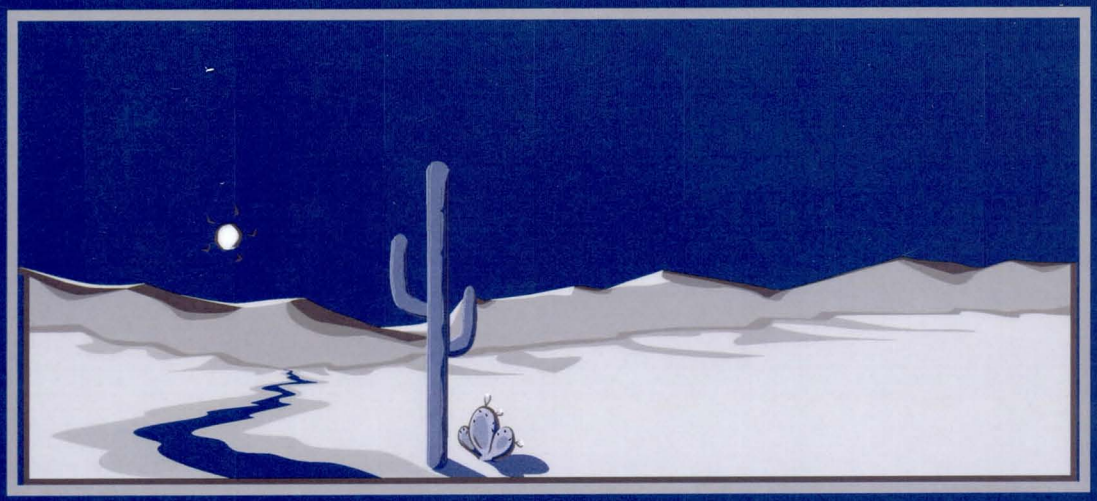
UPPER CAVE CREEK/APACHE WASH



Watercourse Master Plan

Technical Summary

Flood Control District

A690.209

April 2001

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List of Attachments

Attachment 1 - Data Collection Report
Attachment 2 - Survey and Mapping Report
Attachment 3 - Hydrology Report
Attachment 4 - Hydraulics and Sediment Report
Attachment 5 - Lateral Stability Assessment Report
Attachment 6 - Biological Analysis Report, Upper Cave Creek
Attachment 7 - Cultural Resources Inventory Report
Attachment 8 - Alternatives Analysis Report

1 Introduction

The Flood Control District of Maricopa County (District) teamed with the City of Phoenix to develop a ***Watercourse*** Master Plan for Upper Cave Creek and several of its main tributaries. A ***watercourse*** master plan is a comprehensive flood management plan based on hydrologic and hydraulic analyses, lateral migration potential, future land use development, and environmental considerations. Historically, floodplain management within the City of Phoenix and Maricopa County has not considered bank ***erosion***, the potential long-term lateral movement of a ***watercourse*** over time, or future growth patterns within a watershed. The State of Arizona recently established Arizona Revised Statute 48-3609.01 that enables local flood control agencies to identify sensitive ***watercourses*** for inclusive floodplain management through a process of ***watercourse*** master planning.

Upper Cave Creek

The study area, shown on Figure 1, includes Cave Creek from Cave Buttes Dam, which is located near the intersection of Jomax Road and Cave Creek Road, to the Carefree Highway, a length of approximately six miles. Cave Buttes Dam provides flood protection for the Phoenix metropolitan area and effectively divides Cave Creek. The portion of Cave Creek upstream of Cave Buttes Dam is referred to as Upper Cave Creek. The study area initially included Upper Cave Creek from the Carefree Highway north to the Tonto National Forest boundary. That ***reach*** of Upper Cave Creek was removed at the request of the Town of Cave Creek after the first public meeting. At the same time, the lower portions of Paradise Wash, Apache Wash, and Desert Hills Wash, located south of the Carefree Highway and within the city limits of Phoenix were added to the study area. Each of these desert ***watercourses*** have significant desert riparian vegetation, and the potential exists for bank ***erosion*** and lateral migration of their ***channel*** banks to occur over time, particularly if vegetation along the banks is removed or disturbed by natural or human activities. The study area is generally defined as a 500-foot perimeter beyond the known 100-year floodplain of these ***watercourses***, as determined by the Federal Emergency Management Agency (FEMA).

This report describes the master plan purpose and goals, the ***watercourse*** characteristics, and the ***watercourse*** management plan alternatives and recommendations. Many terms used in this report have definitions specific to the purpose of this study. There are also technical terms used that require definition. These terms are italicized, and defined in the glossary.

2 Master Plan Purpose and Goals

Much of the relatively undeveloped lands located within the study area has not been identified for preservation, and therefore faces development pressure in the near future. In recent years, there has been increasing controversy surrounding the future of desert ***watercourses*** such as Upper Cave Creek. This controversy centers on the continuance of traditional

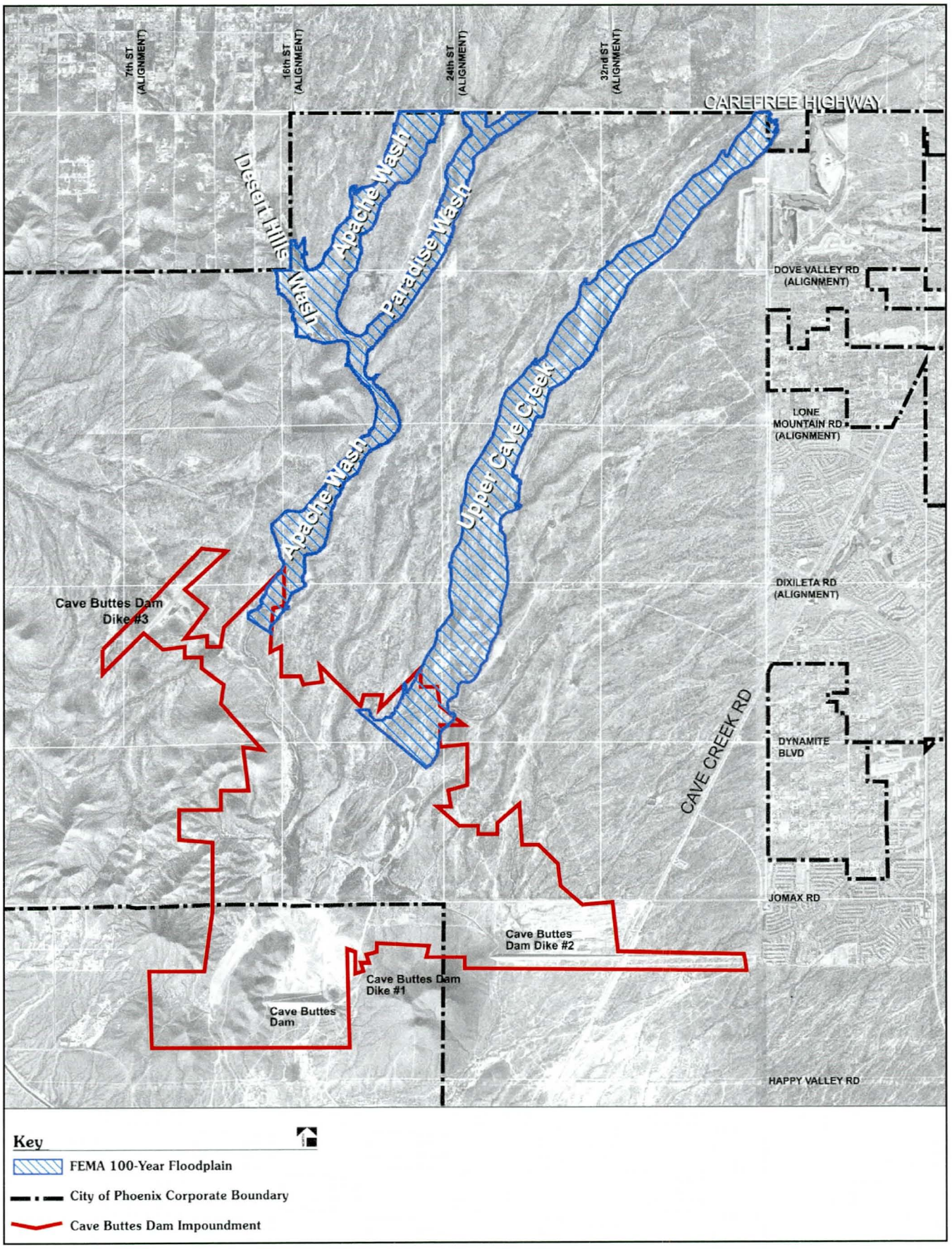


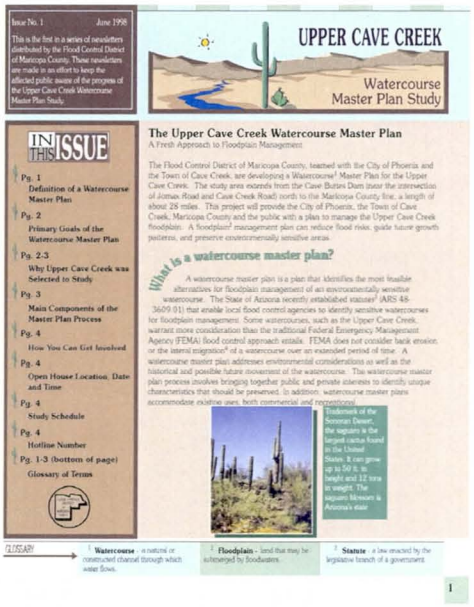
Figure 1. Study Area

development practices and trends versus an increasing support for maintaining open-space corridors. Traditionally, as development takes place, bank stabilization, levees, and basins have been constructed to control flooding. These structural alternatives are costly, destroy natural ***watercourse*** corridors, and create negative impacts upstream and downstream. Because public safety and welfare are affected, these negative impacts are usually addressed using public funds. Opportunities for implementation of a long-term floodplain management plan diminish as development increases.

The purpose of the Upper Cave Creek and Apache Wash Watercourse Master Plan (WCMP) is to examine the benefits, opportunities, and weaknesses of various flood control solutions, including structural, soft-structural, and nonstructural measures, and to recommend a management plan. This includes examining the ***watercourses*** as components of the overall watershed system. The primary goals of the WCMP are:

- **Protect existing and future residents from the 100-year flood event and damages associated with potential lateral migration of the *watercourse*.**
- **Consider structural and nonstructural alternatives.**
- **Reduce public funds spent on flood control and emergency management.**
- **Consider sensitive habitats and cultural resources in the evaluation of alternatives.**
- **Consider multiple-use activities for floodplain areas.**
- **Consider landscape aesthetics and desired landscape character of floodplain area.**

3 Public Involvement Program


Issue No. 1 June 1998

This is the first in a series of newsletters distributed by the Flood Control District of Maricopa County. These newsletters are made in an effort to keep the affected public aware of the progress of the Upper Cave Creek Watercourse Master Plan Study.

UPPER CAVE CREEK
Watercourse Master Plan Study

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Pg. 2 Primary Goals of the Watercourse Master Plan
Pg. 2-3 Why Upper Cave Creek was Selected to Study
Pg. 3 Main Components of the Master Plan Process
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Pg. 1-3 (bottom of page) Glossary of Terms

The Upper Cave Creek Watercourse Master Plan
A Fresh Approach to Floodplain Management

The Flood Control District of Maricopa County, teathed with the City of Phoenix and the Town of Cave Creek, are developing a Watercourse[1] Master Plan for the Upper Cave Creek. The study area extends from the Cave Buttes Dam (near the intersection of Jomax Road and Cave Creek Road) north to the Maricopa County line, a length of about 28 miles. This project will provide the City of Phoenix, the Town of Cave Creek, Maricopa County and the public with a plan to manage the Upper Cave Creek floodplain. A floodplain[2] management plan can reduce flood risks, guide future growth patterns, and preserve environmentally sensitive areas.

What is a watercourse master plan?

A watercourse master plan is a plan that identifies the most feasible alternatives for floodplain management of an environmentally sensitive watercourse. The State of Arizona recently established statutes[3] (ARS 48-3609.01) that enable local flood control agencies to identify sensitive watercourses for floodplain management. Some watercourses, such as the Upper Cave Creek, warrant more consideration than the traditional Federal Emergency Management Agency (FEMA) flood control approach entails. FEMA does not consider bank erosion, or the lateral migration[1] of a watercourse over an extended period of time. A watercourse master plan addresses environmental considerations as well as the historical and possible future movement of the watercourse. The watercourse master plan process involves bringing together public and private interests to identify unique characteristics that should be preserved. In addition, watercourse master plans accommodate existing uses, both commercial and recreational.

Trademark of the Sonoran Desert, the saguaro is the largest cactus found in the United States. It can grow up to 50 ft. in height and 12 tons in weight. The saguaro blossom is Arizona's state

GLOSSARY
[1] **Watercourse** - a natural or constructed channel through which water flows.
[2] **Floodplain** - land that may be inundated by floodwaters.
[3] **Statute** - a law enacted by the legislative branch of a government.

1

June 1998 Newsletter

Throughout the study process, public involvement was an integral component of the WCMP, and included agency partnering, public meetings, newsletters, a web site, and presentations at various community meetings. A partnering workshop was held in June 1998 with the State and local agencies to clearly define lines of communication and the needs and expectations of each stakeholder. As part of the initial phase of the study, a public involvement plan was developed to outline the goals of the public involvement program, describe the types and formats of public meetings and presentations, and identify the various out ***reach*** techniques and methods. In addition, a web site was developed to provide information about the study to the public.

An initial newsletter was developed in June 1998 and distributed to property owners within the study area as well as to the affected agencies. This initial newsletter introduced the study, defined a ***watercourse*** master plan, and announced the first public workshop, held on June 25, 1998 at the Desert Sun Elementary School in Cave Creek. At the meeting, which was advertised in the Foothills Sentinel, Sonoran News, and the Arizona Republic newspapers, the District and

June 25, 1998 Public Workshop

the consulting team members made a brief slide presentation. After the presentation, the participants broke into smaller working groups, which later reconvened to share their major concerns and issues. The majority of the questions/comments from the public centered on private property/development issues and what effect the master plan would have on development. The comments centered on the study area north of the Carefree Highway and were not supportive of the ***watercourse*** master plan concept. The Town of Cave Creek requested that the study area within the Town of Cave Creek be removed from the project shortly after that meeting. The District agreed to change the study limits, and added in Apache Wash, Paradise Wash and Desert Hills Wash, as described previously.

A second newsletter was prepared and distributed after the exclusion of the area north of Carefree Highway from the study area and the addition of Apache Wash, Paradise Wash, and Desert Hills Wash. Information in the September 1999 newsletter included a description of the change in the study area limits and summarized the technical, environmental, and land use considerations. A public workshop was held on December 9, 1999. The District and consulting team members made a brief presentation on the proposed flood management alternatives under consideration. The participants expressed a general interest in finding out about the study, and related their support for the ***watercourse*** master plan and the preservation of the drainages and their associated vegetation.

December 9, 1999 Public Workshop

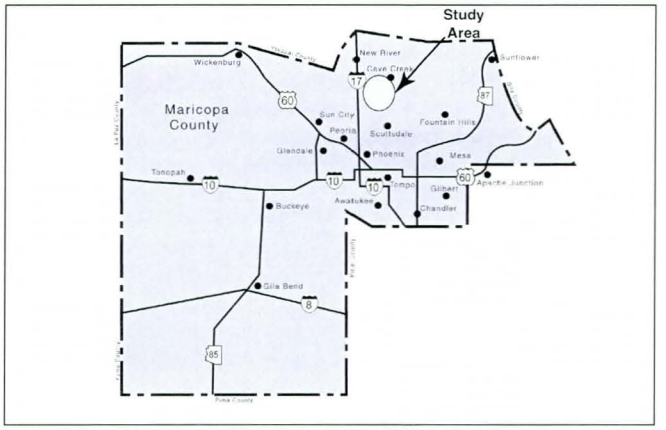
In addition to the public meetings, the District and consulting team members have made formal presentations to the Cave Creek Town Council, City of Phoenix City Council Desert Preserves and Open Spaces Subcommittee, Desert View Village Planning Committee, City of Phoenix Planning and Zoning Commission, and the City of Phoenix Parks and Recreation Board. These presentations were made at major milestones throughout the study process.

4 Watercourse General Characteristics

A. Study Context

The study area is located within the Phoenix city limits, in the northern portion of Maricopa County. The region immediately surrounding the study area is commonly known as the Desert Foothills of the New River Mountains. The perimeter of the study area overlaps lands within unincorporated Maricopa County and the Town of Cave Creek. The small rural community of Desert Hills is located to the west of the study area, with Dove Valley Ranch and Tatum Ranch residential communities lying to the east. Lands within the study area are primarily owned by the Arizona State Land Department and

are generally undeveloped, except for the sand and gravel mines. Elevations within the ***watercourse*** range from approximately 1,800 feet above mean sea level at Carefree Highway to 1,620 feet above mean sea level at Cave Buttes Dam. Minor elevation differences within the study area provide panoramic views of distant vistas, adjacent landforms, undeveloped desert areas, and urban development. The desert ***watercourses*** within the study area are generally undisturbed, with the desert riparian vegetation adjacent to the ***watercourse channel*** intact, except where sand and gravel mining has been conducted.



Study Area Vicinity

B. Regional and Local Planning Strategies

In 1987, the study area was part of the City of Phoenix's adopted General Plan for Peripheral Areas C and D. The General Plan for Peripheral Areas C and D provided recommendations regarding land use and development characteristics for build-out of the planning area. The Phoenix City Council approved the 1993 Desert Preserve Preliminary Plan recommending 11,000 acres of primary and secondary ***watercourses***, scenic corridors, and utility corridors be preserved in the northern growth area of the city. The 1994 North Land Use Plan was prepared in response to development pressures within the Peripheral Areas C and D. Strategies identified in the North Land Use Plan, related to the preservation of Upper Cave Creek, recognized the importance of ***watercourses*** in determining appropriate land use densities, and recommended lower density development (0 to 1.2 units per acre) to minimize the impact of floodwaters on adjacent properties. The Desert View Village Planning Committee, whose planning area includes the study area, and the Phoenix City Council approved the recommendation put forth in the 1994 North Land Use Plan as an amendment to the General Plan.

Desert Riparian Vegetation

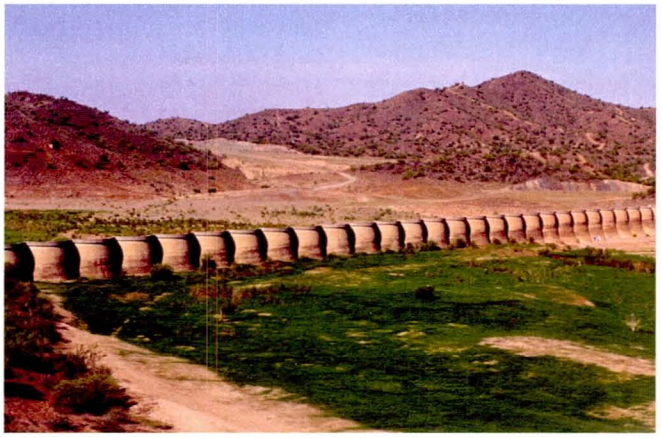
The Maricopa Association of Governments (MAG) Regional Council adopted the Desert Spaces plan for the 9,200 square mile region of Maricopa County in 1995. The intent of this plan was to provide a nonregulatory framework directed toward establishing a regional open-space network by defining regionally significant mountains, rivers, ***watercourses***, and upland desert. The Desert Spaces plan identified Upper Cave Creek and the Union Hills as having outstanding open-space values. Utilizing the 1993 Desert Preserve Preliminary Plan and the 1995 Desert Spaces plan, the Sonoran Preserve Master Plan was approved by the Phoenix City Council in 1998. The stated goals of the plan were not only to preserve significant portions of the Sonoran desert, but also to preserve the natural hydrologic processes. These goals can be accomplished by preserving the ***FEMA 100-year floodplain***[1] and ***floodway***, and buffers wide enough to allow for the natural meandering of the ***watercourse*** over time. Significant portions of Upper Cave Creek, Apache Wash, and Paradise Wash within the study area are recommended for preservation under the Sonoran Preserve Master Plan. The residents of the City of Phoenix voted in May of 2000 to pursue acquisition of lands held by the Arizona State Land Department that were identified in the 1998 Sonoran Preserve Master Plan.

[1]*Words in italics are defined in the Glossary.*

C. Watercourse Characteristics

Cave Creek is a large ***ephemeral watercourse*** that originates in the New River Mountains that extend north to the Black Hills. The elevation of the ***watercourse*** ranges from 4,400 feet at its origin to 1,620 feet at Cave Buttes Dam. Just south of the Maricopa/Yavapai County line, the ***watercourse*** forms a narrow ***channel*** that dissects the New River Mountains. Flowing onto the lower lying ***bajada*** of Paradise Valley, Upper Cave Creek cuts a wider swath through ancient valley fill. In the study area, Cave Creek and its tributaries flow between banks of varying erodibility. Near the ***watercourse***'s southern limit, gravelly loams have been deposited over a broader area. Downstream of Cave Buttes Dam, Cave Creek historically connected with the Salt River through downtown Phoenix.

Currently, Cave Creek Dam and Cave Buttes Dam impound flood flows. Cave Creek Dam was built in 1923, and is a reinforced concrete barrel arch structure. In 1979, the US Army Corps of Engineers built the earthen Cave Buttes Dam just downstream of Cave Creek Dam to replace Cave Creek Dam. A ***channel*** was excavated around the west abutment of Cave Creek Dam to allow equalization of the flood pools. The older Cave Creek Dam no longer provides flood protection, but was preserved because of its historic significance. The presence of Cave Creek Dam has an impact on flood inundation of potential recreation areas upstream of Cave Buttes Dam.



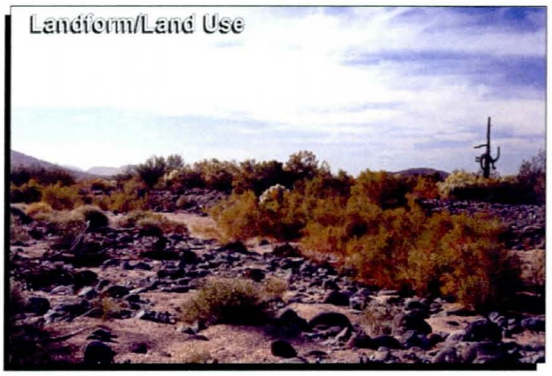
Cave Creek Dam

Apache Wash is a main western tributary of Upper Cave Creek, with its headwaters lying just east of Apache Peak. Apache Wash merges with Upper Cave Creek immediately upstream from Cave Creek Dam. Paradise Wash and Desert Hills Wash are two smaller ***watercourses*** that enter Apache Wash from the north and west, respectively. Desert Hills Wash is the longer of the two tributaries, originating along the southwestern slope of an unnamed butte located southwest of Apache Peak. Paradise Wash begins along the southern slopes of the Cave Creek Recreation Area, and flows into Apache Wash approximately 1,000 feet downstream from the confluence of Apache Wash and Desert Hills Wash.

As part of the study process, Upper Cave Creek, Apache, Desert Hills, and Paradise Washes were categorized into segments with similar characteristics, called reaches. These reaches were defined based on landscape character, including vegetation, landforms, land use, and special features, and the geomorphologic and hydraulic considerations of each ***watercourse***. Figures 2 through 7 illustrate the unique characteristics of the reaches. The floodplain management alternatives developed for the WCMP were based on the analyses of these reaches. The characteristics of each ***reach*** are idenified in Tables 1 and 2.

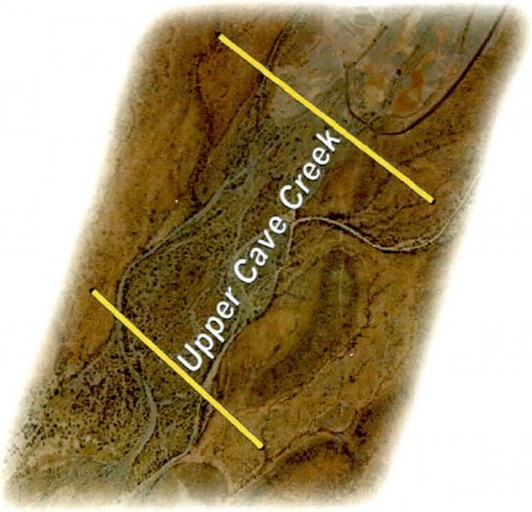
5 Watercourse Technical Characteristics

Detailed technical analyses were performed as a basis for development of the ***watercourse*** master plan. Existing watershed and ***watercourse conditions*** were compared with anticipated future ***watershed*** and ***watercourse conditions*** for the purpose of planning, not just build-out in the watershed, but for the transition between existing and future conditions.



- Braided or multiple channels create low, rolling landforms.
- Channel bottom varies from sandy to cobble surface cover.
- Land use is undeveloped with cattle grazing permitted and unauthorized recreation use.

- Relatively uniform vegetation cover between braided channels.
- Mesquite trees, desert broom, and burrobush are common.



- Braided channels

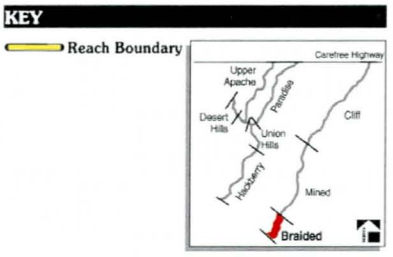
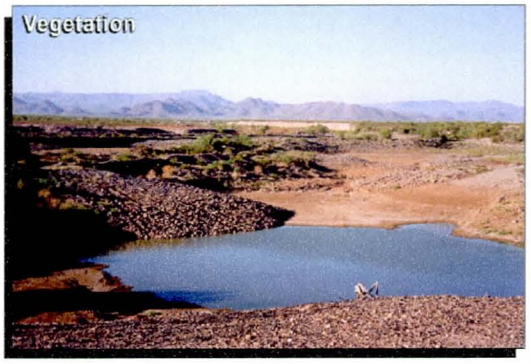
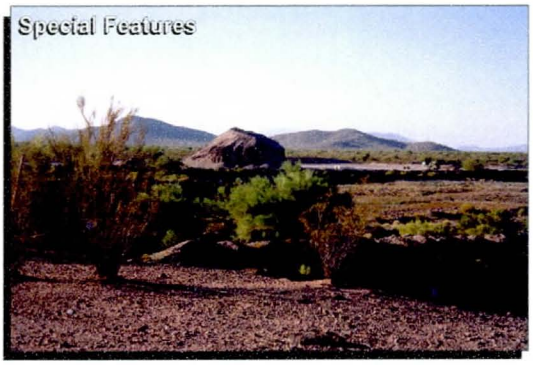


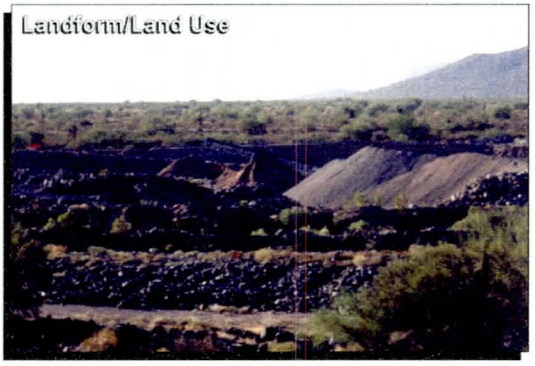
Figure 2. Braided Reach Landscape Character



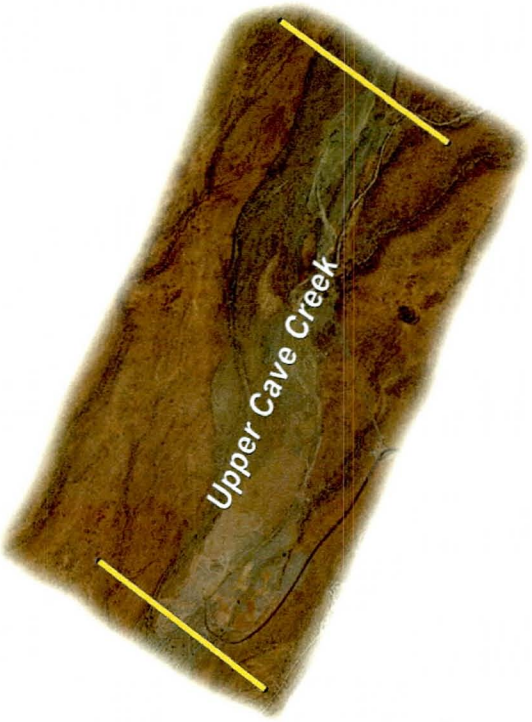
- Sparse vegetation with minimal ground cover.
- Indigenous vegetation (primarily shrubs such as desert broom) has regenerated in some areas.



