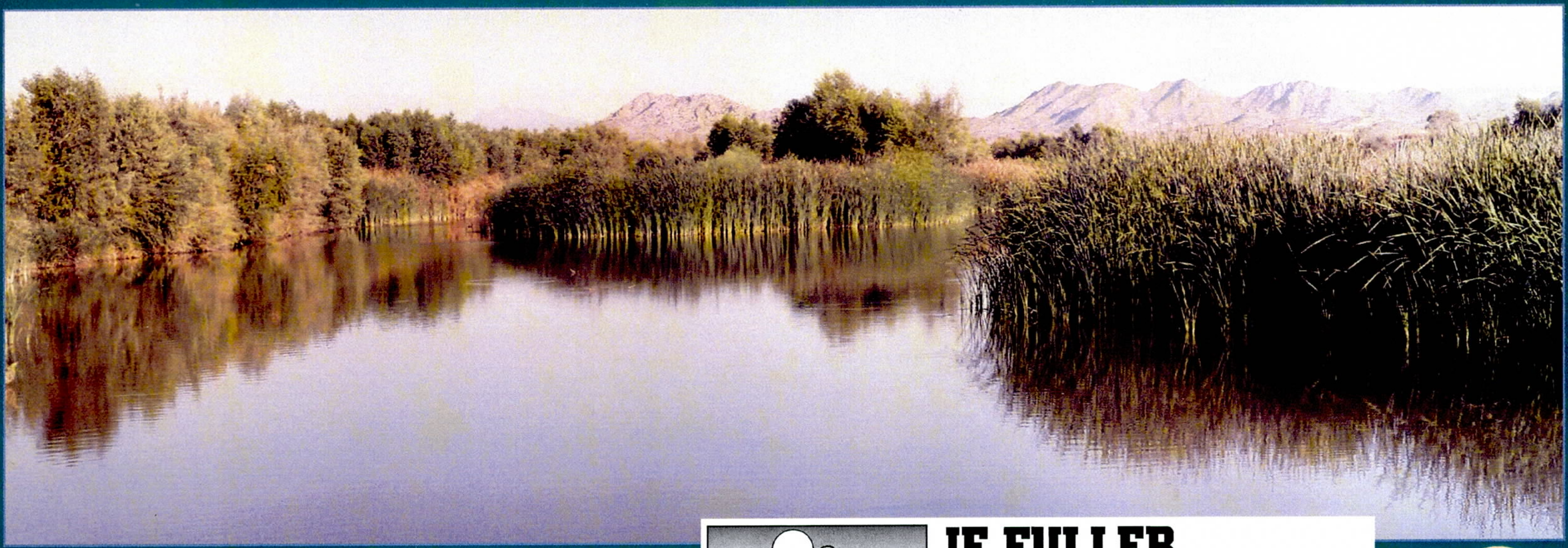
Attachment 5
LATERAL MIGRATION ANALYSIS REPORT

Flood Control District of Maricopa County

El Rio Watercourse Master Plan and Area Drainage Master Plan

Contract FCD 2001C024
Stantec Project No. 82000240



JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.

Stantec

September 2005
Revised December 2005

FINAL REPORT

EL RIO WATERCOURSE MASTER PLAN

Lateral Migration Analysis Report

Prepared for

Stantec

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CHAPTER 1: INTRODUCTION

STUDY LOCATION

The El Rio Watercourse Master Plan study area extends along the Gila River from just upstream of the Agua Fria River confluence to the State Highway 85 (SR85) Bridge, a distance of approximately 17.5 miles (Figure 1). The Gila River drains about half of the land area within the State of Arizona and includes many significant tributaries, including the San Pedro, Santa Cruz, and Salt Rivers.

PROJECT OBJECTIVES

The El Rio Lateral Migration Analysis Report (LMAR) supports the El Rio Watercourse Master Plan (El Rio WMP) prepared by Stantec Consulting (Stantec) for the Flood Control District of Maricopa County (District) under contract FCD 2001C024. JE Fuller/Hydrology & Geomorphology, Inc. (JEF) was retained by Stantec to prepare the LMAR and estimate potential lateral migration of the Gila River within the El Rio WMP study reach. The following four primary tasks were scoped by the District and Stantec for the LMAR:

1. Field Investigation
   a. Conduct field visits to the study reach to observe and document channel and floodplain conditions, to observe evidence of recent and historical flood impacts, to document evidence of past lateral channel movement, to describe surficial characteristics, and to collect data for use in the lateral stability assessment.
   b. Prepare maps of geologically-recent landforms along the study reach using existing data, such as previously completed geologic mapping and historical aerial photographs. The objective of the landform mapping was to identify evidence of geologically recent lateral channel movement, and to constrain the limits of potential movement by the presence of geologically old surfaces.
2. Interpretation of Historic Data
   a. Document and compare historical channel positions to identify the location and magnitude of historical change and lateral movement.
   b. Prepare maps showing channel boundary locations during the period of record, and prepare side-by-side plots of aerial photographs from different years of coverage.
   c. Compare historical and recent topographic maps of the study reach to identify and quantify trends in lateral and vertical (aggradation and/or degradation) channel change.
   d. Quantify and characterize channel changes that occurred during the 1978, 1980, 1993 and 1995 floods relative to changes observed during the remainder of the period of record in relation to antecedent conditions in the study reach and watershed.
   e. Identify areas within the study reach that are most likely to experience future lateral migration, and/or long-term scour and deposition, and areas, if any, that are recommended for more detailed geomorphic investigation.

3. Delineate a Regulatory Erosion Hazard Zone (EHZ) - Delineate a single regulatory Erosion Hazard Zone for the study reach for each side of the floodplain based on the results of the lateral stability assessment. The primary objective of the Lateral Migration Analysis will be to define the corridor width required to preserve the pre-project channel form and function of the study reach.
4. Prepare a Lateral Migration Analysis Report – Prepare a report describing the analysis results, and discussing how the potential EHZ was determined, and how it may affect flood control issues within the area. \

REPORT ORGANIZATION

This report is organized as follows:

- Chapter 1: Introduction. This chapter lists the goals and objectives of the lateral migration analysis and report.

- Chapter 2: Study Area Description. This chapter provides background information on the regional geologic setting, hydrology, and human impacts within the study reach.

- Chapter 3: Historical Channel Movement. This chapter describes the how the morphology of the study reach has changed during the historical period, provides quantitative measurement of the magnitude of channel change, and summarizes information about changes in the vertical profile of the river.

- Chapter 4: Field Assessment. This chapter summarizes and documents observations of channel conditions relating to potential lateral and vertical channel movement.

- Chapter 5: Erosion Hazard Zone Delineation. This chapter describes how the recommended erosion hazard zone was delineated.

- Chapter 6: Conclusion. This chapter summarizes information presented in the lateral migration analysis and makes river management recommendations.

- Chapter 7: References. This chapter lists references cited in the report.

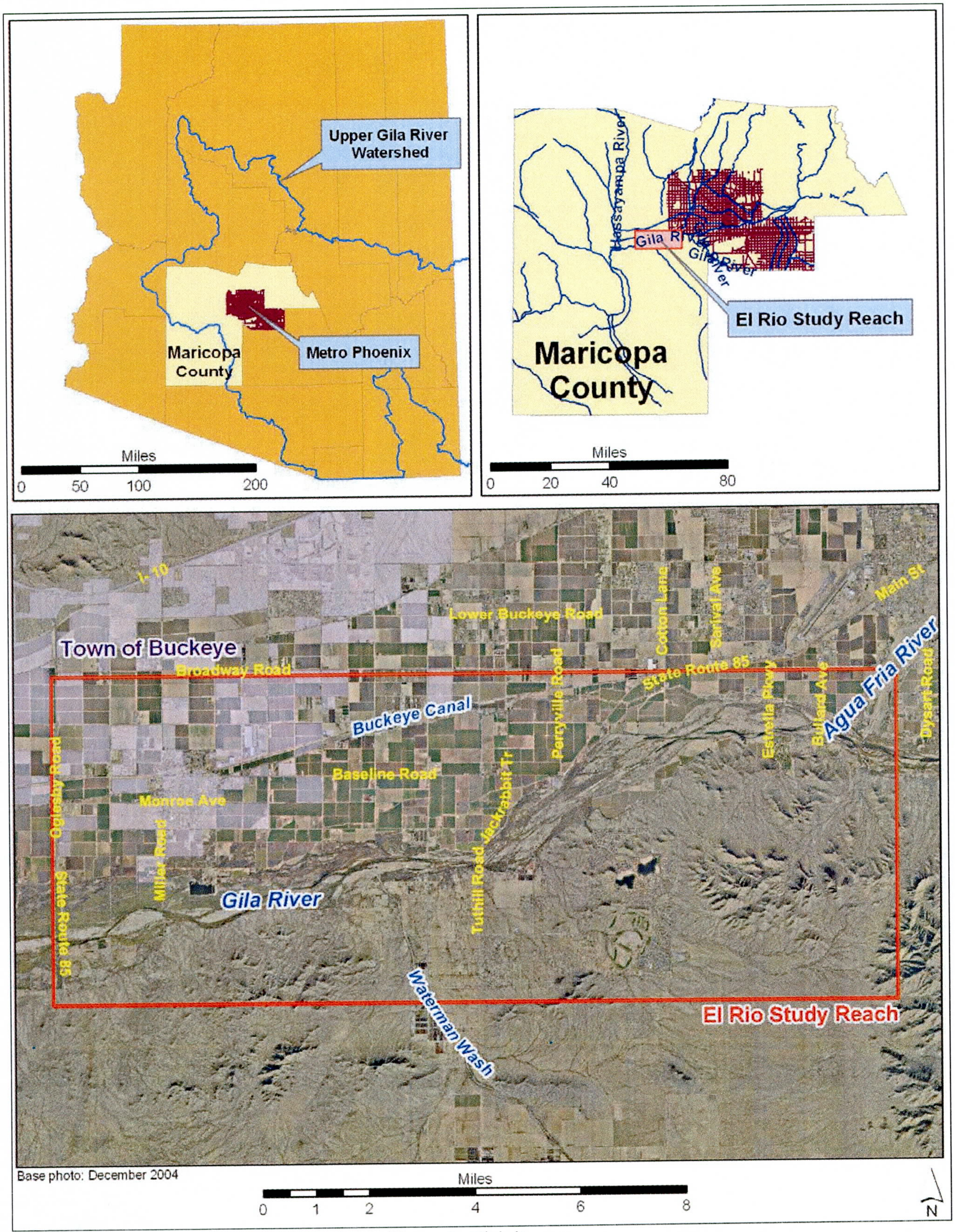


Figure 1. Vicinity map

CHAPTER 2: STUDY AREA

OVERVIEW

The Gila River originates in the Mogollon Mountains of western New Mexico, flows through south-central Arizona, and terminates at the Colorado River near Yuma, Arizona (Figure 2). The drainage area of the Gila River at upstream end of the El Rio study reach is approximately 51,000 square miles. Although about 400 perennial streams contribute runoff to the Gila River system, during the summer most of the river downstream of Duncan, Arizona remains dry due to irrigation diversions and water storage in 11 major dams (ADWR, 2005). Within the El Rio study reach, perennial flows in some reaches are maintained by effluent discharge from the Tolleson waste water treatment plant (WWTP), 91st Avenue WWTP, and the 23rd Avenue WWTP. Additionally, agricultural return flows contribute seasonal runoff within the study reach.

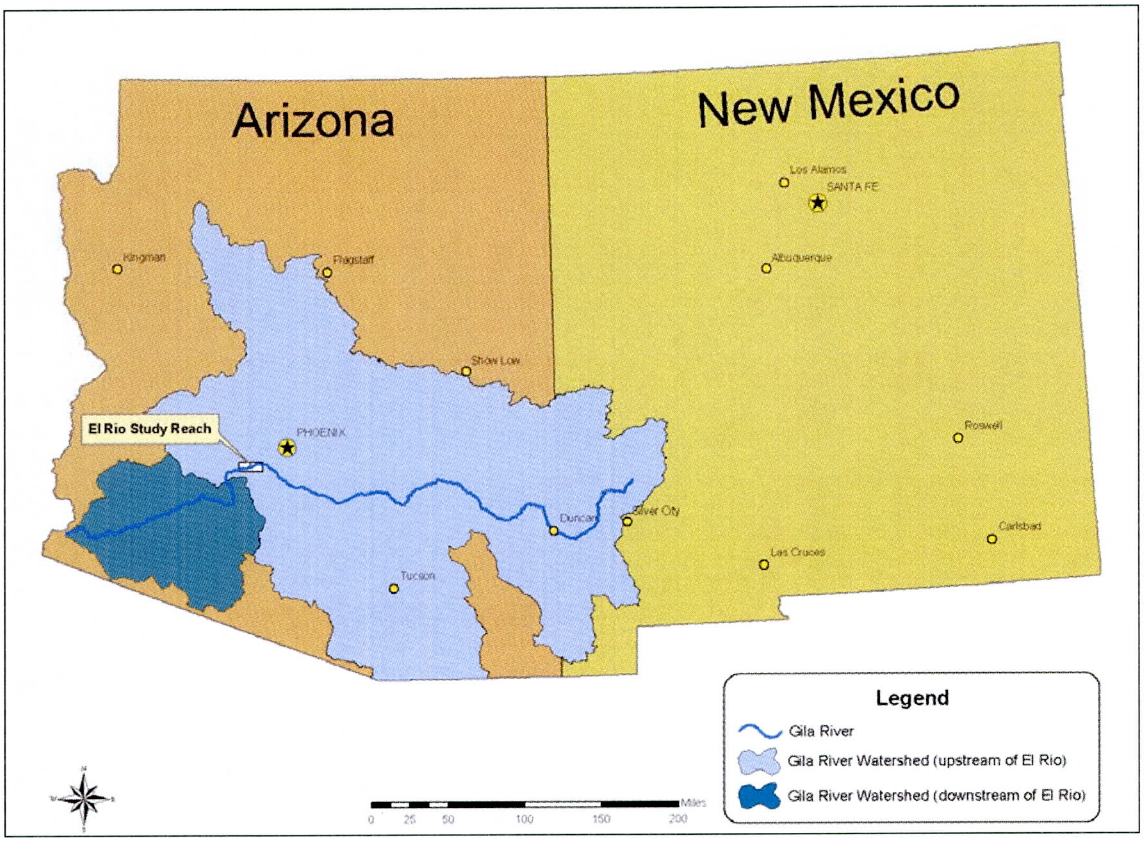


Figure 2. Gila River watershed

Information presented in this chapter includes the following:

- Geologic Setting
- Hydrology
- Human Impacts

GEOLOGIC SETTING

Understanding the overall geology of the study area is fundamental to understanding and predicting the types and magnitudes of channel processes. Identification of individual geologic units and their extent within the study reach provides valuable information about where the river has been in the past, the relative time frame of channel movement, and more importantly, allows prediction of where the river might move in the future. Arizona Geological Survey (AZGS) mapping of the bedrock and surficial geology (Reynolds, 1997) was used as the basis of geological information for the El Rio study reach, as shown in Figure 3.

Regionally, the El Rio study reach lies within a very wide alluvial valley called the Buckeye Valley, which is bounded on the south by the Estrella Mountains and the Buckeye Hills, and on the north by the piedmont slopes of the White Tank Mountains. Elevations within the study area range from about 810 feet near the Gila River thalweg to 1,774 feet in the adjacent mountains (HLC, 2003). The river valley has a longitudinal slope of approximately five feet/mile (0.1%).

