sheet flow areas differ from natural sheet flow areas in that the identifying soil and vegetative characteristics may be obscured by development. Urban sheet flow areas are usually identified from historic records of unconfined flooding. Urban sheet flow areas occasionally may be identified by detailed topographic maps that show low relief in known flooding areas.

- Anastomosing flow is quasi-sheet flooding with slightly incised flow lines which creates a system of interwoven channels. Anastomosing flow is found in

intermittent to perennial stream systems with net long-term erosion, in contrast to braided streams which are characterized by net short-term deposition, and which occur within well-defined floodplains. Anastomosing flow differs from sheet flow (greater) and distributary flow by the (lesser) degree of flow line incision.

- Agricultural sheet flow occurs on land surfaces that have been graded or flattened for agricultural use. Lack of topographic variation within the field areas creates sheet flow conditions. Agricultural sheet flow areas differ from natural sheet flow areas in that soil and vegetative identifying characteristics may be obscured by regrading or leveling for irrigation and crop development. Agricultural sheet flow areas may be identified from pre-development photographic or topographic data, or from historic records of flooding.

- Overland flow is the movement of water resulting from rainfall on hill slopes in upper watershed areas prior to entering defined channels. The rules of development in this document should not be applied to overland flow areas.

- Perched flow originates along well-defined channels where overbank flooding becomes separated from the main flow path, and develops hydraulic characteristics unique from the main channel. Perched flow is not considered sheet flow, unless it meets other characteristics described above.

- Braided flow occurs where flow within a well-defined channel or floodplain is divided into separate flow paths created by shifting patterns of sediment deposition. Braided flow is not a form of sheet flow.

2.6.2. Technical References:

- Federal Emergency Management Agency (FEMA), 2003, Guidelines and Specifications for Flood Hazard Mapping Partners –Appendix E: Guidance for Shallow Flooding Analyses and Mapping. Available at www.fema.gov/library.

- Arizona Department of Water Resources (ADWR). State Standards for Floodplain Management: http://www.azwater.gov/dwr/Content/Publications/default.htm

    - (SS4-95) Standard for Development Within Sheet Flow Areas

- Flood Control District of Maricopa County, 2003, Piedmont Flood Hazard Assessment for Floodplain Management for Maricopa County, Arizona – User's Manual (PFHAM). Available from: Flood Control District of Maricopa County

2.6.3. Rules of Development for Sheet Flow Areas

Policy SF(1): Single Lot Site Conveyance. For single-lot development in the sheet flow areas, flows should not be concentrated beyond a typical shallow swale around the

structure. Swales shall daylight and broaden to the natural flow conditions on the downstream side of the proposed structure.

Policy SF(2): Subdivision Flow Concentration. Drainage design in sheet flow areas shall limit the concentration of flows and preserve overland flow paths. Where flows are concentrated or channelized, appropriate scour and erosion protection shall be applied to the channelized areas. Concentrated flows shall be returned to the natural flow condition prior to exiting the property. Note that returning channelized flow to a natural sheet flow condition without adverse impacts to downstream properties is difficult to achieve and is therefore not recommended. Methods for assessing adverse impacts are provided in Appendixes 5.2 and 5.8. Use of open space and low residential densities to convey sheet flows is the preferred method of development in sheet flow areas.

Policy SF(3): Drainage Master Plan. A drainage master plan should be developed for any subdivision located in a sheet flow area. Among other requirements, the drainage master plan should demonstrate that the roadway network that serves the divided property has no adverse impact to drainage patterns and runoff concentration. In general, the street layout should be designed to cross perpendicular to the primary flow direction to prevent capture and diversion of overland flow. Additional policies and guidance for road crossings and other structures are provided in Section 3 of this document.

Policy SF(4): Method of Analysis. Design guidelines and development standards to be used in the sheet flow areas from State Standard 4-95. Standards cited in State Standard 4-95 for development in sheet flow areas are categorized into required and recommended development standards. Also acceptable are FEMA Guidelines and Flood Control District of Maricopa County's Piedmont Flood Hazard Assessment Manual (PFHAM) methodologies.

Policy SF(5): Finished Floor Elevation. Elevate the lowest finished floor elevation of habitable structures. The finish floor elevation may be estimated utilizing Method of Flow Analysis procedures cited in State Standard 4-95. Note that significant backwater conditions may occur in sheet flow areas upstream of roadways with drainage structures that are not sized for the 100-year flood. Flood depths resulting from these backwater conditions may exceed depths indicated by local geomorphology or field conditions. In such areas, the finish floor elevations should be elevated at least 0.5 foot above the elevation of the roadway which creates the backwater condition. For subdivisions planned in sheet flow areas, finished floor elevations should be established by detailed engineering analyses, which may require two-dimensional modeling.

Policy SF(6): Structure Alignment. Homes in sheet flow areas should be aligned parallel to the primary flow direction. Streets in sheet flow areas should be oriented perpendicular to the primary flow direction.

Policy SF(7): Development Density. Zoning densities higher than 1 residence per acre (RAC) are not recommended in designated sheet flow areas, unless drainage studies that analyze potential concentration of flow and downstream impacts are completed or

regional flood control facilities are constructed. Development restrictions in low density sheet flow areas should include restrictions on perimeter fencing and limitation of site grading to specific building envelopes.

Policy SF(8): Use of ADMP GIS Data. The ADMP GIS delineates areas subject to sheet flow. Rules of development for sheet flow shall be used for any parcel(s) shown within sheet flow areas in the ADMP GIS. Note that the location of the ADMP GIS sheet flow zones may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. It is possible that some sheet flow zones were not identified in the ADMP. In the course of due diligence and site analyses, site developers and their engineers should evaluate the watershed to see if the project site is subject to sheet flow.

Policy SF(9): Rules of Development for Riverine Floodplains. Sheet flow areas are subject to floodplain hazards. Therefore, all of the riverine floodplain rules of development indicated in Table 2-5 also apply to sheet flooding areas.

Table 2-5. Riverine Floodplain Rules of Development Applicable to Sheet Flow Areas

Rule	Policy	Sheet Flow Areas
No Adverse Impact	FP(1)	X
Floodplain Delineation Required	FP(2)	X
Development in FEMA Floodplains	FP(4)	X
Use of ADMP GIS	FP(3)	X
Floodplain Development Discouraged	FP(5)	X
Maintain Natural Drainage Patterns	FP(6)	X
Finished Floor Elevations	FP(7)	X
Encroachment Limits	FP(8)	X
Floodplain Modification	FP(9)	X
Fences & Walls	FP(10)	X
Scour Protection	FP(11)	X
Site Grading	FP(12)	X
Structure Alignment	FP(13)	X

2.7. Ponding Areas

2.7.1. Hazard Description

Ponding is the result of runoff collecting in areas that have no outlet. FEMA considers such areas to be a type of shallow flooding unless they are caused by backwater from a defined channel and the depth does not exceed three feet. These rules of development apply both to shallow (< 3 ft) and deeper ponding areas.

Figure 2-10. Ponding area upstream of farm levees near Santa Cruz River.

Definitions

Ponding. Ponding is a type of floodplain in which flood levels are controlled by a structure that blocks or restricts flow, in which no well-defined channel exists, and where the flood water has near-zero velocity. Ponding occurs in natural and developed watersheds.

Types of Ponding Areas

- Natural Ponding Areas. Natural ponding areas occur in topographic depressions. Natural ponding areas are somewhat rare features and are geologically short-lived features that tend to be filled with sediment over time.

- Manmade Ponding Areas. Manmade ponding areas are far more common than natural ponding areas, and are caused by constructed features such as roadway embankments, levees, canals or railroad grades that block natural flow paths. Manmade ponding areas are most common in sheet and distributary flow areas where well-defined flow paths do not exist. Ponding often occurs in farmlands where field leveling and irrigation structures block and obscure the natural drainage pattern.

2.7.2. Technical References:

- Federal Emergency Management Agency (FEMA), 2003, Guidelines and Specifications for Flood Hazard Mapping Partners –Appendix E: Guidance for Shallow Flooding Analyses and Mapping. Available at www.fema.gov/library.

2.7.3. Rules of Development for Ponding Areas

In addition to the rules of development presented below, Article 12 of the Pinal County Floodplain Ordinance lists floodplain requirements for ponding areas.

Policy P(1). Ponding Limit Floodplain Delineation. All areas upstream of roadway, canals, dams and earthen embankments shall be evaluated to determine if ponding conditions exists. If no detailed ponding data are available, the ponding depth shall be assumed to be at least equal to the elevation of the embankment crest.

Policy P(2). Finished Floor Elevations. Finished floor elevations should be at least one foot above the 100-year ponding elevation. Where detailed information is not available, the finished floor elevations for single lot residential development may be set at one foot above the structure crest controlling the ponding elevation.

Policy P(3). Removing Ponding Areas. Removing ponding areas by site grading or by breaching the controlling embankment is permitted only if an engineering analysis is performed that demonstrates no adverse impact to adjacent properties.

Policy P(4): Development in Ponding Areas. The following rules apply to development in ponding areas:

- Specific consideration should be given to prevent development in ponding areas behind the canals and railroad lines
- Areas inundated downstream of the canals and railroad lines where storm water runoff overtops these structures should be identified and mitigated
- Development plans should retain water on-site to decrease excess pressure on canal banks
- Avoid disrupting existing drainage pattern along canals and railroad lines, and maintain current flow and volume along streets and roads.

Policy P(5): Engineering Analyses. Detailed engineering analyses may be required to determine ponding elevations. Such analyses may include generation of hydrographs

using detailed rainfall/runoff models, hydrologic and hydraulic routing of hydrographs, development of stage-storage-discharge relationships for the ponding area, hydraulic rating of outflow control structures, and hydraulic modeling of flow parallel to the impoundment structure. In some cases, two-dimensional modeling may be required to accurately account for both the hydrologic and hydraulic characteristics of the flooded area. The engineer should distinguish between static and flowing ponding areas when selecting the appropriate modeling tool(s).

Policy P(6): Use of ADMP GIS Data. The ADMP GIS delineates areas subject to ponding. Rules of development for ponding areas shall be used for any parcel(s) shown within ponding areas in the ADMP GIS. Note that the location of the ADMP GIS ponding areas may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. It is possible that some ponding areas were not identified in the ADMP. In the course of due diligence and site analyses, site developers and their engineers should evaluate the watershed to see if the project site is subject to ponding conditions.

Policy P(7): Rules of Development for Riverine Floodplains. Ponding areas are subject to flood hazards. Therefore, all of the riverine floodplain rules of development indicated in Table 2-6 also apply to ponding areas.

Table 2-6. Riverine Floodplain Rules of Development Applicable to Ponding Areas

Rule	Policy	Ponding Areas
No Adverse Impact	FP(1)	X
Floodplain Delineation Required	FP(2)	X
Development in FEMA Floodplains	FP(4)	X
Use of ADMP GIS	FP(3)	X
Floodplain Development Discouraged	FP(5)	X
Maintain Natural Drainage Patterns	FP(6)	X
Finished Floor Elevations	FP(7)	X
Encroachment Limits	FP(8)	X
Floodplain Modification	FP(9)	X
Fences & Walls	FP(10)	X
Scour Protection	FP(11)	
Site Grading	FP(12)	X
Structure Alignment	FP(13)	

2.8. Farmlands

2.8.1. Hazard Description

Much of Pinal County was originally settled as farm land. Historical farming activities dramatically altered the natural channels and floodplain in these farmlands, resulting in some unique floodplain hazards.

Figure 2-11. Aerial photograph of farmlands with remnants of natural drainage paths.

<u>Definition</u>

For the purposes of these rules of development, an agricultural area floodplain is any area in which historical or recent farming has resulted in field grading that obscures the natural drainage pattern, where irrigation structures block, divert or alter the natural drainage pattern, or where flood irrigation features have historically prevented most on-site flow from leaving the farmed area.

Some the special considerations for drainage design in retired farmlands include the following:

- Lack of Defined Flow Paths. Historical natural flow paths typically were obscured by field leveling and agricultural activity. Therefore points where runoff enters and exits the property may be difficult to discern. In many cases, defined concentration points may not exist at the property boundaries.

- Incidental Retention. Agricultural fields often provide storm water retention because perimeter irrigation berms and canals, high infiltration rates on tilled soils, and ponding on laser-leveled fields. Conversion of agricultural lands to more hydraulically efficient paved and landscaped developed surfaces eliminates the incidental retention leading to increased storm water runoff rates and volumes, and potential adverse offsite impacts.
- Embankments. Removal of canals, flood irrigation levees, and field boundaries can cause changes in historical runoff patterns that may have unintended adverse onsite and offsite drainage impacts.
- Canal Termination Points. Irrigation tailwater and storm water may be conveyed and discharged from the downstream end of certain canals.

2.8.2. Technical References:

- Federal Emergency Management Agency (FEMA), 2003, Guidelines and Specifications for Flood Hazard Mapping Partners –Appendix E: Guidance for Shallow Flooding Analyses and Mapping. Available at: www.fema.gov/library.

2.8.3. Rules of Development for Farmlands

Policy A(1): Regional Drainage Plan. Master planned communities and subdivisions should include a regional drainage plan that indicates the proposed connections to properly sized regional drainage facilities and conveyance corridors. Where no regional drainage plan exists, it may be necessary to fully retain onsite runoff, while providing adequate conveyance of offsite flows through or around the development.

