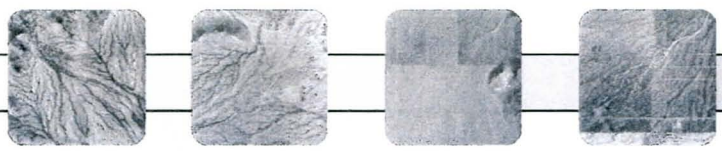

2008C007 Task 2.3

Historical Development on Alluvial Fans

Prepared for: Flood Control District of Maricopa County

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August 3, 2009

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1. Executive Summary

The purpose of this technical memorandum is to assess the successes, failures, and/or drainage problems associated with historical development on alluvial fan landforms in Maricopa County. The primary objective of this memorandum is to assess the nature of flood hazards and damages associated with development on alluvial fans in Maricopa County.

Four individual site locations were chosen and approved by District staff (Ahwatukee, Pima Canyon, Reata Wash & Lost Dog) for the study of historical development on alluvial fan landforms. (Figure 1-1) The study site locations were identified using historical and recent aerial photographs, NRCS soils mapping and topographic mapping. The four study sites include areas of dense urbanization, single lot development, and developments with major structural drainage measures.

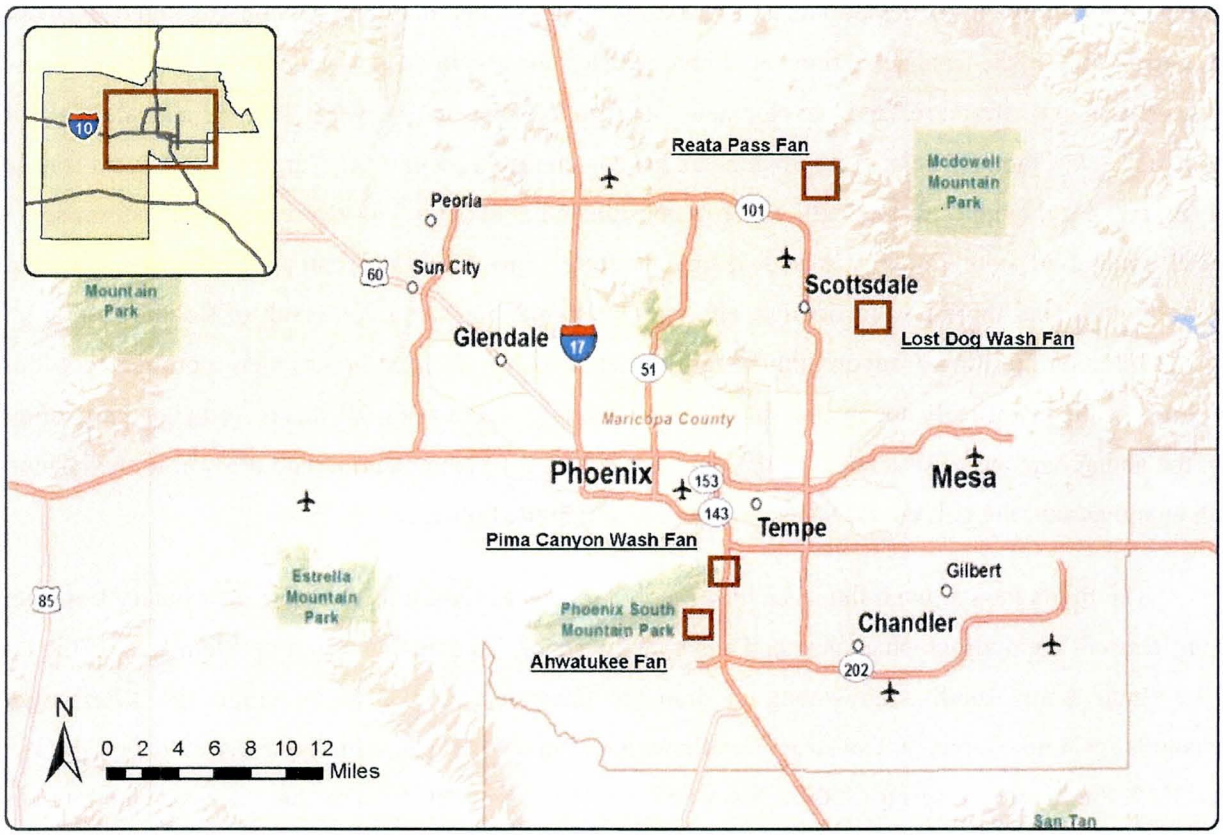

Figure 1-1 Location map showing all four historical fan sites.

The Ahwatukee alluvial fan was an active alluvial fan prior to development in the late 1980's. Prior to development, the Ahwatukee fan wash lost both capacity and definition at its hydrographic apex, as previously contained flow was converted to broad sheet flow over much of the upper fan area. The

upper fan had been the site of repeated sediment deposition over time as water spread out and lost both depth and momentum giving this area distinctive geomorphic texture. The alluvial fan landform remained undeveloped until the mid-1980's when rapid and dense suburban single-family-unit development over the entire fan landform occurred. Upstream of the apex flows were dammed and floodwaters were routed to the toe via a concrete-lined trapezoidal channel. No homes or structures on or around the fan have been flooded to date. The concrete-lined channel, despite being heavily damaged during one large event, has never overtopped. Sedimentation in the channel and expansion / contraction issues surrounding the channel joints are problems that are addressed routinely by the channel owners, a private home owners' association, which regularly maintains the channel.

Pima Canyon Wash alluvial fan was an active alluvial fan prior to development in the late 1980's. Due to low topographic relief at the toe of the fan, the town of Guadalupe had been continually flooded by shallow sheet flow and sediment, and has had damaged homes and infrastructure since the 1930's. Since the 1930's, extensive development has taken place on the fan including the construction of I-10 and the Guadalupe FRS, channelization of Pima Wash, construction of residential subdivisions and transportation infrastructure, and development of a golf course in the wash bottom and alluvial fan floodplain. Development-related improvements have been tested by one very large rainfall event (on the fan surface, not the upper watershed), which was estimated at about a 350-year event. This storm sent a record amount of both floodwater and sediment along Pima Canyon Wash to the Guadalupe FRS. Several homes near the fan were flooded, although the inundation was not a result of flooding along the main channel on the Pima Canyon alluvial fan. In addition, the flooded homes were not located within the limits of the historically active alluvial fan area. Although record rainfall was recorded on parts of the fan, the actual damage to structures on the fan were minimal. Sedimentation and erosion in the channel both in and around the golf course will continue to occur in the future.

The Reata Pass alluvial fan has a moderately large watershed, a large active distributary flow area downstream of the hydrographic apex, and a classic fan shape. To date the largest problem area on the fan is the Pima Acres subdivision where no drainage infrastructure was built within the 1960's-style rectangular grid development. Construction of homes in Pima Acres started in the early 1990 and the area was 75 % built out by spring 2009. Elsewhere on the fan, sedimentation has clogged culverts and blanketed dip crossings during small floods, creating a maintenance burden on both the City and the local home owners' associations. Development on the upper portion of Reata Pass fan preserved much of the natural, distributary drainage patterns of the fan landform, with the natural wash corridors designated and protected by City regulations as environmentally sensitive wildlife habitat. While no significant flood

damages have been reported on the Reata Pass Fan, neither have there been any storm events greater than a 10-year event since development began, and the flood mitigation infrastructure is largely untested.

Lost Dog Wash, until modern development in the area between 1997 and 2005, was a small active alluvial fan characterized by unconfined distributary flow downstream of the apex. Development confined Lost Dog Wash to an engineered channel that routes flood water down the western portion of the fan, under the intersection of 120th Place and Via Linda Road to the CAP where the water is ponded and routed northwest to the nearest crossing of the CAP canal. Lost Dog Wash has not seen any significant rainfall since the fan developed, and the drainage structures remain substantially untested over the last 10 to 15 years.

Based on our analysis, we conclude that the engineered drainage systems at the four historical alluvial fan study sites have performed adequately during the 20 year period of record, at least with respect to controlling the flow uncertainty and sedimentation associated with active alluvial fans. The range of structural measures used included a peak-scalping detention basin, a concrete-lined channel, an earthen channel with drop structures, mass grading (golf course & development), a regional detention basin (at the fan toe), levees, diversion dikes, culverts, dip crossings, and bridges, as well as some non-structural regulatory measures. Although there has been only one near-regulatory type event on only one of the fans, and the systems remain largely untested, the record indicates the following:

- No homes on the fans have been damaged by alluvial fan flooding in the past 20 years.
- The structural measures, while they have sustained some damage and required sediment maintenance, have essentially performed their intended function thus far.
- No evidence of adverse impacts from channel avulsions, excessive sedimentation or scour have been recorded.
- Periodic sediment removal is required, especially near the upper end of the fans, but has not been excessive or beyond the capacity of the HOA's or the local jurisdiction.

Given the episodic and probable low return frequency of fan-altering (avulsive, excessive sedimentation, etc.) flood events, the conclusions listed above should be carefully weighed in light of the short period of record at the four fan sites.

2. Introduction

2.1 Study Purpose

The purpose of this technical memorandum is to assess the successes, failures, and/or drainage problems associated with historical development on alluvial fan landforms in Maricopa County. The primary objective of this memorandum is to assess the nature of flood hazards and damages associated with development on alluvial fans in Maricopa County.

2.2 Study Authorization

This study is performed for the Flood Control District of Maricopa County (FCDMC, or the District) under Contract No. 2008C007 Task 2.3.

Project 2008C007 is a refinement to the current Piedmont Flood Hazards Assessment Manual (PFHAM) methodology. The purpose of the refinement is to identify engineering procedures to determine flood hazards on alluvial fan landforms, recommend hazard mitigation measures, further refine the landform designations and make recommendations for updating the PFHAM.

2.3 Study Introduction

Four individual site locations were chosen (Ahwatukee, Pima Canyon, Reata Wash, and Lost Dog) to study the effectiveness of flood mitigation measures that have been used historically on alluvial fan landforms in the metropolitan Phoenix area. (Figure 2-1) The study site locations were identified using historical and recent aerial photographs, NRCS soils mapping and topographic mapping. The four areas include areas of dense urbanization, single lot development, and developments with major structural drainage measures. Study sites were selected that covered the longest period of development, had varying types of development and had different flood mitigation measures. The pre-development landforms were then classified using the District's PFHAM Stage 1 categories.

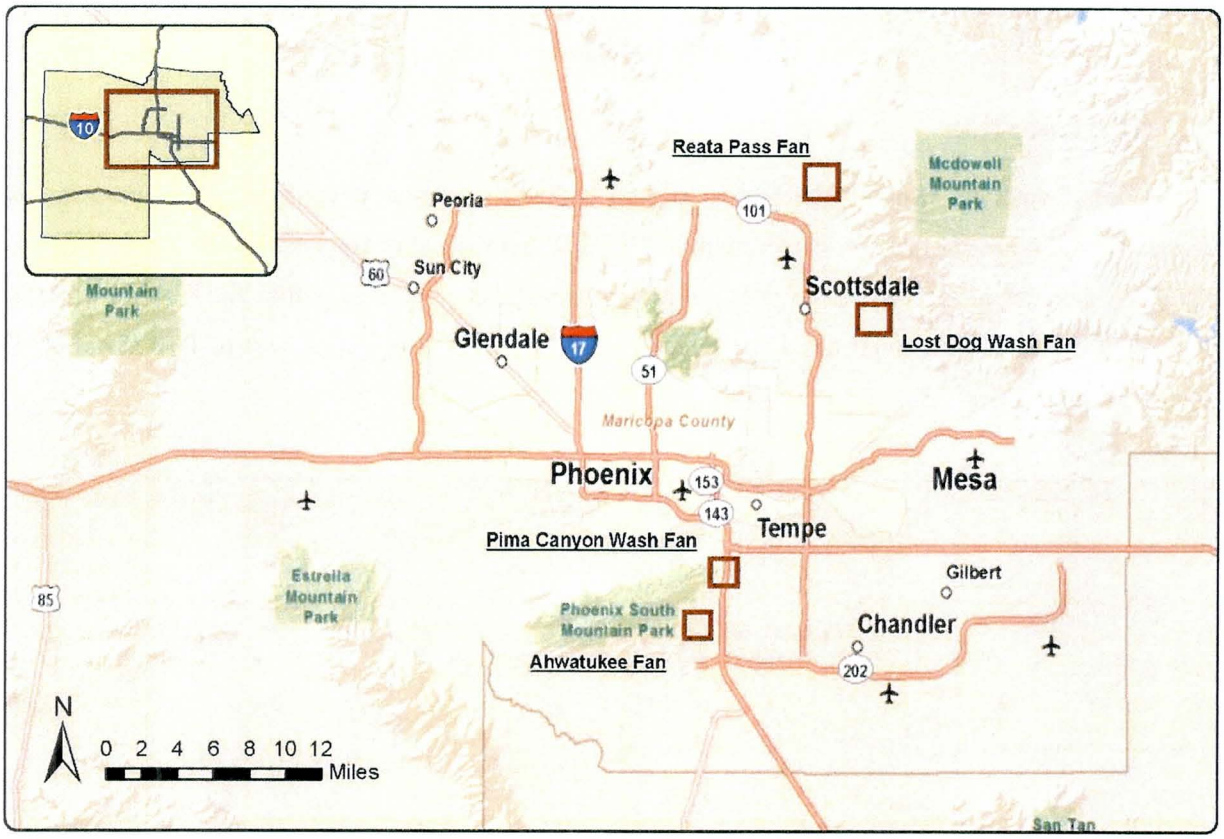

Figure 2-1 Location map showing all four historical fan sites.

Changes in the historical landform characteristics were documented for each site. Investigation of each study site included review of: historical and recent aerial photographs, construction plans- if available, historical and recent topography, rainfall records, and interviews with maintenance staff, long-term residents, local floodplain managers, or home owners associations to find anecdotal or systemic information regarding the performance of drainage structures, maintenance problems, and flood damages.

Finally, the effectiveness of structural or non-structural flood mitigation measures at each study site were documented based on the information collected. Recommendations are provided within the conclusion of the technical memorandum on how to apply these findings to the Integrated Alluvial Fan Hazard Assessment Methodology.

3. Ahwatukee Fan

3.1 Site Location

The Ahwatukee Alluvial Fan site is located within the southeast valley of Phoenix, Arizona. Both the alluvial fan and apex are located within T1N R3E Section 24 of the Gila & Salt River Meridian (G&SRM). The fan is located in the community of Ahwatukee which is within the City of Phoenix incorporated limits. The alluvial fan apex is located approximately two miles west of I-10 at about the Warner Road alignment.

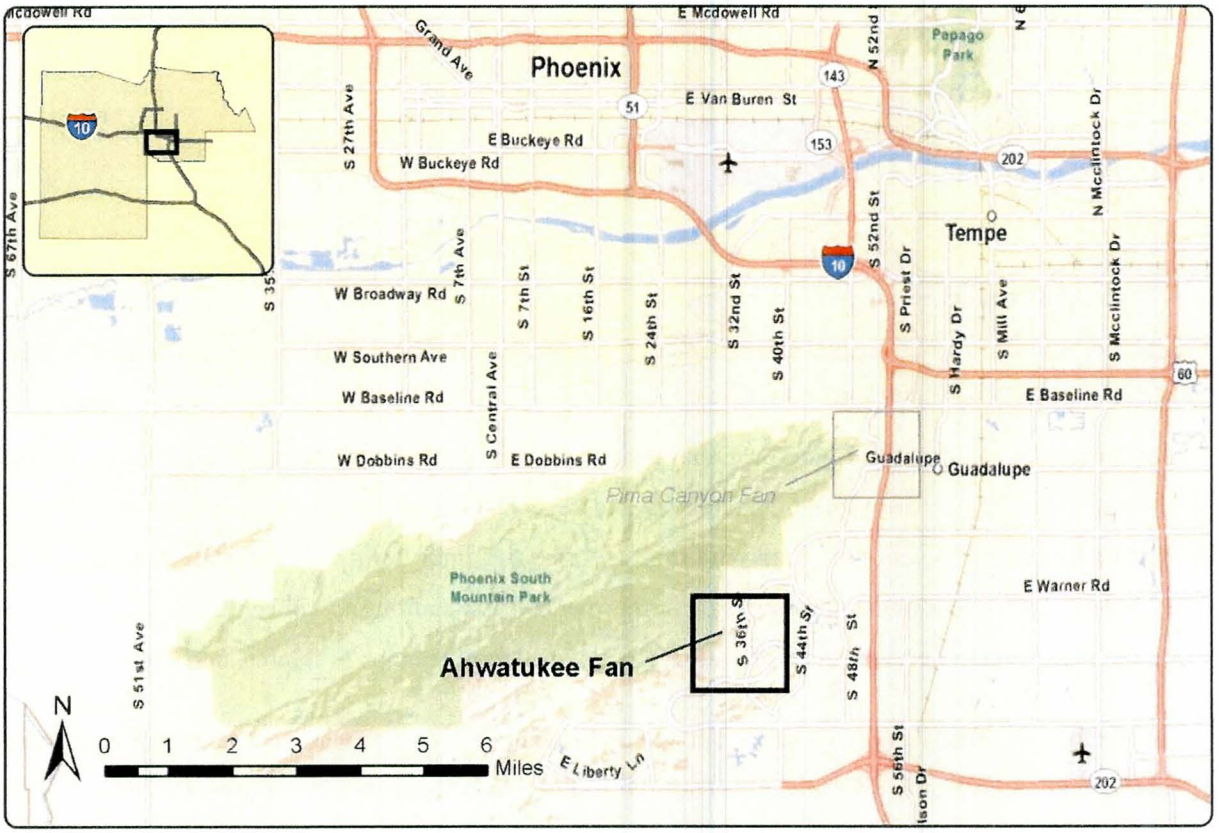

Figure 3-1 Location Map: Ahwatukee Fan.

The Ahwatukee Fan watershed is 1.7 square miles in area, and drains a portion of the southeast flanks of South Mountain. The watershed, up to the apex of the fan, is contained within Phoenix South Mountain Park and remains undeveloped.

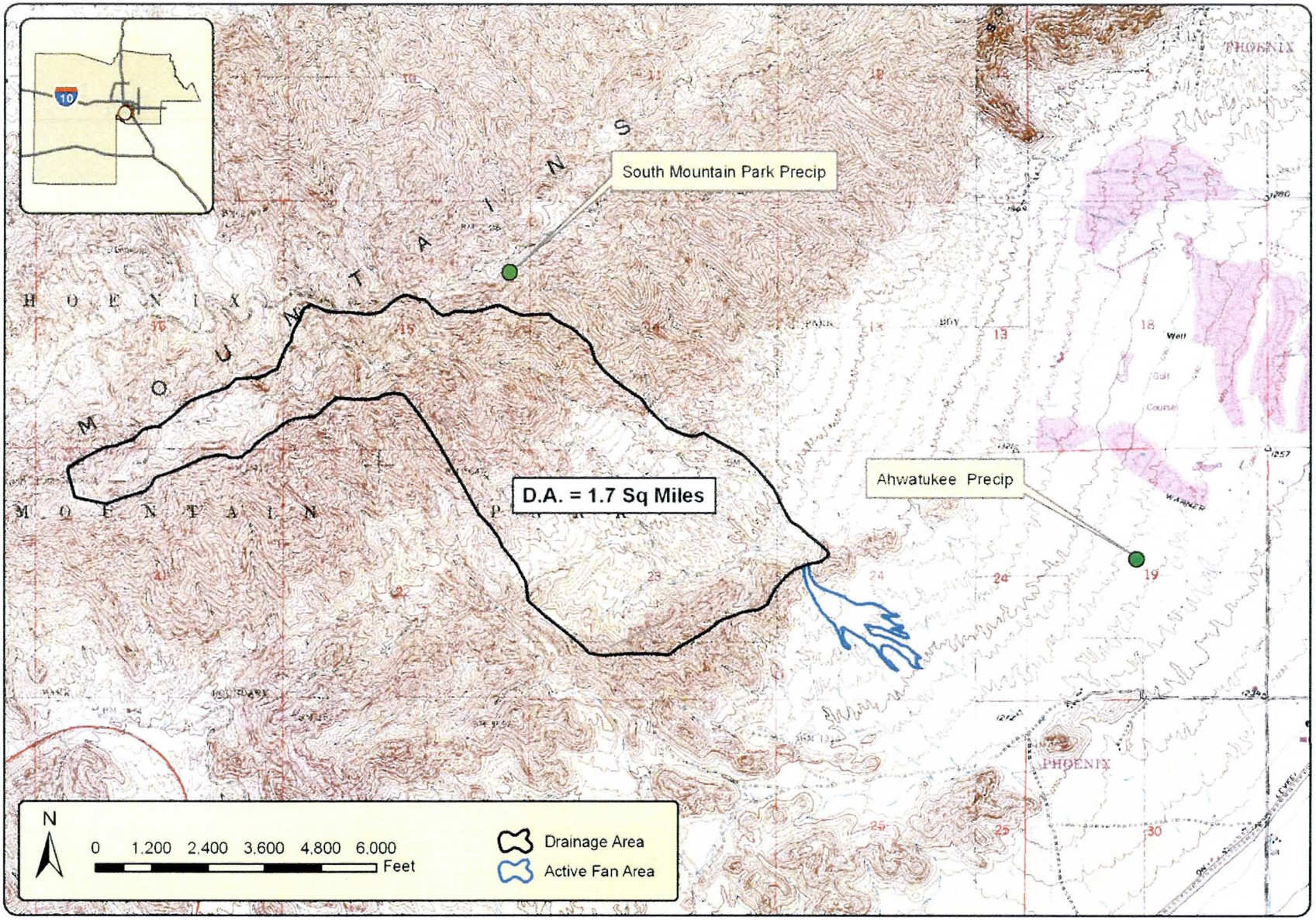

Figure 3-2 Ahwatukee Fan Drainage Area Map.

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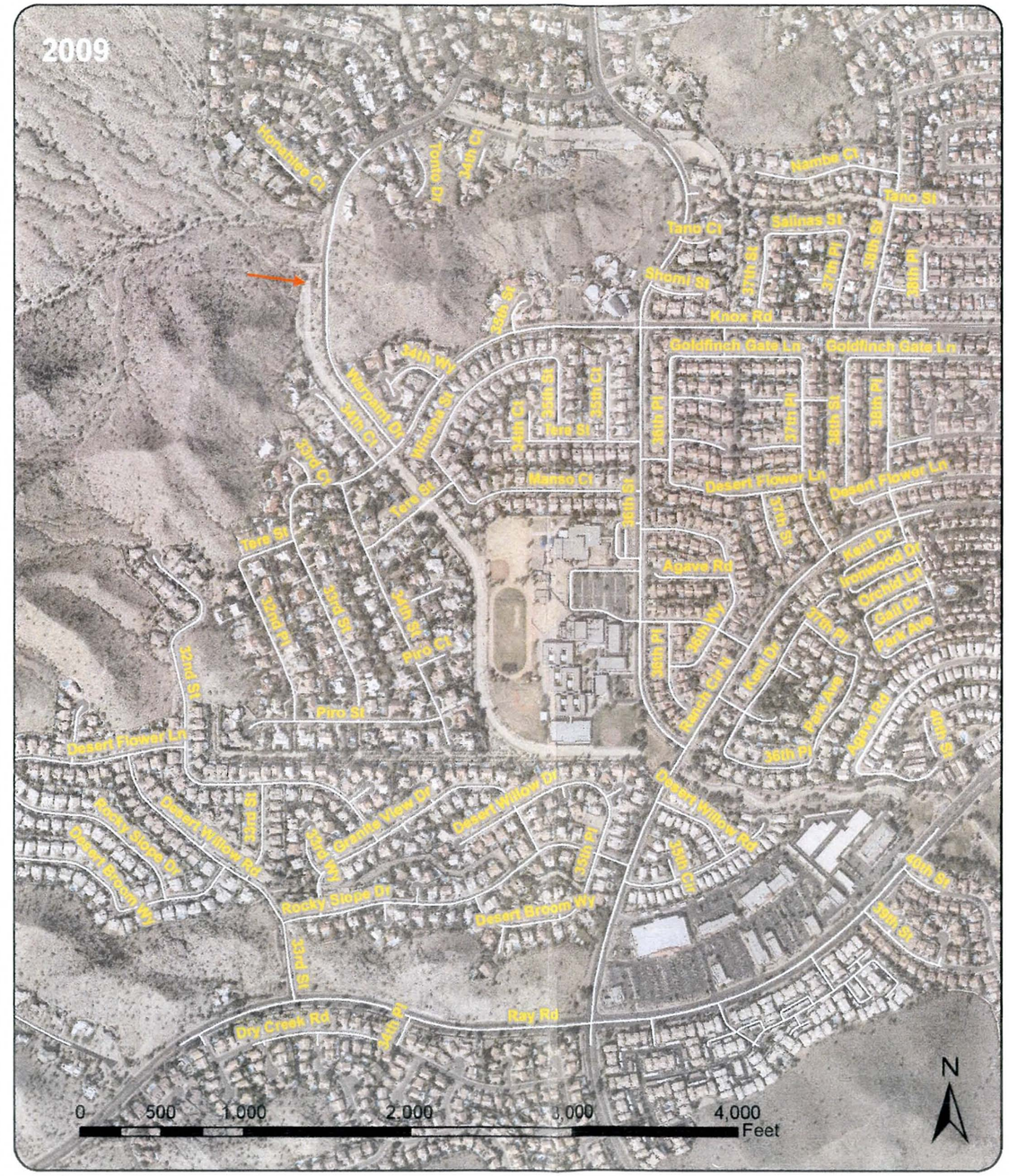


Figure 3-3 Ahwatukee Fan (before development).

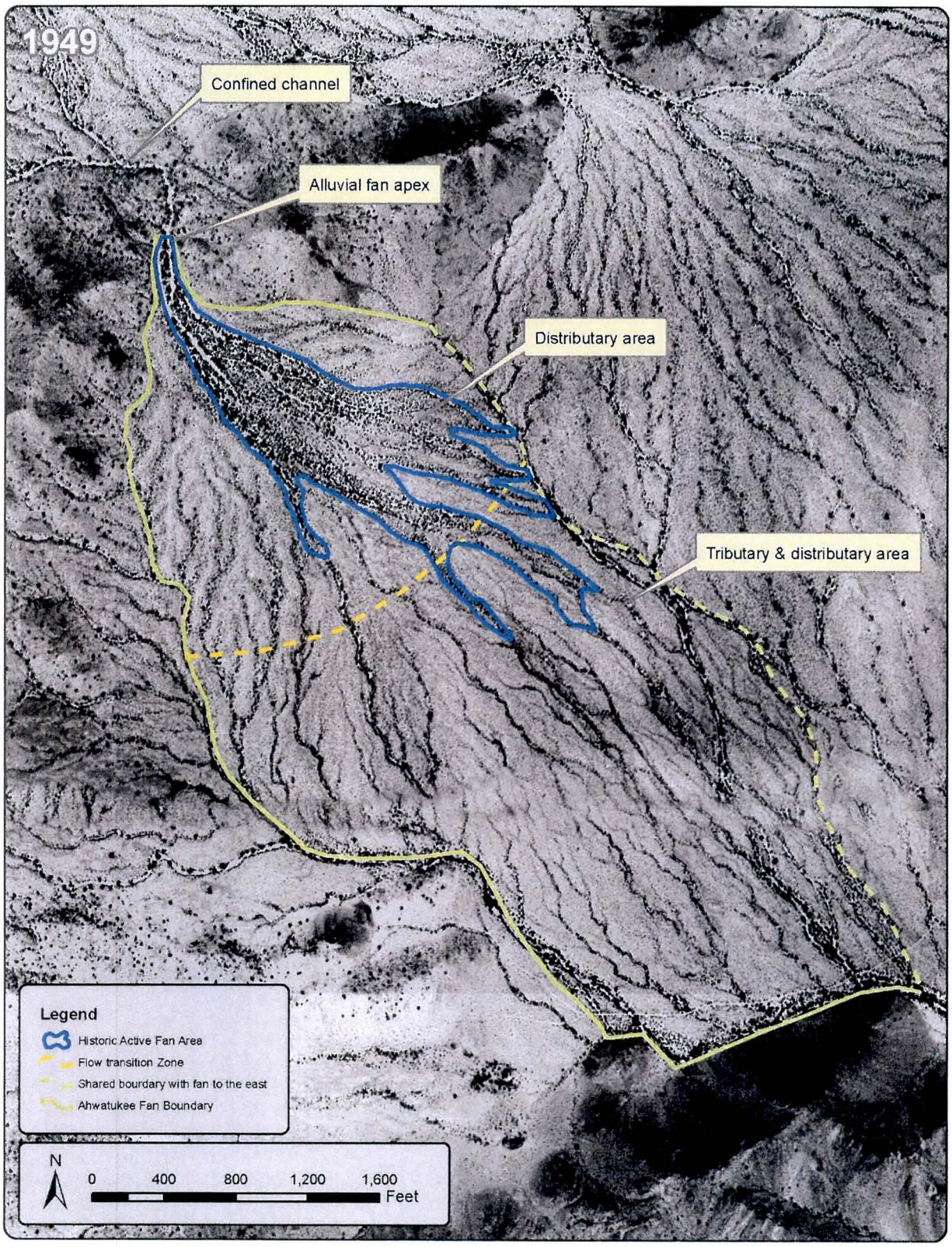


Figure 3-4 Ahwatukee Fan Landform Boundary (pre-development).

Figure 3-5 Ahwatukee Fan Points of Interest & Photo Locations.

As seen in Figure 3-4, the apex of the historical alluvial fan is northwest of the present day intersection of Knox Road and Warpaint Drive. The wash, unnamed on USGS quads, collects flows off South Mountain, enters the historical photograph from the west (on the upper left) then makes a sharp right turn to the south (river right) through a narrow canyon, the present day location of Warpaint Drive. The wash then loses capacity and spreads out as distributary flow over much of the upper portion of the fan. In the 1949 photograph (Figure 3-3) the active portion of the fan can is characterized by a "salt and pepper" stippled pattern characteristic of distributary and shallow sheet flow areas. The active portion of the fan extends down fan approximately as far as the present location of North Ranch Circle Drive.

After flood water flows down fan over the distributary areas, in the upper third of the fan, the sheet flow is conveyed into more defined, slightly incised flow paths. The flow paths are both tributary and distributary but do not contain the same "salt and pepper" stippled pattern as the active areas upstream. These incised flow paths convey the flood water to the toe of the fan where they join another wash, flowing from the west, and continue downstream.

3.1.1 NRCS Soils Mapping

Figure 3-6 presents the soil survey information for the Ahwatukee Fan study area. The source of the soil survey data is the NRCS (formerly the SCS) Soils Survey of Eastern Maricopa and Northern Pinal Counties, Arizona, 1974. In Figure 3-6 the historically active alluvial fan area was delineated from the 1949 aerial and is included as a blue outline on the 2009 aerial photograph background. This was done to provide perspective of where the historical active alluvial fan surface was in comparison to modern residential development in the area. Soil survey units are labeled individually but also grouped by major landform type that each unit typically represents.

Upstream of the apex are two soil units: Ro (Rock Land) and Ru (Rough Broken Land). Both these units have been shaded brown in the figure and classified as 'Mountain Slopes.' Rock Land consists of areas that are 50 to 70 percent exposed rock, and is used to describe steep sloping bedrock mountains in the study area. Runoff is typically very rapid and erosion active in these areas. Rough Broken Land (Ru) is moderately sloping to very steep. This unit is often dissected by many intermittent V-shaped drainage channels and separated by irregular narrow ridges.

The entire alluvial fan landform is composed of Antho gravelly sandy loam (AoB), and bordered on each side by Tremant gravelly loam (TrB). Antho gravelly sandy loam (AoB) forms on gentle, 1-3 percent slopes, on the upper portions of alluvial fans. Tremant gravelly loam (TrB) consists of well

drained soils on old alluvial fans. In Figure 3-6 the (AoB) Antho Series has been shaded yellow to depict alluvial fans while the (TrB) Tremant Series has been shaded blue to depict older, inactive alluvial fans. The Ahwatukee alluvial fan is composed of soils typically found on alluvial fans and bordered by older fan terrace soils.

3.1.2 Surficial Geology

Figure 3-7 presents the surficial geology of the Ahwatukee Fan study area, as mapped on the AZGS Phoenix South Geology 100,000 scale, Open File Report 97-5, by Reynolds and Skotnicki. In Figure 3-7 the historically active alluvial fan area was delineated from the 1949 aerial and included as a blue outline on the 2009 aerial photograph background.

The bedrock units of the ridgeline that lies to the north of the study area are composed of granite and breccia (Tg and Tcb). Tg (Tertiary Granite) is the same unit that composes most of the South Mountain Range and formed in the middle Tertiary, roughly 65 million to 2 million years before the present.

The majority of the Ahwatukee alluvial fan landform lies within the Qy geologic unit. Qy (Quaternary Young Alluvium) forms low terrace and alluvial fan deposits. Qy, a Holocene unit less then 10,000 years old, is the youngest geologic unit in the study area.

Bordered on both the east and the west the Qy unit is bounded by the older Qm2. Qm2 is an upper to middle Pleistocene alluvium. The Pleistocene Epoch dates from approximately 1.8 million to 10,000 years before present.

3.1.3 Topography

Figure 3-8 presents the topography for the Ahwatukee alluvial fan study area. The topography shown is USGS 10-foot topography from the Lone Butte quadrangle dated 1952. In Figure 3-8 the historically active alluvial fan area was delineated from the 1949 aerial and included as a blue outline on the 2009 aerial photograph background.

The contours immediately downstream of the apex of the fan are smooth, radial in shape and bend in the downstream direction. Topographic contours become more crenulated downstream of the outlined blue distributary area indicating more defined flow paths near the toe of the fan.

Figure 3-6 NCRS Soils: Ahwatukee Fan.

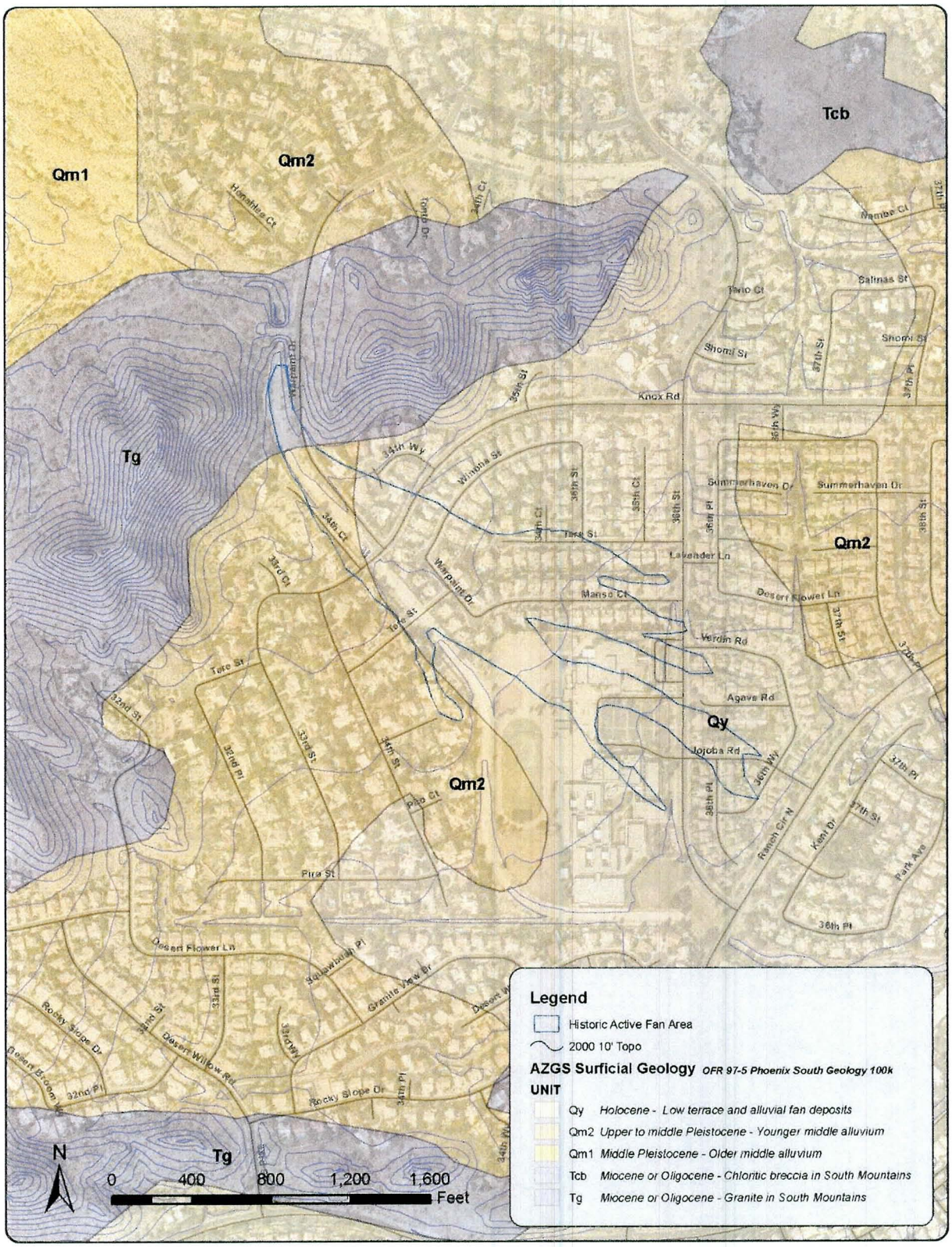


Figure 3-7 AZGS Geology: Ahwatukee Fan.