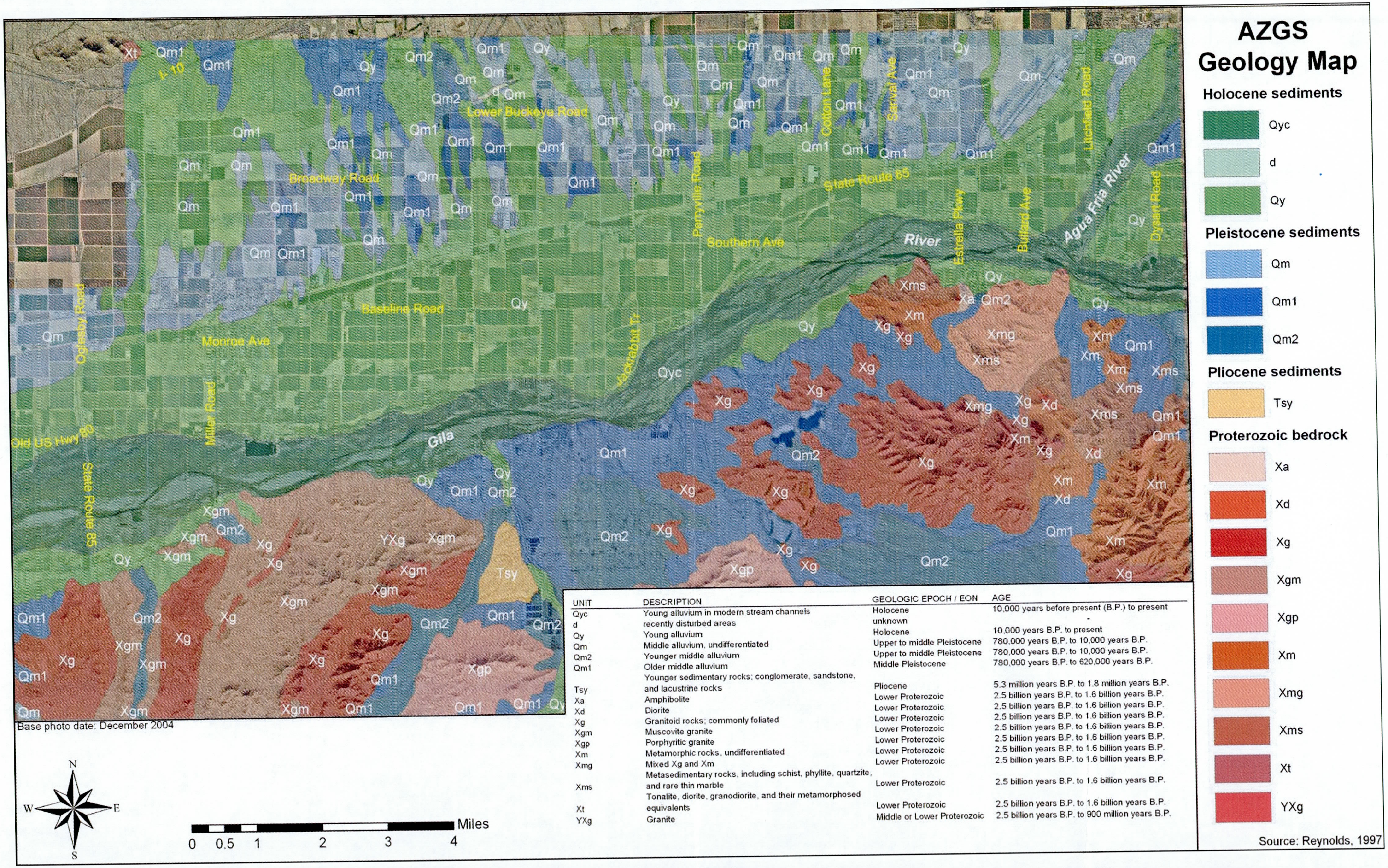
The following types of geologic information are presented in this section:

- Subsurface Geology
- Surficial Quaternary Geology
- Subsidence & Depth to Ground Water
- Soils

Subsurface Geology

The subsurface alluvial geology within the study reach has been divided into the following three major units, as shown in Figure 4 (HLC, 2003):

- Lower Alluvial Unit (LAU) – The LAU is predominantly a conglomerate intermixed with finer grained lenses. The LAU has no direct influence on current river morphology or lateral stability.
- Middle Alluvial Unit (MAU) – The MAU is a thick sequence of finer grained sediments associated with low energy lacustrine environments. The unit grades into fluvial sands and gravels. Within the study reach the MAU is defined by thick clay sequences. Geologists logging borings for the new Cotton Lane Bridge interviewed during field work indicated that 30-60 foot thick clay unit consistent with the MAU description were encountered during drilling. Because of its depth below the surface, the MAU has no known impact on the current river morphology.
- Upper Alluvial Unit (UAU) – This unit is composed of gravel, sand and silt with minor amounts of clay. It is unconsolidated and grades from gravel and cobbles near the present thalweg to fine floodplain deposits in adjacent areas. The existing river channel is formed in the UAU.



UNIT	DESCRIPTION	GEOLOGIC EPOCH / EON	AGE
Qyc	Young alluvium in modern stream channels	Holocene	10,000 years before present (B.P.) to present
d	recently disturbed areas	unknown	-
Qy	Young alluvium	Holocene	10,000 years B.P. to present
Qm	Middle alluvium, undifferentiated	Upper to middle Pleistocene	780,000 years B.P. to 10,000 years B.P.
Qm2	Younger middle alluvium	Upper to middle Pleistocene	780,000 years B.P. to 10,000 years B.P.
Qm1	Older middle alluvium	Middle Pleistocene	780,000 years B.P. to 620,000 years B.P.
Tsy	Younger sedimentary rocks; conglomerate, sandstone, and lacustrine rocks	Pliocene	5.3 million years B.P. to 1.8 million years B.P.
Xa	Amphibolite	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xd	Diorite	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xg	Granitoid rocks; commonly foliated	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xgm	Muscovite granite	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xgp	Porphyritic granite	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xm	Metamorphic rocks, undifferentiated	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xmg	Mixed Xg and Xm	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xms	Metasedimentary rocks, including schist, phyllite, quartzite, and rare thin marble	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
Xt	Tonalite, diorite, granodiorite, and their metamorphosed equivalents	Lower Proterozoic	2.5 billion years B.P. to 1.6 billion years B.P.
YXg	Granite	Middle or Lower Proterozoic	2.5 billion years B.P. to 900 million years B.P.

Figure 3. AZGS geology map

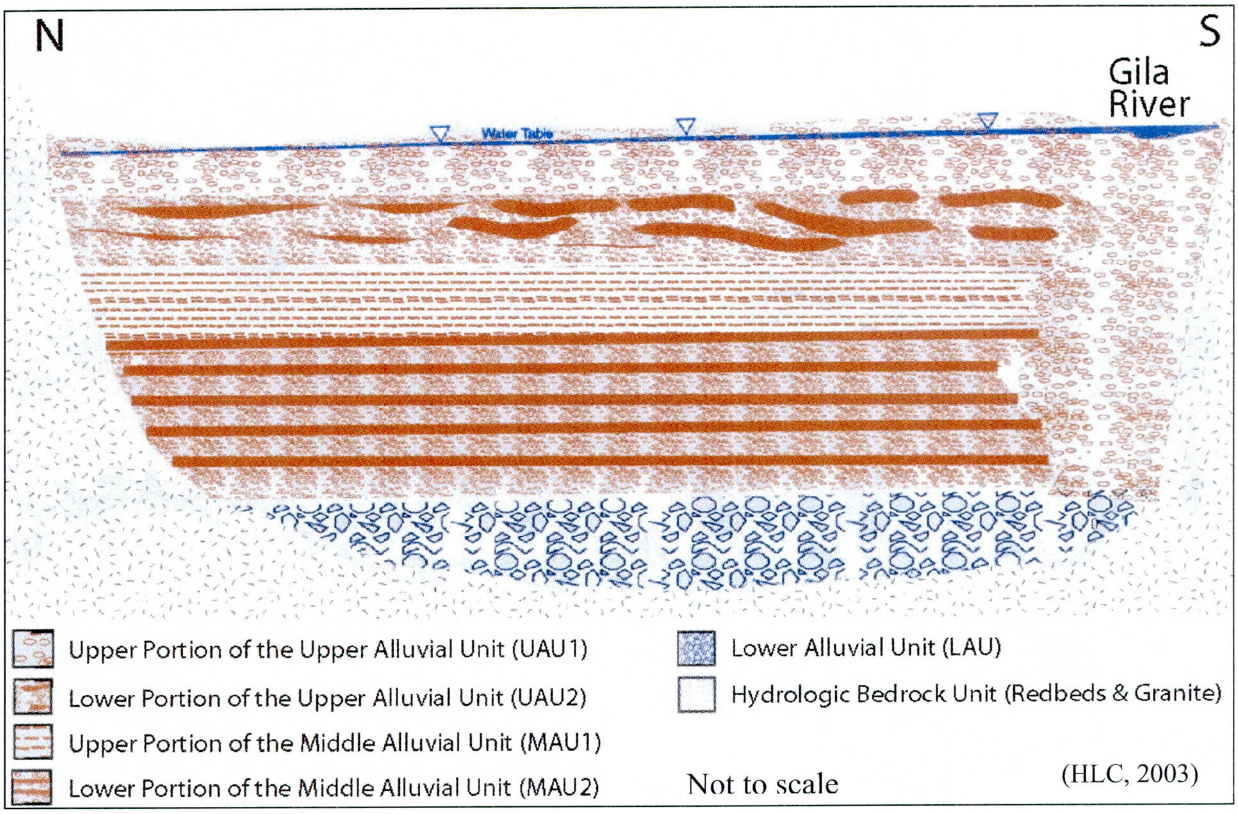


Figure 4. Typical north-south geologic cross-section through the study reach

The idealized subsurface geology cross section shown in Figure 4 provides some other information related to lateral channel stability. First, the active river corridor appears to have occupied only a small portion of the cross section for a very long time during placement of the MAU. During placement of the UAU, the material composition indicates that the active channel of the Gila River may have occupied a much larger portion of the valley. Second, the UAU is composed of materials that are relatively consistent across the entire alluvial valley fill area. That is, the entire Buckeye Valley is composed of materials deposited and therefore, readily transported by the river. Therefore, no physical barrier to lateral erosion exists along the north side of the existing Gila River floodplain. Third, bedrock forms a natural barrier to erosion along the south side of the active Gila River floodplain. Therefore, the river may tend to preferentially erode to the north during widening events. Finally, shallow ground water exists in the vicinity of the existing active river corridor, as described below.

Surficial Quaternary Geology

Relative age determination of Quaternary[1] geologic units provides information regarding long-term history of channel processes, river stability, and helps place field and historical observations of channel behavior in their geologic context. The age of stream terraces adjacent to the main channels provides information on past stream bed elevations and

[1] The Quaternary geologic Period is comprised of the Pleistocene and Holocene geologic Epochs and spans approximately 1.8 million years before present (B.P.) to the present.

positions that can be used to hindcast where the stream was in the past, and may be used to forecast where the river may be located in the future. AZGS Quaternary geologic mapping (Reynolds, 1997) was used to identify the river corridor occupied by the Gila River in the past 10,000 years (the Holocene Period). Comparing this geologic information with aerial photography aids in the estimate of the river corridor width needed to maintain its natural form and function.

Table 1 lists the AZGS Quaternary units shown in Figure 3. The relative ages of these units can help determine where the active Gila River has been located within the Quaternary Period, but more importantly, where it has not been. Figure 5 shows only the Quaternary units in addition to their relation to the floodplain and floodway, and the compound and active channel corridors (as defined in Chapter 3).

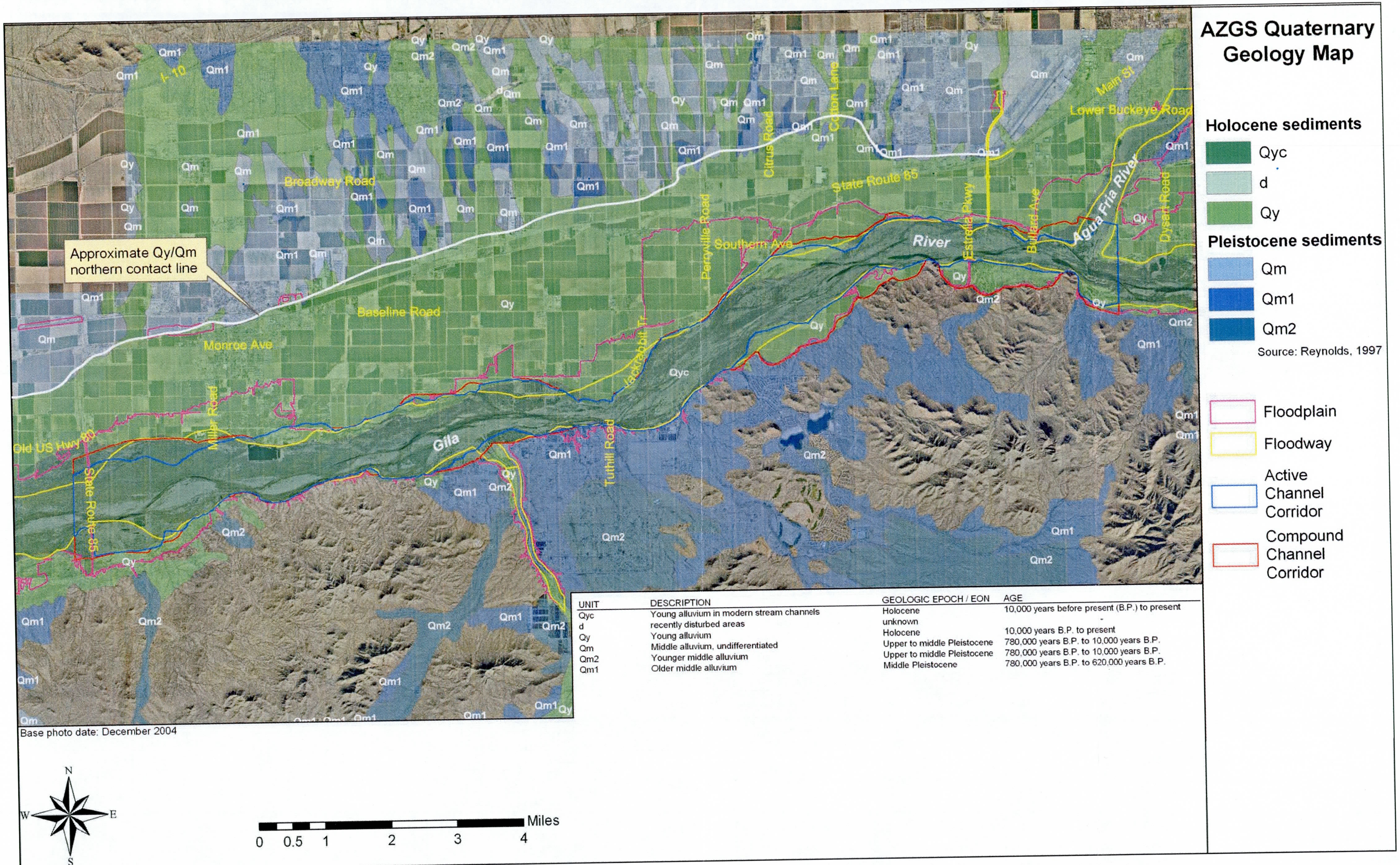
Table 1. AZGS Quaternary geologic units

Unit ID	Description	Geologic Epoch	Age
d	Recently disturbed areas	Recent	Unknown
Qyc	Young alluvium in modern stream channels	Holocene	10,000 years B.P. to present
Qy	Young alluvium	Holocene	10,000 years B.P. to present
Qm	Middle alluvium, undifferentiated	Upper to middle Pleistocene	780,000 years B.P. to 10,000 years B.P.
Qm2	Younger middle alluvium	Upper to middle Pleistocene	780,000 years B.P. to 10,000 years B.P.
Qm1	Older middle alluvium	Middle Pleistocene	780,000 years B.P. to 620,000 years B.P.

The corridor defined by unit Qy represents the maximum area which the Gila River has occupied in the past 10,000 years. Most of the land within the Qy unit is occupied by agriculture and a significant portion of the town of Buckeye. The northern contact between the Qy and Qm units indicates the northernmost extent of the active Gila River during the Quaternary (2,000,000 years). That is, the Gila River has not extended north of the Qy/Qm contact in 10,000 years. The same logic can be applied to the southern contact between Qy and Qm. These contacts "bracket" the age of the Gila River corridor and illustrate the maximum area of active channel processes within a geologic context. Historical information described in Chapter 3 further refines the width of the active channel corridor within a more recent time frame.

The footprint of the Qy unit is significantly greater than that of the current regulatory floodplain. Although a few isolated areas of Qy surfaces may have been inundated by geologically recent large-magnitude, low-frequency floods, as indicated by the photographic record, the majority of the Qy surface has not been significantly altered by flooding. However, in the context of the past 10,000 years, the geologic map shown in Figure 5 indicates that floods have inundated the Qy surface and that it is plausible the active river channel and thalweg[2] may have existed within the Qy area during that

[2] The thalweg represents the lowest point of the most active, modern channel position of a stream or river.