Policy A(2): Single Lot Development Finished Floor Elevations. Because of the potential for ponding upstream of irrigation structures, finished floor elevations for single lot residential development should be set at the controlling elevation of adjacent embankments, canals, or levees, unless a site-specific engineering study is provided to determine an appropriate 100-year water surface elevation.

Policy A(3): Use of ADMP Discharges. Discharge estimates from the ADMP GIS may not be used to establish pre-development regulatory flow rates in farmlands.

Policy A(4): Use of ADMP GIS Data. The ADMP GIS delineates farmlands. Rules of development for farmlands shall be used for any parcel(s) shown within farmlands in the ADMP GIS. Note that the location of the ADMP GIS farmlands may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. It is possible that some farmlands were not identified in the ADMP. In the course of due diligence and site analyses, site developers and their engineers should evaluate the watershed to see if the project site is within an historical or active agricultural area.

Policy A(5): Canal End Points. Development at the termination points of canals should be designed to prevent damage from irrigation tailwater and storm water discharges from the canal, in addition to flooding from other sources at the property.

Policy A(6): Hydrologic Modeling in Farmlands. Engineers should coordinate with the County Engineer prior to initiating hydrologic modeling of farmlands to assure the pre- and post-development peak discharge and runoff volumes are appropriately modeled.

Policy A(7): Rules of Development for Riverine Floodplains. Some farmlands are subject to flood hazards. Therefore, the riverine floodplain rules of development indicated in Table 2-7 also apply to flood prone farmlands.

Table 2-7. Riverine Floodplain Rules of Development Applicable to Farmlands

Rule	Policy	Farmlands
No Adverse Impact	FP(1)	X
Floodplain Delineation Required	FP(2)	X
Development in FEMA Floodplains	FP(4)	X
Use of ADMP GIS	FP(3)	X
Floodplain Development Discouraged	FP(5)	X
Maintain Natural Drainage Patterns	FP(6)	X
Finished Floor Elevations	FP(7)	X
Encroachment Limits	FP(8)	X
Floodplain Modification	FP(9)	X
Fences & Walls	FP(10)	X
Scour Protection	FP(11)	X
Site Grading	FP(12)	X
Structure Alignment	FP(13)	X

2.9. Hillside Slopes

2.9.1. Hazard Description

Development is discouraged on hillside areas with slope of fifteen percent (15%) or greater to protect the integrity and appearance of steeply sloping hillside areas and to preserve scenic view corridors: The Pinal County ADMP identifies hillside slopes of 6 to 10%, 10 to 15% and 15% and greater slopes. For the purposes of these Rules of Development, slopes of 15% or greater are identified as areas where development should be avoided.

Figure 2-12. Photograph of hillside slope area with steep channels and potential drainage issues.

2.9.2. Technical References:

- Pinal County ADMP Subarea Watershed Reports

2.9.3. Rules of Development for Hillside Areas

<u>Policy H(1): Hillside Development</u>. The following development rule for hillside areas applies in Pinal County:

- Slopes of 15% or greater should remain as undeveloped natural open space.
- The open space within lots, common open space areas with slopes 15% or greater, or natural area washes that may carry drainage, should be identified and secured

by an open space and/or drainage easement and be maintained by the lot owner or homeowners association.

- Wherever possible in hillside areas, intrusion into skyline vistas shall be avoided.
- Ridge lines should remain as undeveloped natural open space.

Hillside slope categories delineated as part of the ADMP GIS were based on relatively coarse aerial photography and topographic mapping. Developers of individual parcels should document slope conditions using more detailed information whenever possible.

Policy H(2): Drainage Channels. Drainage channels on steep slopes often flow at supercritical velocities. If supercritical velocities cannot be avoided in the engineering design, the following shall be provided:

- Additional freeboard at bends, lateral and vertical transitions, and confluences
- Debris and trash control structures to prevent debris from entering the channel
- Energy dissipaters at channel outlets
- Structural grade control or full channel lining
- Bank protection
- Inspection, maintenance and operation plans

Policy H(3): Driveways. Driveways shall be aligned to not capture street runoff and so that surface runoff from the driveway is directed away from buildings and/or garages.

Policy H(4): Flow Concentration. Site grading should be conducted to minimize concentration of overland flow.

Policy H(5): Road Drainage. Road drainage in steep slope areas should be designed to convey the required discharge without adverse impact to adjacent parcels, with logical outfall to a facility or channel with adequate capacity, and with adequate cross drainage facilities.

2.10. Subsidence & Earth Fissure

2.10.1. Hazard Description

Subsidence and earth fissuring are geologic hazards known to occur in Pinal County, particularly in portions of the County where historic farming and ground water pumping occurred. Subsidence can impact drainage patterns by changing elevations to the point of creating adverse channel slopes. Earth fissures can divert natural runoff patterns, but are themselves exacerbated by runoff.

<u>Definitions</u>

Subsidence is a lowering in the elevation of the ground surface, a process which occurs as the underlying aquifer is drained, resulting in decreased volume because of pore collapse and compression of the sediment materials.

Earth fissures are tension cracks formed in alluvial basins, generally due to land subsidence. Earth fissures can cause damage to buildings, roads, canals, channels and other constructed features.

Figure 2-13. Ground (left) and aerial (right) photographs of eroded and gullied earth fissures. Photos courtesy of AMEC, Inc.

2.10.2. Technical References:

- Land Subsidence, Earth Fissures, and Water-Level Change in Southern Arizona, by H.H. Schumann and R.B. Genualdi, 1986, scale 1:500,000. Arizona Geological Survey Open File Report 86-14.

- Bibliography on Arizona Earth Fissures and Related Subsidence, With Selected References for Other Areas, by Steven Slaff, 1990, 28 p., Arizona Geological Survey Open File Report 90-7.

- Field Guide to Earth Fissures and Other Land-Subsidence Features in Picacho Basin, Pinal County Arizona, by R.C. Harris, 1999 Arizona Geological Survey Open File Report 99-26.

2.10.3. Rules of Development for Subsidence & Earth Fissure Areas

Policy SEF(1): New Development. All new development should be evaluated for potential impacts due to earth fissures by consulting earth fissuring maps prepared by the Arizona Geological Survey or by consultation with a Registered Geologist with expertise in earth fissures. Where potential for earth fissuring exists, appropriate mitigation measures should be included in the design.

Policy SEF(2): Design of Structures. All regional drainage facilities should be design to accommodate expected future subsidence and earth fissuring. The design may include avoidance of problem areas or other mitigation measures.

Rules of Development

Section 3. Specific Development Types

3.1. General Considerations

Rules of development for the following specific types of construction are presented in this chapter:

- Section 3.2: Road Crossings
- Section 3.3: Utility Crossings
- Section 3.4: Detention/Retention
- Section 3.5: Dams
- Section 3.6: Levees & Embankments
- Section 3.7: Canals & Irrigation Structures
- Section 3.8: Storm Drains & Channels
- Section 3.9: Sand & Gravel Mining

For each development type, a definition and example photographs are provided, and technical references are provided, in additional to the discussion of the hazard specific rules of development. It is highly recommended that individuals developing property in Pinal County also contact qualified registered professional engineers to obtain more site-specific information regarding the design constraints at specific development parcels.

In case of conflict between rules of development and other policy or regulatory guidelines, the following two guiding principles for development in Pinal County should be considered to apply universally:

- **No Adverse Impact**. All development shall have no adverse impact on the pre-development hazard level on any adjacent property.

- **Existing Regulations Enforced**. All development shall comply with all existing local, state and federal floodplain regulations.

As defined in the Pinal County Floodplain Ordinance, **development** means any man-made change to property, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations, or storage of materials or equipment.

3.2. Road Crossings

3.2.1. Description

Rules of development for the following types of watercourse road crossings are discussed in this section:

- Culverts
- Bridges
- At-Grade Crossings
- Canal Crossings

Figure 3-1. Examples of bridge and culvert crossings in Pinal County. Note scour evidence at bridges and deposition at culverts.

Existing road crossing structures were inventoried as part of the Pinal County ADMP and are included in the ADMP GIS.

3.2.2. Technical References:

- Pinal County Drainage Manual, Volume 1 & 2. Available at: http://www.co.pinal.az.us/PubWorks

- Federal Highway Administration (FHWA) Publications. Available at: http://www.fhwa.dot.gov/engineering/hydraulics/library
    - HDS-5 – Hydraulic Design of Culverts
    - Highways in the River Environment
    - HEC-18 – Evaluating Scour at Bridges
    - HEC-22 – Urban Drainage Design Manual

3.2.3. Rules of Development for Road Crossings

General Rules for Road Crossings

Policy RC(1): No Diversion. Roadway alignments should be designed in such a manner that runoff collected by the roadway is conveyed to its historic flow path. Roadways should be designed to not divert flows.

Policy RC(2): Alignment. Roadway crossings should be designed so that the roadway alignment is perpendicular to the watercourse and should be located at narrow floodplain and erosion reaches. New roads should be aligned to avoid placement of pavement within and parallel to wash corridors. Except where there is no practical alternative, road intersections should not be located over watercourses.

Policy RC(3): Braided Streams: Roadway crossings at locations where the watercourse is braided are discouraged. Wide or multiple crossings that minimize flow contraction and disruption of sediment continuity are recommended where braided watercourse must be crossed.

Policy RC(4): Scour Protection. Roadway crossings should be designed to minimize downstream scour, minimize the risk of erosion of roadway approaches, and maintain sediment continuity up to the bank-full discharge. Scour protection is required to assure structure stability and to mitigate impacts of any flow acceleration or sediment discontinuity.

Policy RC(5). All-Weather Access. Roadway design in subdivisions should provide for all-weather access routes to all platted lots. All-weather access criteria for specific road classifications are provided in the Pinal County Drainage Manual.

Policy RC(6): Crossing Dimensions. All crossings, regardless of the type, should be designed to minimize disruption of sediment transport continuity upstream and downstream of the crossing. Crossings that mimic the natural main channel depth, width and slope at the crossing location will have the least impact. Crossings that widen, narrow, deepen or flatten the main channel will require frequent maintenance and will be more at risk of failure than crossings that maintain the natural channel geometry.

Policy RC(7): Invert Elevation. Lowering of local base level by excavating the crossing section below its natural grade is strongly discouraged. Adverse impacts of lowering the

natural grade range from sediment deposition, with loss of capacity and frequent maintenance problems, to upstream headcutting, with increased bank erosion and upstream structure failure.

Rules of Development for Culverts

The design of culvert structures takes into consideration public safety, long-term function and maintenance, and impacts to the channel form and function. Typically, the impact of culvert crossings on a watercourse system is primarily a function of their size in relationship to design discharge, channel and floodplain morphology, clogging potential, sediment transport capacity, and scour potential. Undersized culverts and culverts that create significant headwater ponding can have detrimental impacts to both upstream and downstream properties. The impacts of undersized culverts on channel stability include the following:

- Sediment Deposition. Much of a stream's sediment load will be deposited in the headwater pool at the culvert inlet. The volume of sediment deposited depends on the culvert capacity relative to the discharge, the duration of the ponding condition, the geometry of the ponding area, and the size of the sediment in transport. Sediment deposition decreases channel (and culvert) capacity, increases the potential for overbank flooding and avulsions, and requires maintenance to restore conveyance capacity. Culvert rise (height) at a minimum should be as high as the average main channel bank height. In the event of width and height limitations due to constraints or the inability of a structure to convey the design event, increasing the height dimension or providing relief culvert structures in the overbank areas should be considered before increasing the width. Culverts that do not obstruct the main channel will have less frequent impacts on channel stability.

- Scour Hole. A scour hole may form at the culvert outlet due to accelerated velocity through the culvert, discharge of sediment-deprived water, and turbulence at the culvert/channel interface. Design of culvert structures shall include an evaluation of the scour potential at the outlet of the structure and provisions for channel protection at the outlet shall be provided.

- Long-Term Degradation. Where a significant percentage of the sediment load is deposited upstream of a culvert due to headwater ponding, discharge of clear water may result in degradation downstream until the channel slope adjusts to the new sediment supply. Culverts shall be designed so that the disruptions to the natural sediment transport capabilities of the wash are minimized. Oversized (relative to channel width and floodplain geometry) culvert structures, which increase the width of the channel in order to minimize the height or depth of ponding, can also have detrimental impacts to both upstream and downstream properties.

- Long-Term Aggradation. Increasing the width of a channel to accommodate a culvert structure would change the sediment transport capacity of the channel.

During frequent events or events lesser than the design capacity of the culvert structure sediment would be deposited in the section of channel that has been widened. Accumulation of sediment would decrease both the capacity of the channel and the capacity of the structure ultimately resulting in flooding impacts to adjacent properties. Culvert span (width) should be as wide as the main channel (top of left bank to top of right bank) where channels are well defined. Culverts that do not obstruct the main channel will have less frequent impacts on channel stability than culverts that block the main channel.

Policy RCC(1): Overtopping. Culvert crossings designed to overtop during the 100-year flood should be designed with embankment, road surface, and tailwater scour and erosion protection for overtopping flows. Allowable overtopping depths are detailed in the Pinal County Drainage Manual.

Policy RCC(2): Maintenance Access. Provide drivable access to culvert crossings of major watercourses to facilitate access by maintenance vehicles. Major watercourses are defined as those with 100-year discharges greater than 10,000 cfs.