- Artificial landforms and small ponds are present.
- Mining equipment and facilities are visible.



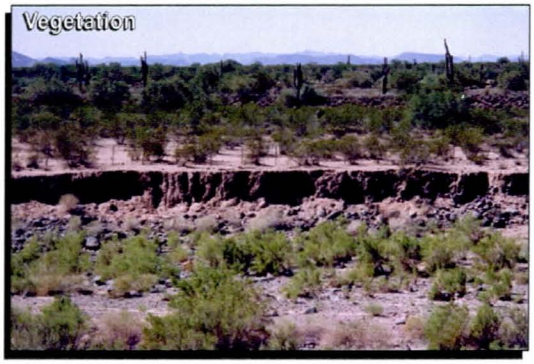
- Creek channel and character modified substantially by mining operations.
- Artificial landforms are prominent and contrast with flat terrain adjacent to watercourse.
- Current land use is sand and gravel mining operation.



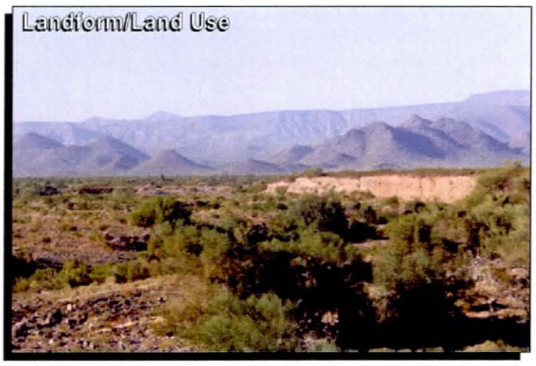
KEY

Reach Boundary

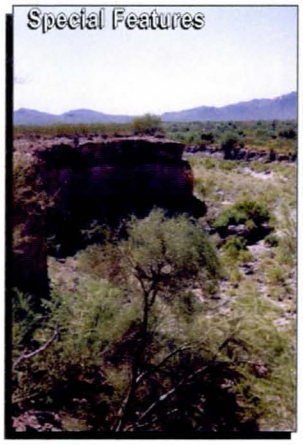
Figure 3. Mined Reach Landscape Character



- Mesquite, palo verde, and acacia trees are common.
- Vegetation is relatively sparse/open.
- Light-colored soil of cliff's face contrasts with vegetation color.



- Vertical cliffs create distinct landform.
- Cliffs contrast with flat terrain adjacent to watercourse.
- Width of creek channel varies.
- Channel bottom generally sandy with occcasional cobble surface cover.
- Land use is primarily undeveloped with evidence of unauthorized recreation uses.



- Cliff face is a prominent visual feature and defines east edge of Cave Creek.
- Landfill, overhead transmission lines and towers, and Carefree Highway bridge structure are visible.
- Cliffs provide opportunity to view surrounding landscape and distant mountain ranges.

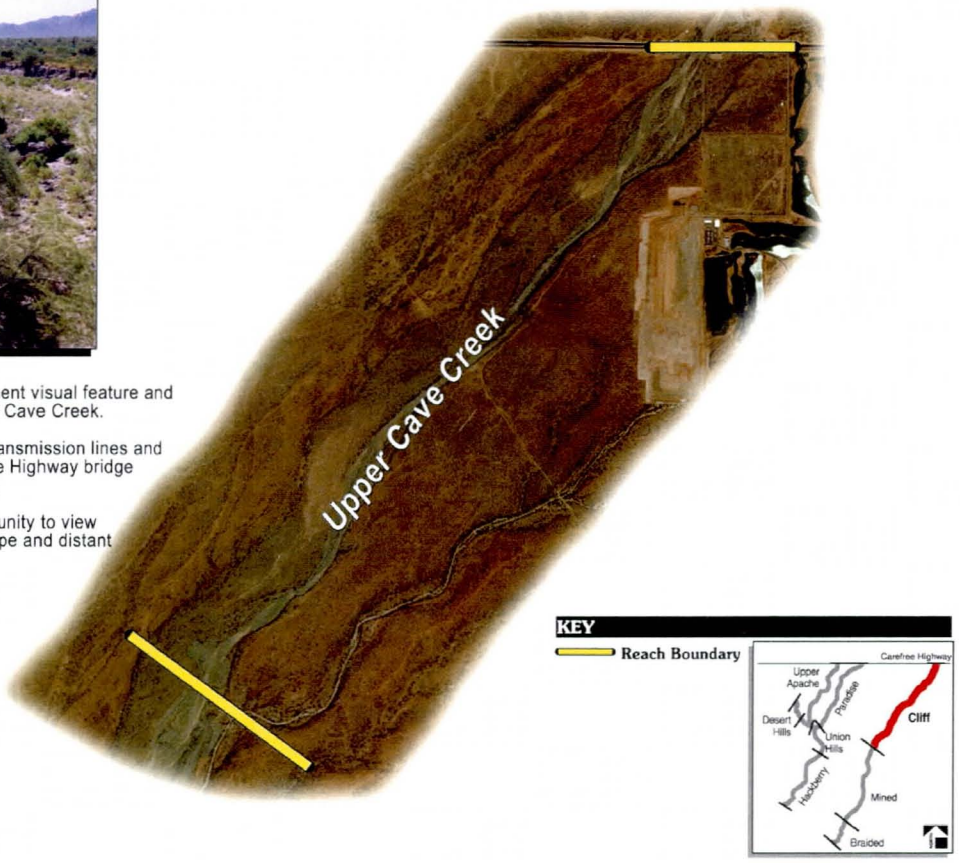
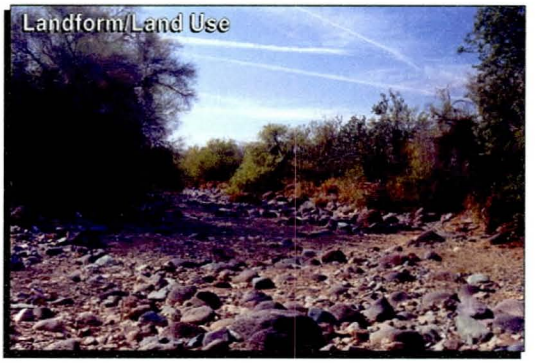
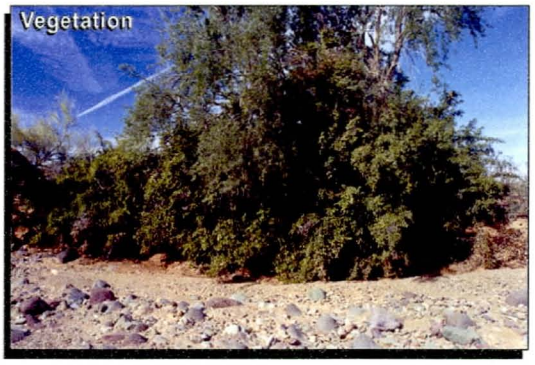


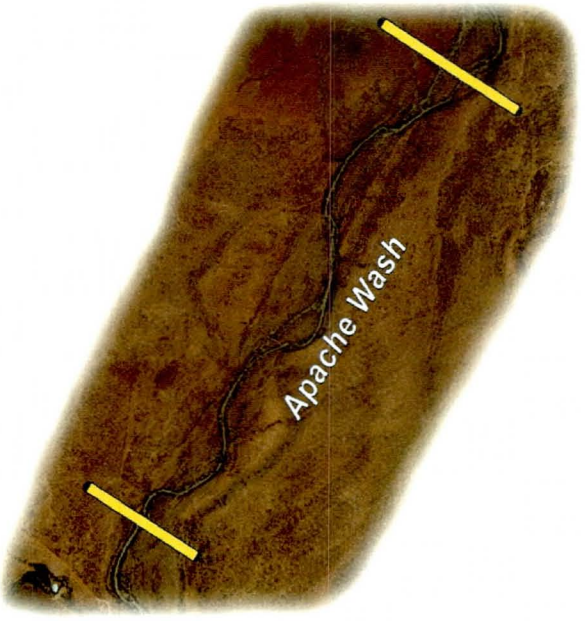
Figure 4. Cliff Reach Landscape Character



- Channel width varies and bottom surface cover is predominantly cobble.
- Wash channel has relatively low bank heights.
- Land use is undeveloped, with cattle grazing permitted and unauthorized recreation use.



- Vegetation includes mesquite, desert hackberry, and acacia trees.
- Wash vegetation contrasts with the upland desert scrub in terms of density, color, and texture.



- Breaks in wash vegetation provide opportunity to view adjacent landforms.
- Dense vegetation lining wash creates a distinct pattern in the landscape, marking the location of the watercourse.

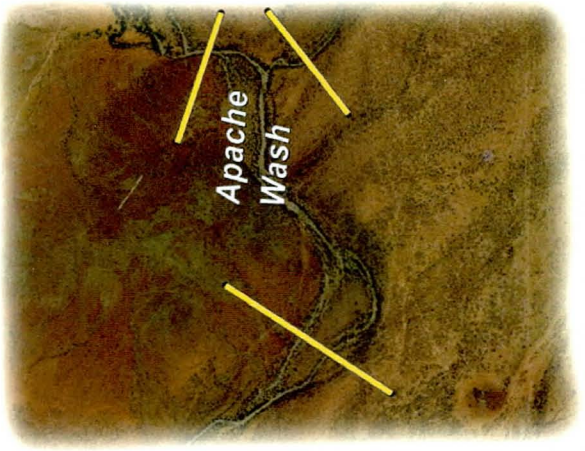
KEY

Reach Boundary

Figure 5. Hackberry Reach Landscape Character

- Union Hills and watercourse are distinct landforms.
- Channel width varies and bottom cover includes sandy and cobble surfaces.
- Land use is undeveloped with cattle grazing permitted and unauthorized recreation use.
- Channel banks vary in height.

- Vegetation includes mesquite, palo verde, desert hackberry, and acacia trees.
- Vegetation on hillside blends with wash vegetation.



- Exposed rock outcroppings add visual interest to watercourse.
- Union Hills form channel edge.

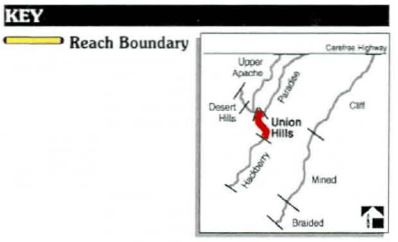
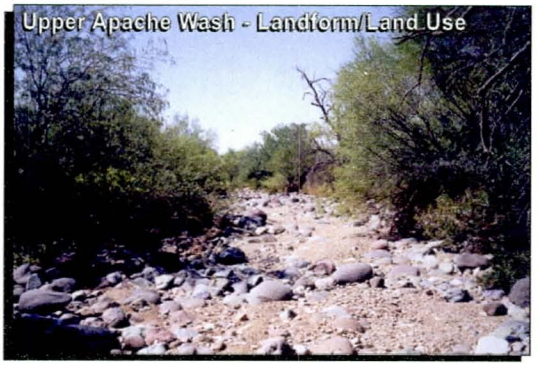


Figure 6. Union Hills Reach Landscape Character

- Dense vegetation of mesquite and acacia trees line wash banks.
- Wash vegetation contrasts with the upland desert scrub vegetation in terms of density, color, and texture.



- Wash channels have relatively low bank heights.
- Channel bottoms vary from sandy to cobble surface cover.
- Channel width relatively narrow.
- Land use is undeveloped with cattle grazing permitted and unauthorized recreation.

- Dense vegetation lining washes create distinct patterns in the landscape marking the location of the watercourses.
- Vegetation spatially encloses and limits views to the wash channel.

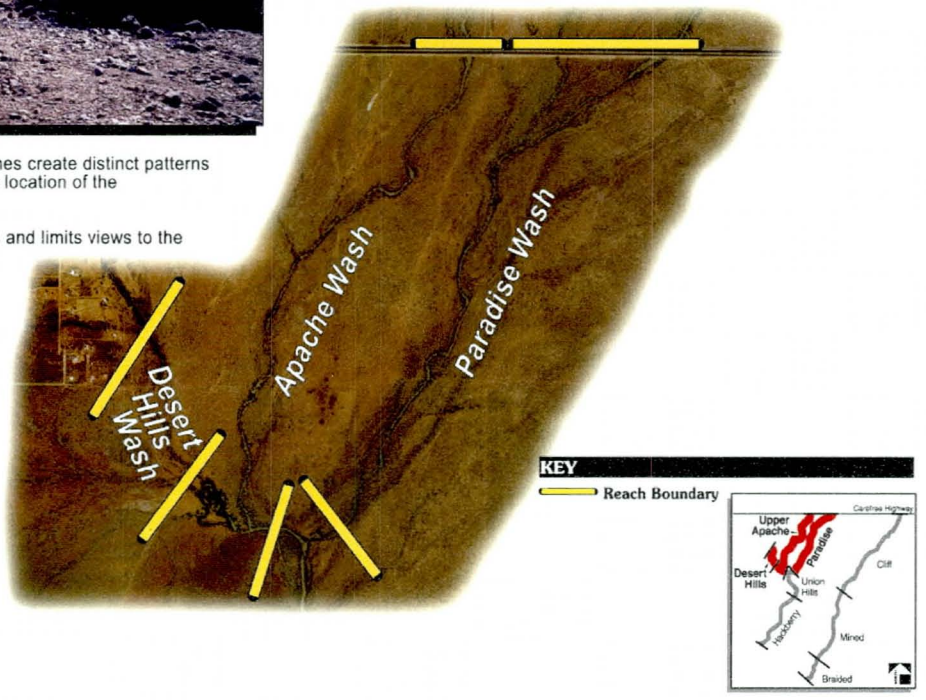


Figure 7. Upper Apache Reach, Paradise Reach, and Desert Hills Reach Landscape Character

Table 1 Upper Cave Creek Reach Descriptions					
Reach	**Vegetation**	**Landform**	**Land Use**	**Special Features**	**Hydraulic/Geomorphologic**
Cave Creek – Cliff Reach	Mesquite, palo verde, and acacia trees are common. Vegetation is relatively sparse/open. Light-colored soils of cliffs face contrasts with vegetation color.	Vertical cliffs create distinct landform. Cliffs contrast with flat terrain adjacent to watercourse. Width of creek channel varies. Channel bed generally sand and gravel, with occasional cobble/boulder surface cover.	Land use is primarily undeveloped, with evidence of unauthorized recreation uses, such as off-road vehicles and target shooting.	Cliff face is a prominent visual feature that defines the east edge of Cave Creek. Landfill, overhead transmission lines and towers, and Carefree highway bridge structure are visible. Cliffs provide opportunity to view surrounding landscape and distant mountain ranges.	Wide, braided, well-defined main channel is covered by gravels and boulders. High, infrequently flooded floodplain used for irrigated agriculture by Hohokam people. Floods have high velocities and moderate to high depths. Channel has degraded up to 10 feet in past.
Cave Creek – Mined Reach	Sparse vegetation, with minimal ground cover. Indigenous vegetation, primarily shrubs such as desert broom, has regenerated in some areas.	Creek channel and character modified substantially by mining operations. Artificial landforms are prominent and contrast with flat terrain adjacent to watercourse.	Current land use is sand and gravel mining operation.	Artificial landforms and small ponds are present. Mining equipment and facilities are visible.	Past in-channel mining operations have deepened and diverted channels, increasing main channel capacity and potential for long-term scour. Channel degraded due to historical in-channel mining.
Cave Creek – Braided Reach	Relatively uniform vegetation cover between braided channels. Mesquite trees, desert broom, and burrobush are common.	Braided or multiple channels create low, rolling landforms. Channel bottom varies from sandy to cobble surface cover.	Land use is undeveloped, with cattle grazing permitted and unauthorized recreation uses, such as off-road vehicles and target shooting.	Poorly defined natural drainage corridors.	Braided, multiple channels with sand and gravel bed materials. Low-flow channels shift frequently within floodplain. Low, frequently flooded floodplain, with minimal evidence of historical degradation.

Table 2 Apache Wash/Desert Hills Wash/Paradise Wash reach descriptions					
Reach	**Vegetation**	**Landform**	**Land Use**	**Special Features**	**Hydraulic/Geomorphologic**
Desert Hills Wash, Upper Apache Wash, and Paradise Wash Reach	Dense vegetation of mesquite and acacia trees line watercourse banks. Watercourse vegetation contrasts with the upland desertscrub Vegetation, in terms of density, color, and texture.	Watercourse channels have relatively low bank heights. Channel bottoms vary from sandy to cobble surface cover. Channel width is relatively narrow.	Land use is undeveloped, with cattle grazing permitted and unauthorized recreation uses, such as off-road vehicles and target shooting.	Dense vegetation lining watercourses create distinct patterns in the landscape, marking the location of the watercourses. Vegetation spatially encloses and limits views to the watercourse channel.	Single channel with alternating boulder riffles and gravelly pool areas. Channel confined within well-defined, inset watercourse corridor. High, erosive flood velocities and depths.
Apache Wash – Union Hills Reach	Vegetation includes mesquite, palo verde, desert hackberry, and acacia trees. Vegetation on hillside blends with watercourse vegetation.	Union Hills and watercourse are distinct landforms. Channel width varies and bottom cover includes sandy and cobble surfaces. Channel banks vary in height.	Land use is undeveloped, with cattle grazing permitted and Unauthorized recreation uses, such as off-road vehicles and target shooting.	Exposed rock outcroppings add visual interest to watercourse. Union Hills form channel edge.	Bedrock from nearby Union Hills limits erosion. Main channel has alternating sandy and boulder reaches, and a wide shallow cross section. Low floodplain with small over-bank flow paths.
Apache Wash – Hackberry Reach	Vegetation includes mesquite, desert hackberry, and acacia trees. Watercourse vegetation contrasts with the upland desertscrub in terms of density, color, and texture.	Channel width varies, and bottom surface cover is predominantly cobble. Watercourse channel has relatively low bank heights.	Land use is undeveloped, with cattle grazing permitted and Unauthorized recreation uses, such as off-road vehicles and target shooting.	Breaks in watercourse vegetation provide opportunity to view adjacent landforms. Dense vegetation lining watercourse creates a distinct pattern in the landscape, marking the location of the watercourse.	Single, main channel, with sand and gravel bed material. Dense bank vegetation minimizes direct erosion of banks. Low floodplain, with small overflow channels from both frequent and rare flooding.

The technical analyses performed are based on key assumptions regarding the management of the watershed. Successful implementation of the WCMP is therefore contingent watershed management to maintain the validity of the key assumptions.

The District plans to coordinate with communities in the WCMP study area to implement the appropriate watershed planning components. This is done as a part of the District's Area Drainage Master Study (ADMS) and Area Drainage Master Plan (ADMP) processes. ADMP's are planned for the Upper Cave Creek and Apache Wash watersheds to address watershed issues. The key assumptions made for this study regarding management of the watershed are that land managers will:

- **Implement the City of Phoenix and Maricopa County's 100-year, 2-hour retention ordinance requirement for zoning classifications with densities greater than 1 unit per acre.**
- **Preserve the natural *watercourse* system wherever possible. An ADMP for the watershed should quantify the *watercourses* to be preserved. If channelization or *floodplain encroachment* becomes necessary, travel times through the watershed should match existing natural conditions as closely as possible.**
- **Sediment loads in the natural *watercourse* system should not increase or decrease significantly as a result of development or other human disturbances in the watershed. Where significant changes may result, appropriate mitigation measures must be implemented to maintain long-term *watercourse* stability.**
- **Maintain peak discharges for the 2-year, 10-year and *100-year storms* at or below the *future watershed con dition* levels estimated in the WCMP. Maintain the release of future condition runoff volumes to the water courses from all three storms as close as possible to the WCMP estimated *future watershed condition* runoff volumes. This approach is necessary to help meet the goal of minimizing changes to *sediment yield*, and to support natural riparian vegetation along the *watercourses*.**
- **Implement the MAG 1995 General Land Use Plan for the watershed.**

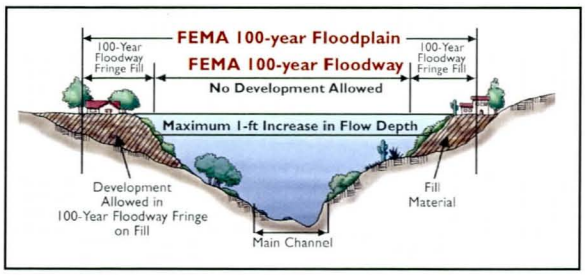


Figure 8. Typical Section of FEMA Regulatory Criteria

The plan considers the natural processes of ***erosion***, ***sedimentation*** and ***channel*** migration. ***Erosion***, ***sedimentation***, and ***channel*** migration are major safety concerns that current FEMA regulations, as illustrated in Figure 8, do not adequately address. The ***channel*** bottom may erode or fill as a result of flooding. If it erodes, ***channel*** banks may become unstable and collapse. If the ***channel*** bottom fills through ***sedimentation***, the floodplain can widen, potentially damaging property and structures and endangering lives. In addition, ***watercourses*** need a certain amount of riparian corridor in which to function naturally. Because the ***watercourse*** constantly changes overtime, as shown in Figure 9, the ***watercourse*** master plan incorporates a riparian corridor to protect property from the impacts of these natural

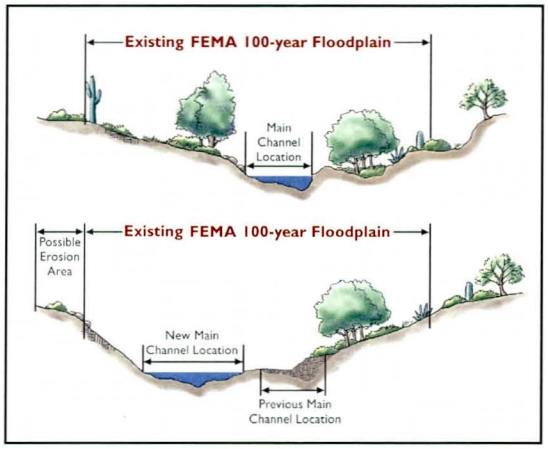


Figure 9. Cross Section of Potential Channel Migration

processes. Therefore, the WCMP must consider the natural movement of the ***watercourse***. Understanding ***erosion***, ***sedimentation***, and ***channel*** migration and identifying appropriate methods to analyze these processes (***hydrology*** and ***hydraulics***) are critical to creating viable alternatives for ***watercourse*** management. Technical considerations relating to this understanding are described in following sections.

A. Hydrology

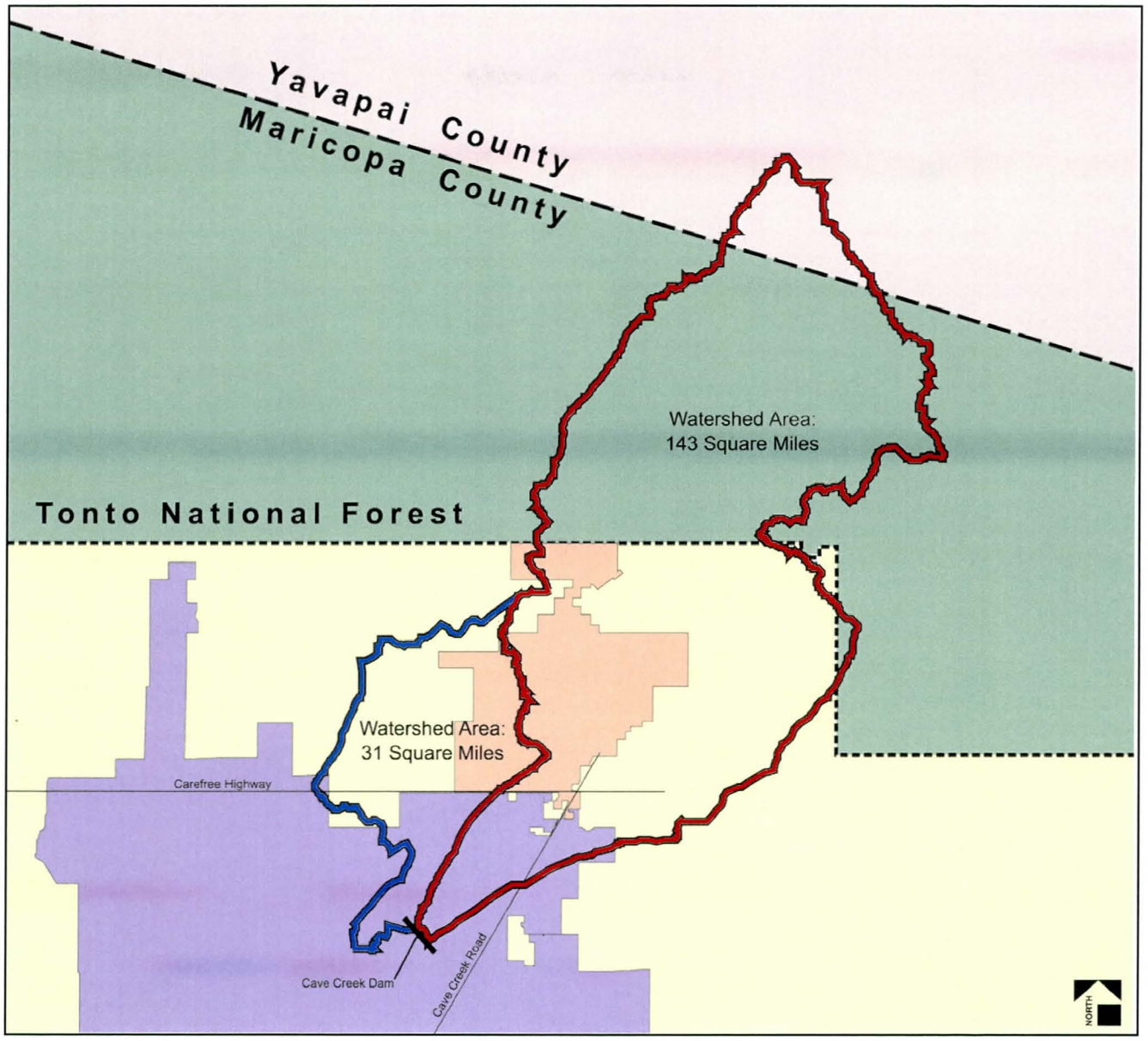
The hydrologic analyses conducted as a part of this study were as follows:

- ***Hydrology*** **for** ***existing watershed conditions*** **for the 2-, 10- and 100-year** ***recurrence interval*** **storms.**
- ***Hydrology*** **for** ***future watershed conditions*** **for the 2-, 10- and 100-year** ***recurrence interval*** **storms.**
- **Estimation of ponding elevations upstream of Cave Creek Dam and Cave Buttes Dam for the 2-, 10-, 50- and 100-year** ***recurrence interval*** **storms.**
- **Testing of alternative** ***watercourse*** **management plans to estimate** ***cumulative impacts*** **on peak discharges in the study area resulting from** ***floodplain encroachments.***

The hydrologic ***computer models*** were used to estimate the volume and peak discharge of stormwater runoff that can be expected from storms of varying magnitude. The current FEMA HEC-1 ***computer models*** were used as models of ***existing watershed conditions***, and were modified to simulate ***future watershed conditions***. Models were developed for the 2-, 10- and 100-year ***recurrence interval*** storms of 24-hour duration. The ***hydrology*** models are building blocks used for development of the hydraulic and sediment models described in the following section, and the analyses of potential ***lateral channel migration*** described in the ***Lateral Channel Migration*** section. The hydrologic models are also used to test for ***cumulative impacts*** resulting from ***floodplain encroachment*** proposed under the ***watercourse*** management alternatives. Refer to Figure 10 for a map illustrating the watershed of Upper Cave Creek and Apache Wash. The results of the existing and future watershed condition hydrologic models are shown in Table 3. The complete documentation of the hydrologic modeling is contained in Attachment 3.