UNIT	DESCRIPTION	GEOLOGIC EPOCH / EON	AGE
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Figure 5. AZGS Quaternary geology map

extended time period. There are several reasons why modern inundation limits may differ from the geologic record indicated by the extent of the Qy surface. First, modern diversion and impoundment by upstream dams have reduced peak discharges, and consequently, the extent of the floodplain to the extent of the Qyc unit. Second, regional channel incision that occurred throughout the Southwest may have impacted the Gila River in the study reach, deepening the channel and perching the most distal floodplain terraces. Finally, human efforts (Chapter 2) have tended to push the river toward the south and cutoff former overbank flow paths located outside the current regulatory floodplain, but within the Qy unit. In a general context, the floodway and the active and compound channel corridors parallel the Qyc unit, indicating the Gila River has been confined to that corridor since at least the early 20th century and is unlikely to re-occupy or significantly inundate the Qy units unless upstream conditions and human occupation of the Buckeye Valley change dramatically, both of which are unlikely scenarios.

Subsidence & Depth to Ground Water

Subsidence is a geologic phenomenon in which the ground surface becomes lower over time. Subsidence can happen naturally, or as in the case of the Phoenix Basin, as the result of human activities such as ground water withdrawal. Surveys of subsidence in the west Phoenix Basin have shown as much as 18 feet of surface subsidence caused by compaction of basin fill sediments that occurred due to groundwater pumping (Shumann et al. 1995). Figure 6 shows a map of ground lowering in the west Phoenix Basin just north of the study reach. These data show that while land subsidence has been significant north of the study area, the effects of subsidence had not reached the Gila River corridor by 1991. If subsidence extends to the river channel, the result will likely be an increase in slope upstream of the subsidence cone, and decrease downstream. Increased slope would lead to increased incision (long-term scour) and lateral erosion. Decreased slope would lead to sediment deposition, loss of channel capacity and widening of the floodplain. However, given the shallow depth to ground water, subsidence within the El Rio study reach is unlikely over the next several decades.

Presently there is no evidence of significant subsidence within the study reach limits. The El Rio Groundwater Evaluation Study performed by HLC (2003) concluded that the groundwater table throughout much of the study reach is presently less than 10 feet below the surface, further indicating that the potential for subsidence is low. Figure 7 is a depth-to-groundwater map illustrating the shallow depths. Shallow ground water impacts on river stability include the following:

- Vegetation Growth. Shallow ground water increases bank and floodplain vegetative growth. Vegetative growth generally increases channel stability. However, in the El Rio study reach, excessive Tamarix growth may induce sediment deposition in some areas, and/or divert flooding around dense Tamarix stands toward previously unflooded or non-eroded land surfaces.
- Aggregate Mining. Shallow ground water in subsurface excavations can limit the rate of headcutting during floods by reducing the free overfall distance and the time to fill the excavation with flood water.

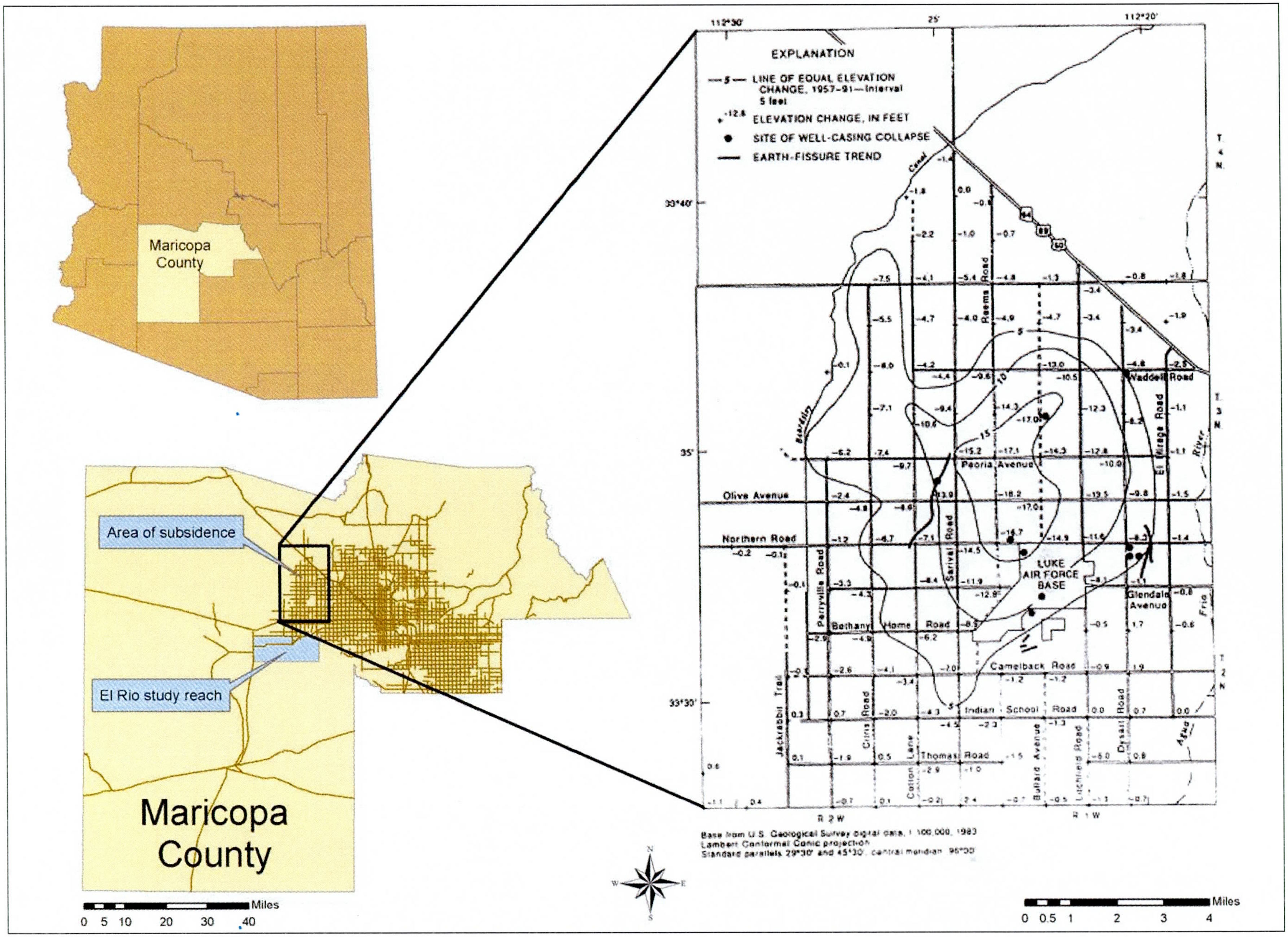


Figure 6. Land subsidence in the west Phoenix Basin (1957 – 1991) in relation to the El Rio study reach

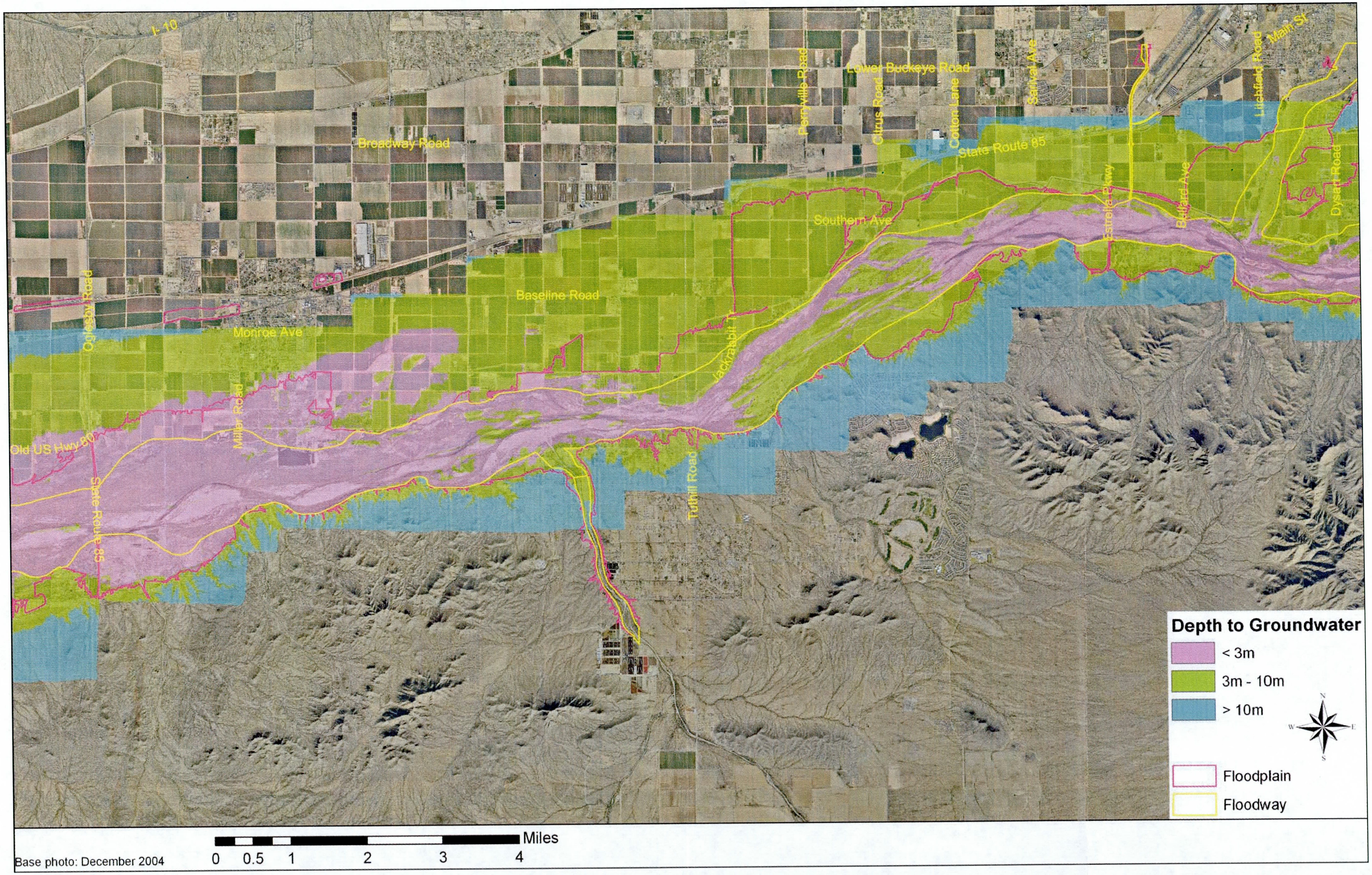


Figure 7. Depth to groundwater

Soils

Analysis of soils data can provide information on the evolution of a river system. Natural Resources Conservation Service (NRCS) soil mapping data were collected and analyzed for the El Rio study reach using NRCS regional soils associations as well as detailed NRCS soils mapping. Soils described by the NRCS are often grouped into regional Soil Associations. A Soil Association is a landscape that has a distinctive pattern of soils and normally consists of one or more major soils and at least one minor soil. The two soil associations found within the study reach were the *Marana-Sasco-Denure Association* and the *Carrizo-Brios-Antho Association*. A general description of each soil unit within these associations is listed in Table 2.

Table 2. General NRCS soil descriptions

NRCS Soil	Description
Marana-Sasco-Denure Association	
Marana	The Marana series consists of deep, well drained, moderately permeable soils formed in stream alluvium. Marana soils are on stream terraces and have slopes of 0 to 2 percent.
Sasco	The Sasco series consists of very deep, well drained soils formed in mixed alluvium. Sasco soils are on stream terraces and have slopes of 0 to 1 percent.
Denure	The Denure series consists of very deep, somewhat excessively drained soils formed in fan or stream alluvium. Denure soils are on relict basin floors, stream or fan terraces and have slopes of 0 to 8 percent.
Carrizo-Brios-Antho Association	
Carrizo	The Carrizo series consists of very deep, excessively drained soils formed in stratified alluvium from mixed sources. Carrizo soils are on flood plains and alluvial fans, fan aprons and fan terraces and have slopes of 0 to 9 percent.
Brios	The Brios series consists of very deep, excessively drained soils that formed in mixed and stratified alluvium. Brios soils are on flood plains and alluvial fans and have slopes of 0 to 5 percent.
Antho	The Antho series consists of very deep, somewhat excessively drained soils formed in mixed and stratified alluvium. Antho soils are on alluvial fans and flood plains and have slopes of 0 to 5 percent.

(Source: NRCS, 1999)

The primary purpose for analysis of NRCS soils data was to identify geomorphic surfaces based on soil characteristics, that have been subject to active fluvial processes in recent geologic history, and thus may be subject to future lateral erosion. Additionally, the NRCS soils mapping was of greater detail than the AZGS surficial geology mapping, and thus could be used to supplement the geologic analysis. The long history of agricultural development along the right overbank floodplain of the Gila River overwrote much of the natural surficial evidence of differing geomorphic surfaces used by the AZGS to distinguish map units. The NRCS soil survey relies more heavily on subsurface information than the AZGS mapping, and thus provided data not available to the AZGS.

As shown in Table 2, the *Carrizo-Brios-Antho Association* represents the active Gila River corridor. The *Marana-Sasco-Denure* soils underlie the right overbank area along the study reach. These associations comprise the transition from active channel processes within the Gila River and the active piedmont slope processes of the White Tank Mountains. The outermost boundary of the *Marana-Sasco-Denure* soils represents the maximum extent of river processes during recent geologic time and thus aids in bracketing the zone of lateral erosion hazard.

Table 3 lists each NRCS detailed soils map unit identified within the study reach. Based on interpretations of these detailed soils descriptions prepared by the NRCS, a landform type was assigned to each soil. These landform categories were then grouped and mapped to illustrate their geographic relationships, as shown in Figure 8. Figure 8 also shows the AZGS geologic units for comparison, and illustrates the enhanced detail of the NRCS soil data. For example, the Qy geologic unit to the north of the Gila River contains multiple NRCS soil units that have been interpreted into several different landform types. Based on the NRCS mapping, much of the AZGS Qy unit is shown to be a river terrace (rather than floodplain) with linear braided corridors of overbank flow paths parallel to the modern active channel corridor. These overbank flow paths were probably perched and abandoned due to historic incision of the river and reduction of flood peaks due to upstream storage, and are not currently part of the active river system.