Policy RCC(3): Culvert Dimensions. For most crossings, the total culvert span should be at least as wide as the main channel bankfull width, and the culvert rise should be at least as high as the bankfull elevation. Normally, the only exception to this rule is where a deeply incised channel has a much greater capacity than the design event.

Policy RCC(4): Clogging. Culvert crossings should be designed to account for potential clogging due to the accumulation of sediment and debris. A fifty percent (50%) clogging factor should be used, or a debris control device provided, except in usual situations where either the culvert size or watershed characteristics preclude clogging.

Rules of Development for Bridges

Bridges that span the floodplain typically have no measurable impact on channel stability. Bridges with narrow openings are functionally like a culvert, and have the impacts on channel stability described above. Based on their likely impacts on channel stability, the following rules of development for bridge crossings design are recommended for watercourses in Pinal County:

Policy RCB(1): Bridges. Bridges are generally preferable to culverts for major watercourses. Bridges typically have less impact on channel stability than culverts due to the wider opening and decreased likelihood of headwater ponding.

Policy RCB(2): Relief Structures. Where braided or multiple channels exist, drainage relief structures (culverts) outside of the main channel should be provided to maintain overbank flow paths, preserve overbank conveyance, and prevent floodplain sedimentation, instead of widening one of the multiple channels to provide conveyance of the design event at one location.

Policy RCB(3): Maintenance. Bridge crossings should be regularly maintained and inspected to identify potential problems and impacts to channel stability.

Policy RCB(4): Maintenance Access. Provide vehicular access to bridge crossings of major watercourses to facilitate access by maintenance vehicles. Major watercourses are defined as those with 100-year discharges greater than 10,000 cfs.

Rules of Development for At-Grade Crossings

At-grade, or dip, crossings typically have only minimal or localized impacts on watercourse stability. More commonly, the streams impact the at-grade crossing, rather than vice-versa. Flow over the at-grade crossing can cause erosion of the pavement and subgrade, deposition of sediment in the road section, and disruption of traffic flow. Channel stability impacts commonly observed near at-grade crossings that need to be mitigated include the following:

- A scour hole often forms on the downstream side of an at-grade crossing due to acceleration of flow over the hydraulically smooth roadway surface and increased turbulence as flow transitions back at the natural channels bed. In most cases, formation of a scour hole does not impact stream reaches located far from the at-grade crossing; however, the development of a scour hole could undermine the at-grade crossing, leading to failure of the facility. Upstream and downstream cut-off walls shall be designed for paved at-grade crossings.
- A paved at-grade crossing of a channel reach which is experiencing degradation will ultimately function as a grade control structure. Until equilibrium is achieved, downstream degradation will continue, increasing the drop immediately downstream of the at-grade crossing. Long-term degradation shall be considered in determining the depth of cut-off walls.
- The profile of the roadway at the at-grade crossing shall be sufficient to pass the design event so that the roadway does not capture and divert flows from the upstream wash.
- If the at-grade crossing is constructed at an elevation slightly above the natural channel bed, deposition will occur upstream of the crossing. Deposition leads to expansion of the floodplain, and may increase the risk of avulsions and accelerate formation of the downstream scour hole. The minimum elevation of an at-grade crossing shall not be higher than the existing channel invert.

Policy RCD(1): Dip Crossings. Dip crossings are preferred to culvert crossings for access on driveways and local streets.

Policy RCD(2): Flow Depth. At-grade roadway crossings (roadway dip sections) of watercourses should only be considered for watercourses that are characterized by shallow flow conditions. At-grade roadway crossings in rural and low density residential land use areas are acceptable (specific design criteria such as allowable depth of flow over the roadway will need to be met) with agency approval.

Rules of Development for Canal Crossings

Policy RCCa(1): Maintain Conveyance. In some locations, runoff is conveyed parallel to the upstream face of canal embankments. Road approaches that cross canal embankments should be designed to preserve and allow existing conveyance parallel to the canal, rather than create ponding areas and create overtopping hazards.

3.3. Utility Crossings

3.3.1. Description

Utility installations in or near floodplains may be vulnerable to damage by scour, erosion, inundation, and hydrodynamic forces if the crossings are poorly designed. Disruption of utility service can have major impacts on the local and regional economy. Utility crossings may include any of the following types of installations:

- Overhead crossings
- Underground (buried) crossings

Utilities not crossing, but installed parallel to river corridors are also subject to these rules of development. Typical utilities include water and sewer pipelines, gas pipelines, and electric, cable, telephone, fiber optic communication lines. The most common types of drainage-related failure include the following design deficiencies:

- Burial Depth. Underground crossings not buried below the short-term and long-term scour depth can be exposed and fail during floods.
- Foundation. Power poles in the floodplain with foundations not designed for scour can be undermined and fail.
- Setback. Utilities not adequately set back from washes with lateral erosion hazards can be exposed and fail during floods.
- Debris. Debris accumulation can dramatically increase scour, contribute to hydrodynamic loading and create impact forces that exceed the design.

Figure 3-2. Flood and erosion damaged sewer (left) and power (right) utilities.

3.3.2. Technical References:

- Pinal County Drainage Manual, Volume 1 & 2. Available at: http://www.co.pinal.az.us/PubWorks

- Federal Highway Administration (FHWA) Publications. Available at: http://www.fhwa.dot.gov/engineering/hydraulics/library
    - Highways in the River Environment

3.3.3. Rules of Development for Utility Crossings

Utility crossings, if properly constructed, have no inherent impact on channel stability since they are typically buried beneath the channel or extended overhead.

Policy UC(1): Burial Depth. Underground utilities should be buried below the 100-year total scour depth in the main channel, including long-term scour. Utility lines have been damaged due to exposure by long-term scour on numerous streams in Arizona.

Policy UC(2): Setback. Where the potential for lateral channel migration exists, underground utilities should be buried at the same depth in the overbank areas or erosion hazard zone as in the main channel, to prevent exposure after movement of the main channel. Construct outside the floodplain and erosion hazard zone or provide scour and erosion protection.

Policy UC(3): Pole Foundation. Utility poles should be placed outside the floodplain and erosion hazard zone. Where it is necessary to place utility poles within the floodplain, they should be designed to withstand scour, debris impact and hydraulic forces including debris accumulation.

Policy UC(4): Utilities at Bridges. Bridges – attach to downstream, rather than upstream side of bridges.

Policy UC(5): Utilities at Culvert & At-Grade Crossings. Utilities located at culverts or at-grade crossings should be located on the upstream, rather than downstream side of the culvert or at-grade crossing.

Policy UC(6): Construction Impacts. Direct impacts on channel stability can occur during utility construction due to disturbance of bank and floodplain soils and vegetation. Where vegetation is removed, the underlying soils are more vulnerable to erosion and scour. If floods occur before the vegetation is reestablished, erosion of the construction alignment may occur and initiate erosion of adjacent channel reaches. Mitigation of construction impacts should be included in the approved grading plan.

3.4. Detention/Retention

3.4.1. Description

Retention may be the most effective tool available to mitigate adverse hydrologic impacts from development. Additionally, retention may have possible complementary benefits with respect to requirements of the Clean Water Act.

Figure 3-3. Example of grass-lined landscaped detention basin.

Guidelines for the standard practice of retaining the volume of runoff from the 100-year, 2-hour event can be found in the Pinal County Drainage Manual.

3.4.2. Technical References:

- Pinal County Drainage Manual, Volume 1 & 2. Available at: http://www.co.pinal.az.us/PubWorks/

- Pima County Department of Transportation and Flood Control District & City of Tucson Stormwater Detention/Retention Manual. Available at: http://www.tucsonaz.gov/dsd/Stormwater_detention-retention_manual.pdf

3.4.3. Rules of Development for Detention/Retention Basins

Policy DR(1): Retention Volume. The 100-year, 2-hour storm volume should be retained for all commercial and subdivision developments unless it is demonstrated not to be feasible because of unique site conditions. In the rare case that retention is not feasible an acceptable alternative is detention that reduces post-development peak discharges to pre-development magnitudes. In such cases, the developer must demonstrate no adverse impact to adjacent properties and watercourses due to the increase in flow volume.

Policy DR(2): Basin Siting. The location and configuration of retention areas should be shown on the site plan. The criteria and guidelines for retention facilities outlined in the Pinal County Drainage Manual should be followed. In particular, the location of basins should meet the following:

- Retention areas shall be located such that they effectively capture runoff from the impervious surfaces on the lot.
- Retention areas do not have to be located in a single basin; multiple retention areas are allowed.
- Retention areas shall not be placed in a regulatory floodplain such that off-site runoff is intercepted in the retention area.
- Drain time for retention basins will be approved with approval of the septic system.

Policy DR(3): Post-Development Discharge. Post-development peak discharges draining from a development cannot exceed pre-development magnitudes.

3.5. Dams

3.5.1. Description

Most Pinal County dams and/or levees in the general definition include engineered or non-engineered earthen embankments in varying heights placed in a watercourse to impede, divert or impound drainage runoff. Development downstream of a dam is subject to potential flood hazards from dam failure and/or dam overtopping. Development upstream of dams is subject to flood inundation hazards within the dam impoundment area. The locations of known dams and areas downstream of dams have been identified in the Pinal County ADMP.

The Arizona Department of Water Resources (ADWR) Dam Safety Section regulates non-federally owned dams 25 feet in height or greater or dams that impound greater than 15-acre-feet of storage or dams 6-feet in height or greater that impound 50-acre-feet. Hazard classifications for dams are determined by the potential for loss of human life and extensive property damage. Criteria for design and evaluation of dams can be found on the ADWR website at: www.azwater.gov/dwr.

Figure 3-4. Historical dam embankment damage at Picacho Reservoir. Photo courtesy of AMEC, Inc.

Definition

A dam is any embankment or artificial barrier, together with any appurtenant works, which impounds water. Structures that create above-ground reservoirs and lagoons are considered dams. A fill or structure intended solely for highway or railroad use that does not permanently impound water as determined by the County is not considered a dam. Most dams in Pinal County that meet the general definition consist of engineered or non-

engineered earthen embankments of varying heights placed in watercourses to impede, divert or impound drainage runoff.

3.5.2. Technical References:

- ADWR Dam Safety Division Guidance Documents. Available at: http://www.azwater.gov/dwr/Content/Find_by_Program/Dam_Safety_and_Flood_Mitigation/default.htm
- Bureau of Reclamation, 1987, Design of Small Dams.
- Federal Energy Regulatory Commission Engineering Guidelines http://www.ferc.gov/industries/hydropower/safety/guidelines/eng-guide.asp
- U.S. Army Corps of Engineers Engineering Manuals http://www.usace.army.mil/inet/usace-docs/eng-manuals/em.htm
- U.S. Army Corps of Engineers Technical Letters http://www.usace.army.mil/inet/usace-docs/eng-tech-ltrs/etl-cw.html
- Natural Resources Conservation Service Engineering http://www.nrcs.usda.gov/technical/ENG/
- U.S. Bureau of Reclamation Earth and Geology Manuals http://www.usbr.gov/library/BRreclamation.html

For Design, Repair or Analysis of Dams:

- USBR 1981 Freeboard Criteria and Guidelines
- USBR 1998 Prediction of Embankment Dam Breach Parameters
- FEMA 1998 Selecting and Accommodating Inflow Design Floods for Dams
- NOAA 1984 Hydrometerological Report No 49
- USBR 1996 Concrete Repair Manual
- NRCS 1994 Gradation Design of Sand and Gravel Filters

3.5.3. Rules of Development for Dams

Policy D(1): Failure Potential. The structural integrity and possible failure of existing earthen dams/embankments shall be evaluated within the study area. The foundation investigation shall consist of borings, test pits, and other subsurface explorations as deemed necessary. These investigations shall be performed so as to define the soil and rock stratigraphy and the groundwater conditions. Laboratory testing of the undisturbed and remolded soil specimens, and rock samples shall be required, as well as stability, settlement analyses, and fissure studies, unless it can be demonstrated by a Registered Professional Engineer or Geologist to the satisfaction of the County that these analyses are not necessary.

Policy D(2): Dam Performance. Unless a current hydrologic/hydraulic study is available, a hydrologic and hydraulic evaluation shall be performed by a Professional Engineer to evaluate dam and spillway and outlet works performance and level of protection provided.

Policy D(3). ADMP GIS. Areas downstream of dams are identified in the Pinal County ADMP GIS. Rules of development for dams shall be used for any parcel(s) shown within denoted dam areas in the ADMP GIS. Note that the location of the ADMP GIS dams may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. It is possible that some dams were not identified in the ADMP. In the course of due diligence and site analyses, site developers and their engineers should evaluate the watershed to see if the project site contains, or is downstream of, any dams.

Policy D(4). Impoundment Limits. Unless a detailed hydrologic study is available or it can be demonstrated by a Professional Engineer to the satisfaction of the County, the dam impoundment area will be considered flood prone up to top of embankment elevation. No development shall be allowed within storage pool.