As described in section 4C, Cave Creek Dam was constructed in 1923 and replaced by Cave Buttes Dam in 1979. Cave Buttes Dam was designed and constructed by the US Army Corps of Engineers. That dam was designed to impound the Standard Project Flood (SPF), and to safely pass the Probable Maximum Flood (PMF) through the emergency spillway, both of which are much greater than the 100-year flood. Cave Creek Dam lies within the impoundment area of Cave Buttes Dam and was bypassed by a ***channel*** excavated around the old dam at the time of construction of Cave Buttes Dam. Cave Creek Dam provides very limited flood retarding capabilities for the area between Cave Buttes Dam and Cave Creek Dam before the bypass ***channel*** begins to flow.

The City of Phoenix plans to develop the impoundment areas between Cave Creek Dam and Cave Buttes Dam, and upstream of Cave Creek Dam, for parks and recreation purposes. For planning purposes, City planners must consider the flood hazards associated with more frequent events than those used to design the two dams. The 2-, 10-, 50-, and 100-year existing and future condition storms were evaluated at the two dams to determine the ponding depths that can be expected in the impoundment areas. As mentioned above, Cave Creek Dam, although replaced by Cave Buttes Dam, still functions as a flood retarding structure for the smaller, more frequent storms. This is important to the City of Phoenix because Cave Creek Dam may provide a certain level of flood protection for the area between Cave Creek Dam and Cave



Key

- City of Phoenix
- Town of Cave Creek
- Tonto National Forest
- Yavapai County
- Maricopa County
- **Upper Cave Creek Watershed**
- Apache Wash Watershed

Figure 10. Watershed Map

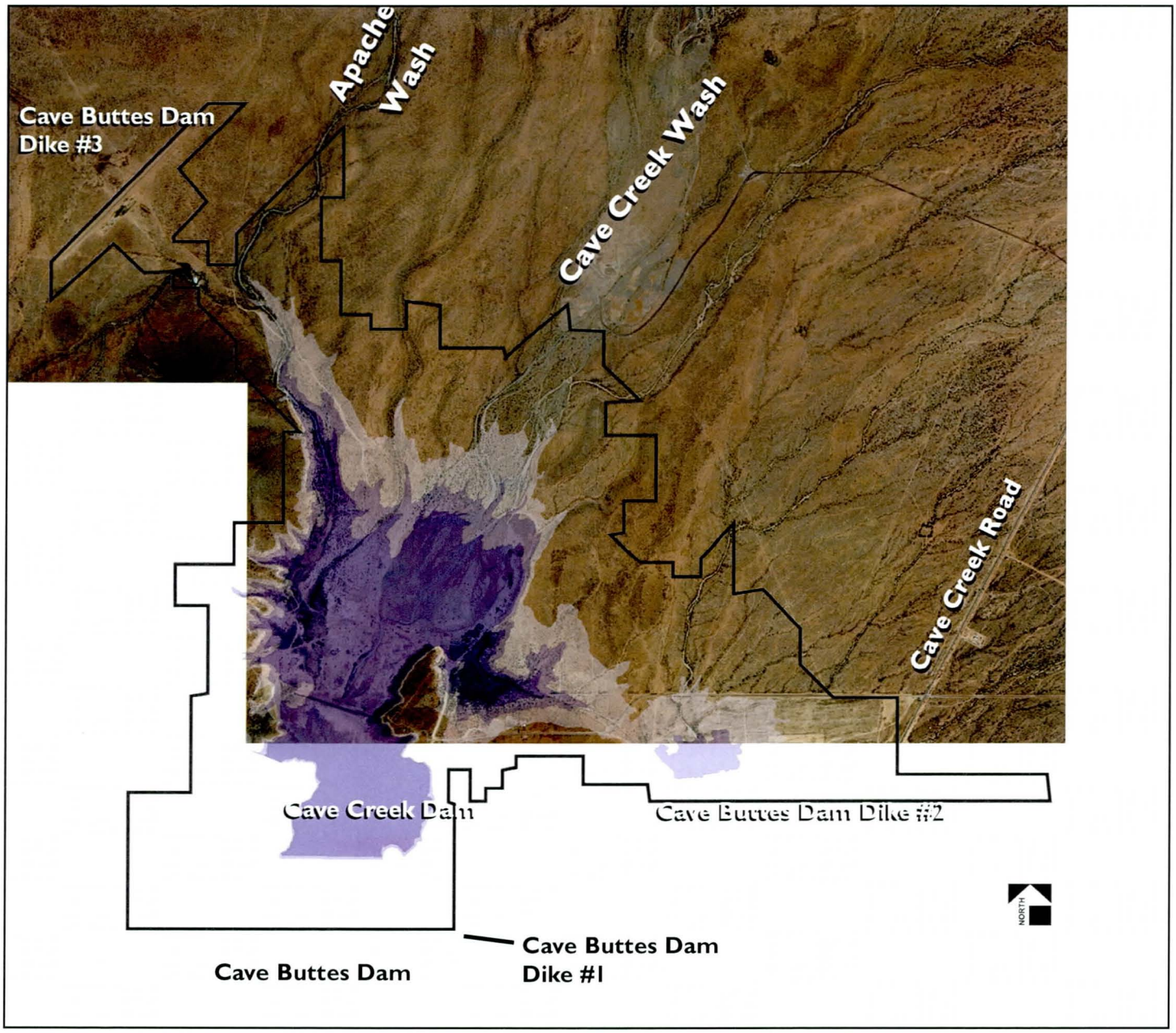
Buttes Dam. This could allow more time for evacuation of the area between the two dams. In addition to estimating ponding depths for the storms evaluated, the level of protection provided by Cave Creek Dam is evaluated. Refer to Figure 11 for a depiction of the two dams and the estimated limits of ponding from the future condition storms upstream of the dams.

It was determined that Cave Creek Dam provides a level of protection from the 2-year ***recurrence interval*** storm. During a 2-year storm, the equalizer ***channel*** cut around Cave Creek Dam is not overtopped. However, at peak, about 1450 cfs is released from Cave Creek Dam through the low-level outlet during the 2-year future condition storm. Cave Creek Dam provides minimal protection for the area between Cave Creek Dam and Cave Buttes Dam during a 10-year storm, and virtually no protection during a ***100-year storm***. After the equalization ***channel*** around Cave Creek Dam is overtopped, which occurs for both the 10-year and ***100-year storms***, the area between the two dams is filled by floodwater within a short period of time. The average elevation of the land between the two dams is 1570 feet above sea level. The elevation of the crest of the bypass ***channel*** around Cave Creek Dam is 1626.5 feet. During a 2-year future condition storm, a peak stage of approximately 1626 is reached in the area between Cave Buttes Dam and Cave Creek Dam. This occurs within approximately 47 hours after the start of precipitation. Upstream of Cave Creek Dam, the peak stage of approximately 1626 occurs within approximately 21 hours after the start of precipitation. Also during a 2-year future condition storm, a stage of 1575 (an average pond depth of 5 feet) is reached between the two dams within 12 hours. During a 10-year future condition storm, a stage of 1575 (an average pond depth of 5 feet) is reached between the two dams within 10 hours. The entire area between the two dams fills to the crest of the Cave Creek Dam equalization ***channel*** within 19 hours during a 10-year storm.

Table 3
Summary of Hydrologic Modeling Results

Location	Drainage Area sq.mi.	Peak Discharge in cfs					
		2-year		10-year		100-year	
		Ex.	Fut.	Ex.	Fut.	Ex.	Fut.
Cave Creek at Carefree Hwy.	124.4	6,200	7,900	16,200	18,300	33,800	35,900
Cave Creek at Cave Buttes Dam	142.5	6,400	8,800	18,100	20,800	38,100	41,500
Apache Wash at Carefree Hwy.	6.5	1,400	1,500	3,900	4,100	7,200	7,400
Apache Wash D/S of Desert Hills Wash	20.3	2,200	2,300	6,600	7,500	13,500	13,900
Apache Wash U/S of Paradise Wash	20.3	2,200	2,300	6,600	7,500	13,500	13,900
Apache Wash at Cave Buttes Dam	30.6	3,100	3,700	9,500	10,400	18,400	19,300
Paradise Wash at Carefree Hwy.	4.7	970	1,100	2,800	3,000	5,200	5,400
Desert Hills Wash at Carefree Hwy.	9.8	1,600	1,800	4,800	5,100	8,900	9,300
Cave Creek and Apache Wash at Cave Buttes Dam	172.9	6,900	9,300	18,900	21,700	39,400	42,800

U/S is an abbreviation for upstream.
D/S is an abbreviation for downstream.
cfs is an abbreviation for cubic feet per second.



Key

- Future 2-year Pool Flooding Limits
- Future 10-year Pool Flooding Limits
- Future 100-year Pool Flooding Limits
- FCDMC Property Boundary/Recreation Area

Figure 11. Cave Buttes Dam Ponding Limits

B. Hydraulics, Erosion and Sedimentation

Information needed for understanding the physical aspects of how ***watercourses*** in the study area function were obtained through ***hydraulics***, ***erosion*** and ***sedimentation*** modeling. The models were then used as one of the engineering techniques for estimating the potential for ***lateral channel migration***, described in section 5C, as well as for other purposes. The models were also used to test the ***watercourse*** management alternatives. Complete documentation of the study ***hydraulics***, ***erosion***, and ***sedimentation*** modeling is provided in Attachment 4.

1. Hydraulics

Computer models developed for the current ***FEMA 100-year floodplain*** delineation study were used as a basis for hydraulic modeling of the study ***watercourses***. The FEMA ***computer models*** were adjusted for the purposes of this study, and then modified to simulate estimated ***future watershed conditions***. The ***computer models*** were also used to estimate results for 2-year and 10-year ***recurrence interval*** storms. The results of these ***computer models*** were then used to provide base input data for the sediment models, as well as to identify water surface elevations, provide hydraulic data for ***scour*** computations and potential lateral migration analyses, and provide a starting point for testing management alternatives. The complete details of the hydraulic modeling effort are contained in Attachment 4.

2. Erosion and Sedimentation

Erosion and ***sedimentation*** analyses were performed for the study area of the Upper Cave Creek, Apache Wash, Paradise Wash and Desert Hills Wash ***watercourses***. The components of the ***erosion*** and ***sedimentation*** analyses are:

- **Estimating the volume of *sediment yield* from the study watershed.**
- **Estimating *erosion* or *sedimentation* in the *watercourses* during floods.**
- **Estimating sediment deposition during floods in Upper Cave Creek due to the backwater effects of Cave Creek Dam and Cave Buttes Dam.**
- **Estimating the potential impacts of *erosion* and *sedimentation* on the structural components proposed for the WCMP alternatives. These components include existing and proposed structures, such as bank protection, *channel* grade-control structures and bridges.**

Sediment yield data from various regional studies were compiled and analyzed to estimate the ***sediment yield*** from the Upper Cave Creek and Apache Wash watersheds. An estimate of ***sediment yield*** from the Upper Cave Creek and Apache Wash watersheds is needed, in combination with the sediment transport modeling, to estimate the sediment deposition that will occur from floods, over time, upstream of Cave Creek Dam and Cave Buttes Dam. The ***sediment yield*** analyses indicate that the ***sediment yield*** from a watershed similar to Cave Creek, 100 square miles in area, ranges from 0.2 to slightly more than 0.3 ***acre-feet*** per square mile per year. The U.S. Army Corps of Engineers estimated a ***sediment yield*** of 0.31 ***acre-feet*** per square mile per year for the design of Cave Buttes Dam. That dam was designed and constructed with

allowance for 100 years of estimated loss of flood storage capacity due to ***sedimentation***. The combined water-shed area of Upper Cave Creek and Apache Wash at Cave Creek Dam is approximately 173 square miles, resulting in an estimated average annual watershed ***sediment yield*** of about 54 ***acre-feet***. The total estimated ***sediment yield*** for the 100-year flood is 245 ***acre-feet***. Most of this sediment volume will be deposited upstream of Cave Creek Dam, although deposition of finer sediments will occur between Cave Creek Dam and Cave Buttes Dam. Maricopa County has been removing some of the excess sediment upstream of Cave Creek Dam on a routine basis. This type of continuing maintenance activity will be necessary, and should be considered when designing recreation facilities or flood control structures in the area.

The U.S. Army Corps of Engineers HEC-6 computer program was used to estimate the ***erosion*** and ***sedimentation*** trends and magnitudes of the study ***watercourses*** for the 10- and 100-year floods. The HEC-6 models address ***channel*** bed vertical movement. ***Main channel erosion*** and ***channel*** migration is interpreted from those results. Review of the modeling results provides insight into the range of general ***scour*** or *deposition* that can be expected to occur during a single flood in individual reaches of each ***watercourse***. Results of the computer modeling analysis indicate that Upper Cave Creek could experience ***scour*** or deposition of up to 3 feet during a major flood such as a 100-year flood. The results for Apache Wash indicate ***scour*** could be as much as 6 feet and *deposition* as much as 3 feet during a 100-year flood. The results for Paradise Wash indicate ***scour*** could be as much as 1 foot and *deposition* as much as 2 feet during a 100-year flood. The results for Desert Hills Wash indicate ***scour*** and *deposition* could be as much as 1 foot during a 100-year flood. A detailed discussion of the results of ***erosion*** and ***sedimentation*** analysis is presented in Attachment 4.

The ***erosion*** and ***sedimentation*** analyses also included ***scour*** analysis computations. ***Scour*** computations are used to determine the maximum potential ***scour*** and, hence, the depth for designing the structural components of the various WCMP alternative management plans considered. For this study, the design ***scour*** depths included single-event ***scour*** and long-term ***degradation*** (***erosion*** expected to occur over the life of a structural component). The maximum single-event ***scour*** consists of several components:

Cave Buttes Recreation Area

- **General *scour* depths discussed above.**
- ***Bed-form scour* (see definition below).**
- **Bend *scour* (added only on the outside of bends).**
- **Local *scour* (added where *channel* grade-control structures are proposed).**

Long-term ***degradation*** occurs in reaches where the ***channel*** bottom is continually lowering from flood to flood due to ***erosion***. The estimated drop in the ***channel*** over time is added to the maximum single-event ***scour*** components to obtain the total design ***scour*** depth. If the long-term ***degradation*** depth is found to be excessive, grade-control structures along the ***channel*** bottom become necessary. For the purpose of this study, the term "excessive" was defined as the point when the cost to increase the depth of required bank protection exceeds the cost of installing grade-control structures to control bed ***degradation***. For the purpose of this study, the depths of required bank protection are considered to be reasonable. Only one grade-control structure was found to be necessary due to potential ***head-cutting*** upstream from the sand and gravel mined ***reach***.

The primary structural flood control measure used in the ***watercourse*** management alternatives is bank protection. Bank protection is a constructed lining designed to prevent the ***main channel*** banks from eroding horizontally and damaging

improvements made within the ***FEMA 100-year floodway fringe*** or an ***erosion*** hazard area. Bank protection must be constructed to extend below the lowest point in the natural ***channel*** bottom, which includes accounting for total ***scour***. This depth is commonly referred to as the *toe-down depth*. Generally, bank protection is also extended above the 100-year water surface elevation. Bank protection is typically part of structural features designed to remove land located within the ***FEMA 100-year floodway fringe*** from the ***FEMA 100-year floodplain***. As described above, the required toe-down depth below the ***channel*** bottom is determined using the design ***scour*** depth. The required height above the 100-year water surface elevation is based on a factor of safety referred to as *freeboard*. Two types of bank protection, relative to the potential for ***erosion*** to occur, are described for the purpose of this study. They are *maximum depth* and ***minimum depth bank protection***.

The ranges of design ***scour*** depths for ***maximum depth bank protection*** requirements for each ***reach*** of the WCMP are shown in Table 4. The depths listed are the below-ground requirements measured from the bottom of the ***main channel*** at a specific location. The required depths vary within each ***reach*** and along each bank. The minimum and maximum values are the shallowest and deepest requirement in the ***reach***, respectively. The average provides an estimate of the average depth, weighted by length of ***channel*** over which it applies. Refer to Attachment 8 for detailed documentation of ***scour*** computations performed for proposed structural components of the management alternatives.

Table 4
Total Design Scour Depths, by Reach

Reach Name	Total Design Scour in feet		
	Minimum	Maximum	Average
Cave Creek Cliff Reach	3.5	14.3	9.3
Cave Creek Mined Reach	2.3	15.6	6.5
Cave Creek Braided Reach	3.3	17.7	7.5
Apache Wash Upper Apache Reach	1.9	16.1	9.0
Apache Wash Union Hills Reach	7.1	14.8	13.3
Apache Wash Hackberry Reach	1.9	16.1	9.0
Desert Hills Reach	2.4	8.6	6.2
Paradise Reach	1.9	16.1	9.0

C. Lateral Channel Migration Potential

The potential for ***lateral channel migration*** was extensively evaluated for the four ***watercourses*** in the study area. The components for this evaluation include:

- **Study area characteristics,**
- **Historical analyses.**
- **Geomorphic analyses.**
- **Engineering analyses.**

The results of the lateral migration analyses were used to delineate ***erosion*** hazard zones. Refer to Attachment 5 for documentation of the ***lateral channel migration*** analyses.

1. Study Area Characteristics

The stability of the Upper Cave Creek and Apache Wash systems is directly affected by several characteristics of the study area. The first characteristic studied was the geologic setting, the understanding of which is fundamental to predicting the ***lateral channel migration*** potential of the study ***watercourses***. Upper Cave Creek and Apache Wash are located on an incised alluvial fan formed about 1 million years ago. Climate change over the past 10,000 years caused the streams to incise into the alluvial fan and form more riverine features, such as terraces and defined ***channels***. No bedrock outcrops are in the study area, except near the Union Hills along Apache Wash. Geologic evidence suggests that future ***channel*** movements are likely to be confined within the corridor of geologically recent terraces located near the ***main channels*** (soils less than 10,000 years old).

The second characteristic studied is ***hydrology***. The hydrologic evaluation included use of the hydrologic model data discussed in section 5A, the study of ***watercourse*** and precipitation gage records, and the seasonality of precipitation, and historical floods. Hydrologic data suggests that the ***watercourses*** are normally dry, and that most significant ***channel*** changes will occur during large floods.

The third characteristic studied is stream classification. The primary objective of stream classification is to match measurable ***watercourse*** characteristics with expected ***watercourse*** responses. This evaluation was used as an indication of whether or not a detailed study of lateral migration was warranted for these ***watercourses***. The Brice and Rosgen stream classification systems results indicate that Upper Cave Creek and Apache Wash have many characteristics typical of ***braided watercourses*** and ephemeral ***watercourses***, that lateral movement should be expected for both ***watercourses***, and that a more detailed evaluation of lateral stability is warranted.

2. Historical Analysis

A basic assumption of any geologic analysis is that "understanding the past, as preserved in the geologic record, is the key to understanding the future" (NRC, 1996). In the case of the Upper Cave Creek and Apache Wash ***Watercourse*** Master Plan geomorphic analysis, this means that to predict the future lateral migration, past river behavior must be thoroughly understood. The following data sources were used to obtain this understanding:

- **Published summaries of the archaeological record.**
- **Published descriptions of regional geology.**
- **Historical maps and aerial photographs.**
- ***Channel* descriptions from historical General Land Office (GLO) surveys.**
- **Field evidence of past *channel* and floodplain changes.**

Historical information illustrates the types of ***channel*** changes that have occurred in the study area during the past 100 years, and suggests the types of ***channel*** change that can be expected in the future. Archaeological data collected along Upper Cave Creek imply that ***channel erosion*** has affected the Upper Cave Creek ***watercourse*** corridor for more than 1,000 years. Archaeological data also suggest that during the period of Hohokam occupation, Upper Cave Creek changed from an intermittent ***channel*** with frequent shallow over-bank flooding to an incised, ***braided watercourse*** that rarely inundated its floodplain. These data indicate that the ***erosion*** documented during the historical period is not simply the result

of recent human impacts on the ***channel*** and *watershed*. Natural cycles of ***watercourse degradation*** and lateral migration must be accounted for in the ***watercourse*** management plan.

Comparison of historical maps and aerial photographs indicate that Upper Cave Creek has been subject to both bank and avulsive lateral movement during the past 50 years. Gradual bank ***erosion*** averaged less than one foot per year in the study area, but ***avulsions*** caused shifts of more than 1,000 feet. The earliest historical records, General Land Office (GLO) survey notes and plat maps, indicate that Upper Cave Creek generally moved towards the west and north between 1894 and 1981, with varying degrees of magnitude. The greatest magnitudes of lateral movement on Upper Cave Creek occurred in the downstream portion of the study area, particularly in the Braided Reach. The GLO data document apparent ***channel avulsions*** on Upper Cave Creek and Apache Wash in which the ***channel*** moved up to 1,300 feet across the floodplain. The magnitude of bank ***erosion*** on Upper Cave Creek and Apache Wash was significantly less, with lateral moves ranging from 4 to 82 feet between 1894 and 1981. The evidence of large lateral ***channel avulsions*** in the past serves as a warning of the potential for future changes. Paradise Wash and Desert Hills Wash were more stable laterally than Upper Cave Creek or Apache Wash during the period of record. Comparison of digitized ***channel*** positions before and after the 1993 flood indicated ***avulsions*** could occur during a flood with a 25-year ***recurrence interval***. Except at areas where ***avulsion*** occurred, bank ***erosion*** during the 1993 flood was minimal in most of the study ***reach***. However, field evidence suggests that local bank failures occur periodically at ***channel*** bends or along unvegetated banks throughout the study ***reach***.

Comparison of ***channel*** elevations obtained from topographic mapping and aerial photographs indicates that Upper Cave Creek exhibited a trend toward net ***degradation*** from 1960 to 1999. A total ***degradation*** of up to 10 feet occurred between 1962 and 1996 in portions of the study area, primarily along reaches where in-stream sand and gravel mining occurred. ***Degradation*** occurred at a much faster rate during the 18-year span from 1962 to 1979 than during the 17-year span from 1980 to 1996. Mixed trends of ***degradation*** and ***aggradation*** occurred along Apache Wash, with an estimated maximum annual ***degradation*** rate of about 0.3 feet/year. Topographic data show that Paradise Wash generally experienced slight ***aggradation*** or no significant change between 1962 and 1990, with a maximum ***aggradation*** rate of 0.1 feet/year. Desert Hills Wash has experienced ***degradation*** at an average rate of about 0.2 feet per year within the study limits.

3. Geomorphic Analyses

The geomorphic analyses used in this study evaluated the topography of the ***watercourses*** and the adjacent terrain in order to estimate past and future ***channel*** movement. These estimates can then be used to define the land area subject to ***erosion*** and required by the ***watercourse*** to preserve its natural function. Three basic analyses were completed:

- **Field assessment techniques.**
- **Geomorphic mapping.**
- **Geomorphic assessment techniques.**

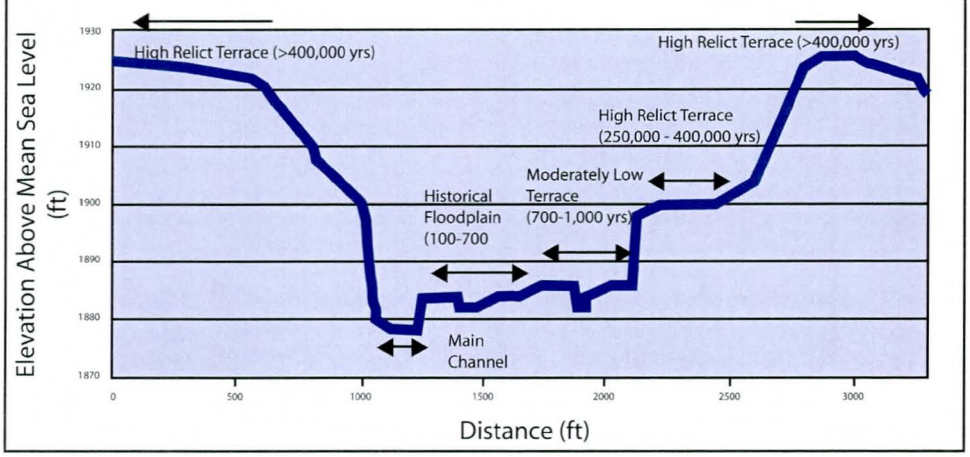
The geomorphic analysis techniques relied on field observations, interpretation of the surficial geology, and application of empirical and theoretical data to evaluate the lateral stability of the four major ***watercourses*** in the study area. Field observations made along Upper Cave Creek indicate the study ***reach*** is subject to lateral ***erosion*** and ***channel avulsions***, has experienced historical ***degradation***, and has been extensively impacted by human activities. Field observations made along Apache Wash, Paradise Wash, and Desert Hills Wash indicate that the study reaches are more laterally stable than Upper Cave Creek, and have not experienced significant long-term ***degradation*** or human impacts. Field data suggest

Cave Creek Field Observation

that the frequency of ***channel avulsions*** on Upper Cave Creek, particularly in the Mined and Braided Reaches, is greater than on Apache Wash or Paradise Wash. The stability predictions associated with the stream classification schemes also indicated that the ***watercourses*** in the study area are susceptible to rapid lateral migration and bank ***erosion***.