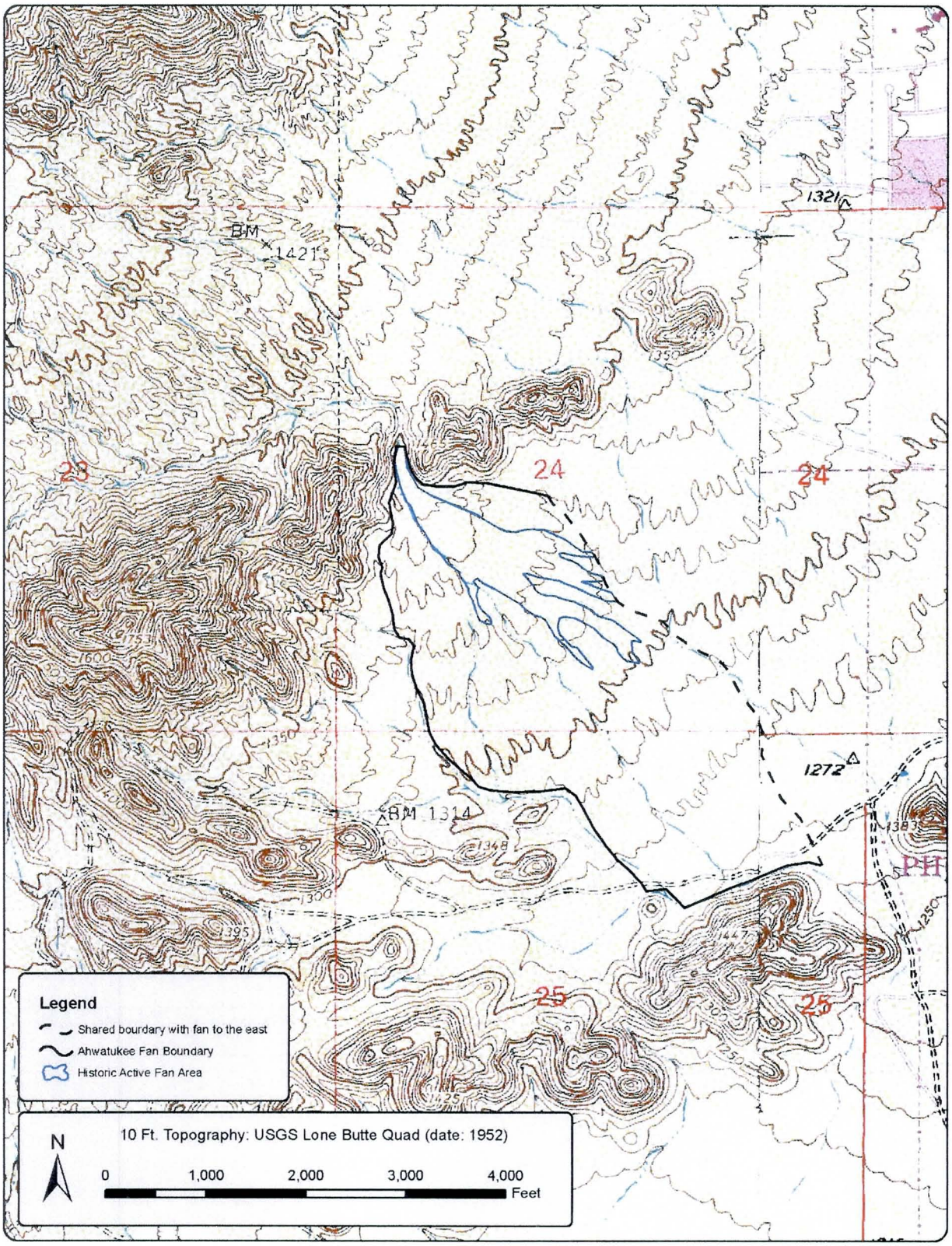


Figure 3-8 Topographic Mapping: Ahwatukee Fan.

3.1.4 Watershed and Fan Parameters

The following tables enumerate specific statistics about the watershed and fan area. Details are also included about the type and location of engineered structures within the study area.

Item	Value	Source
Watershed area (apex)	1.7 square miles	USGS Quad
Watershed slope		
Upstream of apex (3.3 – 1.2 miles)	8.1 percent slope	USGS Quad
Upstream (1.2 miles to apex)	3.8 percent slope	USGS Quad
Channel Slope		
Apex to 0.5 miles downstream	1.8 percent slope	USGS Quad
ACE-8 Channel	1.5 percent slope	FCDMC year 2000 ten foot topography
Q100 at apex	2778 cfs	USGS Water Supply Paper 2433 (Drainage Area = 1.7 Sq. Miles, Median Elevation: 1800 ft)
Fan Profile Shape	Concave up	USGS Quad
Max Elevation in Drainage Area	2586 ft	USGS Quad
Elevation at apex	1350 ft	USGS Quad
Minimum Elevation in fan	1270 ft	USGS Quad

Table 3-1 Watershed and Fan Parameters

Structure	Type	Location
Dam, two 6'x 6' box culverts	Roller-Compacted Concrete (RCC) dam	Upstream of apex
ACE -8 Channel (Ahwatukee Custom Estate 8)	Concrete-lined trapezoidal channel	From apex to Ranch Circle Rd. (continues downstream in a network of engineered channels until Pecos Rd
Knox Rd Crossing	RCBC Culvert crossing	Intersection of Knox Rd and ACE-8 Channel (1200 feet downstream of the dam)
Piro St Channel	Trapezoidal channel feeder channel to ACE-8 channel	Channel running parallel to and south of Piro St.
Retention Basin	0.8 acre grass lined basin	At termination of ACE-8 channel, West of intersection of 36th St and Ranch Circle Rd.
Sediment Ramp	Sediment ramp – later covered with gunite	At termination of ACE-8 channel, at entrance to retention basin
Ranch Circle Road Culverts	Drop inlet RCBC culvert crossing	South of intersection of 36th St and Ranch Circle Rd.

Table 3-2 Structure Parameters

3.1.5 PFHAM Stage I Landform

Task 2.3.3 requires that the pre-development landform be classified as to the "probable" landform type using the PFHAM Stage 1 categories. A PFHAM Stage 1 landform classification for an alluvial fan consists of the following elements:

- *Composition.* The landform is composed of alluvium (sediment material transported by the streams that formed the landform.
- *Morphology.* The landform has the shape of a fan, either partially or fully extended.
- *Location.* The landform is located at a topographic break where the primary watercourse loses capacity.

The Ahwatukee Fan landform is shown to be composed of alluvium, as shown by the NRCS detailed soils mapping (Figure 3-6) and AZGS surficial geology mapping (Figure 3-7). As shown in Figure 3-8, the landform has the radial contours characteristics of a partially extended fan. The site is located at the topographic break formed where the main wash traverses the narrow canyon along the Warpaint Drive alignment and the channel changes from a single thread channel to a bifurcated distributary pattern (Figures 3-4 and 3-8). Therefore, the landform is properly classified as an alluvial fan landform.

3.2 Development History

3.2.1 Development History Timeline

Historical aerial photographs of the Ahwatukee Fan are shown on the following pages. On each photograph is the delineation of the active fan area (as delineated from the 1949 aerial). This delineation is included as a point of reference because the landform becomes quite obscured with build-out of residential developments in the area. All of the following aerial photography was obtained from the FCDMC.

The oldest aerial image of the study area is from 1937. The 1937 aerial photograph resolution is not as crisp as the following set, taken in 1949, but still evident is the active area in the upper portion of the fan. It is represented in the photograph as a consistent gray-toned area with a lack of defined drainage paths.

The 1949 photograph is the highest resolution pre-development aerial photograph of the study area. In 1949 there was no development, roads, or even paths in the study. According to the U.S. Census Bureau the population of metropolitan Phoenix was only about 332,000 people in 1950, and the community of Ahwatukee did not exist. Besides dense residential growth, other changes on the fan surface since 1937 include a more clearly distinguishable flow split area in upper middle portion of the distributary flow area. The channel that flows from the apex along the northeastern edge of the fan is more clearly visible in this photograph also.

By 1979 the first minor paths and roads are visible in the area. Two paths cross the fan, one crosses the fan at the apex, and the second road crosses the fan at the eastern extents of the active fan portion, but most of the alluvial fan landform remains undisturbed. Changes since 1949 on the landform also include: (1) denser vegetation near the fan apex and, (2) a smoother texture in the area between the two south-western fingers of the distributary. This may indicate that the area had been inundated and subject to sedimentation prior to the date of the later aerial.

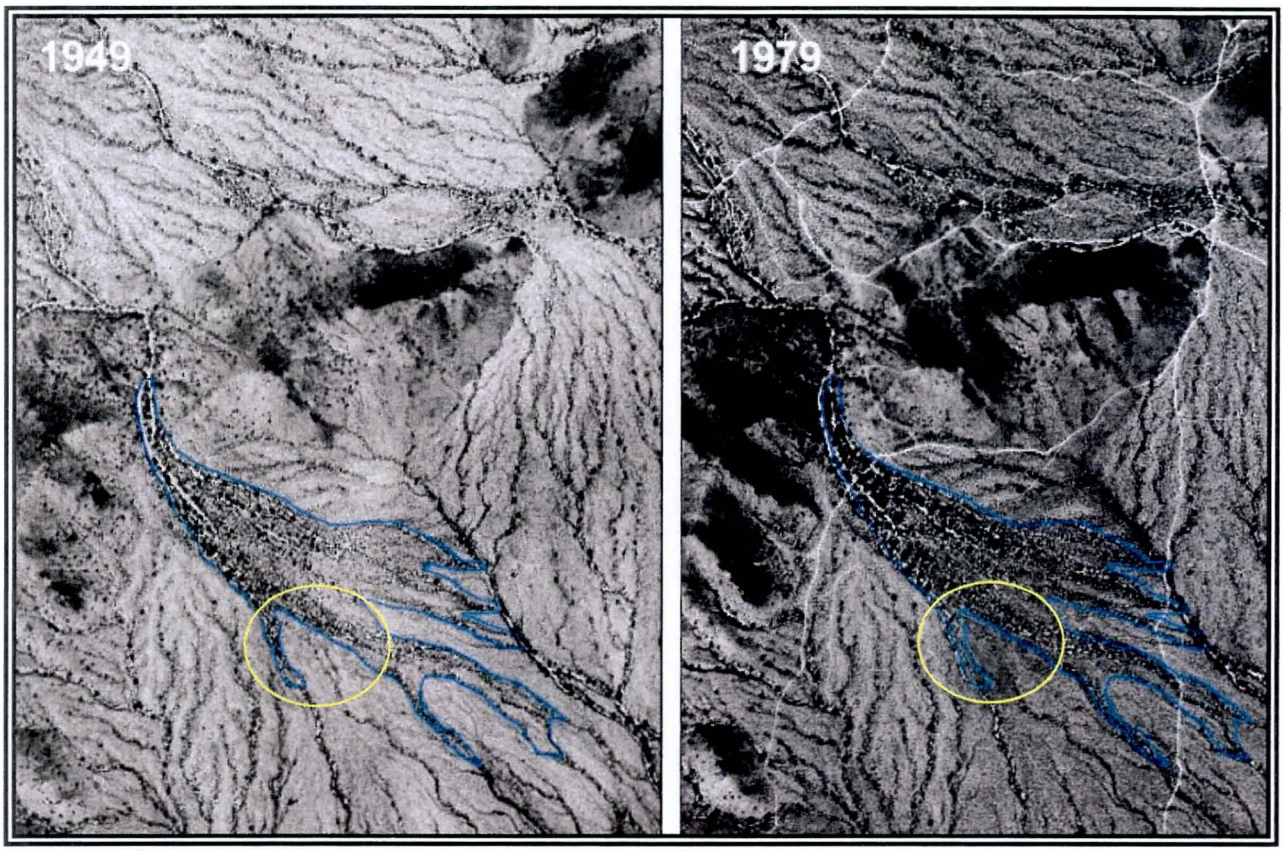


Figure 3-9 Ahwatukee Fan Landform Changes 1949 -1979.

In the late 1980's an engineered drainage system was constructed across the fan surface. The drainage system consisted of a small, peak-scalping dam upstream of the hydrographic apex and a lined trapezoidal channel that traverses the fan landform. The exact year the dam was completed is not known.[1] Culverts were built through the dam to convey a metered flow into a concrete-lined trapezoidal channel that then conveys the flow toward North Ranch Circle Drive. From Ranch Circle North, flow continues into an engineered meandering lined channel owned by Mountain Park Ranch Home Owners' Association. From there, the flow continues through a series of channels owned by various home owners' associations and continues two miles, daylighting south of Pecos Road, at which point the channel flows into rangeland without engineered drainage facilities. Interestingly, while the lined channel follows the original channel alignment immediately downstream of the apex, it deviates significantly from the natural channel alignment after about 2,000 feet and follows a completely artificial alignment thereafter.

The 1993 aerial shows the aforementioned changes. Starting in the mid to late 1980's Ahwatukee began to be extensively developed. Within the study area dense suburban single lot development took place, major road improvements were designed and installed and drainage improvements where

[1] The City of Phoenix does not retain development plans older than 20 years. Thus development plans for the study area are not readily available.

constructed to route floodwaters through the development. The engineering firm listed on the Final Plat for the area "Ahwatukee Custom Estates-8" is Brooks Hersey & Associates Inc. The final plat is dated July, 1985. Brooks Hersey & Associates, now Brooks Strand Associates Inc., did not have any drainage reports on the channel built in the area, and identified as "Drainage Tract A" on the Final Plat. Although the plans for the dam could not be found, Art Brooks, the owner of Brooks Hersey & Associates, which designed the dam, stated that the purpose of the roller compacted concrete dam was to reduce flood peaks to 1600 cfs.

Kyrene de la Colina Elementary School and Centennial Middle School were built in the middle of the project area in 1990, immediately adjacent to the concrete-lined channel. The public schools are under the jurisdiction of the City of Phoenix, while the homes and drainage channel in the project area are managed by a Home Owners Association, the Ahwatukee Board of Management.

The concrete-lined trapezoidal channel continues south of the dam, routed under a set of box culverts at Knox Rd, continues southeastward until the Middle School property, at which time it turns south and then east adjacent to the middle school boundary. South of the middle school the channel empties into a grass lined drainage basin before crossing underneath Ranch Circle North Road. The drainage basin routes water under the road to connect with a meandering rock lined channel that conveys the flow further downstream out of the project area.

The 1997 photograph shows continued development south of the project area, with additional road improvements to 34th Way, which is northeast of the intersection of Knox Road and Warpaint Drive.

By 2003 with the completion of a few remaining homes in the area, development is completely built-out. The study area today is similar to the early 2000's, and is substantially unchanged with respect to the drainage system since the early 1990's. .

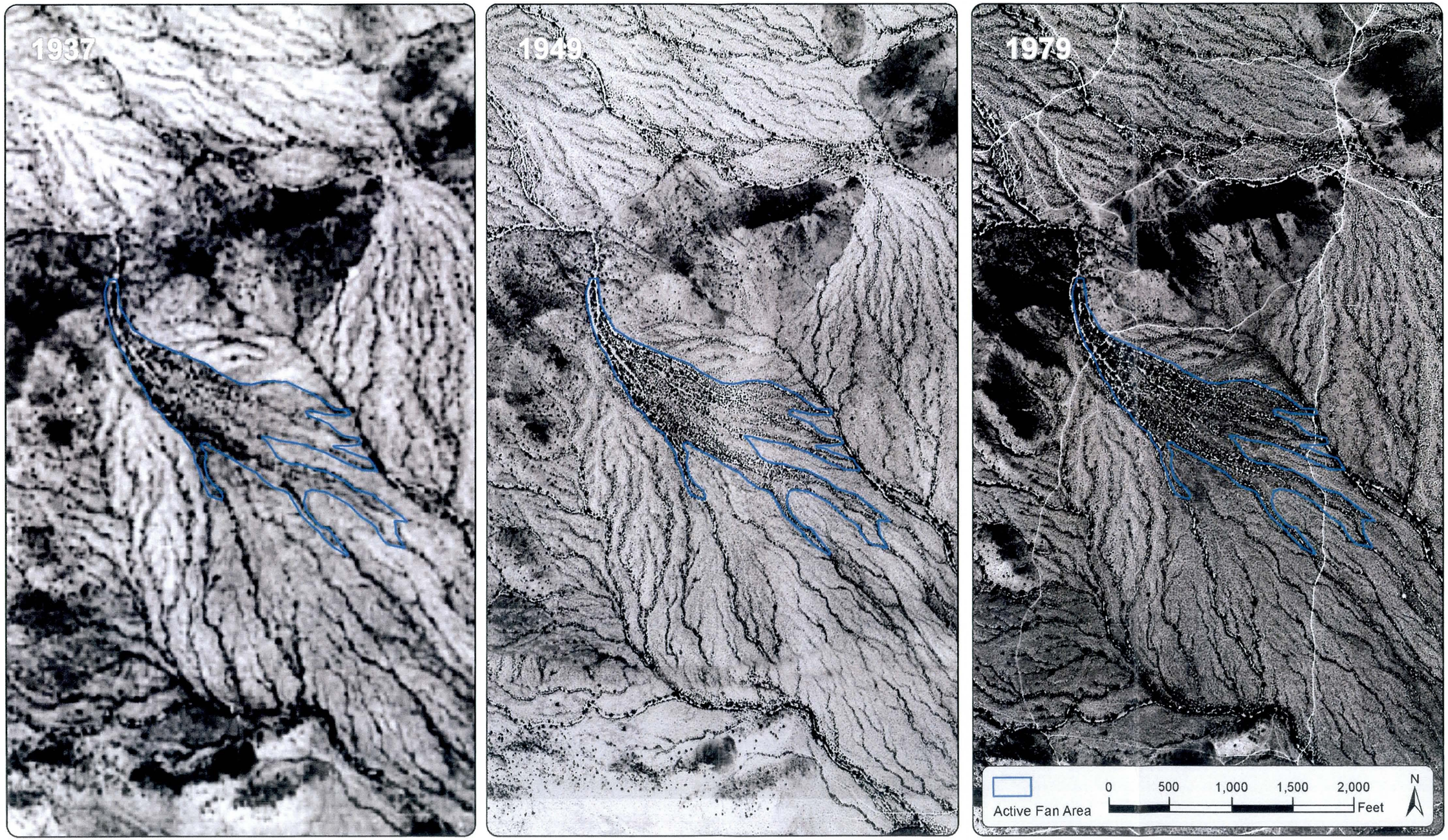


Figure 3-10 Historical Aerial Photos: Ahwatukee Fan 1937-1979.

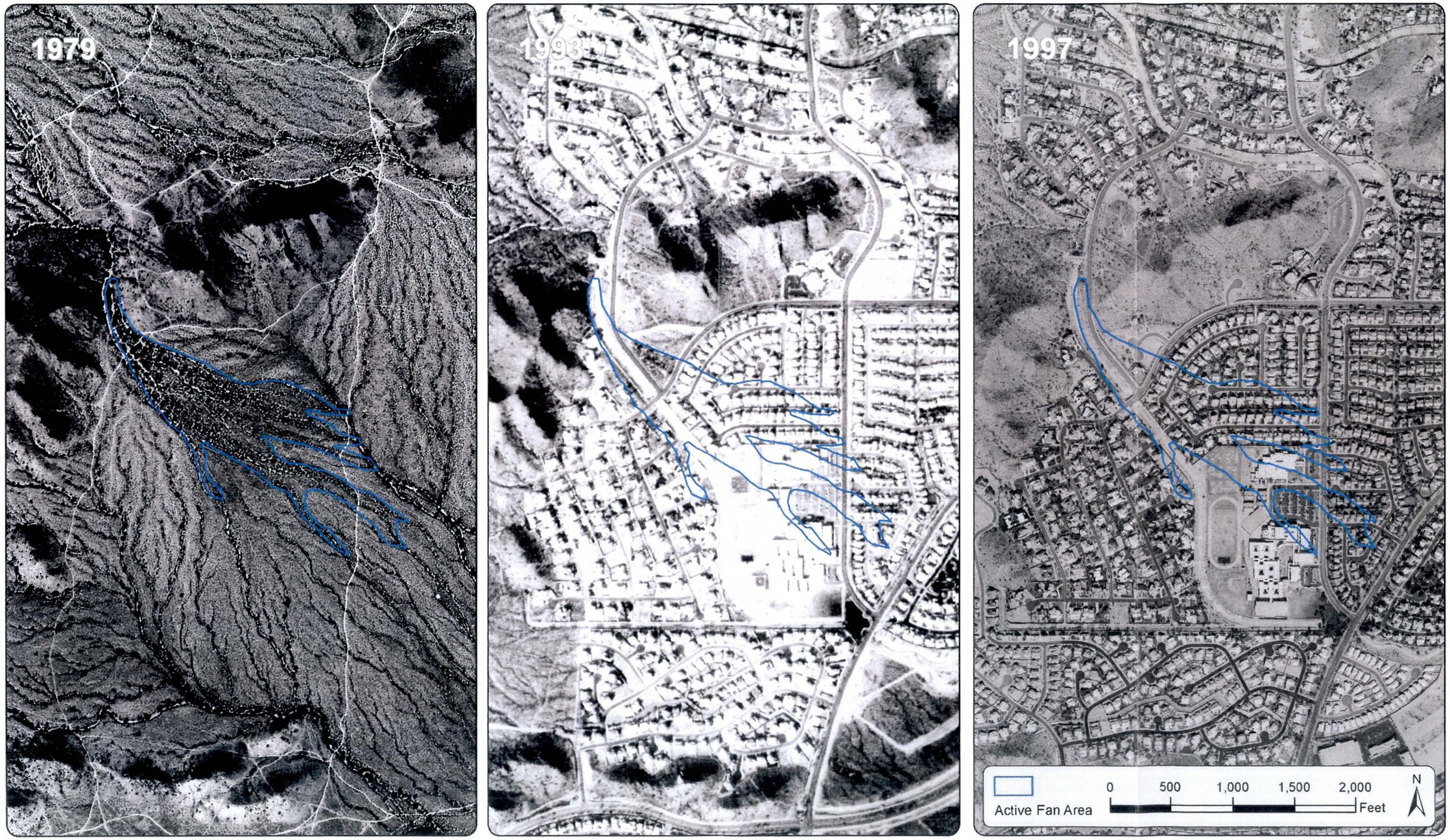


Figure 3-11 Historical Aerial Photos: Ahwatukee Fan 1979-1997.

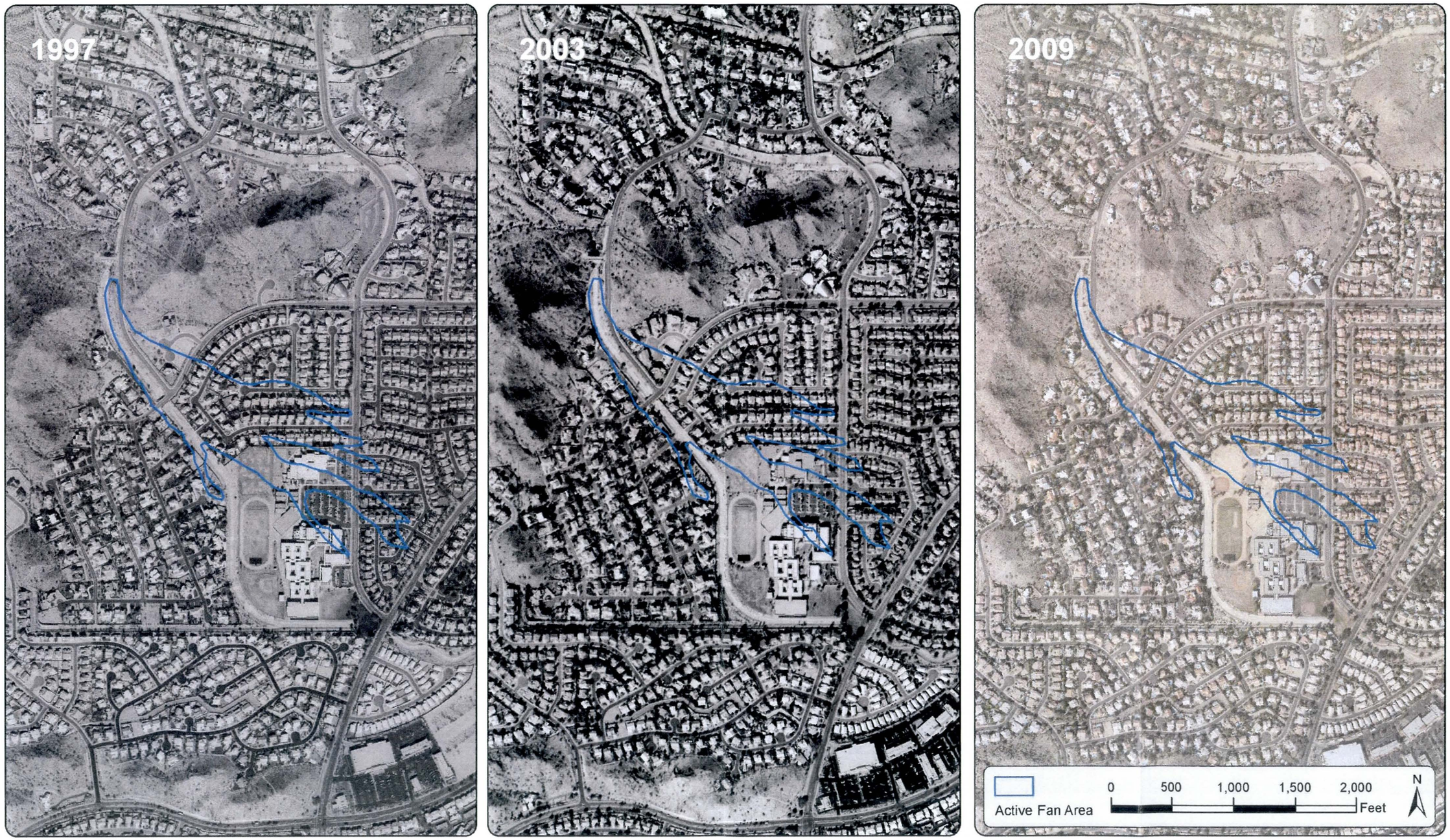


Figure 3-12 Historical Aerial Photos: Ahwatukee Fan 1997-2009.

3.3 Hydrology

The locations of the nearest rain gages have been located in relation to the watershed boundary in Figure 3-2. The FCDMC rain gage closest to the study area is located 1.25 miles east, near the intersection of Warner Rd. and 44th St. (#6550). The gage has been continuously reporting data since March 1996. Since that time, the average rainfall per year is 6.74 inches with the wettest year on record being 2005 with 13.94 inches and the driest year on record being 2002 with 3.03 inches of rainfall reported. The FCDMC also has a rain gage located in South Mountain Park (#6510) and just 0.1 miles outside the upper limits of the study area watershed. This has been continuously reporting data since October 1982 (with only 3 months of missing or partial data). Since its installation, the median rainfall in the upper portion of the watershed has been 7.64 inches with the wettest years on record being 1983, 1993 and 2005 with total rainfall being 13.50," 13.33" and 13.27" respectively. The largest storms near the watershed have been:

- 30 year storm: 2.05" in 6 hours on 08-02-2005 (FCD #6550)
- 20 year storm: 1.46" in 1 hour on 07-13-2008 (FCD #6550)
- 50 year storm: 3.23" in 24 hours on 08-15-1990 (FCD #6510)
- 40 year storm: 2.01" in 3 hours on 08-15-1990 (FCD #6510)
- 35 year storm: 2.13" in 6 hours on 08-03-2005 (FCD #6510)

The General Manager of the Ahwatukee Board of Management, who has been working in the project area ever since it was built-out in the early 1990s, said that the largest event he can remember occurred during August 2005. During this event, the concrete-lined channel that routes water through the HOA flowed full, from bank to bank. The dam upstream, he states, was nearly overtopped. This was an intense, localized storm, which did considerable damage to the concrete-lined channel. Damage from this event will be covered in more detail in the next section of this report. The HOA did not report any damage to drainages that neighbor the study area.

3.4 Flood Mitigation Measures

3.4.1 History

As mentioned above, a concrete-lined trapezoidal channel was built on the fan to convey flood water through the project area from the apex to the toe. A roller compacted concrete (RCC) dam was

built just above the apex, approximately 400 yards upstream of the Warpaint Drive / Knox Rd intersection. The concrete channel is 4100 feet in length from the dam to E. Ranch Circle North Drive.

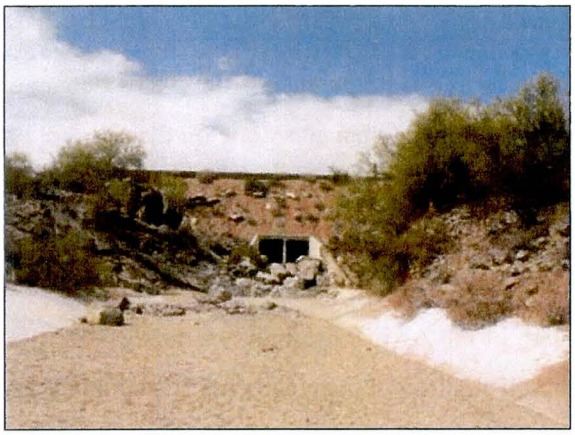
Neither the design plans nor party who has jurisdiction over the dam were identified. Both the City of Phoenix and the home owners' association denied having any jurisdiction over the dam (the City was aware of its existence). The City has not retained any of the design plans for the dam, channel or surrounding communities. From field observations, the RCC dam appears to be about 20 feet wide at the top, 120 feet long, and is covered by a thin veneer of soil. A two-cell concrete box culvert serves as the principal outlet and meters flow into the concrete channel. The dam serves as the dividing point between the natural wash in the upstream watershed and the engineered channel downstream. The concrete trapezoidal channel downstream of the dam is locally referred to as the ACE-8 channel, as it runs through the Ahwatukee Custom Estates No.8 Subdivision.

At the outlet of the culvert through the dam are 10-20 several ton boulders lying in the wash. Several of these boulders are attached to the channel bottom and sides with concrete, others are not. The intended purpose of these boulders at the outlet of the culverts is not known, but they may have been placed as energy dissipaters or for aesthetic reasons. Downstream of the dam for approximately 100 yards, sediment drops out in a series of sandy riffles. The ACE-8 channel crosses under Knox Road in a concrete box culvert, over Tere Street in a dip crossing, and passes Centennial Middle School heading first due south and then due east. As the channel takes a 90 degree turn left going from south to east it picks up flow from the Piro Channel which joins it from the west. (The Piro channel, runs parallel to Piro St, and picks up local runoff from the development directly west of the active fan area.)

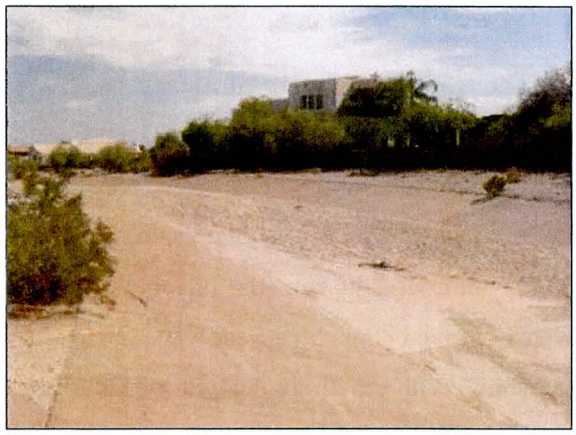
After the channel turns east (at the south end of Centennial Middle School) the channel drops into an engineered, grass-lined basin. Downstream of the drainage basin, the water flows under East Ranch Circle North Drive into a channel maintained by the adjacent Mountain Park Ranch Home Owners Association. The channel was designed and built with a four foot drop structure at the basin entrance, but over the course of ten years enough sediment has built up at the drop structure to create a ramp of sediment from the channel into the drainage basin. This sediment was later graded and gunite was laid over the top of the ramp, effectively eliminating the drop structure. The volume sediment stored in the ramp structure is estimated at about 7.4 cubic yards.

3.4.2 Photograph locations

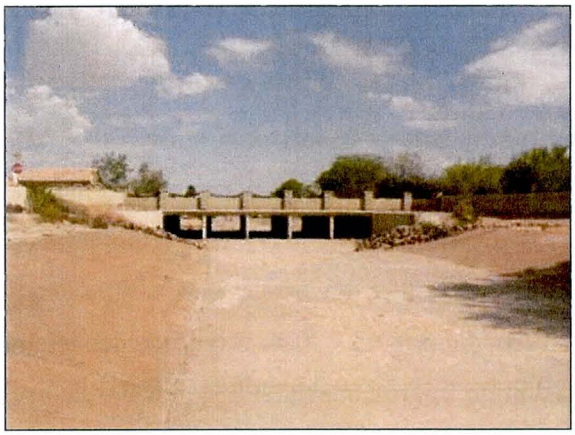
Following is a set of field photos. The location of each photograph has been noted in Figure 3-5, which also labels other important reference locations in the study area.



1. ACE-8 Dam
Downstream of the dam, looking upstream

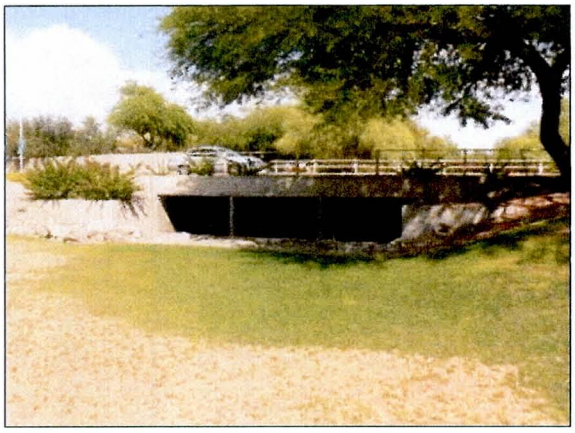


2. ACE-8 Channel
Downstream of the dam, looking downstream



3. Knox Road Crossing
Looking upstream

4. Drop / Ramp Structure
South of Centennial Middle School



5. Outlet to channel downstream
Culverts underneath Ranch Circle Road

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3.4.3 System Maintenance

The Ahwatukee Board of Management is responsible for the maintenance of the ACE-8 channel from the dam to where the wash crosses East Ranch Circle North. Maintenance is done on the channel on a routine basis twice a year and involves removing sediment from the channel, and inspecting for damage and debris. Sediment is removed from the channel bottom and graded out onto the overbank area, effectively removing it from the channel system. It is estimated that 10 - 15 yards of sediment are removed from the channel per year. The channel downstream of the ACE-8 channel is a trapezoidal rock lined channel, with small engineered meander bends. The channel owner downstream, Mountain Park Ranch HOA, did not report any sedimentation problems or maintenance needs with their section of the channel.

The ACE-8 channel has had recurring expansion and contraction problems at the channel joints. Joints that become offset from one another are routinely cut away with a concrete saw and patched.

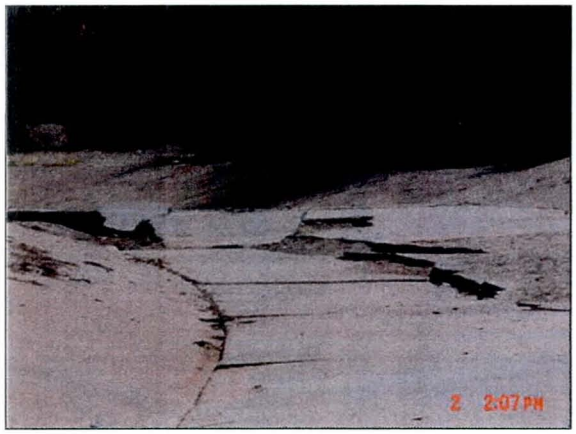
The most severe damage to the channel occurred during a large storm in August 2005. The Ahwatukee Board of Management reports that during this event the dam was nearly overtopped and the channel flowed full. The flow had enough force to displace and carry as many as ten 6 to 8 ton boulders from the rock dissipater at the dam outlet a distance of about 1,500 feet downstream, as well as many smaller 3-4 ton boulders downstream as far as Centennial Middle School. One large boulder is still lodged in the culvert under North Ranch Circle Drive. In addition, approximately 200 feet of the channel bottom and sides were ripped out and damaged by the floodwaters and a large quantity of sediment was also deposited in the channel.