Policy D(5). Stock Ponds. Stock ponds are typically small enough to be classified as low hazard dams (See Policy D(10) on Dam Classification and Downstream Impacts). In general, if it can be demonstrated by a Professional Engineer to the satisfaction of the County that a stock pond is low hazard and that the pond does not have the potential for significant impact within a hydrologic area, then it may be omitted from the hydrologic (HEC-1) model for the watershed. However, if the stock pond has significant volume or hazard potential it shall be included in the hydrologic analyses prepared by a Professional Engineer for the watershed area and/or for the dam analysis, design, repair or removal plans. Absent an engineering analysis, it will be assumed that a stock pond has significant hydrologic impact and/or potential for downstream hazards if any of the following apply:

- Impoundment volume greater than 5% of the watershed 100-year 1 hour volume.
- Height of spillway greater than six feet
- Distance to nearest downstream structure of less than 200 feet
- Documented history of embankment failure

Policy D(6). New Dams Discouraged. No dam may be constructed for the purpose of storing, conserving, or retarding water, or for any other purpose, unless the person or governmental agency desiring the construction has been authorized by Pinal County. Excavated basins are preferred to dams.

Policy D(7). Design of New Dams. Hydrologic, hydraulic and geotechnical analysis shall be done and plans and specifications prepared by a Professional Engineer for design of all new dams. The bases, references, calculations, and conclusions relative to hydrologic, hydraulic, and structural design studies and to the design of spillways and outlet works shall be provided in a design report. Design procedures that have been established by the Arizona Department of Water Resources, United States Army Corps of Engineers, the United States Department of Interior Bureau of Reclamation, the Federal Energy Regulatory Commission and the United States Department of Agriculture Natural Resources Conservation Service are generally accepted as sound engineering practice. A written summary of the design references and assumptions that are used shall be included in the information that is submitted to County. Design Reports shall also include:

- Rainfall and runoff data
- Reservoir inflow hydrographs
- Reservoir area-storage volume elevation data to the top of dam elevation
- Spillway elevation-discharge data
- Reservoir flood routings and backwater analyses
- Emergency Action Plans
    - Spillway Inundation Mapping of Critical Routing Reach
    - Dambreak Analysis/Mapping
- Operation and Maintenance Manual

Design plans and specifications shall be prepared by a Professional Engineer in accordance to Pinal County standards and shall contain all necessary easements for access of structure and maintenance.

Policy D(8). Ownership. It is the dam owner's responsibility to fund maintenance, repair and inspection. An Operation and Maintenance Manual, Emergency Action Plan and a regular schedule of maintenance and periodic inspection should be set up for each dam. Drainage (flood control) districts may be set up for this purpose.

Policy D(9). Dam Removal. All plans to remove, alter, or repair a dam located in Pinal County must be prepared by a Professional Engineer and approved by the County.

Policy D(10). Dam Classification and Downstream Impacts. Dams shall be divided into three hazard potentials, which shall be known as low, significant, and high hazard potential. The County shall establish a dam's appropriate classification by using the following ADWR criteria as a guideline.

- Low Hazard Potential- Dams assigned the low hazard potential classification are those where failure or inadequate operation results in no probable loss of life and low economic and/or environmental losses. Losses are principally limited to the owner's property.
    - Property losses including but not limited to rural buildings.
    - Damage or disruption to local roads.
- Significant Hazard Potential- Dams assigned the significant hazard potential classification are those dams where failure or inadequate operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns.
    - Disruption of a public water supply or wastewater treatment facility, release of health hazardous industrial or commercial waste, or other health hazards.
    - Flooding of residential, commercial, industrial, or publicly owned structures.
    - Flooding of high-value property.
    - Damage or disruption to major roads including but not limited to interstate and state highways, and the only access to residential or

other critical areas such as hospitals, nursing homes, or correctional facilities.
    - Damage or disruption to railroads or public utilities.
    - Damage to downstream to other dams or levees. Damage to dams or levees can include, but is not limited to, overtopping of the structure.
- High Hazard Potential- Dams assigned the high hazard potential classification are those where failure or inadequate operation results in probable loss of life. Economic, environmental or other losses can also occur but are not required for the dam to receive this classification.

Policy D(11). Periodic Inspection of Dams. A dam is a man-made structure that is constructed of materials subject to erosion, corrosion, weathering and deterioration. Depending on many factors, a dam may either deteriorate slowly or quickly, but every dam will deteriorate over time. If problems with the dam go unnoticed, and repair and maintenance measures are not taken, the dam can fail, causing property damage downstream and possible loss of life. Problems that are not recognized and corrected will progress.

Periodic inspections and evaluations of all dams shall be done in compliance with the approved Emergency Action Plan to assure that their continued operation and use does not constitute a hazard to life, health, or property. The classification of each dam shall be reviewed during each periodic or other inspection and may be changed as a result of such inspection. The inspection report of a dam shall be prepared for the owner by a Professional Engineer.

3.6. Levees & Embankments

3.6.1. Description

Levees and levee-type embankments are located throughout Pinal County, particularly in existing and former farmlands. Levees have the potential to divert, concentrate, obstruct or impound surface water runoff. The locations of many levees and embankments are identified in the Pinal County ADMP.

Definition

An embankment is any artificial barrier which diverts, retards or obstructs runoff. A levee is any artificial barrier together with any appurtenant works that will divert or restrain the flow of a stream or other body of water for the purpose of protecting an area from inundation by flood waters.

Figure 3-5. Leveed portion of the Santa Cruz River near Maricopa, Arizona.

3.6.2. Technical References:

- USACE Levee Design- EM110-2-1913
  http://www.usace.army.mil/publications/eng-manuals/em1110-2-1913/basdoc.pdf

- FEMA NFIP Regulations, Part 65.10 – Areas Protected by Levees. Available at: http://www.access.gpo.gov/nara/cfr/waisidx_02/44cfr65_02.html

3.6.3. Rules of Development for Levees

Policy LE(1): FEMA Criteria. FEMA has specific criteria relating to design, construction, maintenance, and certification of levees. Flood control levees must meet the current effective FEMA policies to be considered as flood control structures.

Policy LE(2): Failure Potential. The structural integrity and possible failure of existing earthen levees shall be evaluated within the study area. The foundation investigation shall consist of borings, test pits, and other subsurface explorations as deemed necessary. These investigations shall be performed so as to define the soil and rock stratigraphy and the groundwater conditions. Laboratory testing of the undisturbed and remolded soil specimens, and rock samples shall be required, as will stability, settlement analyses, and fissure studies, unless it can be demonstrated by a Registered Professional Engineer (P.E.) or Professional Geologist (P.G.) to the satisfaction of the County that these analyses are not necessary.

Policy LE(3): Levee Performance. Unless a current hydrologic/hydraulic study is available, a hydrologic and hydraulic evaluation shall be performed by a registered engineer to evaluate levee performance and level of protection provided. Hydraulic analyses shall be conducted to determine flood elevations for stream reaches affected by the levee. The analyses shall provide flood depth and velocity data during the 100-year and for the top-of-levee flood event. The impact of flood depths and velocities on the levee and adjacent property and structures shall also be provided.

Policy LE(4). ADMP GIS. Areas downstream of levees are identified in the Pinal County ADMP GIS. Rules of development for levees shall be used for any parcel(s) shown within denoted levee areas in the ADMP GIS. Note that the location of the ADMP GIS levees may not be precise on any given parcel and should be checked during site visits, from site survey data, or by inspection of aerial photographs. It is possible that some levees were not identified in the ADMP. In the course of due diligence and site analyses, site developers and their engineers should evaluate the watershed to see if the project site contains any levees.

Policy LE(5). Impoundment Limits. Unless a detailed hydrologic study is available or it can be demonstrated by a Registered Professional Engineer (P.E.) to the satisfaction of the County, the levee ponding area will be considered flood prone up to top of embankment elevation. No development shall be allowed within storage pool.

Policy LE(6). New Levees Discouraged. No levee may be constructed for the purpose of storing, conserving, or retarding water, or for any other purpose, unless the person or governmental agency desiring the construction has been authorized by Pinal County. Future development of areas upstream, downstream, and adjacent to the levee shall be considered in the design. The levee shall operate safely during all floods up to the design

flood elevation. The levee must be protected from or designed to prevent erosive velocities along the structure and its foundation.

Policy LE(7). Design of New Levees. Hydrologic, hydraulic and geotechnical analysis shall be done, and plans and specifications prepared by, an Arizona-registered professional engineer for design of all new levees. The bases, references, calculations, and conclusions relative to hydrologic, hydraulic, and structural design studies shall be provided in a design report. Design procedures that have been established by the United States Army Corps of Engineers (USACE), and FEMA are generally accepted as sound engineering practice. A written summary of the design references and assumptions that are used shall be included in the information that is submitted to County.

Hydraulic analyses shall be conducted to determine flood elevations for stream reaches affected by the construction of a levee. The analyses must provide flood depth and velocity data during the 100-year and for the top-of-levee flood event. For construction of new levees, the flood depths and velocities must be determined with and without the levee. The impact of increased flood depths and velocities on property and structures must be provided. The levee must be protected from or designed to prevent erosive velocities along the structure and its foundation. New FEMA regulations now require that all levees providing 100-year storm protection must be certified by FEMA. Design Reports shall also include:

- Discharge/probability data
- Hydrographs
- Valley cross-sections
- Descriptive hydraulic information concerning bridges and other structures that influence the hydraulic characteristics of the watercourse
- Scour calculations/erosion control design
- Stream elevation-discharge-storage data
- Stream flood routings and flood profiles
- Operation and Maintenance Manual
- Freeboard
    - High hazard levees, the minimum elevations of the top of the levee shall be at least three feet higher than the maximum adjacent water surface elevations during passage of the design flood.
    - Significant and low hazard levees, the minimum elevations of the top of the levee shall be two feet higher than the maximum adjacent water surface elevations during passage of the design flood.

Design plans and specifications shall be prepared by a registered engineer in accordance to Pinal County standards and shall contain all necessary easements for access of structure and maintenance.

Policy LE(8). Ownership. It is the levee owner's responsibility to fund maintenance, repair and inspection. A regular schedule of maintenance and periodic inspection should

be set up for each levee. Drainage easements shall be obtained to facilitate maintenance of the structure and access. Drainage (flood control) districts may be set up for this purpose. Pinal County will not accept ownership or maintenance responsibility for levee-dependant flood control solutions without the express written consent of the County Engineer.

Policy LE(9). Levee Repair/Removal. All plans to remove, alter, or repair a County levee must be prepared by a registered engineer and approved by the County.

Policy LE(10). Levee Classification and Downstream Impacts. Levees shall be divided into three hazard potential zones, which shall be known as low, significant and high hazard potential. The County shall establish a levee's appropriate classification by using the following ADWR criteria as a guideline.

- Low Hazard Potential- Levees assigned the low hazard potential classification are those where failure or inadequate operation results in no probable loss of life and low economic and/or environmental losses. Losses are principally limited to the owner's property.
    - Property losses including but not limited to rural buildings.
    - Damage or disruption to local roads.
- Significant Hazard Potential- Levees assigned the significant hazard potential classification are those levee where failure or inadequate operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns.
    - Disruption of a public water supply or wastewater treatment facility, release of hazardous industrial or commercial waste, or other health hazards.
    - Flooding of residential, commercial, industrial, or publicly owned structures.
    - Flooding of high-value property.
    - Damage or disruption to major roads including but not limited to interstate and state highways, and the only access to residential or other critical areas such as hospitals, nursing homes, or correctional facilities.
    - Damage or disruption to railroads or public utilities.
    - Damage to downstream to other dams or levees. Damage to dams or levees can include, but is not limited to, overtopping of the structure.
- High Hazard Potential- Levees assigned the high hazard potential classification are those where failure or inadequate operation results in probable loss of life. Economic, environmental or other losses can also occur but are not required for the levee to receive this classification.

Policy LE(11). Periodic Inspection of Levees. A levee is a man-made structure that is constructed of materials subject to erosion, corrosion, weathering and deterioration. Depending on many factors, a levee may either deteriorate slowly or quickly, but every levee will deteriorate over time. If problems with the levee go unnoticed, and repair and

maintenance measures are not taken, the levee can fail, causing property damage downstream and possible loss of life. Problems that are not recognized and corrected will progress. Periodic inspections and evaluations of all levees shall be done to assure that their continued operation and use does not constitute a hazard to life, health, or property. The classification of each levee shall be reviewed during each periodic or other inspection and may be changed as a result of such inspection. The inspection report of a levee shall be prepared for the owner by a Registered Professional Engineer.

Policy LE(12). Areas Downstream of Levees. Development in areas protected by levees and embankments shall follow current Pinal County floodplain and drainage regulations, as well as current FEMA guidelines for floodplain delineation and flood mitigation. Potential drainage impacts on areas downstream of levees and embankments may include changes in contributing watershed area, flow duration, channel stability (erosion or deposition), flood magnitude, and flow direction, as well as possible impacts from levee or embankment failures. The engineer of record for the proposed development shall make a prudent assessment of the level of protection provided by upstream levees and embankments, the potential impacts on the proposed development, and the affect of FEMA regulatory and levee certification policies on the flood hazard.

3.7. Canals & Irrigation Structures

3.7.1. Description

A variety of irrigation and water supply canals are located in Pinal County. Canal embankments and related irrigation facilities often disrupt natural drainage patterns by obstructing or diverting natural channels, impounding runoff, or concentrating shallow flooding through culverts or channels. In some cases, storm water is captured and conveyed by canal systems.

Figure 3-6. Aerial photograph of canal with road crossing and alteration of natural drainage pattern.