Table 3. Detailed NRCS soil descriptions

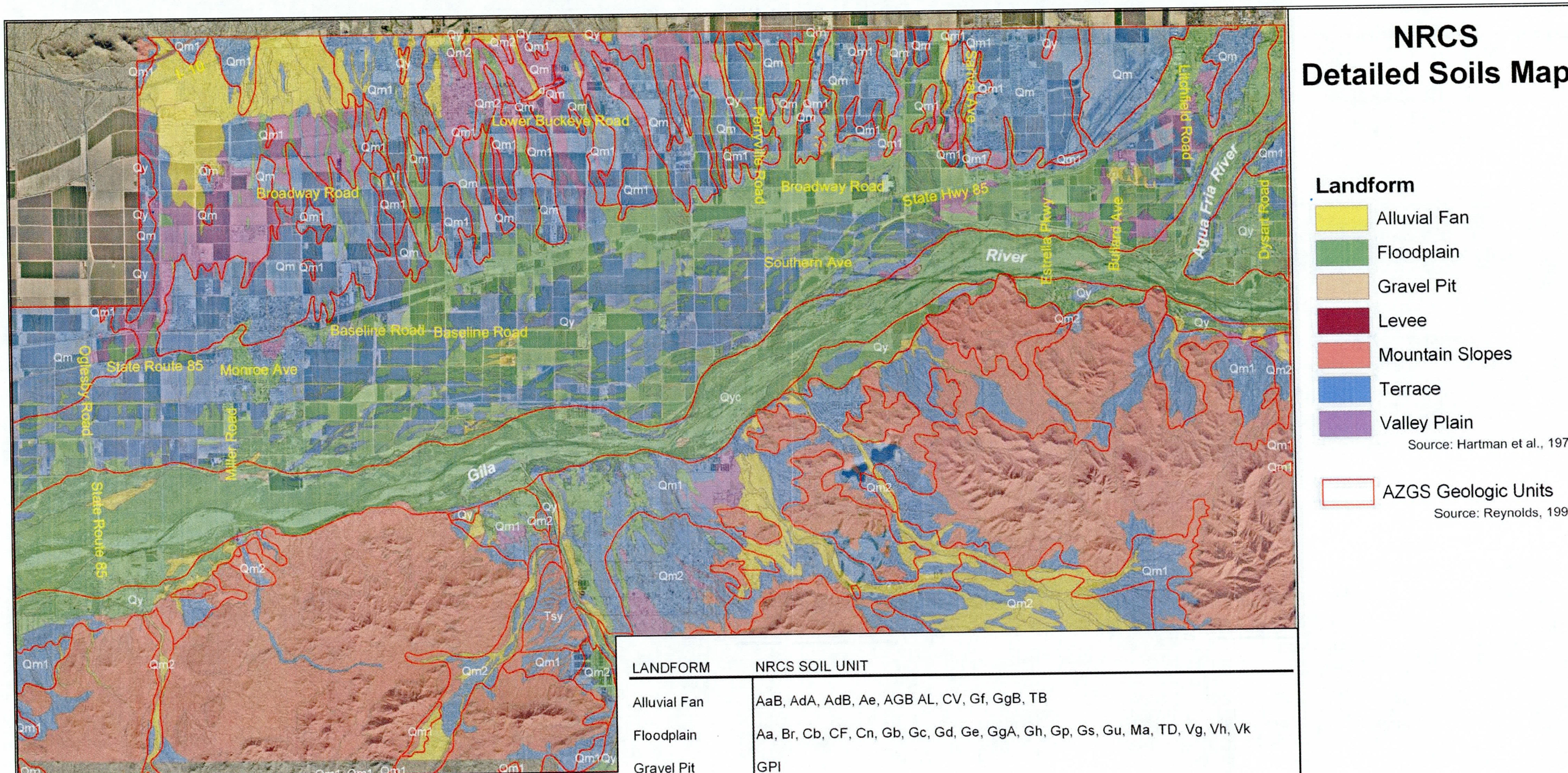
NRCS soils map units	Component Soil Series	Position	Important Characteristics	Subgroup, Order	Interpreted Landform
Agualt loam (Aa)	Agualt - 85%	On floodplains, low terraces and alluvial fans	Formed on recent alluvium; areas long and narrow; moderately alkaline and calcareous throughout profile	Typic Torrifluvents, Entisols	Floodplain
Antho sandy loam (AbA)	Antho - 85%	On broad alluvial fans and low stream terraces	Surface drainage provided by dendritic pattern of shallow channels spaced at 100- to 300-foot intervals	Typic Torrifluvents, Entisols	Alluvial Fan
Antho sandy loam, saline-alkali (Ac)	Antho - 80%	On valley plains	Surface somewhat hummocky and drained by dendritic pattern of shallow channels spaced at 100- to 300-foot intervals; strongly alkaline at about 14 inches	Typic Torrifluvents, Entisols	Valley Plain
Antho-Carrizo complex (AfA)	Antho - 50% Carrizo - 30%	On long narrow stream terraces parallel to stream channels	Narrow terraces cut by one or more meandering channels; Carrizo in old stream channels through larger areas of Antho, these channels are 2 - 5 feet above present stream channel; together form a braided pattern	Typic Torrifluvents, Entisols Typic Torriorthents, Entisols	Terrace
Antho-Carrizo complex (AGB)	Antho - 35% Carrizo - 30% Maripo - 20%	On alluvial fans 1 to 3 miles from mountains and in some broader stream channels	Surface drainage provided by dendritic pattern of shallow stream channels spaced at 50- to 200-foot intervals; Carrizo soil is in or adjacent to old stream channels that form a braided pattern across larger bodies of Antho soils; Maripo is in transitional areas between Carrizo and Antho	Typic Torrifluvents, Entisols Typic Torriorthents, Entisols Typic Torrifluvents, Entisols	Alluvial Fan
Avonda clay loam (An)	Avonda - 75%	On stream terraces and valley plains along the Gila, Salt, and Agua Fria Rivers	Long narrow areas about 1/4 to 1 mile from, and parallel to, major stream channels	Typic Torrifluvents, Entisols	Terrace
Avondale clay loam (Ao)	Avondale - 85%	On alluvial plains and low stream terraces	Long narrow areas about 60 acres in size; strongly effervescent throughout	Typic Torrifluvents, Entisols	Terrace

NRCS soils map units	Component Soil Series	Position	Important Characteristics	Subgroup, Order	Interpreted Landform
Avondale clay loam, saline-alkali (Ap)	Not specified	On stream terraces along the margins of the Gila and Salt Rivers	Moderately to strongly saline and alkaline	Typic Torrifluvents, Entisols	Terrace
Brios sandy loam (Bs)	Brios - 80%	On low terraces near major drainageways and on alluvial fans	Surface somewhat hummocky; formed in recent alluvium	Typic Torrifluvents, Entisols	Terrace
Carrizo and Brios soils (CF)	Carrizo - 45% Brios - 35% Vint - 20%	In or adjacent to channels of the Gila, Salt, and Hassayampa Rivers	Hummocky and dissected by many small stream channels and old meander cutoffs; lower areas flooded every 5 to 20 years; flooding changes soil material and occasionally the course of the main channel; Vint not present in all areas; Carrizo generally in lower positions nearest stream channels, Vint somewhat dunelike in appearance in slightly higher positions along the outer rims of the mapped areas, with the Brios soil intermediate to the Vint and Carrizo	Typic Torriorthents, Entisols Typic Torrifluvents, Entisols Typic Torrifluvents, Entisols	Floodplain
Carrizo gravelly sandy loam (Cb)	Carrizo - 85%	In stream channels, on low terraces near stream channels, and on alluvial fans	Formed in recent alluvium deposited on floodplains along major streams and along stream channels in alluvial fans; source of sand and gravel for construction	Typic Torriorthents, Entisols	Floodplain
Cashion clay, saline-alkali (Cn)	Cashion - 80%	On floodplains and low terraces of the Gila and Salt Rivers	Some areas are long narrow strips that have a concave surface; dark grayish-brown, generally calcareous throughout	Typic Torriorthents, Entisols	Floodplain
Cherioni-Rock outcrop complex (CO)	Cherioni - 50% Rock outcrop - 20%	On low hills and lower slopes of mountains	Dissected by stream channels cut 3 to 20 feet below the surface; stones cover 50 to 90 percent of the surface; slopes range from 3 to 25 percent	Typic Durorthids, Aridisols not applicable	Mountain Slopes
Gilman fine sandy loam (Ge)	Gilman - 80%	On floodplains, alluvial fans, and low terraces	Somewhat hummocky	Typic Torrifluvents, Entisols	Floodplain

NRCS soils map units	Component Soil Series	Position	Important Characteristics	Subgroup, Order	Interpreted Landform
Gilman fine sandy loam, saline-alkali (Gf)	Gilman - 80%	On lower ends of alluvial fans and on low stream terraces along the Gila and Salt Rivers	Low mounds up to 2 feet in height surround brush; white crust covers surface in areas; strongly affected with saline and alkali salts	Typic Torrifluvents, Entisols	Alluvial Fan
Gilman loam (GgA)	Gilman - 80%	On stream terraces, valley plains, and alluvial fans	Areas long and narrow and parallel to stream channels	Typic Torrifluvents, Entisols	Floodplain
Gilman loam, saline-alkali (Gh)	Gilman - 85%	On floodplains and low terraces along the Gila and Salt Rivers, Centennial Wash, and small streams near Wintersburg	A few areas are flooded for a period of about 5 hours once every 10 years; hummocky and in areas dissected by v-shaped gullies 1 to 4 feet deep spaced at 10- to 200-foot intervals; areas between gullies frequently slicked over or coated with a white slat crust	Typic Torrifluvents, Entisols	Floodplain
Gilman loam, clayey subsoil variant, moderately saline (Gp)	Gilman variant - 95%	On floodplains and low stream terraces along the Gila and Salt Rivers	Areas not level; areas slightly concave and in some areas covered by a thin, white salt crust; underlain at 20 to 40 inches by a violently effervescent clayey sediment	Typic Torrifluvents, Entisols	Floodplain
Glenbar clay loam (Gt)	Not specified	On valley plains and alluvial terraces parallel but 1/4 to 1 mile from the Gila, Salt, and Agua Fria Rivers	Dark brown, sticky and plastic, strongly effervescent	Typic Torrifluvents, Entisols	Terrace
Glenbar clay loam, saline-alkali (Gu)	Not specified	On floodplains and low alluvial terraces along the Gila and Salt Rivers	Surface layer texture somewhat coarser than Gt, 8 to 12 inches thick and from very fine sandy loam to silt loam, affected by salts and alkali	Typic Torrifluvents, Entisols	Floodplain
Glenbar clay (Gv)	Not specified	On low terraces and valley plains	Similar to representative Glenbar profile but with more clay in surface layer	Typic Torrifluvents, Entisols	Terrace
Gravel pit (GPI)			Gravel pits at time of soil survey (soil survey date 1977, aerial photo base in survey 1973)	Not applicable	Gravel Pit

NRCS soils map units	Component Soil Series	Position	Important Characteristics	Subgroup, Order	Interpreted Landform
Gunsight-Rillito complex (GYD)	Gunsight - 40% Rillito - 40%	On old alluvial fans In circular spots near drainageways, and near the tops of fans; on old fans and stream terraces	Dissected by series of stream channels at 100- to 500-foot intervals; channels range from a few feet to as much as 30 feet deep; Gunsight soils mainly on the top of fans and are high in lime content	Typic Calciorthids, Aridisols Typic Calciorthids, Aridisols	Terrace
Laveen loam, saline-alkali (Ld)	Laveen - 80%	Formed in alluvium on old alluvial fans and old valley plains adjacent to major stream channels	Often covered by black, algal crust; underlain by strongly alkaline horizon at 8 to 30 inches; large concentration of lime in lower depths	Typic Calciorthids, Aridisols	Terrace
Maripo sandy loam (Ma)	Maripo - 80-85%	Parallel to intermittent stream channels	Formed in recent alluvium on alluvial fans, low stream terraces and floodplains; slightly effervescent; underlain by strongly effervescent gravelly sand at 20 to 40 inches	Typic Torrifluvents, Entisols	Floodplain
Rock outcrop-Cherioni complex (RS)	Rock outcrop - 65% Cherioni - 20%	On mountainsides and some low hills	Mainly exposed bedrock and very cobbly or stony soils	Not applicable Typic Durorthids, Aridisols	Mountain Slopes
Torripsamments and Torrifluvents, Frequently Flooded (TD)	not specified	Present channel of major streams	Recently deposited stratified sediments of intermittent streams; similar to Carrizo and Brios only more frequently flooded; mainly sandy and composed of 5 to 80 percent gravel and cobbles		Floodplain
Vint fine sandy loam (Vh)	Vint - 80%	On floodplains and low terraces along major streams	Generally hummocky unless cultivated; surface layer is pale-brown fine sandy loam 6 to 14 inches thick	Typic Torrifluvents, Entisols	Floodplain

(Source: Hartman et al., 1977)



LANDFORM	NRCS SOIL UNIT
Alluvial Fan	AaB, AdA, AdB, Ae, AGB AL, CV, Gf, GgB, TB
Floodplain	Aa, Br, Cb, CF, Cn, Gb, Gc, Gd, Ge, GgA, Gh, Gp, Gs, Gu, Ma, TD, Vg, Vh, Vk
Gravel Pit	GPI
Levee	LEVEE
Mountain Slopes	CO, GA, RS
Terrace	AbA, AfA, An, Ao, Ap, Bs, Bt, CA2, CrB, EPD, Go3, Gt, Gv, GWD, GxA, GxB, GYD, HLC, Lb, LcA, LcB, Ld, Mr, Pa, PeA, PeB, PRB, PsA, PT, RaA, RaB, RbA, RbB, RpE, Ta, Te, TrA, TrB, TSC, Tu, Wg
Valley Plain	Ac, Ch, Cp, Es, Gr, Le, Mo, Va

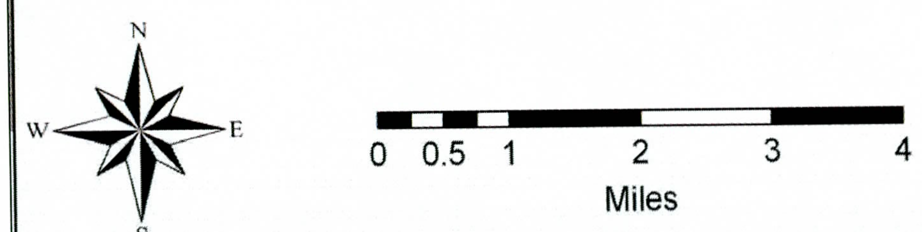


Figure 8. Detailed NRCS soils map

HYDROLOGY

The hydrology of the El Rio study reach is discussed in WCMP project documentation prepared by Stantec Consulting and other WCMP team members. Only hydrologic data related to prediction of riverine erosion are presented in this Chapter. Like many Arizona streams, the hydrology of the Gila River has changed dramatically due to human influences, as discussed later in this Chapter. Historical changes in the natural hydrology of the Gila River include reduction of flow volume and peak discharges due to upstream impoundments and diversions, addition of effluent base flow, and changes in seasonality of runoff due to irrigation and tailwater releases from reservoirs. Past studies have demonstrated that these types of changes tend to destabilize river systems, making them more subject to riverine erosion.

Riverine erosion on arid-region streams is directly related to peak discharge. In arid lands, large floods or periods of prolonged flooding tend to reshape the fluvial environment more significantly than long periods of "average" floods. Figure 9 is a plot of annual peak discharge for the USGS gage (#09519500) located below Gillespie Dam. This plots shows a period of large floods occurred between 1890 and 1930, and a period lacking large floods occurred between 1940 and 1965. The occurrence of flood and drought cycles relative to historical channel movement is addressed in Chapter 3 of this report.

Mean daily discharge estimates plotted from several USGS gage stations in the Gila River watershed are plotted in Figure 10 to demonstrate season variation of flow relative to position in the watershed. At the El Rio study reach, a higher percentage of the annual flow volume and peaks occurs during winter and early spring than in summer and fall. Therefore, one can expect the most significant changes in channel position to occur during winter.

Written descriptions of the hydrology of the Gila River near the study reach were considered to illustrate changes in flow and river conditions during the modern period of Anglo occupation. Prior to the Anglo settlements within the Phoenix Basin around 1870, the Gila River was perennial from the Salt River confluence to the Colorado River (Ross, 1923). Early 16th century Spanish explorers described the native peoples living along the Gila as fishermen (JEF, 2003). These early descriptions would indicate a thriving riparian environment with relatively consistent seasonal flows. Accounts of channel conditions dating to 1846 describe a wide, braided system with defined channels that conveyed the majority of low flow (the compound and active channel model defined in Chapter 3). Lieutenant William Emory of the 1846 Kearny Expedition described the lower Gila River as "about 100 yards wide, flowing along a sandy bottom," while a rancher in 1889 described the river between Buckeye and Gillespie Dam as having hard sloping banks lined with cottonwoods and bushes, with five to six feet deep flow running clear and containing many fish (Ross, 1923).