To estimate the magnitude of the 2005 flood, the ACE-8 Channel bankfull discharge was estimated using Manning's equation at 2,555 cfs, with a velocity of 23 ft/s. This flow rate is lower than, but near the 100-year discharge estimate of 2,778 cfs obtained from regional regression equations. Given that this estimate is larger than the 1,600 maximum outflow for the RCC dam, the estimate is considered crude and approximate with respect to the August 2005 flood.

- Manning's Equation: Q=V*A, V=k/n (A/P)^2/3 (S)1/2
- Area = 106.8 sq. ft., Wetted perimeter = 48', K= 1.49
- Concrete channel slope = 0.015 (ft/ft), N value for concrete lined channel = 0.013

The Ahwatukee Board of Management estimates that 10-12 truck loads of sediment (~50-120 cubic yards) were removed from the wash after that one event. The channel repair cost more than $25,000. The large boulders that had washed downstream were removed from the wash and placed back in their original position just below the dam.

It is theorized that the flood water was able to tear out the channel lining by getting underneath just one slab at first, most likely exploiting a weak joint or one that was slightly separated due to contraction / expansion. After one portion of the wash was torn away, the water was able to erode sediment out from underneath adjacent slabs.



6. Concrete lining damaged
Downstream of the dam, looking upstream

7. Sedimentation
50-120 cubic yards of sediment

8. Scour under lining
Downstream of the dam, looking upstream

9. Sedimentation
25,000 dollars in total damages to channel

3.5 Conclusions

Prior to residential development in the late 1980's, the Ahwatukee alluvial fan landform had a moderate-sized active area near the apex. Development occurred as part of a master planned community, which was based in part on a regional-scale, privately funded drainage master plan. The engineered drainage master plan for the alluvial fan included a peak-scalping RCC dam and a concrete channel that only partially followed the pre-development channel alignment.

The drainage system has been tested by at least one large storm event in August 2005 that approached the magnitude of a 100-year event based on crude post-flood stage estimates, though rainfall measurements at the District gages were significantly less than 100-year depths. Since development began in the area, the largest rainfall events to happen at the two neighboring gages have been a 50-year 1-hour storm in the upper watershed in 1990 and a 30-year 6-hour storm in 2005 recorded just one mile to the east. While there have other flow events in the ACE-8 channel, such flows are rare and have typically been no more than a few cfs.

Based on our analysis, we conclude that the engineered drainage system has performed adequately during the 20 year period of record, at least with respect to controlling the flow uncertainty and sedimentation associated with active alluvial fans. No homes or structures on or around the fan have been flooded in the past 20 years. The concrete-lined channel, despite flowing full and being heavily damaged during the August 2005 event, has never overtopped. Sedimentation in the channel and expansion / contraction issues surrounding the channel joints are problems that are addressed routinely by a private home owners' association, the Ahwatukee Board of Management, who maintains the channel regularly. Sediment maintenance reported is only required in the upper portion of the channel system, with no maintenance reported downstream of North Ranch Circle Drive. The performance of the engineered drainage system is predicated on the following:

- Periodic sediment removal from the lined channel and basins.
- Regular repair of the concrete channel.
- Occurrence of floods that do not exceed the design frequency.

4. Pima Canyon Fan

4.1 Site Location

Pima Canyon Alluvial Fan is located at the northeast end of the Phoenix South Mountain Park, in T01S R04E Sections 4 and 5. Following the Guadalupe Road alignment the fan apex is located approximately 0.25 miles west of the I-10, near the intersection of Guadalupe Road and 48th Street.

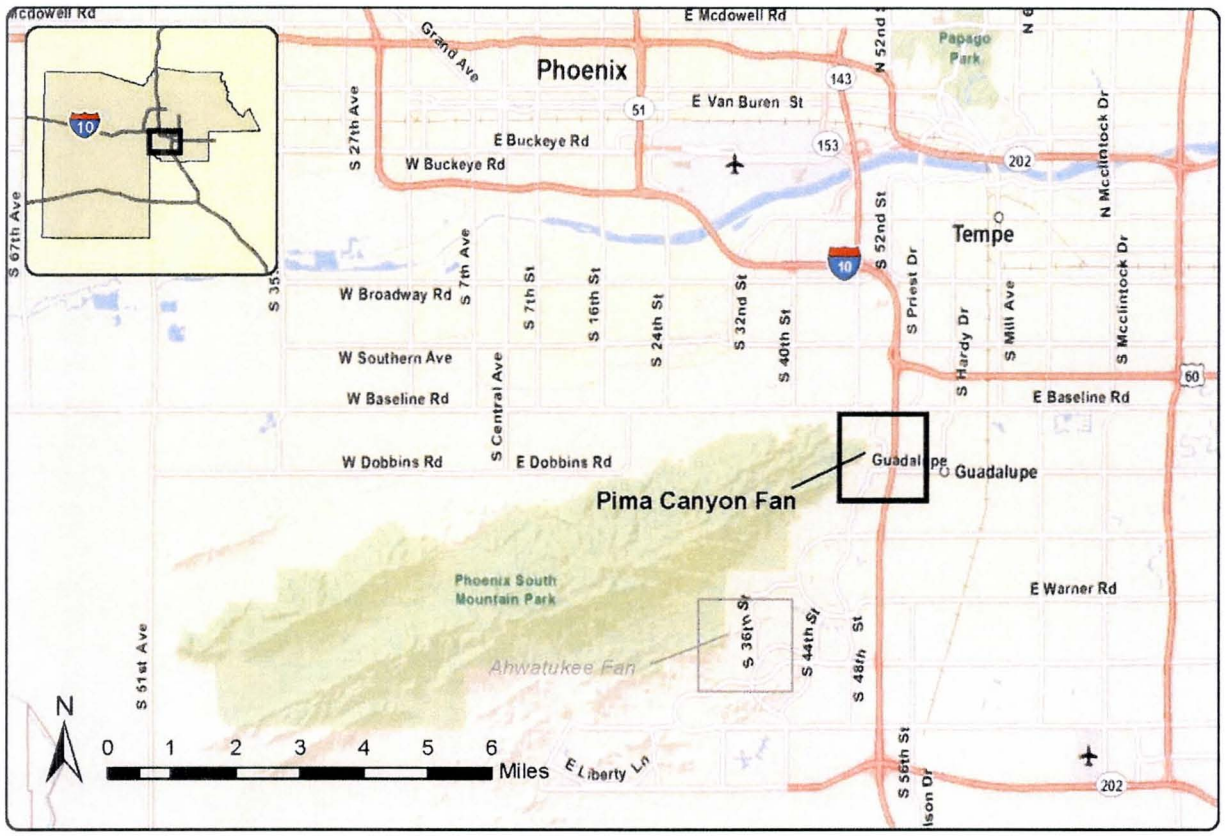


Figure 4-1 Location Map: Pima Canyon Fan.

The Pima Canyon Fan watershed is about 1.5 square miles in area and drains a portion of the northeast flanks of South Mountain. The main watercourse is called Pima Canyon Wash, which flows easterly out of South Mountain in a natural channel until about 2,000 feet upstream of the apex, where the wash crosses the Phoenix South Mountain Park boundary into the Arizona Grand Resort Golf Course and continues downstream. Within the golf course, the natural wash has been modified by grading with some channelization. The watershed within the Phoenix South Mountain Preserve remains undeveloped. The watershed downstream the park boundary is completely developed with golf course greens, homes and road infrastructure.

Although the study area is within the City of Phoenix, the roads, streets, culverts or drainage infrastructure are privately owned and maintained by the Pointe at South Mountain Home Owners' Association.

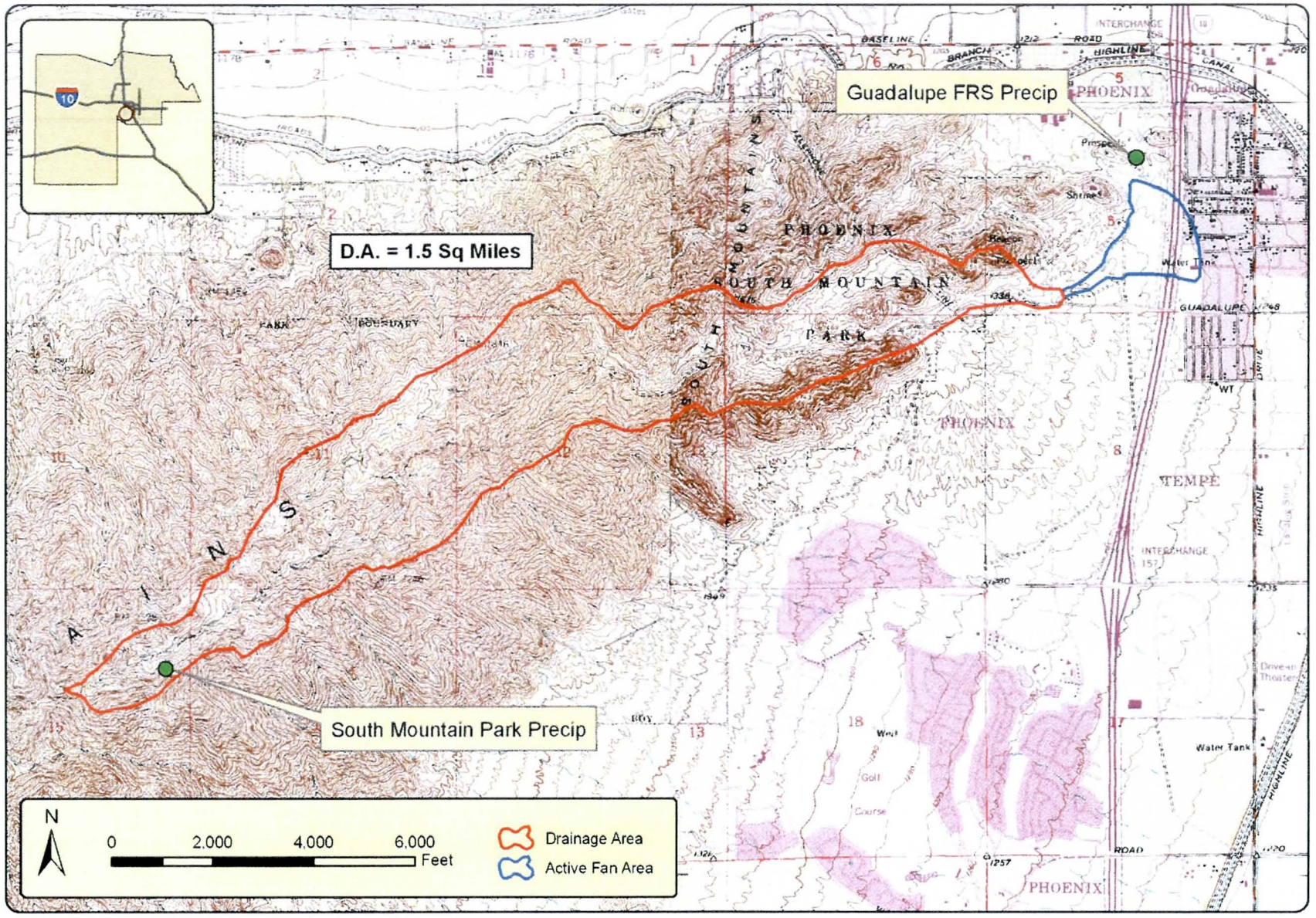


Figure 4-2 Drainage Area: Pima Canyon Wash.

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Figure 4-3 Pima Canyon Fan Before & After Development.

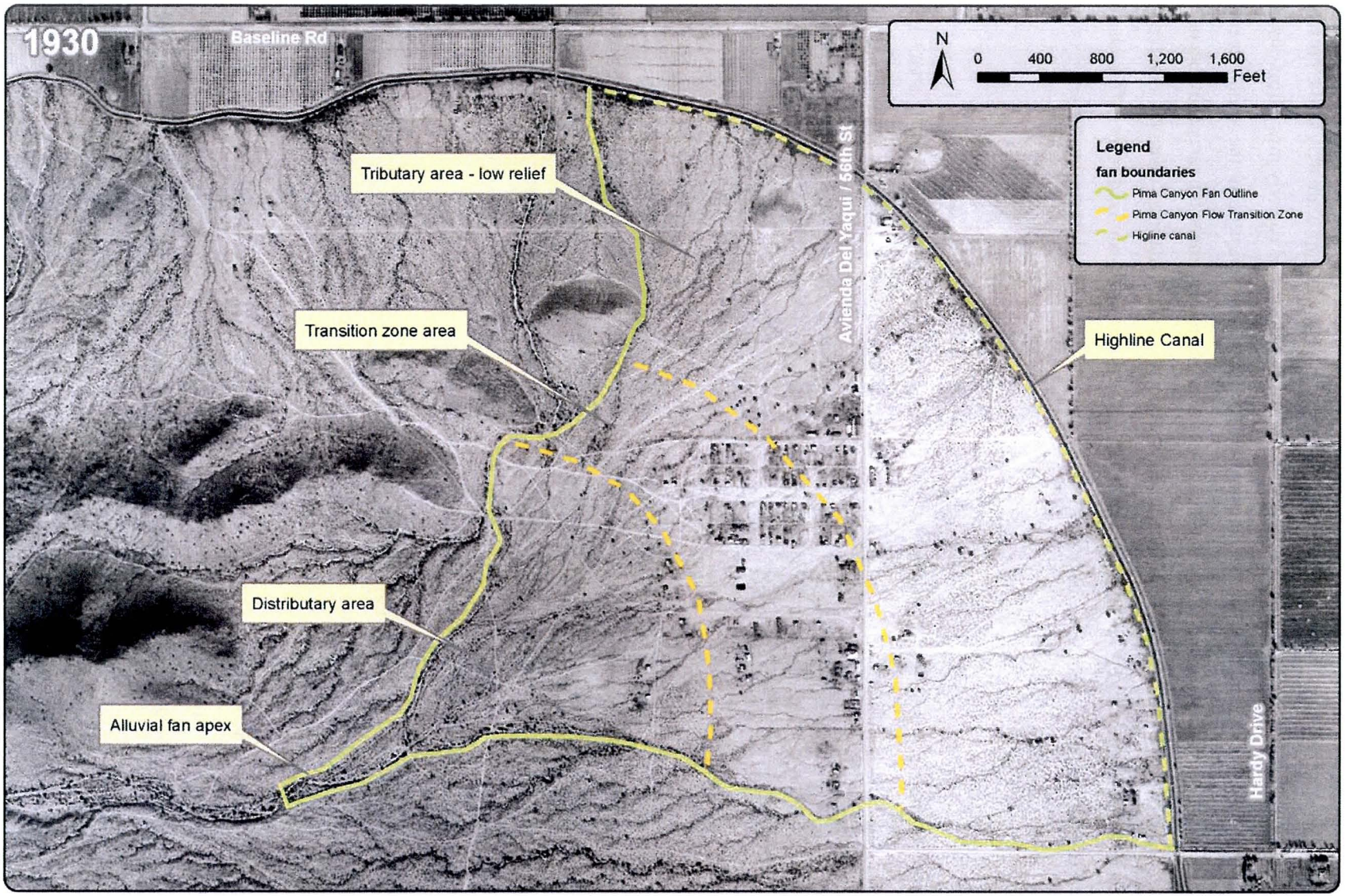


Figure 4-4 Pima Canyon Alluvial Fan Landform.

As seen in Figure 4-4, the apex of the alluvial fan apex in 1930 was approximately at the present 48th Street / Hazel Drive intersection. Historically, Pima Canyon Wash flowed easterly away from South Mountain and was contained within its natural channel until its apex, at which point the wash became distributary. As the flow paths of Pima Canyon Wash split from one another near the apex they become less defined in the downstream direction. Flood water leaving the poorly defined channels continued down fan as sheet flow inundating the Town of Guadalupe with flood water and sediment. This was a continuing problem for the Town of Guadalupe until the Guadalupe FRS (Flood Retarding Structure) was constructed in the mid 1970's.

4.1.1 NRCS Soils

Figure 4-5 presents the NRCS Soil Survey information for the Pima Canyon Fan study area. The source of the soil survey data is the Soil Survey of Eastern Maricopa and Northern Pinal Counties, Arizona (1974). In Figure 4-5 the historically active alluvial fan area was delineated from the 1930 aerial and included as a blue outline on the 2009 aerial photograph background. This was done to provide perspective of where the historical active fan surface was in comparison to modern residential development in the study area. Soil Survey units are labeled individually, and also grouped into the major landform that each unit typically represents.

The entire alluvial fan landform is contained within the Antho soil series, AoB and AnB. The Antho series is typically found on alluvial fans and contains well drained soils with shallow slope between 0 – 3 %. AnB (Antho sandy loam), found at the toe of the fan, is a soil that typically forms on alluvial fans. AoB (Antho gravelly sandy loam), while very similar to AnB, has between 15-35 % gravel by volume and is typically found on the upper portions of alluvial fans.

The linear green soil unit represented at the throat of the fan at the apex is the former location of a gravel pit. Mining on the gravel pit started in the late 1950's and the pit remained a geomorphic feature on the fan until development reclaimed the pit in the early 1980's.

Bordering the Antho series in the northern portion of the study area are Rock Land 'Ro' and Rough Broken Land 'Ru' soil units. Both these units have been shaded brown to represent Mountain Slopes. Rock Land consists of areas that are 50 to 70 percent exposed rock, and is used to describe steep sloping bedrock mountains in the study area. Runoff is typically very rapid and erosion active in these areas. Rough Broken Land is moderately sloping to very steep. This (Ro) unit is often dissected by many intermittent V-shaped drainage channels and separated by irregular narrow ridges.

The Antho series is bordered on the east by the Valencia sandy loam (Va), a well drained soil series on valley plains and alluvial fans, and southwest by the Tremant gravelly loam (TrB), a well drained soil on old alluvial fans and shaded light blue on the map.

4.1.2 Surficial Geology

Figure 4-6 presents the surficial geology for the Pima Canyon Alluvial Fan study area. The source of the geologic survey data is Arizona Geologic Survey (AZGS) Geologic Map of the Mesa 30' X 60' Quadrangle, by Kneale. In Figure 4-6, the historically active alluvial fan area was delineated from the 1930 aerial and included as reference in a blue outline on the 2009 aerial photograph background.

The bedrock unit that lies just to the west and north of the fan are composed of Granodiorite (Tgl). This is the same unit that composes most of the South Mountain Range. Tertiary Granite (Tg) formed in the middle Tertiary Period, sometime between 65 million and 2 million years before the present.

The whole of the Pima Canyon Alluvial Fan landform lies within the Quaternary Young Alluvium (Qy) unit. Qy forms low terrace and alluvial fan deposits. Qy, a Holocene unit (less then 10,000 years old), is the youngest geologic unit in the study area.

The Qy unit of the alluvial fan is bounded by the older Quaternary Middle Alluvium (Qm). Qm is an upper to middle Pleistocene alluvium, and often found on dissected alluvial fan and terraces. The Pleistocene Epoch dates from 1.8 Million to 10,000 years before present.

4.1.3 Topography

Figure 4-7 shows 10-foot contour interval topography of the Pima Canyon alluvial study area from the USGS quadrangle map. Within the traced blue outline of the fan landform one can see topographic contours on the alluvial fan bowing in the downstream direction with the classic extended fan shape.

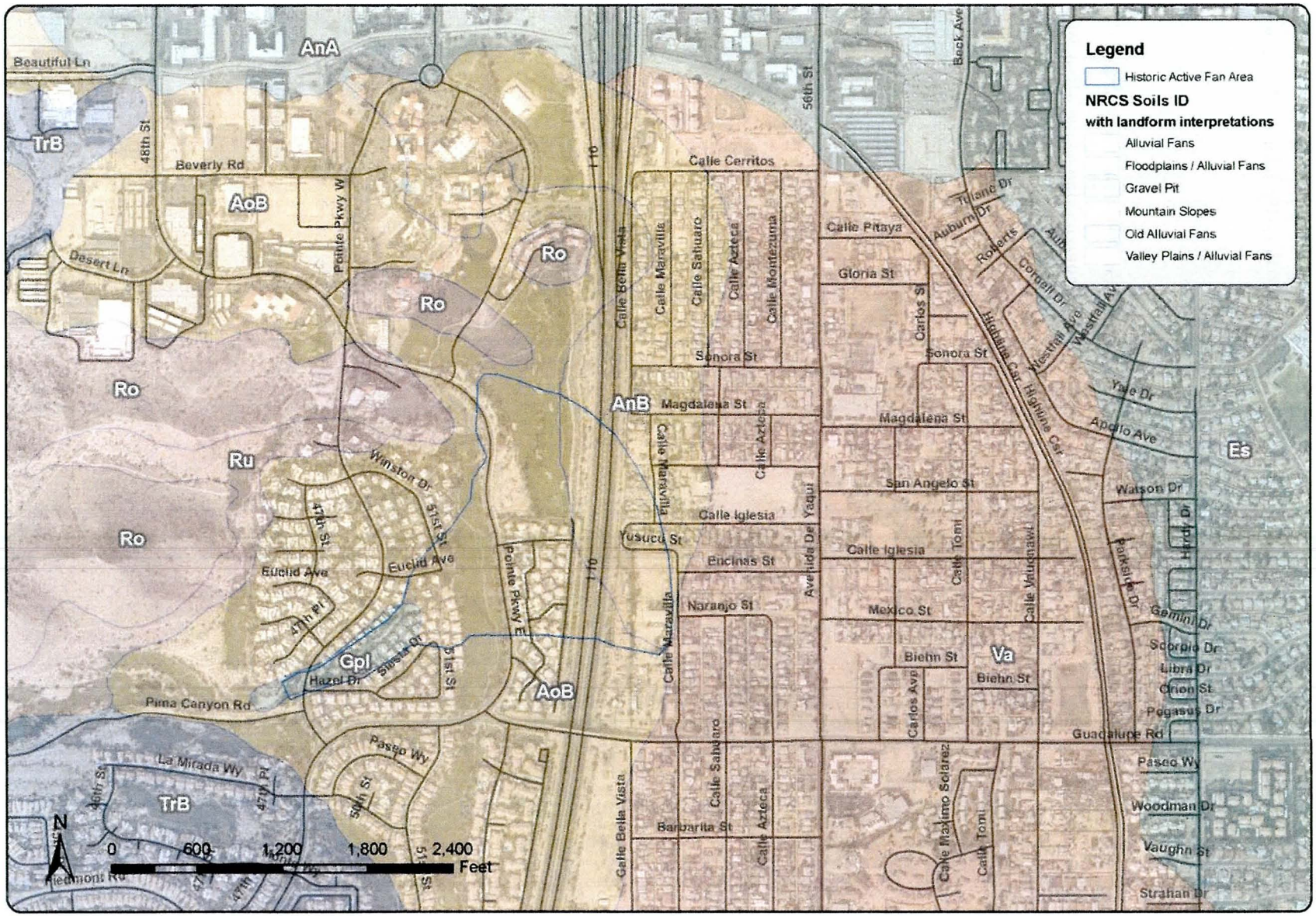


Figure 4-5 NRCS Soils: Pima Canyon Fan.

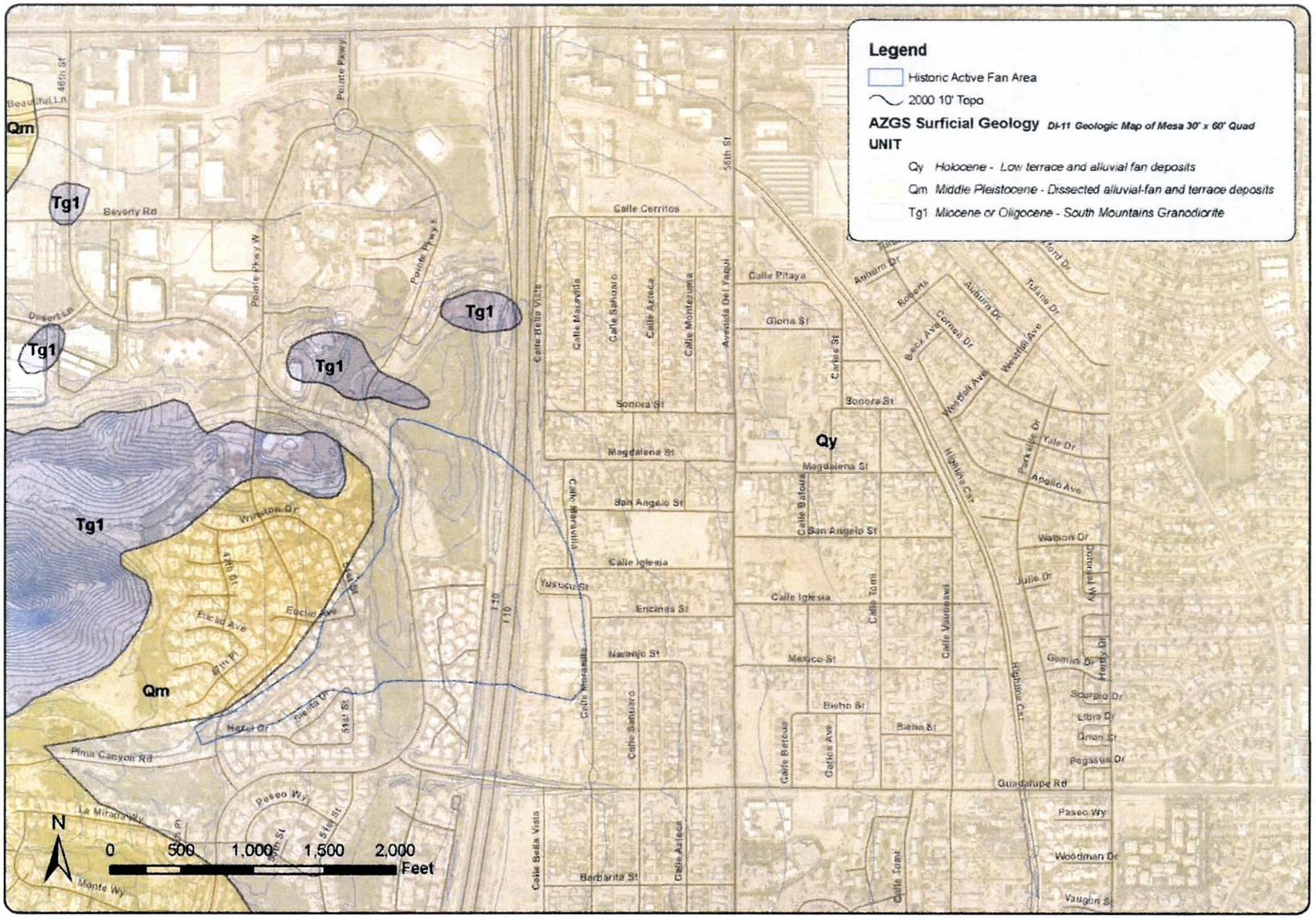


Figure 4-6 AZGS Geology: Pima Canyon Fan.

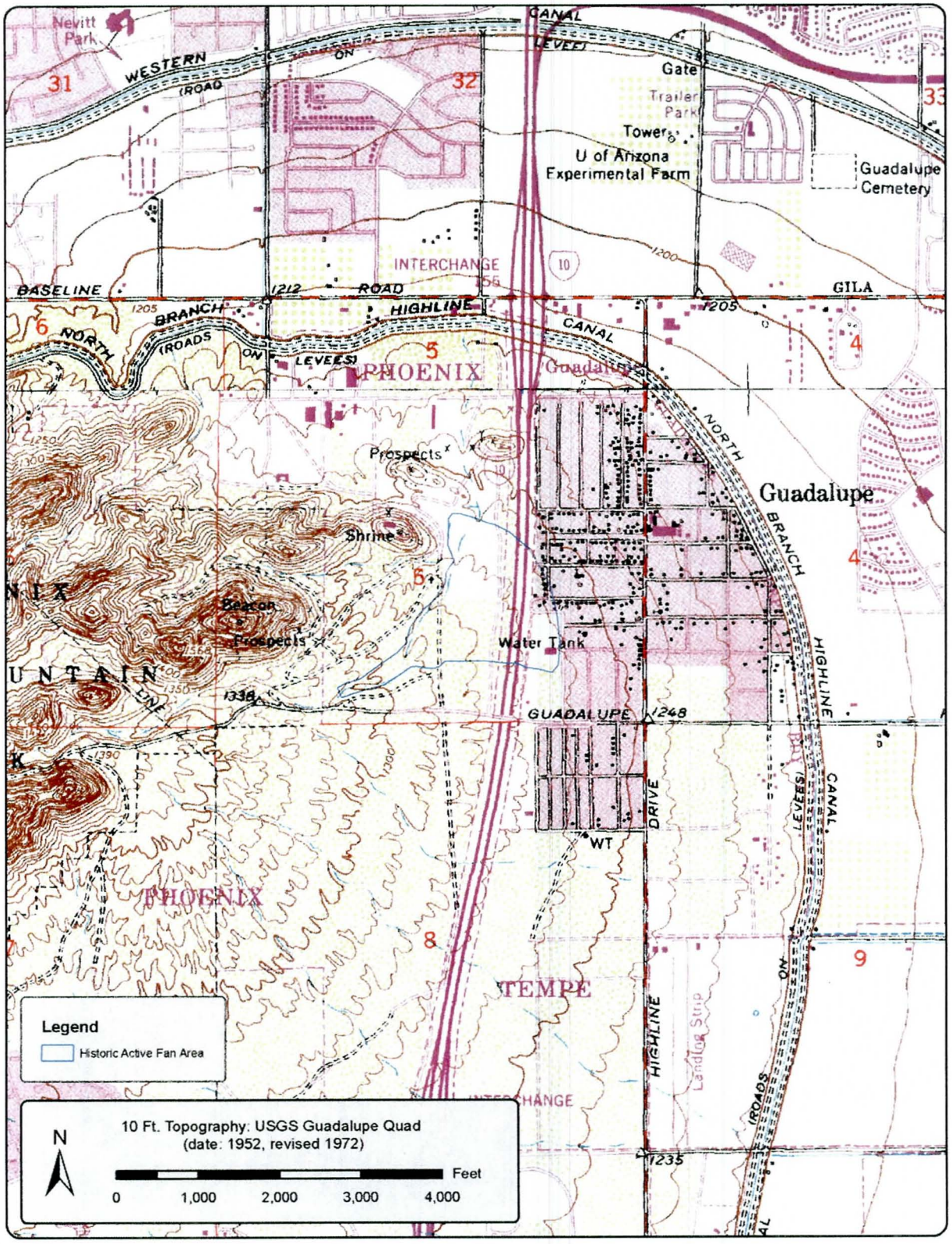


Figure 4-7 Pima Canyon Fan Topographic Mapping.

4.1.4 Watershed and Fan Parameters

The following tables enumerate specific statistics and about both the watershed and fan area. Details are also included about the type and location of engineered structures within the study area.

Item	Value	Source
Watershed area (apex)	1.5 square miles	USGS Quads
Watershed slope Upstream of apex (2.8 to 1.9 miles) Upstream of apex (1.9 to 0.5 miles) Upstream of apex (0.5 miles to apex)	 7.7 % 2.6 % 1.6 %	 USGS Quads USGS Quads USGS Quads
Fan slope (Apex to 0.25 miles downstream)	1.5%	USGS Quads
Q100 at apex	2525 cfs	USGS Water Supply Paper 2433 (D.A. =1.5, Median Elevation = 1800 feet)
Fan Profile Shape	concave	USGS Quads
Max Elevation in Drainage Area	2555 ft	USGS Quads
Elevation at apex	1310 ft	USGS Quads
Minimum Elevation in fan	1210	USGS Quad (at Highline Canal)

Figure 4-8 Watershed and Fan Parameters

Structure	Type / Date	Location
Interstate I-10	Constructed: 1959-1969	Transects fan 2000 feet below the apex
Gravel pit	Dug: 1949-1959	Below apex of fan
Guadalupe Flood Retarding Structure	Constructed: 1969-1979	Immediately west of I-10
Realignment of Pima Wash	Originally designed as grass lined channel, now natural gravel bottom	From apex to 1500 feet below
48th Street / Pima Wash crossing	8' foot CMP culvert	48th St / Pima Canyon Wash, at historical apex location
Development		
Town of Guadalupe	Pre-1930	On fan near the toe
Arizona Grande Resort Golf Course	Late 1980's, early 1990's	Upstream of apex and with-in the basins of the FRS downstream of the apex
Pointe South Mountain Development	Late 1980's to present	Upper portion of the alluvial fan.

Figure 4-9 Structures on Pima Canyon Wash

4.1.5 PFHAM Stage I

Task 2.3.3 requires that the pre-development landform be classified as to the "probable" landform type using the PFHAM Stage 1 categories. A PFHAM Stage 1 landform classification for an alluvial fan consists of the following elements:

- *Composition.* The landform is composed of alluvium (sediment material transported by the streams that formed the landform.
- *Morphology.* The landform has the shape of a fan, either partially or fully extended.
- *Location.* The landform is located at a topographic break where the primary watercourse loses capacity.

The Pima Canyon landform is shown to be composed of alluvium, as shown by the NRCS detailed soils mapping (Figure 4-5) and AZGS surficial geology mapping (Figure 4-6). As shown in Figure 4-7, the landform has the radial contours characteristics of a partially extended fan. The site is located at the topographic break formed where the main wash exits South Mountain Park and the channel changes from a single thread channel to a bifurcated distributary pattern (Figures 4-4 and 4-7). Therefore, the landform is properly classified as an alluvial fan landform.

4.2 Development History

A set of historical and recent aerial photographs are shown on the following pages. On each photograph, the delineation of the active fan area from the 1930 aerial is outlined in blue. This delineation is included as a point of reference because the natural features of the landform become obscured after development occurs in the area. All of the aerial photography was obtained from the FCDMC.

The oldest aerial image of the study area is from 1930. In 1930, Pima Canyon Wash flowed in a northeasterly direction out of South Mountain to the apex of the fan. At the apex of the fan, the primary Pima Wash channel split into roughly three less well defined channels. The first channel flowed north-toward Baseline Road, the second channel northeast toward the Town of Guadalupe and the third channel flowed east. Several break outs can be seen from each of these channels as they extend to the toe of the fan. At these break outs and other locations where the channels lose capacity, flood waters probably extended over the fan as sheet flow. The surface of the fan in 1930 appears to be relatively smooth with minimal lateral relief. This smooth surface characteristic is a distinctive contrast from the tributary incised drainage that can be seen on older fan terraces on both sides of the fan. By 1930, the Town of Guadalupe had roughly 15 homes built within the fan limits. At this time, there were no roads visible. Only a few small paths cross the fan. Interestingly, in 1930 the Baseline Road alignment is already visible as a linear feature in the upper most portion of the photograph.

By 1949, the Town of Guadalupe had approximately 50 homes built within the study area. The three channels that split at the apex are more defined; and the northeast channel has a wider bottom width than it did in 1930. This may be due to a major flood that occurred in 1934 (Guadalupe Watershed Work Plan, p. 10). Also, by 1949, two significant trails cross the fan, one at the toe and another mid-fan.

By 1959, a gravel pit had been dug near the apex, as shown on the NRCS Soil surveys. The Town of Guadalupe continued to expand to both the north and the south. Also visible in 1959, is the El Paso Gas line excavation across the fan. The gas line bisected the fan and the alignment can be seen running almost due north and south in the middle of the photograph.

By 1969, the I-10 had been built across the toe of the fan. The Guadalupe Watershed Workplan 1971 contains an excellent description of how the I-10 construction affected drainage downstream through the Town of Guadalupe. "The…construction of the Highway altered the paths of any flooding that occurred in past yeas so that flooding that will occur in the future will be different from what it has been in the past. The I-10 Highway provides for drainage from water running off of the upper portion of

the watershed; however, there are no confined channels below the outlets of the culverts so when water leaves the end of the culvert it will again spread out to a fan flood condition" (Guadalupe Watershed Workplan, p. 52). Large storms on both September 14 and 16, 1969 also caused extensive flooding in Guadalupe, damaging homes, businesses, canals, and ditches, inundating crops, and damaging railroads and industrial property (Guadalupe Watershed Workplan, p. 12). The Guadalupe FRS (Flood Retarding Structure) was built in the early 1970's to help prevent future floods from devastating Guadalupe. The FRS was built on a north-south alignment along the west side of I-10. The Guadalupe FRS is clearly visible in the 1979 aerial photography.