The ages and relative heights of the geomorphic surfaces in the study area provide information on how recently they have been flooded or subjected to lateral ***erosion***. An example is shown in Figure 12. Note that the ***Main Channel*** is characterized by soils less than 100-years old, the adjacent historical floodplain by soils in the range of 100 to 700 years, and adjacent terraces ranging from 700 to greater than 400,000 years in age. This ***channel*** and terrace system is typical of Upper Cave Creek and Apache Washes. The existing ***channels*** of Upper Cave Creek and Apache Wash have experienced net ***degradation*** over the last 700,000 years, which means that future ***channel*** movements are likely to be confined within the corridor of geologically recent surfaces located near the ***main channels*** (soils less than 10,000 years old).

Figure 12. Geomorphic Surfaces - Cave Creek at Carefree Highway



The geologic record indicates that portions of Upper Cave Creek, Apache Wash and Paradise Wash have been subjected to ***channel avulsions*** for at least the past 10,000 years. Except in reaches affected by ***channel avulsions***, geologic evidence preserved in the soils record indicates that the rate of net ***channel*** change has been slow (<1ft/yr laterally, <0.01ft/yr vertically), during recent geologic time. The scale of lateral ***channel*** change observed in the recent geologic record was not significantly different than the scale of historical changes documented in section 5C.2, except where the ***watercourses*** are disturbed by human activities. The rate of net ***degradation*** since the middle Pleistocene and early Holocene was about 10^{-4}ft/yr; and 10^{-2}ft/yr, respectively. Modern rates of incision (1960-1999) estimated from topographic mapping and aerial photographic interpretation average about 10^{-1}ft/yr to 10^{-2}ft/yr, somewhat faster, but within the range of long-term geologic rates of incision.

Channel movement measured by comparison of historical aerial photographs is not significantly different in rate or scale than the rate suggested by interpretation of the geomorphic surficial mapping. The rates of lateral movement have been

fastest on the youngest, less indurated (hard) surfaces, and slowest along the margins of the older, more indurated surfaces. Upper Cave Creek and its major tributaries are located within a descending series of inset and progressively younger terraces. The older terrace margins serve as a practical limit for predicted future rapid ***channel*** change, although the older terraces are also subject to (slower) lateral ***erosion***. Geologic evidence preserved in the soils and surficial characteristics indicate that the Mined Reach of Upper Cave Creek was subject to ***channel avulsions*** and had a multiple ***channel*** pattern prior to the incision caused by in-stream mining. If this ***reach*** were to recover from the human-induced incision, it would probably be subject once again to ***avulsions***.

Longitudinal profile analyses using historical topographic mapping of Upper Cave Creek and its three tributaries in the study area, indicate that there has been historical ***degradation***, although some localized areas have experienced net ***aggradation***, in the past 40 years. No natural grade-control exists in the beds of the ***watercourse channels***. The concrete box culverts on Apache Wash and Paradise Wash at the Carefree Highway provide grade-controls at the upstream end of the study limits. No evidence of progressive long-term ***scour*** was observed at the downstream sides of the Carefree Highway culverts. However, it was noted that those structures are undersized, which has the effect of increasing the floodplain width upstream of the Carefree Highway due to surcharge at the highway embankment. The surcharge has resulted in sheet flow over the Carefree Highway, which has increased the width of the ***FEMA 100-year floodplain*** downstream of the Carefree Highway, as well.

Channel geometry analyses predict a straight, braided ***channel*** pattern for Upper Cave Creek, with less strongly expressed braiding expected on Apache Wash and Paradise Wash. Desert Hills Wash is likely to maintain its existing, slightly sinuous to weakly meandering ***channel*** pattern in the future. The ***channel*** geometry analysis indicates that the ***watercourses*** in the study are more erosive than similar ***watercourses*** in other areas. The slopes are steeper, the ***channel*** velocities higher, and the depths greater. Upper Cave Creek will tend to erode its banks during floods that exceed the 10-year event, but will experience only localized bank ***erosion*** during the 2-year flood. Likewise, Apache Wash and Paradise Wash will experience only local bank ***erosion*** during 2-year floods, but will tend to widen during the largest floods. The ***reach***-averaged existing and predicted widths for Apache Wash differ by a factor of two to three for the 100-year event, indicating a strong tendency for lateral ***erosion*** during extreme floods. Desert Hills Wash has a tendency to widen and erode its banks during any flood, according to the hydraulic geometry equations. The ***channel*** geometry analysis indicates that almost all of the ***watercourse*** reaches in the study area are steeper than the equilibrium slope, are incised, and experience erosive velocities during most flows.

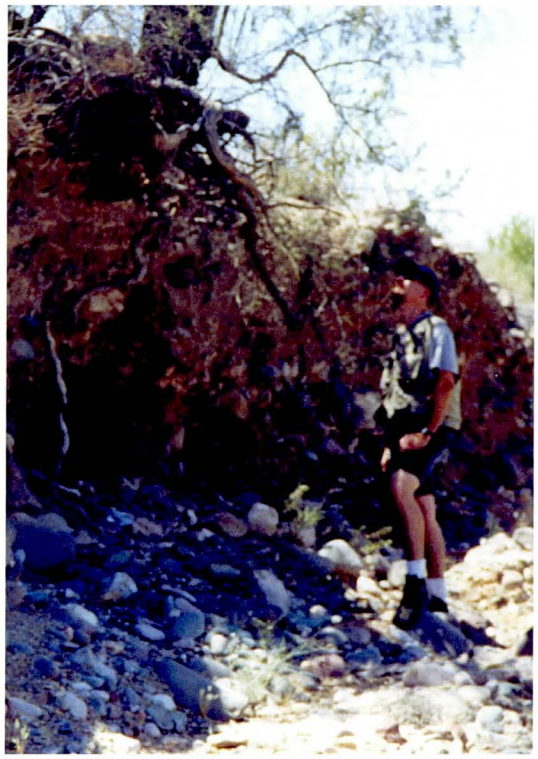
The results of the hydraulic geometry regression equation analyses indicate that the study reaches are incised more than the average ***ephemeral watercourse*** in the semiarid United States, with the exception of the Hackberry Reach of Apache Wash. The slower increase in width as discharge increased implies that the ***channels*** have well-consolidated banks, which constrain lateral ***erosion*** while concentrating erosive energy on the bed of the ***channel***. Desert Hills Wash may be the most efficient ***watercourse*** in the area at transporting sediment through and out of the system, and appears to be close to equilibrium.

4. Engineering Approaches to Lateral Stability Assessment

The engineering approaches used for lateral stability assessment were focused on estimating the potential for, and magnitude of, bank ***erosion***. The approaches used were based on the following:

- **Hydraulic data.**
- **Sediment data.**
- **Engineering methodologies.**

Bank ***erosion*** can occur as a result of high velocity flow against the bank, undercutting of banks as a result of ***channel degradation*** due to ***scour***, decreased bank stability resulting from a loss of bank vegetation, or a decrease in sediment supply to the ***watercourse*** from tributaries and the watershed. The engineering approaches were focused on interpretation of the HEC-6 modeling results, equilibrium slope analyses, and general and long-term ***scour*** analyses. The HEC-6 results indicate that ***erosion*** will occur during large floods, with lesser or minimal ***erosion*** occurring during smaller floods. Sediment deficits (***channel*** bed ***erosion*** volumes predicted by HEC-6) were translated into bank ***erosion*** distances, and converted to average-annual bank ***erosion*** rates. The predicted bank ***erosion*** distances are similar for Upper Cave Creek, Apache Wash, and Paradise Wash, despite differences in discharge, flow duration, and field conditions. Field and historical evidence suggests that Apache Wash and its tributaries have experienced less lateral migration than Upper Cave Creek, due to denser bank vegetation, lesser historical incision, and less direct human disturbance. The predicted bank ***erosion*** distances are lowest for Desert Hills Wash.



Typical bank erosion and undercutting

General and long-term ***scour*** estimates for the ***watercourses*** in the study area indicate that significant ***scour*** is expected for Upper Cave Creek. Significant but lower amounts of ***scour*** are expected for Apache Wash and Paradise Wash. The predicted amount of ***scour*** for Desert Hills Wash is the lowest of the four ***watercourses*** considered. The greatest amount of ***scour***-induced bank ***erosion*** is therefore predicted for Upper Cave Creek. The engineering analyses indicate that the ***watercourses*** in the study area are generally subject to net ***degradation***, and will continue to entrench and ***scour*** in the future. This supports the results from the historical and geomorphologic analyses. However, ***aggradation*** is occurring over time in the Braided Reach and into the Mined Reach of Upper Cave Creek because of the presence of Cave Buttes Dam.

D. Erosion Hazard Zones

The results of sections 5A through 5C were used as the basis to define Erosion Hazard Zones for the ***watercourses*** in the study area. The ***erosion*** hazard boundaries were defined based on consideration of the following information:

- **Field data.**
- **Stream Classification.**
- **Historical *Channel* Changes.**
- **Archaeological Data.**
- **Mapping of Geomorphic Surfaces.**
- **Longitudinal Profile Analysis.**

- Hydraulic Geometry and Regime Equations.
- Expected *Channel* Patterns.
- Allowable Velocity.
- Equilibrium *Channel* Slope.
- Armoring Potential.
- Stable Bank Slope.
- HEC-6 Modeling Results.
- Expected Lateral *Erosion* Mechanisms.
- Impacts of Mining-Induced Entrenchment.

Three *erosion* hazard zones have been defined and are shown on Figures 13 through 18. These are:

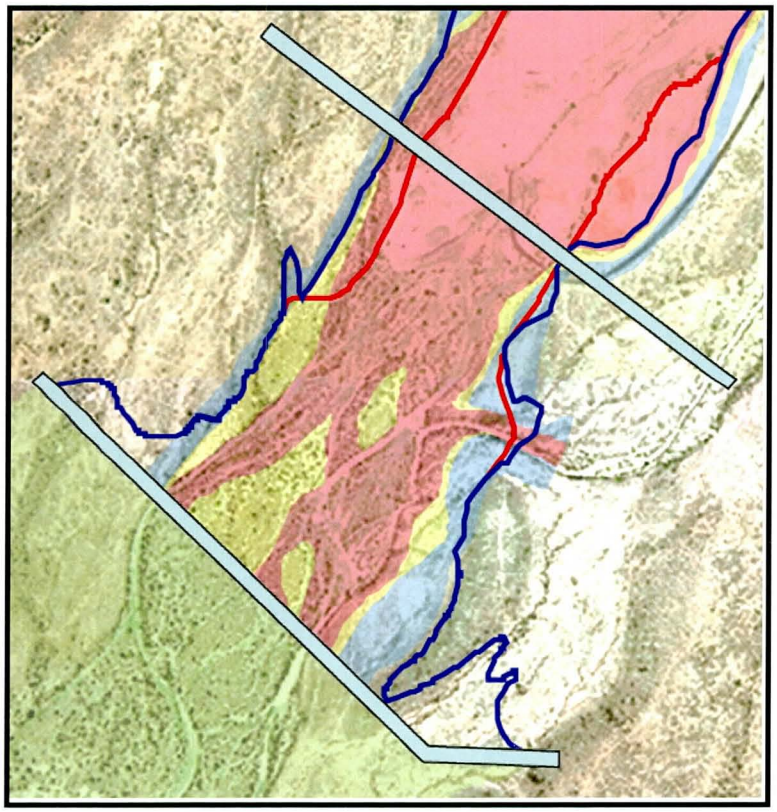
- Severe *Erosion* Hazard Zone.
- Lateral Migration *Erosion* Hazard Zone.
- Long-Term Erosion Hazard Zone.

1. Severe Erosion Hazard Zone

The Severe Erosion Hazard Zone is comprised of the active *watercourse channels* and adjacent areas likely to be eroded during a single major event, such as the 100-year flood. The Severe Erosion Hazard Zone is also comprised of the area likely to be removed if the bank angle were to be reduced to the *natural angle of repose*. The basis of mapping for the Severe Erosion Hazard Zone included the following:

- Bank *erosion* equivalent to the 100-year HEC-6 future conditions sediment deficit.
- Bank *erosion* resulting in a 3:1 bank slope (approximate *natural angle of repose*).
  2- or 10-year regime *channel* width, if wider than the existing active *channel*.
- Areas within the bed and banks of existing active *channels*.

In addition, areas within the limits of existing sand and gravel-mining operations were considered to be in the Severe Erosion Hazard Zone, since no engineered *erosion* protection was observed near the mine pits during field visits.

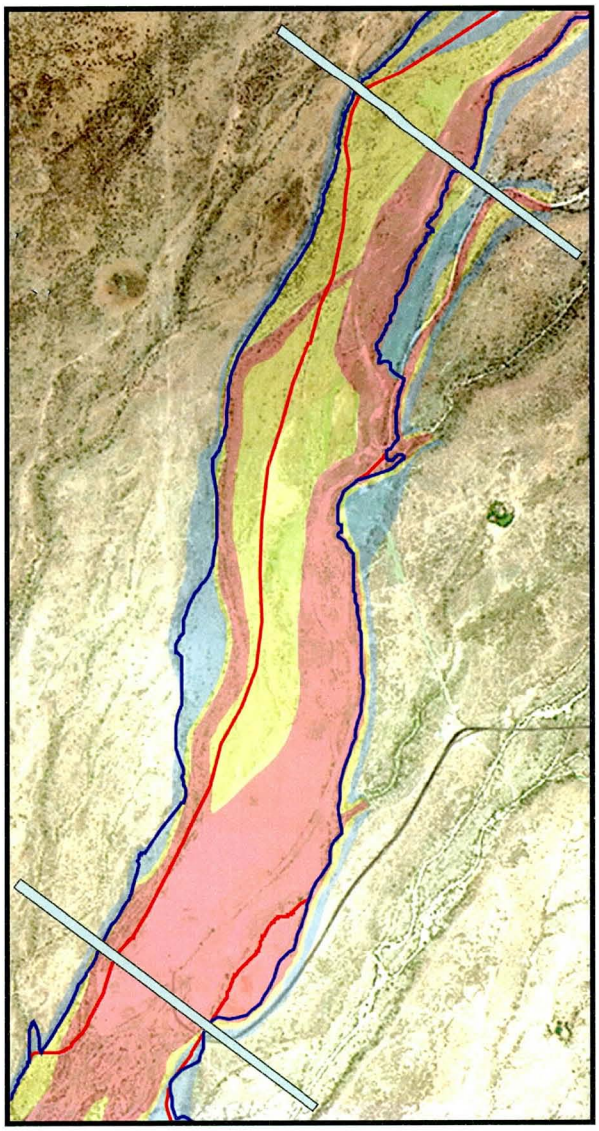


Key

- Severe Erosion Hazard Zone
- Lateral Migration Zone
- Long Term Erosion Zone
- Standard Project Flood Ponding Area
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary

Reach Key Map:

Figure 13. Braided Reach Erosion Hazard Zones



Key

- Severe Erosion Hazard Zone
- Lateral Migration Zone
- Long Term Erosion Zone
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary

Reach Key Map:

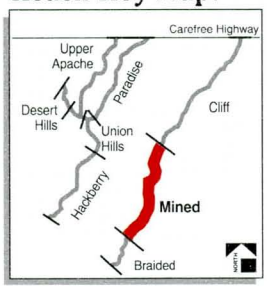
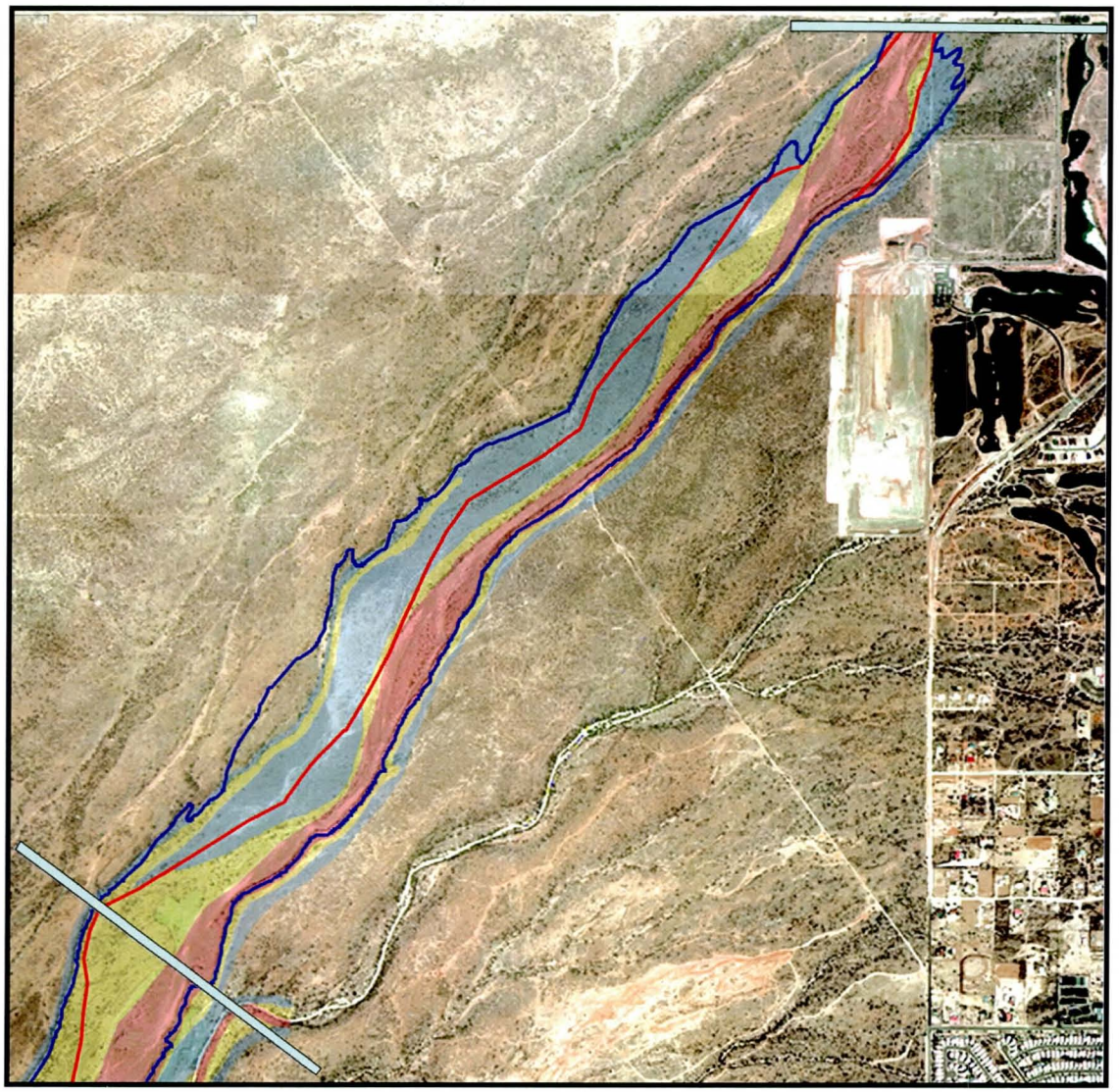


Figure 14. Mined Reach Erosion Hazard Zones

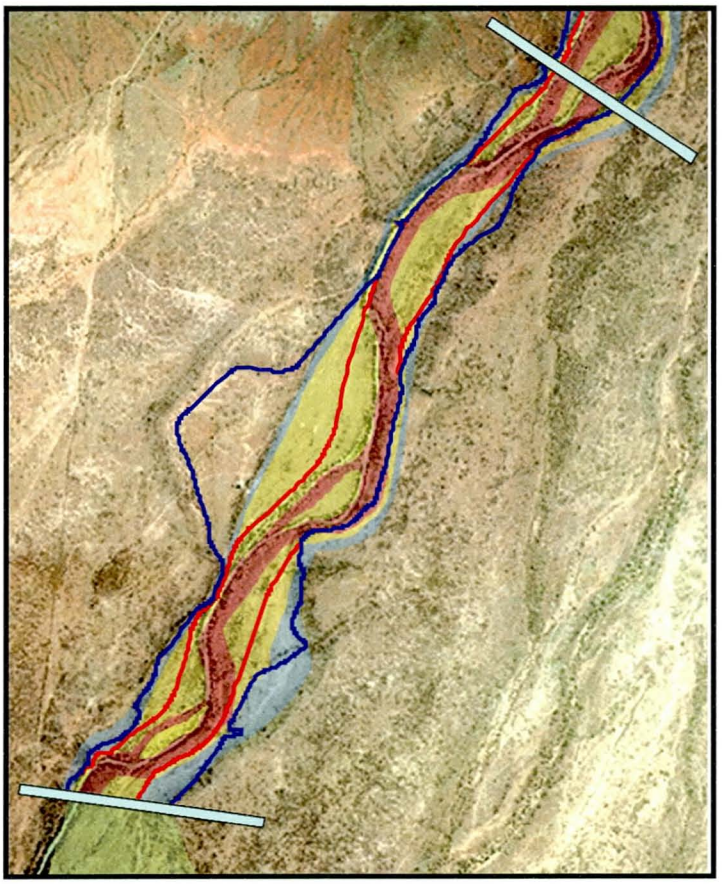


Key

- Severe Erosion Hazard Zone
- Lateral Migration Zone
- Long Term Erosion Zone
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary

Reach Key Map:

Figure 15. Cliff Reach Erosion Hazard Zones

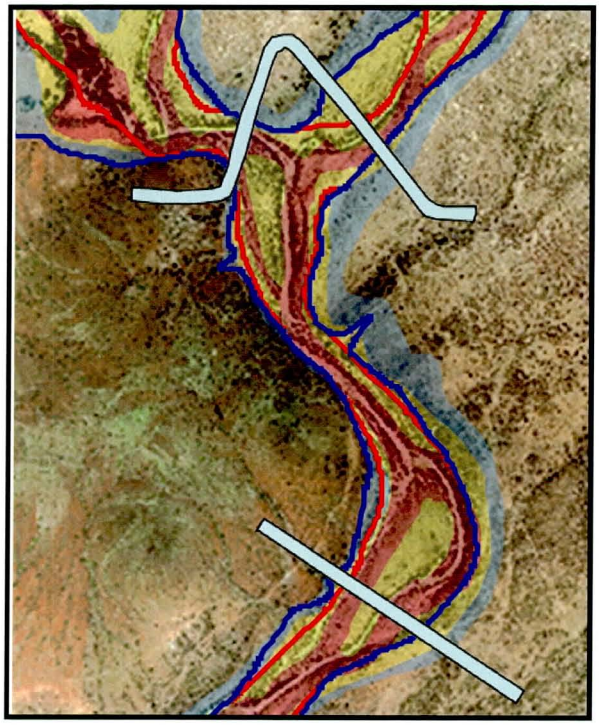


Key

- Severe Erosion Hazard Zone
- Lateral Migration Zone
- Long Term Erosion Zone
- Standard Project Flood Ponding Area
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary

Reach Key Map:

Figure 16. Hackberry Reach Erosion Hazard Zones

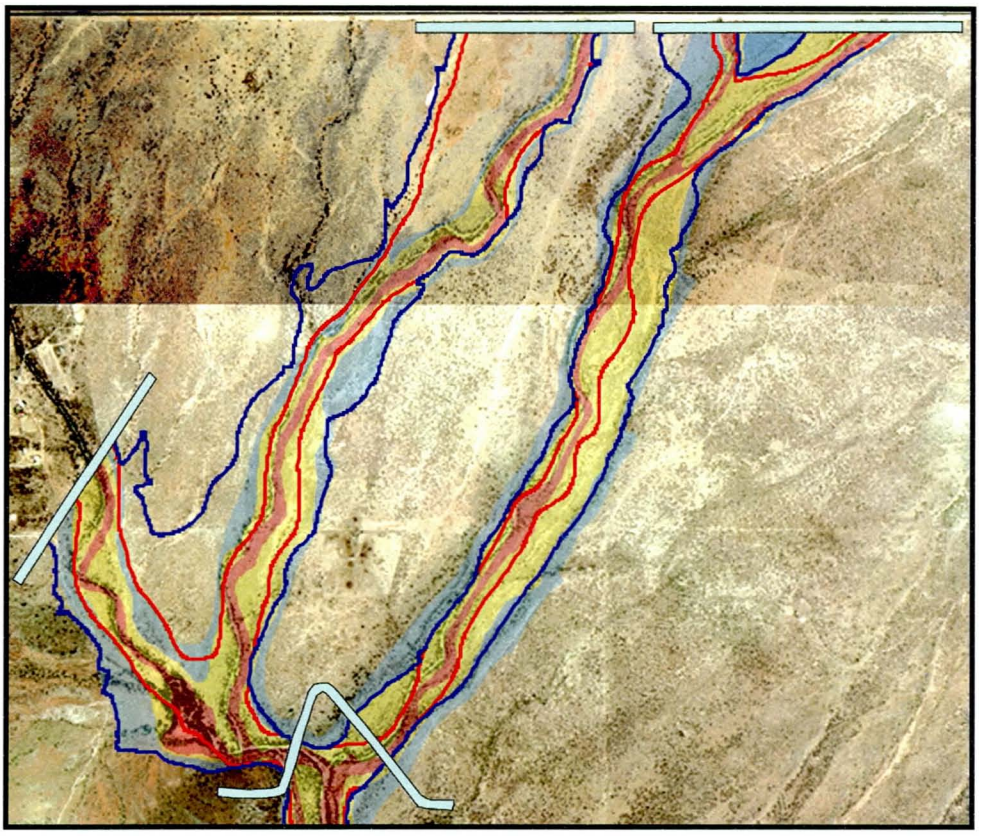


Key

- Severe Erosion Hazard Zone
- Lateral Migration Zone
- Long Term Erosion Zone
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary

Reach Key Map:

Figure 17. Union Hills Reach Erosion Hazard Zones



Key

- Severe Erosion Hazard Zone
- Lateral Migration Zone
- Long Term Erosion Zone
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary

Reach Key Map:

Figure 18. Upper Apache Reach, Paradise Reach, and Desert Hills Reach Erosion Hazard Zones

2. Lateral Migration Erosion Hazard Zone

The Lateral Migration Erosion Hazard Zone consists of the area adjacent to the ***main channel*** likely to be eroded by a "typical" series of floods over a sixty-year planning period, plus the ***erosion*** that would be caused by a single major event such as the 100-year flood. The Lateral Migration Erosion Hazard Zone also includes the natural ***channel*** movement due to geomorphic processes such as meander migration or ***channel avulsion***. The basis of mapping for the Lateral Migration Erosion Hazard Zone included the following:

- **Probability-weighted bank *erosion* that is equivalent to the HEC-6 future conditions sediment deficit applied over a 60-year planning period, plus the 100-year HEC-6 future conditions sediment deficit.**
- **2-, 10-, or 100-year regime *channel* width, if wider than the existing active *channel*.**
- **Limits of historical *channel* movement and geologically recent *channel avulsions*.**

The limits of the Lateral Migration Erosion Hazard Zone were widened in reaches where evidence of ongoing ***erosion*** was observed, and in reaches where accelerated ***erosion*** was expected due to ***channel*** bends or banks steeper than the ***natural angle of repose***. In general, the Lateral Migration Erosion Hazard Zone includes areas outside, but adjacent to, the active ***channel*** of Upper Cave Creek and its tributaries.