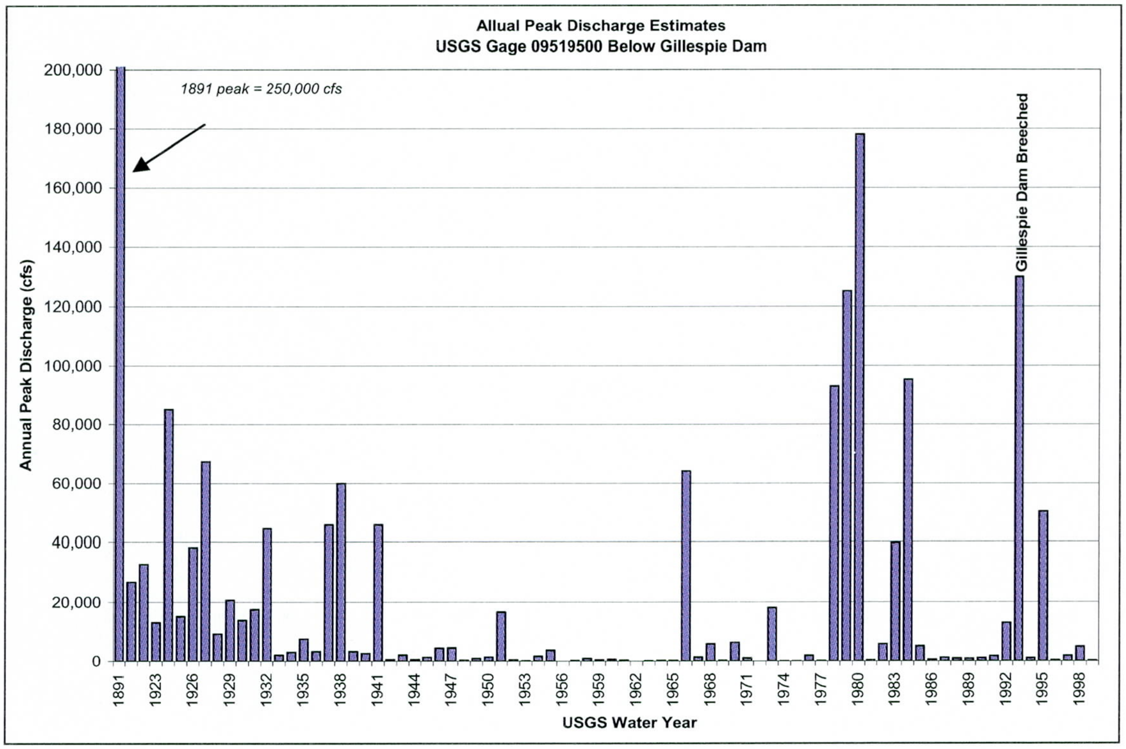


Figure 9. USGS annual peak discharge estimates

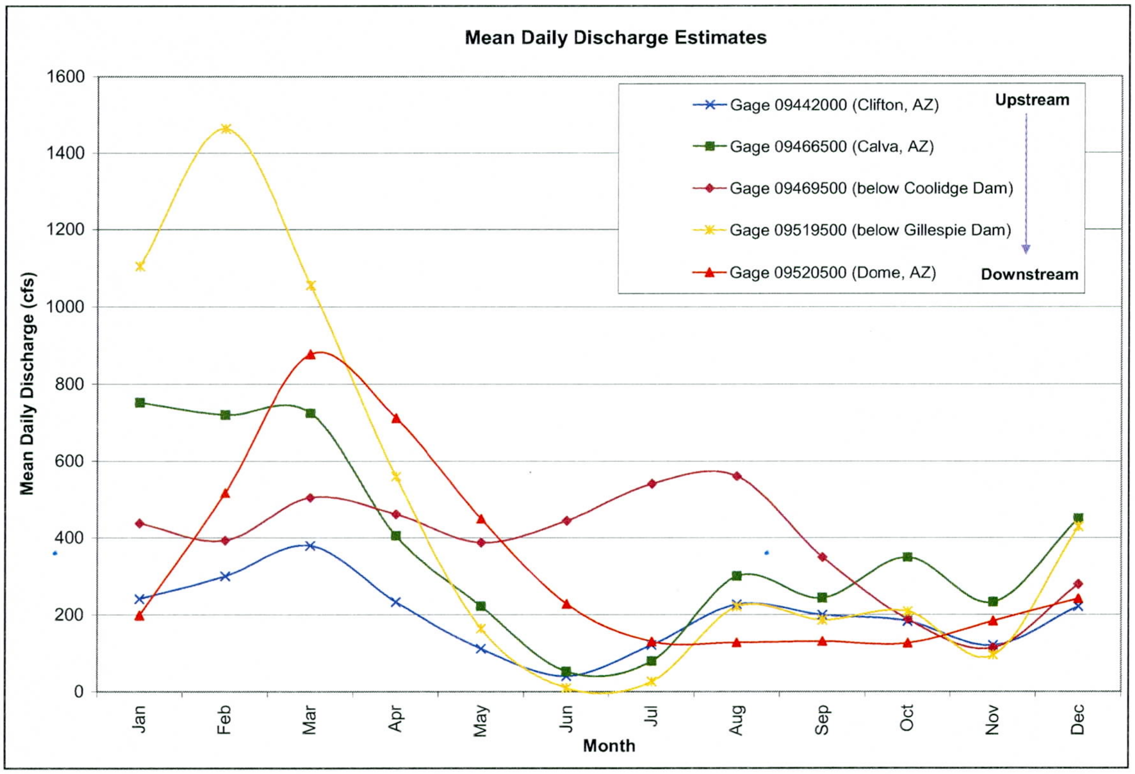


Figure 10. USGS mean daily discharge estimates

The present hydrologic regime of the Gila River downstream of the Salt River confluence is dramatically different than the conditions in the historic descriptions. Today, the river would remain dry much of the year due to upstream diversions and impoundment by dams, except for the release of treated effluent. The vegetation characteristics also are vastly different than those described historically. Treated effluent from wastewater treatment plants serves as the primary source of surface water flow in the study reach. These minimal discharges have created thin, narrow channels within the active channel corridor that no longer reflect any natural flow regime. The Gila River within the El Rio study reach is now a flood-dominated system. Large magnitude, low frequency floods are the primary cause of the river's present-day morphology. The evolution to a flood-dominated system has implications on river stability. Dryland rivers are inherently more unstable and more prone to changes in channel configuration than perennial rivers (Graf, 1988). A 1993 study titled *Historical Geomorphology of the Gila River* by Gary Huckleberry for the Arizona State Land Department Gila River Navigability Study concluded the following:

> *The chronology of channel dynamics on the lower Gila River is less certain, however it appears that dramatic channel transformations occurred in 1890 and 1891, approximately 15 years earlier than that for the upper and middle reaches. It appears again that two catastrophic floods were instrumental in the destruction of flood plain vegetation and causing dramatic bank erosion (Ross, 1923). Although construction of Roosevelt Dam on the Salt River limited the magnitude of flood flow reaching the lower Gila River after 1911, the lower Gila River was still experiencing excess sediment and water generated from the upper and middle Gila River reaches and possibly other tributaries during the time of statehood. Consequently, channel planform and geometry of the lower Gila River in 1912 can also be characterized as mostly shallow and braided.*
>
> *Although system instability is believed to have been climatically driven on the Gila River, one cannot ignore anthropogenic mechanisms as well. At the turn of the century, the Gila River watershed was experiencing considerable vegetation change due to cattle grazing and removal of flood-plain vegetation for agricultural purposes (Bahre, 1991). Removal of grass from hill slopes accelerates runoff leading to larger peak discharges in main trunk streams, and removal of flood plain vegetation exposes banks to greater erosion. Because a rare climatic event corresponded in time to considerable landscape degradation near the turn of the century, it is not possible to separate the natural and anthropogenic causes of the channel changes on the Gila River. Obviously both processes play a role. However, a basic premise of this study is that the Gila River responds to secular climatic variability by radical changes in channel configuration, and that periods of increased, large flood frequency correlate with unstable, braided channel conditions.* (Huckleberry, 1993)

Although the vegetative characteristics of the Gila River are dramatically different today than they were historically, the following description provides insight into what a "natural" Gila River may have looked liked near the time of Arizona statehood in 1912:

> *By 1920, the segment in Buckeye Valley wandered over a sandy flood plain between cut banks 5 to 15 feet high. The flood plain varies in width but is a mile or more in most places. The water meanders in shifting channels and does not cover more than a small part of its flood plain except during unusually great floods.* (Ross, 1923)

In summary, the following types of hydrologic change have occurred in and affected the El Rio study reach:

- Decreased Peak Discharge. With decreased peak discharge less of the river valley is inundated and impacted by flooding. Smaller floods tend to have less energy for reshaping the river corridor.
- Decreased Annual & Flood Flow Volume. With decreased flow volume, less geomorphic work is performed, and the channel-forming discharge tends to be shifted to more rare, larger floods and away from the average annual flood. Reduced main stem flooding and flow volume increases the relative impact of tributary sedimentation on main stem morphology.
- Removal of Small Floods & Natural Base Flow. Removal of small floods and natural base flow tends to allow the low flow channels to become choked by vegetation, and may induce increased braiding and discontinuous channels.
- Addition of Very Low Effluent Discharges. Vegetation tends to grow to the margin of open water areas. Very low effluent discharges can be conveyed in small channels, resulting in fewer continuous open channels capable of conveying flood flows.
- Change in Flow Seasonality. Irrigation deliveries and irrigation tailwater outflows occur in different periods and at different rates than the natural flow regime. Changes in flow seasonality have a profound impact on vegetative reproductive cycles and contributes to the influx of Tamarix and other exotic species.

HUMAN IMPACTS

The Gila River has been a focal point of human activity in Arizona beginning with diversion of river water for agriculture over two thousand years ago. Since that time human activity has steadily increased along the Gila River corridor including dam construction, agricultural encroachment of the river corridor, sand and gravel mining, and bridges. A temporal chronology listing the flood, land use, dam construction, and development history of the Gila River and the study reach is shown in Table 4 and attached in Appendix A.

Decade	FLOODS[1]	LAND USE[2, 3, 4, 5]	BRIDGES AND OTHER CONSTRUCTED WORKS[6]	DAMS & DIVERSIONS[5, 7]
1820s		1824: Anglos began trapping beaver along Lower Gila		
1840s		-1846: Kearny's "Army of the West" conducted 1st systematic exploration of the Gila River		
1850s		-1857: Anglo farming began on lower Gila near Wellton -1859: Gila River Indian Reservation established		
1860s		-1868 Ingall's Survey		
1870s		-1872: Cattle grazing in Gila River Valley -1872: Copper Mountain Mining District -Late 1870s: S.P. Railroad		
1880s		-1888: Buckeye Post Office Established		-Mid-1880s: Earliest reports of agricultural diversions -1888: Buckeye Canal
1890s	-Feb 1891: 250,000 cfs	-1892: 10,000 acres were being farmed in Buckeye Valley		
1900s				-1908: Granite Reef Dam (Salt River) -1911: Roosevelt Dam (Salt River)
1910s		-1915: salt cedar introduction in the Safford area		-1911: Roosevelt Dam (Salt River) -1916: Ashurst-Hayden diversion works authorized
1920s	-Jan 4, 1922: 32,700 cfs -Dec 28, 1923: 85,000 cfs -Sep 28, 1926: 38,300 cfs -Feb 18, 1927: 67,300 cfs	-Late 1920s: Cotton becomes dominant crop in Buckeye Valley		-1921: Gillespie Dam (Gila R.) -1923: Ashurst-Hayden Dam (Gila R.) -1926: Mormon Flat Dam (Salt R.) -1927: Pleasant Dam (Salt R.) -1927: Horse Mesa Dam (Salt R.) -1928: Coolidge Dam (Gila R.)
1930s	-Feb 11, 1932: 44,500 cfs -Feb 9, 1937: 45,800 cfs -Mar 5, 1938: 60,000 cfs			-1930: Stewart Mtn. Dam (Salt River) -1939: Bartlett Dam (Verde River)
1940s	-Mar 16, 1941: 45,800 cfs	1949: First sand and gravel mining evidence from aerial photography		-1946: Horseshoe Dam (Verde River)
1950s		-1953: Estrella Mtn. Regional Park established		-1959 Painted Rock Dam
1960s	-Jan 2, 1966: 64,200 cfs		-1969: original State Route 85 Bridge	
1970s	-Mar 3, 1978: 92,900 cfs -Dec 20, 1978: 125,000 cfs			
1980s	-Feb 16, 1980: 178,000 cfs -Feb 10, 1983: 39,800 cfs -Oct 5, 1983: 95,200 cfs		-Early 1980s: FCDMC 1000 ft. corridor clearing project -1981: Tuthill Road Bridge -1982: Bullard Ave. Bridge -1987: Estrella Pkwy. Bridge	
1990s	-Jan 9, 1993: 130,000 cfs -Feb 16, 1995: 50,000 cfs		-1995: State Route 85 Bridge	-1992: New Waddell Dam (Agua Fria River) -1993 Gillespie Dam breached during flood
2000s				

Historic and modern agriculture within the Buckeye Valley (1870s–2000s)

Sand and gravel mining within the Buckeye Valley (1940s–2000s)

1 Source: Annual peak discharge values, USGS Gage #09519500 below Gillespie Dam
2 Source: Tellman, et al. (1997)
3 Source: Rogers (2002)
4 Source: Arizona Stream Navigability Study for the Upper Gila and San Fransisco Rivers (ASLD, 1997)
5 Source: Arizona Stream Navigability Study for the Gila River: Colorado River confluence to the Town of Safford (ASLD, 2003)
6 Source: As-Built and Plan Engineering Documents
7 U.S.G.S. Water Supply Paper Number 1313, p. 595

Table 4. Temporal chronology

Dams

The Gila River has been affected by the construction of dams beginning in 1908, when construction of Roosevelt Dam on the Salt River was begun. Gillespie Dam, located approximately 15 miles downstream of the study reach, was completed in 1921 for irrigation diversion. The dam was breached during floods in 1993 and has not been repaired. In 1923 the Ashurst-Hayden Dam (approximately 65 miles upstream of the study reach) was completed for the purpose of diverting irrigation water to farmers in the Florence-Casa Grande area. Coolidge Dam (approximately 145 miles upstream from the study reach) was completed in 1929 and presently serves as the only large storage dam on the river. The last major dam on the Gila River main stem, Painted Rock Dam, was completed in 1959 by the U.S. Army Corps of Engineers. Painted Rock Dam (approximately 50 miles downstream of the study reach) was designed as a flood control structure for the lower Gila River and lower Colorado River. Figure 11 compares historic and modern sites along the Gila River including some dam locations. Dam construction within the Gila River watershed has resulted in a reduced surface water supply and reduced peak flood discharges. Table 5 lists the dams within the watershed and their associated watercourse.

Table 5. Dams in the Gila River watershed

Dam	Watercourse
Ashurst-Hayden Dam	Gila River
Painted Rock Dam	Gila River
Coolidge Dam	Gila River
Horseshoe Dam	Verde River
Bartlett Dam	Verde River
Theodore Roosevelt Dam	Salt River
Horse Mesa Dam	Salt River
Mormon Flat Dam	Salt River
Stewart Mountain Dam	Salt River
Granite Reef Dam	Salt River
New Waddell	Agua Fria River

The following statement from Hugo Farmer, presented at a state congressional hearing in 1941, summarizes the impacts of dams on the river, ground water quality, and agriculture:

> *By the first of the year 1931, five storage dams had been completed on the Gila River and its tributaries...and such dams...cut off the fresh water supply which normally fed the underground waters beneath the [Gila] project lands. Within 3 years thereafter the water in many of the district wells became highly impregnated with soluble salts, and since that time, excepting only during the year 1941...the water in the district wells has become increasingly salt ...and average 6,300 parts per million. This brought about the abandonment of many formerly prosperous farms...At present the farmers, because of the extremely salty water, are limited to the production of Bermuda grass and alfalfa...* (Tellman et al., 1997)