By the early 1980's, the first residential development west of the I-10 was built and 48th Street was constructed across the fan near the apex. The gravel pit had been reclaimed with fill and Pima Wash had been realigned to preferentially follow only one of its historical flow paths. A large 8-foot circular corrugated metal culvert was placed under 48th Street to convey the wash. Pima Canyon Wash had been channelized as a grass-lined wash that conveyed runoff to the lower portions of the fan. About 600 feet downstream from the 48th Street crossing, a drop structure had been installed in the channel. The grass lined channel was constructed as far downstream as the El Paso gas line alignment. In addition, most of the alluvial fan landform had been extensively graded, with the construction of I-10, the Guadalupe FRS, realignment of Pima Wash, construction of 48th Street and the residential subdivision. By 1986, only a small portion of natural fan landform surface is visible.

In 1989 the Arizona Grand Resort Golf Course was built on the fan. Fairways were located in the vacant flood pool areas of the Guadalupe FRS and upstream of the apex of Pima Canyon Wash, both in and alongside the wash.

By the early 1990's both the golf course and the residential development on the alluvial fan were complete. No major development has taken place on the Pima Canyon alluvial fan landform since the mid 1990's. Pima Wash was engineered as a grass-lined channel up to the El Paso Gas pipeline alignment, at which point it empties completely into Fairway 6 of the Arizona Grand Resort Golf Course. Fairway 6 is located in the first of two large detention basins that are part of the Guadalupe FRS. Water then flows down Fairway 6 to Fairway 5, crosses under South Pointe Parkway in a large box culvert which also serves as a Golf Cart tunnel, and finally empties into the main FRS basin.

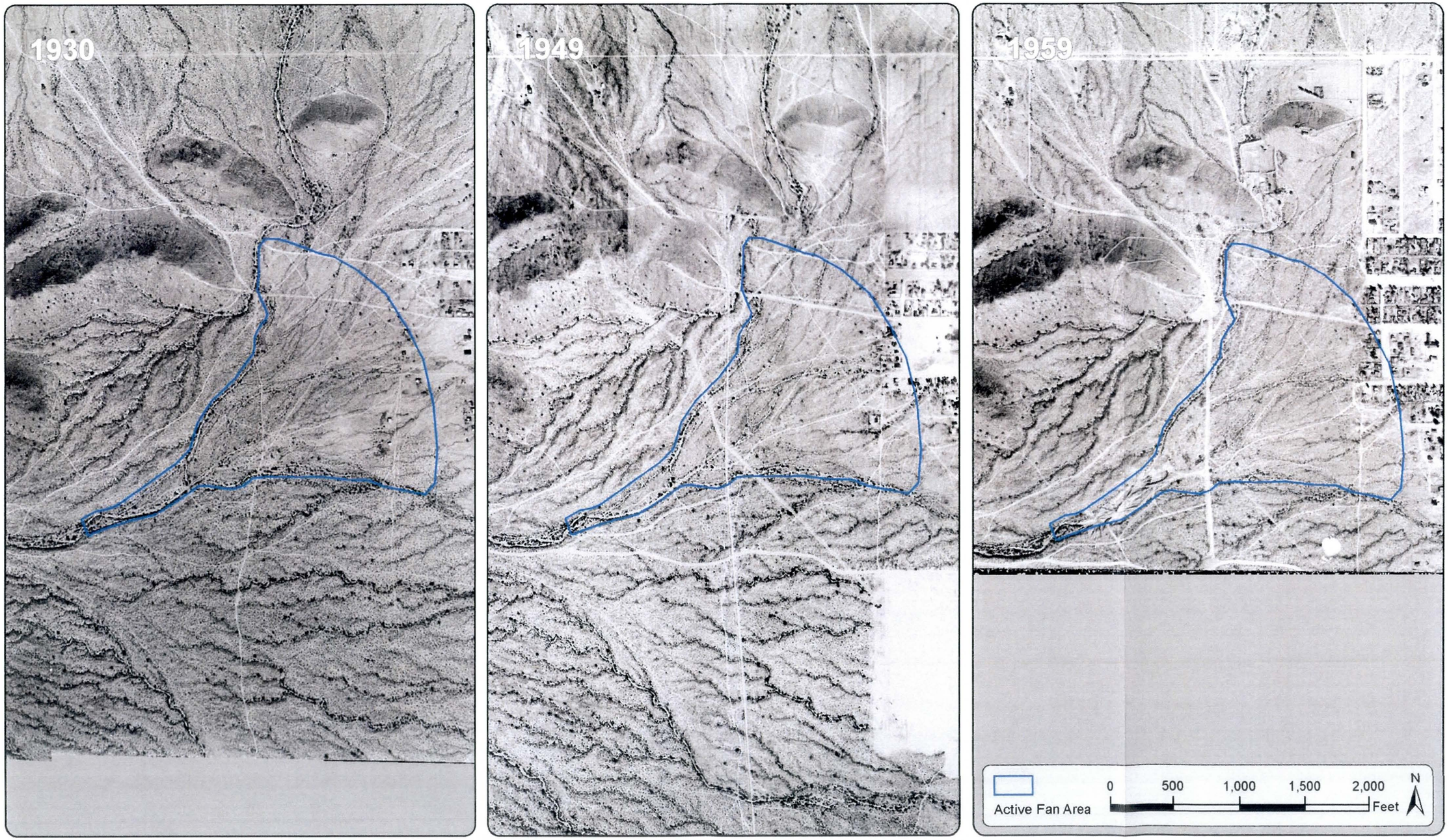


Figure 4-10 Historical Aerial Photos: Pima Canyon 1930 – 1959.

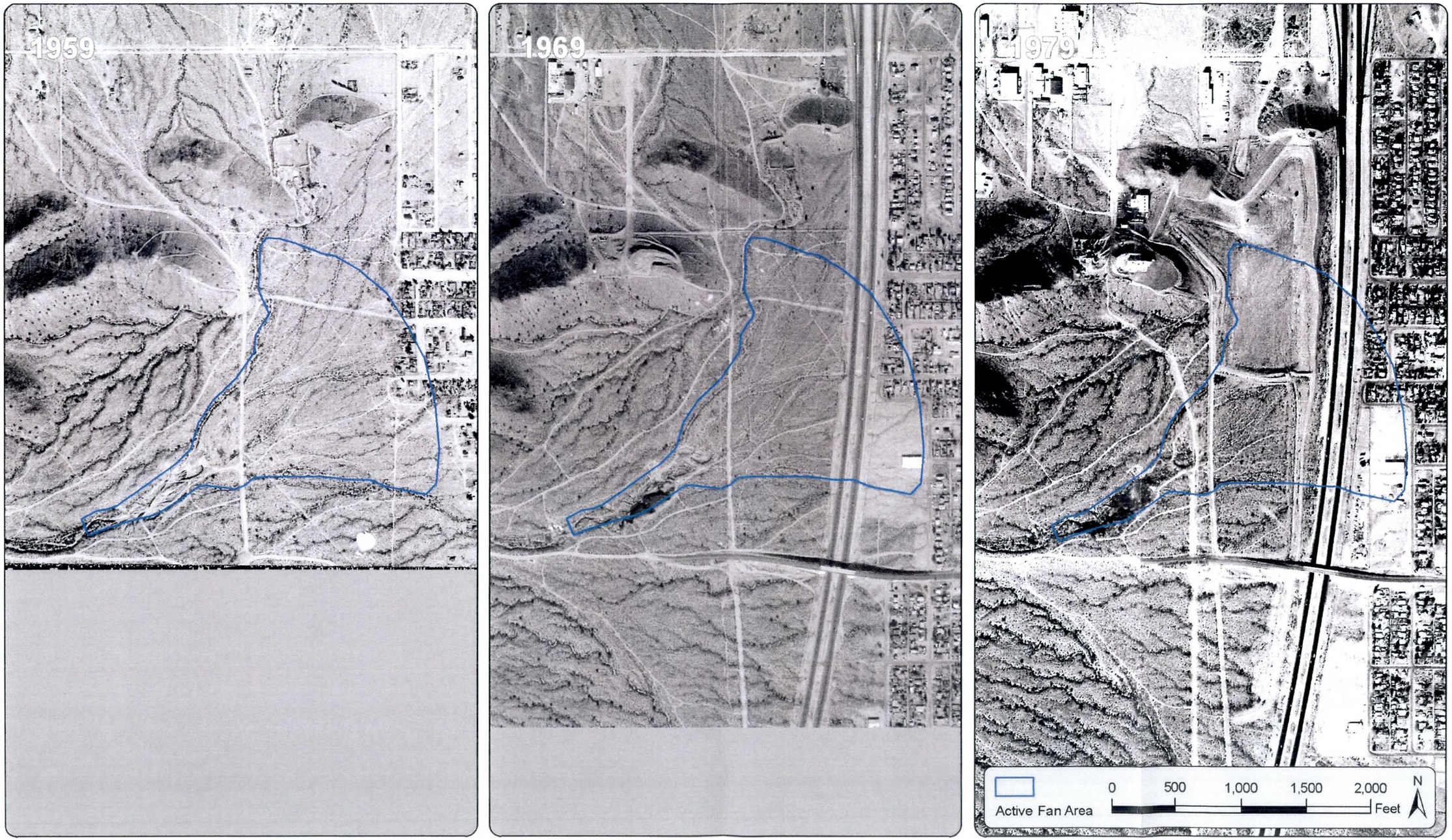


Figure 4-11 Historical Aerial Photos: Pima Canyon 1959 – 1979.

Figure 4-12 Historical Aerial Photos: Pima Canyon 1979 – 1997.

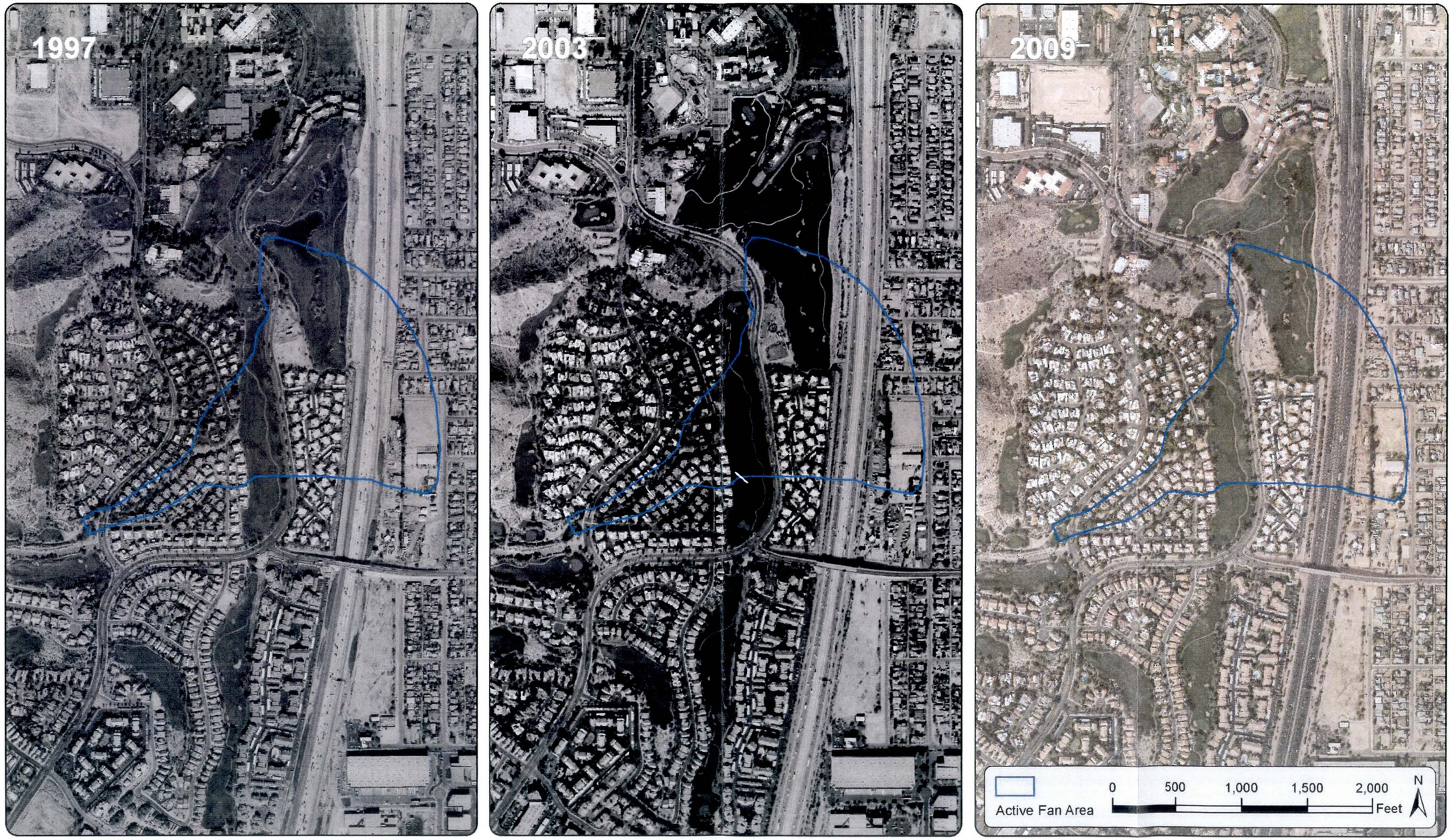
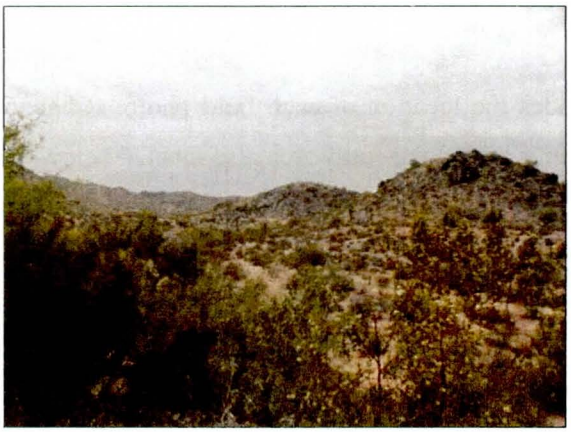


Figure 4-13 Historical Aerial Photos: Pima Canyon 1997 – 2009.

4.2.1 Photograph locations and areas of interest

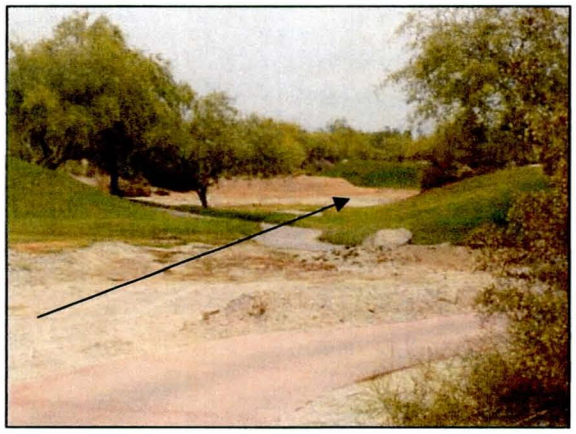
The figure below is a reference key which includes the location of each field photo. Channel alignments, boundary, streets and major engineered structures within the study area also labeled below.

Figure 4-14 Pima Canyon Photo & Structure Locations.



1. Upper Watershed
View looking west into Phoenix South Mountain Preserve

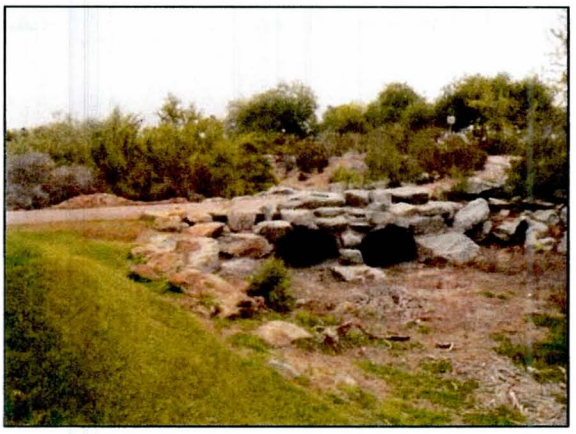
2. South Mountain preserve boundary
View looking across Pima Canyon Wash as it enters Golf Course



3. Looking Downstream at Fairway #14
Pima Wash at Arizona Grande Resort Golf Course

4. Looking Downstream at Fairway #13
Pima Wash at Arizona Grande Resort Golf Course

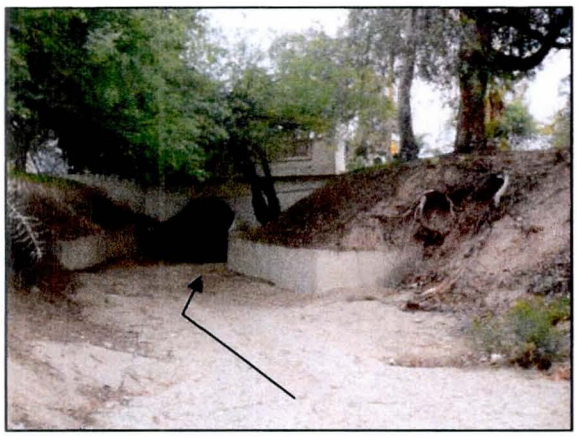
5. Foot Bridge
Scour below dashed black line



6. Looking Downstream
Pima Wash at Arizona Grande Resort Fairway #13

7. Erosion at Fairway #13
Pima Wash erosion during July 13,2008

8. Looking Upstream at 48th St. crossing
Pima Wash at Arizona Grande Resort Golf Course



9. Looking Downstream
Pima Wash at Arizona Grande Resort Golf Course

10 Downstream side of 48th St. crossing
Pima Wash at Arizona Grande Resort Fairway #13

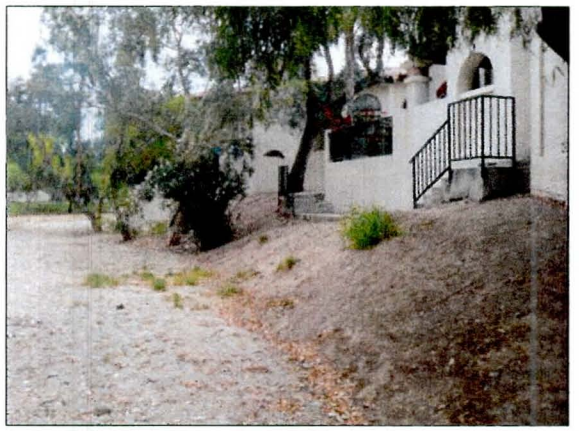
11. Design condition was grass lined channel
Looking downstream, Pointe South Mountain HOA

12. Looking Downstream at channel
Pointe South Mountain HOA

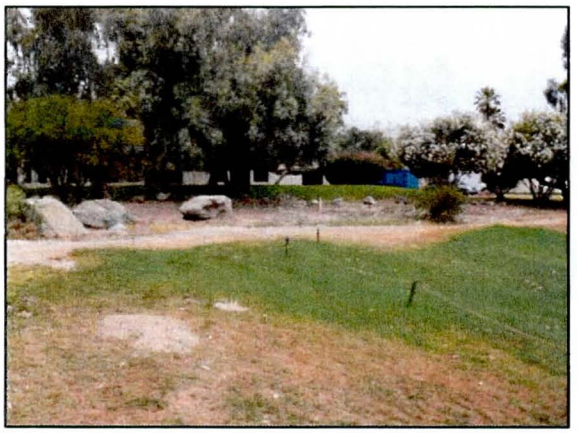
13. Looking Downstream
Grade control structure

14. Looking Upstream
Grade control structure

15. Looking at left bank of channel
Pointe South Mountain Home Owner's Association

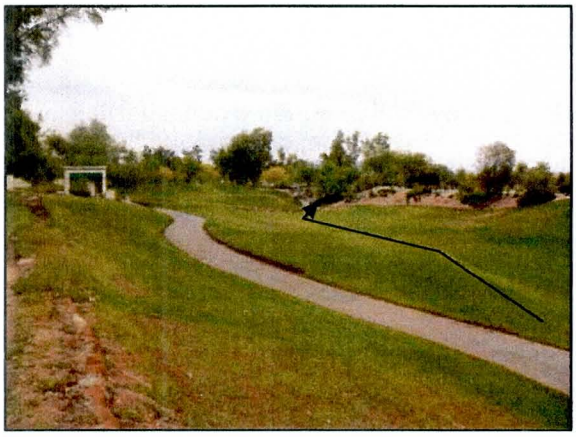


16. Looking at right bank of channel
Pointe South Mountain Home Owner's Association

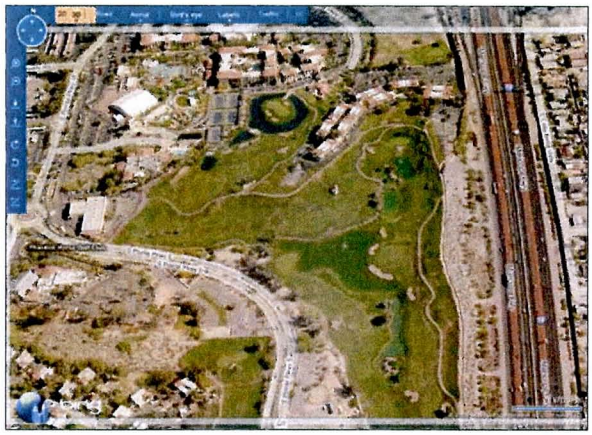


17. Looking at outflow of channel onto fairway # 6
Pointe South Mountain Home Owners' Association

18. Looking upstream, fairway #6, retention basin 1
Arizona Grande Resort Golf Course



19. Looking downstream, fairway #6, retention basin 1



20. Aerial view of FRS and final retention basin
(Source: bing.com)

4.3 Hydrology

Modern development on and interaction with the Pima Canyon alluvial fan extends further back in history than any of the other three historical review sites. Aerial photograph records extend back to 1930. References in the literature to historical floods on the fan date back as far as 1934. The Guadalupe Watershed Workplan (p. 10) refers to major floods in 1934, 1952, 1965 and 1969.

The first FCDMC Rain / Stage gage was installed on the Guadalupe FRS in June 1989, and has been in continuous operation since that time. Since 1989 the average rainfall per year has been 6.34 inches per year, with the wettest year on record being 2008 with 11.34 inches of rainfall reported. The largest storms to occur in the project area since the gage was installed in 1989 have been:

- 307 year storm: 2.28 inches in 1 hour on 07-13-2008
- 18 year storm: 2.48 inches in 24 hours on 11-15-1993

The July 13, 2008 storm was the largest event in recorded history in the project area. The following statistics about the storm were provided by the FCDMC.

- 2.28 inches was measured at the Guadalupe FRS rain gage in one hour.
- The storm was greater than a 307-year storm point rainfall using NOAA Atlas 14.
- The average rainfall over the Guadalupe FRS watershed was 1.69 inches (using locally adjusted NEXRAD radar data).
- Two FCDMC observer network gages in the area recorded 3.75" and 2.98" for the storm.
- Estimated total runoff volume from the storm contained in the FRS was 30 acre-feet.
- The majority of the rain fell on the developed portion of the watershed.
- Peak discharge flow rates at the 48th St. / Pima wash crossing were estimated to be between 200-300 cfs. (Estimates were made from high water marks in the natural portion of the watershed.)
- Inflow to the FRS is estimated to have averaged 1000 cfs during the most intense portion of the storm.

4.4 Flood Mitigation Measures

As mentioned above, an engineered drainage system was built on the fan that alters the natural alluvial fan landform geomorphology and drainage pattern. None of the structures referenced below are located upstream of the fan apex, although there are some undersized drainage crossings located within the golf course upstream of the historical apex. The drainage system consists entirely of constructed channels from the apex to the large basins that comprise the Guadalupe FRS, which is located near the toe of the fan. There is one principal outlet for the FRS that, when opened, releases water into a pipe that carries it north to the Highline Canal.

About half a mile upstream of the historical fan apex, Pima Canyon Wash exits the Phoenix South Mountain Park. At this point, the wash flows between and on the greens and fairways of the Arizona Grand Resort Golf Course. The historical course of the wash disappears in many places as the fairways have been designed in the wash bottom and in the surrounding floodplain. The wash continues east within the golf course fairways until it reaches the 48th Street crossing. The wash then passes underneath 48th Street in a large 8-foot corrugated metal pipe. Historically, in this area the wash had freedom to flow down several divergent flow paths from this point. Today, Pima Canyon Wash has been channelized down one of the historical flow path alignments. Levees and/ or fill have been placed around the channel to limit it from seeking its historical channels.

The section of Pima Canyon Wash from the 48th Street culvert to the golf course was designed to be a grass-lined channel. Today, it is no longer grass-lined, but rather has a sandy gravelly bed with weakly vegetated to un-vegetated side slopes. No documentation or anecdotal evidence was found indicating the reason for the change in channel condition. In many cases vertical retaining walls that bound residential yards or serve as structure foundations comprise the wash bank. Interestingly, the northern historical channel of the fan remains preserved in the present day topography but is cut off from channel flow by a levee and is severed by subdivision roads with no designed drainage crossings.

Approximately 600 feet downstream of the 48th Street crossing is a grade control structure. Built across the wash in the early 1980's, this drop structure is level with the wash bottom on the upstream side, then drops vertically two feet on the downstream side, effectively creating a stair step in the channel profile. Pima Wash continues downstream of the grade control structure for another 500 feet before it outfalls into a fairway of the Arizona Grand Resort Golf Course. There is a 16 foot, steeply sloped drop from the channel to the fairway as the wash empties out onto the fairway. The historical alignment of the

El-Paso gas line lies immediately upstream of the 16 foot drop. While no design drawings were available it is presumed that the wash was kept at grade until it crossed the gas-line alignment and was then allowed to empty out into the first designed basin of the Guadalupe FRS. There is no evidence of any grade control or erosion protection at the outfall onto the fairway. Once on the fairway the historical wash disappears as all the flow is then routed to the Guadalupe FRS embankment via the grassy golf course fairways.

During the July 13, 2008 storm the FCDMC recorded a peak stage impoundment at the Guadalupe FRS at 9.41 ft (Gage Height), with a peak volume of 36 acre-feet. The FCDMC did the post-flood clean up of the principal spillway / principal outlet after the storm. Approximately 1 CY of sand was removed. The minor amount of sediment debris at the outlet was probably caused by all the sediment deposited upstream in the lowest elevations of the final retention pond area. The golf course maintenance crews, who did the final clean up of the FRS retention area, estimated that as much as 240 cubic yards of sediment and debris were hauled away as a result of the July 13, 2008 impoundment event.

Upstream of the apex, during the same July 13, 2008 event, a series stair step headcuts moved upstream of 48th Street. These headcuts have been progressing upstream yearly during the largest storms of each rainy season. Sediment eroded from the headcuts was deposited in a series of bars immediately downstream. A large amount of sediment was deposited in the 48th Street culvert and the channel downstream of 48th Street during the event. Approximately 12-18 inches of sediment was deposited in the culvert, which had to be removed by a front-end loader to restore clearance for the horse path through the structure. Sediment from the 2008 event can be seen in bars and bed load deposits that dropped out downstream of the 48th Street crossing. The bed load deposited during this event decreases in size downstream from the 48th Street crossing to where the wash empties out onto the golf course.

Sedimentation is also an issue elsewhere on the fan. The residential developments in the area, including Pointe at South Mountain, which is located on historical fan surface, were designed primarily with underground storm drains. This infrastructure, according to a representative from Pointe South Mountain Home Owners' Association, was built undersized, quickly became plugged with sediment and is very difficult to clean out. The residential development in the area was also not designed to retain any water onsite. It was designed to convey 100 percent of the flow downstream. Note that this problem area is no longer hydraulically connected to the upper watershed of the alluvial fan.

The July 13, 2008 storm did flood several homes near the study area. These homes were not flooded by waters from Pima Canyon Wash, but rather by a parallel drainage directly to the south, known

locally as Mulligan Wash. Flooding did occur and may have resulted from any of a number of factors including: clogged storm drains, overgrown drainage channels, poorly designed subdivision drainage, and the largest rainfall event on record.

4.4.1 Maintenance Needed

As the wash enters the golf course green and fairways it routinely drops some sediment on the grass and golf-cart paths. The cart paths are routinely cleared of sediment after any sizable storm event but the sediment on the greens and fairways, while occasionally raked and removed, is typically claimed by the quick growing Bermuda grass. This process of entrapping sediment in the growing grass has effectively raised the bed of Pima Wash in several places by as much as 12" where the bed of the wash is in the fairway itself. Also, the 48th St. wash crossing occasionally needs to be cleared of sediment.

4.5 Conclusions

Prior to residential development in the late 1980's, the Pima Wash alluvial fan had a large active area downstream of the apex, although it is likely that a significant portion of the lower fan surface was subject only to shallow sheet flooding. Flooding from the fan did cause damage to the nearby Town of Guadalupe. Development of the fan surface occurred as part of a master planned community, which was based in part on a regional-scale, privately funded drainage master plan. The engineered drainage master plan for the alluvial fan included earthen channels that extended from upstream of the apex to a golf course located within the impoundment of a regional FRS (dam) near the toe of the fan.

Since the development was completed in the mid 1990's the system has been tested by at least one very large magnitude storm. Estimated to be in excess of a 350 year storm (on the fan surface – the frequency was much less in the upper watershed above the apex), this event sent a record amount of floodwater and sediment down the Pima Canyon Wash. While record rainfalls were recorded, actual flood damage on fan was minimal and consisted primarily of sediment deposition that required removal. Both sedimentation and erosion in the channel and around the golf course occurred during the flood, and are likely to continue to occur in the future.

Based on our analysis, we conclude that the engineered drainage system has performed adequately during the 20 year period of record, at least with respect to controlling the flow uncertainty and sedimentation associated with active alluvial fans. No homes or structures on or around the formerly active portions of the fan have been flooded in the past 20 years. There is no record that the earthen channel overtopped or significantly eroded its banks. The sediment deposition that occurs during floods

and rare flows from Pima Wash appears to be adequately handled by the private HOA and golf course maintenance crews. The performance of the engineered drainage system is predicated on the following:

- Periodic sediment removal from the channel and basins.
- Occurrence of floods that do not exceed the design frequency

5. Reata Wash Fan

5.1 Site Location

5.1.1 Location Map

The Reata Pass Fan site is located in northeast Scottsdale, Arizona within Sections, 16, 17, 19, and 20 of T4N R5E. The Reata Pass Fan is located along the western flank of the McDowell Mountains, approximately 3 miles northeast of the 101-Pima Freeway Curve. Since the Reata Pass alluvial fan landform is large, this historical analysis focuses on the upper portion of the landform from the apex near the intersection of Pinnacle Peak Road and Church Road to the Thompson Peak Parkway alignment.

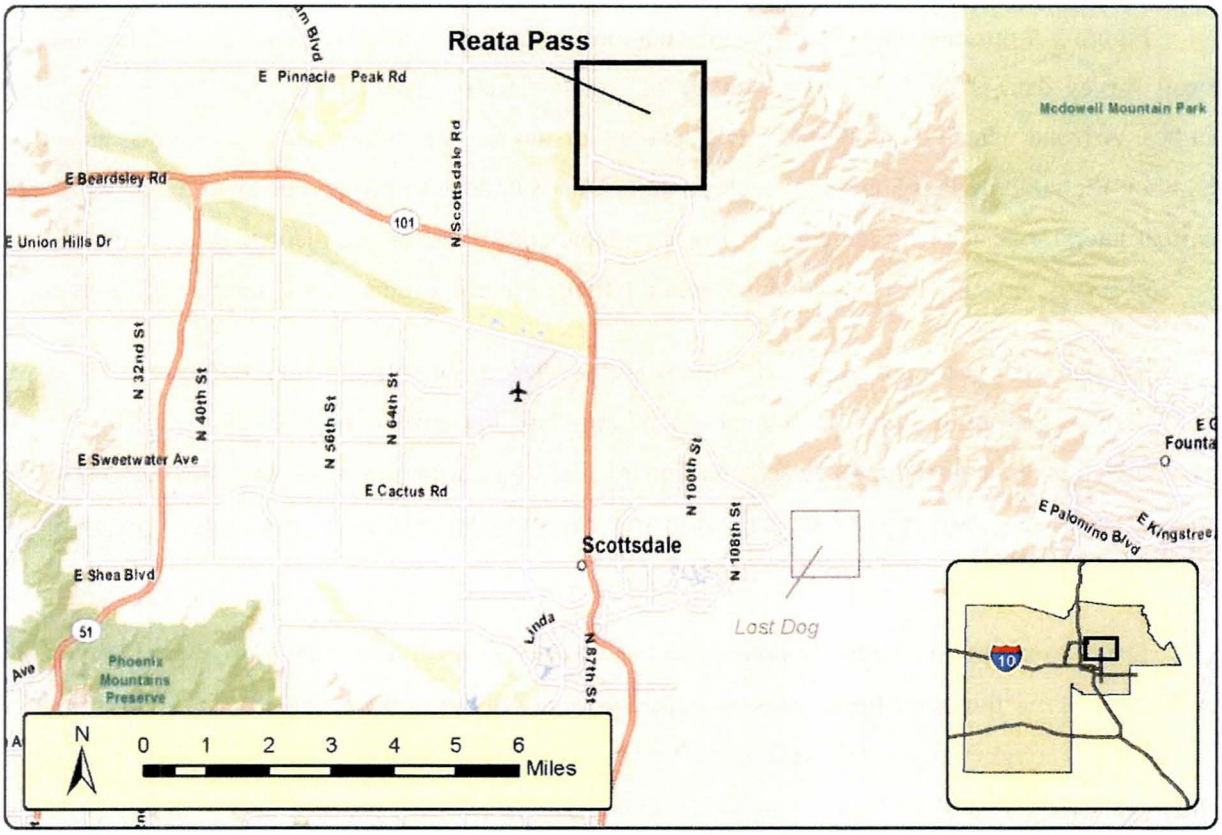


Figure 5-1 Location Map: Reata Pass Fan.

The Reata Pass Fan watershed area is approximately 8.0 square miles in area directly above the hydrographic apex,[2] and drains portions of the northern and western flanks of the McDowell Mountains, as well as the surrounding piedmont. The watershed includes steep mountain slopes, which are not

[2] Additional mountain drainage areas contribute below the primary hydrographic apex.

developed and gently sloping piedmont areas which are mostly developed with residential homes and golf courses. The upper half of the study area flows through the Pinnacle Peak Heights and Pinnacle Peak Vistas I and III subdivisions. The lower portion of the study area is occupied by the DC Ranch master planned community.

As seen in Figure 5-3 the primary hydrographic apex of Reata Pass alluvial fan is just south of the intersection of Pinnacle Peak Road and Via Ventosa. At the apex, flow splits in two main directions: (1) to the south, which is referred to as Reata Wash, and (2) to the southwest, which is locally referred to as Dobson Wash. Reata Pass Fan historically has been and still is an active alluvial fan, with significant sediment deposition and transport on the fan surface.

5.1.2 NRCS Soils Mapping

Figure 5-6 presents the soil survey information for the Reata Pass Fan study area. The source of the soil survey data is the NRCS Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona. In Figure 5-6, the lateral extents of the fan are delineated and included as a blue overlay on the 2009 aerial photograph background. This was done to provide perspective of where the historical lateral extent of the fan surface was in comparison to modern residential development in the area. Soil survey units are labeled individually in the figure but also grouped into major landform types.

The fan surface from the apex to Thompson Peak Parkway consists of four soil units. The apex, Reata Wash and Dobson Wash are composed of unit No. 8 (Arizo cobbly sandy loam). Arizo is "characterized by excessively drained soils on floodplains… [ ]. ..Runoff is slow, and the hazard of water erosion is severe…. [also] the riparian habitat in some areas of the Arizo unit is extremely important to wildlife" (Aguila-Carefree Soil Survey, p.16).

Downstream of the southwest branch, known as Dobson wash, is soil unit No. 6 (Anthony-Arizo complex), which is found on floodplains and drainageways. Between the Arizo (8) on the east and the Anthony-Arizo complex (6) on the west is the Tres Hermanos-Anthony complex (121). This soil unit is found on fan terraces, stream terraces, and their associated floodplains. Runoff is slow in this area and hazard of water erosion is slight. Downstream of the Anthony-Arizo Complex (6) is the Momoli gravelly sandy loam (90), which is also a deep well drained soil on fan terraces. Runoff is slow and the hazard of water erosion is slight.

Bordering the fan on the east are several rock outcrop soil units (31) which are part of the McDowell Mountains. On both the east and the west are other fan terrace soil units.

