Rio Verde Area Drainage Master Plan

FCD 2001C056

Part 1 - Existing Conditions

May 2004

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Since 1962

In association with:

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC

Flood Control District of Maricopa County

Rio Verde
Area Drainage Master Plan

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OTHER DOCUMENTS

A. Technical Appendix (Separate Document)

B. Floodplain Work Maps, 1 inch =200 feet, sheets 1 to 17 (Bound Separately)

C. Floodplain Delineation- Roughness Coefficients, HEC-RAS Report, Cross Section Plots, Stream Profiles, Reduced Scale Floodplain Work Maps and HEC-RAS Files on CD-ROM.

I. INTRODUCTION

A. Project Purpose

The purpose of the Rio Verde Area Drainage Master Plan (ADMP) is to identify flooding problems, flooding sources, and flooding hazards in the Rio Verde area and to identify alternatives to mitigate those hazards.

The ADMP is being conducted with three objectives in mind:

- To develop a comprehensive list of known **flooding problems** impacting the study area
- To develop **alternative solutions** to alleviate or mitigate the flooding problems associated with the 100-year event, and
- To produce a **recommended solution** to alleviate or manage the flooding resulting from the 100-year event.

The first phase of the study is to perform engineering investigations that include the review of existing hydrology and the development of future condition hydrology, review of the floodplain delineations that the FCDMC currently has on file, and hydraulic analyses of the distributary flow system. These investigations will help identify feasible flood control features and/or measures that will reduce potential damages to property or loss of life from storm water runoff in the Rio Verde area.

B. Project Location

The Rio Verde watershed is located in Maricopa County, Arizona, and is generally bounded by the Tonto National Forest on the north, the McDowell Mountain Regional Park to the south, the Verde River to the east, and approximately the 115th Street alignment to the west. The total watershed area is about forty (40) square miles. **Figure I-1** shows the location of the study area in a regional context. The ephemeral washes in the area generally drain from west to east into the Verde River.

The Rio Verde watershed consists of large areas of natural desert with two master planned communities, Tonto Verde and Rio Verde, each of which already has their own drainage system in place. Pockets of residential development, mostly one-acre lots or larger, exist with several areas of mass vegetation removal and equestrian usage. The majority of the roadways in the study area are graded and unpaved, with the exception of Rio Verde Drive, 136th Street, 144th Street north of Rio Verde Drive, and the streets within the master planned communities and newer developments.

C. Project Need

The Rio Verde area is rapidly developing with one-acre lot single-family residences and subdivisions. Many single lot residences are being formed by lot splitting. The County has limited authority to regulate single lot development. As a result, road crossings, stock tanks, diversions, and other human induced changes to the watershed have resulted in erosion, deposition, and redistribution of flooding and erosion hazards in the area. Activities associated with development such as the removal of vegetation, compaction of soils, and construction of impervious surfaces like roof tops, paved roads and parking areas will increase the magnitude of the flooding and erosion hazards in the area. The cumulative impact of lot splitting and single lot development under existing limited regulation could exacerbate these problems.

D. Interagency Coordination

The Flood Control District of Maricopa County is the lead agency for the project. The following stakeholder agencies are included in project coordination:

- Maricopa County Department of Transportation (MCDOT)
- Maricopa County Planning & Development Department
- City of Scottsdale
- Tonto National Forest
- Arizona State Land Department (ASLD)
- Maricopa County Parks and Recreation Department

E. Special Interest Groups

Input was also received from:

- Rio Verde Horseman's Association
- Rio Verde Foothills Alliance
- Rio Verde Master Planned Community
- Tonto Verde Master Planned Community

F. Public Involvement

The public involvement activities for the project have included:

- Public meetings
- Resident Survey
- Project informational website at (http://www.fcd.maricopa.gov/projects/RioVerde/)
- Development of a **Citizens Work Group** to provide input and feedback during the project.

G. Project Authorization

Arizona Revised Statutes Title 48, Chapter 21, requires the Flood Control District Board of Directors to identify flood control problems and plan for the construction of facilities, which will eliminate or minimize flooding problems. To this end, the Rio Verde ADMP project was authorized under contract FCD 2001C056 between the Flood Control District of Maricopa County and Dibble and Associates Consulting Engineers, Inc.

Figure I-1. Study Area

II. DATA COLLECTION RESULTS

A. Existing and Planned Drainage Facilities

Because of the rural nature of the area, there are few constructed drainage facilities, most of which are small roadway culverts. There are several stock ponds in the study area which tend to act as retention facilities. The existing drainage facilities are shown on **Figure II-1**.

1. Culverts

There are several new culverts associated with development along both 144th and 136th Streets. Also, there are many culverts on private land which home owners have installed to handle local drainage within their property. Additional detailed culvert information can be found in the Culvert Rating Curve Technical Appendix, prepared by Dibble & Associates, for the 2-D Analysis.

2. Stock Ponds

There are approximately 18 stock ponds (tanks) within the study area, some of which have been breached by the owner(s). One of the larger ponds, the Black Hills Tank, is within Scottsdale City limits. This tank is classified by ADWR as a low-hazard jurisdictional dam. A low-hazard dam is defined by ADWR as a dam where "*failure or improper operation of a dam would be unlikely to result in loss of human life but would produce low and intangible losses, and result in no disruption of lifeline services that require more than cosmetic repair. Property loss would be limited to rural or agricultural property, including equipment and isolated buildings*". **Table II-2** shows other possible types of dam classifications.

B. History of Flooding

Area newspapers such as the Sonoran News and Fountain Hills Times were researched for documentation of flooding in the Rio Verde area. While several articles are found regarding flooding in Fountain Hills, no articles specific to flooding in the Rio Verde study area were found. This is most likely due to the sparse development and, until recently, limited media coverage of the area.

Table II-1 shows the two FCDMC ALERT rain gages in the study area, each with more than 10-years of data. The data indicate that within the period of record, the study area has only experienced one storm with a rainfall greater than 3-inches in a 24-hour period with the highest 24-hour intensity of 3.43-inches.

Table II-1 Rainfall Data

		I_{10}~2.1 inches		I_{10}~2.4 inches	
Sensor ID #	Sensor Name	Highest 6hr Intensity	Highest 6hr Intensity-Date	Highest 24hr Intensity	Highest 24hr Intensity-Date
5900	Asher Hills	1.46	8/26/1997	2.56	11/15/1993
5930	Fraesfield Mtn.	2.36	8/22/1992	3.43	8/22/1992

Sensor ID #	Sensor Name	Elevation (feet msl)	Data Begins	# Storms >= 1.0 in/24hrs	# Storms >= 2.0 in/24hrs	# Storms >= 3.0 in/24hrs
5900	Asher Hills	1680	08/02/90	27	4	0
5930	Fraesfield Mtn.	2660	08/02/89	42	9	1

Table II-2 Dam Hazard Classification

Hazard Potential Classification	Probable Loss of Human Life	Probable Economic, Lifeline and Intangible Losses
Very Low	None Expected	Economic & lifeline losses limited to owner's property or 100-yr floodplain. Very low intangible losses identified.
Low	None Expected	Low
Significant	None Expected	Low to High
High	Probable – One or more expected	Low to High (not necessary for this classification)

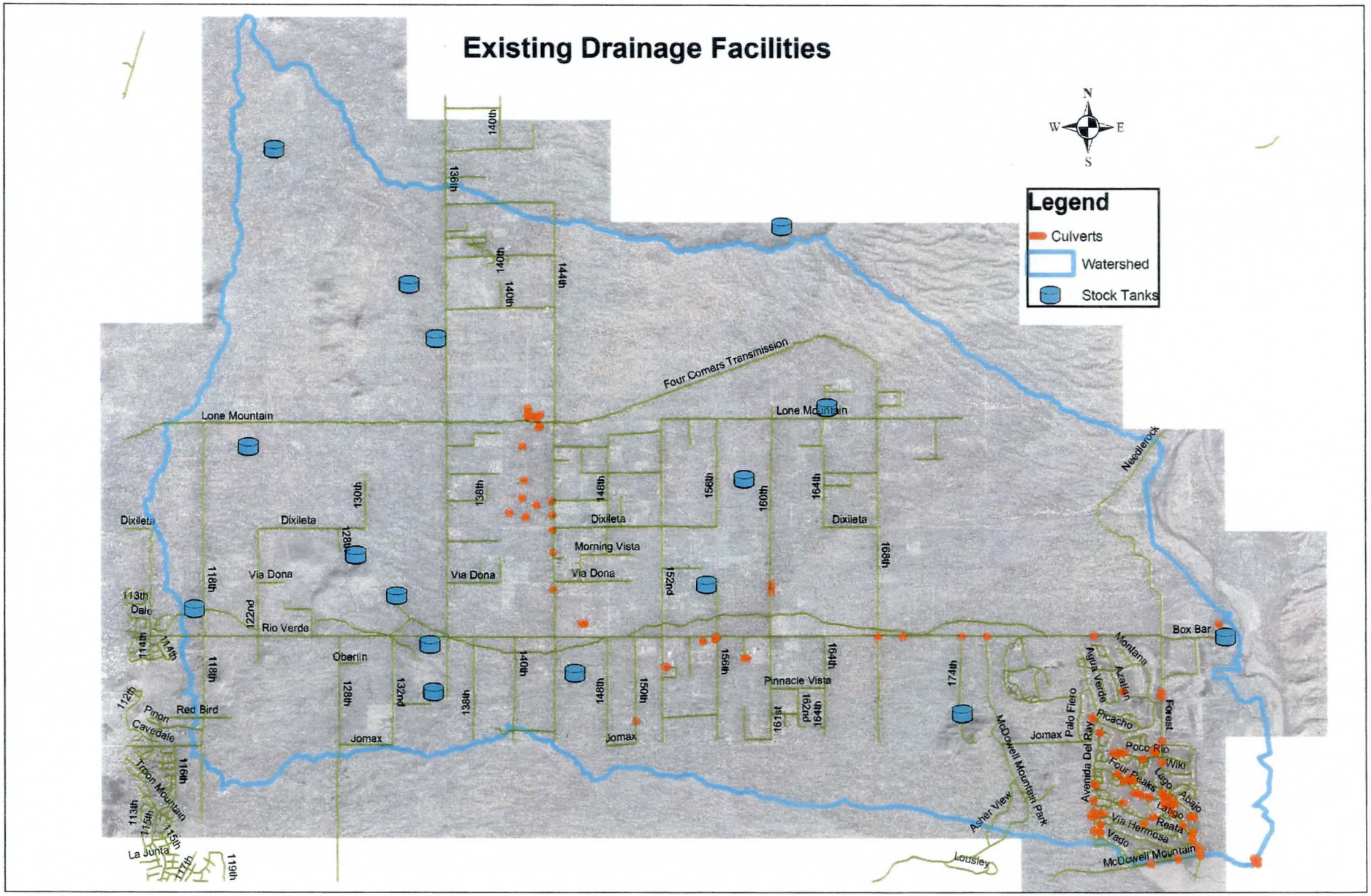

Figure II-1. Existing Drainage Facilities

C. Existing Studies

There have been four (4) previous floodplain delineation studies of parts of the Rio Verde area. They are:

- *Rio Verde North Floodplain Delineation Study* conducted by Burgess & Niple Inc. and Wood Patel & Associates, Inc. in October 1994.
- *Rio Verde South Floodplain Delineation Study* conducted by McLaughlin Kmetty Engineers in August of 1995.
- *Floodplain Delineation Study of Rio Verde South Extension* conducted by J.E. Fuller Hydrology and Geomorphology in May of 1999.
- *Rio Verde North Extension Floodplain Delineation Study* conducted by David Evans & Associates in August of 2002.

Floodplains mapped in those studies are shown on **Figure II-2**.

D. Planned Developments

There are two primary types of development taking place within the Rio Verde area – subdivisions and individual lot developments.

1. Subdivisions

Subdivisions are required to prepare a Drainage Report/Plan for the site. This type of development typically considers drainage elements in their plans such as retention basins and culvert crossings. They are also required to consider floodplains in their designs in order to keep new homes from being built in them. Subdivisions known to be in the planning stages within the study area are shown on **Figure II-3** and are as follows:

- Desert Estates
- Granite Mountain Ranch
- Rio Mountain Estates
- Scottsdale National
- The Golf Club at Scottsdale
- Tonto Verve – Unit 9
- Vista Verde

2. Individual Lot

Individual lot development is predominant in the area at the current time. Individual lot developments are typically built one at a time by individual lot owners. Regulations on this type of development are less formalized than the larger subdivision developments. This has resulted in a non-uniform development with a wide variation in the treatment of drainage issues. Currently, this type of development requires a drainage clearance from the FCDMC.