3.7.2. Technical References:

- Pinal County Drainage Manual, Vol. 1 & 2 (2006). Available at: http://co.pinal.az.us/PubWorks

3.7.3. Rules of Development for Canals & Irrigation Structures

Policy C(1). Flow Diversion. New canal construction should not divert or obstruct natural flow paths.

Policy C(2). Storm Water Discharge. Canals should not be used to discharge storm water from any development.

Policy C(3). Overtopping and Failure. Design of subdivisions downstream of canals should account for potential overtopping and/or failure of the canal as a source of additional offsite flood runoff.

Policy C(4): Canal End Points. Development at the termination points of canals should be designed to prevent damage from irrigation tailwater and storm water discharges from the canal, in addition to flooding from other sources at the property.

Policy C(5): Overchutes & Cross-Canal Drainage. Overchutes and cross canal drainage facilities should be designed to convey the 100-year discharge, and should account for upstream sediment deposition and downstream scour.

Policy C(6): Road Crossings. In some locations, runoff is conveyed parallel to upstream side of canal embankments. Road approaches that cross canal embankments should be designed to preserve and allow existing conveyance parallel to the canal, rather than create ponding areas and create overtopping hazards.

3.8. Storm Drains & Channels

3.8.1. Description

Storm drains and channels include subsurface closed conduits, open channels, and other constructed linear drainage facilities. Specific design criteria for storm drains are provided in the Pinal County Drainage Manual (Volumes 1 & 2).

Figure 3-7. Storm drain inlets with debris, sediment and maintenance issues.

Channelization is generally known to have the following impacts on channel stability:

- Velocity. Channelization generally increases channel velocities. Velocity is exponentially related to sediment transport rates and erosion potential.
- Depth. Channelization can increase the flow depth by eliminating the floodplain area available for conveyance. Increased depths result in greater scour depths and higher velocities.
- Discharge. Channelization eliminates the area available for storage of floodwaters on the floodplain, resulting in decreased attenuation and increased peak discharges downstream. Increased peak discharges are directly related to increased sediment transport rates and erosion.

- Design Standards. Engineered flood control channels are typically designed to a 100-year standard. Therefore, damage may occur to development adjacent to a 100-year channel (or to the channelization itself) if flow rates greater than the 100-year event occur. If design discharges change due to watershed changes or revisions to hydrologic modeling standards, retrofit solutions are needed to maintain the same standard of protection.
- Design Life. Engineered structures have a limited design life, require regular maintenance and inspection, and need eventual replacement.
- Equilibrium Slope. Because of the increase in discharge, velocity, and depth, the stable slope is generally flatter than the existing channel slope, which will cause long-term scour and require grade control to prevent undercutting of bank protection.
- Downstream Impacts. Instability should be expected at the outlet of a channelized reach due to changes in velocity, sediment supply, and discharge. Depending on the channel geometry, the expected response can range from lateral channel migration, erosion and scour to sediment deposition and overbank flooding.

Channelization should be allowed only where it can be demonstrated that no long-term or short-term off-site impacts to channel stability occur, that downstream reaches are adequately protected from erosion and flooding, and a long-term maintenance and inspection program is adopted. Where structural flood control measures are necessary, the design and installation of such structures should complement the environment and be accomplished with the least disturbance to the natural setting. Design guidelines and standards for structural flood control improvements are provided in the Pinal County Drainage Manual.

3.8.2. Technical References:

- Pinal County Drainage Manual, Vol. 1 & 2 (2006). Available at: http://co.pinal.az.us/PubWorks
- ADWR State Standards:
  - (SS7-98) Standard for Watercourse Bank Stabilization
  - (SS8-99) Standard for Stormwater Detention/Retention
  - (SS9-02) State Standard for Floodplain Hydraulic Modeling

3.8.3. Rules of Development for Storm Drains & Channels

Policy SD(1): Drainage Manual. Storm water conveyance facilities such as open channels, ditches, swales, roadways, culverts, storm drains, and natural watercourses are to be evaluated in conformance with the Pinal County Drainage Manual.

Policy SD(2): 100-Year Capacity. The capacity of storm water conveyance facilities upstream of a proposed development should be evaluated to determine the facility's ability to convey the 100-year peak discharge draining to it, including any split flow from adjacent watersheds.

Policy SD(3). Split Flow. The design of storm water conveyance facilities shall take into consideration offsite drainage impacting a development including potential split flow from adjacent watersheds, split flow from upstream conveyance facilities due to the facilities' limited conveyance capacity, and flow from a potential failure of an upstream facility.

Policy SD(4): Sedimentation. The designer of drainage facilities shall undertake the appropriate level of erosion, sedimentation, and hydraulic analysis to safely convey the design peak discharge.

Policy SD(5): Water Surface Elevation. Design water surface elevations for excavated channels shall be below adjacent natural ground (including design freeboard).

Policy SD(6). Irrigation. Prohibit use of irrigation canals as an outfall for storm water runoff.

3.9. Sand & Gravel Mining

Rules of Development for sand and gravel mining are provided in the Sand and Gravel Mining Floodplain Use Permit Application Guidelines.

Figure 3.8. In-stream and floodplain mining near Schnepf Road on Queen Creek.

3.9.1. Technical References:

- Pinal County Department of Public Works Sand and Gravel Mining Floodplain Use Permit Application Guidelines. Available at: http://www.co.pinal.az.us/PubWorks/

Rules of Development

Section 4. General Development Policies

4.1. Pinal County Drainage Regulations

The rules of development listed in this document are intended to elucidate and clarify drainage regulations and policies presented in the most current versions of the following Pinal County documents:

- Pinal County Floodplain Management Ordinance
- Pinal County Subdivision Regulations
- Pinal County Subdivision Ordinance
- Pinal County Subdivision Design Standards
- Pinal County Drainage Manual, Volumes 1 & 2

Any conflict with the documents listed above is unintended. In the case of such conflict the user should default to the regulations listed above and request guidance from the County Engineer.

4.2. Drainage Report Required

The following criteria are provided to assist landowners determine if a drainage report is required:

- Required by any Pinal County Drainage Regulation Document
- Required by any ADWR State Standard
- Subdivision of land into three or more lots
- Modification of regulatory floodplain
- Development with a regulatory floodway
- Development within an erosion hazard zone or erosion setback area
- Professional judgment of the County Engineer due to site specific conditions

In general, a drainage report may be required by the County if the proposed development is located within a floodplain or erosion hazard zone, if there is potential for adverse impacts to adjacent properties, or if unusual site conditions exist. Single lot development adhering to the recommendations and data provided in the Pinal County ADMP documents generally will not require a separate drainage report, unless the conditions listed above apply.

4.3. Development Categories

Some of the rules of development described in this document are intended only for major developments and will not be applied to minor developments. The definitions in Table 4-1 describe major and minor development categories.

Table 4.1 Pinal County Rules of Development Categories	
Major Development	**Minor Development**
Residential Subdivisions Commercial Subdivisions Commercial Development (> 5 acres) Public Roads & Highways Public Utilities & Infrastructure Flood Control Facilities Canals & Irrigation Structures	Residential Construction - Single Lot Building Permits for Single Family Residences Single Lot Commercial Developments (< 5 acres)

4.4. Local Jurisdiction Drainage Regulations

Development within incorporated communities and sovereign lands of Native American communities in Pinal County must comply with local regulations and policies. The following incorporated communities and sovereign lands are located in Pinal County:

- Ak-Chin Indian Community
- Apache Junction
- Casa Grande
- Coolidge
- Eloy
- Florence
- Gila River Indian Community
- Kearny
- Maricopa
- San Carlos Indian Reservation
- Superior
- Tohono O'odham Nation

The following incorporated communities are subject to Pinal County policies:

- Arizona City
- Dudleyville
- Hayden
- Mammoth
- Oracle
- Oracle Junction
- Riverside
- San Carlos
- San Manuel
- Winkleman

Rules of Development
Section 5. Appendixes

The following information is provided in the Rules of Development Appendixes:

- Appendix 5.1: Drainage Review Checklist
- Appendix 5.2: Low Impact Criteria for Floodplain Encroachment
- Appendix 5.3: Level III Erosion Hazard Analysis Task List
- Appendix 5.4: Guidance for Identifying Channel Bank Location
- Appendix 5.5: Guidance for Identifying Avulsion Erosion Hazard Areas
- Appendix 5.6: Technical References for Erosion Hazard Delineation
- Appendix 5.7: Hydrologic/Hydraulics Analysis Procedures for Split Flow Areas
- Appendix 5.8: Impacts Analyses on Alluvial Fans
- Appendix 5.9: References

5.1. Drainage Review Checklist

<u>Minor Development Checklist</u>

Floodplain Use Permit Application Form

____1. Application form completed?
____2. Site plan attached?

Site Plan Requirements **(Also See State Standard 6-96)**

____1. Project name and address
____2. Legal description or assessor's tax id of property
____3. Property owner name, address and phone number
____4. Site location and vicinity map or description
____5. Source of topographic data, if any

Pinal County Drainage Review Elements

____1. Check site location on ADMP GIS for the following:

____Delineated floodplain/floodway?	See Section 2.2
____ADMP thalweg line?	See Sections 2.2-2.3
____Split flow area?	See Section 2.4
____Alluvial fan flooding area?	See Section 2.5
____Sheet flow area?	See Section 2.6
____Ponding area?	See Section 2.7
____Farming area?	See Section 2.8
____Hillside slope area?	See Section 2.9
____Subsidence & fissure area?	See Section 2.10
____Downstream of embankment area?	See Section 3.5

____2. Check aerial photographs and topographic maps for the following:

____Defined watercourse with potential floodplain?	See Section 2.2
____Erosion setback from watercourse needed?	See Section 2.3
____Channels dividing in downstream direction?	See Section 2.4
____No defined flow paths upstream?	See Section 2.6
____Canals or embankments downstream?	See Section 2.7
____Farmlands with irrigation structures?	See Section 2.8
____Steep hilly terrain?	See Section 2.9
____Downstream of embankment area?	See Section 3.5

____3. Field check items:

____High water marks, flood debris, sediment deposits
____Nearby drainage structures – culverts, channels, storm drains, condition
____Nearby embankments, dams, levees – upstream & downstream
____Channels on or near property – condition, stable banks, erosion
____Evidence of site grading

Major Development Checklist

Site Plan Requirements

____1. Project name and address
____2. Legal description or assessor's tax id of property
____3. Property owner name, address and phone number
____4. Site location and vicinity map or description
____5. Source of topographic data & benchmark/datum
____6. Engineer & Surveyor professional seal

Drainage Report Requirements

____1. Engineer's professional seal
____2. Documentation & calculations supporting engineering design
____3. Design drawings and specifications
____4. Computation of off-site drainage rates & routes
____5. Delineation of on-site drainage (floodplain delineation)
____6. Computation and design of detention/retention facilities
____7. Demonstration of no adverse impact to adjacent properties

Pinal County Drainage Review Elements

____Delineated floodplain/floodway?	See Section 2.2
____ADMP thalweg line?	See Sections 2.2-2.3
____Split flow area?	See Section 2.4
____Alluvial fan flooding area?	See Section 2.5
____Sheet flow area?	See Section 2.6
____Ponding area?	See Section 2.7
____Farming area?	See Section 2.8
____Hillside slope area?	See Section 2.9
____Subsidence & fissure area?	See Section 2.10
____Downstream of embankment area?	See Section 3.5

____2. Check aerial photographs and topographic maps for the following:

____Defined watercourse with potential floodplain?	See Section 2.2
____Erosion setback from watercourse needed?	See Section 2.3
____Channels dividing in downstream direction?	See Section 2.4
____No defined flow paths upstream?	See Section 2.6
____No defined flow paths upstream?	See Section 2.6
____Canals or embankments downstream?	See Section 2.7
____Farmlands with irrigation structures?	See Section 2.8
____Downstream of embankment area?	See Section 3.5

____3. Design of drainage structures

____Road crossings	See Section 3.2
____Utility crossings	See Section 3.3
____Detention/Retention basins	See Section 3.4
____Levees, embankments & dams	See Sections 3.5-3.6
____Storm drainage & channels	See Section 3.8

5.2. Low Impact Criteria for Floodplain Encroachment

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

- Velocity. Encroachment generally increases channel and overbank velocities. Because velocity is exponentially related to sediment transport rate and erosion potential, higher velocities generally cause increased scour and lateral erosion rates.

- Flow Depth. Encroachment increases the flow depth by reducing the channel and floodplain area available for conveyance. Increased depth results in higher risk of avulsions, greater scour depths, and increased erosive force on the channel banks. In addition, velocity generally increases with depth.

- Discharge. Encroachment decreases the area available for storage of flood waters on the floodplain, resulting in decreased attenuation and increased peak discharges downstream. Increased discharge is directly related to increased flow depths and velocities. Therefore, increased peak discharges are directly related to increased sediment transport rates and erosion.

- Design Standard. Development in encroached areas is typically designed to a 100-year standard. Therefore, damage will occur to development and/or flood control structures in encroached areas at flow rates greater than those of the 100-year event.

- Degree of Encroachment. The greater the degree of encroachment of the floodplain and main channel, the greater the impact on channel stability. For example, encroachment that leaves the 10-year floodplain unchanged will have less impact on channel stability than encroachment that modifies the 2-year floodplain.