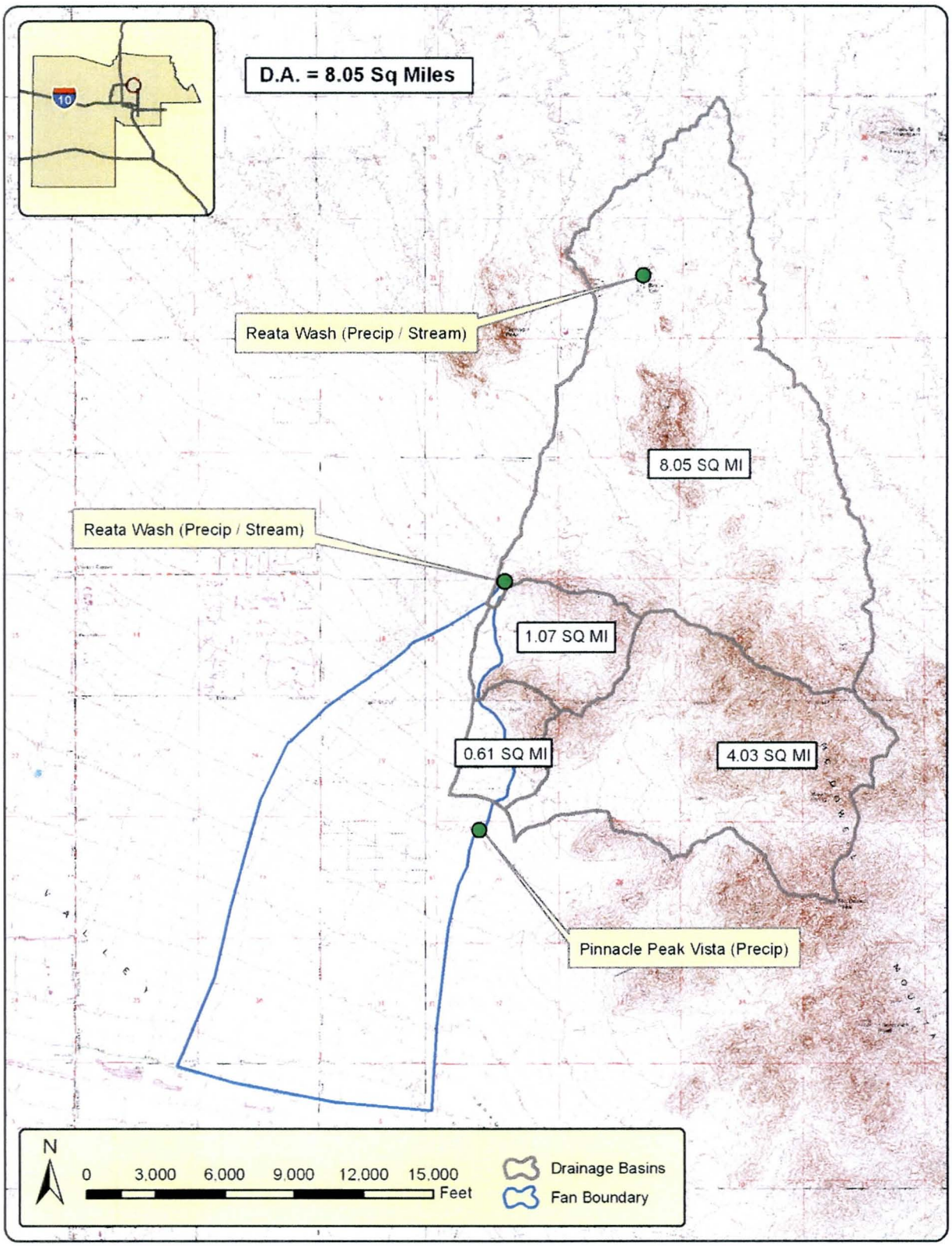


Figure 5-2 Reata Pass Fan Drainage Area & Gage Locations.

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Figure 5-3 Reata Pass Fan Before & After Development.

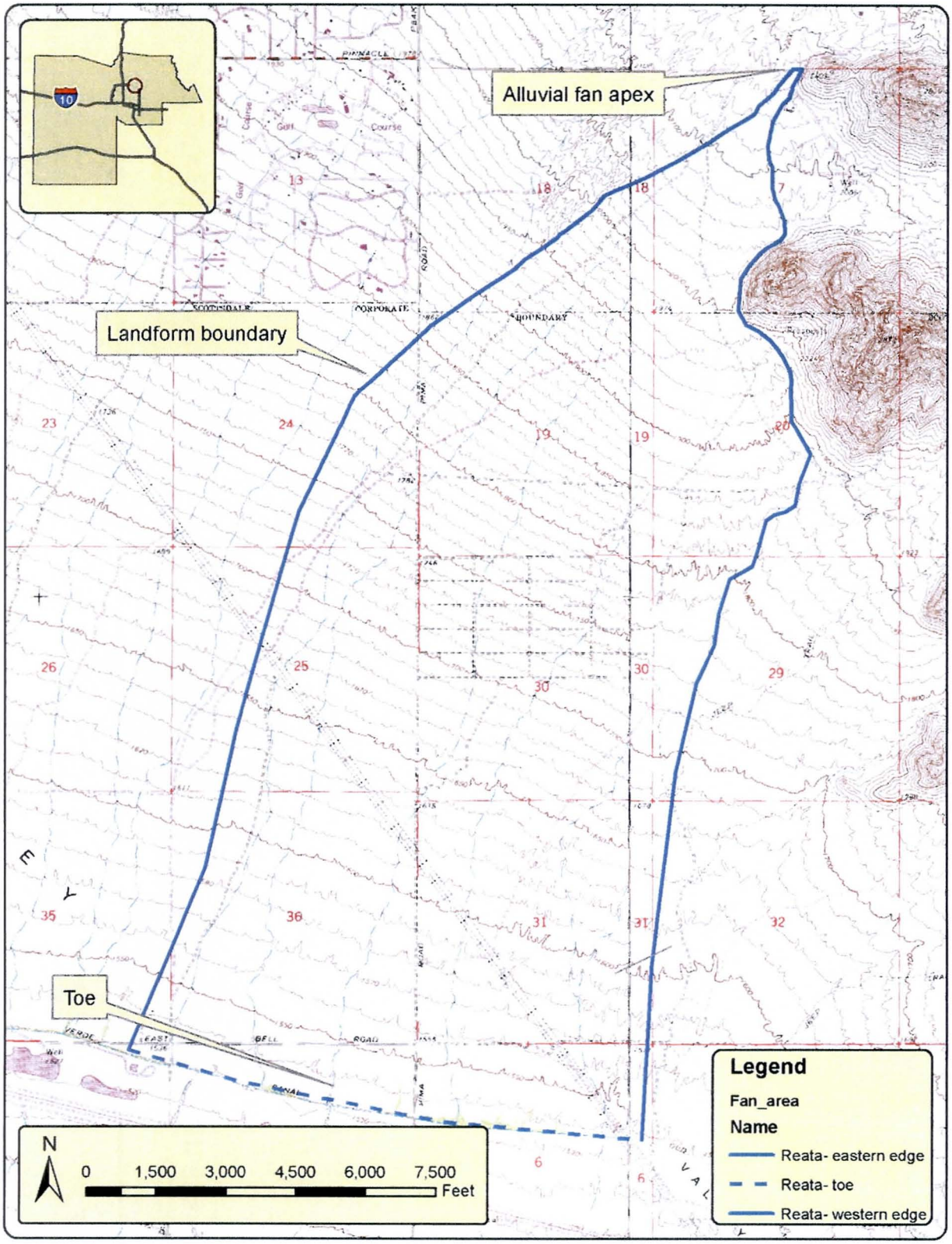


Figure 5-4 Reata Pass Fan Landform Boundary (whole fan).

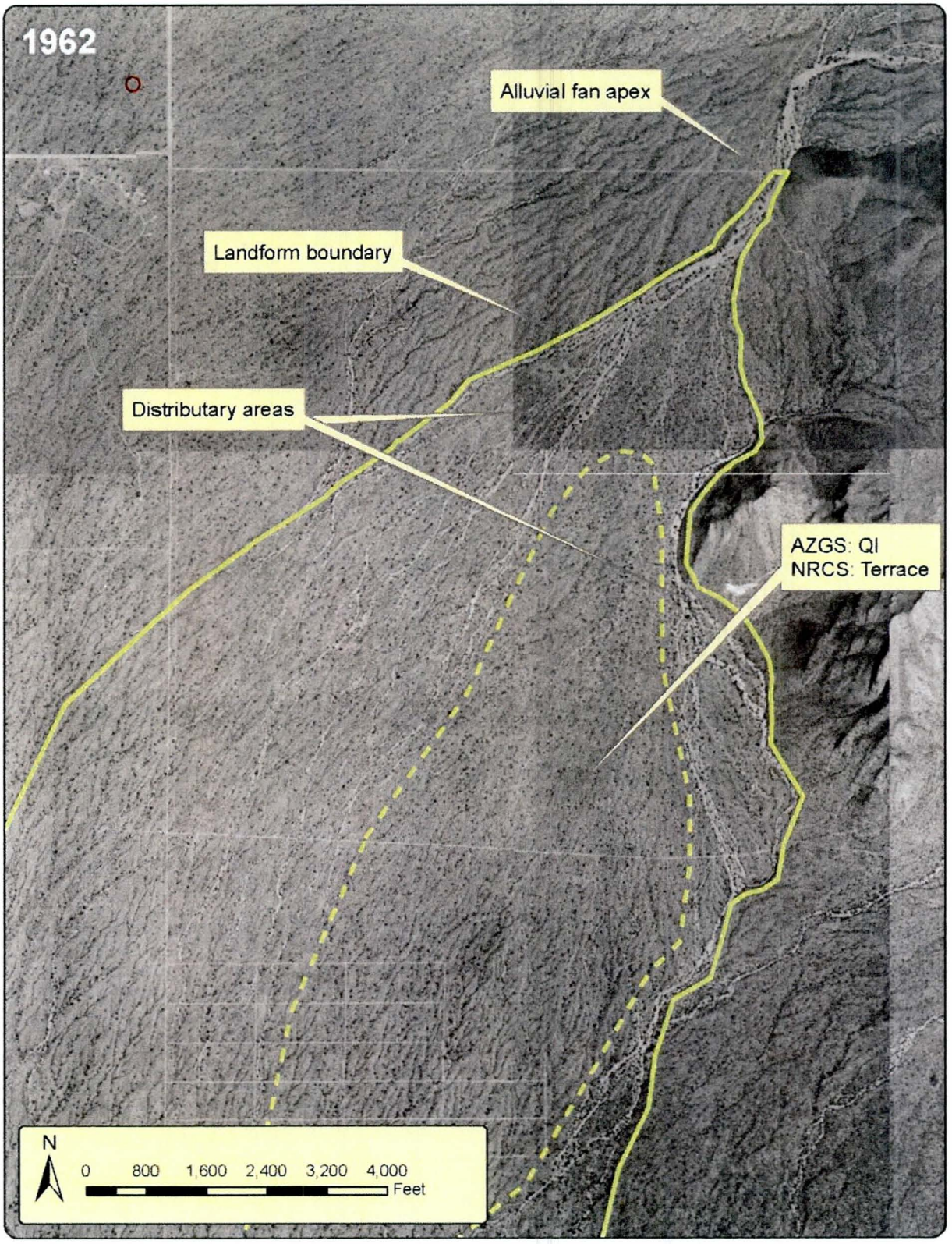


Figure 5-5 Reata Pass Fan Landform Boundary.

5.1.3 AZGS Surficial Geology

Figure 5-7 presents surficial geology mapping for the Reata Fan study area from the AZGS geologic map of portions of the Theodore Roosevelt Lake 30' x 60' Quadrangle, Richard and Spencer, 1998. The lateral extents of the historical alluvial fan area have been delineated from the 1962 aerial and included as a blue outline on the 2009 aerial background.

The bedrock units of the McDowells that lay to the east of the alluvial fan are composed of early Proterozoic Quartzite (Xsq). The three geologic units that compose the fan itself are: Qy, Qm and Ql.

Approximately half the study area is composed of the Qy unit. Qy (Quaternary Young Alluvium) forms low terraces and alluvial fan deposits. Qy, a Holocene unit (less than 10,000 years old) is the youngest geologic unit in the study area. Qy covers all the highly visible drainage pathways on the alluvial fan surface.

Portions of the fan that are not Qy are composed of Qm or Ql. Both of the units are Pleistocene in age: (Ql) late Pleistocene and (Qm) middle Pleistocene. These units are typically found on moderately dissected to dissected portions of alluvial fans and fan terraces. The oldest Quaternary unit found in the study area lies just to the west of the apex. This unit Qmo, middle to early Pleistocene in age, is found on older, heavily dissected fan terraces, evident by the heavily crenulated topographic contours in that area.

5.1.4 Topography

Figure 5-8 shows the topography for Reata Pass alluvial fan from 7.5 minute USGS quadrangle maps. As demonstrated in the topography and enumerated in the table below, Reata Pass fan has the steepest fan surface gradient of the four historical fan sites studied.

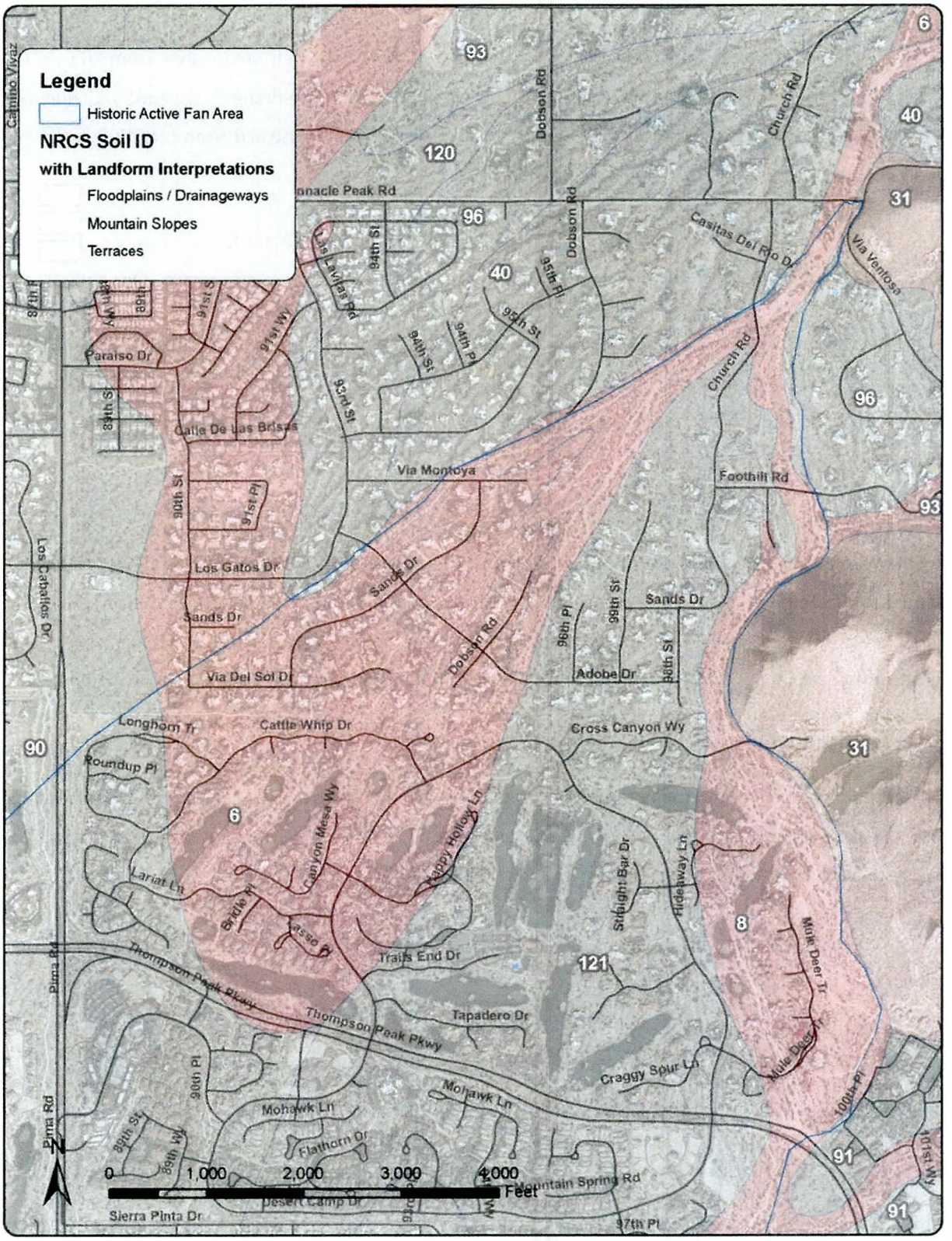


Figure 5-6 NRCS Soils: Reata Pass Fan.

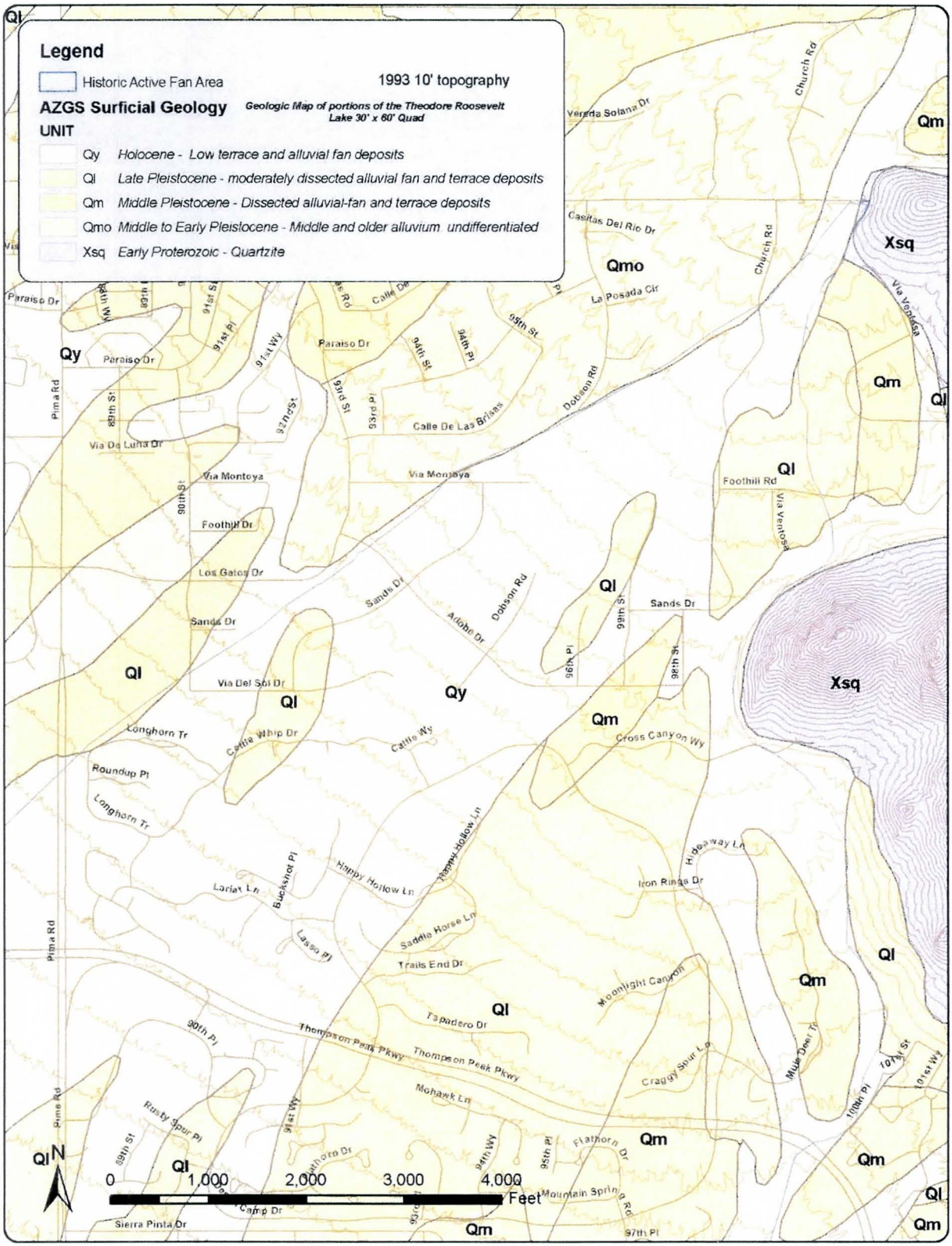


Figure 5-7 AZGS Geology: Reata Pass Fan.

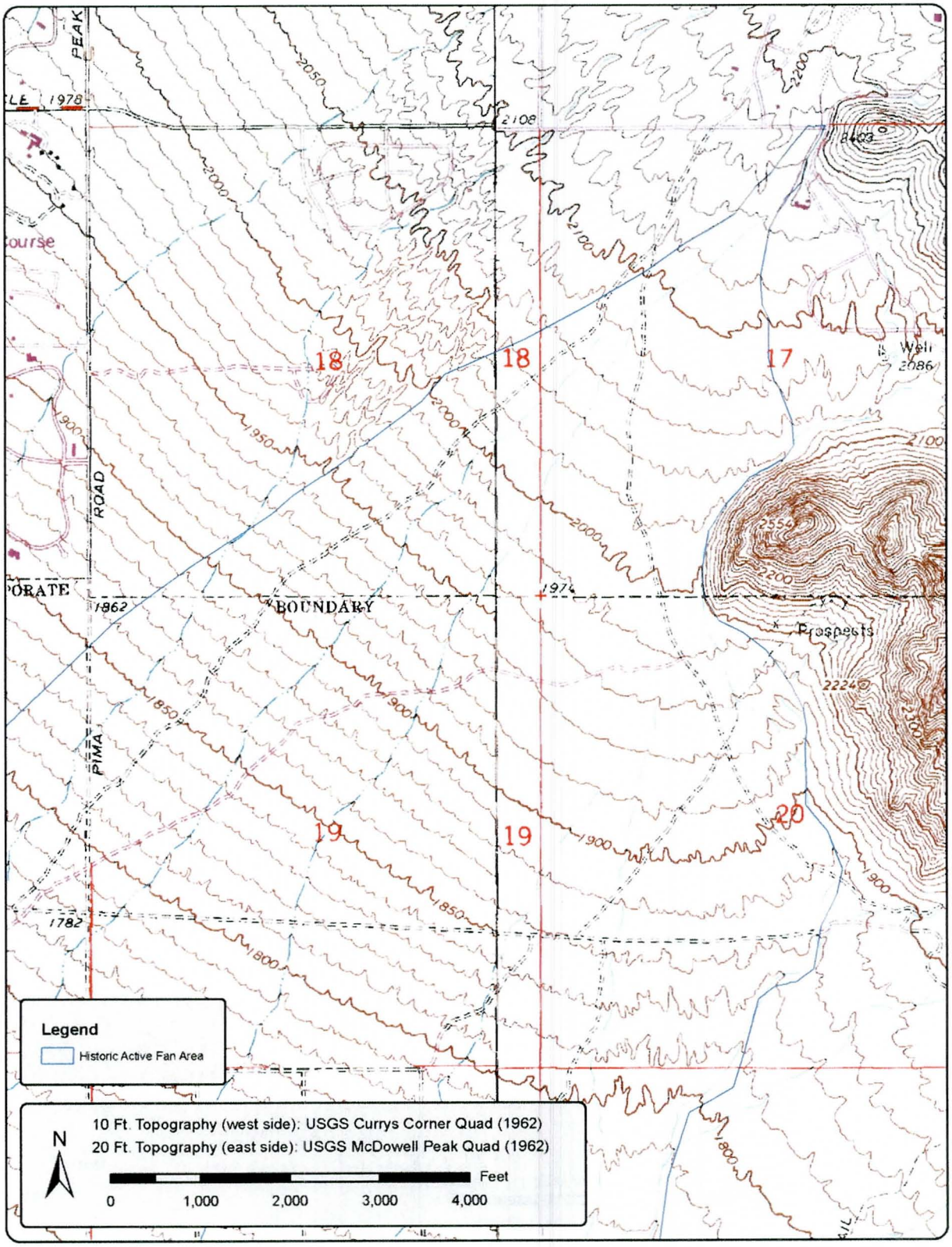


Figure 5-8 Topography: Reata Pass Fan.

5.1.5 Watershed and Fan Parameters

Item	Value	Source
Watershed area (upstream of apex)	8.1 square miles	USGS Quads
Watershed slope 3.2 miles upstream to apex	 3.4 %	 USGS Quads
Fan slope (Apex to 1.92 miles downstream) (1.92 miles to 4.65 miles ds)	3.3 % 2.0 %	USGS Quads
Q100 at apex	13,671 (24-hr)	City of Scottsdale Storm Water Master Plan
Fan Profile Shape	concave	USGS Quads
Max Elevation in Drainage Area	3880 ft	USGS Quads
Elevation at apex	2185 ft	USGS Quads
Minimum Elevation in fan	1520 ft	USGS Quads

Figure 5-9 Watershed and Fan Parameters

Structure	Type / Date	Location
Box culverts at apex	Concrete boxes	Pinnacle Peak Rd / Reata Pass Wash
Church Rd wet water crossing	Dip crossing	Church Road, south of Casitas Del Rio Dr
Foothills Rd culvert crossing	1 three foot dia. CMP	
Adobe Dr wet water crossing 1	Dip crossing	Between Los Gatos Drive and Sands Dr
Adobe Dr wet water crossing 2	Dip crossing	Between Sands Dr and Dobson Rd
Adobe Dr wet water crossing 3	Dip crossing	Between Dobson Rd and 96th Pl
Legacy (Union Hills) / 96th St Culvert	Two 8' x 4' box culverts	West of 96th St on Legacy

Figure 5-10 Structure Information

5.1.6 PFHAM Stage I

Task 2.3.3 requires that the pre-development landform be classified as to the "probable" landform type using the PFHAM Stage 1 categories. A PFHAM Stage 1 landform classification for an alluvial fan consists of the following elements:

- *Composition.* The landform is composed of alluvium (sediment material transported by the streams that formed the landform.
- *Morphology.* The landform has the shape of a fan, either partially or fully extended.
- *Location.* The landform is located at a topographic break where the primary watercourse loses capacity.

The Reata Pass Fan landform is shown to be composed of alluvium, as shown by the NRCS detailed soils mapping (Figure 5-6) and AZGS surficial geology mapping (Figure 5-7). As shown in Figure 5-8, the landform has the radial contours characteristic of a partially extended fan. The site is located at the topographic break formed where the main wash leaves the mountain canyons and enters the piedmont

upstream of Pinnacle Peak Road and the channel changes from a single thread channel to a bifurcated distributary pattern (Figures 5-3 and 5-8). Therefore, the landform is properly classified as an alluvial fan landform.

5.2 Development History

Historical and recent aerial photographs of the study area are provided on the following pages. A delineation of the historical fan limits (delineated from the 1962 aerial) is outlined on each photograph to facilitate their comparison. This delineation is included as a point of reference because the landform becomes more obscured with subsequent years of development in the area. All of the aerial photography was obtained from the FCDMC.

5.2.1 Development History

The oldest aerial image of the study area is from 1962, which indicates that no development had taken place in the study area. The only man made features visible in the 1962 photograph are the alignments of Pima Rd (a north-south trace on the west side of the photo), Pinnacle Peak Rd (an east-west trace intersecting the fan at the apex), and an unnamed road transecting the fan near the bottom of the photograph. Interestingly, the subdivision outline (rectangular grid pattern) of Pima Acres is visible in the lower left hand corner of the photograph even though the first homes in that area where not built for another 20-25 years.

By 1976, there was only one home built near the fan landform. The home is located directly east of the apex outside the historical limits of the fan. The drainage channels at the apex and downstream appear more clearly defined than they do in the 1962 aerial, especially along Reata Wash as it heads south from the apex. This may be due in part to the large June 22, 1972 flood (See Appendix K of the 2003 PFHAM).

By the early 1990's, many custom homes had been built on the fan landform, primarily in the Pinnacle Peak Vistas and Pinnacle Peak Height subdivisions. According to a representative of the Pinnacle Peak HOA, the roads and homes in the upper portion of the fan were built to minimize disturbance to the natural channel conditions and to preserve the fan's natural drainage pattern. Restrictions were placed on modifying the wash in any way, and limitations were placed on where the lot structures were to be built. The site topography was also accounted for when choosing the building pad, which was required to be built on the topographically high portion of the lot. In addition, since all of Reata Pass fan is mapped in a FEMA AO zone, homes were required to be elevated on fill. Finally, each site plan was required to be engineered to ensure no rise in the regulatory floodplain.

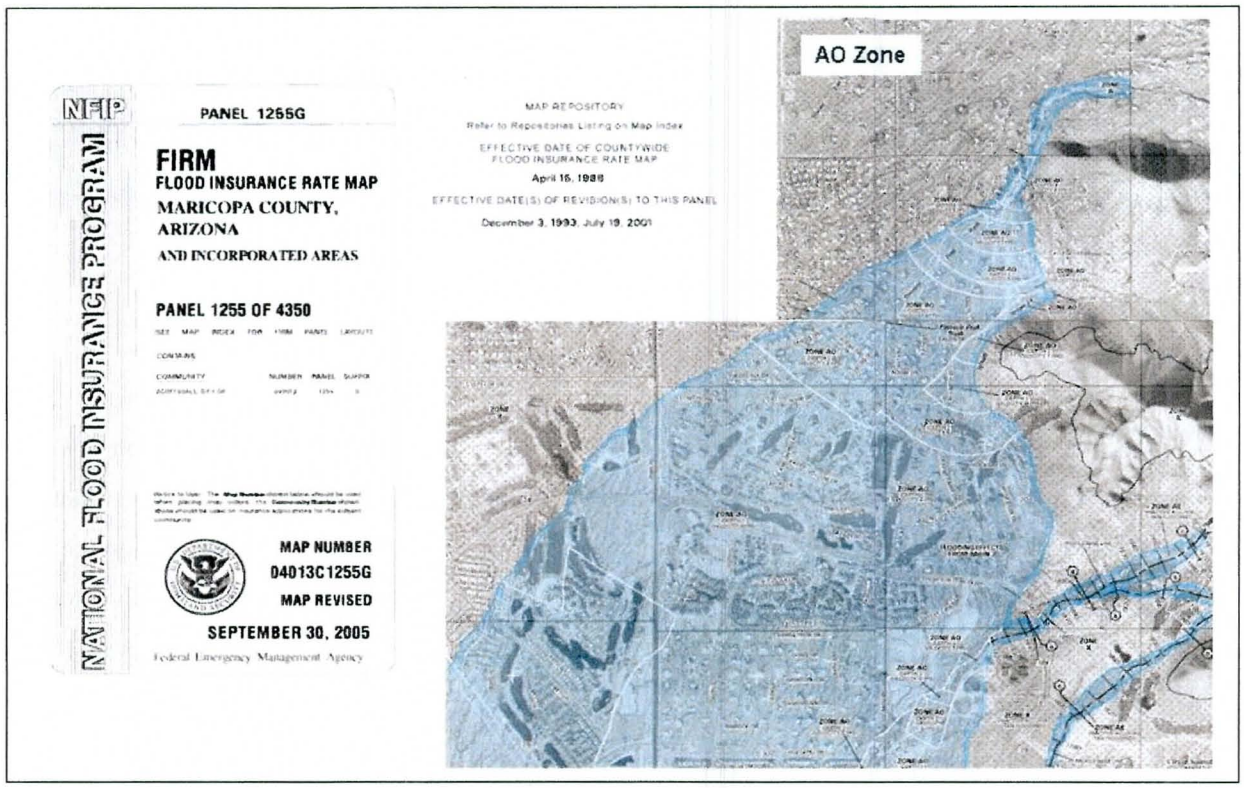


Figure 5-11 Reata Pass Fan FEMA Floodplain Map (FIRM).

All of the road crossings built on the upper portion of the fan, below the apex, but above the boundary of DC Ranch, are dip-crossings built at grade, with one exception. There is a culvert at the Foothill Road crossing of Reata Wash. Unlike the upper portion of the fan upstream of the DC Ranch boundary, the lower portion of the Reata Pass Fan has been highly modified and graded, including engineered channels, levees, and large bridge structures on Thompson Peak Parkway and other major roads.

The Greenbelt

Much of the development on the Reata Pass fan is tied up in the history of the City of Scottsdale's Desert Greenbelt project. The Desert Greenbelt project would have effectively channelized Reata Wash from apex and routed the flow down the Reata Wash corridor on the east side of the fan. A levee at the apex was designed to allow a limited amount of water to flow down Dobson Wash, the other historical fan flow path, to sustain the riparian habitat in those areas.

The DC Ranch community was designed and constructed using the Desert Greenbelt post-construction design discharges, which included the Reata Wash channelization element. However, for a

variety of reasons, the citizens of Scottsdale and its City Council abandoned the Reata Pass elements of the Desert Greenbelt project and it was never built.

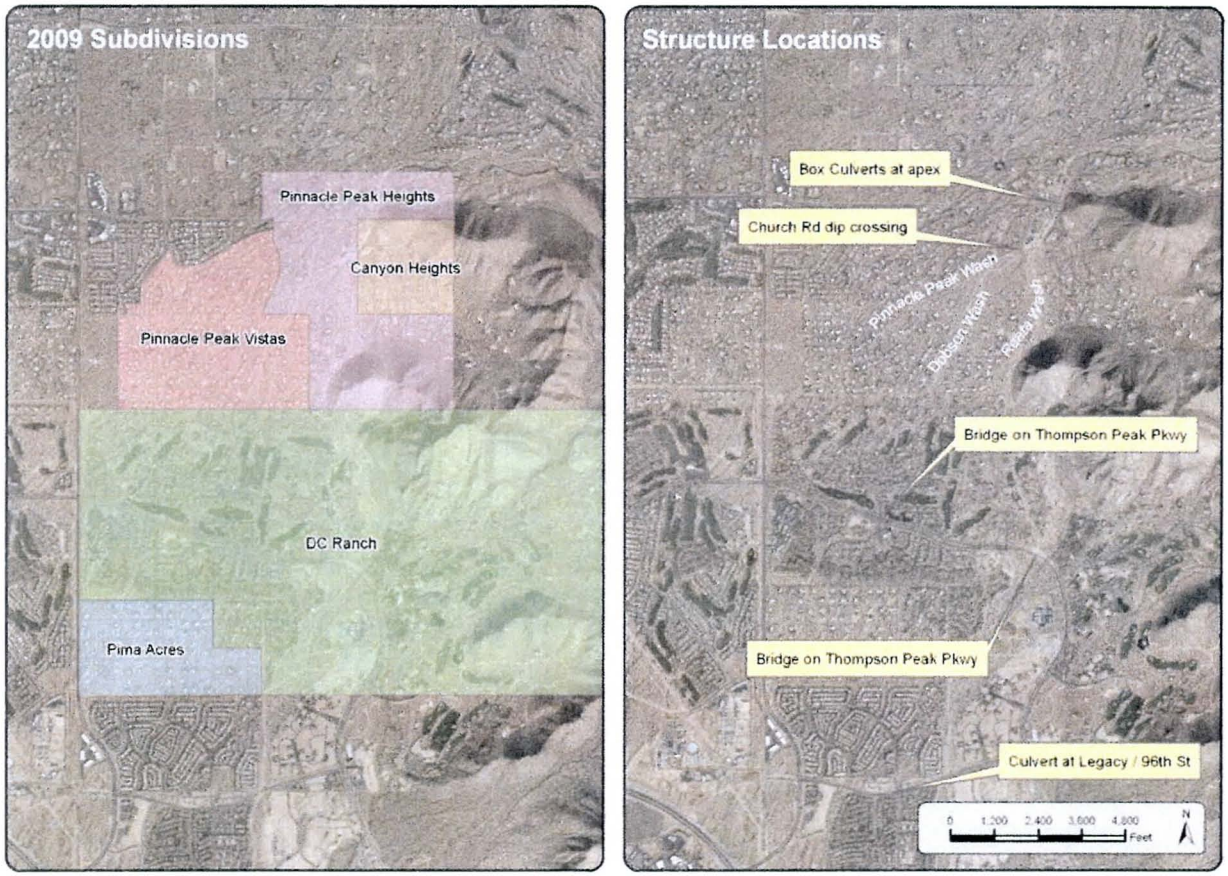


Figure 5-12 Reata Pass Fan Subdivisions and Structures.

During the late 1990's, DC Ranch began to develop the lower portion of the study area, north of Thompson Peak Parkway. DC Ranch is a master-planned golf course community with moderately dense residential development. Development in the late 1990's proceeded under the assumption that Reata Wash would be levied at the apex and the bulk of the flow would be channelized down Reata Wash on the east side of the fan. The result was that some residential homes in DC Ranch were built in the wash bottom with no protection from upstream flows even though the levee measures planned at the apex were never built. There have been no known flooding problems with these homes to date, probably due to the lack of significant rainfall in the ten years since their construction. Homes built in the wash may be inundated during large magnitude floods, potentially posing a risk to the safety, life and property of the residents. The homes in the wash may also restrict conveyance, potentially inundating adjacent areas.

Thompson Peak Parkway was built across the fan between 1993 and 1997, and included bridges to accommodate both Reata Wash on the east side of the fan and Dobson Wash (combined with other break offs from it) on the western side of the fan. Also, by this time, the golf course at DC Ranch had been built on the fan.