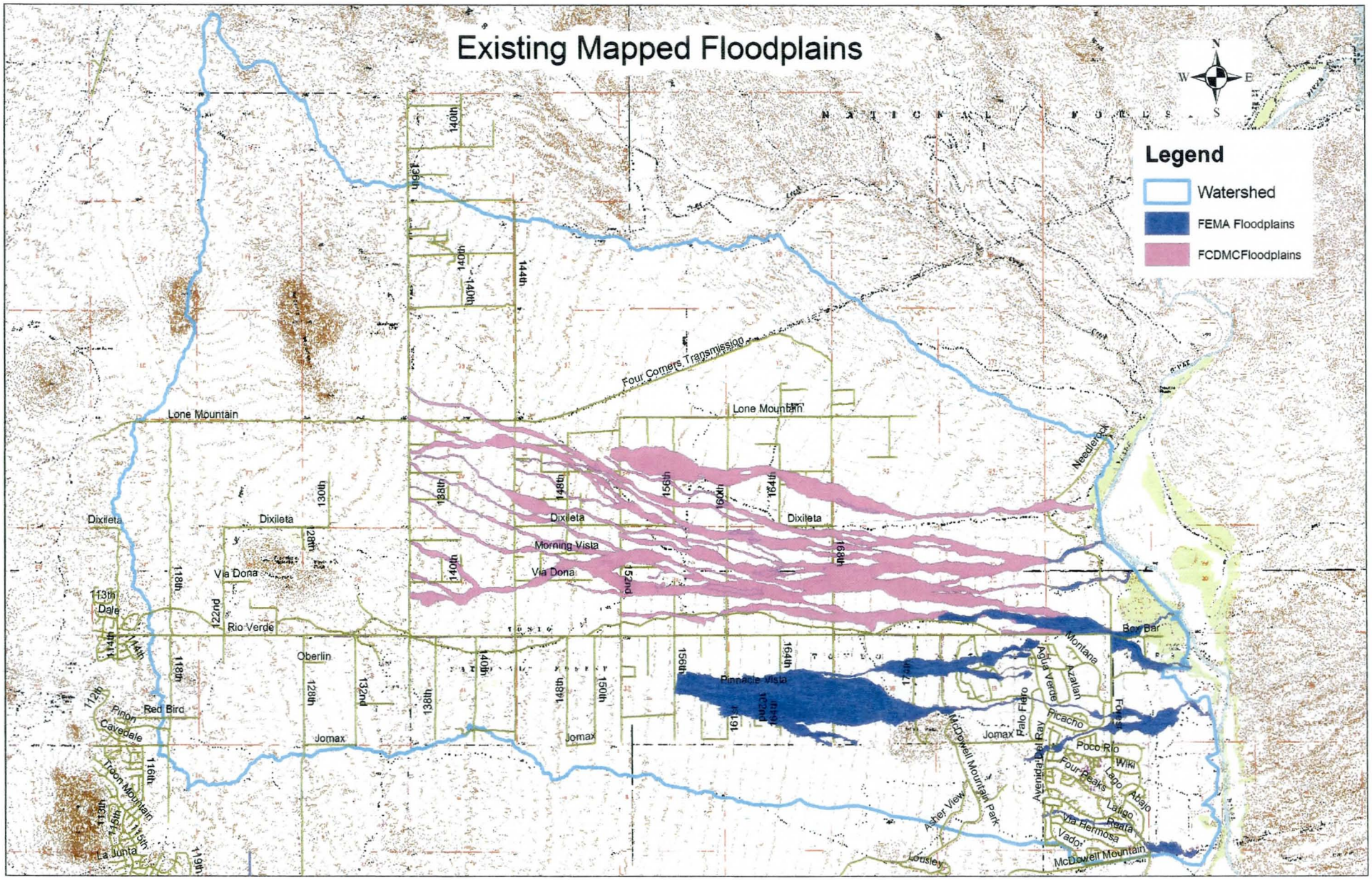

Figure II-2. Existing Floodplains

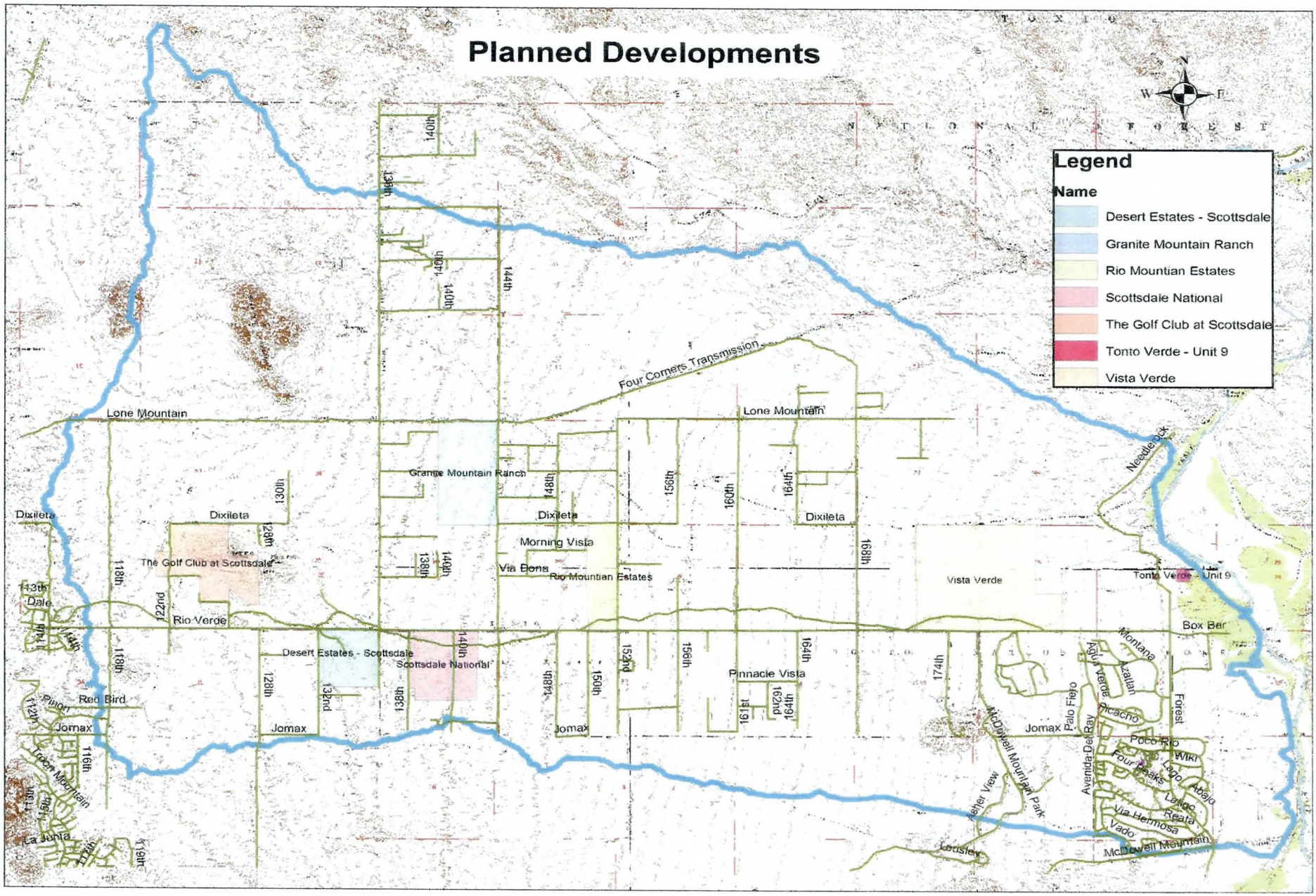

Figure II-3. Planned Developments

E. Existing and Planned Major Utilities

Arizona Bluestake was contacted to obtain a list of utility providers for the area. According to Bluestake, the utilities listed in **Table II-3** exist within the Rio Verde area;

Table II-3 Utility Providers

Utility Company	Contact	Phone Number
Arizona Public Service	Kim Smallwood	602-493-4451
City of Scottsdale	Karen Lockhart	480-321-2440
COX Communications	Rob Russell	623-322-7215
Qwest	Conflict Liaison	480-768-4420
Southwest Gas	Mapping Dept.	
Midvalle Telephone Exchange	No reply to Utility Letter	
Salt River Project (Power)	Sue Moore	602-236-8069
Rio Verde Utilities	Unable to Contact	

Each of these Utility Companies was contacted to identify any existing infrastructure within the study area. Most responded by providing their utility system maps. Two utility providers were unable to be contacted (Midvalle Telephone Exchange and Rio Verde Utilities). While the area contains numerous utilities, in a wide range of types and sizes, this report only considers major utilities that would either be costly to relocate (i.e. fiber optic) or difficult because of physical constraints (i.e. gravity sewer). Therefore, minimum requirements were placed on the utilities to be considered in this report as shown in **Table II-4**.

The only major utility in the study area is electric. There are two systems in place which are 69,000 Volts or larger. These are shown on **Figure II-4**. The Four Corners Transmission Main is the system which traverses the area generally from east to west. The smaller system in the southeast corner of the study area is a 69,000 Volt distribution system owned by SRP.

Table II-4 Minimum Utility Size for Consideration

Utility Company	Minimum Size or Type for Consideration
Arizona Public Service	69,000 Volts
City of Scottsdale (water/sewer)	12"
COX Communications	Fiber Optic
Qwest	Fiber Optic
Southwest Gas	High Pressure
Salt River Project (Power)	69,000 Volts

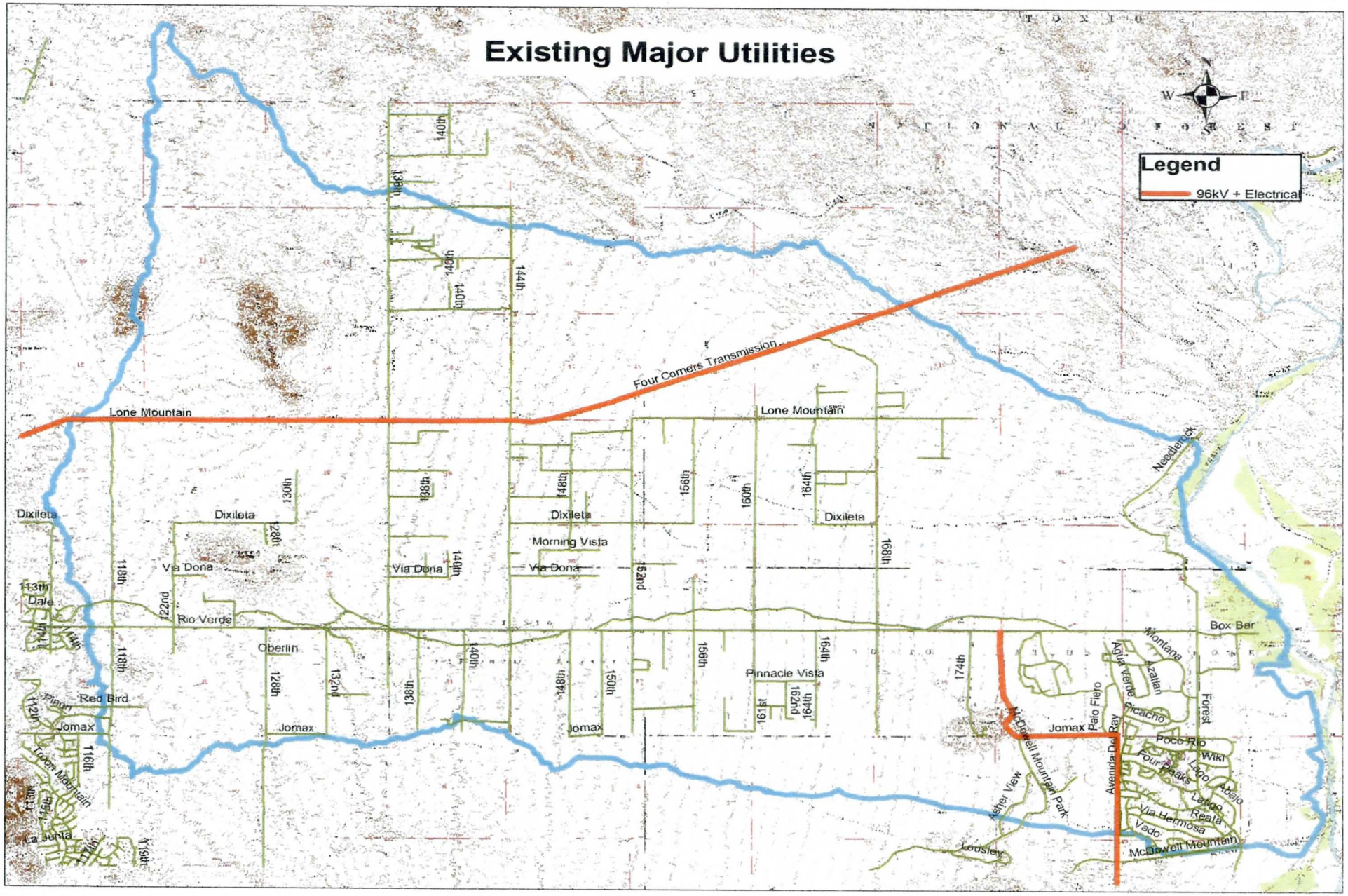

Figure II-4. Existing Major Utilities

F. Agency Contacts

Meetings were conducted with representatives from Maricopa County Parks and Recreation Department, Maricopa County Department of Transportation (MCDOT), the City of Scottsdale, and Tonto National Forest (TNF). The purpose of the meetings was to inform each agency of the project purpose, scope and schedule, to identify any known flooding problems, improvement plans or other related issues within the study area, and to give the opportunity to voice any specific concerns about the project. The following is a summary of each agency's response.

1. Maricopa County Parks and Recreation

McDowell Mountain Park forms the southern project study boundary and is operated by the Maricopa County Parks and Recreation Department. The Department's intent for **McDowell Mountain Park** is to keep it as natural as possible and to minimize impacts of development. The Department does not want drainage facilities such as retention/detention basins constructed within the park boundaries.

2. Maricopa County Department of Transportation

Maricopa County Department of Transportation (MCDOT) noted that many existing roads do not meet their minimum standards. They do not maintain the numerous private roads within the area. Currently, MCDOT only maintains Rio Verde Drive but plans to accept Dixileta Drive, Lone Mountain Road and 144th Street into the County system. Due to lack of traffic volume, there are currently no planned MCDOT projects within the area.

3. City of Scottsdale

There is currently a large stock tank, the Black Hills Tank, within the City limits that is classified as a low-hazard jurisdictional dam. This tank is currently owned by the City and they are planning on maintaining the structure.

4. Tonto National Forest

The Tonto National Forest (TNF) is very concerned about the adverse effects of development and the problems of erosion associated with development. The TNF wishes to prevent increases in discharge and the deepening of channels as the area develops, by implementing on-site retention requirements. At some point in the future, the TNF plans on fencing their boundary. They will also be looking into ways to reduce the impacts of ATV's. The TNF does not intend to undertake any Federal land exchanges in the Rio Verde Area.

G. Survey and Mapping

Mapping from several sources is compiled for use in this study. Maps from the U.S. Geologic Survey, print and digital ortho-rectified aerial photographs and floodplain mapping from both FEMA and the FCDMC are utilized. In addition, two foot contour aerial mapping is obtained according to the following table;

Table II-5 Two-foot contour interval mapping

Project	FCD#	Surveyor	Aerial Mapper	Flight Date
Rio Verde North Floodplain Delineation Study	93-06	Chastain-Skillman Inc.	Aerial Mapping Co.	12/22/1993
Rio Verde North Extension Floodplain Delineation Study	98-21	David Evans & Assoc.	Cooper Aerial Co. Inc.	12/4/1998 1/11/1999
Rio Verde South Floodplain Delineation Study	93-07	Alcocer Land Surveyors	Aerial Mapping Co.	12/22/1993
Rio Verde South Extension Floodplain Delineation Study	97-13	Urban Engineers Inc.	Aerial Mapping Co.	10/18/1997
Rio Verde South Extension Floodplain Delineation Study - Update	97-13	Arcadis	Aerial Mapping Co.	1/12/2002

III. EXISTING CONDITIONS

A. Geomorphology

1. Hydrologic Setting

Rainfall occurs predominantly in one of two seasons; the winter rainy season from about November to March; and the summer monsoon from July to September. Winter rainfall events tend to be characterized by longer duration, lower intensity cyclonic storms, while the summer events are thunderstorms with short duration, high intensity rainfall. Occasionally, tropical storm or hurricane remnants cross the area in the late summer and early fall. These storms can generate moderate duration, relatively high intensity rainfall. During all of these rainy seasons, runoff may occur resulting in flood inundation, erosion, and sediment transport across the piedmont.

Brief heavy rain results in rapid runoff that occurs for short periods of time. Fluvial systems, therefore, only infrequently and briefly have the chance to adjust to the water and sediment delivered to them.