To avoid the impacts of encroachment and floodplain modifications, and to facilitate planning and review of proposed development, an acceptable level of impact is defined. The following standards quantify the definition of "low-impact":

- Minimal velocity increases. Specifically:
    - The average 10-year velocity in the channel or overbank should not change.
    - 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 increases. Specifically:
    - The 10-year water surface elevation should not change.
    - The 100-year water surface elevation should not increase or decrease by more than 0.1 foot.

- Minimal disturbance of the main channel. Specifically:
    - No decrease in the bank-full width of the main channel.
    - No excavation or deepening of the streambed in the main channel.
    - No removal of bank vegetation. Where bank vegetation is temporarily disturbed by construction, it should be replaced, monitored for health, and irrigated if required to facilitate its survival.
    - No relocation of the low-flow channel within the floodplain.
    - No blockage of the channel.

- No adverse off-site impacts.

- No erosion, sedimentation, or flood impacts to adjacent properties without written permission of affected property owners.

Designs that do not meet the standards listed above are not considered low-impact alternatives. Non low-impact development and flood control alternatives may be acceptable, if they are properly engineered. Where low impact criteria are not met, the developer should provide detailed engineering analyses demonstrating no adverse impact to adjacent properties.

5.3. Level III Erosion Hazard Analysis Task List

If a proposed development is located within the Holocene[2] floodplain, the risk of lateral erosion may be significant and detailed analyses are warranted. In general, Pinal County 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 County 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.

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[2] See Appendix 5.9 for a glossary of terms

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 man-made 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). Detailed soils mapping may be available in published soil surveys by the Soil Conservation Service or U.S. Forest Service.

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 knick points, 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 using the 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. 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.
    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 localized 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 Pinal County. 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. Erosion Hazard Zone Delineation
    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 shall be provided with the erosion hazard analysis report.

5.4. Guidance for Identifying Channel Bank Location

Identification of the channel banks is required for determining erosion hazard setbacks. In most cases, the location of the channel bank is straightforward and can be readily identified in the field or from topographic maps and aerial photographs. In some cases, the channel bank location is less obvious. Channel bank stations can be identified using the following procedures:

- 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:

- <u>Vegetation</u>. 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, 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 (> 3-5 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,[3] 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.

[3] ADWR Arizona State Standard 3-94, p. 4.

Single Channels

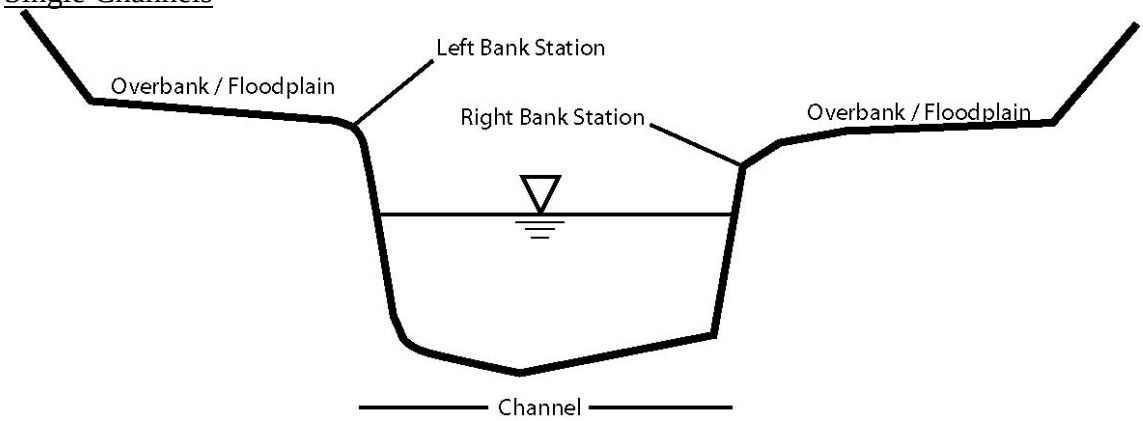

Figure 5.4-1. Recommended bank stations for a single channel cross section. Bank stations are located at the top of the bank at the slope break between the bank and the floodplain.

Multiple Channels

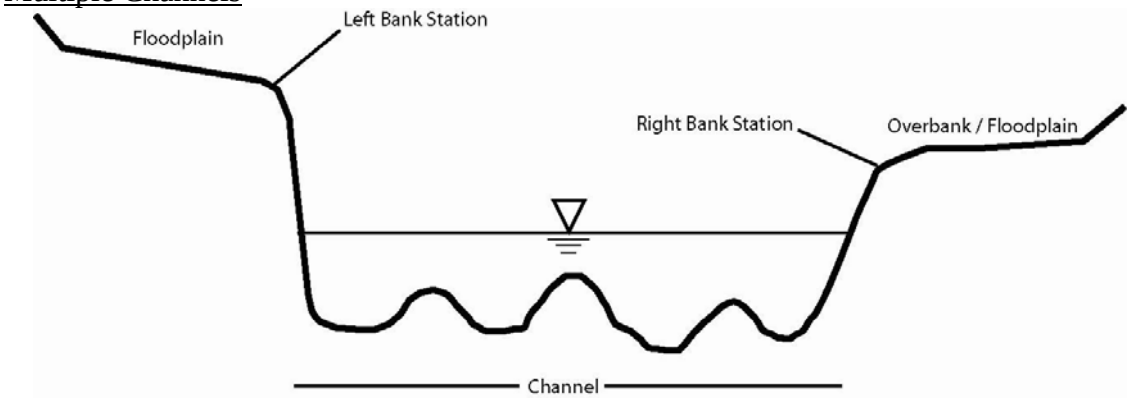

Figure 5.4-2. Recommended bank stations for a multiple channel with shallow islands or bars inundated by the 100-year flood. Low islands are subject to frequent erosion, deposition and channel processes. Bank stations are located at the top of bank at the slope break between the bank and the floodplain.

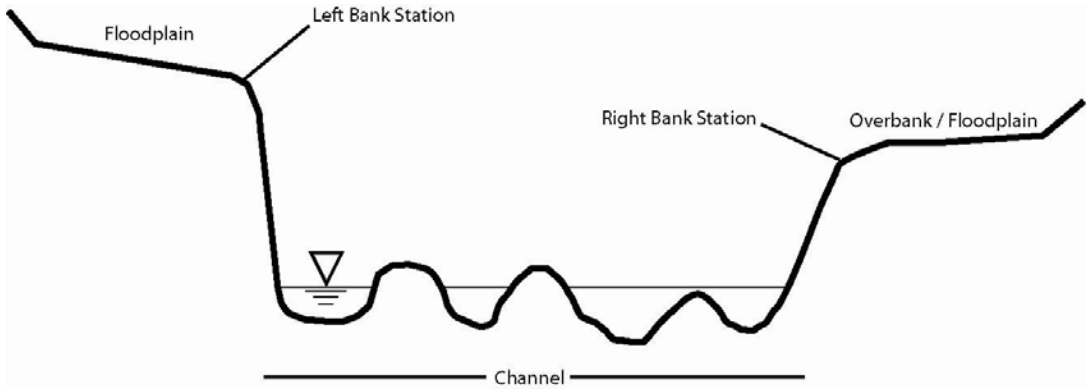

Figure 5.4-3. Recommended bank stations for braided or multiple channels with shallow, insignificant or small islands near the 100-year water surface elevation, but not inundated by the 100-year flood. Low, small islands between active braids are subject to avulsive channel movement or frequent erosion 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.

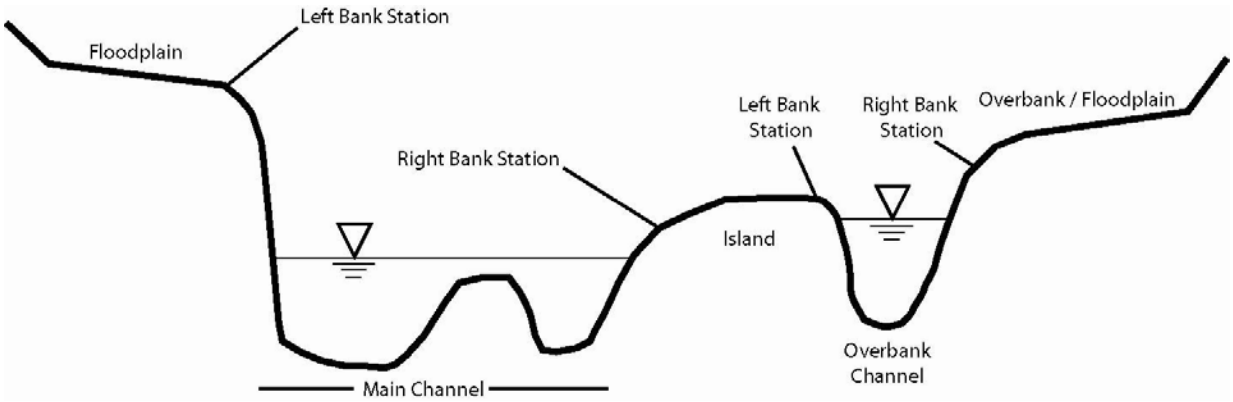

Figure 5.4-4. Recommended bank stations for multiple channels with large, significant islands or for perched channels hydraulically and topographically separated from the main channel. Two sets of bank stations are defined, each with its own erosion hazard area. Where the erosion hazard zones overlap, 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.

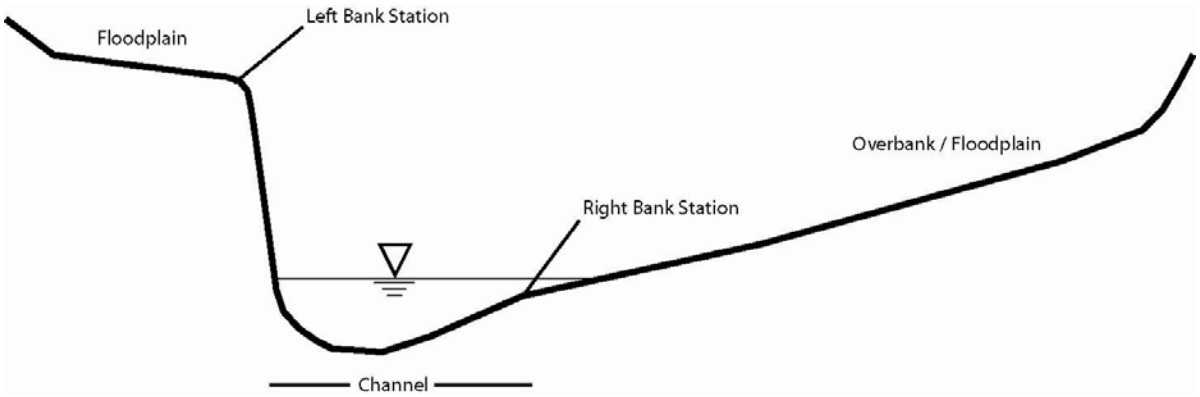

Figure 5.4-5. Recommended bank stations for channels with no defined banks. For this example, the left bank station is defined using the single channel guidelines and the right bank channel is defined using hydraulic criteria at the point where the 100-year flow depth is three feet, or the 100-year depth x velocity^2= 18. In some cases, bank stations in reaches with poorly defined banks can be identified by comparison with upstream and downstream bank locations.

5.5. Guidance for Identifying Avulsion Erosion Hazard 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 the main channel.
4. Lack of, or minimal, topographic relief between the 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.

5.6. Technical References for Erosion Hazard Delineation

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5.7. Hydrologic/Hydraulic Analysis Procedures for Flow Split Areas

Most watersheds have tributary drainage systems where numerous smaller tributaries combine in the downstream direction to form larger streams (Figure 5.7-1). In Arizona, distributary drainage systems, where streams split into two or more disconnected segments in the downstream direction, are relatively common. Watersheds with split channels that do not recombine are called distributary flow areas. Engineering analysis of distributary flow areas is complex, primarily because of uncertainty in determining the watershed area that contributes to a concentration point downstream of a flow split. These guidelines are intended to guide drainage engineers working in distributary flow areas and along channel downstream of flow splits.

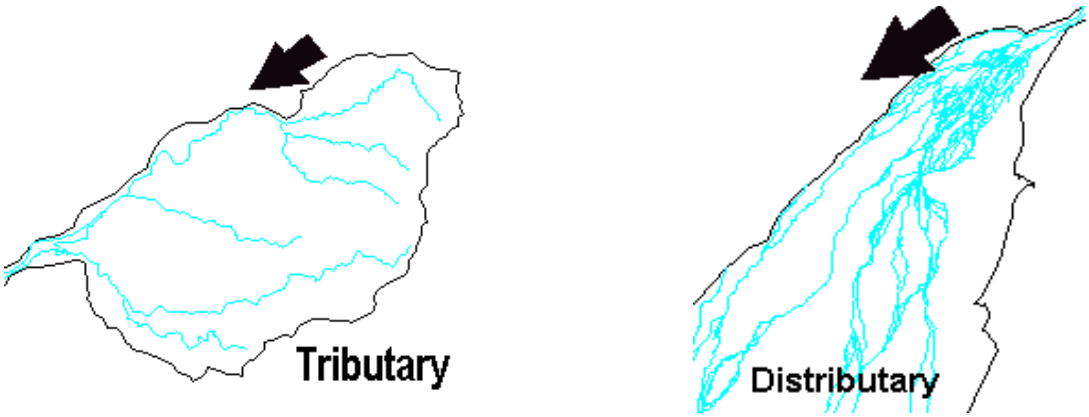

Figure 5.7-1. Example of tributary (left) and distributary (right) drainage patterns.