3. Long-Term Erosion Hazard Zone

The Long-Term Erosion Hazard Zone consists of the floodplain margin area defined by geologic evidence of ***channel*** movement over the past 60- to 1,000-years, and represents expected or potential ***channel*** movement over the next 60- to 1,000-years in the future. The boundary of the expected Long-Term Erosion Hazard Zone envelopes the results of all the predictive methods used to assess ***channel*** stability, in addition to application of engineering judgement and interpretation of the site ***geomorphology***. The basis of mapping the Long-Term Erosion Hazard Zone is the following:

- **Geomorphic mapping.**
- ***Channel* pattern development.**
- **"Meander" migration trend.**
- **Interpretation of potential impact from human activities.**

Portions of areas mapped as older geomorphic surfaces, but adjacent to active ***channels*** and floodplains, were generally included in the Long-Term Erosion Hazard Zone.

6 Watercourse Environmental Characteristics

A general environmental overview of the study area was prepared, specifically identifying the visual characteristics, biological and cultural resources, land use, and recreation opportunities based on existing information and reconnaissance-

level field investigation. The environmental characteristics were then summarized in terms of their influence on the planning process and used in the evaluation of floodplain management alternatives.

Sonoran Desertscrub Vegetation

A. Visual Analysis

The existing visual resources of the study area, which are described below, are based on readily accessible viewpoints within the study area. Readily accessible viewpoints within the study area include the hills surrounding the impoundment area of Cave Creek and Cave Buttes Dams, as well as those along the western edge of the study area. The cliff formations along the northern portion of the Upper Cave Creek also provide a limited viewing opportunity. One lone hill, which lies near the headwaters of Mesquite Tank Wash (a minor tributary to Apache Wash), provides panoramic views when standing on the top of the landform.

Stock Tank

Visual resources of the study area were evaluated in terms of the existing conditions of the landscape. The visual analysis included an identification of distinct features, areas of high and low scenic quality, and location of major viewpoints. Distinct features are those features in the landscape that make a memorable impression such as the cliff formations in the northern portion of Upper Cave Creek or the built element, Cave Creek Dam, in the southern portion of Upper Cave Creek. Scenic quality or attractiveness is based on the human perception of the inherent beauty of visual elements such as landform (mesas, valleys, and mountains), waterform (lakes, rivers, and drainages), vegetation, and built forms within the landscape.

The Visual Analysis, shown graphically on Figure 19, presents the existing conditions of the landscapes within the Upper Cave Creek/Apache Wash study area. The outstanding natural features visible from within the study area include prominent onsite and offsite landforms and vistas across Paradise Valley. The Union Hills dominate the visual setting with smaller, isolated mountain/hill landforms scattered throughout the western and northern portion of the study area. The mountain ranges visually enclose the western edge of the study area. The New River Mountains and the Bradshaw Mountains, to the north and northwest respectively, are striking features visible from the study area. The Sonoran Desert scrub vegetation creates a fabric consistent throughout the study area that is punctuated by statuesque saguaro cacti. The desert ***watercourses*** and the associated dense vegetation along their banks form distinct patterns in the landscape. The water for the stock tank near Cave Creek Dam adds an element of visual interest because of the scarceness of water features within the study area and region.

Cave Buttes Dam

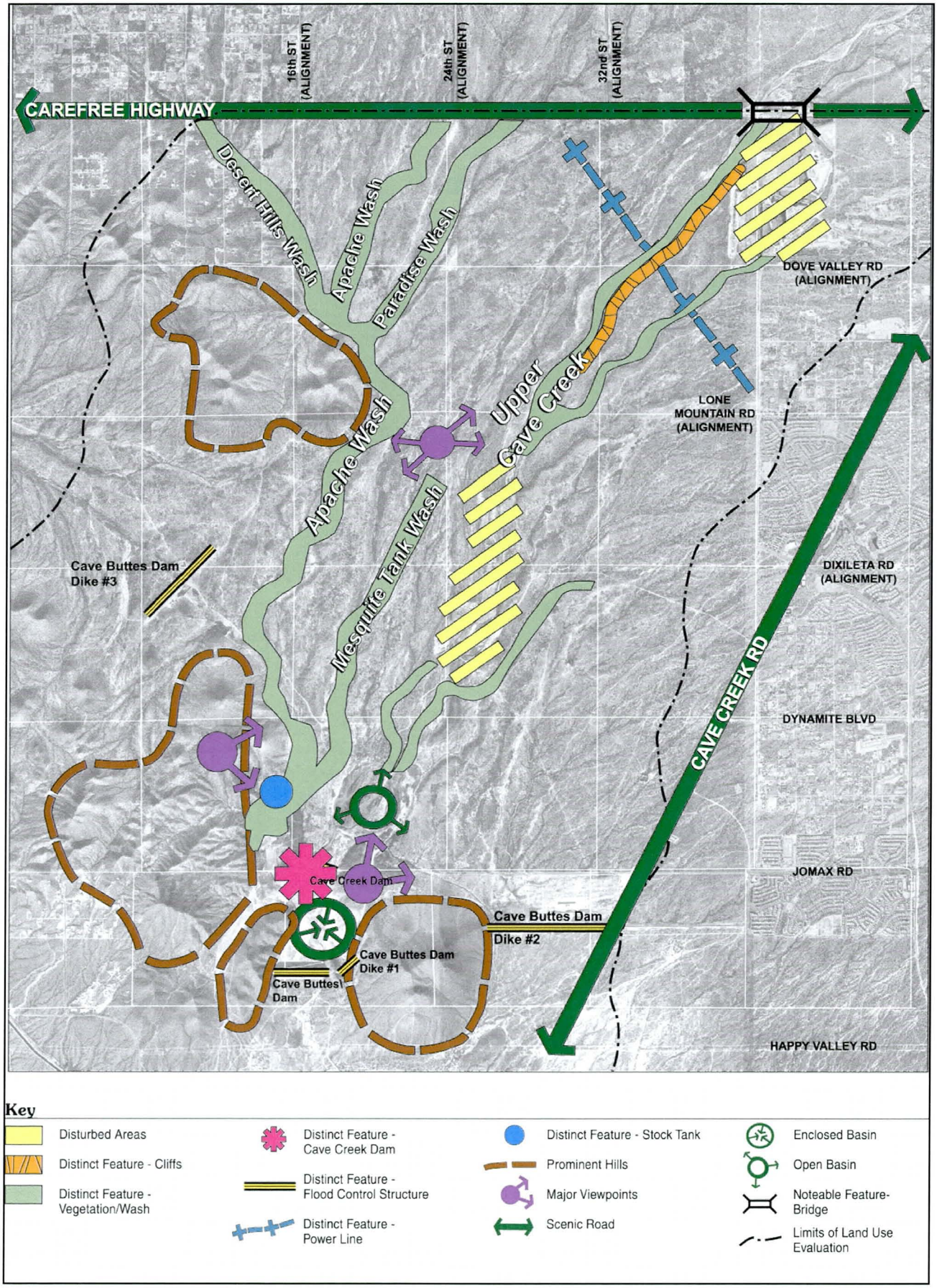


Figure 19. Visual Analysis

Built features within the study area modify the natural landscape. The distinct or memorable built features include Cave Creek Dam, Cave Buttes Dam, Cave Buttes Dam Dike #1, #2, and #3, the bridge structure at the Carefree Highway, and the major overhead transmission line and support towers. Other built features visible from the study area include the County's landfill and the residential developments associated with Dove Valley, the Town of Cave Creek, and Desert Hills.

Areas of low scenic integrity are generally landscapes that have been substantially modified from their natural conditions. The primary example of this in the study area is the large tract of land disturbed by sand and gravel mining along Upper Cave Creek. The mining operations contrast in form, line, and color with the other features in the landscape and dominate the setting along that ***reach*** of the ***watercourse***. Refer to Figure 20 for a graphic depiction of sand and gravel mining leases that have been granted by the Arizona State Land Department along Upper Cave Creek.

Cave Creek Road between Jomax Road and Carefree Highway is a portion of the Desert Foothills Scenic Drive established by Maricopa County in 1963 and adopted by the Phoenix City Council in 1986. The County also designated Carefree Highway as a Scenic Corridor in 1997 in coordination with the City of Phoenix and the other jurisdictional entities adjacent to the highway. These roadways were designated as scenic roadways in order to preserve to the extent possible the natural quality of the adjacent desert vegetation and maintain the vistas of the nearby mountains and valley areas. Both the City of Phoenix and County have established policies for development adjacent to these roadways including ***watercourse***-crossing setbacks in order to preserve the natural desert environment and vistas.

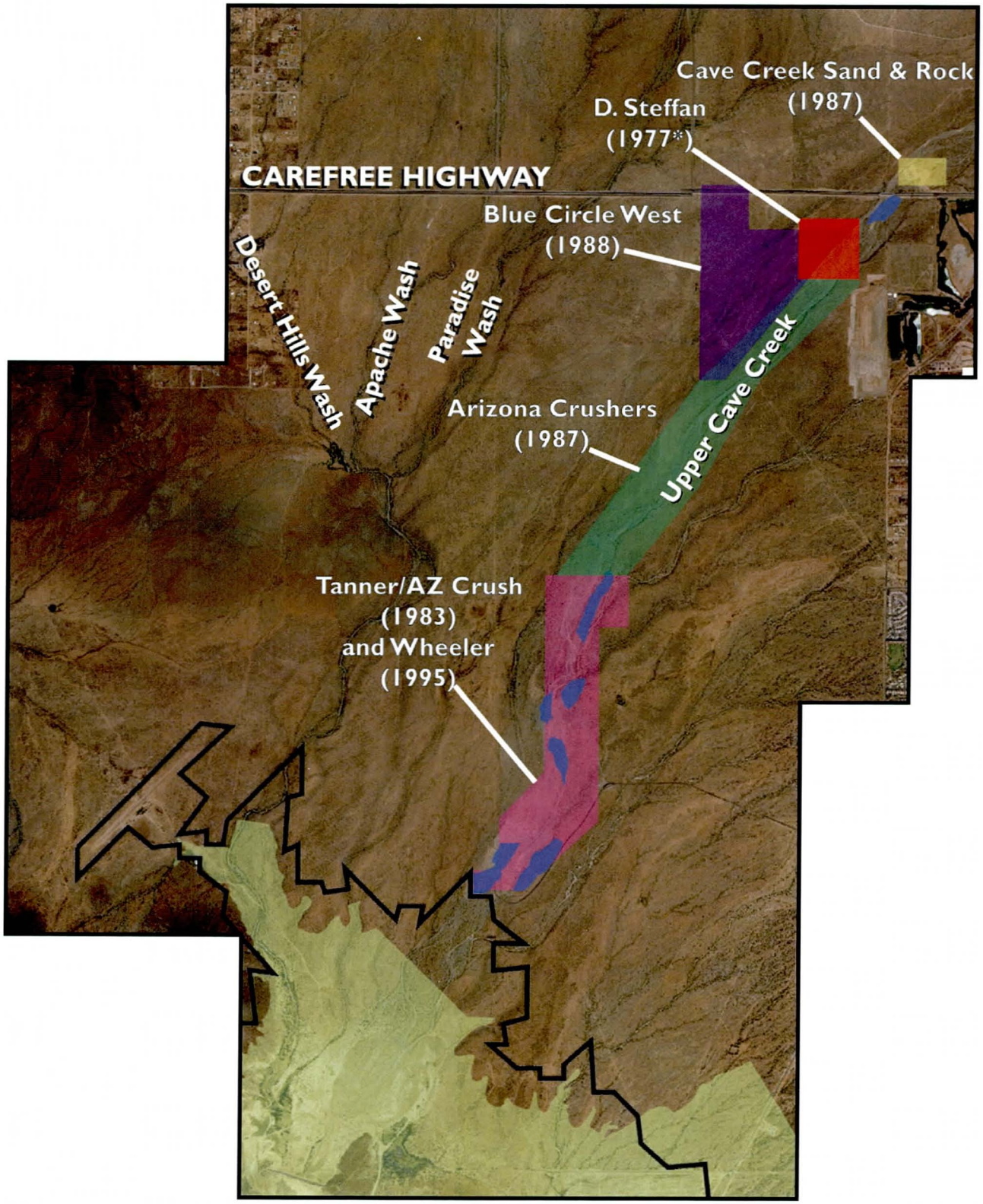
B. Biological and Cultural Resources

1. Biological Resources

The study area contains components of both the Arizona Upland and Lower Colorado River Valley Subdivisions of the Sonoran Desertscrub Biotic Community. The Lower Colorado River Valley Subdivision is more arid than the Arizona Upland Subdivision, and generally exhibits a relatively sparse tree and shrub cover. Overall, a low diversity of tree and shrub species was observed within the study area. The highest plant species diversity was found in the primary and secondary ***channels*** of the ***watercourses***, where the biotic community type is Sonoran Riparian Scrubland. No areas of standing water were observed within the study area, with the exception of a small cattle-watering pond.

The study area was evaluated in terms of its relative ***habitat values*** and types, as shown on Figure 21. ***Habitat value*** refers to the suitability of the landscape for wildlife. Relative ***habitat values*** were determined for the study area and were assigned as high, medium and low. These values reflect the overall suitability of the landscape for a diversity of wildlife species. Habitat type categorizes the landscape in terms of landforms.

Four basic habitat types were used to categorize the existing habitat within the study area. These habitat types are: (1) Streambanks, Side ***Channels*** and Slopes; (2) Upland Areas; (3) ***Main Channel***; and (4) Disturbed Areas. Streambanks, Side ***Channels*** and Slopes (Type 1 Habitat) are considered to have high ***habitat value*** where there is a high tree and shrub density, and a diverse canopy structure. Burrowing and nesting sites associated with streambank structures also offer high ***habitat value***. Upland Areas (Habitat Type 2) are considered to be moderate in ***habitat value*** relative to most Type 1 areas because of the generally more sparse vegetation, and because of the absence of landforms of high ***habitat value*** (such as streambanks) that are found in Type 1. Although the ***Main Channel*** (Habitat Type 3) exhibits the greatest plant species diversity, many of these plants are herbaceous species that do not provide the complex tree and shrub habitat structure required by many animals. The ***main channel*** of the wash is therefore considered to be generally less valuable to wildlife than Types 1 and 2. Disturbed Areas (Type 4 Habitat) are virtually 100% disturbed and without wildlife ***habitat value***.



Key

- Active Mining Areas
- Standard Project Flood Ponding Area

Figure 20. Sand and Gravel Mining Lease Areas

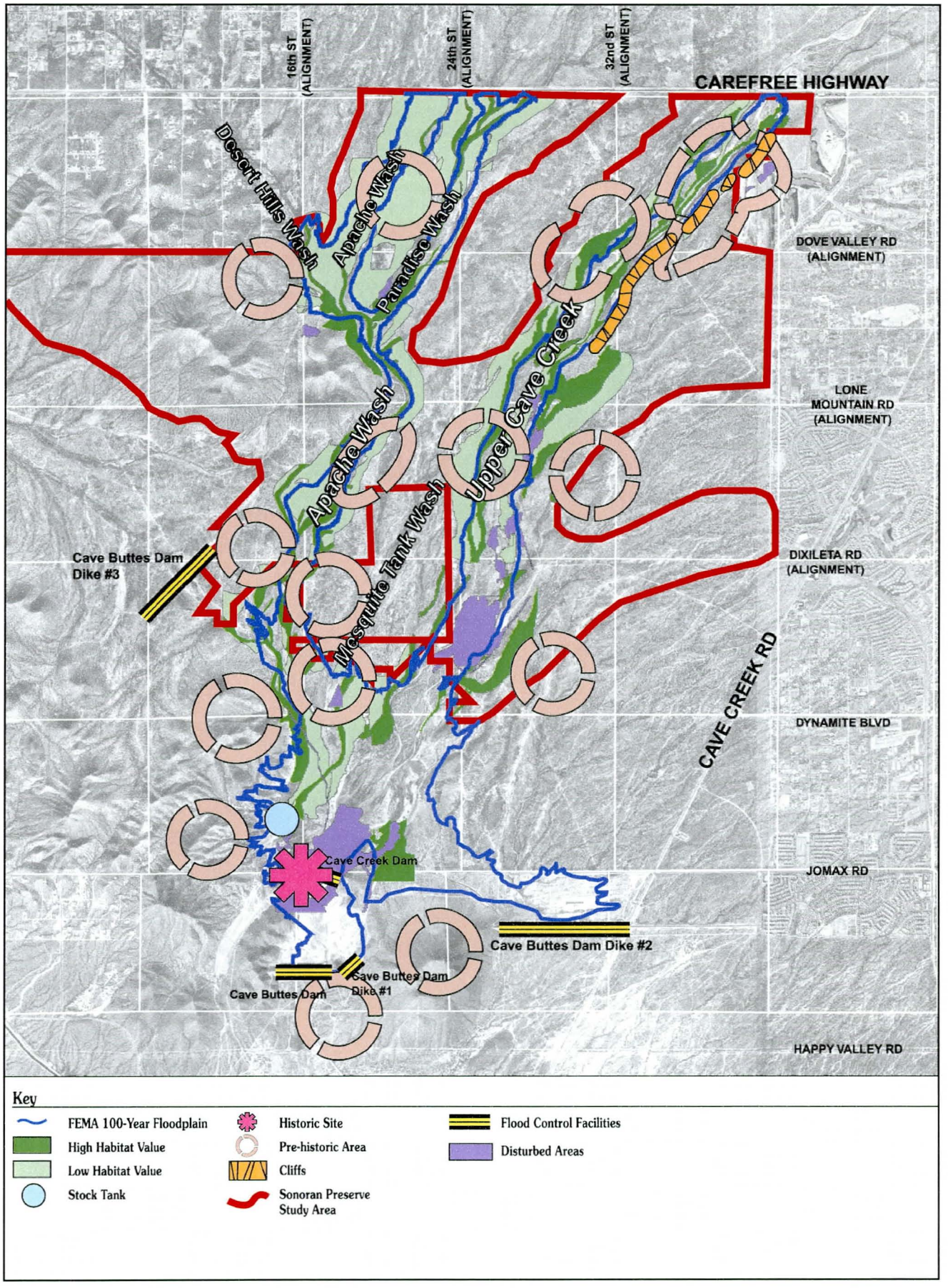


Figure 21. Biological and Cultural Features

Along much of the Upper Cave Creek ***watercourse*** in the northern portion of the study area, the ***main channel*** has eroded a steep, west-facing embankment that provides ideal burrowing and nesting sites, perches and shelters for a variety of animals. Vegetation is also present in the secondary ***watercourses*** and smaller drainages that occur throughout the study area. These smaller washes and drainages are where the highest density and diversity of tree and shrub species are found. These areas are considered to have high ***habitat value*** where there is a high tree and shrub density, and a diverse canopy structure. Burrowing and nesting sites associated with streambank structures also offer high ***habitat value***.

Burrowing and nesting area

Removal of the vegetation and modifications to the natural ***watercourse*** from the sand and gravel mine on Upper Cave Creek has resulted in an area that has low ***habitat value***. Below the sand and gravel mine, Upper Cave Creek is characterized by a broad substrate of predominantly fine sands and gravels resulting from the scouring effects of flood events. Vegetation is generally sparse with a few dominant shrub species confined to sandbars and the immediate watercourse margins. In some areas, the ***main channel*** is extensively braided and supports denser vegetation offering moderate ***habitat value***. Although the ***main channel*** exhibits the greatest plant species diversity, many of these plants are herbaceous species that do not provide the complex tree and shrub habitat structure required by many animals. The ***watercourse*** study area is therefore considered to be generally less valuable to wildlife than the portion of the Upper Cave Creek ***watercourse*** north of the Carefree Highway, outside of the study area.

Along Apache, Desert Hills, and Paradise Washes, high value habitats occur primarily along the narrow reaches with dense trees and at the southern end of Apache Wash, where mesquite bosques exist at the edges of the dam impoundment area. The narrower reaches along the base of the Union Hills are more likely used as travel corridors for wildlife.

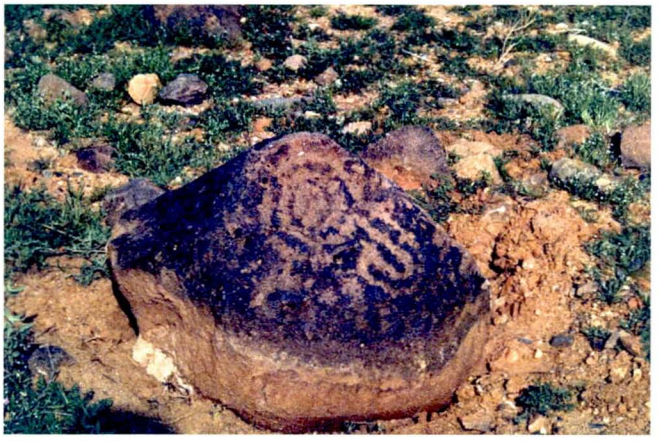
The study area is predominantly desertscrub (Type 2 Habitat) that has been degraded by cattle grazing in some areas and by sand and gravel operations. High value habitats occur primarily as narrow corridors of trees and riparian shrubs in association with side ***channels*** and along the narrow reaches with dense trees of Apache, Desert Hills, and Paradise Washes. Wider areas of Type 1 vegetation only occur near the southern end of the study area, where mesquite bosque exists at the edges of a broad clearing. The overall ***habitat value*** south of Carefree Highway is considered to be moderate.

Harris Hawk

In addition to the evaluation of relative ***habitat value*** and type, the study area was also assessed for its ability to support sensitive species. The sensitive species are those listed under the Federal Endangered Species Act, as well as species listed by the State of Arizona as Wildlife of Special Concern. Within the study area, three sensitive species are pertinent: Cactus Ferruginous Pygmy-owl (*Glaucidium brasilianum cactorum*), Harris Hawk (*Parabuteo unicinctus*) and Sonoran Desert Tortoise (*Gopherus agassizii*). Of these three species, only Harris Hawk was observed, while Sonoran Desert Tortoise sign (burrows and scat) were detected. The study area has suitable habitat for the Cactus Ferruginous Pygmy-owl, a federally listed endangered species.

2. Cultural Resources

Based on an overview of Cave Creek/Apache Wash area, between Carefree Highway and Cave Creek Dam, there is at least 90 previously documented archaeological sites. Refer to Figure 21. The overview was based on existing records from the State Historic Preservation Office, Arizona State Museum, Arizona State University, the Bureau of Land Management office in Phoenix, review of previous archaeological reports for this area (studies extending from the early 1960s to the 1990s), as well as 100% survey along both drainages conducted by Northland Research, Inc. in 1998. The majority of the previously identified sites are prehistoric, with artifact scatters, habitation sites with roomblocks, agricultural fields, and field houses. Rock alignments indicative of agricultural fields are common features documented at most of these sites. Artifacts noted at the agricultural/habitation sites include ceramics, chipped stone and groundstone artifacts. Based almost exclusively on decorated ceramics observed at sites within the project area, most can be dated to the Sedentary period (A.D. 950 to 1150) of the Hohokam cultural sequence; ceramics dating to earlier time periods in this sequence (Pioneer and Colonial periods, spanning the years from A.D. 300 to 800) have, however, been noted in small quantity at some sites.



Petroglyph

Areas of known cultural sensitivity are primarily located along the Holocene terraces of Upper Cave Creek. Surface artifacts are sparse to moderately dense on the southern end of the project area. However, there is a moderately high probability of subsurface features in this area. Based on the review of existing survey reports, any flood management features that would require excavation into undisturbed ground could potentially impact prehistoric resources within the study.

Within the study area there is a significant historic feature. Cave Creek Dam was designed by John S. Eastwood, built in 1923, and consists of 38 arches supported by 39 buttresses. The Dam is considered eligible for the National Register for Historic Places (NRHP) under criterion "a" for its association with the development of flood control projects in the Salt River Valley, and under criterion "c" as an excellent example of an early reinforced concrete multiple-arch dam construction. A draft nomination NRHP form was submitted to the State Historic Preservation Office in 1989 to place the Cave Creek Dam on the NRHP. However, the nomination process was never completed, and the Dam, although considered eligible for the NRHP, currently is not listed.

C. Land Use, Recreation, and Infrastructure

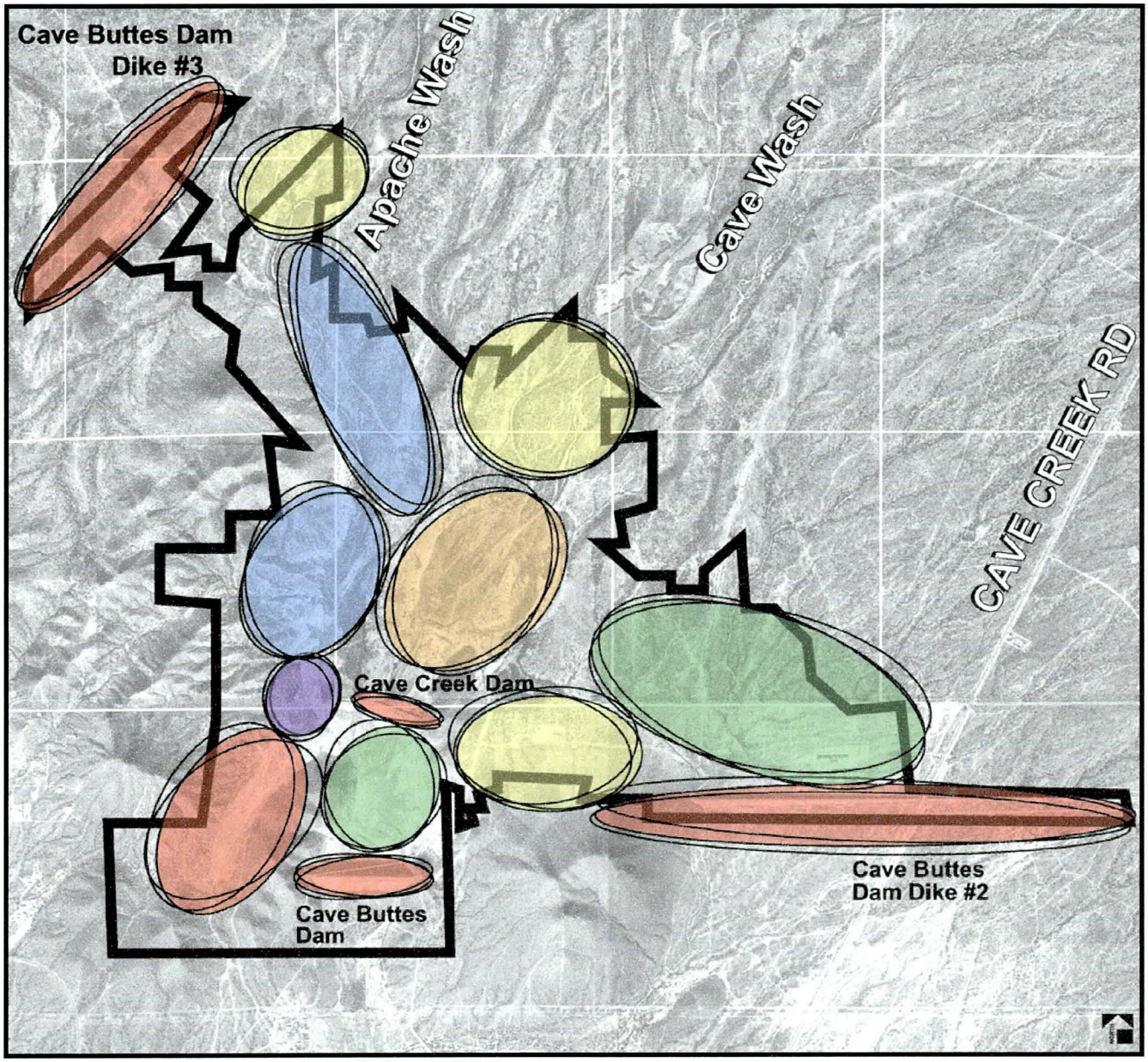
Land within the study area is predominately undeveloped. The State Land Department has issued permits for sand and gravel mining, cattle grazing, and both commercial and recreational hot air ballooning. Shooting, dumping and off-road vehicle use are unauthorized, although they occur. Off-road vehicle use, mining, and historic ranching has created a network of primitive dirt roads throughout the study area. The Flood Control District of Maricopa County (District) owns the Cave Creek Dam and Cave Buttes Dam impoundment area, in which an agreement between the District and the City of Phoenix allows for recreation to occur under the management of the City. This impoundment area is referred to as the Cave Buttes Recreation Area, and is currently being master planned by the City of Phoenix Park and Recreation Department. Multi-use trails are proposed by the City of Phoenix along the ***watercourses*** to provide links to other trails. The closest developed park (Desert Willow Park) is located about 1.5 miles east of the study area.