2. Geologic Setting

The Rio Verde ADMP piedmont sits on the west side of the Verde River north and east of the McDowell Mountains. The area lies near the transition from the Basin and Range to the Central Highlands physiographic provinces. Tectonic activity which drove the construction of the Basin and Range ceased in the area by about 8 million years ago. This was followed by a period of basin filling as adjacent mountain ranges shed sediments. About 2 million years ago large basin axis streams began to cut down as they integrated themselves with the Gila River system. The Quaternary period (past 2 million years), then, has been dominated by erosion as the large Gila tributaries like the Salt and the Verde Rivers lowered themselves into the surrounding Tertiary-aged sediments. Similarly, the tributaries and adjacent piedmonts adjusted to the lowering of local base level. These tributaries, including those in the study area continue to adjust themselves to the lowering of the Verde River.

In addition to adjustments to base level lowering, climate changes over the Quaternary have exerted forces on the system inputs of water and sediment. Changes in vegetation cover and hydrology over the last 2 million years have resulted in a landscape containing alluvial surfaces of various geologic ages from the early Pleistocene to the recent Holocene. The nature and distribution of the Pleistocene surfaces are discussed further in the following sections.

3. Study Zones

The Rio Verde study area has been divided broadly into four zones. A fifth, geologically older, highly entrenched zone was also distinguished within the Tonto National Forest in the northeast portion of the study area. The zones are depicted on **Figure III-1**. For purposes of this report, the five zones have been labeled as follows:

- Pediment & Hillslopes Zone
- Piedmont Zone
- Transport Zone
- Incised Zone, and
- Entrenched Zone

The delineation and designation of the five study zones was made based on the correlation between areas of tributary and distributary flow and geologic and topographic properties. The general direction of flow in the Rio Verde watershed is from west to east, with relatively tributary flow in the upper watershed, large areas of distributary flow heading to the east, and more incised channels approaching the Verde River. **Figure III-1** shows the locations of split flows, indicative of distributary flow, overlain with the surficial geology units and the USGS 7.5 minute quadrangles.

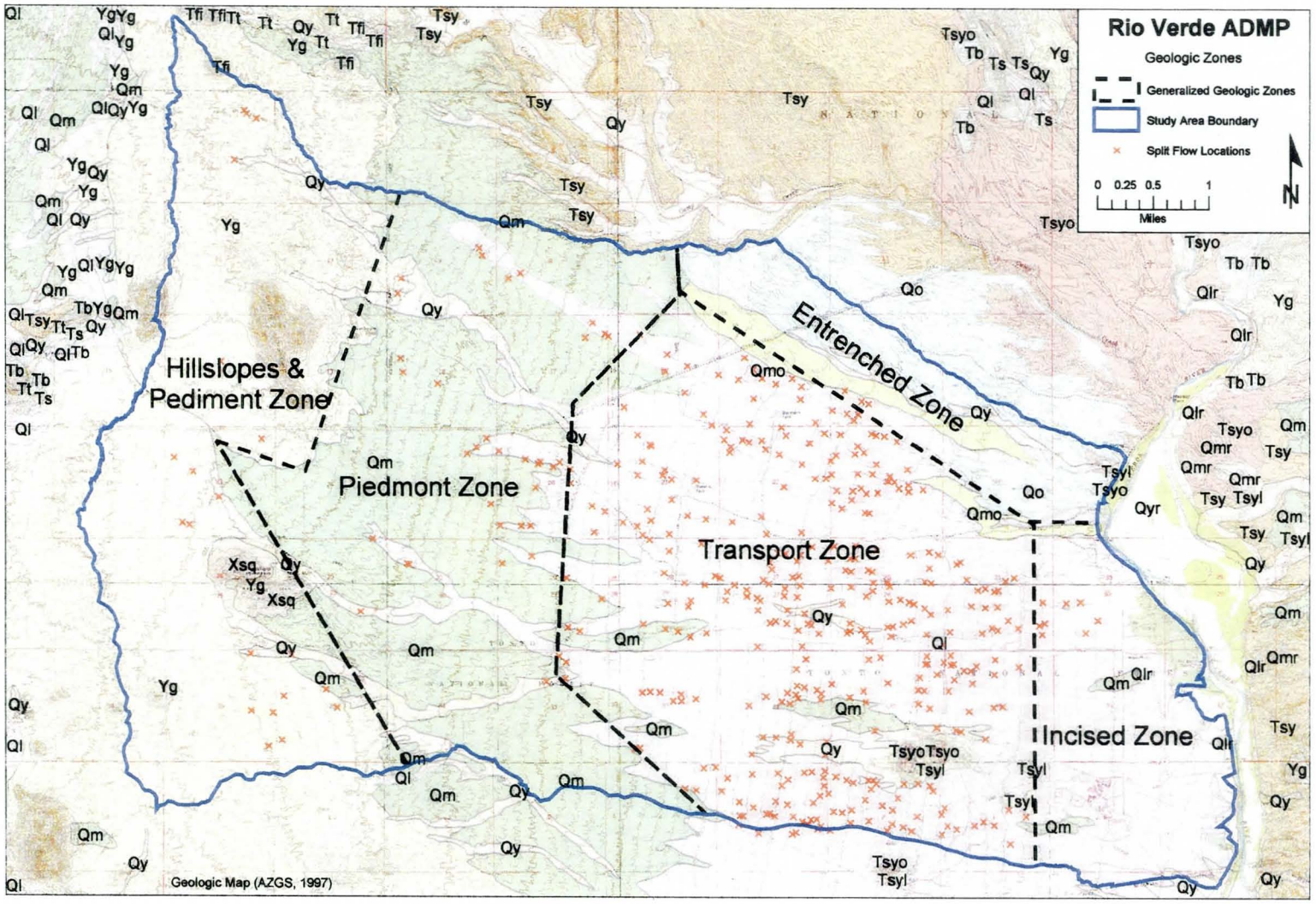

Figure III-1 Generalized Geologic Study Zones for Rio Verde ADMP

The upper watershed consists of geologic unit Yg, an old, bedrock surface, sloping into unit Qm, a middle Quaternary surface of piedmont and fan terraces. The middle and lower watershed consists of unit Ql, a late Quaternary surface of younger alluvium. A small area in the northeast portion of the study area consists of unit Qo. Also, note the difference in the crenulations of the contours going from higher relief within unit Qm to nearly no relief within unit Ql, and high relief within the unit Qo area. The higher relief within unit Qm is evident from the jagged nature of the contour line (crenulations) as compared to the smooth nature of the contour line in unit Ql. If a straight line cross-section were cut along the contour, the jagged contour line would show high relief with numerous small washes and ridges, in contrast to the undefined wash pattern in the low relief section. The vast majority of the split flows are located within the Ql unit.

Figure III-2 shows cross sections taken through portions of the predominant geologic units in each of the five study zones. As just described, note the distinct difference in lateral relief across the units. The differences in lateral relief reflect the variation in the degree of drainage network development and channel patterns between the different units. Drainage network development and channel pattern reflect the geologic age of each unit and strongly influence the nature and distribution of flood and erosion hazards across the study area. The older geologic units exhibit a greater degree of dissection reflected by the greater amount of lateral relief. The relatively younger surfaces have lesser lateral relief which allows flood waters to spread laterally and reflects the shallow distributary channel networks on the Ql surfaces. The low amount of lateral relief on these surfaces also means that water and sediment discharges are more easily redirected by relatively small changes in local topography due to natural or human causes.

The correlation between geologic units, topographic properties and geomorphic features is also observable in longitudinal profiles of three major drainage corridors in the area. The profiles show an overall steep watershed. Average slopes are nowhere less than one percent and are generally greater than two percent throughout almost the entire area. Slopes are generally least across the pediment area and increase through the Qm unit and into the Ql area. Finally, slopes are the highest approaching the Verde River probably reflecting slope adjustments to the Quaternary downcutting of the Verde River.

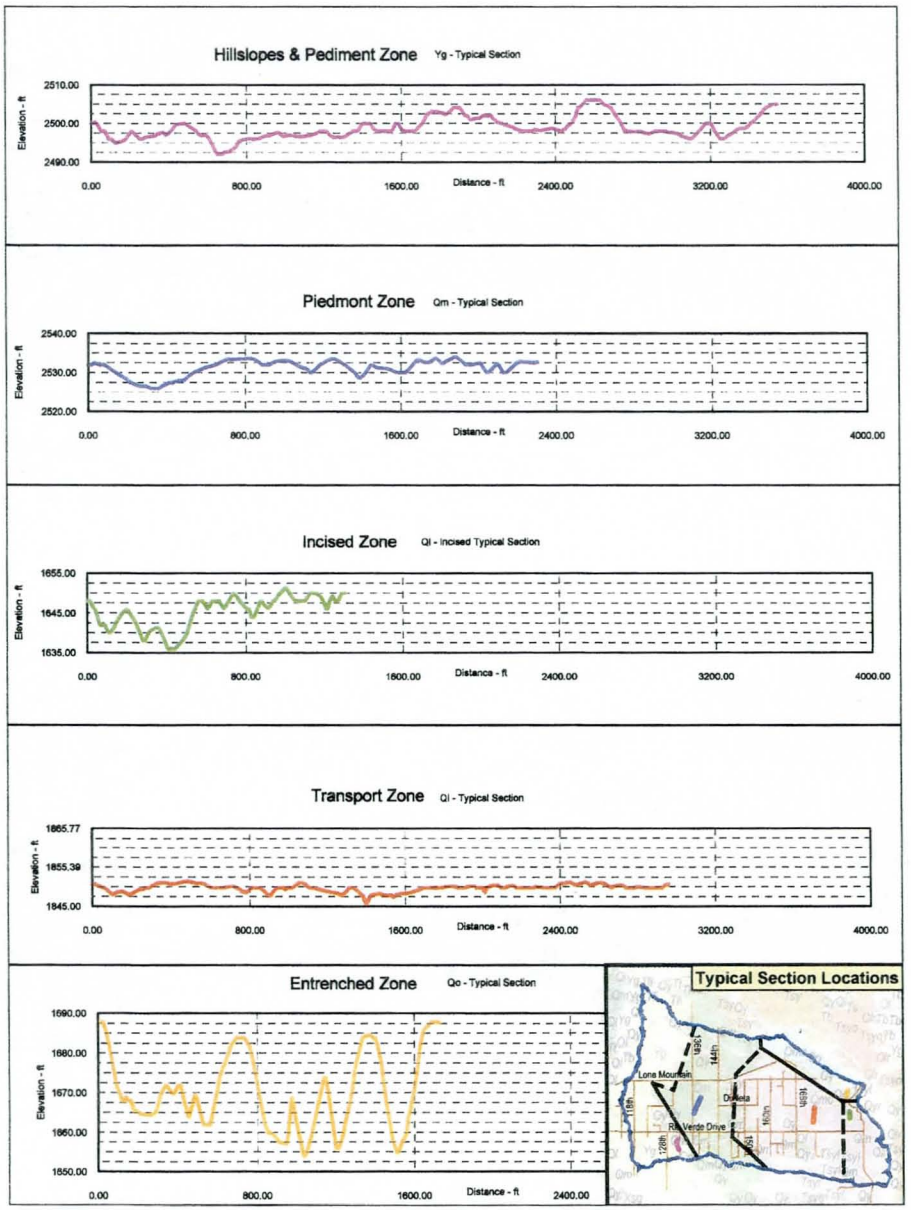

Figure III-2. Representative Cross Sections for Generalized Geologic Zones

The important erosion and sedimentation characteristics in each zone are addressed in the following sections.

a) Pediment & Hillslopes

(1) Geomorphic and Topographic Setting

At the top of the watershed in the western third of the study area is the Pinnacle Peak pediment. The Pinnacle Peak pediment is a broad rounded erosional surface composed largely of Proterozoic (> 540 Mya) igneous and metamorphic rocks, especially coarse-grained granite (Skotnicki, 1997). The pediment is characterized by weathered bedrock covered locally with a thin veneer of alluvium derived from weathering and erosion of the bedrock within the watershed. Bedrock outcrops are common. Runoff is generally confined to broad shallow corridors containing single to multiple small relatively shallow channels.

In addition, the slopes of Fraesfield Mountain and Granite Mountain rise about 400 and 700 feet respectively above the surrounding landscape. These hillslopes provide small, but potentially important, steep watersheds capable of generating brief intense runoff. Slopes range from 1% to 10% on the hillslopes, with an average slope of 1.5% toward the Verde River.

The drainage pattern in this zone is typically tributary with some braided sections. However, the braided sections are confined within geologic constraints. A few split flows occur in this zone, but they are generally hydraulically uncomplicated and can be realistically modeled within a one-dimensional hydraulic model such as HECRAS.

(2) Erosion and Sedimentation

Though the area is predominately bedrock, the soils that have developed in the Pediment and Hillslopes Zone are highly susceptible

to erosion and gullying. The granitic bedrock in the pediment weathers to pebble sized pieces of orthoclase along with smaller sands, silts, and some clays. These weathered sediments are highly erosive. So, while the veneer of sediment in this zone is relatively shallow, channels within this zone are subject to some lateral and vertical erosion within the limits imposed on them by the more resistant bedrock. Additionally, some bedrock within the area is highly weathered. Due to the significant degree of weathering, bedrock is locally subject to lateral and vertical erosion.

Most of the Pediment and Hillslopes Zone lies within the proposed McDowell Sonoran Preserve. If the existing preserve proposal is adopted, the majority of the area west of 136th Street will remain natural into the foreseeable future. Consequently, natural sedimentation processes will continue without significant impacts from human activity. However, the pediment and hillslopes will continue to weather and shed sediments into the Piedmont Zone downstream.

The relatively small particle sizes and steep slopes within the Pediment and Hillslopes Zone combine to facilitate significant sediment transport during even the most frequent runoff events. During a field visit following a 2- to 5-year storm on July 14, 2002, sediment was observed to have been transported through channels in this zone. Depths of flow were typically less than one foot. Therefore, the maintenance of sediment transport continuity even for small events is very important to the preservation of fluvial system form and function.

b) Piedmont Zone

Downhill and east of the pediment lies an area of dissected middle Pleistocene (Qm) alluvial fan terraces. These surfaces have moderate lateral relief of 3 to 6 feet (**Figure III-2**). Channel networks are primarily tributary in form. Some braided channels do exist but they are confined to relatively narrow corridors subject to flooding and erosion across their entire width. Channels in this portion of the piedmont collect and transport water and sediment generated across the upstream hillslopes and pediment onto the lower piedmont.

(1) Geomorphic and Topographic Setting

The Piedmont Zone consists of geologic unit Qm, a middle Pleistocene surface of piedmont and fan terraces. Average slopes in this zone range between 1.8% and 3%, increasing in the downstream direction. Alluvial fans deposited through the middle Pleistocene have been dissected by drainage networks leaving the old fan surfaces about three to six feet or more above the adjacent modern channel systems. These surfaces have experienced appreciable soil development as a result of their isolation from deposition since the middle Pleistocene. Drainage networks are generally tributary, but there are several split flows within this zone (**Figure III-2**). Several broader corridors of young surfaces traverse this zone. These corridors are the primary conduits of water and sediment transported through this zone from the pediment as well as for sediments and runoff generated within this zone.