5.7.1. Hydrology: Watershed Delineation in Distributary and Split Flow Areas

Because flow paths divide in the downstream direction, not all flow from the upstream drainage area may reach a specific concentration point in a distributary or split flow area. The following guidelines are suggested for delineating watershed boundaries for concentration points downstream of or within distributary and sheet flow areas:

- ***Automated Watershed Delineation Tools***. In general, the use of automated watershed delineation tools is discouraged in areas with potential for distributary or split flow. If GIS or other automated watershed delineation tools are used, the drainage area boundaries should be carefully checked to identify places where additional flow might enter (or leave) the watershed. Specific hydrologic/hydraulic analyses should be conducted at each point where flow splits cause runoff to enter or leave the watershed.
- ***Aerial Photographs***. Use of aerial photographs, rather than topographic maps, is recommended as the primary base map for watershed delineation. Flow splits are more easily identified on aerial photographs than on topographic maps. USGS topographic quadrangle maps do not have sufficient accuracy and detail for mapping of complex distributary flow area watersheds. A combination of topographic mapping on an aerial photograph base is the best medium for watershed delineation.

- ***Field Verification***. Whenever possible, watershed boundaries in distributary flow areas should be field checked to look for potential flow splits, evidence of historical overflows, and potential stream piracy locations.
- ***Coordination***. If distributary and split flow conditions are encountered, the engineer should request review of the watershed delineation and hydrologic modeling approach with the appropriate review agencies.
- ***Conservative Estimates***. In most cases, and for relatively simple flow splits, the watershed area should be conservatively estimated to include inflow from splits that contribute runoff at the watershed boundary and to exclude splits that remove flow from the watershed. The long-term consequence of under-estimating the watershed area and design discharge is generally more significant than the consequence of possibly over-estimating the watershed area and design discharge.
- ***Simple Flow Split Areas***. For relatively simple flow splits along watershed divides, the engineer should delineate the main watershed and any contributing watersheds separately, so that the relative contribution from each potential flow source can be evaluated.
- ***Complex Distributary Flow Areas***. In complex distributary flow areas which have multiple interconnected flow bifurcation points, a high percentage of overbank and/or sheet flow, and a potential for channel avulsions, watershed delineation requires understanding of the local and regional geomorphic processes, and may require special expertise to complete the delineation.

5.7.2. Hydrology: Estimating a Design Discharge Downstream of a Flow Split

Unless the flow split is controlled by a well-maintained engineered hydraulic structure, such as a weir or diversion dam, the distribution of flow between channels downstream of a flow split is uncertain and/or subject to change. Sedimentation, scour, vegetative growth, debris, urbanization, and encroachment may change the existing conditions sufficiently to alter the flow distribution over time, or even during a single flow event. Therefore, discharge estimates downstream of flow splits must account for potential future changes in the upstream flow distribution. The following guidelines are suggested for estimating design discharges downstream of flow splits:

- ***Watershed Area***. The watershed delineation guidance listed above should be applied.
- ***Hydraulic Rating of Split Flow Points***. Guidance for hydraulic ratings is provided below. In general, the design discharge estimate should account for potential future changes in channel topography, roughness, allowable encroachment, and debris impacts.
- ***Hydrograph Timing***. Where there are significant differences in watershed size and/or geometry, the timing of the hydrographs from the main watershed and the split flow watershed should be compared. If the timing of the peaks is significantly different, potential split inflows may not significantly change the design discharge.
- ***Contributing Area***. The contributing area of the split flow and main watershed should be compared. Where main watershed is significantly larger than the split

flow contributing area, in most cases it is simpler to just add the split flow watershed to the main watershed, rather than evaluate the split flow contribution. Where the main watershed is significantly smaller than the potential split flow contributing area, hydraulic and geomorphic evaluation of the split flow point is required, or the corridor capacity approach (below) should be applied.

- ***Selecting Concentration Points***. In some cases, where flow splits recombine, evaluation of flow splits can be avoided by judicious selection of concentration points in the watershed model. If concentration points can be selected upstream of the flow bifurcation and downstream of the flow junction, and no flow paths escape between, then the evaluation of the split flow is avoided and becomes a simple question of routing and hydrograph attenuation.
- ***Safety Factor***. A safety factor should be applied to the discharge computed for each split channel such that the total discharge of all downstream channels sums to more than 100 percent. The safety factor used should reflect the relative uncertainty and potential for future change at the flow bifurcation point. In general, no channel should be assumed to convey less than 50 percent of the total upstream discharge.
- ***Historical Trends***. Review of historical and recent aerial photographs may provide clues to geomorphic factors that indicate the long-term trend of flow distribution. For example, stream piracy may lead to formation of a flow split in which the steeper flow path becomes dominant over time and the flatter flow path is eventually abandoned. Such information can be used to estimate appropriate safety factors.
- ***Attenuation Losses***. In distributary flow areas that convey a high percentage of flooding as overbank or sheet flow, attenuation losses such as transmission loss and hydrograph routing effects (floodplain and channel storage) can be significant and may be modeled when estimating downstream flow rates. However, if no regulations exist to prevent future development from altering existing conditions and removing flow attenuation areas, no hydrograph attenuation should be considered.
- ***Tributary Inflows***. The hydrologic modeling should account for tributary and local inflows that contribute runoff in the reach between the flow split location and the concentration point.
- ***Corridor Capacity***. In complex distributary flow areas where watershed delineation is difficult or where the contributing area upstream of a flow split is significantly larger than the main watershed, the design discharge may be dictated by the hydraulic capacity of upstream flow corridor. The flow corridor includes the upstream main channel and floodplain up to the local watershed divides (interfluves). If the estimated discharge exceeds the capacity of the upstream flow corridor, the flow capacity can be used for design purposes. Typically, this approach is only applicable to complex distributary flow areas and sheet flow areas and is generally applied for simple engineering applications and floodplain delineation. If the corridor capacity approach is used, the engineer should consider the following:

- Lateral Weir Rating. The rate of discharge from the corridor should be computed using appropriate lateral weir equations and coefficients that reflect the range of possible site conditions.
- Alternative Flow Path Capacity. The areas conveying any flow exiting the flow corridor must have capacity to carry that flow without causing backwater that would affect the lateral weir calculations.
- Return Flow. There should be no opportunity for flow to return to the upstream flow corridor before reaching the concentration point of concern.
- Future Changes. The potential for future changes to alter corridor capacity should be assessed. Such changes might include upstream development that removes or alters alternate flow paths and long-term scour that increases corridor capacity.

- ***Structural Measures Preferred***. In general, structural measures are recommended for major developments to eliminate or control split flows with engineered structures.

5.7.3. Hydraulics: Floodplain Delineation

The following guidance for hydraulic modeling and floodplain delineation is provided for distributary and split flow areas:

- ***Model Selection***. In complex distributary flow areas, use of a one-dimensional model like HEC-RAS may result in inaccurate, unrealistic or non-conservative results. The effort required to try to force a one-dimensional model to simulate what is essentially two dimensional flow conditions is usually not justified by the limited value of the results.
- ***Two-Dimensional Flow Models***. Use of two-dimensional models is recommended for highly complex distributary flow areas. However, note that use of two-dimensional models may require special training and expertise to achieve useful results. Two-dimensional models should be evaluated for flow continuity and computational stability.
- ***Floodway Modeling***. The following approaches should be considered for delineating floodways in distributary flow areas, and should be coordinated with review agency staff before proceeding:
    - ***Floodway = Floodplain***. For well-defined, incised channels in distributary flow areas, where flow is contained with minimal or no overbank flow, floodways may be assumed to be equal to the floodplain.
    - ***Zero-Rise Floodway***. Because encroachment raises the water surface elevation, and because changes in water surface elevation (as well as the physical encroachment itself) would change the flow distribution between splits and thus adversely impact adjacent channel reaches, an appropriate floodway definition for distributary flow areas is a zero rise condition. That is, no change in the regulatory water surface elevation is allowed and only ineffective flow areas may be developed.
    - ***Depth Criteria***. Many distributary flow areas have low 100-year flow depths, such that a normal one-foot rise due to encroachment may translate

to a 20 to 100 percent increase in flow depth. Such changes in depth will adversely impact sedimentation and erosion along the flow corridor. Therefore, an alternative approach to floodway definition is to consider all areas with depths greater than three feet or areas with a depth-velocity product greater than nine to be a floodway.

    - ***10-Year Floodplain***. Most runoff is conveyed within the 10-year floodplain on most streams in Arizona. Another alternative floodway delineation approach is to use the 10-year floodplain as the floodway boundary.

- ***Alluvial Fans***. Alternative methods for floodplain delineation of distributary flow areas on alluvial fans have been developed by FEMA (See Section 2.5 of this document) and are generally recommended over hydraulic approaches for floodplain delineation purposes. However, hydraulic approaches are recommended for engineering design of structures in distributary flow areas on alluvial fans.
- ***Encroachment Impacts***. Encroachment in distributary flow areas has the following potential adverse impacts, and should therefore be discouraged:
    - ***Velocity Increase***. Increased velocity increases scour and erosion, leading to changes in channel geometry. When the channel geometry changes, the distribution of flow between flow splits changes, with potential adverse impacts to adjacent properties.
    - ***Water Surface Elevation***. The flow distribution between flow splits is altered by encroachment when the water surface increases because of the reduced flow area.
- ***Hydraulic Ratings***. The following factors should be considered when performing hydraulic ratings of split flows.
    - ***Existing = Future*****?** Flow distribution estimates based on hydraulic ratings should consider potential future changes in the variables used to estimate the split, such as channel geometry, roughness, and control elevations.
    - ***Range of Discharges***. The percent of flow distribution at one flow frequency may be significantly different than the flow distribution for a higher or lower flow frequency. A range of discharges should be modeled if performance over a hydrograph duration is required.
    - ***Backwater Modeling***. Backwater conditions may affect the flow distribution and should be considered in the split flow model.

5.8. Impacts Analyses on Alluvial Fans

These guidelines are intended to provide direction to engineers performing technical analyses of new development on alluvial fans in Central and Southern Arizona. Pinal County reviewers will reference these guidelines when reviewing technical submittals that assess potential impacts to adjacent properties and flood control planning. If any conflicts exist between these interim guidelines and adopted County Manuals, Ordinances, Regulations and Policies, or NFIP Regulations, these guidelines will be considered to be superseded.

Section 1: Hydrology. All hydrologic modeling upstream of the alluvial fan apex will be based on detailed HEC-1 modeling developed for existing conditions. Downstream of the hydrographic apex of the alluvial fan, it is recommended to use two-dimensional modeling to account for multiple flow paths, as well as the significant flood storage, infiltration and attenuation that occurs on alluvial fans.

1. Multiple Frequency Models. To obtain hydrologic data for frequencies other than the 100-year event, the following guidelines apply:
    a. Q2 – Engineers may use procedures outlined in the FCDMC Hydrology Manual (i.e., JR=0.1) to adjust the existing condition HEC-1 model or develop new modeling based on the existing condition model.
    b. Q10 – Engineers may use procedures outlined in the FCDMC Hydrology Manual (i.e., JR) to adjust the existing condition Q100 HEC-1 model or develop new modeling based on the Q100 model.
    c. Additional models or discharges may be needed for transportation design or other purposes, but are not required for analysis of alluvial fan impacts at specific locations. Additional, intermediate frequencies may be estimated using ratios and/or probability-weighted plotting of the 2-, 10-, and 100-year peaks.
    d. The existing Q100 HEC-1 model may not address every concentration point downstream of the fan apexes needed for evaluation of individual project impacts. Where peak discharges and hydrographs are required for concentration points downstream of the apex, but upstream of concentration points defined in the existing condition HEC-1 model, they will be computed by delineating subwatersheds based on the existing ground conditions and hydraulic/geomorphic ratings of existing flow splits.
        i. Coordination with County review staff is recommended following initial identification of all significant concentration points along development perimeter boundaries to be evaluated. The intent of this initial coordination meeting is to finalize the number and location of concentration points to be evaluated.
        ii. Coordination with County review staff is also recommended following initial delineation of on-fan watersheds & distributary areas that drain to the concentration points listed above.
        iii. Engineers must coordinate with engineers working on adjacent developments to assure that drainage inflow and outflow concentration points and discharge estimates are compatible. If no coordination

effort between engineers is made and conflicts arise, Pinal County will assume that the higher discharge estimate and larger flow volume estimate is correct for discharge inflow points and the lower peak and volume is correct for discharge outflow points.

iv. Engineers are cautioned against using JD Records when subdividing and modifying the existing condition HEC-1 model. Instead it is recommended that they select an appropriate storm size and revise the models accordingly.

v. Discharge estimates for intermediate and new concentration points should be verified by comparison with the capacity of the geomorphic flow corridor for the concentration point.

vi. It is not necessary or expected that HEC-1 model revisions made to estimate flow data at new or intermediate concentration points will be permanent modifications to the regional HEC-1 model. That is, such model revisions will be made for the purpose of analysis of the particular development only.

vii. Small drainage areas not part of distributary (alluvial fan) system can be modeled separately using the procedures in the FCDMC Hydrology Manual.