By 1999, development had begun at DC Ranch south of Thompson Peak Parkway, with construction continuing until present day. During the early 2000's, DC Ranch was completed upstream from Thomson Peak Parkway, and the custom home communities downstream of the apex were also completed.

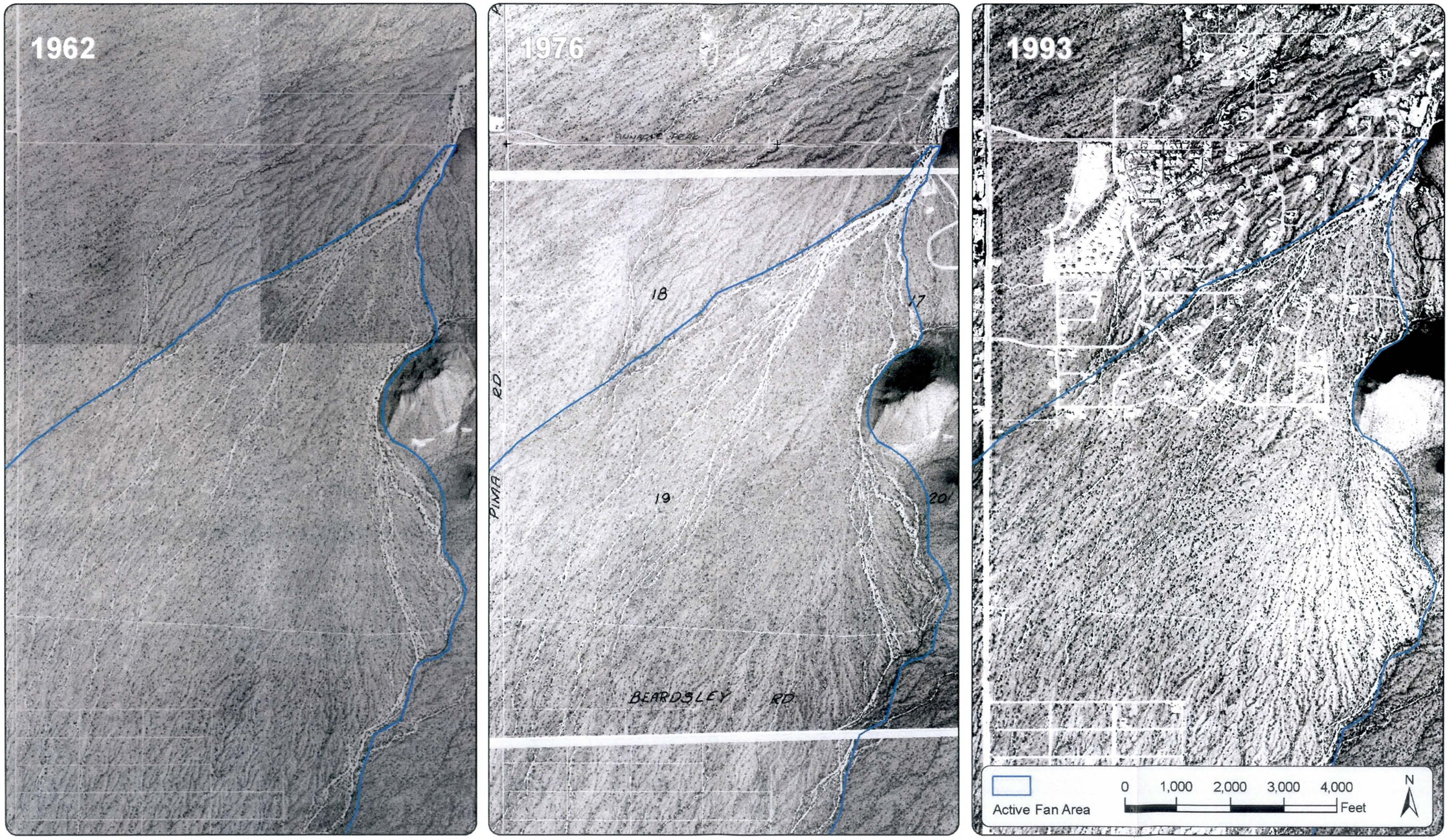


Figure 5-13 Historical Aerial Photos: Reata Pass Fan 1962 – 1993.

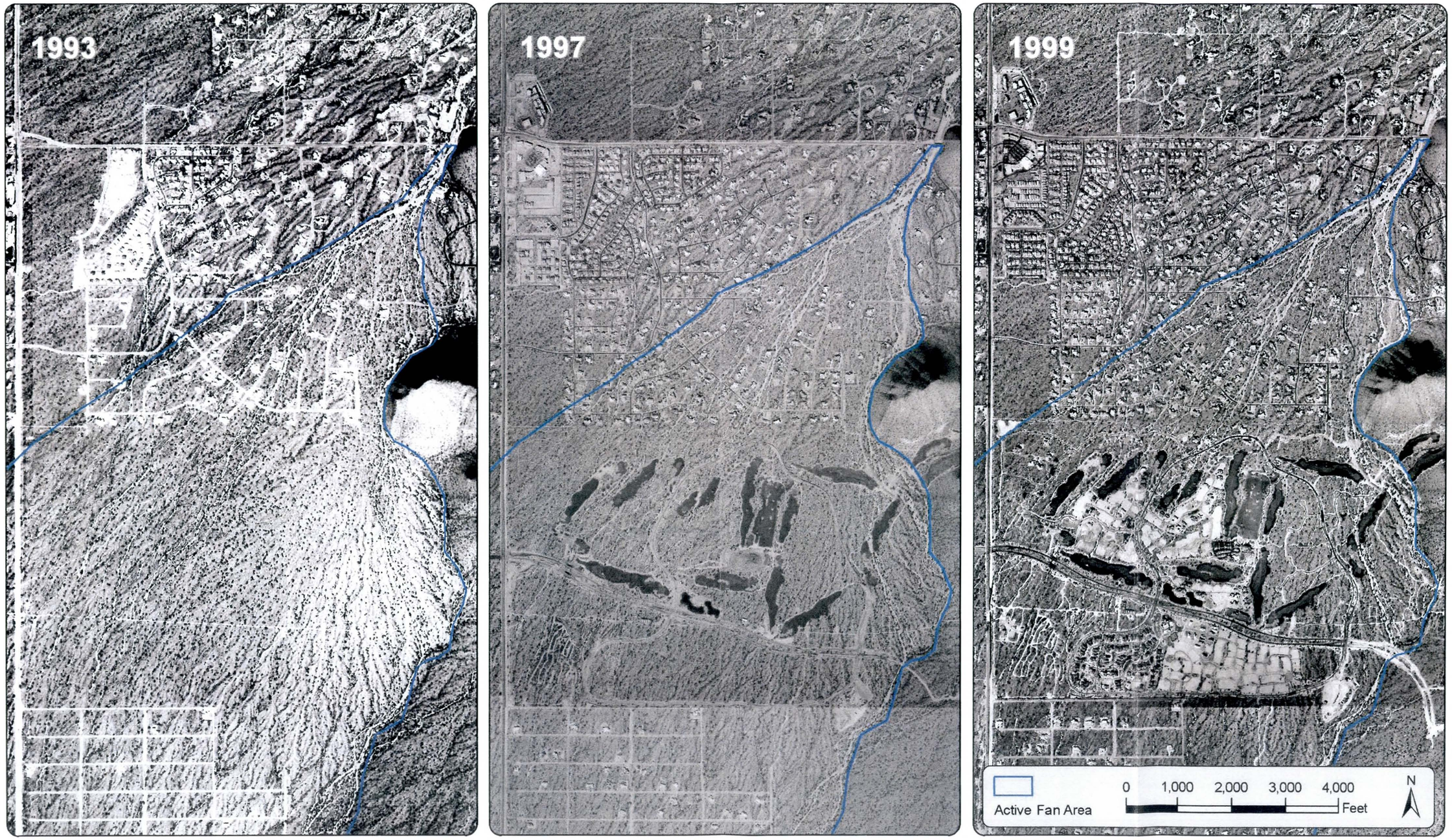


Figure 5-14 Historical Aerial Photos: Reata Pass Fan 1993 – 1999.

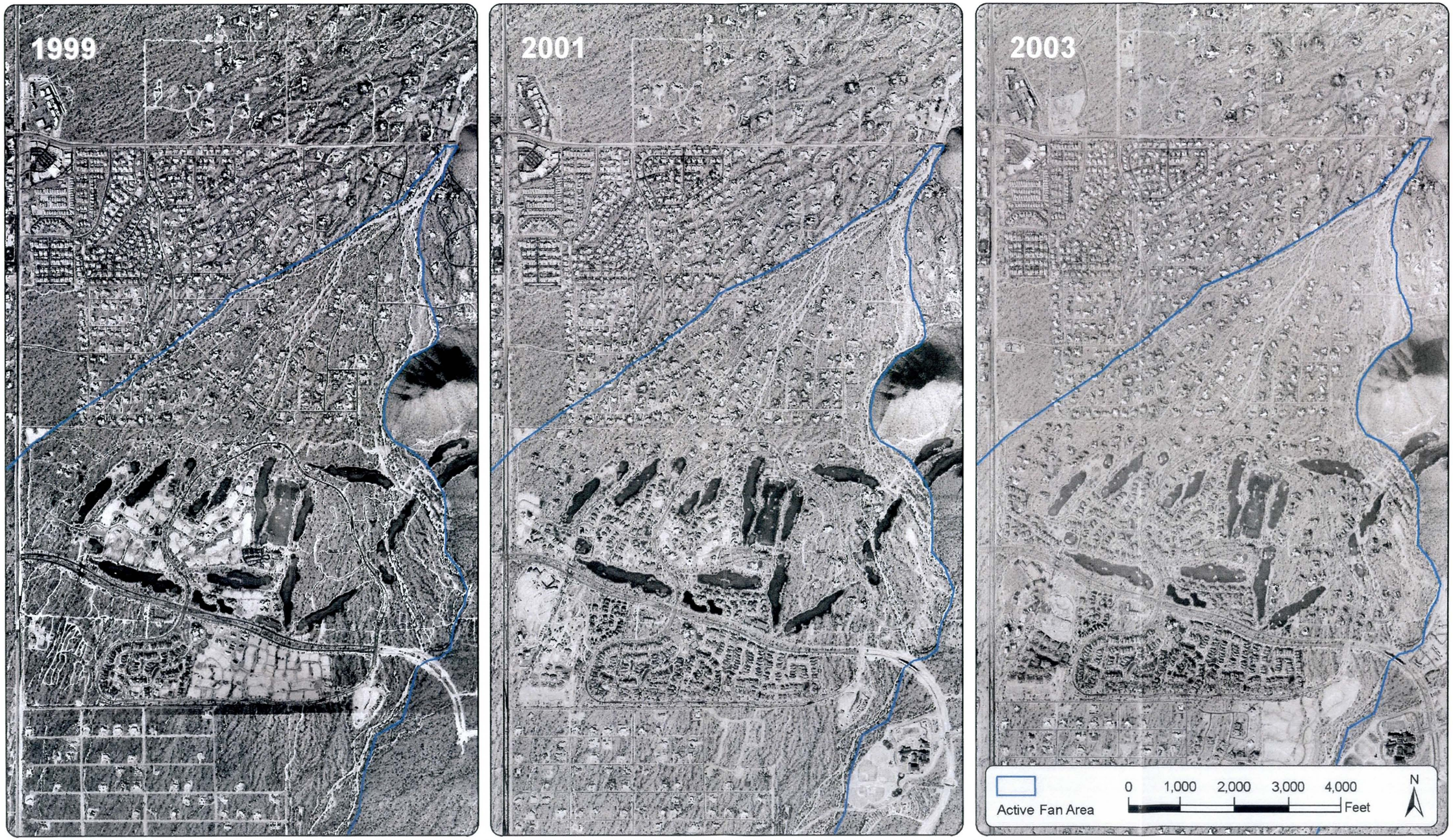


Figure 5-15 Historical Aerial Photos: Reata Pass Fan 1999 – 2003.

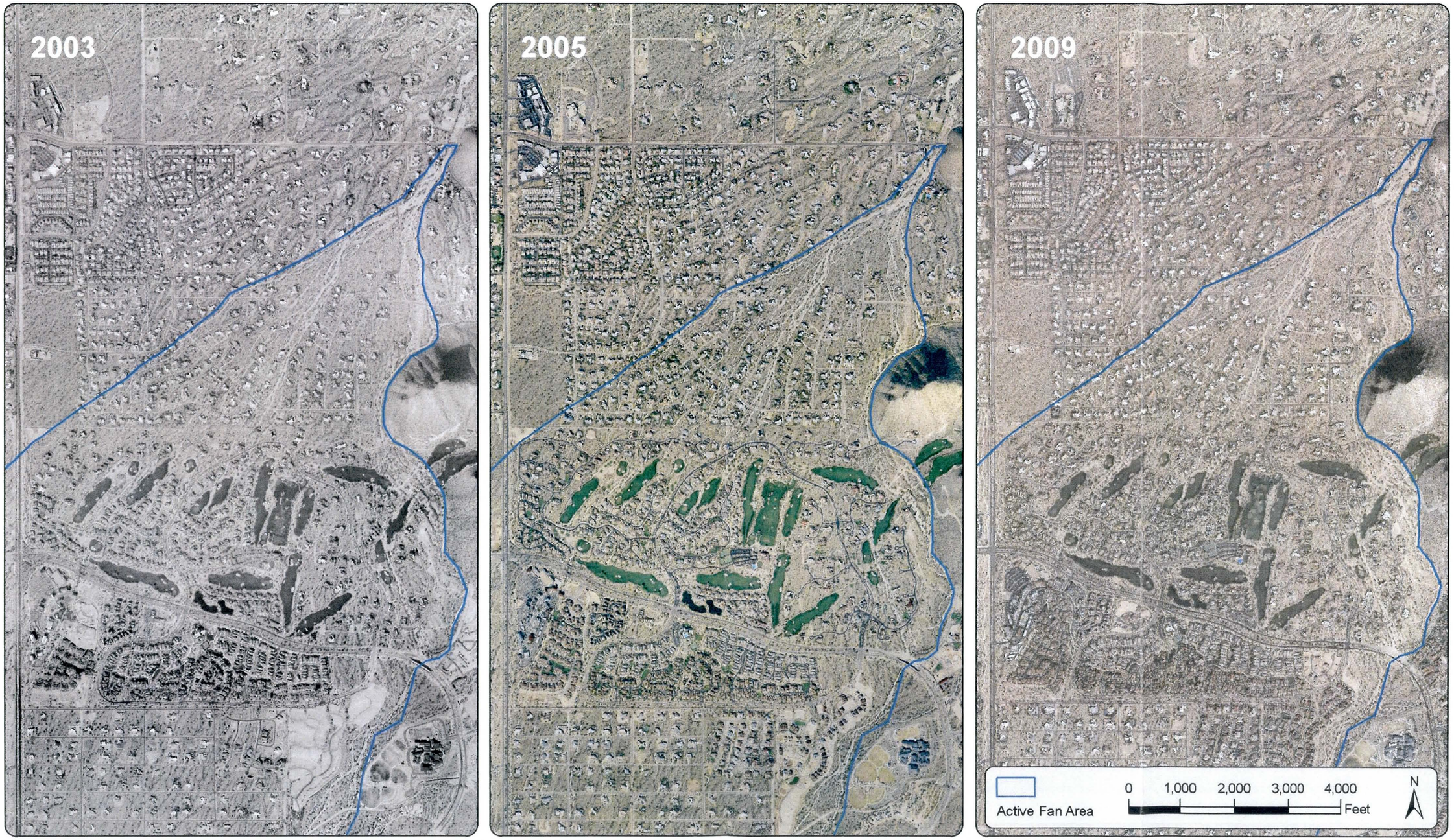


Figure 5-16 Historical Aerial Photos: Reata Pass Fan 2003 – 2009.

5.2.2 Field Photograph Locations

The figure below includes the locations for each of the following field photos. Field photos are identified by the number in the caption below the photo.

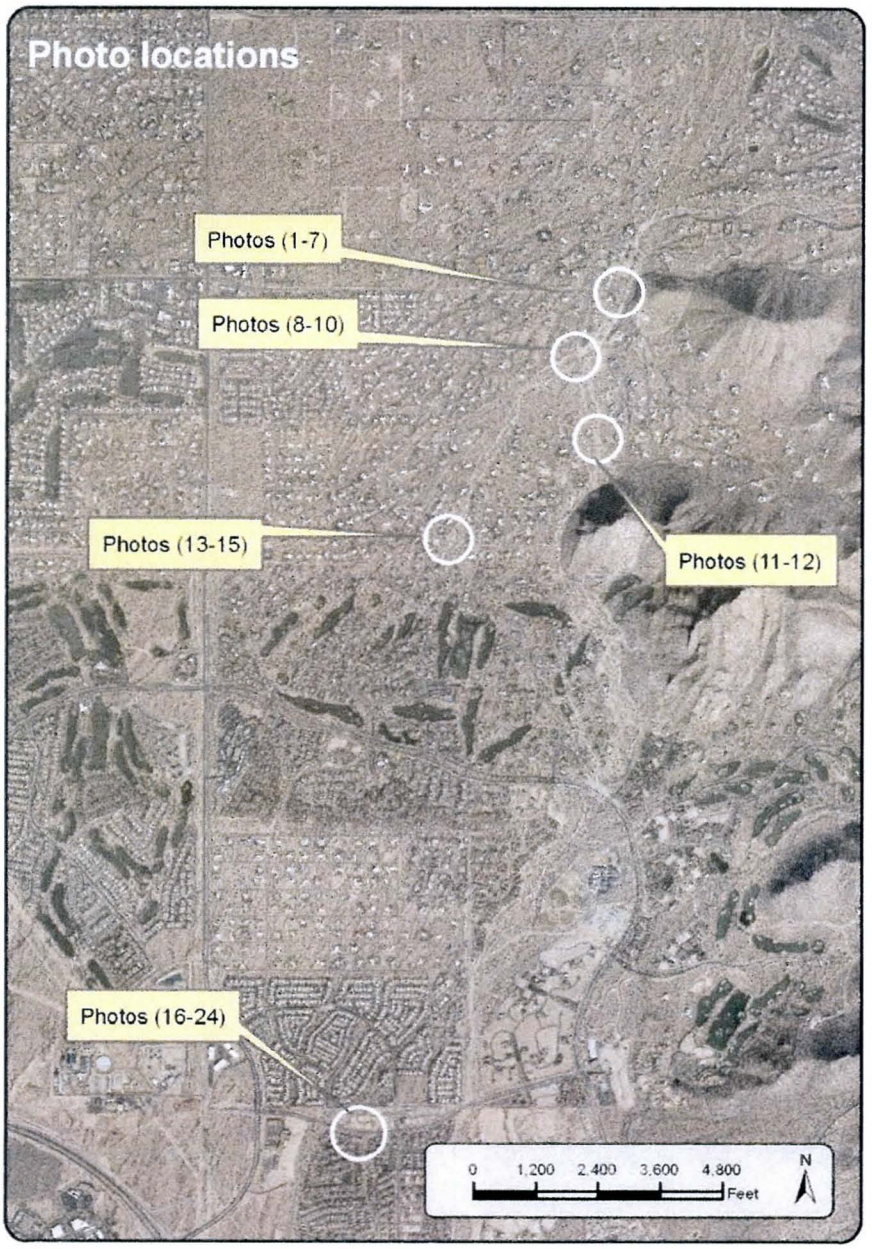
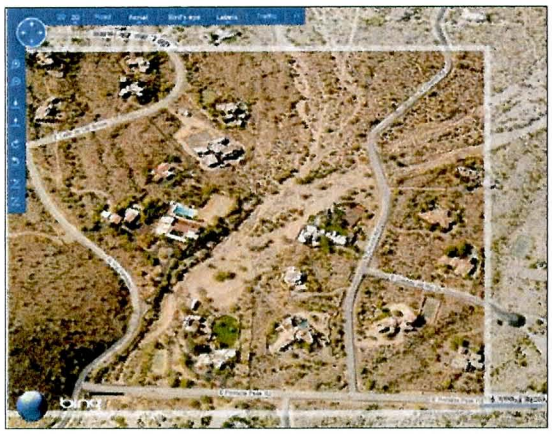


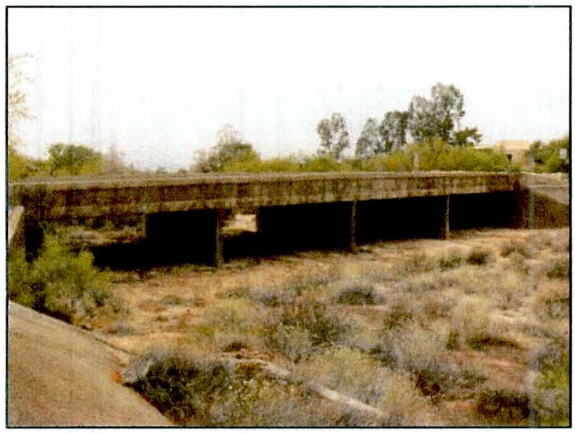
Figure 5-17 Reata Pass Fan Photo Locations.



1. Oblique aerial view looking south at apex
Source: bing.com

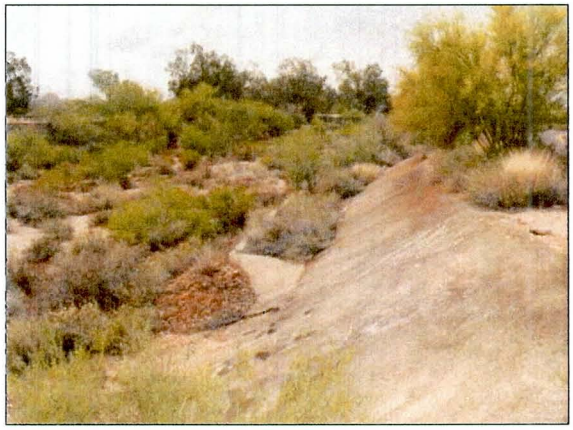
2. Oblique aerial view looking south at Church Rd
Source: bing.com

3. McDowell Mts.
Watershed contains the north slope of the McDowells

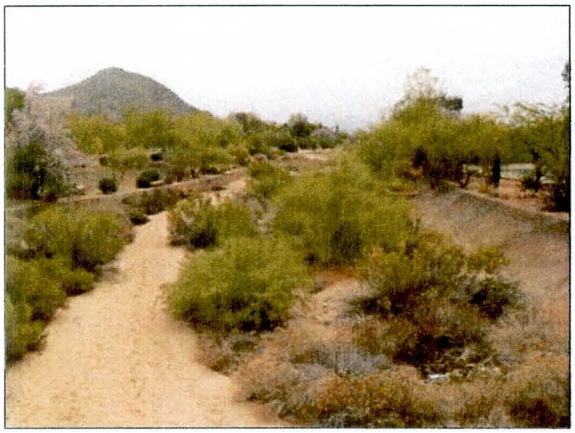


4. Crossing at the apex (Pinnacle Peak Rd)
Four 10' x 20' box culverts

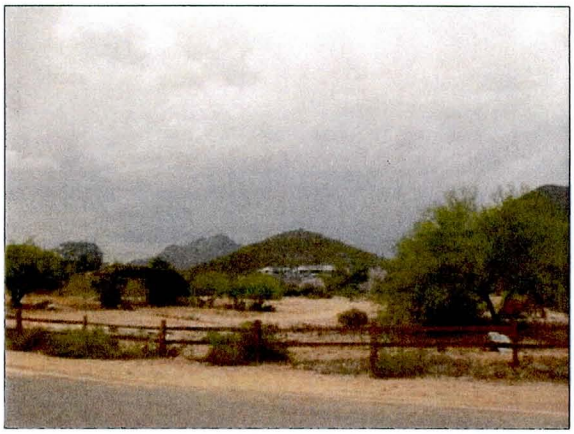
5. Looking downstream from Pinnacle Pk Rd culverts
Reata wash levied on both sides



6. Looking upstream from Pinnacle Peak Rd culverts
Reata wash levee on the left bank



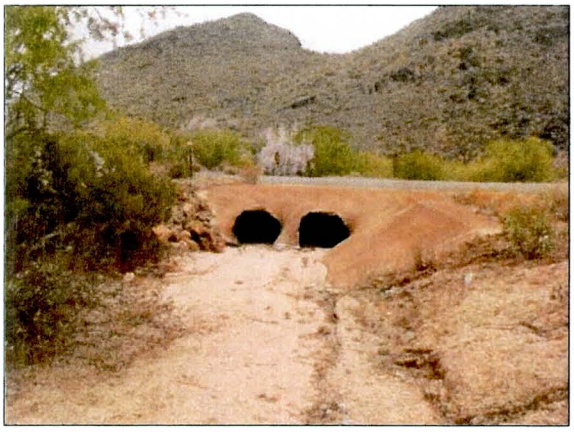
7. Looking downstream from Pinnacle Peak Rd x-ing
Reata wash levied on both sides



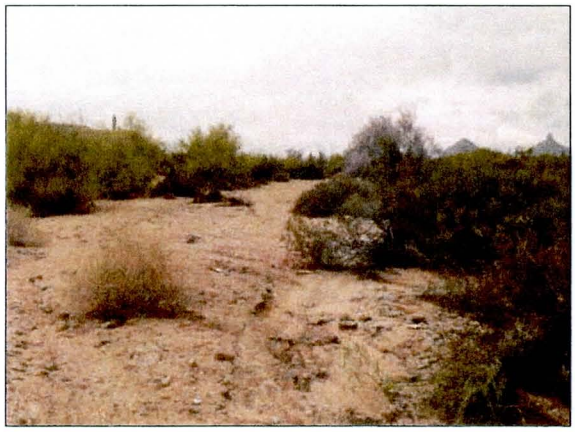
8. At-grade crossing at Church Rd
Looking upstream

9. At-grade crossing at Church Rd
Looking downstream

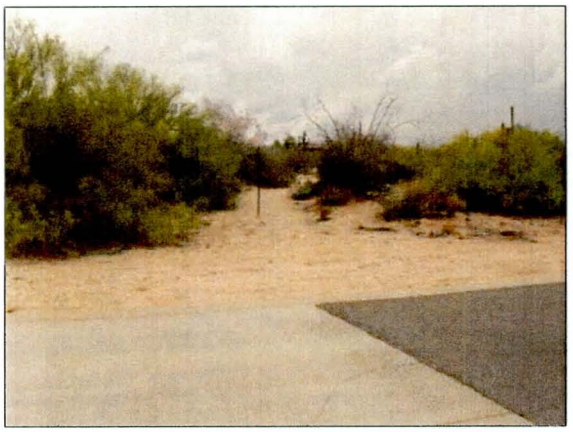
10. At-grade crossing at Church Rd
Looking downstream



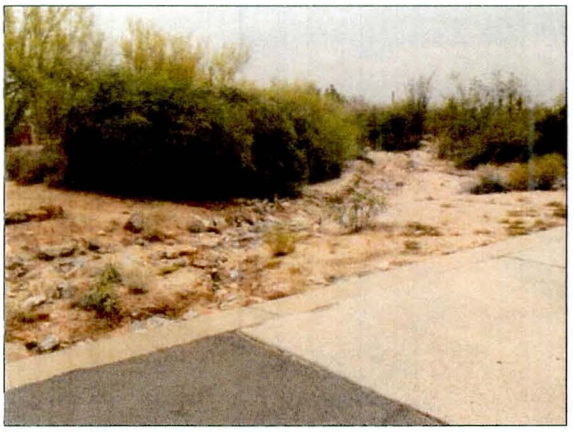
11. Reata Wash at Foothills Drive
Two 3' CMP Culverts



12. Reata wash upstream of Foothills Dr. culverts
Looking upstream



13. Dobson Wash dip crossing at Adobe Dr.
Looking upstream



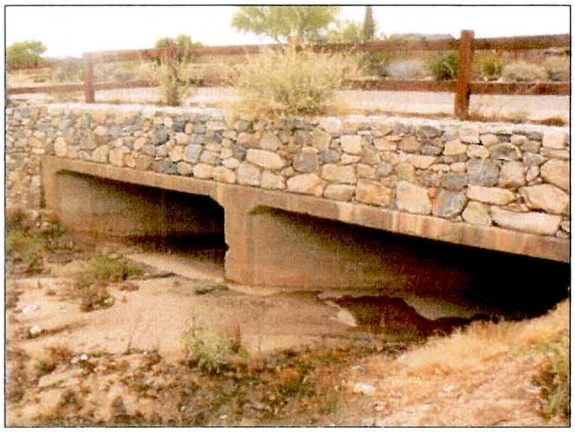
14. Dobson Wash dip crossing at Adobe Dr.
Looking downstream

15. Dobson Wash dip crossing at Adobe Dr.
Looking downstream

16. Legacy road (Old Union Hills) / 96th St
Two 8' x 4' box culverts, As-built: Q = 511 cfs

17. Looking upstream
From the Legacy Road crossing

18. Looking Downstream
At the Legacy Road crossing

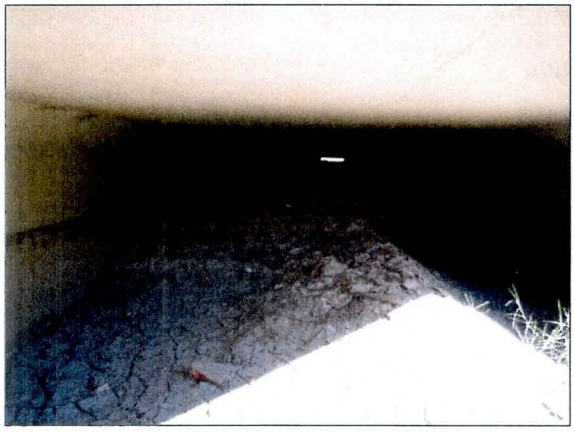


19. Union Hills / 96th St Culverts
Looking at the inlet

20. Looking Downstream
From the Union Hills culverts

21. Culvert clogged 2007-2008
Looking downstream

22. Culvert clogged 2007-2008
Looking downstream



23. Culvert clogged 2007-2008
Looking downstream

24. City of Scottsdale clearing sediment
Looking upstream

5.3 Hydrology

The nearest FCDMC rain gage is located at the apex of Reata Pass Fan. The combined rain and stream gage is located on the Pinnacle Peak Road crossing of Reata Pass Wash. The gage has been in continuous operation since it was installed on May 2001. Since that time the average rainfall per year has been 8.77 inches. The wettest year, in the limited record, was 2005 with a total water-year rainfall of 18.07 inches. The largest rainfall totals at this site have been:

- 5-10 year storm: 15 minute total: 0.91" on 09-03-2006
- 10-25 year storm: 1 hour total 1.61" on 07-31-2005
- 4 year storm: 24 hour total: 2.28" on 03-05-2004

The Reata Pass stream gage located at the same location recorded a maximum water level for the September 2006 event of 1.52 ft, or 649 cubic feet per second. The maximum water level, or extreme, outside the period of record was on August 29, 1996, of 1780 cubic feet per second. Using the rating table this flow rate would have been about 2.5 feet on the gage.

The second nearest FCDMC rain-streamflow gage is at Reata Pass Dam, which is located about 0.5 mile south of Dynamite Boulevard and 112th Street. Reata Pass Dam is located 2.8 miles northeast of the fan apex and is within the fan's watershed. The gage at Reata Pass Dam has been in continuous operation since August 1993. Since that time the average yearly rainfall at the gage site has been 10.38 inches. The two wettest years on record have been 2005 and 1995 with 16.89 and 16.81 inches of rain respectively. The largest rainfall totals at this site have been:

- 10 year storm: 1.54" in 1 hour on 08-29-1996
- 5 year storm: 2.64" in 24 hours on 11-15-1993

Appendix K of the PFHAM (2003) reports that large floods occurred in the area on June 22, 1972 and on August 29, 1996. Specific information on these previous events was not available.

The nearest FCDMC gage on the alluvial fan landform is a rain gage located about 2 miles due south of the apex, near the intersection of Thompson Peak Parkway and East Windgate Pass Drive. This gage has been in continuous operation since May 1998. Since that time the average rainfall per year has been 8.28 inches. The wettest year on record has been 2005 with 16.61 inches. The driest year on record was 2002 with 2.99 inches of rainfall. The largest rainfall totals at this site have been:

- 40 year storm: 1.89 inches in 1 hour on 10-10-2003
- 8 year storm: 2.56 inches in 24 hours on 12-07-2007

The 40 year 1 hour storm that was recorded on fan on 10-10-2003 was recorded at the apex as 1.26 inches in 24 hours. The recorded stream gage height at the apex during this event was 0.38 feet with a rating of 34 cubic feet per second. So while it rained a record intensity in the mid-fan area, it did not have a corresponding record rainfall in the watershed or a sizeable discharge at the apex.

The Reata Pass hydrologic data discussed above are also included below in Table 5-1. This table provides a way to see how a storm at one gage registered on the other nearby gages, or affected the flow at the apex.

Table 5-1 Reata Pass Fan Hydrology

Storm	Reata Pass Wash Stream / Precip (ID:4585)			Pinnacle Peak Vista Precip (ID: 4595)		Reata Pass Dam Precip (ID: 4935)	
	Rainfall Depth (Inches)	Stream Flow Stage = ft (Q in cfs)	Recurrence Interval (years)*	Rainfall Depth (Inches)	Recurrence Interval (years)	Rainfall Depth (Inches)	Recurrence Interval (years)
12/07/2007	0.47 (24 hour)	0.50 (57 cfs)	< 2 yr	2.56 (24 hour)	< 2 yr	0.75 (24 hour)	< 2 yr
09/03/2006	0.91 (15 min)	1.52 (649 cfs)	5-10 year	0.83 (24 hour)	< 2 yr	0.94 (24 hour)	< 2 yr
07/31/2005	1.61 (1 hour)	0.53 (63 cfs)	10-25 year	0.75 (24 hour)	< 2 yr	0.39 (24 hour)	< 2 yr
03/05/2004	2.28 (24 hour)	0.98 (238 cfs)	4 year	1.38 (24 hour)	< 2 yr	1.61 (24 hour)	< 2 yr
10/10//2003	1.26 (24 hours)	0.38 (34 cfs)	< 2 yr	1.89 (1 hour)	40 year	0.91 (24 hour)	< 2 yr
08/29/1996	no data	(1,780)	no data	no data	no data	1.54 (1 hour)	10 years
11/15/1993	no data	no data	no data	no data	no data	2.64 (24 hour)	5 years

*computed Precipitation Frequency Estimates using Reata Dam Site table. Reata Pass Wash Frequency Table not available.

5.4 Flood Mitigation Measures

The Reata Pass Fan is an example of a developed fan that remained similar to its historical condition, in contrast to the previous two sites where full structural measures were used to mitigate flood hazards. The upper portion of the Reata Pass Fan has no regional structural drainage measures to mitigate the flood hazard. Instead, flood mitigation measures were instituted on a lot-by-lot basis, and consisted of building on the natural topographic highs and by elevating structures on fill. Currently, the Home Owners Associations and local residents strictly adhere to regulations that keep the washes in their natural condition. As can be seen from a review of the historical aerial photographs the majority of drainage pathways remain unaltered and the fan still retains most of its pre-development distributary drainage pattern.

Through the DC Ranch development, in the lower portion of the study area, the natural historical channel patterns on the fan were not preserved. A few structures and homes have been built in wash bottoms, which may cause problems during future large magnitude flood events.