The NRCS also describes the hazard of water erosion on these units as slight. However, as noted in subsequent sections of this report, disruptions to the natural sediment transport continuity within this zone can create significant localized deposition and erosion.

(2) Erosion and Sedimentation

Erosion and sedimentation within the Piedmont Zone is generally limited to the major wash corridors crossing or developed on the fan terraces. Localized deposition of channel bars or islands exist within the wider channels and corridors. Lateral erosion occurs locally along cutbanks on the margins of these channels. Lateral erosion of channels within the wider corridors also occurs but is generally localized and associated with confined braided channels or disturbances to local sediment transport continuity such as downstream of stock tanks or

road crossings. Vertical erosion also occurs at road crossings and downstream of stock tanks or other locations where sediment is trapped and clearwater discharges occur. This type of erosion is illustrated on **Figure III-3**. These types of disruptions of sediment transport continuity produce the most dramatic and extensive erosion in the study area.

Figure III-3. Arroyo formation resulting from clearwater stock tank outflows

c) Transport Zone

Further downslope, emanating from the middle Pleistocene surfaces, is a wide area of relatively younger geologic surfaces with low lateral relief (1-3 feet) and many small braided and anastomosing channels with numerous divides and joins (**Figure III-2**). This area is complex hydrologically and hydraulically. Even normally simple concepts like drainage area can be difficult to define throughout this portion of the study area.

(1) Geomorphic and Topographic Setting

The Transport Zone consists of unit Ql, late Quaternary surface of younger alluvium Average slopes though this zone range from 2.2% to 3%, increasing in the downstream direction. The steep slopes and general lack of lateral confinement create an area characterized by relatively shallow flow and wide thin sheets of sediments transported across the area. Shallow, diverging flow and localized thin depositional areas create clearwater scour in the downstream direction where flood water recollects in emerging gullies. Defined washes often flow parallel to one another across this zone. Gullying from clearwater overflows and/or local runoff can capture or join nearby channels to one another. This process of stream piracy is the likely mechanism responsible for the construction of the complex drainage pattern in this zone.

Bull (1997) describes a characteristic channel-pattern sequence associated with discontinuous ephemeral streams that is present in the Rio Verde ADMP study area. The pattern alternates between reaches of degradation and aggradation. Headcuts collect flow into individual trunk channels that convey flow to an aggrading channel fan with a braided distributary channel pattern that ends in an area of diverging sheetflow. The sheetflow then converges to a series of headcuts that collect and concentrate the sheetflow off the end of the fan to the next trunk channel. This pattern repeats itself over and over down the valley, or in the case of the Rio Verde area, down the piedmont.

The trunk channels efficiently transport sediment to the channel-fans which act as temporary storage areas for sediments in these systems. The short duration and frequency of runoff in these systems means that sediments delivered are often not transported through the system given the limited stream power available. Bull says that the scale and length of this pattern varies with the amount of streamflow supplied to the fluvial system.

Bull also states that these discontinuous ephemeral streams are inherently unstable compared to most humid-region streams. In particular these systems are susceptible to changes in climate, land cover, and base level. Changes to hydrology due to urbanization can also induce degradation and migration of the channel-fan pattern.

An additional complexity in the Rio Verde area is that the piedmont in the Transport Zone is a series of parallel and coalescing discontinuous ephemeral streams each exhibiting this repeating channel-pattern sequence. Because these systems overlap laterally, the amount of streamflow supplied to any one subsystem varies from event to event and over time as the piedmont evolves. Localized changes due to natural or human causes can disrupt the current channel-pattern sequence causing a necessary adjustment of the system to the imposed changes. Changes to local base level, sediment transport continuity, and redirection of runoff are the most common causes of disruption to the system.

(2) Erosion and Sedimentation

Due to the complex repeating channel-pattern sequence, erosion and sedimentation occurs broadly over most of the Transport Zone. Sediment throughput from the upper Pediment and Piedmont Zones is transported across this zone downstream to the Verde River. In

general; deposition occurs on the channel-fan features and erosion occurs downstream in the headcutting gullies off the ends of the channel fans. Short relatively straight reaches of channel transport eroded sediments to the next channel-fan downstream. There is a strong correlation between the location of the aggrading channel-fans and the split flow locations shown in **Figure III-1**. Conversely, downstream of many of these locations, broad shallow flow recollects into headcutting gullies. These gullies range from one to three feet in depth and represent the highest amounts of local relief and steepest local slopes in the zone.

In addition to aggradation at channel-fans, human made and natural sediment traps are another mechanism of aggradation in the Transport Zone. Man made sediment traps include stock tanks, culvert crossings, and buildings. Natural sediment traps include sediment buildup behind debris dams formed by tree branches and other flotsam during flooding.

Stock tanks are another cause of significant local aggradation and degradation in the Transport Zone. Nearly all the stock tanks within the watershed exhibit erosion downstream of the tank. In addition to the vertical erosion caused by clearwater discharges around the tanks, lateral erosion is also increased in the vicinity of these new arroyos.

d) Incised Zone

Near the Verde River in the eastern portion of the study area, the wash systems become entrenched as their beds lower in response to the declining base level of the Verde River. The Verde River has cut itself at least 40 feet into its own Pleistocene terraces. This reduction in local base level for the Rio Verde ADMP study area washes has resulted in significant entrenchment within about one mile of the Verde River. The resulting entrenchment prevents avulsive channel changes and limits lateral erosion hazards to those areas close to the steep channel banks.

(1) Geomorphic and Topographic Setting

The Incised Zone also consists of unit Ql, late Quaternary surface of younger alluvium. Average slopes range from 2.5% to 4.5%, increasing in the downstream direction. Channels are downcutting in response to base level changes in the Verde River. Channels are well incised with banks from 4 feet at the top of the zone to more than 30 feet at the Verde River. Tributary slope adjustments have been limited to about one to two miles upstream of the Verde. The distance of slope adjustment is related to the size of the wash. For example, Model A Wash has the largest channel and associated drainage area and has incised the furthest upstream of any of the ADMP study area washes.

(2) Erosion and Sedimentation

Erosion and sedimentation are generally limited to the incising throughflow channels in the Incised Zone. Some lateral erosion of channel banks was observed. Additionally, local runoff and drainage systems are lowering themselves in response to the lowering of local base level. Deposition is limited to the channel beds of the main washes on the recession of floods.

e) Entrenched Zone

The Entrenched Zone is an area of the oldest alluvial surfaces in the study area. It is located in the northeast portion of the area and lies almost entirely within the Tonto National Forest. The drainage networks are tributary and local relief is high.

(1) Geomorphic and Topographic Setting

The Entrenched Zone consists of unit Qo, early Pleistocene to late Pliocene alluvial fans. Channels and drainage networks are highly

entrenched into these old surfaces. Ridge tops are rounded, soils are well-developed, and local relief ranges from ten to thirty feet.

(2) Erosion and Sedimentation

Erosion and sedimentation within the Entrenched Zone is generally limited to the low-lying channels between the high ridges. However, local hillslope erosion and small tributaries formed on the older surfaces do experience erosion. The bulk of sediment transport and deposition in this zone occurs along those washes that occupy the low areas between old, high ridges. Within these low areas, channels vary from relatively simple single channel configurations near the watershed divide to more complex multi-threaded braided washes further downstream.

4. Historical Aerial Photograph Comparison

Historical aerial photographs of the study area were examined to look for changes in channel positions, channel sizes, age of man made features, and other changes that have occurred in the watershed. A set of 1953 photographs was obtained electronically from the Flood Control District. These photos have good visual quality and provided an excellent basis for comparison with the 2002 aerial photographs also obtained from the District. This fifty-year period is about as long a period of photographic record as is available in much of Arizona.

Comparison of these photographs showed a number of changes in the watershed over the fifty-year period. Most of the changes appear to be the product of human activity or the combination of human and natural forces. **Figure III-4** shows an example near 152nd Street and Dixileta Drive. Note the beginning of urbanization and the arroyo formed north of the stock tank in the lower right corner of the 2002 photo.

Comparison of channel positions in locations outside the areas disturbed by stock tanks does not reveal any significant changes in the positions of the primary channels. So, while the system is sensitive to changes imposed on it by sediment transport disruptions or diversions of floodwater, evolution of the drainage network is otherwise taking place at scales smaller than those detectable in the aerial photographs, or over longer time scales than 50 years or both.

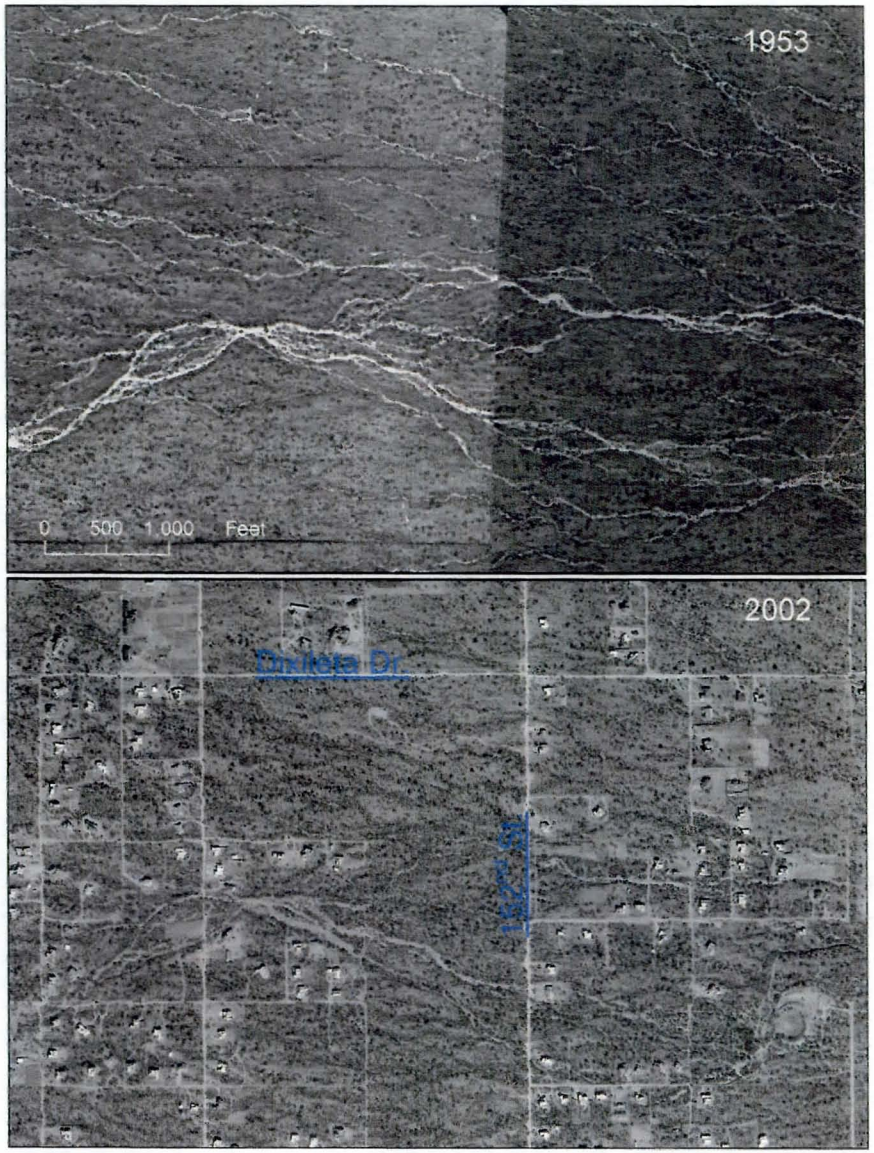

Figure III-4. Comparison of 1953 & 2002 Aerials Near 152nd St. & Dixileta Dr.

B. Hydrology

1. General

The computer modeling of the study area is accomplished by using a combination of one-dimensional and two-dimensional methodologies. The one-dimensional modeling is accomplished using the HEC-1 computer model for hydrology and the HEC-RAS computer model for hydraulics. The two-dimensional modeling uses a single program, FLO-2D to model both hydrology and hydraulics. A Geomorphic Analysis was performed to identify areas of one-dimensional (1D) flow and two-dimensional (2D) flow characteristics within the watershed. The Geomorphic Analysis Report recommended limits for the 1D and 2D modeling areas. The upper watershed in the western section of the study area with steeper slopes and more defined channels is modeled using 1D analysis while the lower areas with unconfined channels and flatter slopes are modeled using the 2D analysis. **Figure III-5** shows the limits of the 1D and 2D modeling areas. The 1D and 2D sections have drainage areas of 20.8 and 25.9 sq. miles, respectively.

2. One-dimensional flow areas (HEC-1)

This section focuses on the hydrologic modeling of the 1D area using HEC-1. The hydraulic modeling of the 1D area with HEC-RAS is described in Section C. *Floodplains*. The 1D area is divided into three separate basins maintaining the original drainage boundaries of three previous drainage studies completed within the Rio Verde area. These basins are identified as the *North-North*, *North-South*, and *South* basins because of their relative location within the watershed. Portions of the original hydrologic models were eliminated in areas that overlap the 2D modeling area to include only the subbasins within the 1D modeling boundaries.