e. Developed conditions (with project) modeling will be prepared based on the following assumptions:

i. Land Cover – full build out for subject property. Since the guidelines dictate that existing Q2, Q10, & Q100 will not be increased due to development, there is no need to address off-site land use changes.

ii. Detention/Retention – on-site retention and detention will be modeled to demonstrate no increase in off-site peak or flow volume. Exceptions for release of non-damaging flows need not be modeled.

iii. Channelization – impacts on routing due to channelization along flow corridors, collection channels and other channels should be included in the developed condition HEC-1 models.

f. Discharge Estimate Downstream of Active Area. In the past, FEMA has dictated that the full apex Q100 be used for design of any flood control or conveyance facilities hydrologically connected to the fan apex. Increases to the fan apex discharge due to tributary inflows also should be considered. More recently, FEMA has considered flow attenuation on alluvial fans, provided that the modeling accounts for flow path uncertainty (future avulsive channel changes) and redirection of flow across the active fan surface.

i. Coordination between upstream and downstream property owners is required for the alignment and design discharge for through-flow corridors.

ii. Discharge estimates based on analysis of the capacity of the geomorphic flow corridor are useful for assessment of existing conditions, but may underestimate the potential discharge for whole-fan solutions connected to the fan apex.

iii. In distal portions of fan outside the active alluvial fan, a flow distribution analysis of some sort that accounts for flow attenuation

and loss may be appropriate for sizing some drainage facilities. However, engineers are cautioned that FEMA requirements may dictate use of the full apex discharge for structure design anywhere below the fan apex, and that District approval does not guarantee FEMA approval.

g. Impact Assessment Standards. The following criteria, if met, will be considered to adequately demonstrate no adverse impact to adjacent properties:
    i. Peak Discharge. An increase in peak discharge for the 2-, 10-, and 100-year flood will be considered an adverse impact.
    ii. Flow Volume. An increase in flow volume for the 2-, 10-, and 100-year flood will be considered an adverse impact. An increased discharge volume is acceptable if it is released into a stable channel at a rate below the threshold of transport. Channel stability will be determined by geomorphic field assessment and evaluation of the equilibrium slope relative to the existing slope. The threshold of transport will be determined by comparison of bed sediment size distributions with transport capacity estimated by an appropriate sediment transport function.
    iii. Decreased Flow. Reduction of flow into any non-jurisdictional (USACE 404 delineation) washes will not be considered an adverse impact.

Section 2: Floodplain Delineation. Floodplain delineations must be completed to District and FEMA standards. Floodplain delineations for alluvial fans must cover entire piedmont, from a point above the apex where no flow path uncertainty exists downstream to the piedmont axial stream or a flood control structure. In addition, the following criteria apply:

1. Active Alluvial Fans (Unstable Areas).
    a. Existing condition floodplain delineations will be based on the PFHAM Stage 3 Methodology (approximate methods).
    b. Developed condition hydraulic data may be based on any model that is on FEMA's list of acceptable hydraulic models.
2. Stable Areas within Alluvial Fan Landforms.
    a. Existing & Developed Conditions. Hydraulic data may be based on any model that is on FEMA's list of acceptable hydraulic models.
3. Non-Structural Solutions. Development outside alluvial fan flood hazard zones delineated by Stage III methodology requires no structural flood control measures, except those that would be required by standard (non-alluvial fan) drainage engineering.
4. For all delineations, lateral tie-in upstream and downstream to effective (approved) floodplain delineations is required by FEMA. Lateral tie-in to Stage III PFHAM delineations is required for CLOMR/LOMR delineations that reflect structural flood control measures.
5. Flow data for floodplain delineations will be obtained as described in Section 1.

Section 3. Sedimentation Engineering. The following guidelines for sedimentation engineering analyses will be applied to the Pinal County area:

1. Sediment Yield
    a. Above Apex. Sediment yield should be computed using appropriate regional methods, such as those outlined in the ADWR Engineering Analysis of Fluvial Systems Manual (1985).
    b. Below Apex. Sediment yield estimates for concentration points located downstream of the alluvial fan apexes should account for sediment storage on fan.
2. Sediment Deposition at Structures on Fan.
    a. Active Fan Areas: In active (unstable) portions of alluvial fans the methodology proposed by R.H. French[4] may be used. Other methods may be used, if approved in advance by District review staff.
3. Structure Maintenance & Operation Agreement.
    a. Public maintenance or underwriting of private maintenance by a public agency is a FEMA requirement for approval of structural measures on alluvial fans.
4. General Channelization Criteria.
    a. If channelizing runoff on the piedmont, the drainage system must collect and store any excess sediment before discharging to downstream property. Designs that pass sediment load greater than capacity of downstream channel (natural or constructed) are not acceptable. The intent of this criterion is to concentrate the natural sediment storage occurring on the fan area prior to being developed.
    b. FEMA and District levee standards apply if channels function like levee. Any channel with the 100-year WSEL above the natural ground elevation or where breach of the channel bank would cause a levee-like failure scenario, will be considered a levee.
    c. Bleed off pipes that divert water into the pre-development natural channel network are acceptable to Pinal County. Note that the USACE may have comments on bleed off pipes relative to 404 permitting, especially as it relates to maintenance and potential clogging.
    d. Containment within a channel is defined based on the following:
        i. Containing the 100-year WSEL (water elevation) plus sediment deposition during a 100-year event and between scheduled maintenance, plus any superelevation or momentum run-up. Flow containment criteria are dictated primarily by FEMA regulations.
        ii. Providing a seepage analysis showing that flow won't penetrate or seep through the channel bank/barrier during the design flood.
        iii. Providing freeboard, as defined in Pinal County Engineering Documents or acceptable alternative Hydraulics Manual (plus sediment deposited). Conceptually, one foot freeboard is acceptable

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[4] "Estimating the Depth of Deposition (Erosion) at Slope Transitions on Alluvial Fans," RH French, JJ Miller, and **S Curtis**, *Journal of Hydraulic Engineering*, Vol. 127, No. 9, September 2001, pp. 780-782.

unless the Pinal County Engineer requires otherwise, given that discharge and sediment estimates may be conservative. However, note that FEMA freeboard standards apply may dictate the level of design.

5. Collector Channels. Collector channels are typically located along the property perimeter, are oriented sub-perpendicular to slope, and collect and convey runoff to centralized drainage facilities.
    a. In Unstable Portion of Alluvial Fans. The following criteria apply to collector channels in active alluvial fan areas:
        i. The channel must convey the full apex water and sediment without overtopping.
        ii. FEMA requirements for collector channels apply and may dictate design criteria for the following:
            1. Freeboard
            2. Momentum run up
            3. Capacity considering potential sediment deposition
    b. In Stable Portions of Alluvial Fans.
        i. The channels must be able to convey full apex discharge without overtopping. See the hydrology criteria above for information relating to sites in distal portion of fan, where a reduced design discharge based on distributed flow analysis may be acceptable.
        ii. The channels are not required to convey the full apex sediment load, if it can be demonstrated by detailed sediment routing, geomorphic analysis, and hydraulic data that sediment is stored upstream of the interception point defined by the collector channel. The channel must convey the sediment supply derived from a routing model and transport capacity analysis of each of the individual defined channels intercepted by the collector channel.
6. Through-Flow Corridor Channels
    a. Scour. Scour in through-flow corridor channels will be estimated based on the following types of analysis, at minimum:
        i. Equilibrium slope. Equilibrium slope methods will be used to determine the need for and spacing of grade control structures, as described in Pinal County Engineering Manuals. Equilibrium slope analysis may be used to estimate long-term scour potential.
        ii. General scour. Scour estimates should include general, bend, and bed form scour elements. Detailed sediment continuity modeling using HEC-6 or other computer modeling is not required, but may be helpful for specific scenarios. Coordination with District review staff prior to initiating modeling is recommended.
        iii. Local scour. Local scour should be computed at structures such as bridges, culverts, grade control structures, contractions, weirs, bank protection and other constructed features.
        iv. Deposition. Potential for sediment deposition should be evaluated using detailed hydraulic data and application of consistent sediment transport functions.

b. Lateral Erosion. Channels should be designed to control lateral erosion. Lateral erosion protection should be sized and toed-down for the maximum channel velocity and channel invert.
c. Channel Type. Channels with levees or sub-grade channels may be used.

7. Detention Basins.
    a. Basins in Unstable Alluvial Fan Areas.
        i. Sediment Storage. Basins must provide capacity for sediment storage, which may be estimated from sediment yield data, for the following events:
            1. Design event (100-yr)
            2. For additional floods that reflect the proposed maintenance scheduling
            3. Trapping efficiency option (probably close to 100%)
            4. In general, sediment storage for the 100-year plus five average annual flood events will be required.
    b. Basins Downstream of Unstable Areas of Alluvial Fans.
        i. Sediment Storage. Basin sediment storage may be estimated based on application of a sediment transport function to the upstream (supply) channels, in a manner similar to the collector channel described above.
8. Offsite Impact Assessment. The general goals of the offsite impact assessment include the following:
    a. Scour downstream of structures should not occur offsite (outside property limits), but may occur if it can be shown that scour will be contained within site boundaries.
    b. Channelization should not push fan processes downstream by conveying all apex sediment to downstream limit of site, nor should it push the fan apex upstream by creating backwater deposition.
    c. Grade control is unlikely to control downstream scour if scour is the result of a sediment deficit created by upstream improvements.
    d. If the peak discharge, flow volume, flow velocities and the bankfull sediment delivery rate are unchanged on off-site properties, it may be assumed that no adverse impacts occur.
    e. Impacts at culverts located at property lines must be addressed.
    f. For the purposes of assessing impacts, it may be assumed that sediment equilibrium conditions exist in the reach immediately upstream of the alluvial fan hydrologic apex.

5.9. References

Arizona Department of Water Resources, State Standards for Floodplain Management

SS1-97, Requirement for Flood Study Technical Documentation
Sets technical documentation standards for Flood Studies that are to be submitted to ADWR or FEMA.

SS2-96, Requirement for Floodplain and Floodway Delineation in Riverine Environments
Provides methodologies for estimating 100-year peak discharges, delineating 100-year floodplain limits, and determining administrative floodway boundaries for watercourse thalwegs in Arizona.

SS3-94, State Standard for Supercritical Flow (Floodway Modeling)
Provides guidelines to be used when modeling floodways for supercritical or near-critical flow conditions in Arizona.

SS4-95 State Standard for Identification of and Development within Sheet Flow Areas
Details minimum floodplain management standards for identification of and development within sheet flooding areas in Arizona.

SS5-96 State Standard for Watercourse System Sediment Balance
Provides guidelines for identification of and development within erosion hazard areas, watercourses with a net sediment deficit, and watercourses with a net sediment surplus. Individual guidelines for: Lateral Migration Setback Allowance, Channel Degradation Estimation, and River Stability Impacts associated with Sand and Gravel Mining.

SS6-05 State Standard for Development of Individual Residential Lots within Floodprone Areas
Site Plan Checklist, Typical Plan and Cross-Section requirements for Individual residential lots within flood prone areas.

SS7-98 State Standard for Watercourse Bank Stabilization
Provides minimum design standards for several bank stabilization techniques.

SS8-99 State Standard for Storm water detention/retention
Provides minimum criteria for sizing Detention and/or Retention facilities.

SS9-02 State Standard for Floodplain Hydraulic Modeling
Provides guidance on mathematical modeling of hydraulic processes in watercourses and floodplains.

SS10-07 State Standard for Hydrologic Modeling Guidelines
Provided guidance on the unique modeling conditions encountered in Arizona.

Arizona Revised Statutes, Title 11

Arizona Revised Statues, Title 48

City of Apache Junction Engineering Guidelines, Adopted August 1, 1995 (Resolution No. 95-19 and Ordinance No. 932)

City of Casa Grande Flood Damage Prevention Code 15.40.1240 (.12550)

City of Coolidge Subdivision Regulations

City of Florence Code, Chapter 4, Article V, Sec. 4-116 adopted County Floodplain Management Ordinance No. 815582

Pima County Ordinance No, 1988-Fc2, Article XII Erosion Hazard Areas and Building Setback Requirements, Article XIV Detention/Retention Systems, Article X Watercourse and Riparian Habitat Protection and Mitigation Requirements, Article XIII Subdivision and Development Requirements

City of Mesa Desert Uplands Guidelines

Pinal County Drainage Ordinance, November 7, 1998

Pinal County Floodplain Management Ordinance No. 81582, 1988

FCDMC, 2002, Draft Riverine Erosion Hazard Delineation and Development Guidelines

FCDMC, 2003, Drainage Design Manual, Volume I, Hydrology, draft dated January 9, 2003.

FCDMC, 1995, Drainage Design Manual, Volume I, Hydrology, revised January 1, 1995.

FCDMC, 1996, Drainage Design Manual, Volume II, Hydraulics

FCDMC, 1986, Floodplain Regulations for Maricopa County, as revised 2006

FCDMC, 1988, The Drainage Regulation for Maricopa County, as revised 2004

FCDMC, 2003, Piedmont Flood Hazard Assessment for Floodplain Management for Maricopa County, Arizona User's Manual.

FEMA, 1999, Riverine Erosion Hazard Area Mapping Feasibility Study.

FEMA, 2003, Guidelines and Specfications for Flood Hazard Mapping Partners.