Existing Land Uses

A preliminary recreation concept diagram was developed by the District in 1999 to look at potential types of uses compatible with the flood management activities that could be developed within the Cave Buttes Recreation Area. Refer to Figure 22. Active use areas could be located along Jomax Road, the area north of the Cave Buttes Dike #2, and in between Cave Buttes Dam and Cave Creek Dam. (Active recreation generally refers to activities like sports courts, ball fields, and group activity areas.) These potential active use areas are relatively flat, easily accessible by the public, and would not conflict with adjacent land uses. The area immediately to the north of the Cave Creek Dam receives significant sediment deposition from the upper ***watercourse*** and requires routine maintenance to remove the sediment to maintain the flood control capacity. This sediment deposition area could be used for active recreation, but with the consideration that any buildings or recreation structures would be covered overtime with sediment deposits. Passive recreation uses could occur in the areas adjacent to the foothills in the western portion of the Recreation Area. (Passive recreation generally refers to recreation associated with trails and un-organized, informal activities.) The passive recreation use areas have more topographic relief, higher ***habitat value***, and inherent scenic value. The portions of the Recreation Area adjacent to the proposed Sonoran Preserve Area could be designated as transition areas that would link the developed recreation uses to the more passive uses associated with the Preserve. There are also locations in the Recreation Area that would not be suitable for any type or very limited recreation use because of their flood control function, such as the spillway areas to the west of the dams and the dike structures. Regardless of the type of recreation use within the Cave Buttes Recreation Area, a flood warning system would be required to advise and inform the public in case of a flood event to evacuate the area.

The majority of Upper Cave Creek, Apache Wash, Desert Hills Wash, and Paradise Wash are identified as part of the Sonoran Preserve Master Plan. The goals of the Sonoran Preserve Master Plan are to: (1) connect significant public open spaces; (2) preserve wildlife corridors and significant desert ecosystems along drainageways; (3) provide passive recreational opportunities; (4) provide alternative transportation corridors; (5) preserve significant views, cultural resources, and visual landmarks; (6) establish management, maintenance, acquisition, and funding guidelines to increase open space standards; and (7) encourage access for people of all abilities to appreciate and enjoy the Sonoran Desert. Those lands owned by the Arizona State Land Department will be purchased with part of the bond funding provided for the plan; and private parcels will be purchased with other funds. Lands not within the designated preserve area are planned for residential development, with densities to be less than 1.2 units per acre. According to the North Land Use Plan, this residential area falls within the "Desert Maintenance Zoning Overlay Sub-District A", and is intended to provide a transition from the Sonoran Preserve to areas of greater density.

As part of the City of Phoenix's Street Transportation Plan, three alternative route alignments for Lone Mountain Road are being evaluated within the study area. These route alignments cross Upper Cave Creek near the sand and gravel mine operations. The City has not yet selected the preferred route. No other new arterial streets are under consideration within the study area. New 69kV overhead transmission lines are being evaluated in the study area by Arizona Public Service (APS).



Key

- Active Use Area
- Passive Use Area
- Transition Area
- Sediment Deposition Area/ Active Non-Structural Use
- No Active Recreation Use/ Flood Control Structure
- No Recreation Use/ Flood Control Structure

Figure 22. Conceptual Recreation Use Diagram at Cave Butttes Dam

D. Planning Influences

Figure 23 illustrates the primary factors that should be considered during the development of floodplain management alternatives. The proposed Sonoran Desert Preserve lands would limit development and its associated infrastructure requirements immediately adjacent to and through the ***watercourses***. Opportunities to incorporate multi-use trails along the ***watercourses*** in accordance with the City's General Plan and Sonoran Preserve Master Plan goals should be considered, and minimally not excluded, from any proposed flood control facilities. In addition, any flood facilities visible from either Carefree Highway or Cave Creek Road should be designed to minimize visual contrast with the surrounding landscape in terms of color, scale or texture. Existing flood control structures and activities must be maintained and their function incorporated in the ***watercourse*** management plan. The proposed Lone Mountain Road alignment must be considered in the evaluation of alternatives. The alignment alternatives through the existing sand and gravel mining area would be preferred over impacting relatively undisturbed areas. Preservation areas include the proposed Sonoran Desert Preserve lands, Cave Buttes Recreation Area, and areas of high habitat, scenic, and cultural resource (both historic and prehistoric) value. Areas are also noted where the landscape would benefit from restoration of disturbed vegetation and/or landforms such as the sand and gravel mine operation.

7 Alternatives Development and Evaluation

Three flood control management alternatives, full-structural, soft-structural, and nonstructural, were developed and evaluated to meet the goals of the WCMP. For the purposes of this study, a structural measure is one that allows for construction of flood protection facilities and/or maintenance activities that result in ground disturbance. Structural solutions include engineered bank protection, channelization, grade-controls, and bio-remediation or bio-engineering such as re-vegetation activities.

The Full-Structural Alternative is a benchmark alternative, representative of the existing floodplain management policy in effect for the study area. That policy allows for ***floodplain encroachment*** up to the ***FEMA 100-year floodway*** limits. The Full-Structural Alternative is based on engineered structural solutions, including bank protection, channelization and grade-control. The Soft-Structural Alternative allows for ***floodplain encroachment*** within the ***FEMA 100-year floodplain***, as long as that ***floodplain encroachment*** does not result in unacceptable impacts within, upstream, or downstream of the study area. Structural measures for this alternative include limited bank protection, environmentally "friendly" grade-control, and bio-remediation or bio-engineered solutions. The Nonstructural Alternative defines the area the ***watercourse*** needs to function naturally, including allowance for long-term ***lateral channel migration***. The basis and components of each proposed management alternative are described in the follow sections.

A. Full-Structural Alternative

The Full-Structural Alternative is based on the current floodplain management policy that allows ***floodplain encroachment*** within the ***FEMA 100-year floodway fringe***. The ***non-encroachment area*** for the Full-Structural Alternative is therefore the ***FEMA 100-year floodway*** limits. The Full-Structural Alternative for this study is based on the use of levees or fill to protect future developments constructed within the ***FEMA 100-year floodway fringe***. A key assumption for this alternative, for cost estimating and evaluation purposes, is that the required structural improvements are constructed at one time, and not on a piecemeal basis over time.

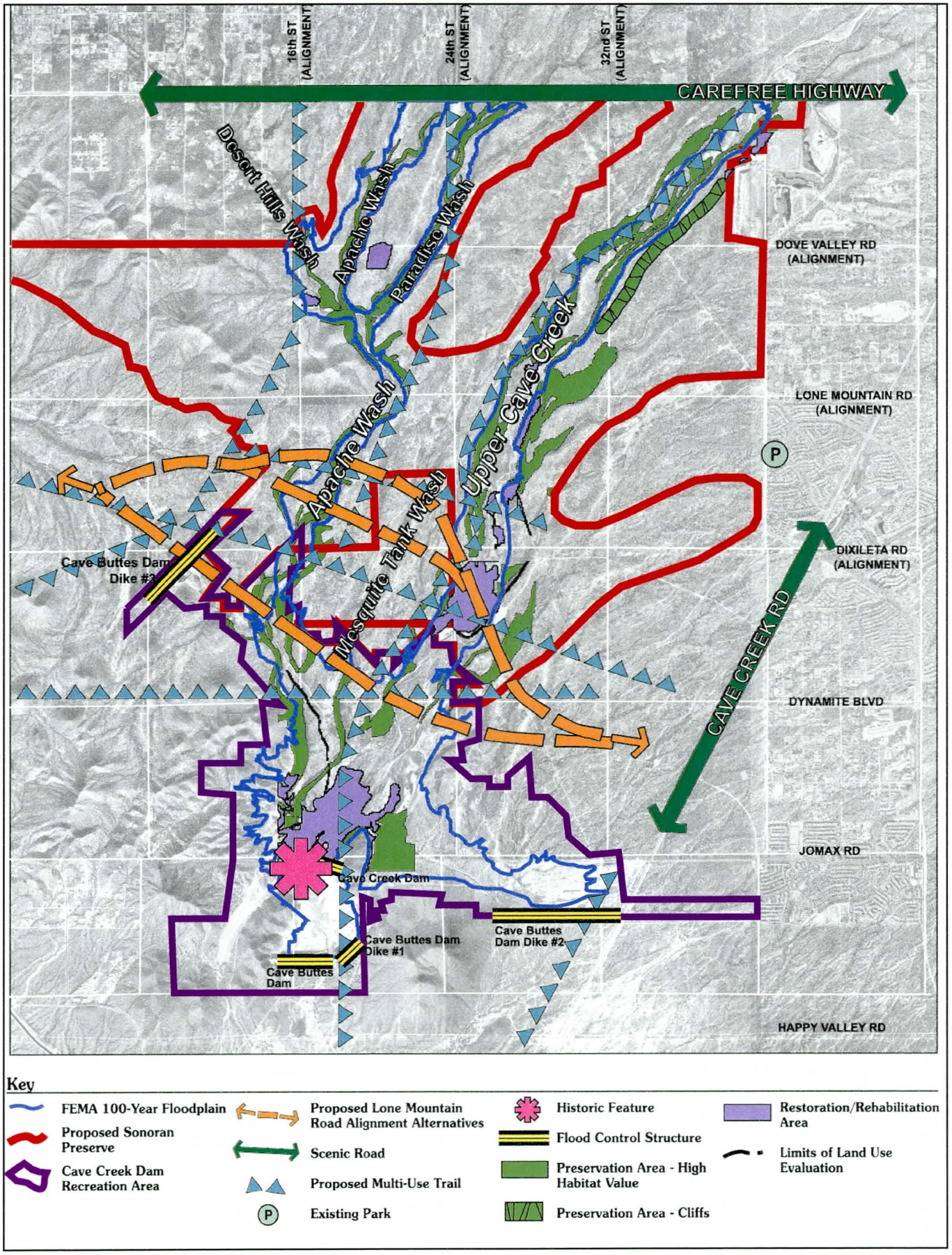


Figure 23. Planning Influences

Upper Cave Creek, Apache Wash, Paradise Wash and Desert Hills Wash were examined on a ***reach***-by-***reach*** basis to determine where structural measures were necessary to implement the alternative. This examination included determining whether the type of structural measure proposed was appropriate. The examination concluded that bank protection was necessary in all reaches except the west bank of the Union Hills Reach of Apache Wash. That bank is rock-faced, very steep, and considered non-erodible. The limits of the ***non-encroachment area*** of the Full-Structural Alternative in this ***reach*** were moved from the ***FEMA 100-year floodway*** to the Long-Term Erosion Hazard Zone boundary. The examination also concluded that bank protection was not appropriate along the east bank of the Cliff Reach of Upper Cave Creek. This bank is nearly vertical, very high (over 20 feet in some areas) and is environmentally sensitive. The cliff provides habitat for a number of wildlife species. Construction of bank protection along this cliff would result in complete destruction of the cliff face, and destruction of the sensitive habitat. Accordingly, the limits of the ***non-encroachment area*** of the Full-Structural Alternative in this ***reach*** were also moved from the ***FEMA 100-year floodway*** to the Long-Term Erosion Hazard Zone boundary.

The types of structural measures considered under this alternative include ***maximum depth bank protection***, and a single grade-control structure. Refer to Figures 24 through 29 for a depiction of the ***non-encroachment area*** for the Full-Structural Alternative for each ***reach***, the location of proposed ***maximum depth bank protection***, and the single grade-control structure. Refer to Figure 30 for a typical cross section of the features of the Full-Structural Alternative. The types of bank protection considered include:

- ***Riprap.***
- ***Gabion mattresses.***
- **Cement Stabilized Alluvium (CSA), which is a coarser form of *soil cement.***

The proposed grade-control structure is located at the upstream end of the Mined Reach on Upper Cave Creek. This structure is necessary to prevent ***head-cutting*** from occurring in an upstream direction outside the mined area. If this ***head-cutting*** were allowed to progress upstream, the toe-down depths required for bank protection would be significantly increased. The deeper bank protection would be substantially more expensive than the cost of the grade-control structure and would also result in greater disruption to the environment during construction. Refer to Figure 31 for a plan view and typical section of the proposed grade-control structure. For the purposes of this study, CSA is the proposed material for use when constructing the grade-control structure. Other materials should be considered for comparison if design of this structure becomes a reality.

Mined area creating head-cutting

The possible future alignments for Lone Mountain Road are shown on Figures 25 and 27. Bridge structures that span the ***FEMA 100-year floodway*** are recommended for the crossings of Upper Cave Creek and Apache Wash. The culverts under the Carefree Highway at Apache and Paradise Washes are undersized and should be modified to reduce the width of the ***FEMA 100-year floodplain*** at the Carefree Highway.

B. Soft-Structural Alternative

The Soft-Structural Alternative is based on the premise that any allowable ***floodplain encroachment*** may have only negligible impacts within, or upstream and downstream, of the study area. Therefore, the ***non-encroachment area*** used to evaluate this alternative is primarily the Lateral Migration Erosion Hazard Zone. For this alternative, structural measures consist of ***minimum depth bank protection***, ***maximum depth bank protection*** in portions of the Cliff Reach, the Hackberry Reach, Desert Hills Reach, Paradise Reach and Upper Apache Reach, and a grade-control structure. Similar to the Full-Structural Alternative, for cost estimating and evaluation purposes, a key assumption for this alternative is that the required structural improvements are constructed at one time, and not on a piecemeal basis over time.

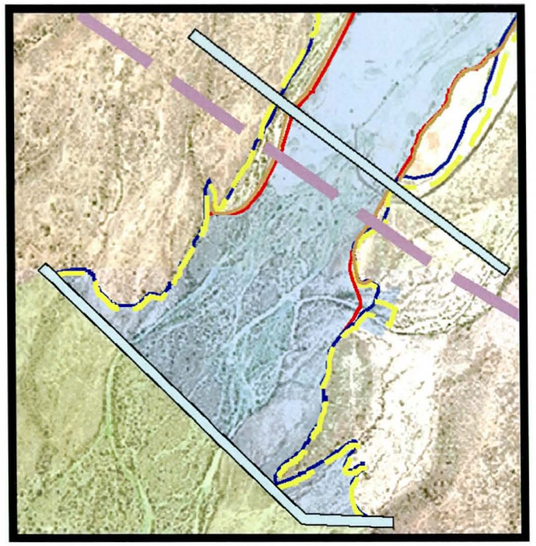
Upper Cave Creek, Apache Wash, Paradise Wash and Desert Hills Wash were examined on a ***reach***-by-***reach*** basis to determine where structural measures were necessary for the Soft-Structural Alternative. The examination concluded that bank protection was necessary where the ***non-encroachment area*** is located within the ***FEMA 100-year floodplain***, except along the west bank of the Union Hills Reach of Apache Wash. That bank is rock-faced, very steep, and considered non-erodible. The limits of the ***non-encroachment area*** of the Soft-Structural Alternative in this ***reach*** were moved from the ***FEMA 100-year floodway*** to the Long-Term Erosion Hazard Zone boundary. Note that the Lateral Migration Erosion Hazard Zone is outside the ***FEMA 100-year floodplain*** in many areas.

The types of structural measures considered under this alternative include ***minimum depth bank protection***, ***maximum depth bank protection***, and a single grade-control structure. Refer to Figures 24 through 29 for a depiction of the ***non-encroachment area*** for the Soft-Structural Alternative for each ***reach***, the location of proposed ***minimum and maximum depth bank protection***, and the single grade-control structure. Refer to Figure 30 for a typical cross section of the features of the Soft-Structural Alternative. The types of bank protection considered were the same as for the Full-Structural Alternative.

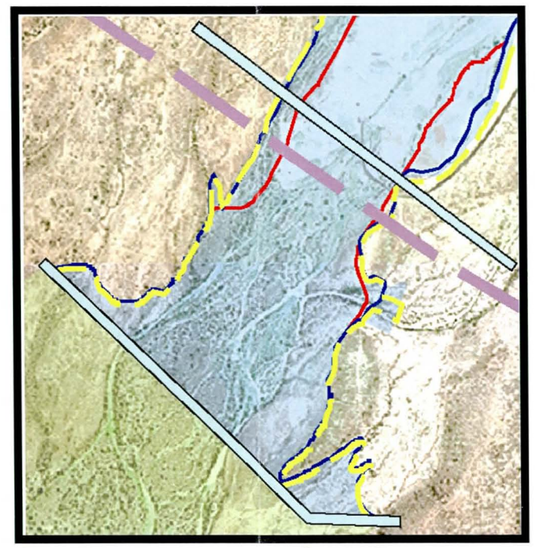
As with the Full-Structural Alternative, the proposed grade-control structure for the Soft-Structural Alternative is located at the upstream end of the Mined Reach. Reinforced concrete is the material proposed for use in constructing the Soft-Structural Alternative grade-control structure. Refer to Figure 32 for a plan view and typical section of the proposed grade-control structure. The grade-control structure proposed for the Soft-Structural Alternative is significantly more visually sensitive and more compatible to wildlife and recreation uses than that proposed for the Full-Structural Alternative.

After construction, neither grade-control structure type will be visible for most of its length for either the Full- or Soft-Structural Alternatives. However, over time, the structure may be exposed at varying locations along its length due to ***erosion*** and ***lateral channel migration***. Under the Full-Structural Alternative, a stepped ***soil cement*** face running in a straight line will be visible. Under the Soft-Structural Alternative, the structure will appear to be a natural cobble-lined feature, similar to the steeper, heavily cobbled reaches of the natural ***watercourse***. The alignment of the grade-control structure will not be linear, the exposed face will vary in slope, and pockets will be left to trap soil for native plant growth. The concrete will be colored to match the native soil, and boulders and cobbles will be hand-placed and in the face of the structure. The surface texture will be similar to the natural ***watercourse*** bottom.

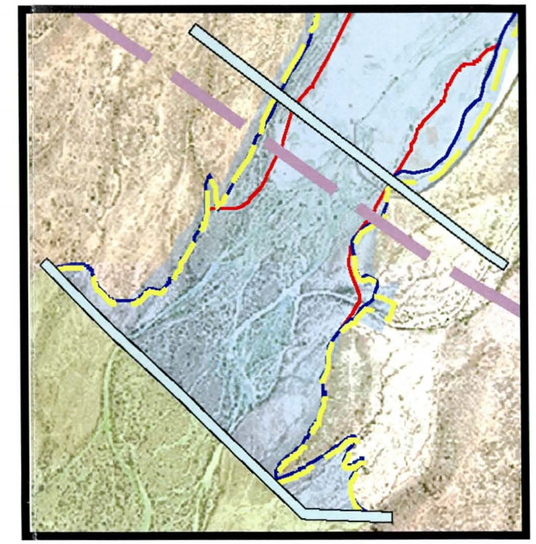
The possible future alignments for Lone Mountain Road are shown on Figures 25 and 27. Bridge structures that span the Lateral Migration Erosion Hazard Zone are recommended for the crossings of Upper Cave Creek and Apache Wash.



Full-Structural Alternative

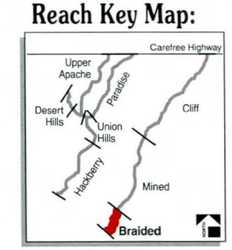


Soft-Structural Alternative



Nonstructural Alternative

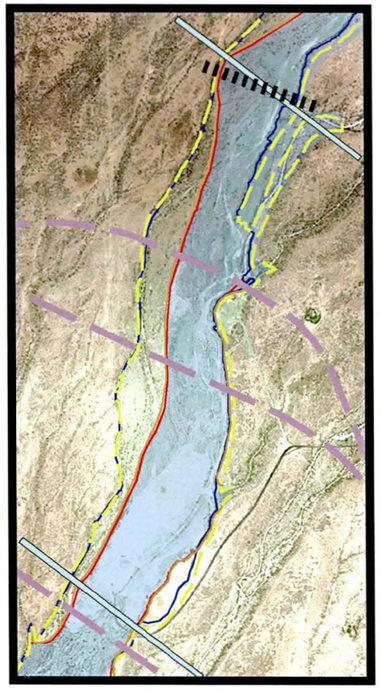
Reach Key Map:



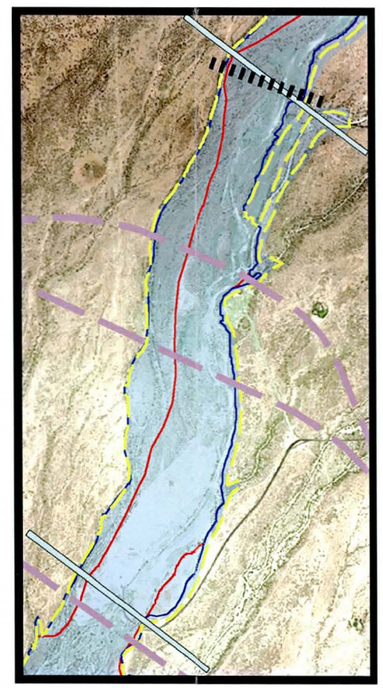
Key

- Non-encroachment Area
- Standard Project Flood Ponding Area
- Maximum Depth Bank Protection
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary
- Proposed Lone Mountain/ Utility Corridors
- Regulatory Line

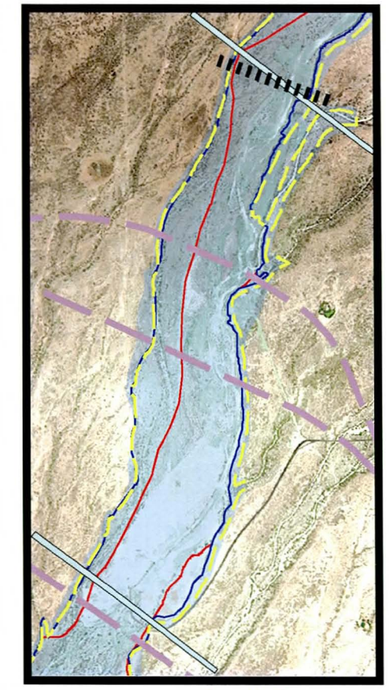
Figure 22. Braided Reach Alternatives



Full-Structural Alternative



Soft-Structural Alternative



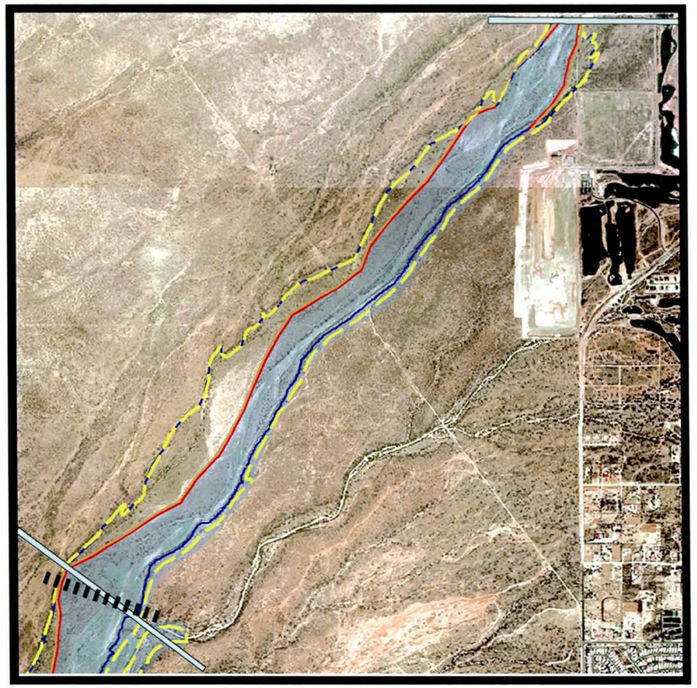
Nonstructural Alternative

Key

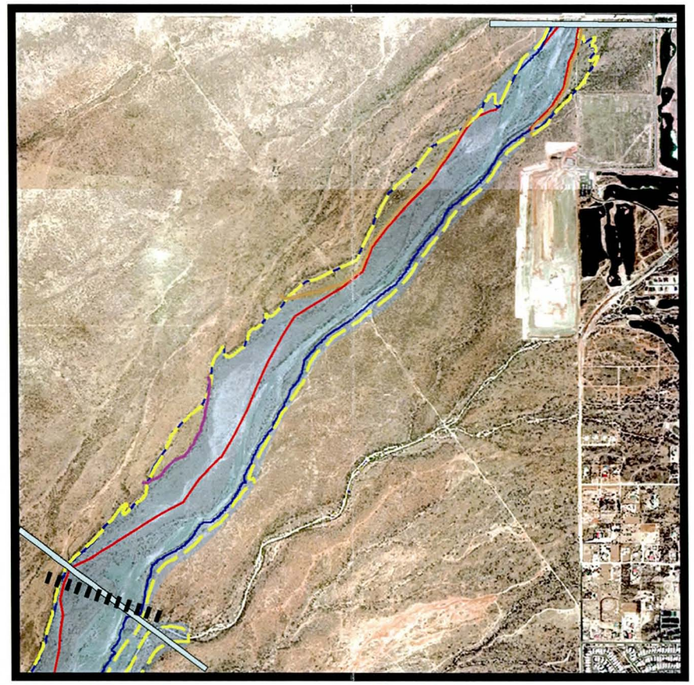
- Non-encroachment Area
- Maximum Depth Bank Protection
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary
- Grade Control Structure
- Proposed Lone Mountain/ Utility Corridors
- Regulatory Line

Reach Key Map:

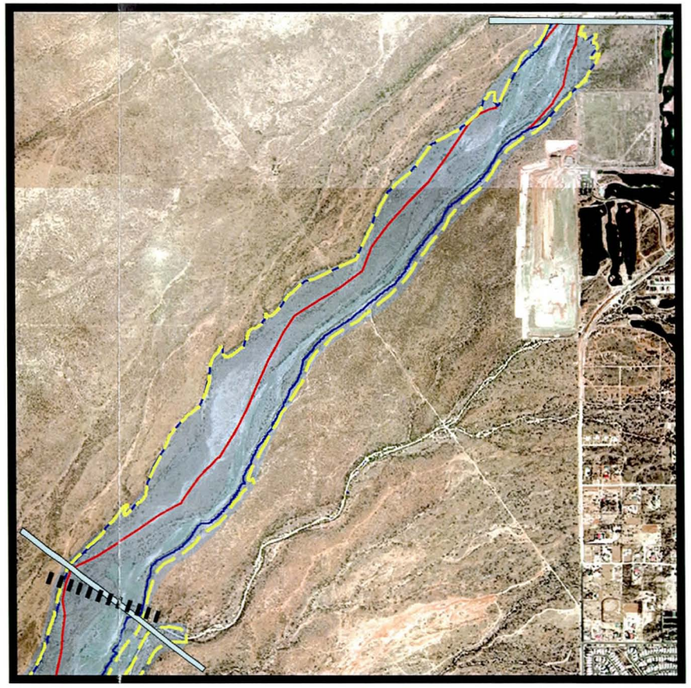
Figure 23. Mined Reach Alternatives



Full-Structural Alternative



Soft-Structural Alternative



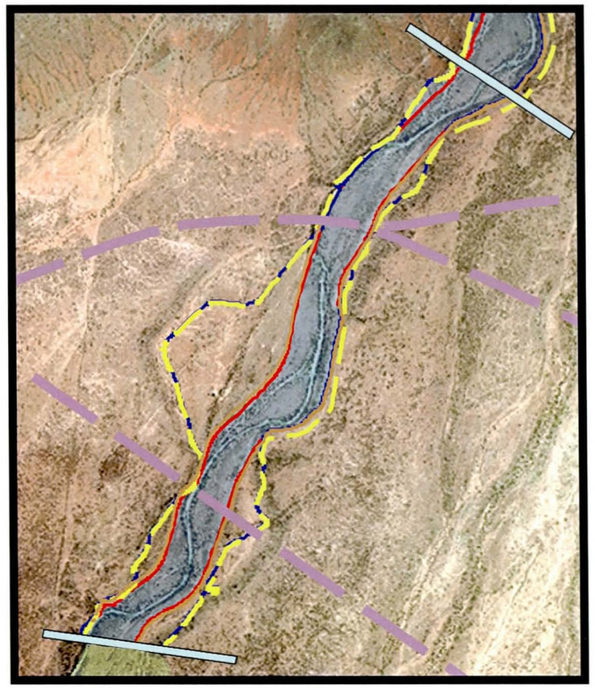
Nonstructural Alternative

Key

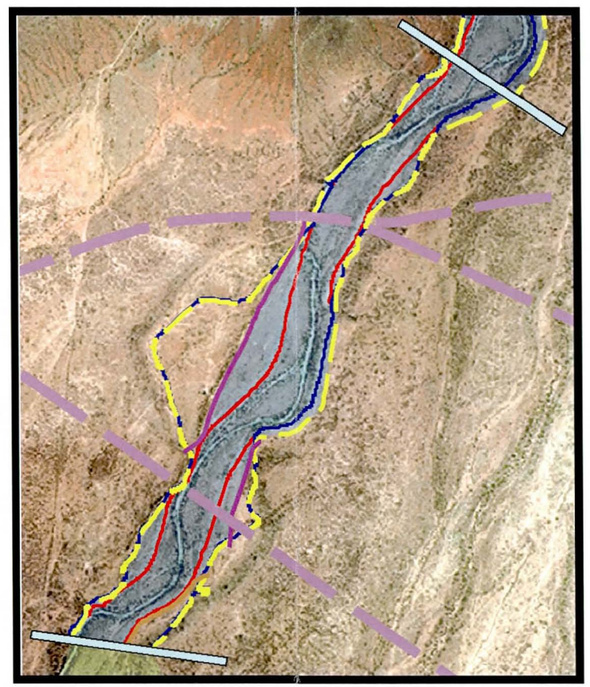
- Non-encroachment Area
- Maximum Depth Bank Protection
- Minimum Depth Bank Protection
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary
- Grade Control Structure
- Regulatory Line

Reach Key Map:

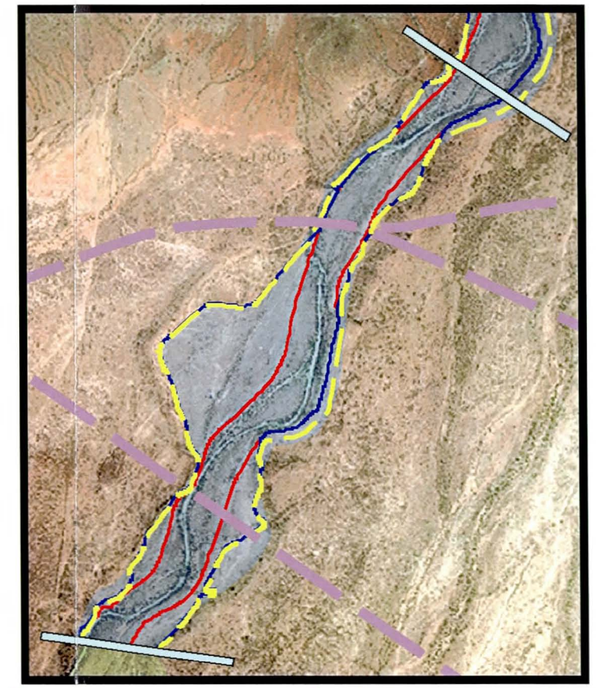
Figure 24. Cliff Reach Alternatives



Full-Structural Alternative



Soft-Structural Alternative



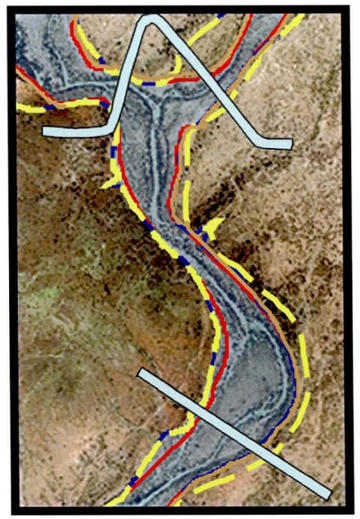
Nonstructural Alternative

Key

- Non-encroachment Area
- Standard Project Flood Ponding Area
- Maximum Depth Bank Protection
- Minimum Depth Bank Protection
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary
- Proposed Lone Mountain/ Utility Corridors
- Regulatory Line

Reach Key Map:

Figure 25. Hackberry Reach Alternatives



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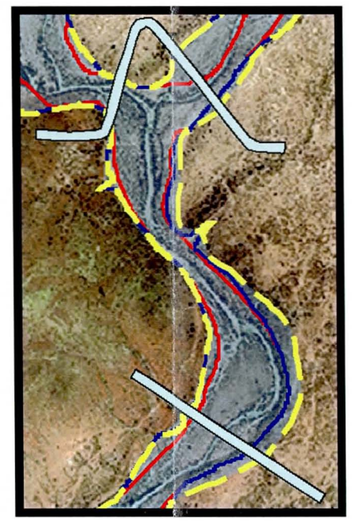
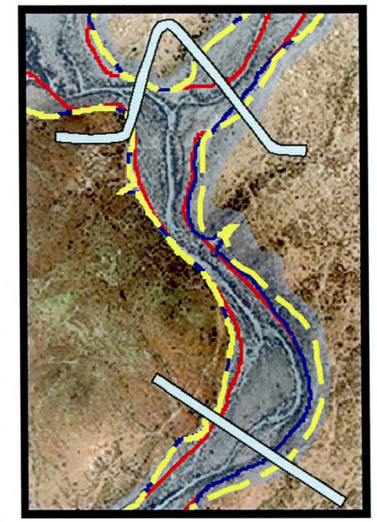


Soft-Structural Alternative



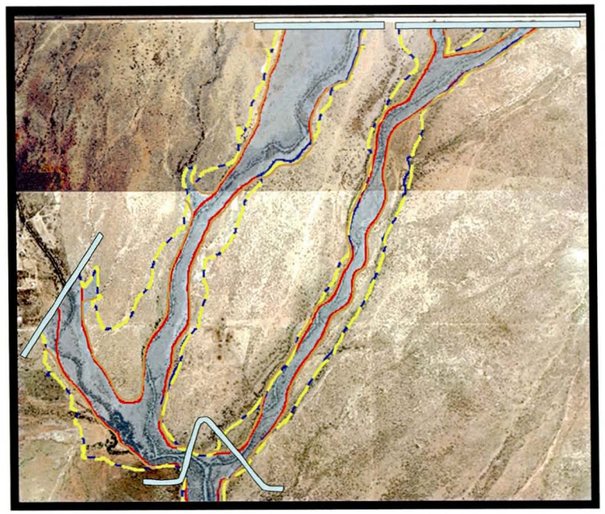
Nonstructural Alternative

Key

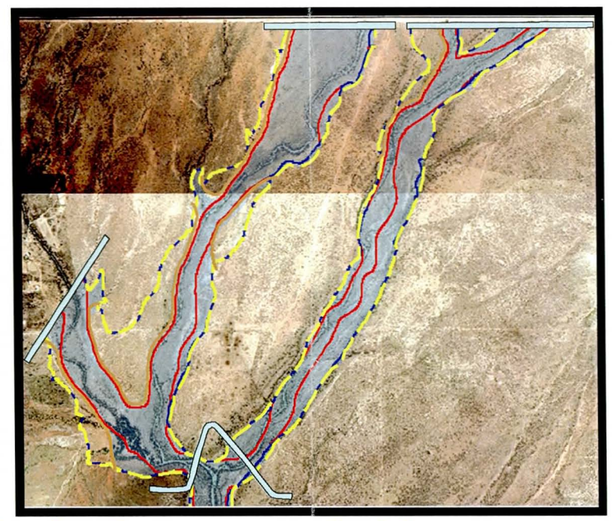
- Non-encroachment Area
- Maximum Depth Bank Protection
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary
- Regulatory Line

Reach Key Map:

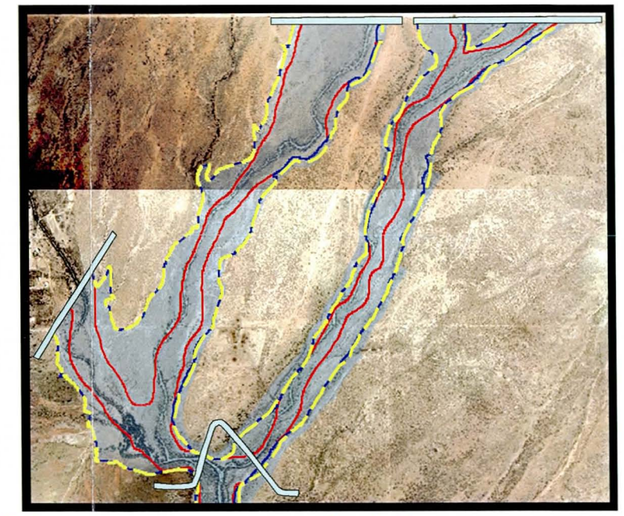
Figure 26. Union Hills Reach Alternatives



Full-Structural Alternative



Soft-Structural Alternative



Nonstructural Alternative

Key

- Non-encroachment Area
- Maximum Depth Bank Protection
- FEMA 100-year Floodplain
- FEMA 100-year Floodway
- Reach Boundary
- Regulatory Line

Reach Key Map:

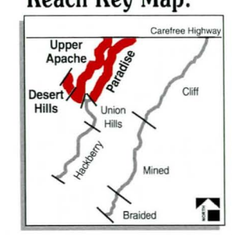
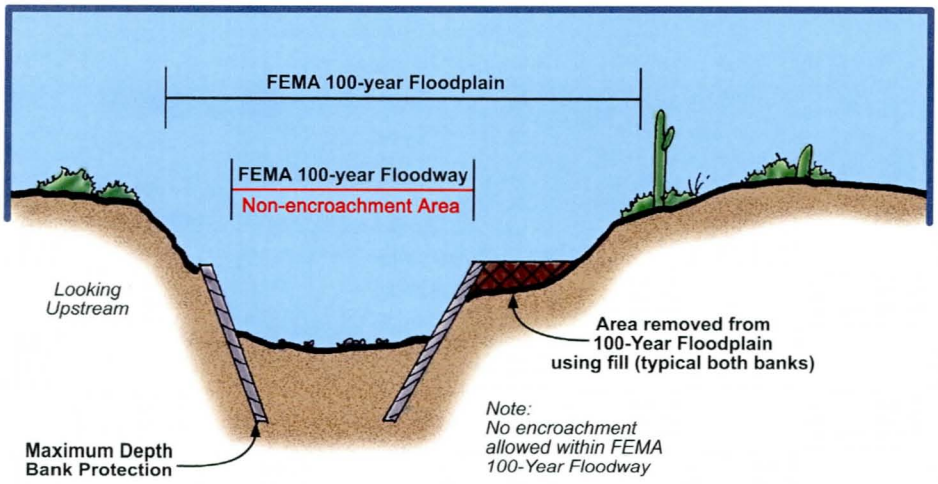
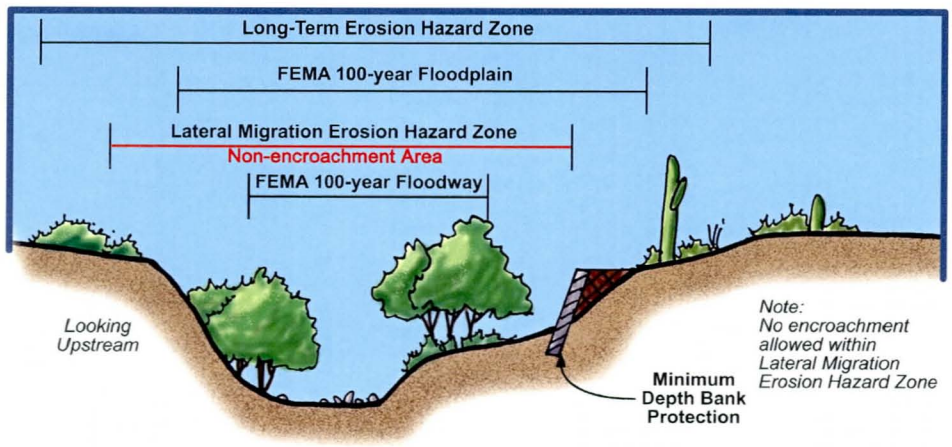


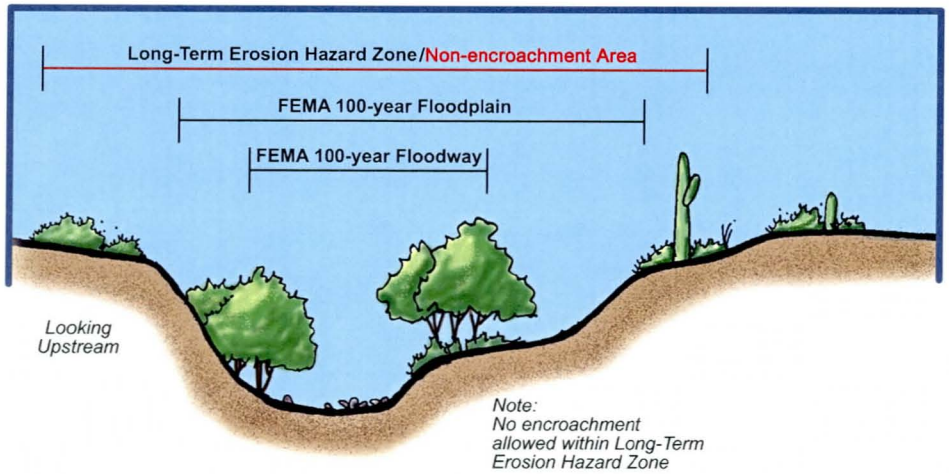
Figure 27. Upper Apache Reach, Paradise Reach, and Desert Hills Reach Alternatives



Full-Structural Alternative

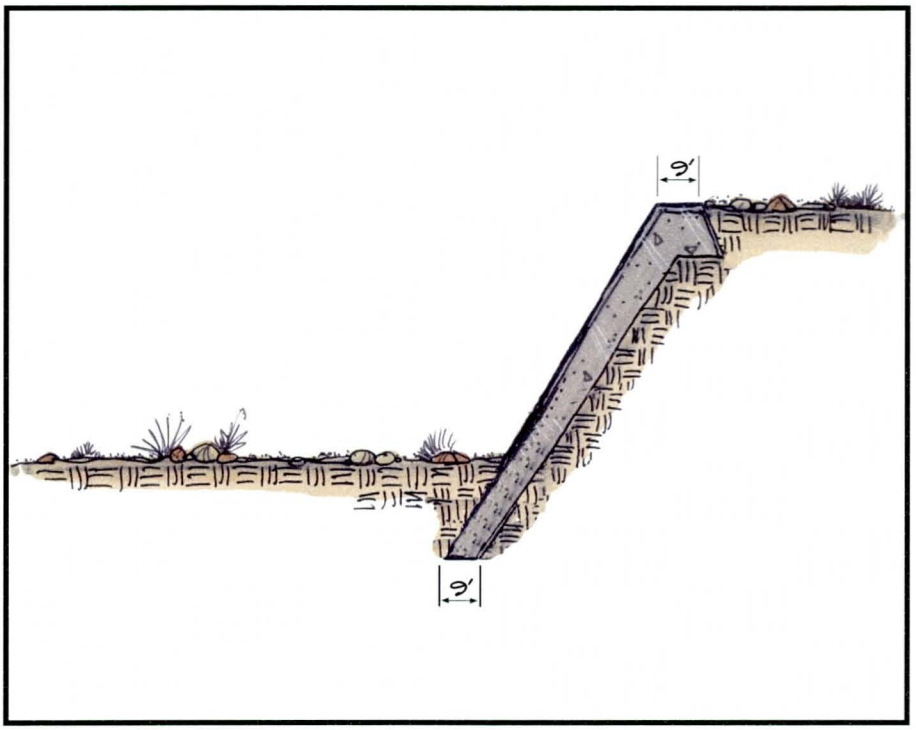


Soft-Structural Alternative

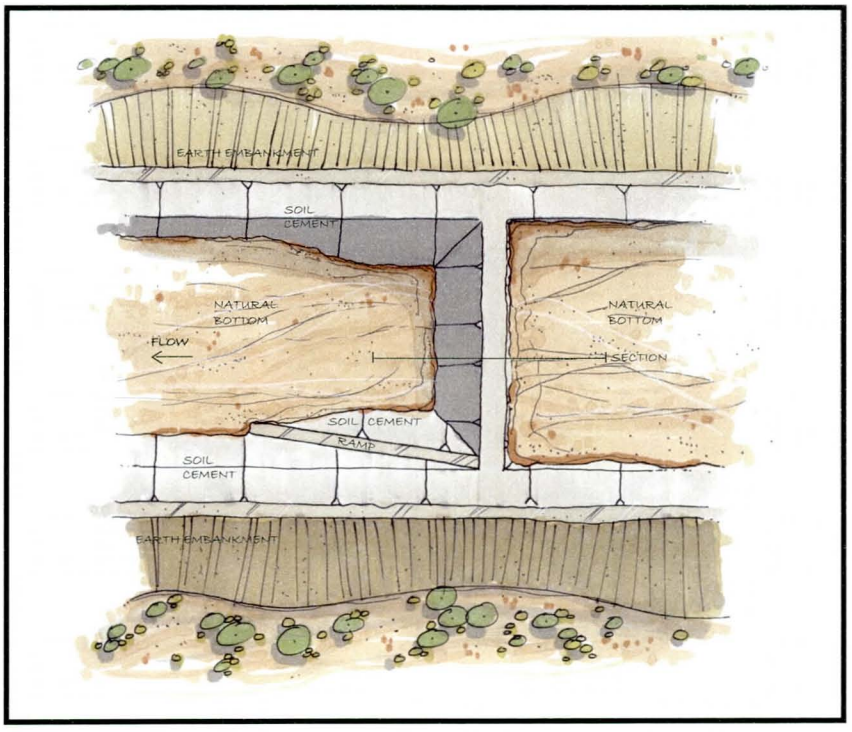


Nonstructural Alternative

Figure 30. Typical Cross-Sections

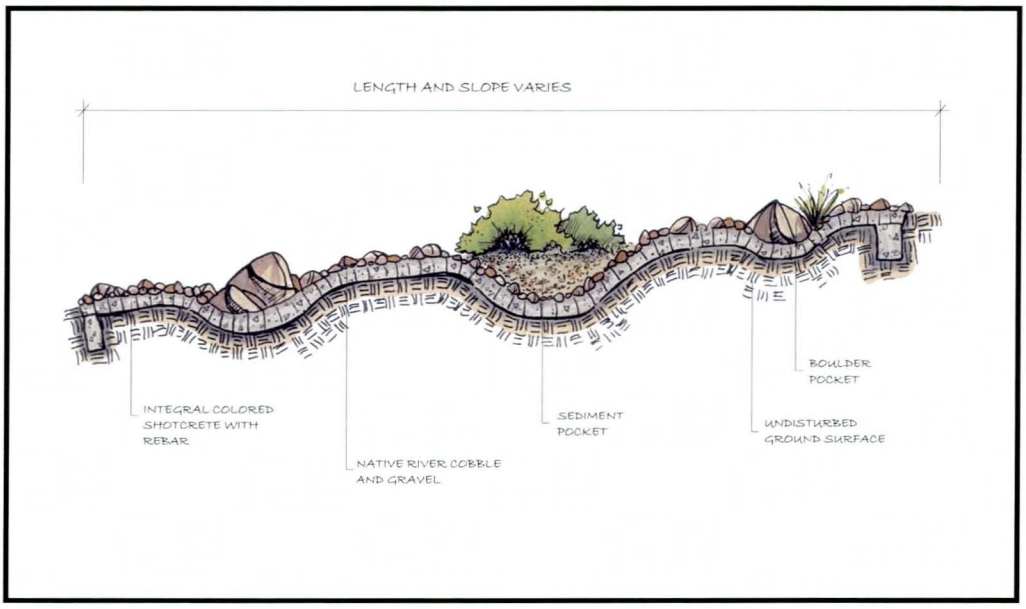


Section View

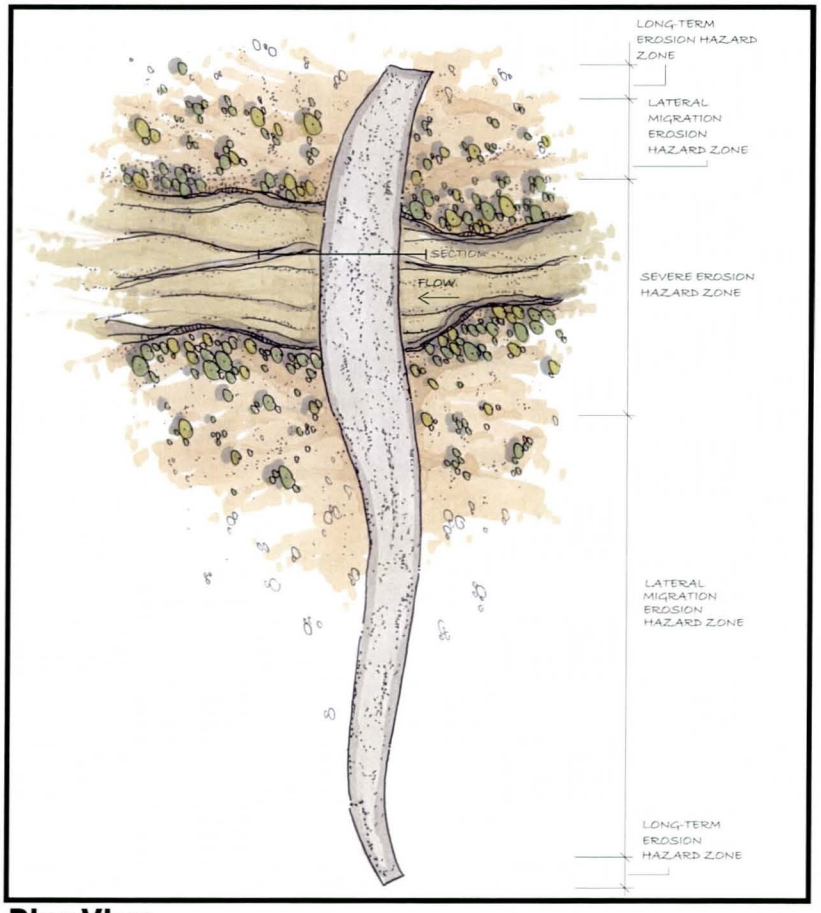


Plan View

Figure 31. Proposed Full-Structural Grade Control Structure



Section View



Plan View

Figure 32. Proposed Soft/Nonstructural Grade Control Structure

C. Nonstructural Alternative

A nonstructural flood control solution allows the ***watercourse*** environment to be sustained in its natural state. The ***non-encroachment area*** for the Nonstructural Alternative is the Long-Term Erosion Hazard Zone or the ***FEMA 100-year floodplain***, whichever is further from the ***main channel***. Refer to Figures 24 through 29 for a depiction of the ***non-encroachment area*** for the Nonstructural Alternative for each ***reach***. A nonstructural solution does not allow for flood protection construction and/or maintenance activities that result in ground disturbance. Examples of nonstructural implementation solutions include developing ordinances, property acquisition, buffer zones, specific area land use plans, vegetation management, and onsite drainage management. Strong enforcement of the implementation strategies is critical to the success of the Nonstructural Alternative.

Again, the possible future alignments for Lone Mountain Road are shown on Figures 25 and 27. Bridge structures that span the Lateral Migration Erosion Hazard Zone are recommended for the crossings of Upper Cave Creek and Apache Wash.

D. Alternative Evaluation

The proposed ***watercourse*** management alternatives were evaluated by application of criteria that measured how well each alternative met the WCMP goals. The evaluation of the management alternatives is based on three, weighted criterion: Public Safety Impacts, weighted a 10; Social/Environmental Impacts, weighted a 9; and Economic Impacts, weighted an 8. The weighting factor represents the "relative importance" of each criterion in the evaluation process. The weighting factors were measured on a scale of 1 to 10, where a score of 10 represented highest importance. The criteria and weighting factors were developed through application of a value engineering process, with consensus reached between the consultant team and representatives of the District.

A rating system was used to measure the effectiveness of each alternative at meeting each criterion. The rating system ranged from 1 to 5. A value of 1 represented a "very low" rating at meeting the goals of the WCMP, a value of 2 represented a "low" rating, a value of 3 represented a "moderate" rating, a value of 4 represented a "high" rating, and a value of 5 represented a "very high" rating. The rating factors for each criterion were established by assigning sub-criterion, or "elements", to each criterion in order to establish a composite rating factor for each of the three main criterions. The description of each element included a benchmark rating that represents the Full-Structural Alternative. The other two alternatives were measured against the Full-Structural Alternative and assigned a rating for each element accordingly. The composite rating factor was determined by normalizing the rating factors for the elements using a weighting process. The element weighting factors were also developed through the value engineering process.