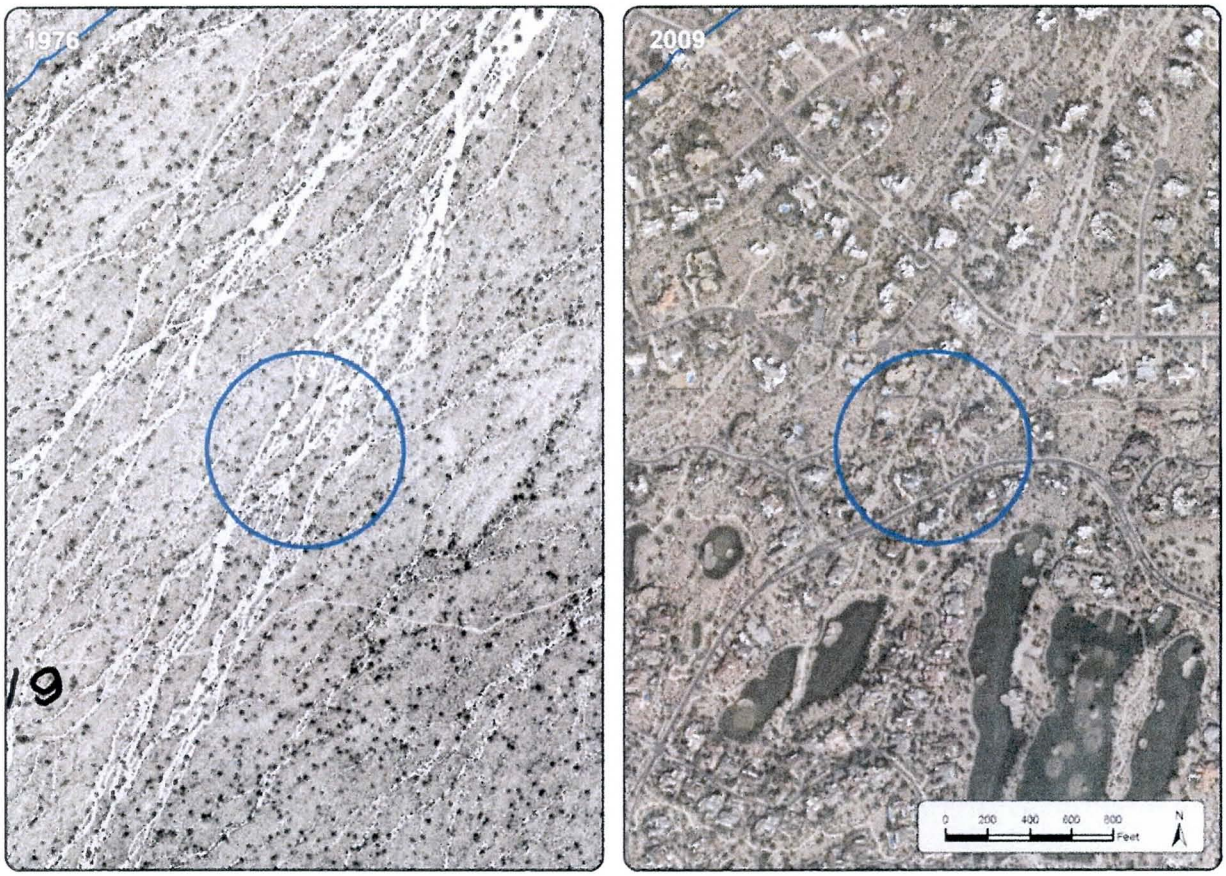


Figure 5-18 DC Ranch Homes Built in Washes.

To date, the largest known flooding problems on fan have occurred in the Pima Acres subdivision downstream of Thompson Peak Parkway. The grid outline of the lot layout at Pima Acres can be seen as early as 1962 on the historical aerial photographs. At the time it was developed, no drainage infrastructure was constructed in Pima Acres to deal with flooding through the area (source: City of Scottsdale, Department of Storm Water Management). Currently, the City is designing measures to mitigate flooding by intercepting the flow along the northern edge of the subdivision. The red dots, on the right side of the figure below depict the at-grade crossings on Reata Pass alluvial fan, the majority of which are within Pima Acres. Flooding problems in Pima Acres include sediment deposition and erosion on roads, damage to landscaping and flood debris.

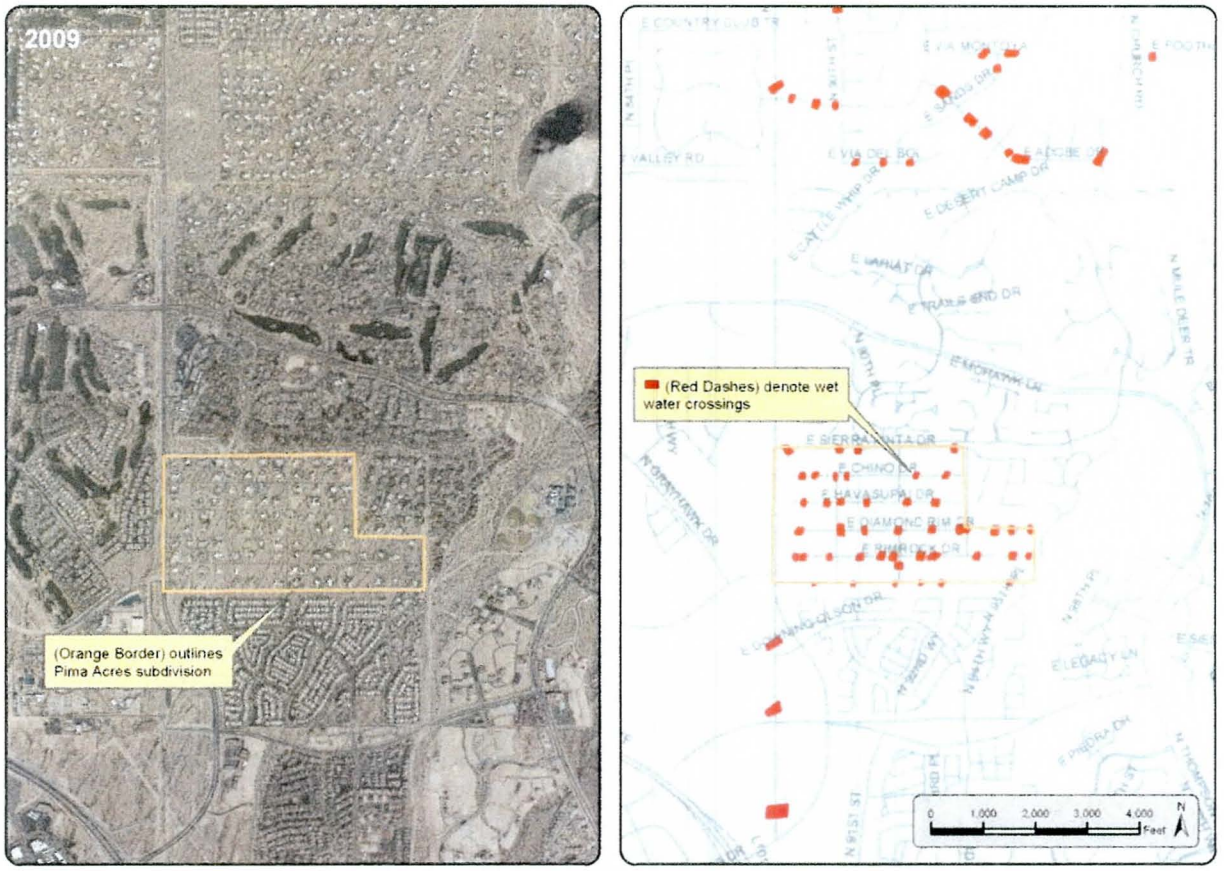


Figure 5-19 Location of Pima Acres Subdivision.

5.4.1 Maintenance Needed

The Chief Foreman of the Drainage and Street Operations Department at the City of Scottsdale commented that the biggest drainage and maintenance problems in the project area are that culverts

frequently clog with sediment. Although there is only one culvert in the upper portion of the fan, there are many culverts, channels and engineered structures on the mid and lower portions of the fan. The culverts in the area, of which the culvert at Legacy / 96th St is a good example, were not designed to transport sediment during the 2- and 5-year events. Routine maintenance of the clogged culverts is a significant maintenance burden. The HOA's on the northern portion of the fan, where dip crossings are used rather than culvert crossings, report that the only maintenance required is clearing a small amount of sediment off the road surface after flow events. This is typically done with a street sweeper.

The natural channels upstream of DC Ranch are not actively maintained, but are regularly (though informally) monitored by the local residents to make sure that the HOA covenant regulations and ordinances to preserve the wash are observed.

The biggest flood-related problem the City of Scottsdale has had on the fan areas is with debris, vegetation or obstructions in the wash. This included landscaping and other debris dumped in washes. Another problem has been residents building small levees or flood walls within the floodplain, and in some cases building stables and horse facilities in the washes. The City of Scottsdale has taken a pro-active stance on dealing with these issues. The City currently employs two full time drainage-inspectors who constantly walk and patrol the washes in Scottsdale looking for violations, writing up citations in order to restore the wash to its natural unrestricted capacity as soon as possible. This program, although instituted recently, has been working very well to keep the washes functioning as designed.

5.5 Conclusions

Development on the upper, most active portion of the Reata Pass Fan preserved to a great extent the natural, distributary drainage patterns of the fan landform, with no development in the most active parts of the upper fan. Some large-lot residential construction has occurred in lower, less active parts of the upper fan, but only on higher ground outside the most prominent existing flow paths. The wash corridors are designated and protected as environmentally sensitive wildlife habitat to help assure their preservation. To date, no major flood damages have been reported in this area, although there have been no large magnitude floods during the period of record that would test the system.

The lower and mid-fan portions of the Reata Pass Fan were developed as mass-graded, master planned communities that significantly altered the natural character of the alluvial fan landform. Drainage problems in these areas have been limited to sedimentation at road crossings (both dips and culverts), local erosion, and minor surface inundation. Again, the lack of significant floods during the

period of record may have contributed to the lack of major flood damages, but the record indicates that the system has performed moderately well during the small floods that have occurred.

Based on our analysis, we conclude that the structural and non-structural elements of the Reata Pass drainage system has performed adequately during the 20 year period of record, at least with respect to controlling the flow uncertainty and sedimentation associated with active alluvial fans. No homes on the fan have been flooded in the past 20 years. Sedimentation at road crossings is addressed routinely by home owners' association or the City of Scottsdale, though at some cost to taxpayers and residents. The past and future performance of the drainage system is predicated on the following:

- Periodic sediment removal from culverts and dip crossings.
- Occurrence of floods that do not exceed the design frequency.

6. Lost Dog Fan

6.1 Site Location

The Lost Dog Wash alluvial fan site is located in northeast Scottsdale, Arizona, in Sections 23 and 22 of T3N R5E. Lost Dog fan is located along the southwest flanks of the McDowell Mountains, approximately four miles east of the Loop 101 Freeway and about 0.5 mile north of Shea Boulevard. Historically, the apex of the alluvial fan was located near the present intersection of North 120th Place and East Via Linda Road.

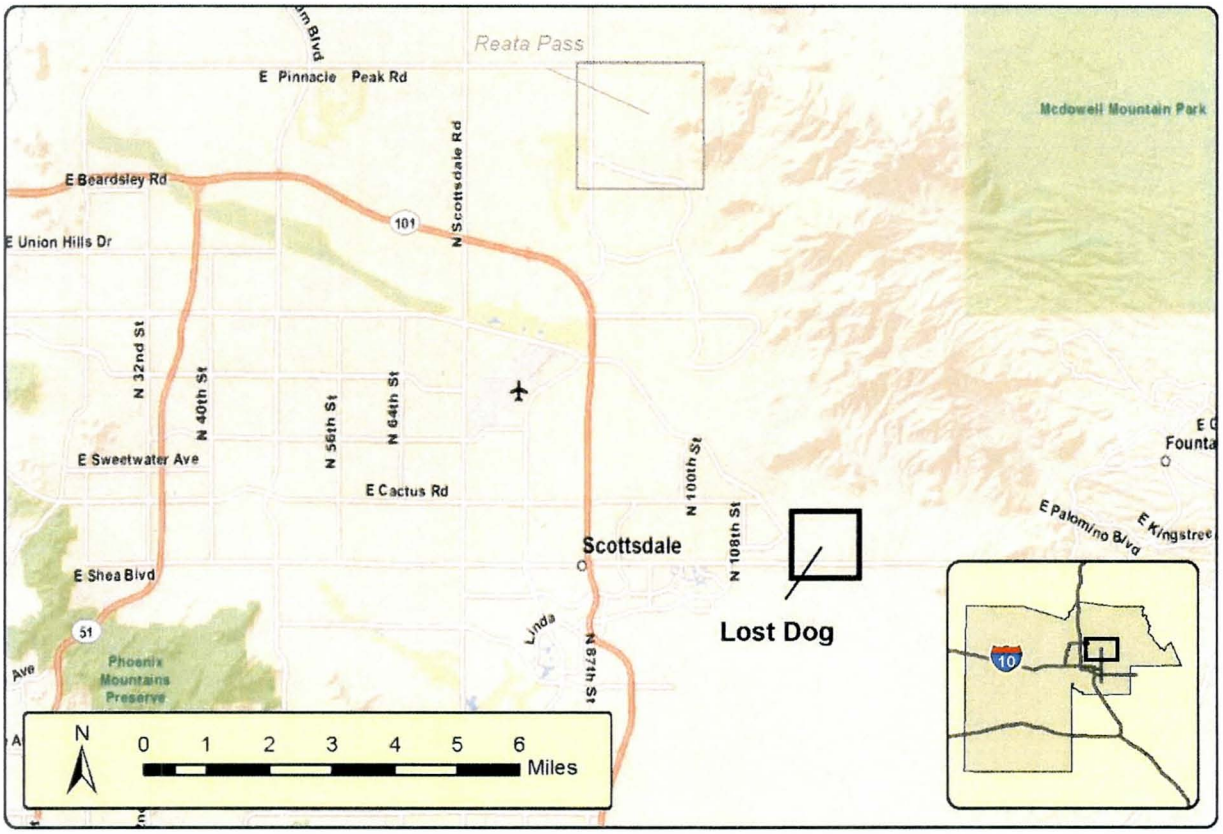


Figure 6-1 Location Map: Lost Dog Wash Fan.

The Lost Dog Wash watershed above the apex is 2.8 square miles, and drains a portion of the southern flanks of the McDowell Mountains. The Lost Dog watershed is located within the McDowell Sonoran Preserve, which remains undeveloped.

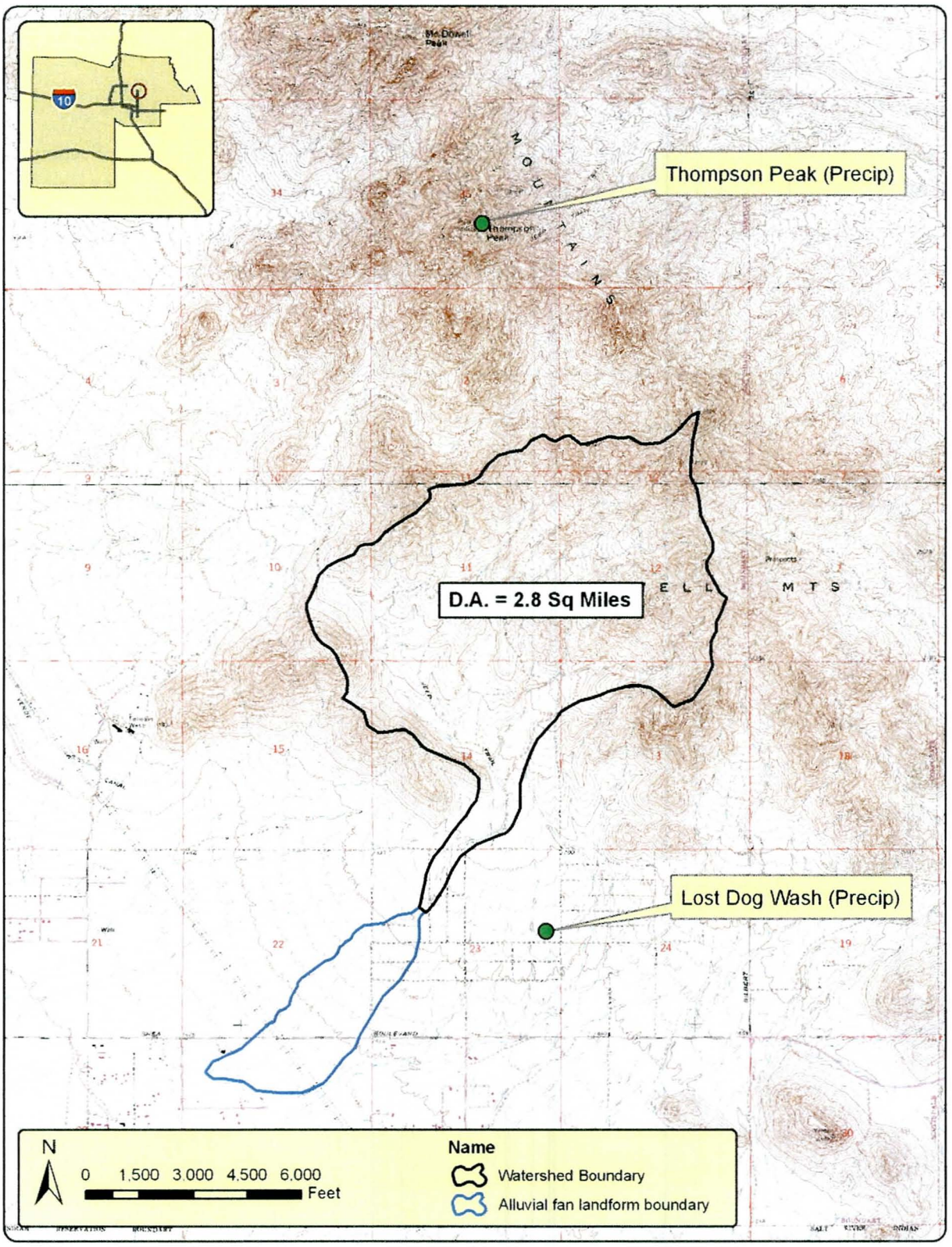


Figure 6-2 Lost Dog Fan Drainage Area & Gage Locations.

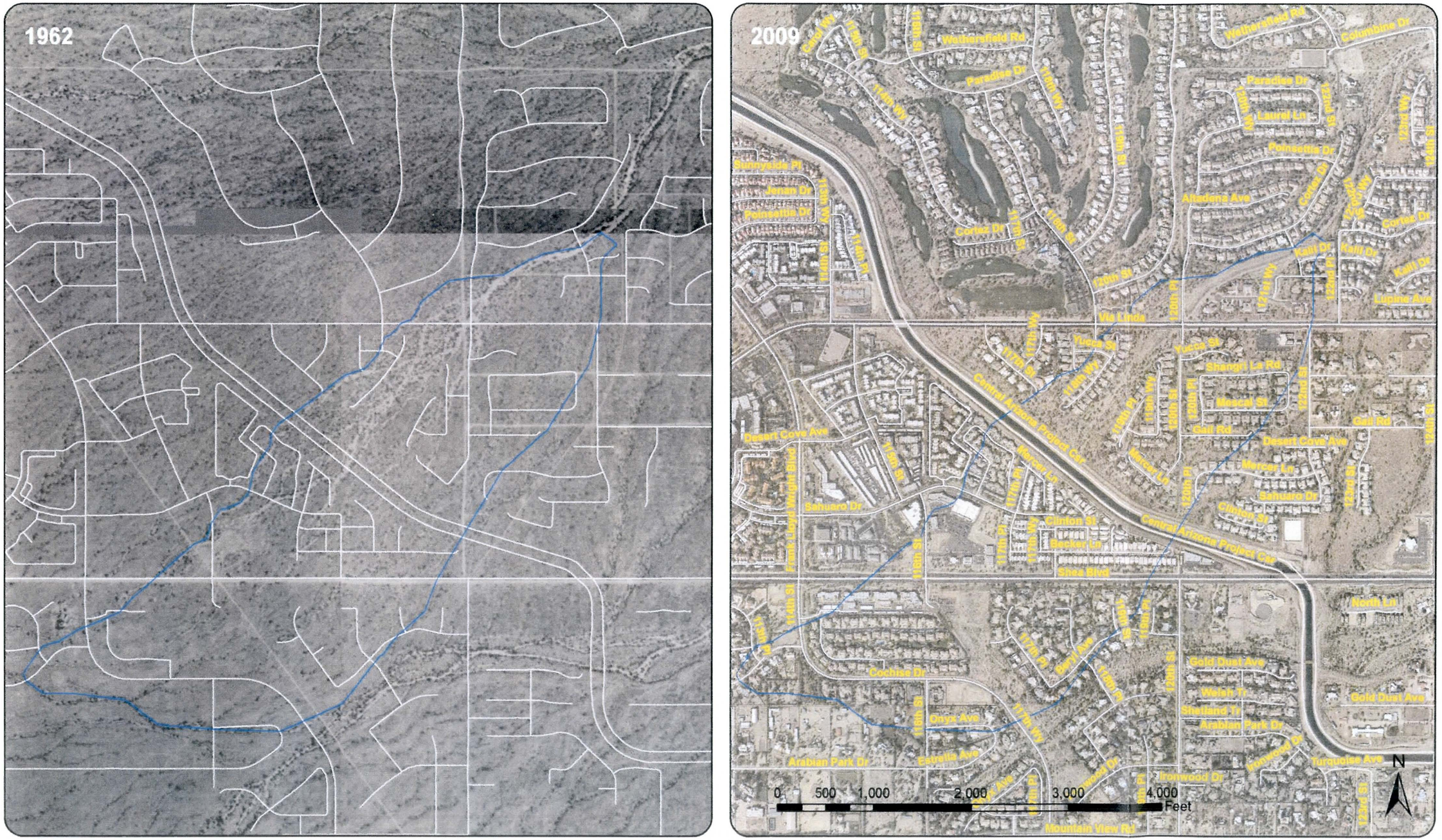


Figure 6-3 Lost Dog Fan Before and After Development.

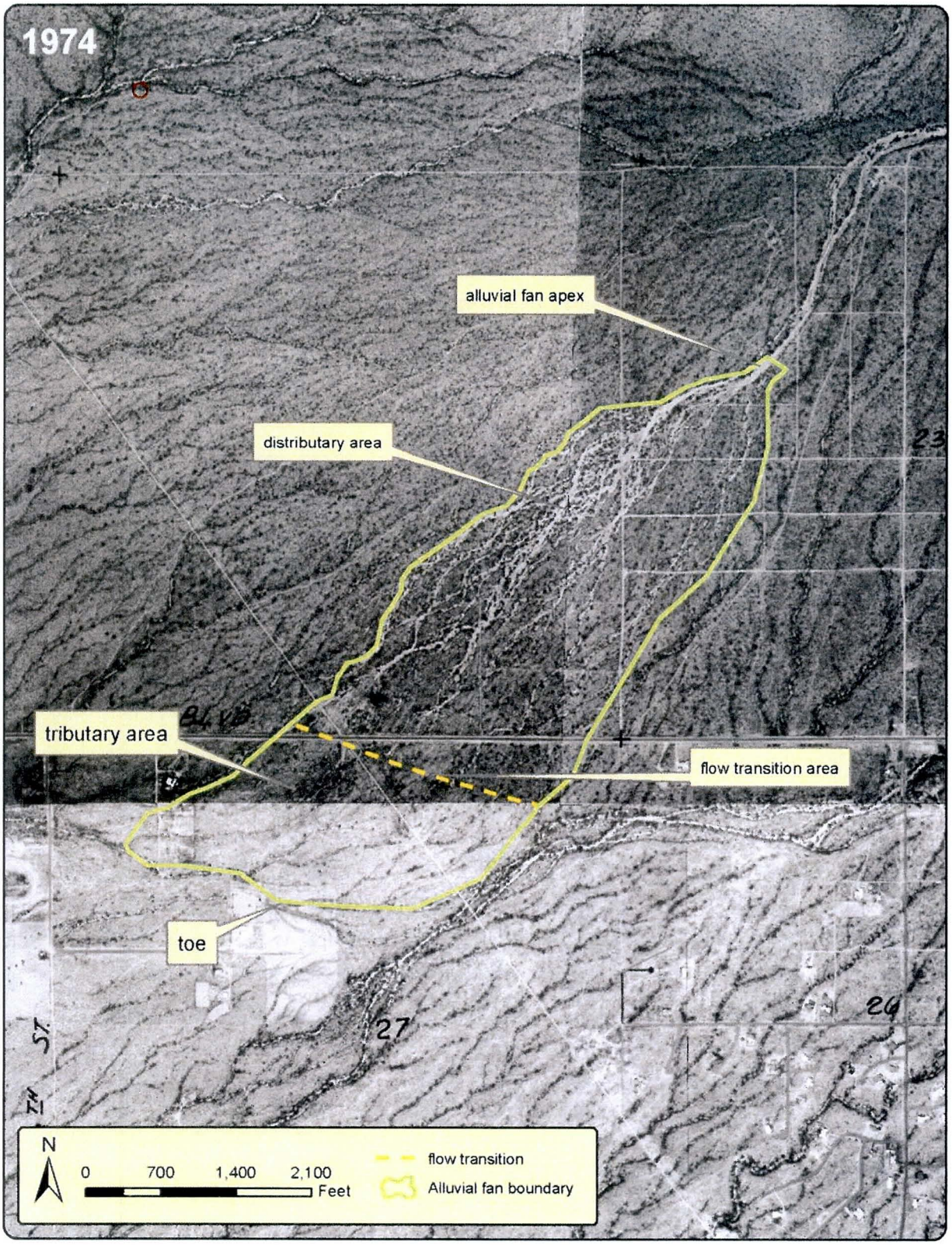


Figure 6-4 Lost Dog Fan Landform Characteristics.

As seen in Figure 6-4 the hydrographic apex of the Lost Dog Fan is located about 1,500 feet northeast of the present intersection of 120th Place and Via Linda Road. Lost Dog Wash, unnamed on USGS quads, flows out of the McDowell Mountains, and becomes distributary about 1.0 mile from the mountain front. Elevations range from 1,400 feet on the lower fan surface to 3,800 feet at the watershed divide in the McDowell Mountains. In the 1962 aerial photograph of Lost Dog the distributary areas can be seen extending down fan from the apex. These distributary channels continue down fan to about the Shea Boulevard alignment, at which point they lose definition and transition to shallow sheet flow. The toe of the fan is delineated where the sheet flow transitions to a low relief tributary drainage pattern before confluencing with a small wash that serves as the axial stream.

6.1.1 NRCS Soils Mapping

Figure 6-5 presents the soil survey information for the Lost Dog study area. The source of the soil survey data is the NRCS Soil Survey of Aguila-Carefree Area, Parts of Maricopa and Pinal Counties, Arizona. In Figure 6-5 the lateral extents of the fan are delineated and included as a blue outline on the 2009 aerial photograph background to provide perspective of where the historical lateral extents of the fan surface were in comparison to modern residential development in the area. Soil survey units are labeled individually in the figure, but are also grouped into major landform types.

The apex and the channel upstream occur within the Brios-Carrizo complex (10), a floodplain map unit. In both the Brios and Carrizo soils permeability is very rapid, and the hazard of water erosion is severe.

Below the apex, the entire alluvial fan landform is mapped in soil unit (3), the Antho-Carrizo-Maripo complex. This soil complex is found on drainageways and floodplains. Antho series is moderate in most respects: permeability is moderately rapid, available water capacity is moderate and hazard from water erosion is moderate. The Carrizo portion of the complex is excessively well drained, water hazard erosion is severe, and channelizing, deposition, and streambank erosion may occur during periods of flooding. The Maripo portion of the complex is deep and well drained, permeability is moderately rapid and run off is slow, and the hazard from water erosion is moderate. Interestingly, the description of this soil complex notes that "the soils in this unit are severely limited for urban use because they are in drainageways and on floodplains that are subject to flooding" (Aguila-Carefree Soil Survey, p. 14).

The units that border the fan landform on the east and the west are the Momoli-Carrizo complex (91) and the Ebon very gravelly loam (44). Both of these soil units are found on fan terraces and stream terraces.

6.1.2 Surficial Geology

Figure 6-6 presents the surficial geology for the Lost Dog Fan study area, as mapped on the AZGS Geologic Map of the Theodore Roosevelt Lake 30' x 60' Quadrangle, Richard and Spencer, 1998. The lateral extents of the historical alluvial fan area have been delineated from the 1962 aerial and are included as a blue outline on the 2009 aerial background.

The mapped extents of the Qy unit very closely represent the historical lateral limits of the alluvial fan landform. Qy (Quaternary Young Alluvium) forms low terraces and alluvial fan deposits. Qy, a Holocene unit (less than 10,000 years old) is the youngest geologic unit in the study area. Qy covers the entire active alluvial fan surface.

Just as in the NRCS mapping, terrace soil units border the fan on the east and west. The AZGS mapped the terrace soil units as Qm, Ql and Qmo, which are Pleistocene-aged: (Ql) late Pleistocene, (Qm) middle Pleistocene and Qmo middle to early Pleistocene. Qm and Ql are typically found on moderately dissected to dissected portions of alluvial fans and fan terraces. The oldest Quaternary unit found in the study area lies just to the southeast the apex. Qmo is found on older, heavily dissected fan terraces.

6.1.3 Topography

As seen in Figure 6-7 the topographic contours bow slightly in the downstream direction near the apex, although bowed contours are visible over a larger scale landform of which the Lost Dog Wash Fan is one element. The lack of well-defined contour bowing on the Lost Dog study area of this report is due to the scale of the USGS mapping and the affect of the coalesced bajada surface. It can also be seen that the slope decreases in the downstream directions because the contours in the toe of the fan are more widely spaced than the contours near the apex.

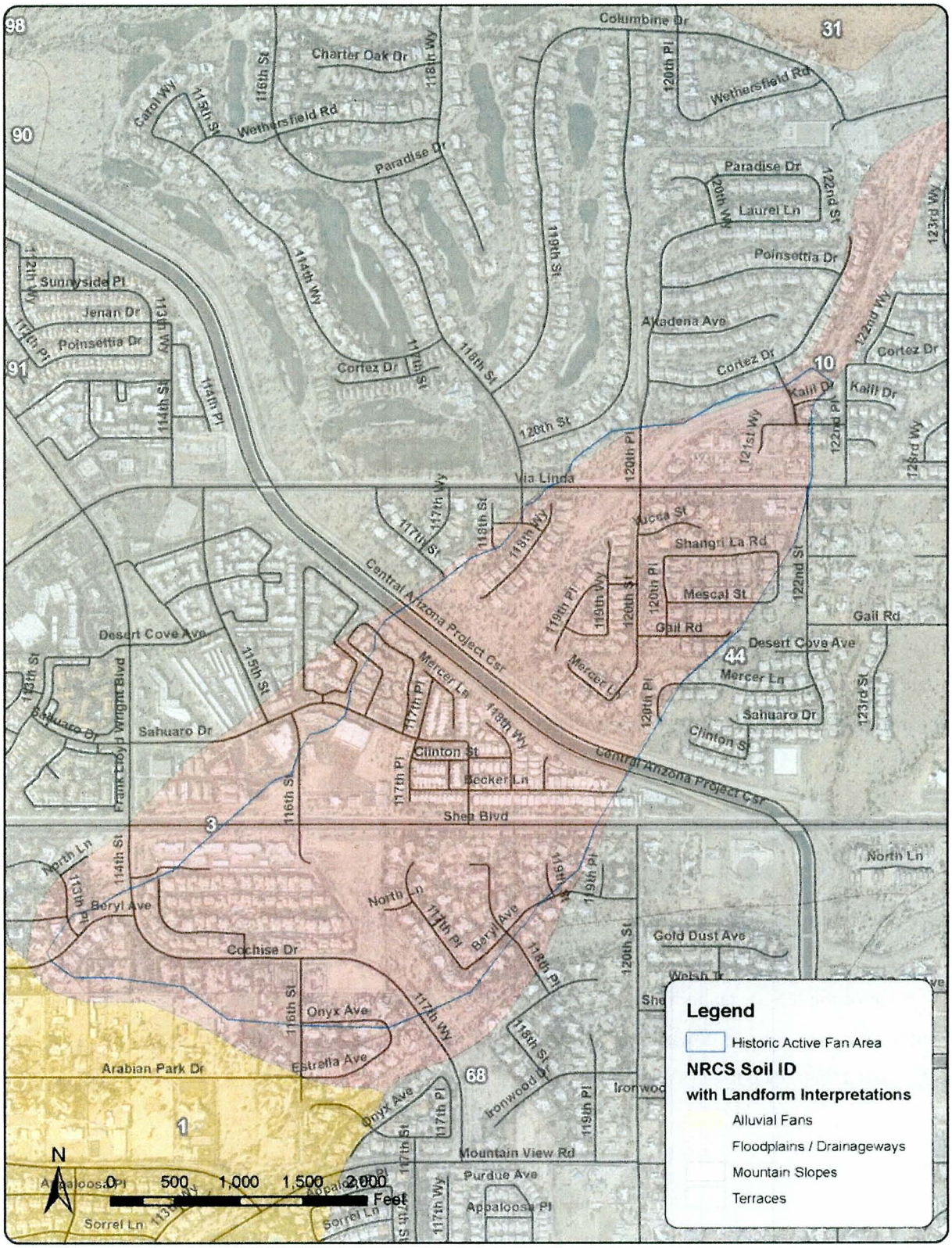


Figure 6-5 NRCS Soils: Lost Dog Fan.

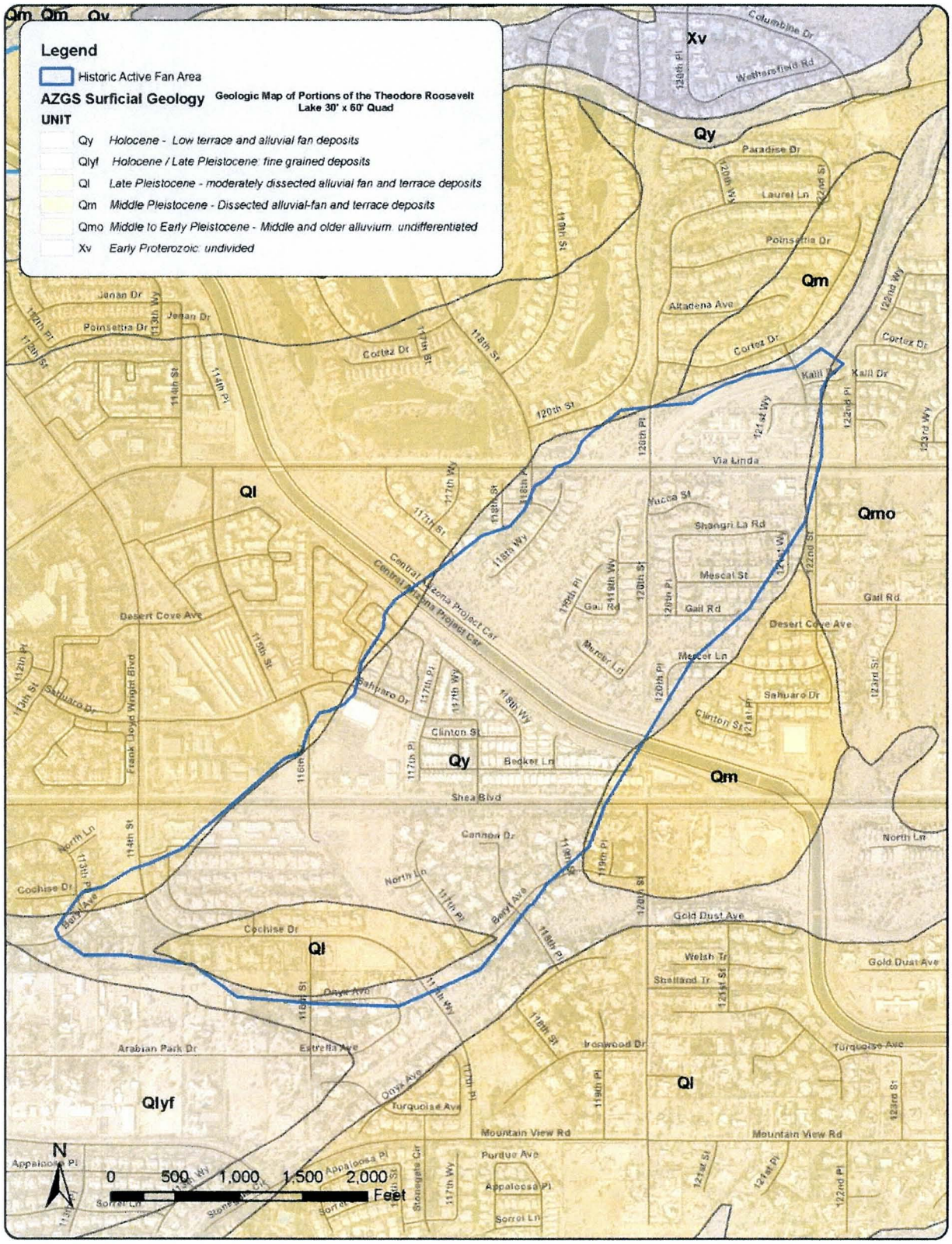


Figure 6-6 AZGS Geology: Lost Dog Fan.