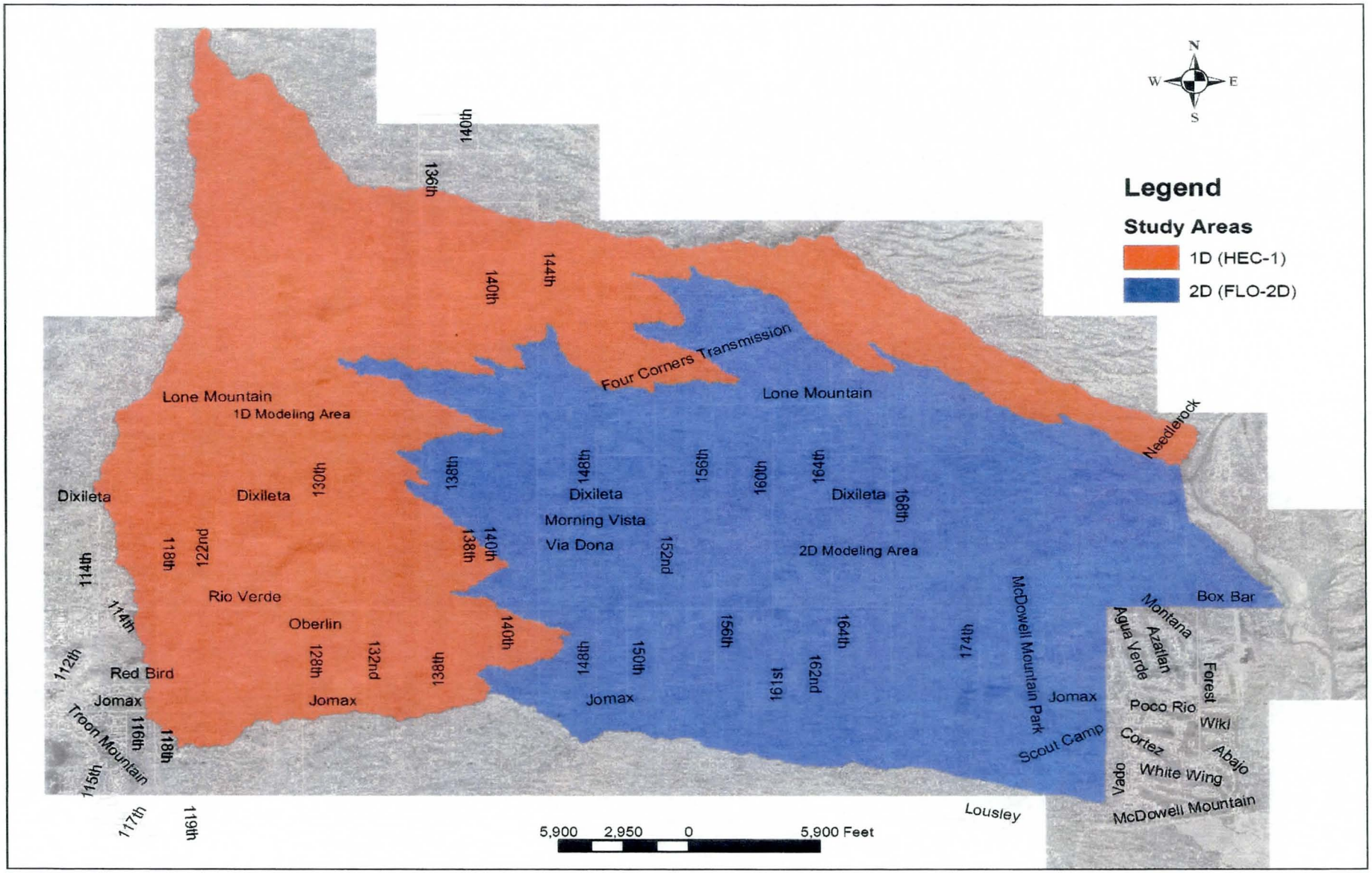

Figure III-5 The Rio Verde Area Showing the 1D and 2D Modeling Locations

As in the original drainage studies, the U.S. Army Corps of Engineer's HEC-1 computer program was used. The development of the HEC-1 models for the three basin areas is aided by the *Drainage Design Management System for Windows* (DDMSW) computer program. DDMSW serves as the pre-processor for the model parameters which builds the HEC-1 models batch input files. The DDMSW program works well with data sets developed within the GIS environment having the advantage of evaluating drainage data as basin attributes to be analyzed with other data sets such as soils and land use.

a) Objectives

The principal objectives of the hydrologic tasks performed for the Rio Verde ADMP are:

- To update the original hydrology from three earlier studies to reflect changes that have occurred in the study area, primarily from residential development, and to include hydraulic features not considered in the earlier studies. This update includes re-delineation of existing drainage boundaries in the southern area using the more detailed 2001 topographic mapping and the 2002 orthophotos of the study area.
- To develop the existing condition models for the 100-year, 24-hour and the 100-year, 6-hour duration storms and to compare the peak flows to determine which duration storm event(s) produces the highest peak discharge for the study area.

b) Data

The principal data and reference material used to perform the hydrologic analysis of the study area are listed below with their respective sources:

- Geomorphic Analysis by JE Fuller/ Hydrology and Geomorphology, Inc. 2002.
- Topographic Map with 2-ft CI from the Flood Control District of the Maricopa County (See table II-5 for dates and suppliers)
- 2002 Orthophotos from the FCDMC.
- Technical Reports and HEC-1 models from original studies from the FCDMC.
- GIS data sets that include soils map, land use, National Forest boundaries, and drainage boundaries of original studies from the FCDMC.
- Drainage Design Manual for Maricopa County, Arizona, Volume I – Hydrology (1995). This reference material provided supplementary information on site data (e.g., precipitation) and outlined hydrologic modeling standards and procedures.

c) Modeling Programs and Tools

The programs and tools used for the hydrologic evaluation of the 1D modeling areas are:

- The U.S. Army Corps of Engineers' HEC-1 computer program (Version: 4.1, Date: June 1998).
- The U.S. Army Corps of Engineers' HEC-RAS computer program (Version: 3.1, Date: November 2002).
- Drainage Design Management System for Windows (DDMSW) program (Version: 1.8, Date: May 14, 2001) developed by KVL Consultants, Inc.
- ArcGIS 8.x developed by ESRI, Inc.
- Microsoft Office Suite developed by Microsoft, Inc.

d) Methodology

The Rio Verde watershed was modeled using methodology set forth in the *Drainage Design Manual for Maricopa County, Arizona, Volume I*

– *Hydrology* ("Drainage Manual"), dated January 1, 1995. The three basin areas were modeled for the 100-year, 6-hour and the 100-year, 24-hour duration storms. The temporal rainfall distributions used were those suggested in the Drainage Manual for the 6-hour and 24-hour duration storms. The Phoenix Mountain S-Graph was used for unit hydrograph development. Rainfall losses were estimated using the Green and Ampt infiltration equation. Hydrographs were routed through the watershed using normal depth channel routing. The flow diversion distribution at split flow locations were evaluated by backwater analysis using HEC-RAS. The evaluated energy grade line at the flow diversion location is the criterion used in apportioning the amount of flows for diversion.

Project hydrology is developed using the U.S. Army Corps of Engineers, HEC-1 Flood Hydrograph Package (HEC-1) computer program. Guidance is given in the Drainage Manual for application of the HEC-1 program within Maricopa County. Additionally, the computer program Drainage Design Management System for Windows (DDMSW), is used to aid in the application of the methods described in the Drainage Manual.

e) Conclusions

The results of the 1-dimensional HEC-1 hydrologic analysis are presented in the Hydrology Technical Data Notebook, a companion volume to this report. The following modeling conclusions are noted:

- The updated models are developed based on the best and most recent data available.
- The delineation of drainage boundaries is based on the 2-ft CI topographic mapping and from the 2002 orthophotos of the study area.
- The land use information for the watershed reflects the existing land developments as shown on the 2002 orthophotos.
- The precipitation data were updated using the NOAA Atlas II (1973) iso-pluvial maps. The precipitation depths used in this study are slightly higher than earlier HEC-1 models.
- The peak flows from the 24-hour duration storm events were predominant in controlling the hydrology of the three basin areas, consistently providing higher peak flows than the 6-hour duration storms.

3. Two-dimensional flow areas (FLO-2D)

The two-dimensional flow modeling was completed by the FCDMC. The modeling results were not available as of this writing. It is anticipated that the results will be incorporated at a later date.

C. *Floodplains*

1. *General Description of the Study Washes*

Floodplains are delineated for approximately 20 miles of washes using the HEC-RAS water surface profiles computer program with widely spaced cross sections (about every 1,000 feet). The upstream study limit for each wash is located where there is at least 500 cubic feet per second (cfs) of flow during the 100-year flood (with the exception of Wash 11E South). HEC-RAS modeling is conducted under the subcritical flow regime. The downstream study limit is located at the two-dimensional study area boundary, with some overlap.

It was decided that wash names should be easily identifiable using only a hydrologic subbasin map. Therefore, wash names are generally taken from the last two alphanumeric digits in the subbasin names. The study washes are shown on the **Key Map, Figure III-6**. Study wash names and their corresponding subbasins in the 1D area are listed in **Table III-1**, with individual wash maps found on **Figure 111-7** through **Figure 111-9**.

The study washes flow through typical Sonoran Desert vegetation, including saguaro, barrel cactus, prickly pear cactus, mesquite, Palo Verde, creosote bush, bursage, and desert grasses.

Manning's roughness coefficients vary from 0.040 to 0.060 for the main channel, and from 0.045 to 0.075 for the over bank areas. Previous floodplain studies were utilized to derive roughness coefficients for the study washes. More information on the roughness value computations is found in the Technical Appendix. The main channel flow for the study washes are typically 0.5 to 1.5 feet in depth before over bank flow commences.

The project mapping for floodplain delineation is based upon Arizona State Plane, Central Region, NAD 1983 Horizontal Coordinate Basis and NAVD 1988 Vertical Coordinate Basis. The river mile zero point on Wash W1 is based upon its confluence with the Verde River. The zero point for River Mile stationing on all other washes is arbitrary and is located within the 2D study area.

Table III-1 – Wash Names

Wash Name	Subbasins
Wash W1	Drains Subbasins B1W1 through B13W1 in the North-North model
Wash W6 North and W6 South	Drain Subbasins B1W6 through B14W6 in the North-North model.
Wash 9B	Drains Subbasins 1B1 through 9B, in the North-South model.
Wash 7B Spill	Drains Subbasins 2B1 through 2B6 and Subbasins 3B1 through 3B2, flowing through the spillway of a jurisdictional dam in the North-South model. The 7B subbasin system was renumbered without renaming the wash.
Wash 11G	Drains Subbasins Drains Subbasins 511G1 through 511G4 in the South model.
Wash 11F	Drains Subbasins 511B1 through 511H in the South model.
Wash 11E North and 11E South	Drains Subbasins 511E1 through 511E2 and Subbasins 511C1 through 511C8.

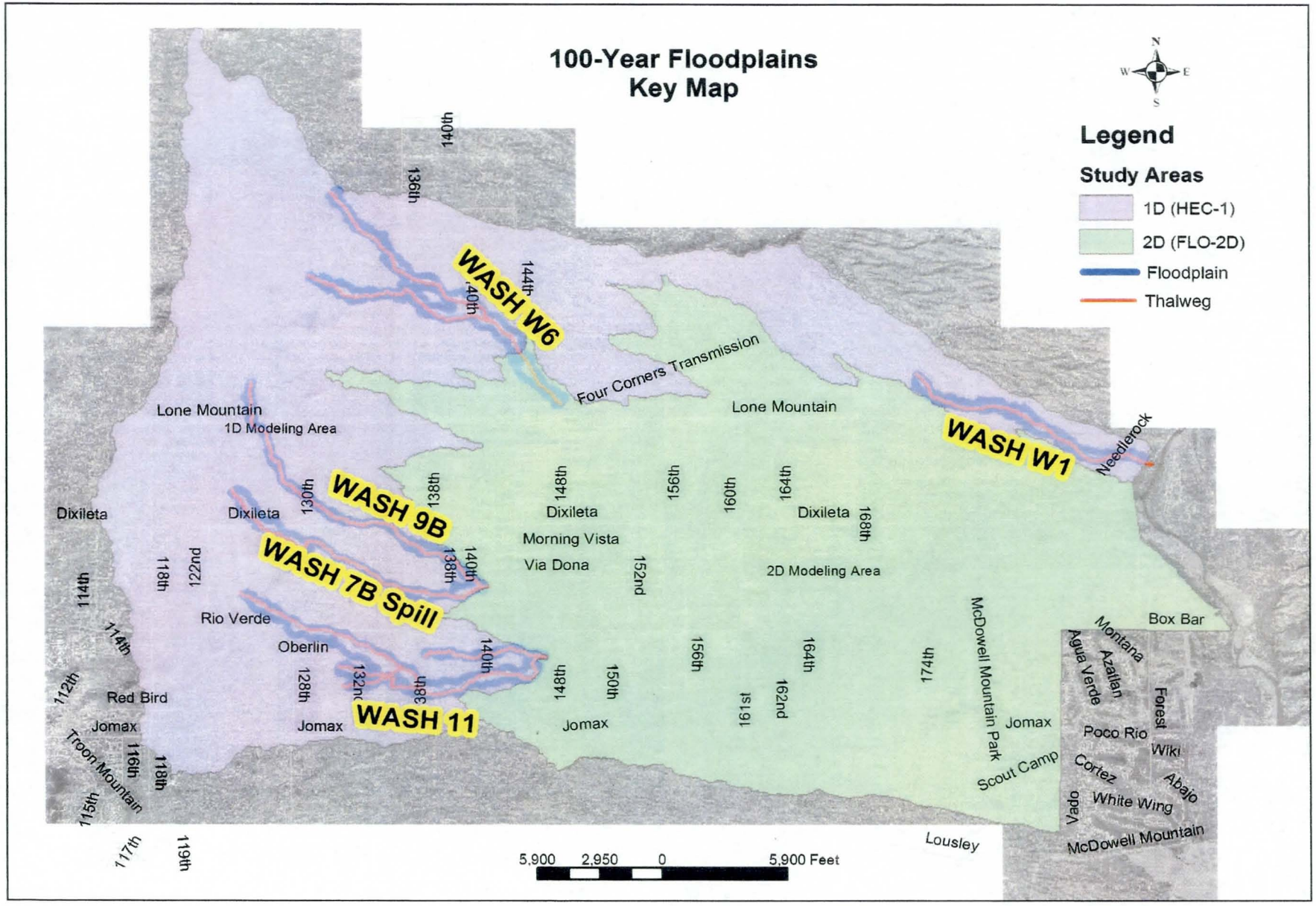
100-Year Floodplains
Key Map
N
W
E
S
Legend
Study Areas
1D (HEC-1)
2D (FLO-2D)
Floodplain
Thalweg
WASH W6
WASH W1
WASH 9B
WASH 7B Spill
WASH 11
Four Corners Transmission
Lone Mountain
1D Modeling Area
Lone Mountain
Needlerock
Dixileta
Dixileta
Dixileta
Morning Vista
Via Dona
Dixileta
2D Modeling Area
Rio Verde
Oberlin
Red Bird
Jomax
Jomax
Jomax
Jomax
Jomax
Troon Mountain
McDowell Mountain Park
Scout Camp
Box Bar
Montana
Agua Verde
Azallan
Forest
Poco Rio
Wiki
Cortez
Abajo
Vado
White Wing
McDowell Mountain
Lousley
140th
136th
144th
140th
130th
138th
148th
156th
160th
164th
168th
118th
122nd
114th
138th
140th
152nd
114th
112th
128th
132nd
138th
148th
150th
156th
161st
162nd
164th
174th
116th
118th
115th
117th
119th
5,900 2,950 0 5,900 Feet