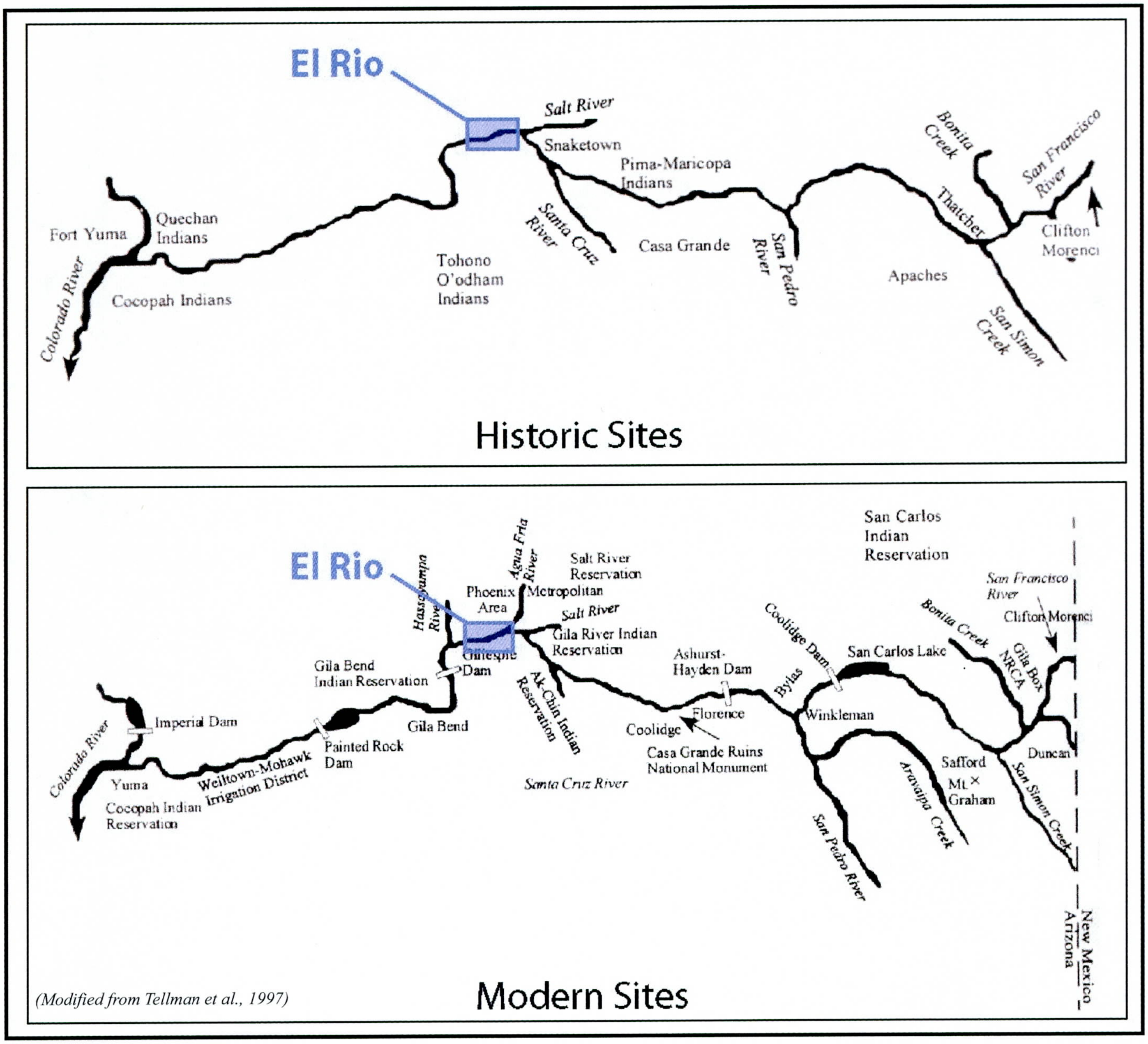


Figure 11. Historic and modern sites along the Gila River

Agriculture

A summary of the detailed analysis of the agricultural history of the Gila River in Tellman et al. (1997) is provided below. The prehistoric Hohokam people began forming communities along the main stem of the Gila River 2,000 years before settlement by Anglos in the late 1800's. The Hohokam used hand-dug canals to divert perennial runoff to large agricultural areas located on low floodplain terraces. The Hohokam settlements lasted until the mid to late fifteenth century. At the time of Anglo exploration of the Phoenix Valley, Pima Indians had settled near the Salt-Gila confluence and relied on the river for subsistence. The presence of these prehistoric people and their more modern descendants indicates a relatively consistent water supply from the Gila River, but constant struggles with shifting river channels, stream bed elevations, and floods.

By the late nineteenth century Anglo-Americans began settling the Gila River corridor. Cattle grazing soon depleted the native grasslands in the upper headwaters. Grazing coupled with drought resulted in increased erosion in the upper basin. The completion of a canal in 1887 near Florence diverted nearly 100% of the river's low flow out of the system, devastating the crops of the Pima Indians located downstream of the diversion. The result of the diversion was a thin, narrow river with sporadic wetland areas. These areas were later cleared and drained for cultivation, many of which have experienced severe damage and/or erosion by large magnitude flooding. Active cultivation remains a thriving practice along much of the Gila River corridor, including along the El Rio study reach. Encroachment of agricultural fields into the prehistoric river corridor has narrowed the apparent active channel corridor and resulted in periodic loss of agricultural lands to river migration.

Photographic evidence of agricultural encroachment into the active river corridor is provided in the Maps Exhibits in Appendix B. Soils mapping shown in Figure 8 also shows that agriculture in the geologic floodplain north of the existing regulatory floodplain occurs on areas formerly dominated by riverine processes.

Sand and Gravel Mining (1937-2004)

History

The extent of sand and gravel mining in the study reach was documented using historic aerial photographs. Areas of sand and gravel mining or excavations, and areas of rock processing were delineated on digital aerial photographs, as shown on Figure 12 for the period 1937-2004.

The largest and most continuous aggregate mining area in the El Rio study reach is near the abandoned community of Allenville which was located south of downtown Buckeye between Miller and Cemetery Roads. The mining activity in this location was most active in the western portion of the area until the 1990's when extensive expansion of the operation began in the eastern area (Figure 13).

There has been some level of aggregate mining within the active channel corridor of the study reach since at least 1949. Active mining is present today and will likely continue in some form in the future. Table 6 lists a general summary of mining activity for the El Rio study reach.

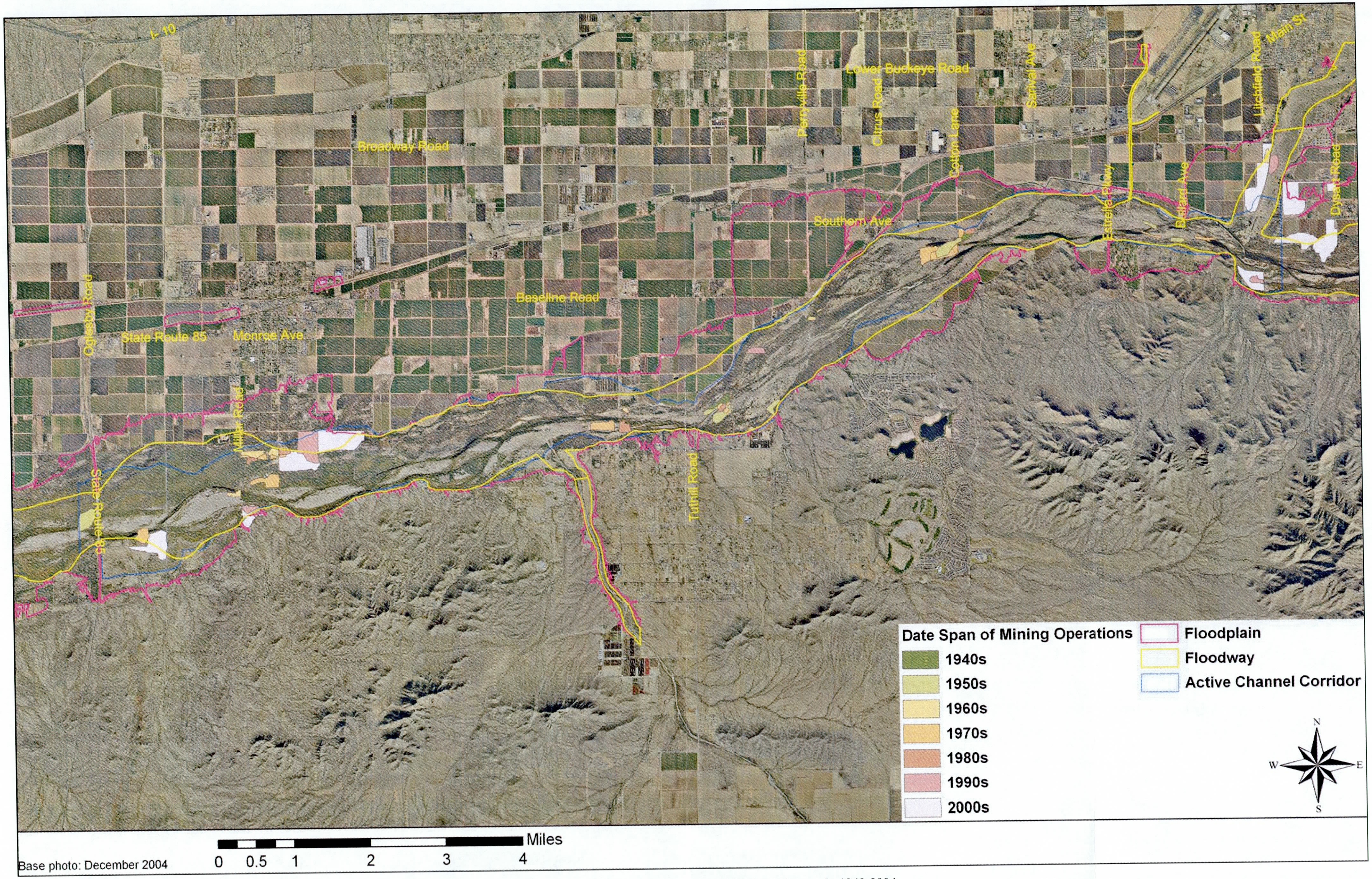


Figure 12. Sand and gravel mining in the El Rio study reach, 1949-2004

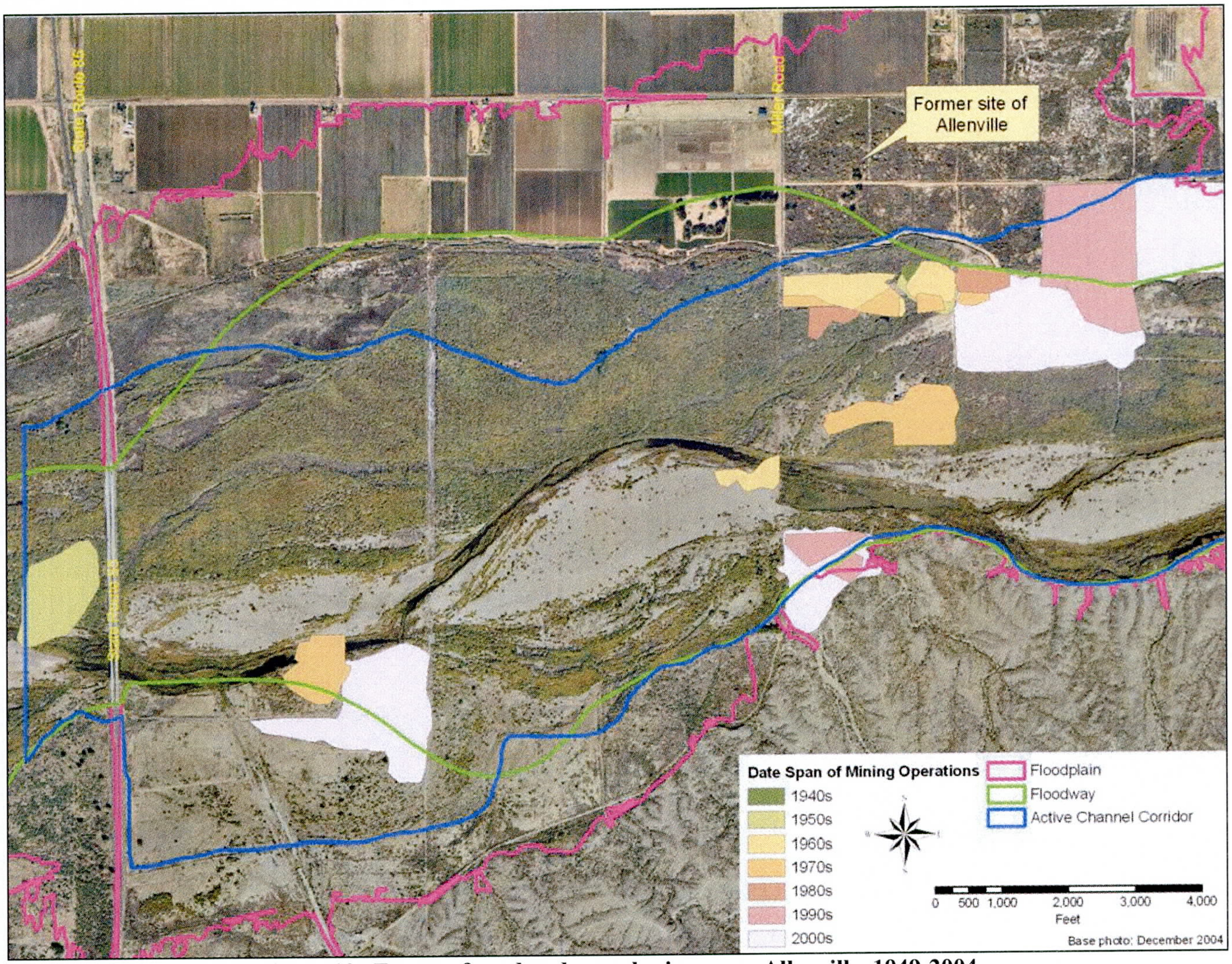


Figure 13. Extent of sand and gravel mines near Allenville, 1949-2004

The earliest excavations for sand and gravel appear in the 1949 photographs. No evidence of sand and gravel operations was evident in the 1937 aerial photos. The extent of aggregate excavation in 1949 is limited both in the number and the total area of pits and operations. The excavation style in the oldest operations differs from modern operations, in that they appear to be relatively shallow. By 1958 another excavation pattern appears, with a star or clam shell appearance (Figure 14). These configurations are probably due to the nature of the machinery available for economical excavation at that time. At least some of the excavations appear to have been related to the construction of roads and/or bridges across the Gila River. Additional excavations appear near the current State Highway 85 crossing in the 1958 photos (Figure 15). The 1958 photos are the first set to show a roadway present at the State Highway 85 alignment. At Jackrabbit Trail, some activity is apparent in 1949, but the more significant activity is seen in 1958 when a new road was constructed over the river (Figure 16). This road was later replaced by the Tuthill Road Bridge.

Table 6. El Rio study reach mining history				
Mining Evident in Photo Record (year)	Total number of Mines[3]	Mine Type(s)	Approx. Total Area Mined (acres)	Number of Mines Still Active in 2004[4]
1949	5	pits, shallow pits, areas of disturbance	35	0
1958	11	pits, shallow pits, stockpiling	115	0
1964	7	pits, shallow excavation, processing, area of disturbance	48	0
1971	5	pits	24	0
1977	15	pits, processing, stockpiling, possible excavation	109	1
1978	3	pits, processing	12	1
1979	1	pit	5	0
1983	4	pits, stockpiles	22	0
1986	2	pits, processing	12	1
1991	1	pit	33	1
1997	4	pits, processing, stockpiles	74	4
2002	10	pits, processing, sample trenches, stockpiles	272	7
2004		Pits, processing, sample trenches, stockpiles	627	6

Presently there are over 90 individual land parcels with past or current aggregate mining, six active operations, and an increasing number of pending sand and gravel permit applications. Figure 17 identifies the locations of the pending applications as of August 2005.

Potential Impacts of Sand and Gravel Mining on Lateral Stability

Adverse impacts of sand and gravel mining on channel geomorphology have been thoroughly documented (Bull et al., 1974; Collins et al., 1990; Kondolf, 1997; Scott, 1973; and others). Three specific processes related to in-stream mining are of primary interest to the channel stability assessment: headcutting, lateral erosion, and long-term degradation. The District's Sand and Gravel Miing Floodplain Use Permit Application Guidelines (JEF, 2003a) document case histories where these types of river impacts have occurred. Any of the case history scenarios in the District Guidelines are applicable to the El Rio study reach.

[3] Source – Interpretations of aerial photography from 1937 through 2004

[4] The number of mines observed in the year indicated in the first column still in operation in 2004 (as interpreted in the 2004 orthophotography).