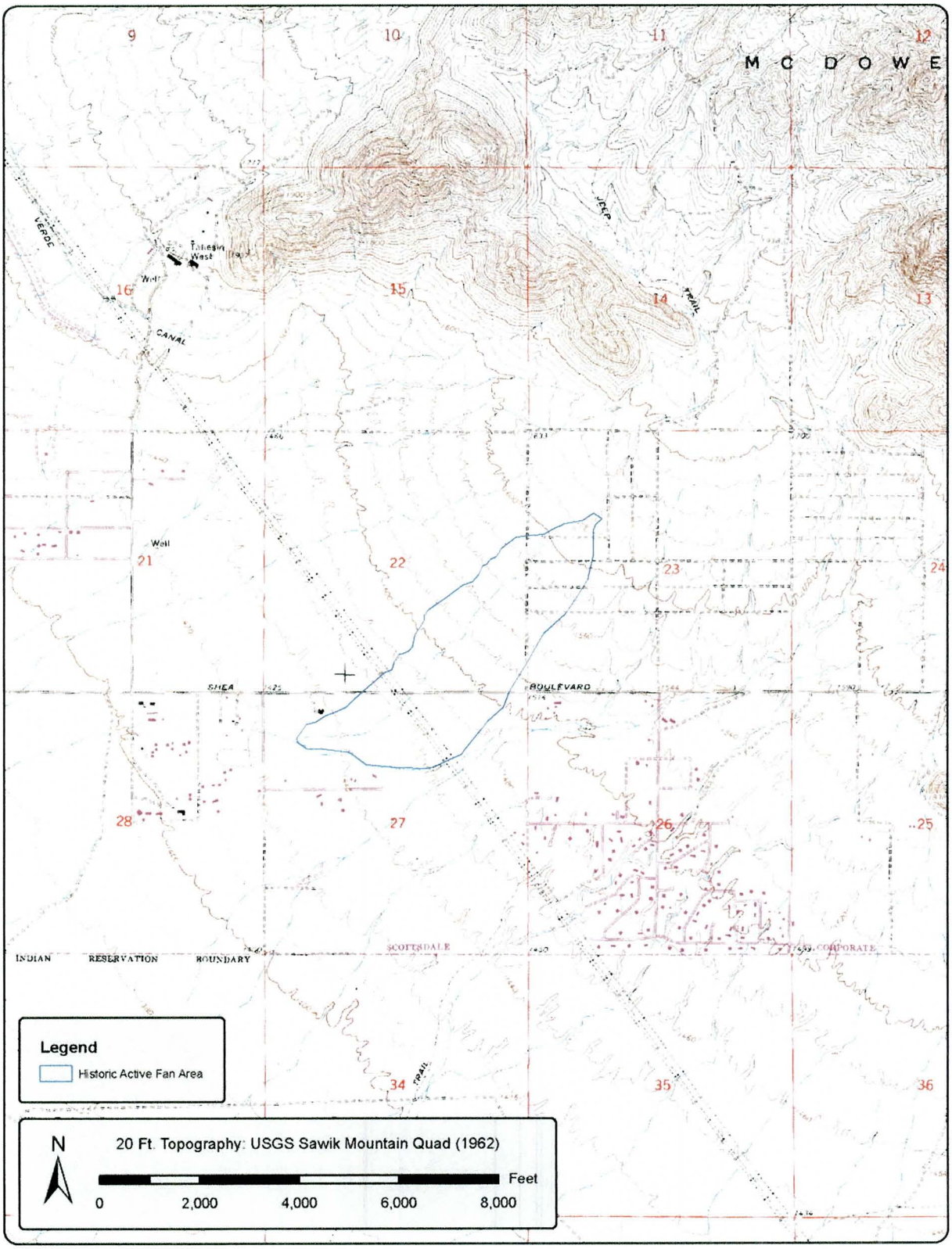


Figure 6-7 Lost Dog Fan Topographic Mapping.

6.1.4 Watershed Parameters

Item	Value	Source
Watershed area (upstream of apex)	2.8 square miles	USGS Quads
Watershed slope (3 miles to 1 mile up stream) (1 miles upstream to apex)	4.2 % 2.7 %	USGS Quads
Fan slope (Apex to toe)	2.5 %	USGS Quads
Q100 at apex	5,000 cfs	Lost Dog Wash Flood Control Project Concept Study [Aug 1995]
Q100 at apex	3,735 cfs	Hydrologic Analysis of Lost Dog Wash CAP [1991]
Fan Profile Shape	concave	USGS Quads
Max Elevation in Drainage Area	3,804	USGS Quads
Elevation at apex	1,625 feet	USGS Quads
Minimum Elevation in fan	1,440 feet	USGS Quads

Figure 6-8 Watershed and Fan Parameters

Structure	Type / Date	Location
CAP – Hayden-Rhodes Aqueduct Dike	Levee	Transverses mid fan
Via Linda / 120th St Con Arch Culverts	Three 20' x 8' Con-arch culverts	Via Linda Road / 120th St.
Channelization (120th / Via Linda to the CAP Dike)	Natural wash bottom, contained with retaining wall on left and right bank	Between the CAP dike and the crossing at Lost Dog Wash crossing at Via Lind Rd.
Channelization (122nd St Bridge to Via Linda)	Naturally lined trapezoidal channel	Lost Dog Wash between 122nd St Bridge to Via Linda Rd
Lost Dog Trailhead Con-arch culverts	Three 36' x 11' arch culverts	Upstream of the apex near the intersection of 124th St and Columbia St.
Development		
Via Linda Estates	Subdivision	On fan, upstream of the CAP and downstream of Via Linda Road.

Figure 6-9 Development & Structure Information

6.1.5 PFHAM Stage I

Task 2.3.3 requires that the pre-development landform be classified as to the "probable" landform type using the PFHAM Stage 1 categories. A PFHAM Stage 1 landform classification for an alluvial fan consists of the following elements:

- *Composition.* The landform is composed of alluvium (sediment material transported by the streams that formed the landform.
- *Morphology.* The landform has the shape of a fan, either partially or fully extended.
- *Location.* The landform is located at a topographic break where the primary watercourse loses capacity.

The Lost Dog Fan landform is shown to be composed of alluvium, as shown by the NRCS detailed soils mapping (Figure 6-5) and AZGS surficial geology mapping (Figure 6-6). As shown in Figure 6-7, the landform has the radial contours characteristics of a partially extended fan. The site is located at the topographic break formed where the main wash exits the shallow canyon that extends to the McDowells' mountain front and the channel changes from a single thread channel to a bifurcated distributary pattern (Figures 6-4 and 6-7). Therefore, the landform is properly classified as an alluvial fan landform.

6.2 Development History

6.2.1 Development History Timeline

Historical aerial photographs of the study area are provided on the following pages, each with an outline of the active alluvial fan delineated from the 1976 aerial photograph. This delineation is included as a point of reference because the landform becomes obscured with the build-out of residential development and transportation infrastructure. All of the aerial photography was obtained from the FCDMC.

The oldest aerial image of the study area is from 1962. At this time, the major flow paths were on the west side of the fan and can be seen as a network of distributary flow channels. There is no development in the study area in the 1960's. At this time, Shea Boulevard was an unpaved road, and its east-west alignment can be seen across the fan of toe. Local unpaved subdividing roads also can be seen dissecting the fan downstream of the apex.

By 1976, the only additional infrastructure in the study area was improvements made to Shea Boulevard. Documentation was unavailable in regards to whether the Shea Boulevard improvements of the time had installed dip crossings or culverts to convey the water past the road crossing. The distributary channels are more distinct on the western side of the fan in 1976. In addition, small channels that split from the apex at the upper north eastern portion can also be distinguished.

By the early 1980's, the Hayden-Rhodes Aqueduct, part of the Central Arizona Project (CAP) canal had been constructed across the midsection of the fan, and which intercepted flow from Lost Dog Wash. While the CAP was able to provide hydrologic design reports, no design construction plans for this reach were available. From field observation we know that no cross drainage was provided to allow flow from Lost Dog to cross the CAP. The CAP ponds water from Lost Dog Wash and routes it northwest along the CAP embankment to a large retention area where there is a water crossing underneath the CAP. Since the time the CAP was built, the alluvial fan landform downstream of the CAP has been effectively cut off from any future flow. A restudy of the hydrology of Lost Dog Wash was conducted by the CAP at the request of the City of Scottsdale in 1991. The estimated 100-year peak discharge at the alluvial fan apex was computed to be 3,735 cubic feet per second (Hydrology Analysis of Lost Dog Wash, p. 6).

By 1993, improvements were made to Via Linda Road. The Via Linda alignment is 0.5 miles north of Shea Boulevard and crosses the fan about 1,500 feet below the hydrographic apex. By 1993, much development has taken place near the fan but nothing, except Via Linda Road, had been built on the fan upstream of the CAP.

By 1997, homes had been built along both sides of the channel upstream of the apex in the Sonoran Arroyos development. The channel at the apex was levied on both sides before crossing under North 122 Street, which was built across the apex. The 122nd Street crossing is a two-span bridge, as seen in the site photographs that follow. In the following two years the fan downstream of the apex was channelized from the 122nd Street crossing to Via Linda Boulevard. This naturally lined trapezoidal channel takes flow from the apex along the west side of the fan surface. The Lost Dog channel then crosses underneath the intersection of Via Linda Road and North 120th Place in a large multi-cell arch culvert (80 feet wide by 300 feet long). Lost Dog Wash exits arch culverts and flows downstream 1,500 feet until it reaches the CAP ponding area. Between the culverts and the CAP, Lost Dog Wash is contained in what was labeled on the subdivision plans as a "Vista Corridor." Along this corridor homes now line each side of the channel downstream of the Via Linda crossing. The native predevelopment flora has been left in the wash bottom indicating that this portion of the wash is still at the natural grade.

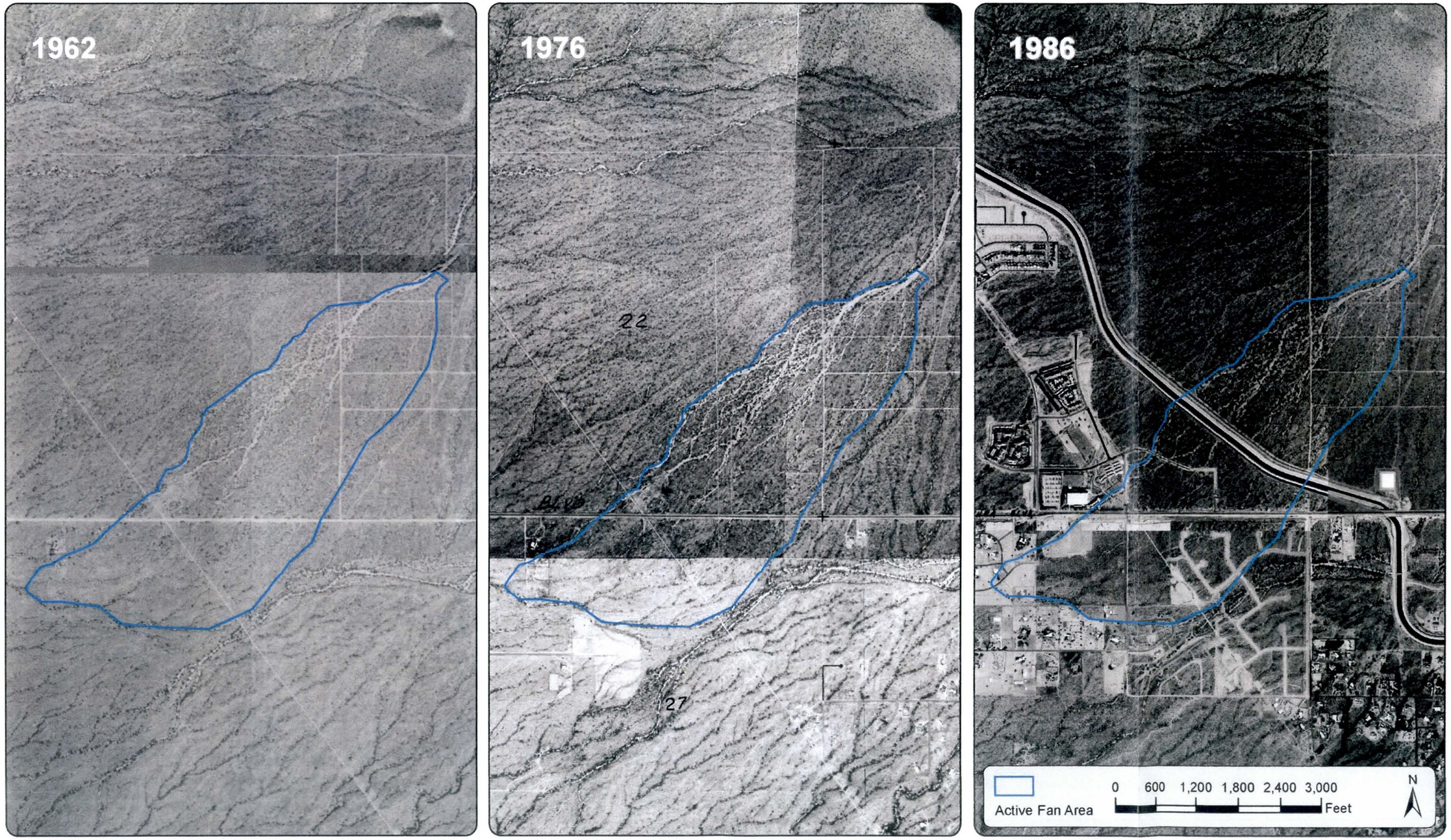


Figure 6-10 Historical Aerial Photos: Lost Dog 1962 – 1986.

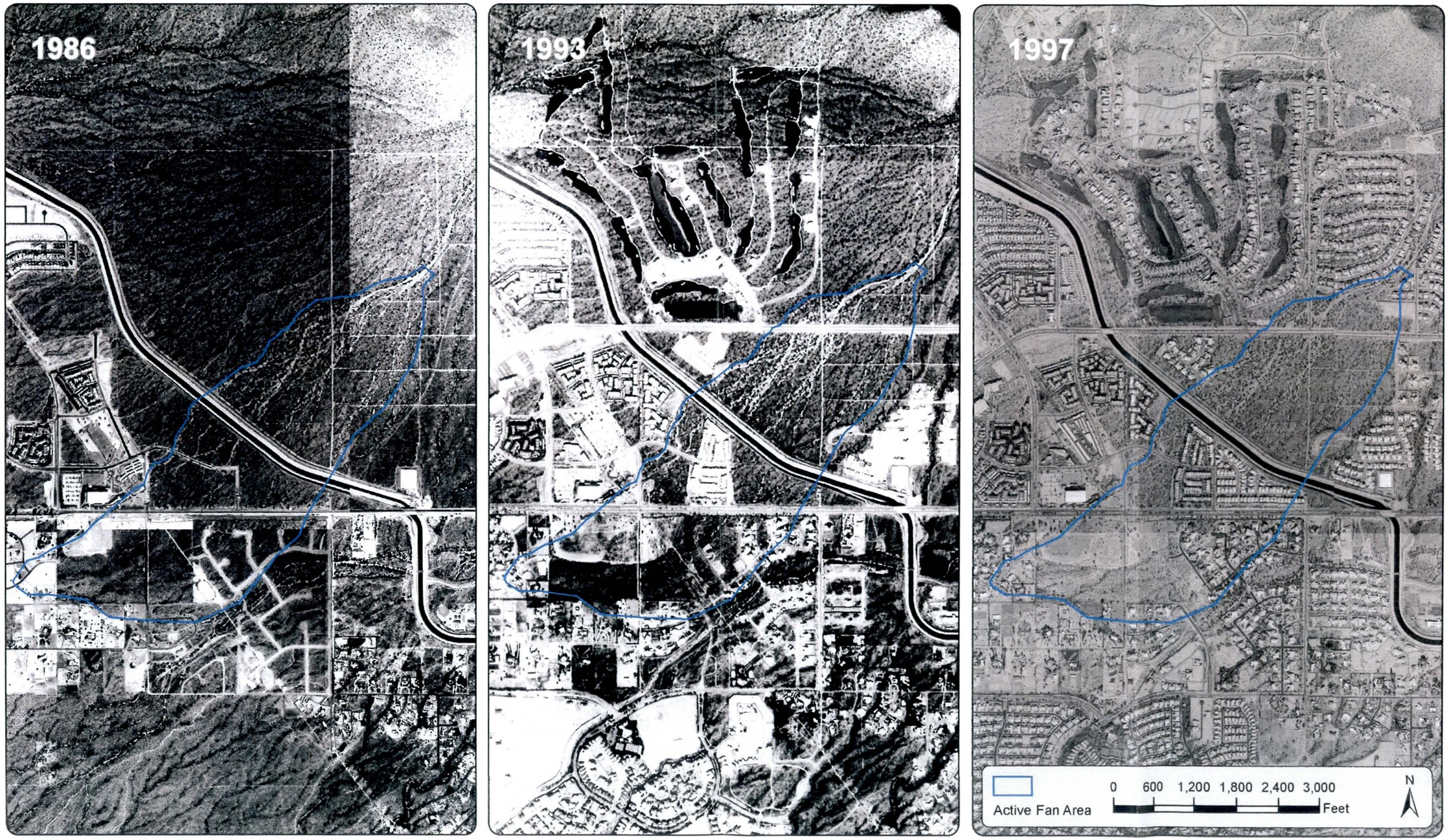


Figure 6-11 Historical Aerial Photos: Lost Dog 1986 – 1997.

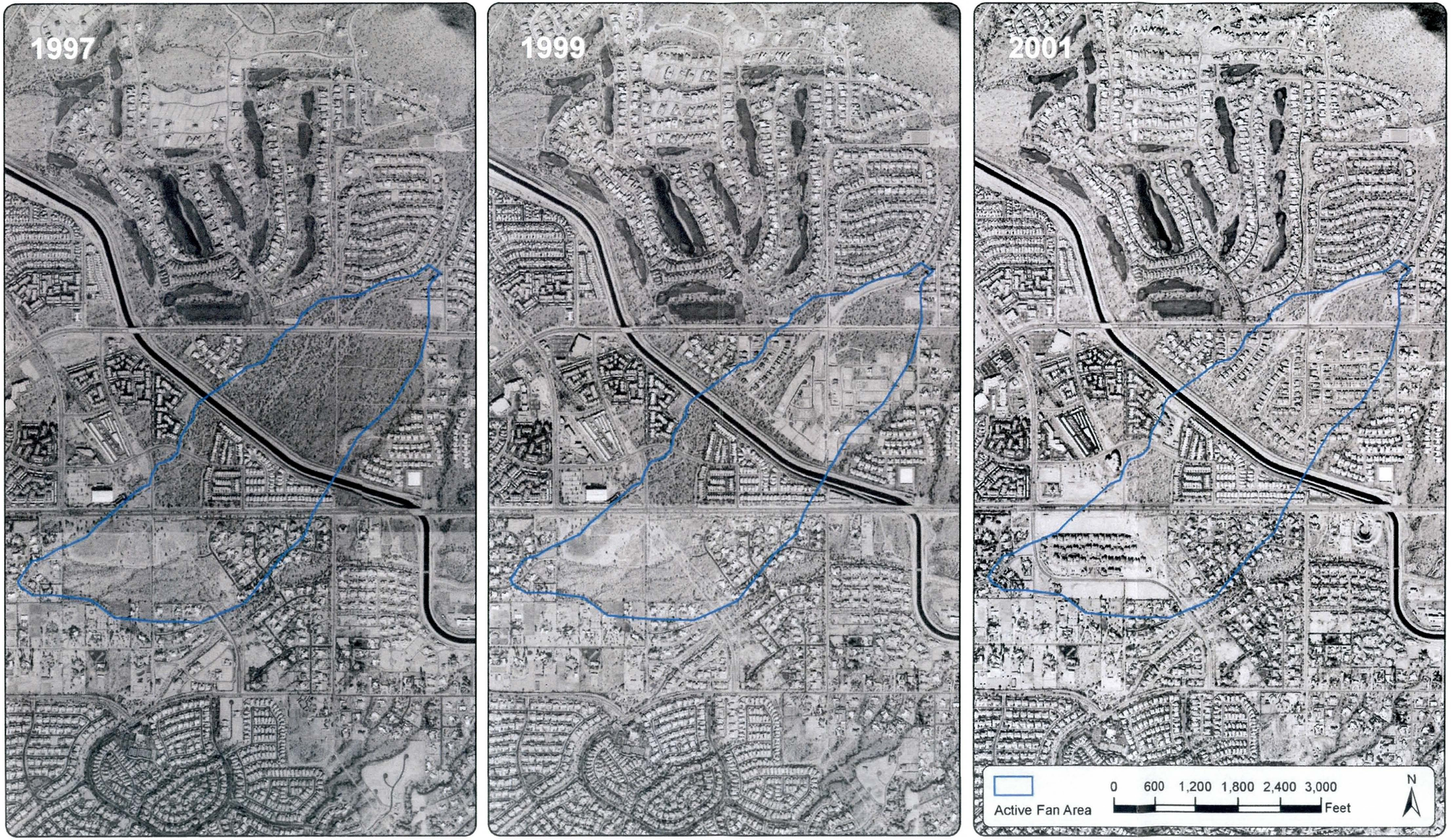


Figure 6-12 Historical Aerial Photos: Lost Dog 1997 – 2001.

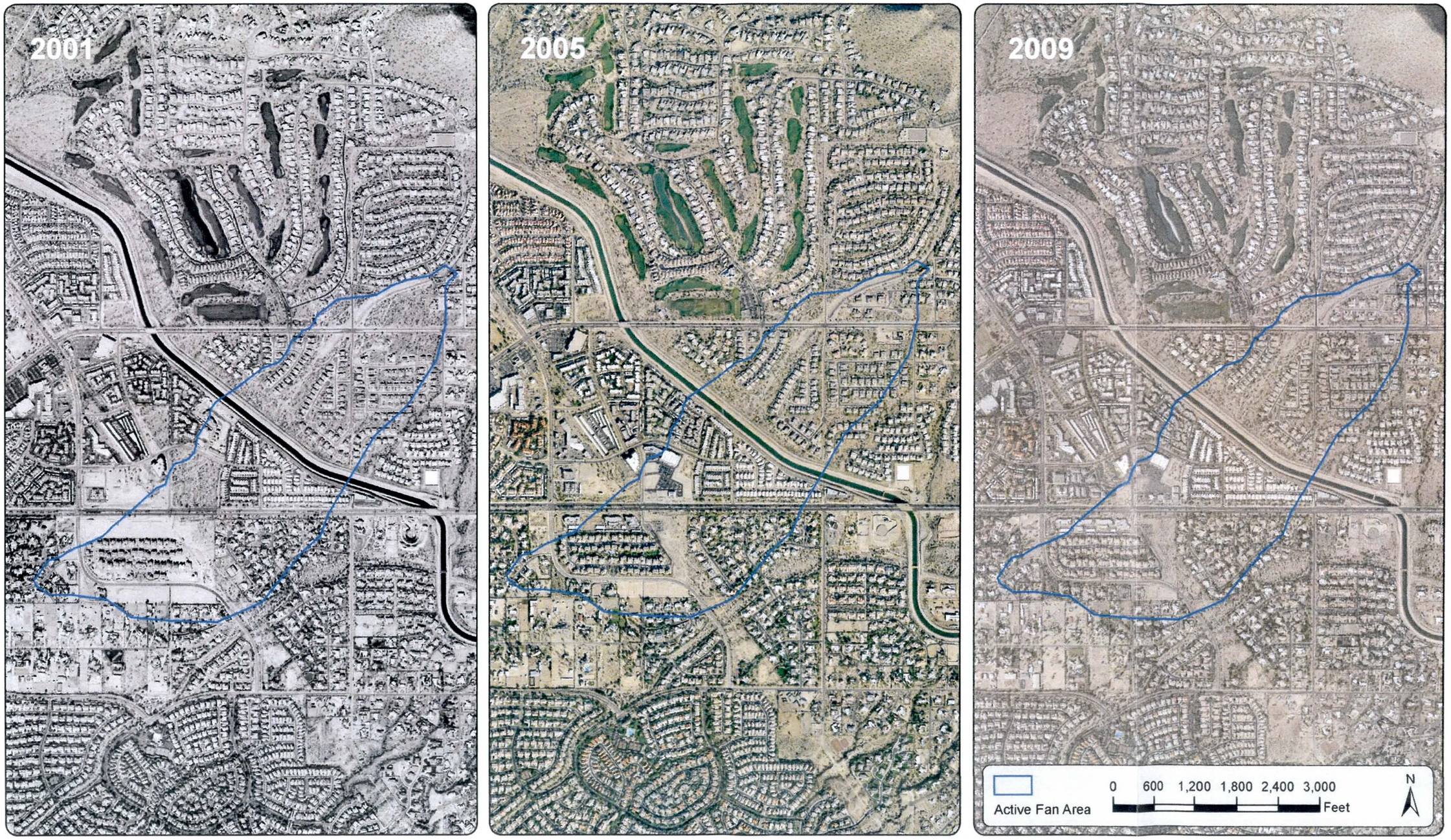


Figure 6-13 Historical Aerial Photos: Lost Dog 2001 – 2009.

6.2.2 Field Photograph Locations

The figure below identifies the subdivision on the left hand side. The right hand side figure below identifies the major structures and channel reaches, along with the locations for each of the field photos. The number of each field photograph is included in the caption below the photograph.

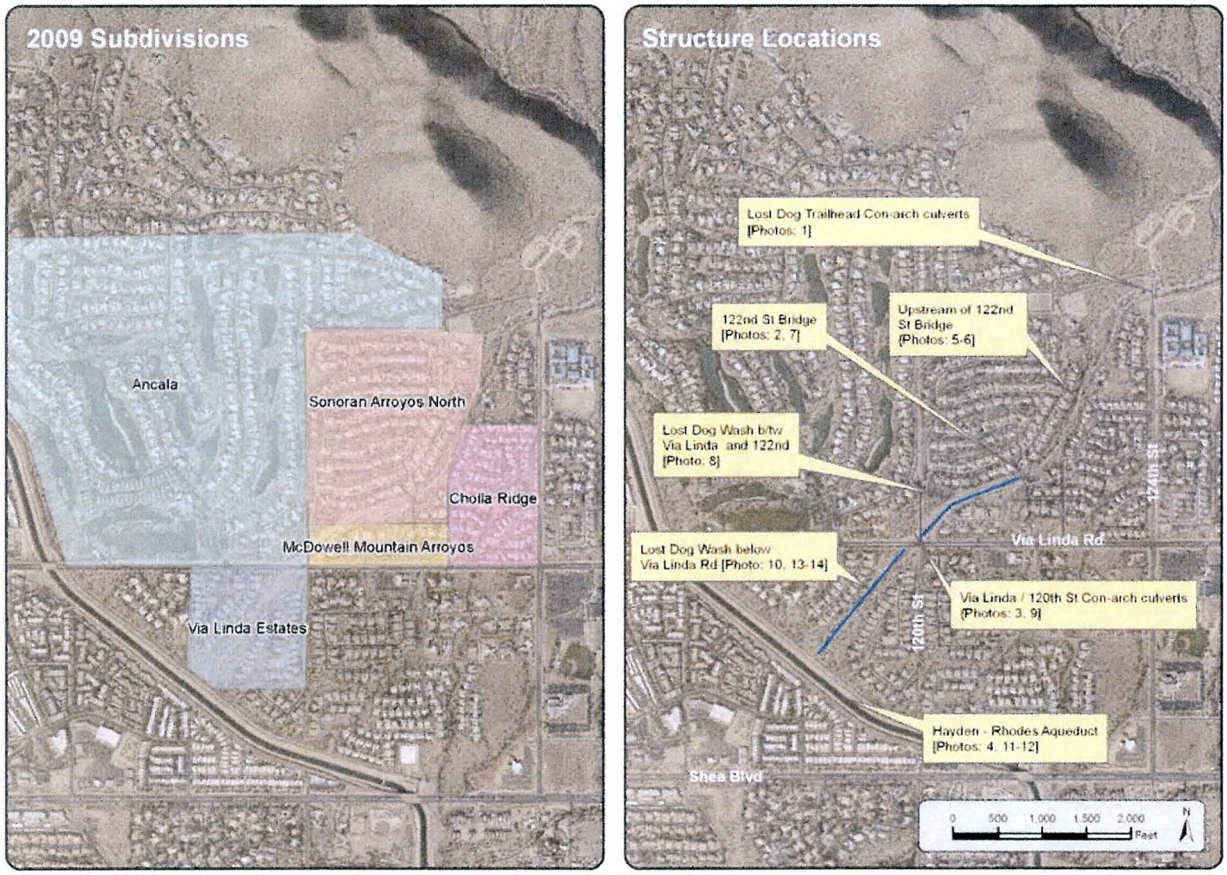
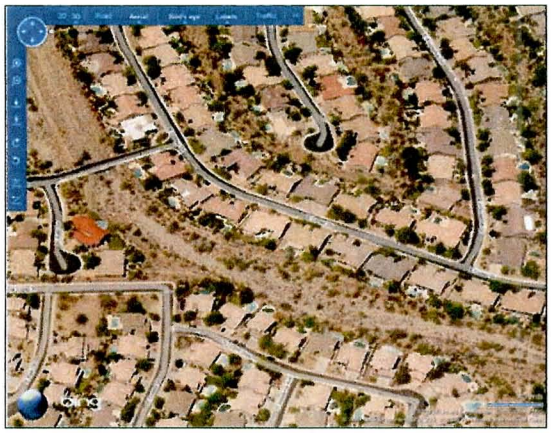


Figure 6-14 Lost Dog Fan Subdivisions & Structures.

1. Lost Dog Trailhead (124th St / Columbia)
Source: bing.com

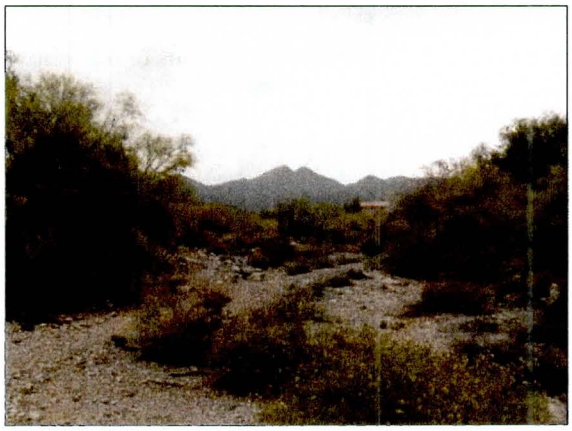


2. Looking Downstream at 124th St bridge
Source: bing.com

3. Via Linda / 120th St culverts
Source: bing.com

4. Oblique view looking at CAP dike
Source: bing.com

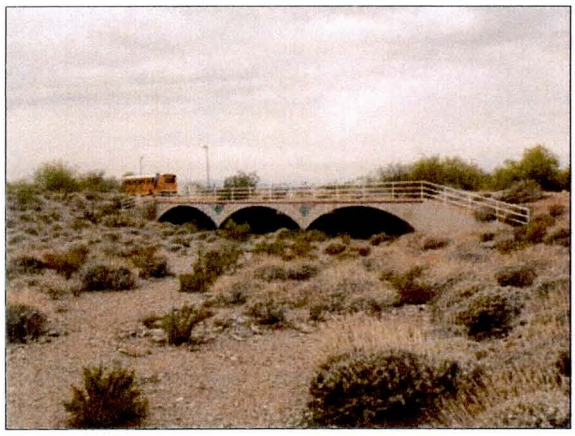
5. Lost Dog Wash upstream of 122nd St
Looking Upstream



6. Lost Dog Wash upstream of 122nd St
Looking upstream

7. Lost Dog Wash at 122nd St Bridge

8. Lost Dog Wash at 122nd St
Looking downstream



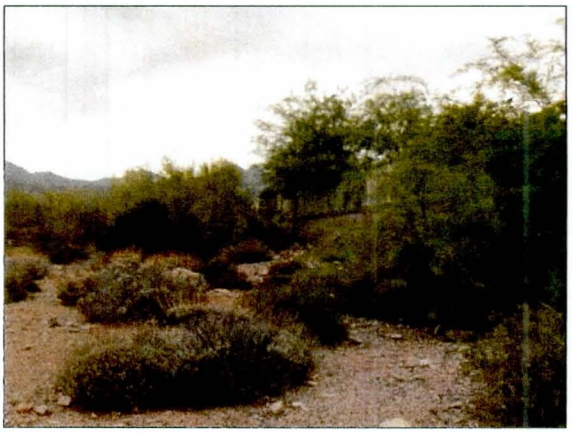
9. Via Linda Rd / 120th St Structure
Three 20' x 8' Con-arch culverts, 225 L.F. in length

10. Lost Dog Wash Chnl downstream of Via Linda Rd
Looking downstream

11. Hayden-Rhodes Aqueduct levee (CAP levee)
Looking northwest along the levee

12. Hayden-Rhodes Aqueduct levee (CAP levee)
Looking northwest along the levee

13. View from CAP levee looking upstream
Can see right bank



14. Upstream of CAP levee looking upstream
Can see left bank

6.3 Hydrology

The nearest FCDMC rain gage in the area is located one mile to the east of the Lost Dog fan, near the intersection of Via Linda and 128th Street. The gage has been in operation since July 1990. Since that time, the average annual rainfall has been 8.17 inches, with the wettest years on record in 1992 and 2005 with 15.55 inches and 12.80 inches per year, respectively. The two largest storms to occur in the project area have been:

- 20 year storm: 1.57" in 1 hour on 07-29-2001
- 12 year storm 1.69" in 3 hours on 08-18-1996

The FCDMC also has a gage at Thompson Peak approximately one mile north of the northern boundary of the Lost Dog watershed. The average yearly rainfall at Thompson Peak is 8.29 inches, with a record 16.3 inches of rain recorded in 1993 and 12.36 inches in 2005. The largest storm on record at Thompson Peak was an event on 08-22-1992.

- 60 year storm: 1.30" in 15 minutes on 08-22-2005, the 24 hour total for this storm was 3.27" giving it a 15 year recurrence interval.

Table 6-1 Lost Dog Wash Fan Hydrology

Storm	Lost Dog Wash Precip (ID: 4595)		Thompson Peak Precip (ID: 5945)	
	Rainfall Depth (Inches)	Recurrence Interval (years)	Rainfall Depth (Inches)	Recurrence Interval (years)
7-29-2001	1.57" (1 hour)	20 years	0.43 (24 hours)	<2 yr
08-18-1996	1.69" (3 hours)	12 years	0.91 (24 hours)	<2 yr
08-22-1992	No data	No data	1.30" (15 min)	60 years

6.4 Flood Mitigation Measures

As a result of development on the Lost Dog Wash alluvial fan, the alluvial fan landform no longer conveys flow in its pre-development state. Development on the fan included bridges, elevated roads, culverts, dikes and levees. Flows from Lost Dog Wash were effectively cutoff mid-fan in the early 1980's by the construction of the Hayden-Rhodes aqueduct (CAP). The aqueduct was built with dikes on either side to protect the CAP from cross drainage, including Lost Dog Wash. No design drawings of the CAP dike were available. Field observations combined with measurements taken from recent FCDMC topography of the area indicate that the CAP dike is raised about five feet above the toe of Lost Dog Fan surface. Subdivision plans for Via Linda Estates indicate that any water flowing down Lost Dog Wash is designed to pond at the CAP dike and then flow northwest approximately 1.2 miles to the nearest CAP water crossing. Lost Dog is now completely channelized from the apex with flows routed down fan to be ponded by the CAP embankment. Residential development has taken place over the entire fan surface with homes lining the channelized wash on both sides. The CAP dike has since the early 1980's effectively cut off the lower portion of the alluvial fan from receiving any flow from the apex. After the dike was installed the lower portion is no longer considered part of the active alluvial fan landform as it no longer receives any flow or sediment from the apex.

Besides the CAP dike, the largest engineered structures on the fan are two channelized sections of the wash with the Via Linda culvert crossing connecting the two. The Via Linda Crossing is at the intersection of Via Linda Rd and 120th St. It consists of three 20' x 8' concrete arch culverts. The City of Scottsdale Street / Field Operations Department inspects the structure once per year and is not aware of any flooding or sedimentation issues associated with that structure.

6.4.1 Maintenance Needed

A representative from the Via Linda Estates (south of Via Linda Rd, north of the CAP) contracts out maintenance of the properties bordering the wash. These maintenance companies do not do any work in the wash itself. No sedimentation, channeling, or flooding issues were reported. The City of Scottsdale Street / Field Operations is also unaware of any maintenance issues associated with the structures on Lost Dog Wash. Also the CAP, Central Arizona Project, was unaware of any damage to the dike due to the Lost Dog Wash fan crossing

6.5 Conclusions

Lost Dog Wash, until modern development in the area was an active alluvial fan with an unconfined distributary flow downstream of the apex. Development in the area has confined Lost Dog to a designed channel that routes flood water down the western portion of the fan, under the intersection of 120th Pl and Via Linda Rd. to the CAP where it is ponded up routed and to the northwest to the nearest CAP crossing.

Like the Reata Pass Fan, the Lost Dog Fan has not seen any significant rainfall / runoff events since the fan has been developed to test its drainage structures. The 60 year-15 minute rainfall occurred in 1992, prior to any residential development on the fan. Since that time the largest event was a 20 year rainfall in 2001 and no available source was aware of any problems resulting from that rainfall. The Lost Dog alluvial fan is a site that is substantially untested due to the lack of significant rainfall in the area in the last 20 years.

Based on our analysis, we conclude that the engineered drainage system has performed adequately during the 10 to 20 year period of record, at least with respect to controlling the flow uncertainty and sedimentation associated with active alluvial fans. No homes or structures on or around the fan have been flooded during the period of record. No sediment or erosion concern were reported or identified in this study.

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7. References

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