Figure III-6

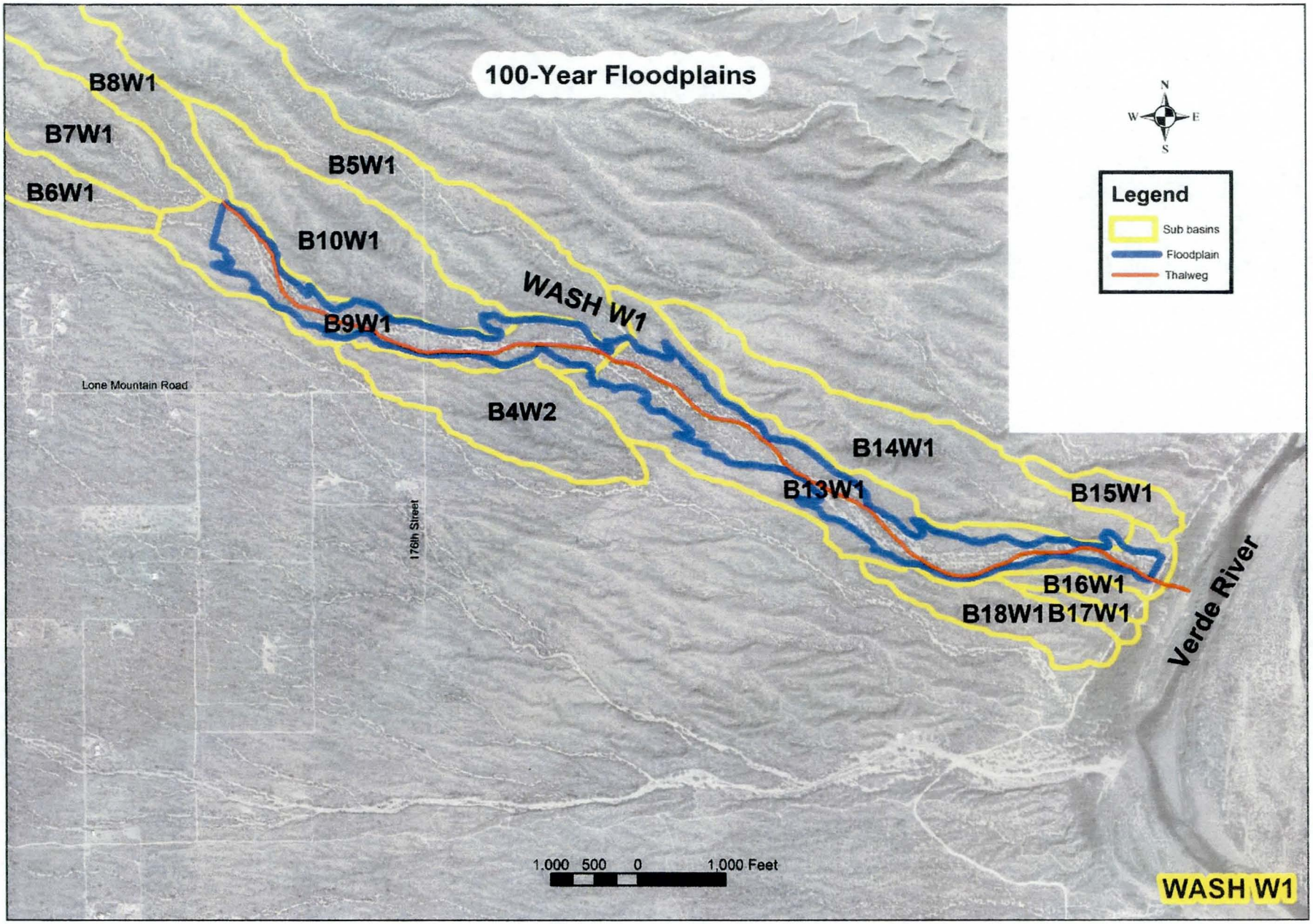
100-Year Floodplains
B8W1
B7W1
B6W1
B5W1
B10W1
B9W1
WASH W1
B4W2
B14W1
B13W1
B15W1
B16W1
B18W1B17W1
Verde River
Lone Mountain Road
176th Street
N
W
E
S
Legend
Sub basins
Floodplain
Thalweg
1,000 500 0 1,000 Feet
WASH W1

Figure III-7

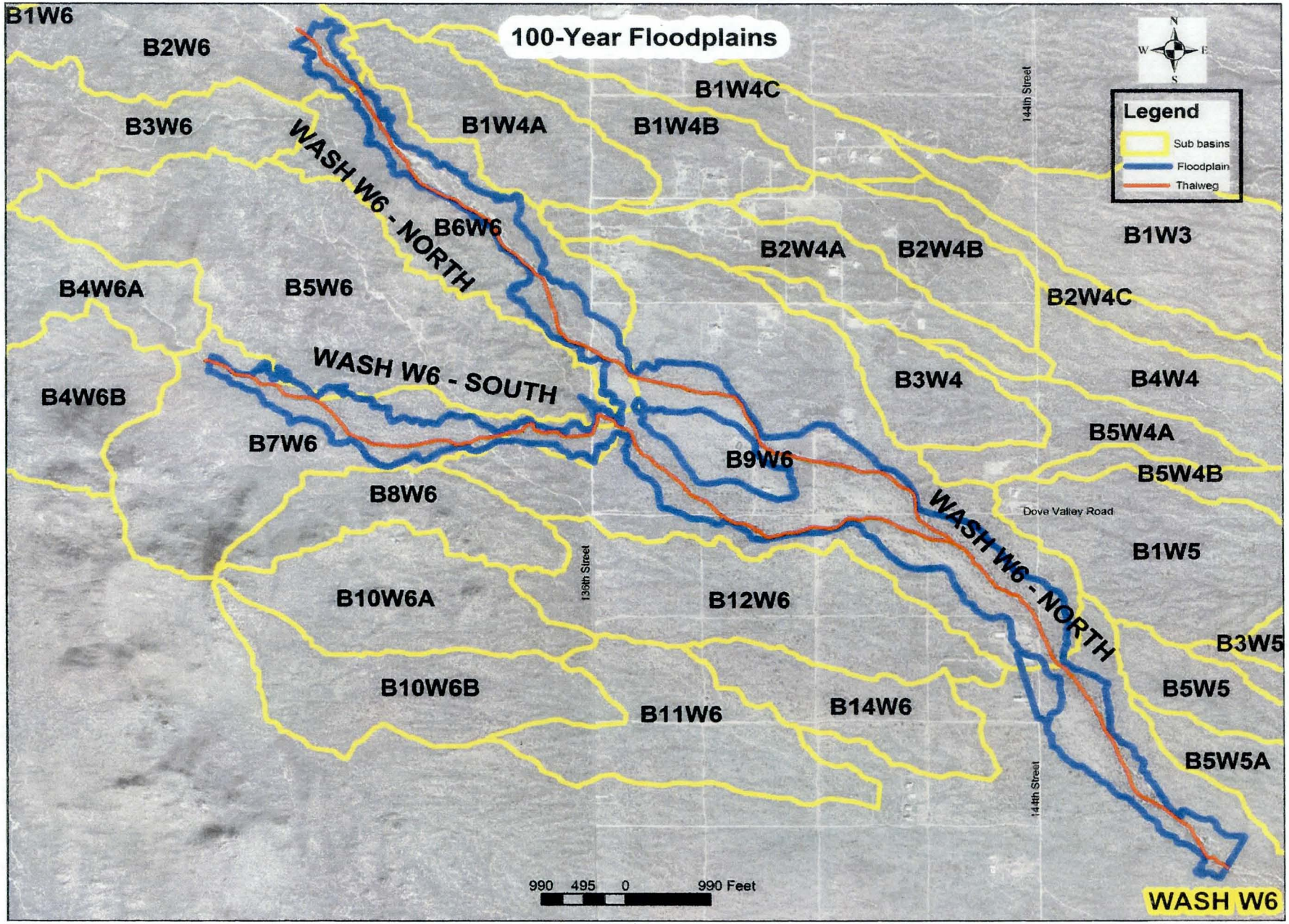
100-Year Floodplains
Legend
Sub basins
Floodplain
Thalweg
N
S
W
E
B1W6
B2W6
B3W6
B1W4A
B1W4B
B1W4C
B6W6
B5W6
B4W6A
B4W6B
B7W6
B8W6
B9W6
B10W6A
B10W6B
B11W6
B12W6
B14W6
B2W4A
B2W4B
B2W4C
B1W3
B3W4
B4W4
B5W4A
B5W4B
B1W5
B3W5
B5W5
B5W5A
WASH W6 - NORTH
WASH W6 - SOUTH
WASH W6 - NORTH
WASH W6
144th Street
136th Street
144th Street
Dove Valley Road
990 495 0 990 Feet

Figure III-8

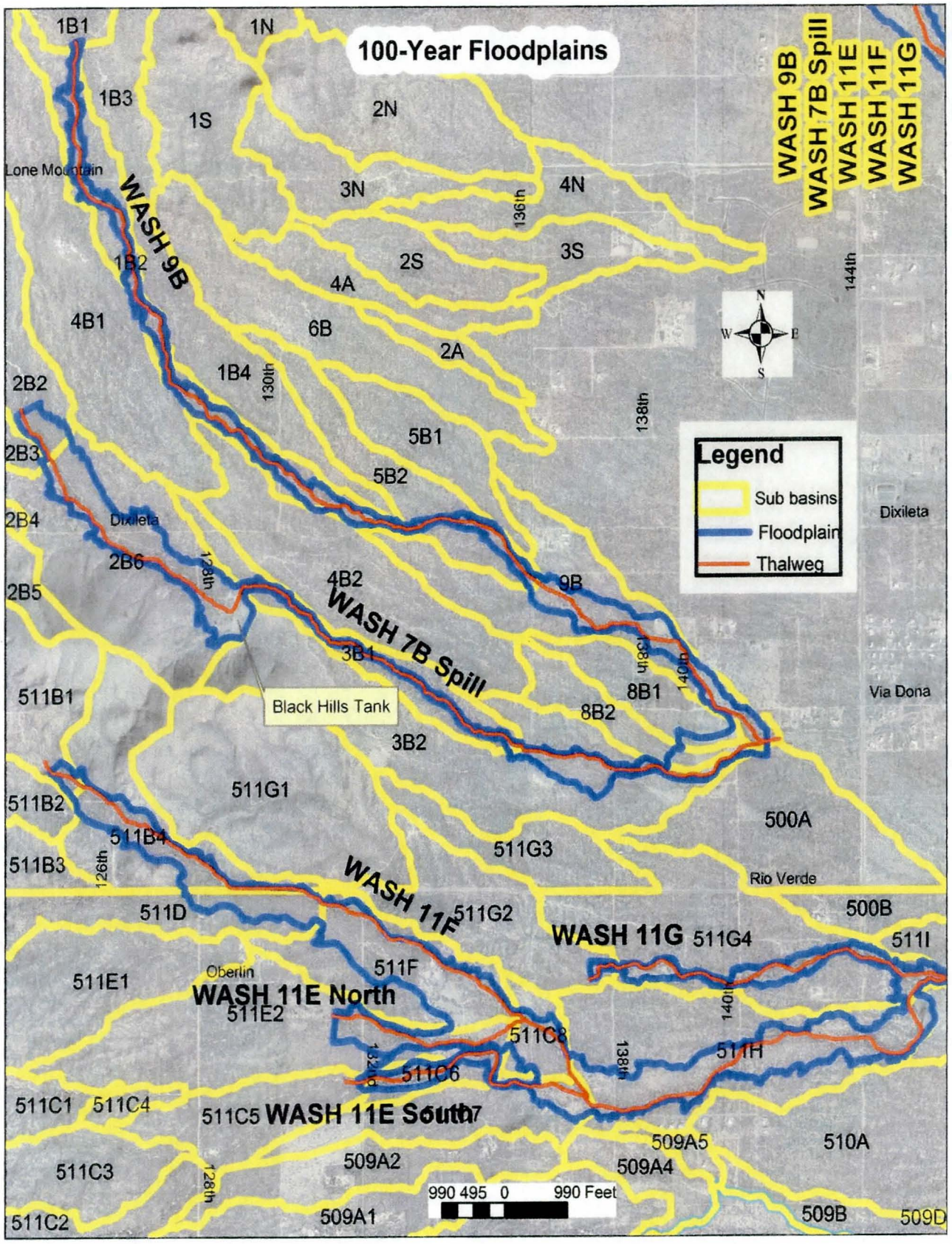
100-Year Floodplains
WASH 9B
WASH 7B Spill
WASH 11E
WASH 11F
WASH 11G
Legend
Sub basins
Floodplain
Thalweg
Lone Mountain
Dixileta
Black Hills Tank
Via Dona
Rio Verde
Oberlin
WASH 11E North
WASH 11E South
1B1
1N
1B3
1S
2N
3N
4N
2S
3S
4A
1B2
4B1
6B
2A
1B4
2B2
2B3
5B1
5B2
2B4
2B6
2B5
4B2
9B
3B1
8B1
8B2
3B2
511B1
511G1
511B2
511B4
511B3
511G3
500A
511D
511G2
500B
511G4
511I
511E1
511F
511E2
511C8
511H
511C6
511C1
511C4
511C5
511C7
509A5
510A
511C3
509A2
509A4
511C2
509A1
509B
509D
136th
144th
130th
138th
128th
140th
126th
990 495 0 990 Feet
N
S
E
W

Figure III-9

The starting water surface elevation for the main washes is from normal depth computations for three identical geometry cross sections situated at ten-foot intervals and adjusted for slope. The three cross sections located downstream of the first point of interest allow the water surface elevation computations to stabilize at the beginning cross section. The starting water surface elevations for tributaries to the main washes are based upon the known water surface elevation in the main wash. These wash tributaries are Wash W6 South, Wash 7B Spill, Wash 11E North, and Wash 11E South.

Hydrologic concentration points are noted in the cross-section descriptions using the corresponding HEC-1 ID's. The flow rates are rounded to the nearest 10 cubic feet per second (cfs). Flow rates obtained from HEC-1 are applied at the appropriate HEC-RAS cross section near the concentration point.

The cross-section data were generated from the mapping DTM for cross sections outside of the Scottsdale National Subdivision. Within the Scottsdale National Subdivision, cross section data was developed by the subdivision engineer from one-foot contour mapping, based upon the same vertical datum as the Rio Verde ADMP project. The mapped hydraulic base line represents the 10,000-station point of the HEC-RAS model for Dibble cross sections. The hydraulic baseline is not at a consistent location for Scottsdale National Subdivision cross sections and instead utilizes a zero station at the left end of each cross section.

Field reconnaissance occurred on October 1, 2002 and May 15, 2003. Selected photographs taken during field reconnaissance are included in the Technical Appendix for the Manning's Roughness Computations section.

Each wash is described below, including the study limits, a general description of the floodplain characteristics as well as any unique or interesting conditions. The hydraulic values reported are summarized from the HEC-RAS model run in the subcritical flow regime.

2. *Floodplain Descriptions*

a) Wash W1 Floodplain Delineation

(1) Study Limits

From the confluence with the Verde River (River Mile 0.00) to a point upstream of 172nd Street (River Mile 2.450), a distance of 2.45 river miles.