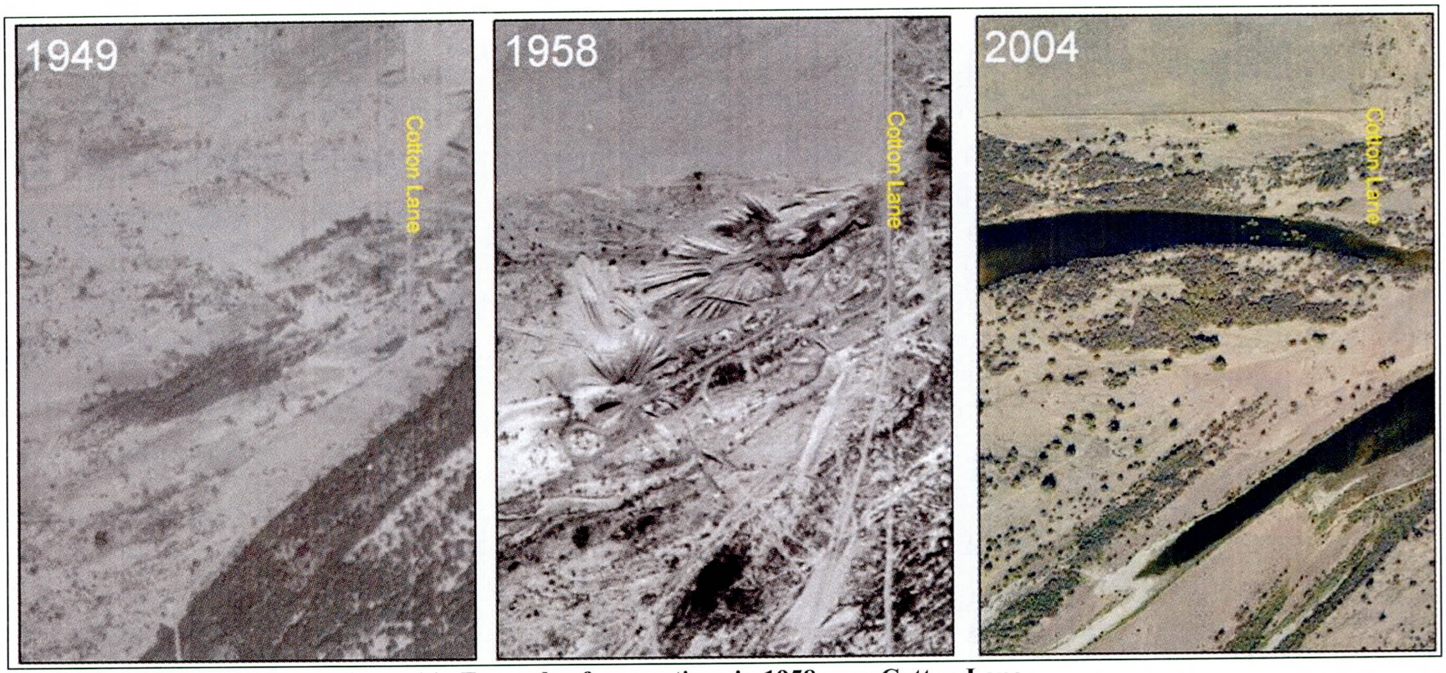


Figure 14. Example of excavations in 1958 near Cotton Lane

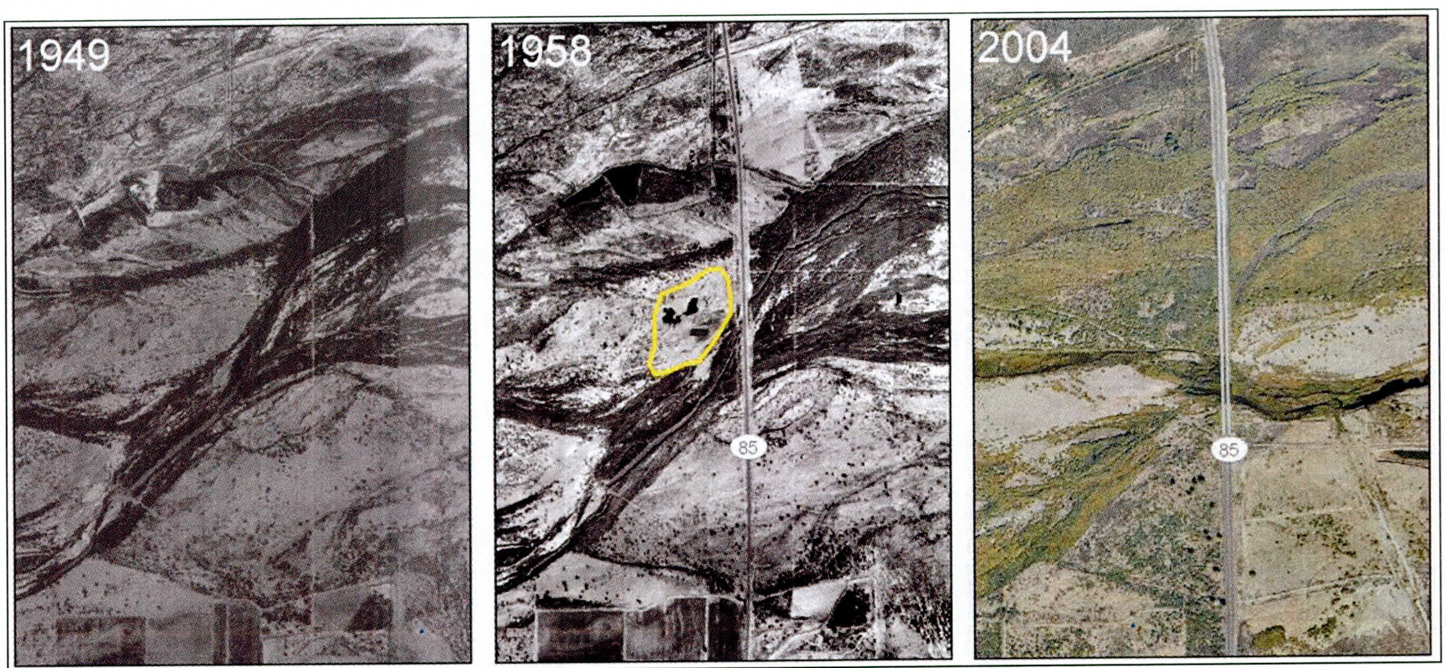


Figure 15. Sand and gravel operations near State Highway 85

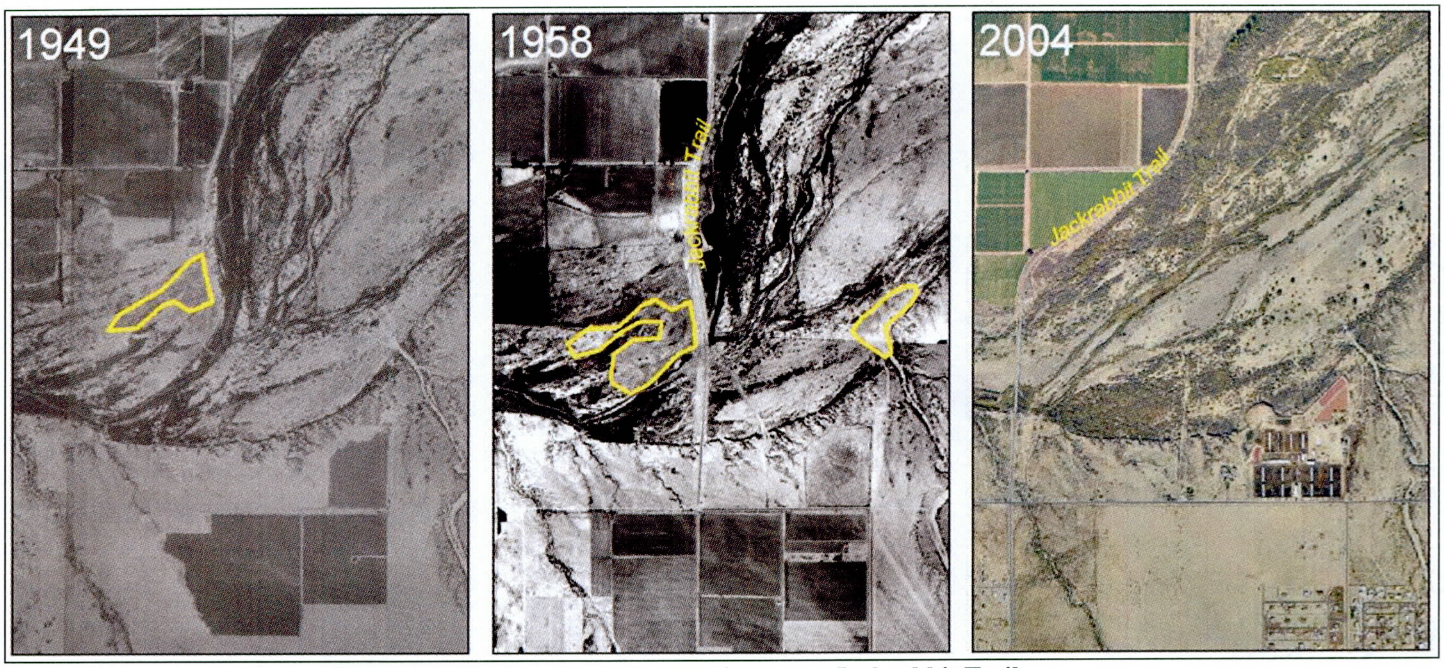


Figure 16. Sand and gravel operations near Jackrabbit Trail

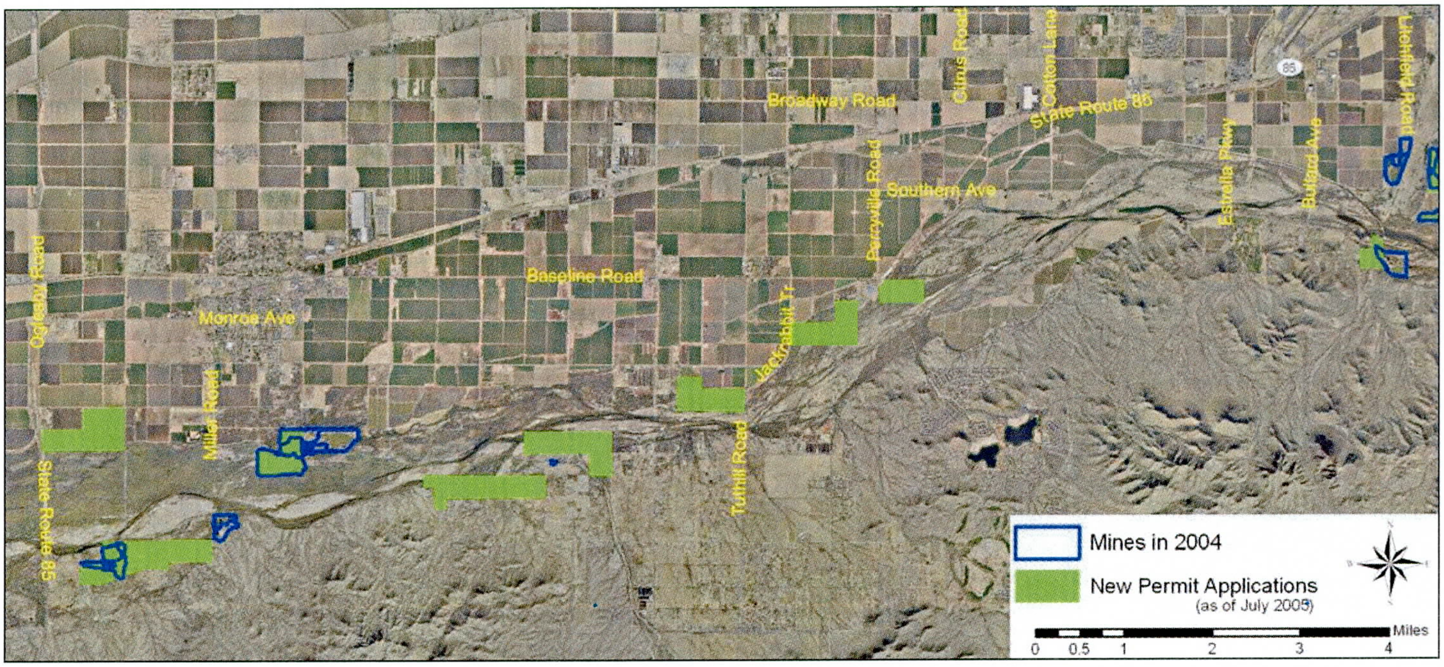


Figure 17. Pending sand and gravel mine permits

SUMMARY

Study area characteristics relating to the regional geology, soils, hydrology, and human impacts were presented in Chapter 2. The following are some of the findings relevant to prediction of lateral stability of the Gila River within the El Rio study reach:

- The study reach lies within a broad alluvial valley composed of deep riverine alluvium. Bedrock control exists along the south side of the river corridor, but no geologic control exists along the north side of the river.
- Surficial geologic mapping provides an outer bound to active river processes within the past 10,000 years at the boundary between Holocene (Qy) and Pleistocene (Qm) geomorphic surfaces. The Gila River formerly occupied an area nearly three times the regulatory floodplain width within the past 10,000 years.
- Detailed NRCS soils mapping further refines the outer boundary for modern river processes and indicates that areas currently outside and north of the regulatory floodplain were formerly part of the river corridor (overbank flow paths), but are now perched and isolated for the active floodplain
- Land subsidence and water table elevations have minimal direct impact on river morphology.
- Human impacts to the study reach include an altered hydrologic regime, floodplain encroachment, construction of bridges, and excavation of in-stream aggregate mines.
- The hydrologic regime of the Gila River has changed dramatically over the past 100 years. Changes included reduction of flood peaks and volumes, elimination of small floods, decreased base flow, changes in flow seasonality, and additional of small perennial effluent discharge.
- The net result of the altered hydrologic regime is decreased lateral stability, and a shift toward a more flood-dominated morphology.
- Sand and gravel mining, both within the active channel banks and in the floodplain of alluvial systems was present since 1949, but has recently increased in land coverage and numbers of mines. Adverse impacts from in-stream mines are well documented for other river systems in the Southwest.

CONCLUSIONS

Construction of dams, agricultural diversion, development encroachment, introduction of non-native vegetation, and sand and gravel mining have significantly impacted the Gila River's form and function. Most of these impacts have occurred relatively recently. The river will continue to respond and adjust to these impacts in the future. The existing characteristics of the river through the El Rio study reach provide information vital to understanding the nature and geographic location of erosion hazards along the river and its floodplain. An understanding of these characteristics along with the river's geology and history will greatly facilitate definition of the extent and magnitude of future erosion hazards. This history and its relevance to future erosion hazards will be detailed in the remaining chapters of this report.

CHAPTER 3: HISTORICAL CHANNEL MOVEMENT

Channel change in a river system occurs by lateral migration (the lateral movement or meandering of the channel banks), channel widening and/or narrowing (change in channel width measured from bank to bank), or by adjustments of the stream bed elevation. Although one of these processes may be dominant, lateral channel change usually occurs from a combination of both. The Gila River within the El Rio study reach has experienced extensive historical lateral movement, both by lateral migration and channel width changes. This Chapter describes quantitative and qualitative estimates of the magnitude of historical channel change in the study reach. The following types of information related to historical channel movement are presented in this Chapter:

- Archaeological Data
- Historical Data Sources
- Geomorphic Components of the Gila River Floodplain
- Lateral Migration Measurement
- Channel Width Change
- Vertical Channel Change
- HEC-6T Modeling Results

ARCHAEOLOGICAL DATA

El Rio Assessment

An archaeological assessment of the El Rio study reach was conducted by Scientific Archeological Services (SAS, 2002) as part of the El Rio WCMP. Information from SAS Report relevant to the LMAR included primarily the identification and location of prehistoric evidence on geomorphic surfaces adjacent to the river corridor. The SAS assessment identified a total of 133 archival sites within the study reach. Of the 133 total sites, 59 contain prehistoric evidence, all from the Hohokam Indians. Specific cultural themes were attributed to many of these sites: Canal Irrigation, Residential Life, Rock Art Production, and Resource Exploitation. Approximately 63% of the prehistoric sites are located within what SAS calls the northern and southern stream terrace of the Gila River. The stream terrace was defined as follows:

> *stream terraces ... typically border drainageways but, unlike them, they are only rarely subjected to overflow. The local stream terrace zone does include some rather narrow remnants situated immediately east and west of the Agua Fria River floodplain and immediately south of the Gila River. However, it is best represented by a very broad area that immediately parallels the northern edge of the Gila River channel and, quite consistently, is about 1.4 to 2.2 miles wide.* (SAS, 2002)

The SAS description of the stream terraces closely matches that of the AZGS Qy geologic unit (see Figure 3). The archeological assessment's significance to the LMAR is that it provides insight into the historic behavior of the Gila River. While it is unlikely that the Hohokam would have established a permanent settlement including a canal system in an area frequently subjected to flooding and channel erosion, the presence of evidence from the site 800 years later indicates that the site has not been subject to lateral erosion since abandonment. Therefore, the prehistoric site locations indicate that the Gila River occupied the same general footprint as exists today. This information, combined with geologic and soils evidence discussed in Chapter 2, extends the period of record of channel movement well beyond the photographic record summarized later in this Chapter, and aids in understanding the long-term behavior of the study reach.

JEF Observations

On October 14, 2002 JEF staff observed several trenches that had been excavated for archeological analysis related to Arizona Public Service (APS) power line tower construction. The trenches were located in the Gila River right-overbank floodplain just outside the compound channel limits (Figure 18), and were identified by the SAS assessment as the Alkali Ruin Residential Life cultural theme. Archeological evidence found included prehistoric roasting pits and irrigation canal remnants (Figure 19). Several roasting pits were found less than 6 inches below the modern surface (Figure 20). The date of Alkali Ruin is A.D. 1200-1300 (SAS, 2002). This information, combined with the shallow depth of the roasting pits, indicates minimal sediment deposition (i.e., minimal inundation since AD 1200) has occurred, and active channel processes have been absent for the past 700 years at this location. This information aids in determining the relative lateral extent of movement within the El Rio study reach.