The score for each criterion was obtained by multiplying the criterion weighting factor by the composite rating factor. The resulting products were summed for each alternative to obtain a total score for the alternative. The highest total score possible for an alternative was 135. The highest possible score for the WCMP is 270. The resulting evaluation criteria and weights of importance are listed in Table 5.

The evaluation for Upper Cave Creek was done separately from the Apache Wash system. The evaluation for the Apache Wash system included Desert Hills Wash and Paradise Wash. Each ***watercourse*** master plan alternative for each ***watercourse*** system received a score for each criterion, and a total score. The higher the score for an alternative, the better the alternative is at meeting the goals of the WCMP. Each criterion, and the application of the rating system to that criterion, is described below.

Table 5 Criteria and Weighting Factors for Evaluation of Watercourse Management Alternatives		
Evaluation Criteria	**Weighting Factor (0-10)**	**Maximum Possible Score ***
Public safety	10	50
Economic	8	40
Social and environmental	9	45
Maximum Possible Score for an Alternative:		**135**

* Maximum Possible Score = Weighting Factor x Rating Factor of 5

1. Public Safety Criterion

The public safety criterion is based on evaluating the threat for loss of human life and possible damage to homes and property resulting from implementation of a given alternative. This criterion is an indicator of how well the proposed management alternative will succeed in reducing or eliminating life threatening, or potentially life threatening, flood and ***erosion*** related hazards, as well as reducing the potential for flood and ***erosion*** related damage to public and private properties. This criterion is also an indicator of how well the proposed management alternative will succeed in achieving overall public safety. The rating factor for public safety was based on a composite rating of several elements. The elements assessed included ***cumulative impacts*** resulting from ***floodplain encroachment***, localized ***erosion*** resulting from intermittent ***floodplain encroachment***, uncertainties associated with the hydrologic and hydraulic models, and facilitation of emergency response. The elements also included an assessment of the risks associated with development in a hazard area, structural failures, storms greater and lesser than the design storm, and incidental hazards. A rating of 5 meant the alternative was found very effective at meeting public safety concerns. A rating of 1 meant the alternative was found least effective at meeting public safety concerns. All the elements under the public safety criterion were assumed to have equal weight. The rating factors used for the Public Safety criterion elements are shown in Table 6.

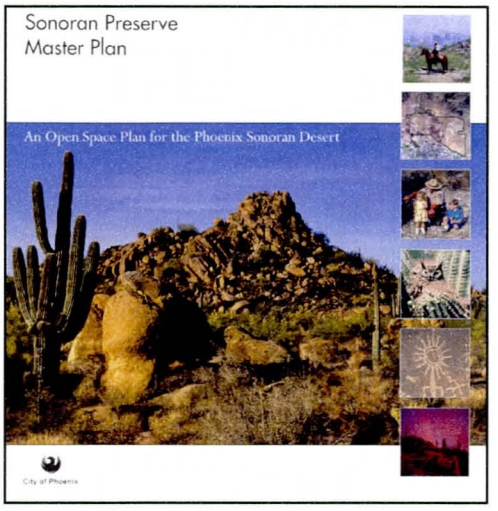
2. Economic Criterion

The rating factor for the economic criterion was based on a composite of weighted rating factors assigned to two elements, implementation and maintenance costs. The implementation cost element was an indicator of the cost of the proposed management alternative to the public, either through increased development costs passed onto future residents of the area who will directly benefit from the improvements (local public), or the costs to the general public. The costs considered include the cost of structural improvements necessary to implement the proposed management alternative (a positive cost). Also considered was the value of land within the ***Regulatory Line*** reclaimed using structural improvements (a negative cost, i.e. benefit), and the value of land outside the ***Regulatory Line*** that must be obtained to implement the alternative (a positive cost). The ***Regulatory Line*** is shown on Figures 24 through 29. The maintenance cost sub-criterion was based on an analysis of maintenance costs for structural components of the three alternatives. A rating of 5 meant that the economic cost to the public was found to be very low. A rating of 1 meant that the economic cost to the public was found to be very high. The rating factors for the Economic Criterion elements are shown in Tables 7, 8, and 9.

3. Social and Environmental Criterion

The rating factor for the social and environmental criterion was based on a composite of weighted rating factors for several elements. These elements were community acceptance, complexity of environmental permitting, impact on wildlife

habitat, visual resource and aesthetic compatibility, multi-use opportunities, and impact on cultural resources. A rating of 5 meant the alternative was found very effective at meeting social and environmental concerns. A rating of 1 meant the alternative was found least effective at meeting social and environmental concerns.



Sonoran Preserve Master Plan

The community acceptance element was based on input from the public involvement process and the fact that the study area location is primarily within the City of Phoenix Sonoran Preserve. Funding for the City of Phoenix Sonoran Preserve Master Plan was approved by 80% of the voters in 1999, indicating broad support for preservation in the City. The Sonoran Preserve Master Plan evolved through an extensive four-year public involvement process. The Sonoran Preserve Master Plan proposes the preservation of approximately 20,000 acres of desert and the natural hydrologic processes within that area, and has the force of policy by action of the City Council. This reflects the nationwide trend towards promoting non-structural approaches and ecosystem preservation, as witnessed by the removal of flood control structures in many parts of the country. Federal agencies such as the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation have, in recent years, significantly changed their focus from hard engineering solutions to include non-structural alternatives, preservation of natural hydrologic functions, and ecosystem restoration. The specific input from the public involvement process was that the preservation of ***watercourses*** and their associated habitat is more important than maximizing developable land by destroying the natural hydrologic processes, which results from encroaching into ***watercourses***. The complexity of environmental permitting element was an indicator of how compatible the proposed management alternative was with the requirements for obtaining necessary environmental permits to implement that alternative. Types of permits considered included NPDES, and Section 404 permits/401 certifications. The impact on the wildlife habitat element was an indicator of how well the proposed management alternative will succeed in preserving or restoring the natural riparian environment found along the study ***watercourses***. The most important indicator was the ability of a given alternative to preserve wildlife habitat or minimize disruption to existing habitat.

Nesting Dove

The visual resource and aesthetic compatibility element was an indicator of the overall appearance projected by the proposed management alternative. The visual resource and aesthetic compatibility criterion was based on the goals of the Sonoran Preserve Master Plan. The key goal for this criterion was maintaining the visual qualities and character identified in the Sonoran Preserve Master Plan. The multi-use opportunities element was an indicator of the potential for using the proposed management ***non-encroachment area*** for uses other than flood and ***erosion*** control. Examples of such uses included passive and active recreation, trails, and open space. The multi-use opportunity criterion was based on the extent of multi-use opportunities available from implementation of a given alternative. The impact on cultural resources criterion is an indicator of how well the proposed management alternative will succeed in preserving cultural resources. The rating factors used for the Social and Environmental criterion elements are shown in Tables 7 through 9.

The scoring results for each alternative by ***watercourse*** is shown in Tables 7 through 9. A summary of scoring for the Upper Cave Creek and Apache, Paradise and Desert Hills Washes alternatives is shown in Table 10. Refer to Attachment 8 for more detailed information on the alternative analyses.

Table 6 Rating for Public Safety Criterion			
Evaluation Criteria (1)	**Full-Structural (2)**	**Soft-Structural (3)**	**Nonstructural (4)**
Upper Cave Creek			
Cumulative encroachment impacts	3	4	5
Localized erosion impacts	4	3	5
Hydrologic modeling uncertainty	3	4	5
Hydraulic modeling uncertainty	3	4	5
Development opportunity	2	4	5
Risk of failure	3	4	5
Flood events greater than design storm	2	3	4
Flood events less than design storm	5	5	5
Emergency response	2	4	5
Incidental use	3	4	4
Average Rating for Upper Cave Creek:	**3.0**	**3.9**	**4.8**
Apache, Paradise and Desert Hills Washes			
Cumulative encroachment impacts	2	3	5
Localized erosion impacts	4	3	5
Hydrologic modeling uncertainty	3	4	5
Hydraulic modeling uncertainty	3	4	5
Development opportunity	2	3	5
Risk of failure	2	3	5
Flood events greater than design storm	2	3	4
Flood events less than design storm	5	5	5
Emergency response	2	3	5
Incidental use	2	3	4
Average Rating for Apache Wash System:	**2.7**	**3.4**	**4.8**

Table 7 Scoring for the Full-Structural Alternative			
Evaluation Criteria (1)	**Rating (1-5) (2)**	**Weighting Factor (3)**	**Score [(2)x(3)] (4)**
Upper Cave Creek			
Public Safety Criteria			
Public safety	3	10	30.0
Totals:	---	10	30.0
Composite Public Safety Criteria Rating (Score/Sum of weighting factors):			3.0
Social and Environmental Criteria			
Community acceptance	3	9	27.0
Complexity of environmental permitting	2	9	18.0
Impact on wildlife habitat	3	6	18.0
Visual resource and aesthetic compatibility	3	5	15.0
Multi-use opportunities	2	4	8.0
Impact on cultural resources	2	4	8.0
Totals:	---	37.0	94.0
Composite Social and Environmental Criteria Rating (Score/Sum of weighting factors):			2.5
Economic Criteria			
Implementation cost	4	8	32.0
Maintenance cost	3	1	3.0
Totals:	---	9.0	35.0
Composite Economic Criteria Rating (Score/Sum of weighting factors):			3.9
Apache, Paradise and Desert Hills Washes			
Public Safety Criteria			
Public safety	2.7	10	27.0
Totals:	---	10	27.0
Composite Public Safety Criteria Rating (Score/Sum of weighting factors):			2.7
Social and Environmental Criteria:			
Community acceptance	2	9	18.0
Complexity of environmental permitting	2	9	18.0
Impact on wildlife habitat	3	6	18.0
Visual resource and aesthetic compatibility	3	5	15.0
Multi-use opportunities	2	4	8.0
Impact on cultural resources	5	4	20.0
Totals:	---	37.0	97.0
Composite Social and Environmental Criteria Rating (Score/Sum of weighting factors):			2.6
Economic Criteria			
Implementation cost	5	8	40.0
Maintenance cost	2	1	2.0
Totals:	---	9.0	42.0
Composite Economic Criteria Rating (Score/Sum of weighting factors):			4.7

Table 8 Scoring for the Soft-Structural Alternative			
Evaluation Criteria (1)	**Rating (1-5) (2)**	**Weighting Factor (3)**	**Score [(2)x(3)] (4)**
Upper Cave Creek			
Public Safety Criteria			
Public safety	3.9	10	39.0
Totals:	---	10	39.0
Composite Public Safety Criteria Rating (Score/Sum of weighting factors):			3.9
Social and Environmental Criteria			
Community acceptance	4	9	36.0
Complexity of environmental permitting	3	9	27.0
Impact on wildlife habitat	4	6	24.0
Visual resource and aesthetic compatibility	4	5	20.0
Multi-use opportunities	4	4	16.0
Impact on cultural resources	4	4	16.0
Totals:	---	37.0	139.0
Composite Social and Environmental Criteria Rating (Score/Sum of weighting factors):			3.8
Economic Criteria			
Implementation cost	2	8	16.0
Maintenance cost	4	1	4.0
Totals:	---	9.0	20.0
Composite Economic Criteria Rating (Score/Sum of weighting factors):			2.2
Apache, Paradise and Desert Hills Washes			
Public Safety Criteria			
Public safety	3.4	10	34.0
Totals:	---	10	34.0
Composite Public Safety Criteria Rating (Score/Sum of weighting factors):			3.4
Social and Environmental Criteria:			
Community acceptance	3	9	27.0
Complexity of environmental permitting	3	9	27.0
Impact on wildlife habitat	4	6	24.0
Visual resource and aesthetic compatibility	4	5	20.0
Multi-use opportunities	3	4	12.0
Impact on cultural resources	5	4	20.0
Totals:	---	37.0	130.0
Composite Social and Environmental Criteria Rating (Score/Sum of weighting factors):			3.5
Economic Criteria			
Implementation cost	5	8	40.0
Maintenance cost	3	1	3.0
Totals:	---	9.0	43.0
Composite Economic Criteria Rating (Score/Sum of weighting factors):			4.8

Table 9 Scoring for the Nonstructural Alternative			
Evaluation Criteria (1)	**Rating (1-5) (2)**	**Weighting Factor (3)**	**Score [(2)x(3)] (4)**
Upper Cave Creek			
Public Safety Criterion			
Public safety	4.8	10	48.0
Totals:	---	10	48.0
Composite Public Safety Criterion Rating (Score/Sum of weighting factors):			4.8
Social and Environmental Criterion			
Community acceptance	5	9	45.0
Complexity of environmental permitting	4	9	36.0
Impact on wildlife habitat	5	6	30.0
Visual resource and aesthetic compatibility	5	5	25.0
Multi-use opportunities	5	4	20.0
Impact on cultural resources	5	4	20.0
Totals:	---	37.0	176.0
Composite Social and Environmental Criterion Rating (Score/Sum of weighting factors):			4.8
Economic Criteria			
Implementation cost	1	8	8.0
Maintenance cost	5	1	5.0
Totals:	---	9.0	13.0
Composite Economic Criterion Rating (Score/Sum of weighting factors):			1.4
Apache, Paradise and Desert Hills Washes			
Public Safety Criterion			
Public safety	4.8	10	48.0
Totals:	---	10	48.0
Composite Public Safety Criterion Rating (Score/Sum of weighting factors):			4.8
Social and Environmental Criterion:			
Community acceptance	5	9	45.0
Complexity of environmental permitting	5	9	45.0
Impact on wildlife habitat	5	6	30.0
Visual resource and aesthetic compatibility	5	5	25.0
Multi-use opportunities	5	4	20.0
Impact on cultural resources	5	4	20.0
Totals:	---	37.0	185.0
Composite Social and Environmental Criterion Rating (Score/Sum of weighting factors):			5.0
Economic Criterion			
Implementation cost	2	8	16.0
Maintenance cost	5	1	5.0
Totals:	---	9.0	21.0
Composite Economic Criterion Rating (Score/Sum of weighting factors):			2.3

Table 10 Summary of Scoring for Upper Cave Creek, and Apache, Paradise and Desert Hills Washes Alternatives							
Evaluation Criteria	**Weighting**	**Full-Structural**		**Soft-Structural**		**Nonstructural**	
(1)	**Factor (2)**	**Rating (3)**	**Score* (4)**	**Rating (5)**	**Score* (6)**	**Rating (7)**	**Score* (8)**
Upper Cave Creek							
Public Safety Criterion	10	3.0	30.0	3.9	39.0	4.8	48.0
Social and Environmental Criterion	9	2.5	22.5	3.8	34.2	4.8	43.2
Economic Criterion	8	3.9	31.2	2.2	17.6	1.4	11.2
Total Scores for Upper Cave Creek:	---	---	**83.7**	---	**90.8**	---	**102.4**
Apache, Paradise and Desert Hills Washes							
Public Safety Criterion	10	2.7	27.0	3.4	34.0	4.8	48.0
Social and Environmental Criterion	9	2.6	23.4	3.5	31.5	5.0	45.0
Economic Criterion	8	4.7	37.6	4.8	38.4	2.3	18.4
Total Scores for Apache Wash System:	---	---	**88.0**	---	**103.9**	---	**111.4**
Watercourse Master Plan							
Public Safety Criterion	---	---	57.0	---	73.0	---	96.0
Social and Environmental Criterion	---	---	45.9	---	65.7	---	88.2
Economic Criterion	---	---	68.8	---	56.0	---	29.6
Watercourse Master Plan Total Scores :	---	---	**171.7**	---	**194.7**	---	**213.8**

8 Recommended Watercourse Master Plan

The recommended management plan for the WCMP is the Nonstructural Alternative. The most important criterion for evaluation of the WCMP alternatives is public safety. The Nonstructural Alternative achieved a total score of 96.0, as compared to scores of 57.0 and 73.0 for the Full-Structural and Soft-Structural Alternatives, respectively. The Nonstructural alternative achieved a total score of 102.4 out of a possible 135 points for Upper Cave Creek, a total score of 111.4 points for the Apache Wash system, and a combined total of 213.8 points for the WCMP study area. These total scores exceeded the scores for the other two alternatives. The Nonstructural Alternative is clearly the most successful at meeting the WCMP goals. A key factor supporting the Nonstructural Alternative is that it also meets the corresponding goals of the Sonoran Preserve Master Plan.

The State Land included within the ***non-encroachment area*** of the Non-Structural Alternative, which is the vast majority of the area, is entirely within the land slated for purchase under the Arizona Preserve Initiative. However, an API designation does not guarantee preservation. The API designation is only good for a maximum of 7 years. After that time frame, the State Land Department is free to place the land on the open market for development. If sold, the State Land Department must sell the land at market value. It is recommended that the land within the ***non-encroachment area*** of the Nonstructural Alternative be designated a very high priority for acquisition under the API. Successful implementation of the Nonstructural Alternative is contingent upon the land acquisition, or if land acquisition becomes infeasible, upon regulatory control of that area through such methods as zoning and density transfers.

Cliffs of Upper Cave Creek

9 Glossary

100-year Storm - A storm with a 100-year ***recurrence interval***. The 100-year storm for the study area results from 5.0-inches of precipitation within a 24-hour period. The 2-year and 10-year storms result from a 24-hour precipitation of 2.3-inches and 3.4-inches, respectively.

Acre-feet - An acre-foot of sediment is an acre of land covered by sediment 1 foot deep.

Aggradation - Aggradation is the progressive raising, over time, of a channel bed in a ***reach*** due to ***sedimentation***.

Avulsion - An avulsion occurs when the ***main channel*** relocates to another part of the floodplain during a flood. This movement may occur suddenly as a result of a single large storm, although a series of floods over a long period of time may also contribute to the avulsive process.

Bajada - A broad, continuous sloping plain, formed by progressive sediment deposition, extending from the base of a mountain range.

Bed-form scour - The bed-form scour component accounts for the dynamic changes that occur in the shape of a moveable channel bed during passage of a flood. The bed of a sand and gravel channel actually forms wave-like anti-dunes with accompanying troughs, which migrate during a flood event. The trough depth must be included in the estimate of total scour depth.

Braided Watercourse - A braided ***watercourse*** is one which contains multiple channels that interconnect with each other. The floodplain of a braided ***watercourse*** is typically broader than other types of ***watercourses***.

Channel - For the purpose of this study, a channel is defined as the portion of a cross section of a ***watercourse*** that carries stormwater. A channel is characterized by its bed and banks. The channel bed is made up of sand, gravel and/or cobbles. The channel banks may be heavily vegetated or have exposed soils. A ***watercourse*** cross section can have multiple channels. These channels may vary in elevation in relation to each other.

Computer Models - Computer models are used in this study to simulate natural functions for existing watershed and ***watercourse conditions***, and to predict future watershed and ***watercourse conditions***. The following computer models are used in this study:

- **Hydrology:** US Army Corps of Engineers HEC-1 program.
- **Hydraulics:** US Army Corps of Engineers HEC-2 and HEC-RAS programs.
- **Sediment Transport:** US Army Corps of Engineers HEC-6 program.

Cumulative Impacts - For the purpose of this study, cumulative impacts are a decrease in public safety, or an increase in cost to the public, within, upstream or downstream of the WCMP study area, resulting from implementation of a proposed management alternative. The key indicator for determining the existence of cumulative impacts is an increase in peak discharge resulting from ***floodplain encroachment***. A change in peak discharge, increasing in the downstream direction as

a result of ***floodplain encroachment***, typically results in increases in flow depth and velocity, and adversely affects the ***sedimentation*** and ***erosion*** characteristics of the ***watercourse***. These effects can jeopardize existing structural flood control improvements or result in increased damage to property. Cumulative impacts have the effect of increasing the cost of floodplain management to the public.

Degradation - Degradation is the progressive lowering, over time, of the channel bed in a ***reach*** due to ***erosion***.

Ephemeral Watercourse - An ephemeral ***watercourse*** is one in which runoff occurs only in direct response to precipitation. An ephemeral ***watercourse*** does not have water flowing in it year round.

Erosion - For the purpose of this study, erosion is defined as the natural process of flowing water removing soil, sand, gravel, or cobbles within a ***watercourse***. Erosion has the effect of changing the ***watercourse*** geometry and increasing conveyance capacity. Erosion occurs naturally along all ***watercourses***, but can be accelerated by human activities such as removal of bank vegetation, sand and gravel mining, or urbanization.

Existing Watershed Conditions - For the purpose of this study, existing watershed conditions are defined as the watershed conditions at the beginning of the WCMP project in April 1998.

FEMA Base Flood Elevation - The FEMA Base Flood Elevation (BFE) is the elevation of the 100-year water surface elevation at the location in question.

FEMA 100-year Floodway Fringe - The FEMA 100-year floodway fringe is defined by FEMA as the area inside the FEMA 100-year floodplain and outside the FEMA 100-year floodway. According to FEMA regulations, buildings or other obstructions to flow can be constructed in the FEMA 100-year floodway fringe provided the structures used for human habitation are raised above the BFE.

FEMA 100-year Floodplain - The FEMA 100-year floodplain is defined by FEMA as an area that is flooded by a 100-year ***recurrence interval*** storm. The area so defined is based on existing watershed and ***watercourse conditions*** at the time of the study. It does not include the effects, over time, of erosion and ***sedimentation*** in the ***watercourse***.

FEMA 100-year Floodway - The FEMA 100-year floodway is defined by FEMA as an area that is reserved for conveyance of floodwaters, in which buildings or other obstructions are not allowed. The FEMA 100-year floodway limits are established by determining the amount of fill that can be placed in the 100-year floodplain without increasing the 100-year depth of flow by more than 1-foot.

Floodplain Encroachment - Floodplain encroachment, as defined by FEMA, means that development, including residential or commercial improvements, could be constructed within the FEMA 100-year Floodway fringe. This could be accomplished using fill to raise building floor elevations above the FEMA 100-Floodplain elevation, or constructing levees to isolate the FEMA 100-year floodway fringe from the FEMA 100-year floodway.

Future Watershed Conditions - For the purpose of this study, future watershed conditions are defined as the watershed conditions resulting from future build-out development of the watershed in accordance with the 1995 MAG General Land Use Plan.

Gabion mattress - A gabion mattress is a wire basket filled with rock that is used as a structural measure for erosion protection.

Geomorphology - Geomorphology is the study of earth landforms and the processes that shape and change them.

Habitat Value - Habitat value refers to the suitability of the landscape for wildlife. Relative habitat values were determined for the study area and were assigned as high, medium, and low.

Head-cut - For the purpose of this study, a head-cut is defined as the upstream migration of a steep drop in the channel bottom. Such a drop can materialize through a sudden increase in the slope of a channel that can be natural or human-induced, which in turn increases the velocity and the erosive potential of the flowing water. This could impact a ***watercourse*** for miles. The head-cut can also be created directly through human activities, such as in-stream sand and gravel mining.

Hydraulics - For the purposes of this project, hydraulics is defined as the study of the ability of the ***watercourse*** to carry storm water. The hydraulic models are used to estimate the depth, width, velocity, energy, and travel time of flow through the study area.

Hydrology - For the purposes of this project, hydrology is defined as the study of surface water runoff from the contributing watersheds. The hydrology models are used to estimate watershed runoff volumes and peak flow rates in relation to time during storm events, for both existing and future conditions.

Lateral Channel Migration - For the purpose of this study, lateral channel migration is defined as the movement of a channel within its floodplain through the processes of bank erosion or channel avulsions. Bank erosion is a natural process whereby soil material is removed from the channel banks during floods.

Main Channel - The main channel is defined as a channel that is continuous throughout the ***watercourse*** and carries the most flow.

Maximum Depth Bank Protection - Maximum depth bank protection is used where a ***watercourse*** management alternative allows development within the FEMA 100-year floodway fringe and the main channel is either at that location or can potentially migrate horizontally to that location. Maximum depth bank protection is located according to the requirements of the ***watercourse*** management alternatives. For example, the Full Structural Alternative presented in section VII specifies that maximum depth bank protection be constructed along the FEMA 100-year floodway limits.

Minimum Depth Bank Protection - Minimum depth bank protection is used where a ***watercourse*** management alternative allows development within the FEMA 100-year floodway fringe, but the main channel is not expected to migrate horizontally to that location. The minimum depth bank protection required must be constructed to the same height as the maximum depth bank protection, but the below-ground depth requirement is much less. The below-ground depth requirement for minimum depth bank protection is 3 feet.

Natural Angle of Repose - The maximum angle of slope that can be maintained by the soil material in a channel bank.

Non-Encroachment Area - For the purpose of this study, a non-encroachment area is the area within a ***watercourse*** management alternative where no floodplain encroachment is allowed. The uses permitted within the non-encroachment area are:

Drainage and stormwater conveyance, in an undisturbed desert state.
Open-space, unimproved (undisturbed desert with native landscape enhancements/restoration permitted).
Open-space, improved (limited to passive and active recreational activities including hiking/riding trails and similar activities within a desert landscape).

Reach - For the purpose of this study, a reach is defined as a portion of a ***watercourse*** in which ***watercourse*** characteristics are similar throughout the reach. Reaches can be defined based on hydrologic, hydraulic or geomorphologic similarities, or on similarities in biologic, visual, or landscape characteristics.

Recurrence Interval - A recurrence interval storm or flood is defined as a storm or flood that has a specific probability of occurring within any given year. For example, the 100-year recurrence interval storm or flood has a 1 % probability of being equaled or exceeded in any given year. The other two recurrence interval storms or floods considered in this study are the 2-year (50 % probability) and 10-year (10 % probability).

Regulatory Line - For the purpose of this study, the Regulatory Line is the Lateral Migration Erosion Hazard Zone limits or the FEMA 100-year floodplain, whichever is furthest from the main channel.

Riprap - A bank protection measure composed of fractured rock of differing sizes.

Scour - For the purpose of this study, scour is defined as a lowering of the channel bed by erosion. Scour occurs at natural or man-made obstructions to flow, or at channel banks. Examples of natural obstructions are trees in the channel, or constrictions in the channel. Man-made obstructions include bridge piers and grade-control structures.

Sediment Yield - Sediment yield is the amount of soil (mainly silt, sand and some gravel) that erodes from the watershed and enters the ***watercourse*** system.

Sedimentation - For the purpose of this study, sedimentation is defined as the natural process of flowing water depositing soil, sand, gravel and cobbles in the ***watercourse*** or on the floodplain. Deposition in the main channel has the effect of changing the shape and dimensions of the channel and decreasing its conveyance capacity.

Soil Cement - Soil cement is a structural erosion protection method that consists of mixing cement with native soils and water, and compacting it in place, and in layers to form a material that is resistant to erosion.

Watercourse - For the purpose of this study, a watercourse is defined as the entire length of a wash to be studied, including the width necessary for the watercourse to function naturally. This includes the watercourse channels, over-bank floodplains, and the area the watercourse has occupied in recent geologic time (<10,000 years).

Watercourse Conditions - The watercourse conditions used in hydraulic modeling are the main channel geometry (i.e., depth, width and slope) and its floodplain (areas outside the main channel that carry water), and roughness (resistance to flow). The main channel and floodplain makeup the watercourse cross section.

Watershed Conditions - A watershed is the land contributing area that collects rainfall and directs it to a watercourse. The primary watershed conditions used in hydrologic modeling are the percentage of contributing area that is impervious to rainfall, the vegetative cover, soil characteristics relating to the ability to absorb and store