(2) Flow and floodplain characteristics

The upstream flow rate is 1,040 cfs just downstream of the confluence of three tributaries. Wash W1 contributes 1,490 cfs to the Verde River just downstream of Needle Rock Road. The wash crosses 176th Street, but otherwise lies in a currently undeveloped area. There are no structures located within the floodplain.

The flow depth ranges from 1.4 to 7.6 feet. The average cross sectional velocity varies from 3.5 to 6.3 feet per second (fps), while the top width changes from 166 feet at the narrowest section to 511 feet at its widest section. The floodplain is contained entirely within the sandy bottom visible in the aerial photographs.

b) Wash W6 North Floodplain Delineation

(1) Study Limits

From the downstream end located approximately 900 feet north and 2,100 feet east of the intersection of 144th Street and Lone Mountain Road (River Mile 0.00) to the upstream end located approximately 11,700 feet north and 3,400 feet west of the intersection of 136th Street and Lone Mountain Road (River Mile 3.058), a distance of 3.06 river miles.

(2) Flow and floodplain characteristics

The wash flows within a relatively undeveloped area. Several dirt roads important to local access are flooded by the study wash, such as 136th Street, 144th Street, and Dove Valley Road. There are approximately 3 structures of various types located within the 100-year floodplain with an additional structure located within an area of sheet flow flooding. Wash W6 North has 1,530 cfs at its upstream study limit, which increases to 3,530 cfs near the point it enters the two dimensional study area.

Wash W6 contains two different flow segments. The portion upstream of 136th Street is riverine, and the flow is contained within a fairly well defined wash, covering the entire bottom. In fact, the floodplain limits in this reach could be drawn solely from the contour map and aerial photograph, due to channel incisement.

From 136th Street east to the downstream limit east of 144th Street, the floodplain becomes much wider and is not easily defined without the HEC-RAS model. Wash W6 South begins to flow parallel to Wash W6 North just east of 136th Street. At this same location, a portion of floodwaters in W6 North appears to flow into W6 South. The amount of split flow cannot be readily determined so the split flow floodplain is approximated and each wash is analyzed with its full flow. This area is more properly suited to future floodplain delineation by 2-dimensional analyses. As an example, just downstream of the split flow area is a large "dry" island located between Wash W6 North and W6 South. However, this area is subject to sheet flow flooding generated from runoff that could easily breakout from the main floodplain and from local rainfall and should not be considered "dry".

Along the entire study reach, the flow depth ranges from 1.8 to 4.8 feet. The average cross sectional velocity varies from 3.5 to 6.9 fps, while the top width varies from 139 feet to 702 feet at its widest section.

c) Wash W6 South Floodplain Delineation

(1) Study Limits

From the confluence with Wash W6 North (River Mile 0.00) to a point approximately 7,400 feet north and 4,500 feet west of the intersection of 136th Street and Lone Mountain Road (River Mile 1.939), a distance of 1.94 river miles.

(2) Flow and floodplain characteristics

The RAS model is started at the location where 660 cfs would flow during the 100-year event. Just upstream of the confluence with Wash W6 North, there would be 1,450 cfs. Runoff in the wash floods two main streets, 136th Street and Dove Valley Road. The starting water surface elevation is from the confluence with Wash W6 North near 140th Street and Dove Valley Road. There is one structure located within an area of sheet flow flooding.

Beginning at 136th Street, Wash W6 South flows parallel to W6 North for about 0.5 miles before the floodwaters join. Refer to the previous description for Wash W6 North for floodplain information east of 136th Street. Flow depths in the wash range from 1.7 to 4.5 feet, the average cross sectional velocity varies from 3.1 to 6.8 feet per second and top widths range from 103 feet to 516 feet, upstream of the confluence with Wash W6 North.

d) Wash 9B Floodplain Delineation

(1) Study Limits

From the confluence with 7B Spill (River Mile 0.00, Approximately 2,200 feet north and 1,500 feet west of the intersection of 144th Street and Rio Verde Drive) to a point approximately 2,000 feet north and

1,900 feet east of the intersection of 122nd Street and Lone Mountain Road (River Mile 3,406), a distance of 3.41 river miles.

(2) Flow and floodplain characteristics

The upstream flow rate is 790 cfs, which actually decreases due to channel storage to 620 cfs before the confluence with Wash 7B. Once Wash 7B joins, there is 1,480 cfs of flow and the RAS model is stopped to study the two dimensional flow characteristics. There is one structure located in the floodplain.

The floodplain is undeveloped except for some structures upstream of the confluence with Wash 7B. The floodplain is generally narrow, and widens to accept inflow from the numerous small tributaries. It is determined that a flow split of undetermined quantity occurs near River Mile 2.5. Runoff leaving Wash 9B at this location does not return to the study wash, and the full flow was used in the main wash downstream of this point. Refer to the *Rio Verde Area Floodplain Delineation*, sheet 13 of 17 for more detail.

There is between 1.1 and 4.1 feet of flow depth for a wash whose floodplain varies from 68 feet to 395 feet. The velocity range is from 2.6 to 6.2 feet per second.

e) Wash 7B Spill Floodplain Delineation

(1) Study Limits

From the confluence with 9B Wash (River Mile 0.00, Approximately 2,200 feet north and 1,300 feet west of the intersection of 144th Street and Rio Verde Drive) to a point approximately 1,800 feet north and 1,100 feet east of the intersection of 122nd Street and Dixileta Drive (River Mile 2.882), a distance of 2.88 river miles.

(2) Flow and floodplain characteristics

The upstream flow rate is 1,550 cfs, which increases to 2,090 cfs at the flood storage area for Black Hills Tank, a stock watering tank that is classified as a jurisdictional dam by the ADWR. As mentioned elsewhere in this report, the City of Scottsdale operates and maintains the dam. There is no low level outlet for the tank, so accumulated runoff ponds until it flows out the principal spillway. This greatly reduces the peak flow in the wash, from 2,090 cfs to 760 cfs. Water in the tank is about 15 feet deep as it reaches the spillway crest. The principal spillway is located on the tank's north side. The downstream flow rate increases to 870 cfs upstream of the confluence with Wash 9B. The starting water surface elevation is from the confluence with Wash 9B, based upon the confluence flow rate of 1,480 cfs. There is one structure located in the floodplain.

The floodplain is undeveloped except for the stock tank and some structures in the floodplain upstream of the confluence with Wash 9B. Wash 7B Spill crosses 136th Street, which is an important access road for property north of Rio Verde Drive. Flood flows vary from wide shallow flow to narrow riverine flow. The flow depth ranges from 2.2 to 4.0 feet. The average cross sectional velocity varies from 0.8 to 6.8 feet per second (fps), while the top width ranges from 52 feet at the narrowest section to 630 feet at its widest section.

f) Wash W11 G Floodplain Delineation

(1) Study Limits

From a point near the confluence with Wash 11F (River Mile 0.00) to the upstream end located approximately 1,100 feet south and 350 feet west of the intersection of 138th Street and Rio Verde Drive (River Mile 1.221), a distance of 1.22 river miles.

Wash 11G runs through the Scottsdale National Subdivision (SN), which has an approved HEC-RAS model. The SN HEC-RAS model

for Stream B (sconatb.prj) was imported into the Dibble & Associates model and renamed Wash 11G. The imported SN Cross-sections are 7 (RM 0.511) through 13.7 (1.221). The Scottsdale National flow rates were revised to match the FCDMC-approved values.

(2) Flow and floodplain characteristics

There is 590 cfs in Wash 11G at the upstream end. This flow rate remains very constant for the next river mile until 144th Street where the flow increases to 960 cfs before the confluence with Wash 11F. After Wash 11F joins Wash 11G, there would be 3,620 cfs during a 100-year flood.

Wash 11G crosses 138th Street, 140th Street and 144th Street. Upstream of the thalweg confluence with Wash 11F, a portion of the flood flows split off at RM 0.147 to join Wash 11F within the mapped confluence floodplain. The full flow is used in each wash at the flow split. Along the study reach, the flow depth ranges from 1.5 to 9.8 feet. The average cross sectional velocity varies from 2.4 to 7.3 fps, while the top width varies from 53 feet to 303 feet at its widest section. The wash's most downstream reach near Wash 11F is deeply incised with flood depths of about 10 feet.

g) Wash W11F Floodplain Delineation

(1) Study Limits

From the downstream end near the confluence with Wash 11G, located approximately 1,300 feet east and 1,300 feet south of 144th Street and Rio Verde Drive to the upstream end (River Mile 3.372) located approximately 1,800 feet north and 2,300 feet east of 128th Street and Rio Verde Drive, a distance of 3.37 River Miles (RM).

Wash 11F runs through the Scottsdale National Subdivision (SN), which has an approved HEC-RAS model. The SN HEC-RAS model for Stream A (sconata.prj) existing conditions was imported into the Dibble & Associates model and incorporated into Wash 11F. The imported SN Cross-sections are 1 (RM 0.669) through 6 (1.283). The Scottsdale National flow rates were revised to match the FCDMC-approved values.

(2) Flow and floodplain characteristics

The study reach begins with 870 cfs and contains 3,150 cfs before the confluence with Wash 11G. The confluence floodplain is based upon a flow rate of 3,620 cfs. Near the confluence with Wash 11G, the study wash drains through an existing stock tank. The tank was designed so that once the tank is full, flood flows are directed around the tank's west edge. There are three structures located in the floodplain.

The floodplain is generally undeveloped. Developed areas include some structures upstream and downstream of the confluences with Washes 11E North and 11E South. Wash 11F crosses, from upstream to downstream, 126th Street, 128th Street, Rio Verde Drive, 132nd Street, 136th Street, 138th Street, 140th Street, and 144th Street, which are important access roads for private property north and south of Rio Verde Drive. Flooding flows vary from wide shallow flow to narrower riverine flow. The flow depth ranges from 1.2 to 6.1 feet. The average cross sectional velocity varies from 2.5 to 7.3 feet per second (fps), while the top width ranges from 225 feet to 668 feet. The stock tank would have about 14 feet of water depth during the 100-year flood. The wash downstream of the tank, including Wash 11G, is deeply incised with flood depths of about 10 feet.

h) Wash 11E North Floodplain Delineation

(1) Study Limits

From the confluence with Wash 11F (River Mile 0.00 Wash 11E North=RM 1.7 Wash 11F) to a point 400 feet west of 132nd Street and approximately 1,900 feet south of Rio Verde Drive (River Mile 0.615), a distance of 0.62 river miles.

(2) Flow and floodplain characteristics

The starting water surface elevation is from the confluence with Wash 11F. The upstream flow rate is 670 cfs, which remains constant until the confluence with Wash 11F, when it increases to 2,780 cfs.

The floodplain is undeveloped except for 132nd Street. Upstream of the confluence with Wash 11F, the flow depth ranges from 1.4 to 2.6 feet. The average velocity varies from 2.7 to 4.0 feet per second (fps), while the top width ranges from 206 feet at the narrowest section to 379 feet at the widest location, excluding the confluence.

i) Wash 11E South Floodplain Delineation

(1) Study Limits

From the confluence with Wash 11F (River Mile 0.00 Wash 11E South=RM 1.4 Wash 11F) to a point about 50 feet west of 132nd Street and approximately 2,800 feet south of Rio Verde Drive (River Mile 0.844), a distance of 0.84 river miles.

(2) Flow and floodplain characteristics

The starting water surface elevation is from the confluence with Wash 11F. The study reach has 350 cfs of flow. At the confluence with Wash 11F, there would be 3,150 cfs during the 100-year flood.

The maximum channel depths vary from 1.0 to 5.7 feet. Flow velocities range from 1.4 to 7.5 fps. The floodplain width sees a variation from 20 feet to 700 feet.

The northern ridge containing the wash is not very substantial and flow begins leaving the wash to the north a short distance east of 132nd Street. Split flows travel to Wash 11E North. The amount of split flow is not quantified, the full flow is used at each Wash 11E South cross section and the area flooded by overtopping flows is noted on the floodplain maps as "Sheet Flow Flooding." Wash 11E south drains to a former stock tank, which has been breached. The floodplain reaches its narrowest width as it travels through the breached embankment. Since the downstream channel is incised and the depth of flow is not deep enough to flood this area, a large dry island is mapped just downstream of the breached tank.

D. Environmental Overview

An environmental overview was conducted by the Flood Control District of Maricopa County in September of 2002. The findings of the overview are presented in *Environmental Overview for the Rio Verde Area Drainage Master Plan* and summarized below.

1. Objectives

The objectives of the environmental overview are to review the existing environment in the study area and to discuss any environmental issues that need to be addressed during the planning process or prior to the project implementation. Being aware of the potential environmental issues within the study area can help avoid delays, reduce unforeseen costs, and ensure compliance with regulations in the project planning, design, implementation, and construction phase. Potential environmental issues that can affect the project planning and implementation phases include hazardous material contamination, environmental regulations, archeological resources, and biological resources. The environmental overview focuses on natural vegetation and wildlife, threatened, endangered, and

sensitive plant and animal species, environmental regulations and permits, and hazardous material issues.

More detailed environmental analysis will be conducted for the various alternatives developed at later stages during the planning process. This will include an archeological assessment to identify the known cultural resources in the area and an alternative analysis to compare the impacts to the environment, cultural resources, as well as other factors, for each alternative.

2. *Conclusions and Recommendations*

The Rio Verde ADMP study area is relatively undisturbed. It is located within the Arizona Upland community of the Sonoran Desert Biome. The Arizona Upland community is characterized by abundant vegetation compared to other desert communities. Many ephemeral washes are located throughout the study area that provide good quality wildlife habitat. Although some of the study area includes residential development, most of the residential areas are low density and have left the native vegetation undisturbed. The cactus ferruginous pygmy owl is the only Threatened and Endangered Species that has suitable habitat in the study area.

Due to the species and structural diversity, as well as the relatively undisturbed character of the study area, much of the Rio Verde study area contains good quality wildlife habitat. Based on a search of the environmental regulatory records, the District and the planning team does not have to be concerned with hazardous material sites within the study area for planning purposes. In the implementation stage, however, the District should conduct a Phase I Environmental Assessment for land that will be acquired or is necessary for construction.

The following recommendations were developed to help the District comply with the environmental regulations and obtain permits, reduce costs associated with environmental issues (e.g., hazardous material issues), avoid delays in the implementation phase, reduce environmental impacts, and support the "kinder and gentler" philosophy the District would like to follow.

- During the alternative evaluation process, environmental impacts must be considered when comparing the various alternatives.
- The District should follow measures to avoid or reduce impacts to the environment, especially along the ephemeral washes and other significantly vegetated areas.
- The District should survey areas with suitable habitat for the cactus ferruginous pygmy owl (CFPO).
- Although the CFPO appears to be the only endangered species with suitable habitat in the study area, project specific locations must be reevaluated during the design phase to determine if habitat, regulations, or the listed species have changed.
- For the proposed alternative, a vegetation survey and habitat evaluation study must be conducted in order to develop a mitigation plan for impacts to the Waters of the U.S.
- For impacts outside of Waters of the U.S. for the proposed alternative, the habitat should be evaluated to determine what environmental issues or regulations will be necessary to follow (e.g., the MBTA)
- The District should conduct a Phase I Environmental Site Assessment and a Cultural Resource inventory for land that will be purchased by the District or will be required for construction.

IV. PROBABLE FUTURE CONDITIONS

A. Developed Conditions Hydrology

The developed conditions hydrology for the study area is based on the assumption that future developments will continue to occur as they have under current development practices and under current zoning regulations with no new guidelines directing development. This scenario will constitute the 'No Action' alternative for comparison with other alternatives that may be considered during development of the project.

Developed conditions runoff is predicted by changing the existing developable desert land use areas in the hydrology model to very low density residential land use, which will have the affect of altering the runoff response of the watershed. Anticipated changes within the watershed will generally decrease the vegetative cover by 60%, increase the impervious areas from 0% to 15%, and decrease the surface retention loss (IA) by 33%. Additionally, the watershed resistance will generally decrease by 10%. The peak runoff rates within the watershed resulting from these changes could increase by an average of 20% above the existing drainage conditions and up to a maximum of 75% (based on the 24-hour storm event).

B. Impact of Development

Development of the Rio Verde ADMP study area will impact the area's hydrologic and fluvial systems. Removal of vegetation, compaction of soils, and construction of impervious surfaces (e.g. roof tops) will increase both the magnitude and frequency of runoff in the area. In addition, diversions, encroachments, and other concentrations of flow will result from placement of home foundations, other buildings, fences, and roadways. All of these changes to the watershed will result in some undesirable outcomes to private property and the natural environment. This section describes the nature of the geomorphic impacts resulting from the interference with the natural water and sediment systems.

The signals of the impacts of urbanization to date are mixed with signs of natural system instabilities. Road crossings, stock tanks, diversions, and other human caused changes to the fluvial systems in the area have resulted in erosion, deposition, and redistribution of flooding and erosion hazards in the area. One of the objectives of the ADMP is to reduce similar impacts in the future.

One of the best methods of prediction of the impacts of development to a fluvial system is by comparison with similar impacts on similar systems. Since some development has already occurred in the Rio Verde area, examination of those effects, if any, provide an excellent starting point for predictions about the future. However, the cumulative impact of complete or near complete development of the area may not be adequately expressed by observations of impacts incurred thus far in the area and may require comparison outside of the area and extrapolation from synthetic and conceptual model results.

1. Observation

a) Fire

Fire has the potential effect of removing significant amounts of vegetation in a watershed. This could be analogous to the removal of vegetation resulting from development. Several large fires have occurred in the area in the past decade or so. The scars of those fires are visible in aerial photographs as well as in the field. Some areas in the eastern portion of the study area have very few remaining large living trees. Fire has also removed the smaller shrubs such as brittlebush. The impact these fires have had on the fluvial system thus far is uncertain. Gullying and local areas of aggradation due to fallen vegetation are widespread throughout the study area, not just in the burned areas.

It is possible that vegetation removal alone is not sufficient to cause significant observable impacts to the fluvial system. Another possibility is that the type of hydrologic event necessary to cause widespread sedimentation impacts did not coincide with the fire event. A third possibility is that the hydrologic consequence of fire is within the range of variability that the fluvial system has already adjusted to.

b) Stock Tanks

The historical aerial photos and field observations indicate that stock tanks have caused significant sediment discontinuities to the fluvial system in the study area. Similar types and magnitudes of impacts could be created by development that results in similar diversions and sediment trapping.

High sediment loads were also recognized by the stock tanks' builders. Some of the tanks have sedimentation basins to segregate sediment from the water collected by the small earthen dams. In addition, many of the tanks were not located directly on washes but rather in an adjacent area and water was diverted to the tank. Presumably this was another strategy employed by ranchers to reduce maintenance efforts.

One of the consequences of trapping sediment flowing to the stock tanks is significant clear water or sediment-free runoff passing to the downstream washes. The result has been significant vertical erosion of the channels immediately downstream (**Figure IV-1**). Not as visibly dramatic, harder to detect, but also important is the deposition of the eroded material in the downstream reaches. Aggradation of downstream reaches can lead to reduced slopes, wider inundation areas and possible redistribution of flood discharges downstream. Aggradation can also be significant upstream where bedload and suspended sediments are deposited.

Figure IV-1 – Example of arroyo formation downstream of stock tank (Photo RV12-6)

The disruption of sediment transport continuity by a stock tank might therefore also be expected to affect the channel-fan pattern sequence. Deposition upstream of a stock tank could aggrade into an existing trunk channel creating a wider shallower flow pattern upstream. Scour downstream of the tank would be expected to create a new trunk channel and subsequent downstream fan. Field observations show the expected new trunk channel in the form of deep arroyos (Figure IV-1). However, other obvious effects to the channel-fan pattern sequence in the vicinity of existing tanks are not seen possibly because the impacts are limited longitudinally to very near to the tanks. As mentioned, existing tanks exhibit significant deposition immediately upstream and arroyo formation downstream. Another factor may be that the reduction in sediment supply due to deposition in the tank exceeds the available load created by erosion in the downstream arroyo and, therefore, new downstream fans are not created. Another possibility is

that the eroded materials are predominantly fine-grained and transported in suspension rather than as bedload which forms the fans. Finally, the timescales associated with aggradational adjustments greatly exceed degradational adjustments (Bull, 1997). Therefore, the adjustments to these relatively new features may not have occurred yet or at least not at an observable scale.

c) Roadway Drainage Crossings

As the area develops, construction of roads will occur. Roadway crossings of drainages were investigated to determine their impacts to the washes.

Dip crossings in the area showed evidence of deposition upstream and scour downstream of the crossings. This behavior is a typical hydraulic response to the grading of a road across a wash. HEC-RAS models of dip crossings demonstrate the changes in channel velocity that cause these changes. Following the July 14, 2002 flood, a number of road crossings were observed to have deposited sediments on the road and eroded downstream from clearwater scour as predicted by the RAS models.

Several culvert crossings also exist in the Rio Verde watershed. Most of the culverts were installed in 2001 and have not experienced many significant flows since construction. In particular, along 144th Street from Rio Verde Drive to Windstone Trail, there are 24 culvert crossings. Some of these are simple circular pipe culverts while others are large multiple cell reinforced concrete box culverts.

Of the culverts at 144th Street, only one thus far shows any adverse impacts on the adjacent reaches. The culvert near Windstone Trail experienced degradation of the upstream areas following the flood on July 14, 2002. The degradation is due to the lowering of the channel invert by the construction of the culvert. **Figure IV-2** shows an example.

Figure IV -2 – View of channel upstream of culvert under 144th Street near Windstone Trail

d) Residences and Other Structures

Another type of impact of development on water and sediment discharge continuity in the Rio Verde area has been from the construction of residential buildings and their associated facilities, such as fences, walls, and horse facilities. **Figure IV-3** shows an example.

Figure IV-3 - View downstream of wall crossing wash

Diversion, collection, or other concentrations of runoff are expected to cause local erosion. Channel entrenchment of one to three feet for reaches up to several hundred feet can be expected from significant concentrations of flow without protective measures. Flow diversion can also cause erosion as the result of changes in channel slope. Flow diversions normally result in longer flow paths. A longer flow path over the same amount of fall reduces the channel slope. As observed at roadway crossings and stock tanks, local reductions in slope usually result in sediment deposition. The resulting clearer water erodes reaches downstream as the flow picks up the lost sediment.

The granitic parent material in the watershed limits channel sediment sizes. Granite weathers into pebble and sand sized clasts, silts, and clays. Sediment samples collected in the study area show that reasonable approximations of D15, D50, and D85 for channels in the area are 0.45 mm, 1.6 mm, and 4 mm respectively. As mentioned previously, slopes in the study area are very steep. Average slope across the piedmont is greater than 1.5 percent throughout the area and greater than 2.5 percent over a significant portion of the area. The combination of small sediment sizes and steep slopes creates an environment where sediment transport rates are very high even at very shallow depths of flow. Further, sediment transport continuity is easily disrupted by local changes in hydraulic conditions. For example, a tree falling in a wash can cause aggradation upstream and degradation downstream of 1 to 2 feet. These seemingly subtle changes can be significant in areas with nominal local lateral relief.

2. *Models*

The synthetic hydrologic models of the area suggest that the 100-year discharges could increase from an average of about 20 percent to as high as 75% with full development of the area as single lots with no retention (i.e. no subdivisions). As a comparison, HEC-1 models performed for the Desert Hills area for the Adobe ADMP showed about a 100 to 200 percent increase in the 2-year discharges given similar types of development.

If it is assumed that the 2-year discharge represents the channel-forming discharge, that is, the flow rate responsible for the shape, size, and planform of the channel system, then some predictions of channel

form adjustments can be made by comparing the 2-year discharges for different scenarios.

Leopold, Wolman, and Miller (1964) report average at-a-station values for ephemeral streams of b =0.29, f = 0.36, and m = 0.34.

$$w = aQ^b,\ d = cQ^f,\ v = kQ^m$$

where; w=width, d=depth, and v=velocity

If full development of the area results in a doubling or trebling of the 2-year discharge, at-a-station hydraulic geometry relationships would predict a 22 percent increase in width, a 28 percent increase in depth, and 27 percent increase in velocity.

Sediment transport rates have been estimated empirically by Zeller-Fullerton (1985) as proportional to $V^{4.3}$. A 27 percent increase in velocity therefore would result in a 280 percent increase in the sediment transport rate.

Bull (1997) suggests that the repeating channel-fan pattern in discontinuous ephemeral streams is an expression of their adjustment to the balance of force and resistance. He expressed this idea with the equation:

$$Ps / Pw = 1.0$$

Where Ps = stream power, and Pw = resisting power.

If the numerator increases due to increases in discharge due to development, then a proportional increase in resisting power should be anticipated. Additional resisting power could come in the form of additional wetted perimeter, decrease in slope, or increased roughness from bedforms or some other source. Increased wetted perimeter means wider channels. Decreased slope means deposition. From a practical point of view adjustments to all of these factors should be expected. Deposition can create wider flow and wider flow can create deposition.

The consequence to the repetitive channel-fan pattern would be a tendency for the development of new channel-fans and/or migration of existing channel-fans in the upstream direction. Flood and erosion hazards would also be redistributed. Buildings, drainage crossings, and other property not previously at risk could become at risk or their degree of risk could be increased as the fluvial system adjusts to the new hydrologic conditions. Eventually, of course, the system should adjust itself to the new conditions. However, Bull suggests that the time scale of such adjustments is on the order of 100 years for degradation and 500 years for aggradation. Therefore, it could be a very long time before a newly stable fluvial system results that is fully adjusted to the impacts of development.

3. Conclusions

The combination of steep slopes, fine-grained sediments, and the complex, ephemeral fluvial systems in the Rio Verde ADMP study area creates a highly unstable, very sensitive environment for passage of flood water and sediment generated by infrequent intense rainfall events. Consequently, perturbations to the system can result in significant erosion, deposition, and redistribution of flood and erosion hazards in the area. Prediction of the exact location of these effects is not easy or precise. Thus far, the most significant impacts have been associated with dramatic disruptions of sediment transport continuity at stock tanks. Adjustments to the fluvial system have occurred in the vertical and horizontal dimensions. The magnitudes have been dramatic vertically, but limited horizontally based on historic observations covering the past 50 years. Quantitative predictions of

adjustments to complete unmitigated development of the area suggest much larger and more widespread effects. Such effects may be felt in the watershed for many decades. Therefore, mitigation of the hydrologic and geomorphic impacts of development is desirable before significant development occurs.

V. REFERENCES

Bull, W. B., Discontinuous ephemeral streams, Geomorphology, 19: 227-276, 1997.

Burgess & Niple Inc. and Wood Patel & Associates, Rio Verde North Floodplain Delineation Study, October 1994.

CMX Group Inc., Master Drainage Report for Scottsdale National, December 2001.

Camp, P.D., Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona: U.S. Soil Conservation Service Report, 306 p., 53 maps, scale 1:24,000, 1986.

David Evans & Associates Inc., Rio Verde North Extension Floodplain Delineation Study Technical Data Notebook (Hydrology), August 2002.

David Evans & Associates Inc., Rio Verde North Extension Conveyance Corridor Limit Analysis, October 2002.

Flood Control District of Maricopa County, Drainage Regulations for Maricopa County, September 1988.

Flood Control District of Maricopa County, Environmental Overview for the Rio Verde Area Drainage Master Plan, September 2002.

Flood Control District of Maricopa County, Floodplain Regulations for Maricopa County, August 1986.

Flood Control District of Maricopa County, Digital Orthographic Aerial Photography, Flight dates December 19 and 27, 2001 and February 21-22, 2002.

JE Fuller/Hydrology & Geomorphology, Inc., Floodplain Delineation Study of Rio Verde South Extension, May 1999.

JE Fuller/Hydrology & Geomorphology, Inc., *Geomorphic Analysis Report,* report prepared for Dibble & Associates Consulting Engineers for Task 3.4 for the Rio Verde ADMP for the Flood Control District of Maricopa County, November 2002.

JE Fuller/Hydrology & Geomorphology, Inc., *Piedmont Assessment Report – Basis For Delineation of Areas With 1-D Vs. 2-D Flow Characteristics,* report prepared for Dibble & Associates Consulting Engineers for Task 3.4.1 for the Rio Verde ADMP for the Flood Control District of Maricopa County, July 2002.

McLaughlin Kmetty Engineers Ltd., Rio Verde South Floodplain Delineation Study Technical Data Notebook (Hydrology), August 1995.

Pinnacle Engineering Inc., Final Drainage Report for The Golf Club at Scottsdale, June 2001.

Spencer, J.E., Pearthree, P.A., and Richard, S.M., Geologic Map of Portions of the Theodore Roosevelt 30' x 60' Quadrangle, Arizona, Arizona Geological Survey Digital Information Series DI-12, version 1.0, 12 p., 2 MS-DOS floppy diskettes, 1998.

U.S. Geological Survey, Digital Orthographic Quarter Quadrangles, GeoTIFF format, 1 meter resolution, UTM, NAD83 projection, 1992.

U.S. Geological Survey, *Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona,* April 1991.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-1 Flood Hydrograph Package Users Manual,* September 1990.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-1 Flood Hydrograph Package Program,* Version 4.1, July 1997.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-RAS River Analysis System Applications Guide,* Version 3.1, November 2002.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-RAS River Analysis System Hydraulic Reference Manual,* Version 3.1, November 2002.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-RAS River Analysis System Users Manual,* Version 3.1, November 2002.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *HEC-RAS River Analysis System Program,* Version 3.1, November 2002.

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