HISTORICAL DATA SOURCES

Historical Photography

The methods used to assess the potential for lateral channel migration of the study reach relied in part on quantification of channel change observed on historical aerial photographs spanning the period from 1937 through 2002. Aerial photography is a valuable tool for characterizing geomorphic channel changes with time. Aerial photograph prints were collected, scanned and semi-rectified using ArcMap 8.2 GIS software. Table 7 lists the historic aerial photographs collected for the El Rio LMAR. A Historic Photo Comparison Exhibit book (Appendix B) was constructed for the purpose of providing a side-by-side comparison of the historic photographs. To facilitate the comparison of time periods, the study reach was divided into ten subreaches (Figure 21), each illustrated in side-by-side plots of the historic aerial photo coverage of that reach. Figure 22 is an example of a photo comparison sheet.

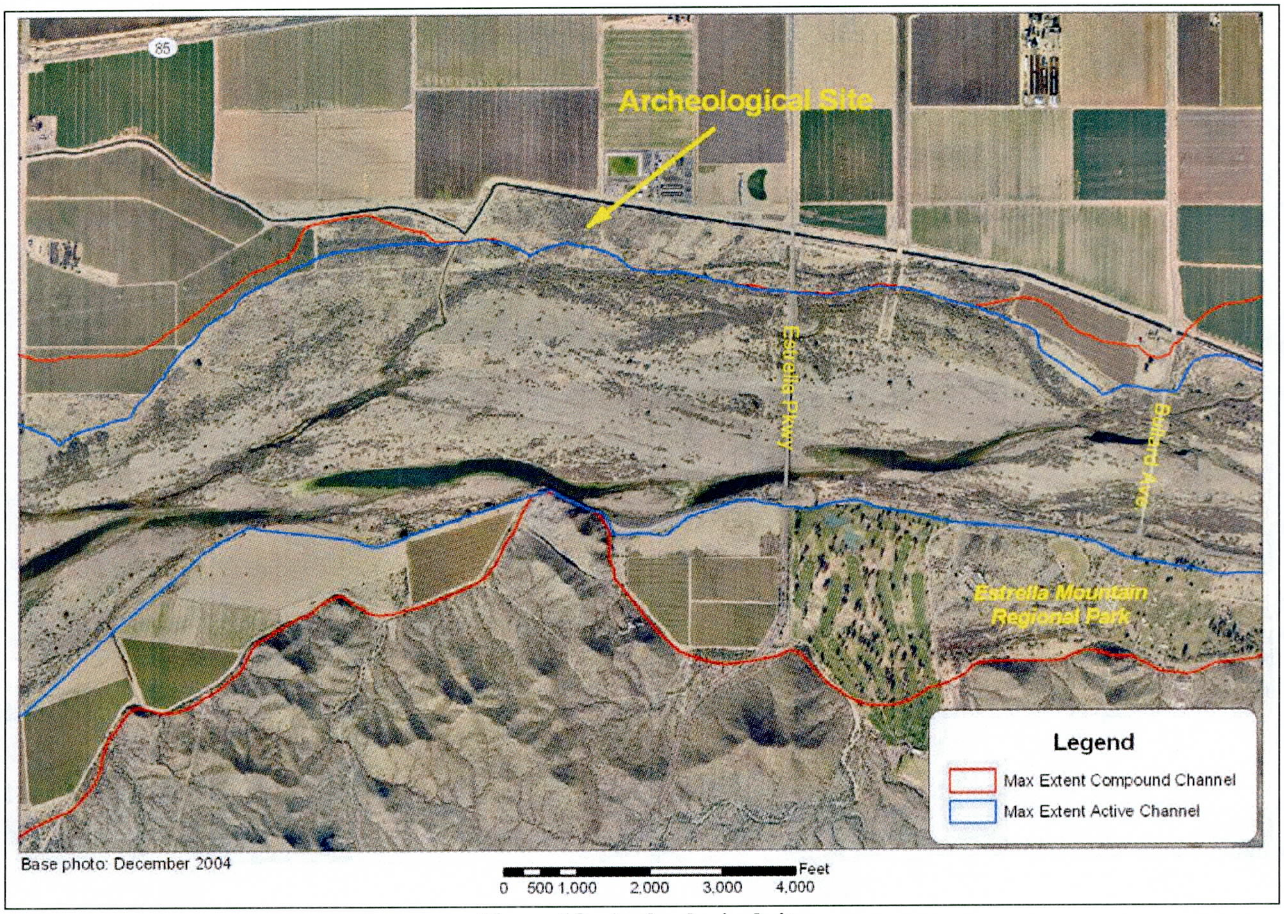


Figure 18. Archeological site

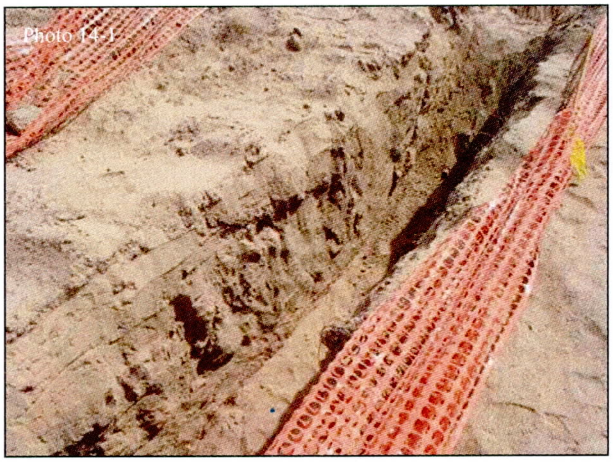


Figure 19. Trench dug for archeological analysis

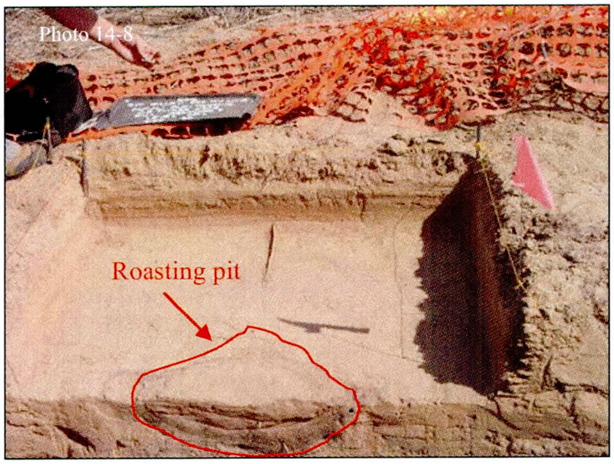


Figure 20. Example of prehistoric roasting pit

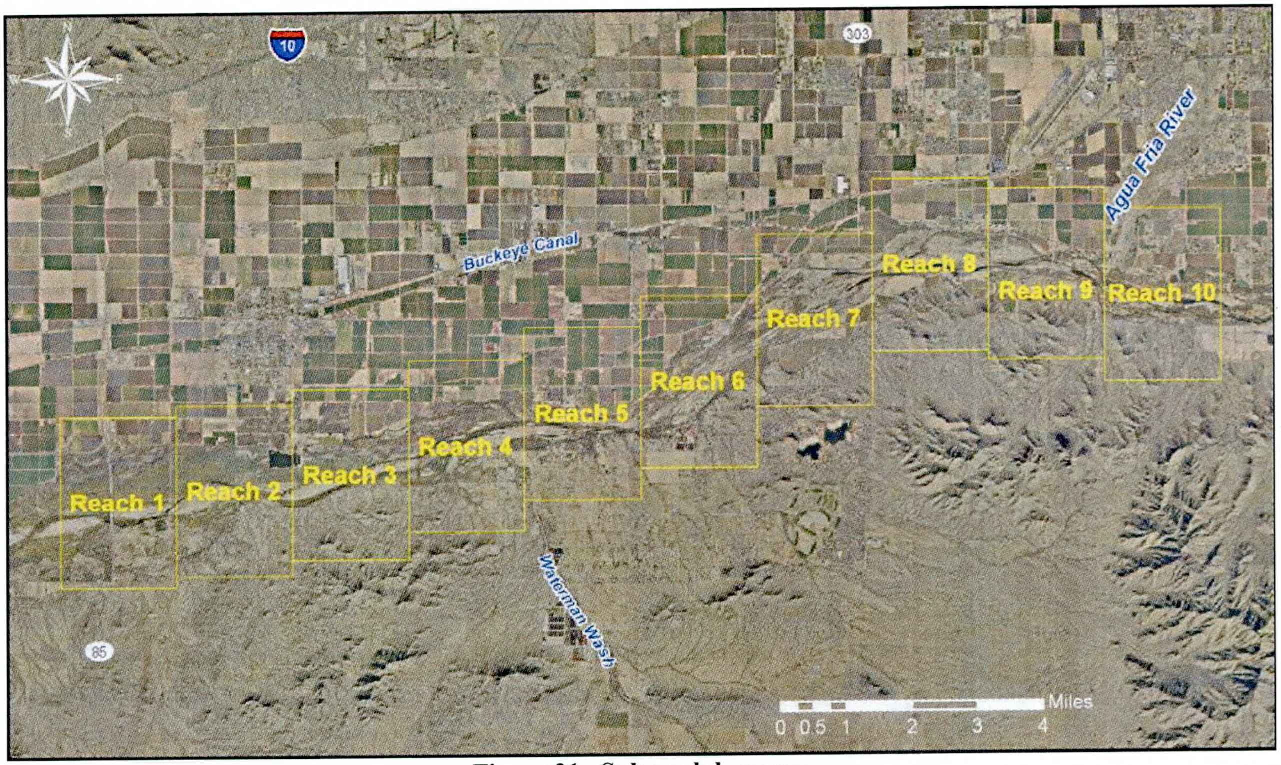


Figure 21. Subreach key map

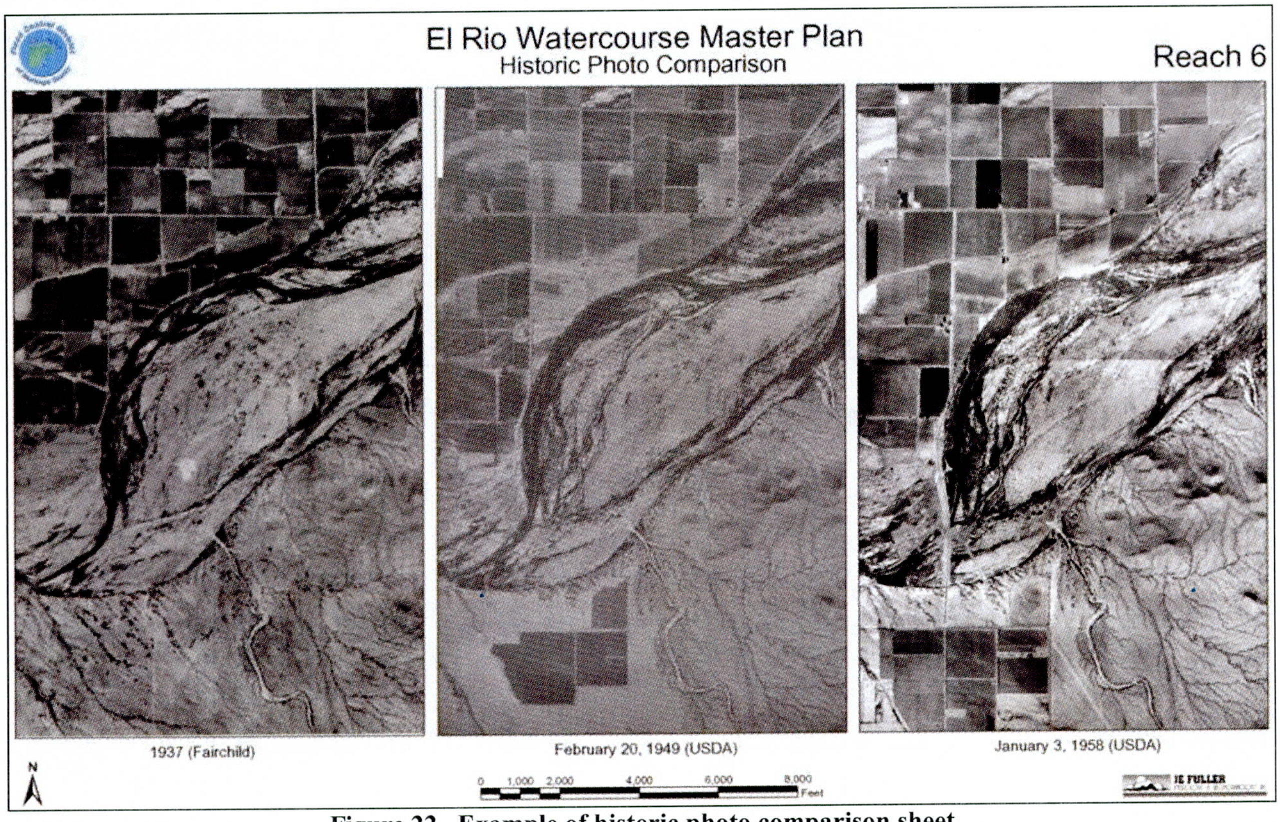


Figure 22. Example of historic photo comparison sheet

Table 7. Collected aerial photography			
Dates	Source	Acquired From	Scale
1937	Fairchild	ASU Map Room	1:24000
2/14/1949 2/20/1949 3/271949	USDA USDA USDA	National Archives & Record Administration	1:20000
1/3/1958 1/5/1958	USDA USDA	National Archives & Record Administration	1:20000
1/21/1964	USDA USDA	Agricultural Stabilization & Conservation Service	1:20,000
1971 (June)	USGS	ASU Map Room	1:78,000
12/1/1977 12/5/1977	Cooper Aerial Cooper Aerial	Cooper Aerial	1:20,000
6/11/1978 6/12/1978	Bureau of Land Management Bureau of Land Management	BLM, Denver	1:24,000
5/13/1979 6/9/1979	USDA USDA	USDA Aerial Photo Field Office	1:40,000
10/14/1983	NASA	USGS	1:31,222
1983 Oblique (Flood)	Aerial Mapping Co. Aerial Mapping Co.	Aerial Mapping Co.	Oblique
3/22/1985	Aerial Mapping Co.	Aerial Mapping Co.	1:31,680
11/20/1986	Aerial Mapping Co.	Aerial Mapping Co.	1:31,680
10/22/1990	USGS	USGS	1:16,000
6/7/1991	USGS	USGS	1:16,000
2/23/1992 4/18/1992 9/6/1992 9/28/1992	USGS USGS USGS USGS	ARIA Image Search	1:40,000
6/26/1993 6/27/1993 7/1/1993	USGS USGS USGS	USGS	1:16,400
4/30/1997 6/29/1997	USGS (NAPP) USGS (NAPP)	USGS	1:40,000
2/20&21/2002	Landata Airborne Systems	DISTRICT	Digital – 1ft pixel
12/3/2004	Landata Airborne Systems	DISTRICT	Digital – 1ft pixel

Aerial Photograph Semi-Rectification Error Analysis

The process of semi-rectification of historical aerial photographs is accomplished by identifying common ground features between the rectification photo of interest and the control data. For the LMAR, the control data were the 2002 orthorectified aerial photography provided by the District. Each digital historical aerial photograph was semi-rectified to the 2002 photos by identifying ground features common to both photo sets. Examples of ground features identified for the LMAR included distinct vegetation, historical buildings, road intersections, and canal crossings. Multiple points were identified on each photograph and were used to semi-rectify each historical photograph. The process of semi-rectification essentially warps the image to fit the control points defined using mathematical functions in ArcMap. Because this process is not orthorectification (which uses a digital elevation model to correct geometric errors inherent with photography caused by relief displacement, lens distortion, etc.), spatial errors remain on the semi-rectified photos.

The magnitude of these errors can be approximated by comparing the distance between ground features in the semi-rectified and orthorectified photos. At the request of the District, such a comparison was done for the LMAR to quantify the error associated with each set of historical photographs. Sixteen comparison points were identified within the study area, each having common ground features visible in every set of historical photos. Figure 23 shows the location of the comparison points. At each comparison point location, the distance between the ground feature on the 2002 photos and the ground feature on the rectified historical photo was measured. These distances represent the rectification error for each photo at this location, which are summarized in Table 8. The results shown in Table 8 can be considered a potential source of error in the historical channel bank delineation analysis described later in this report.

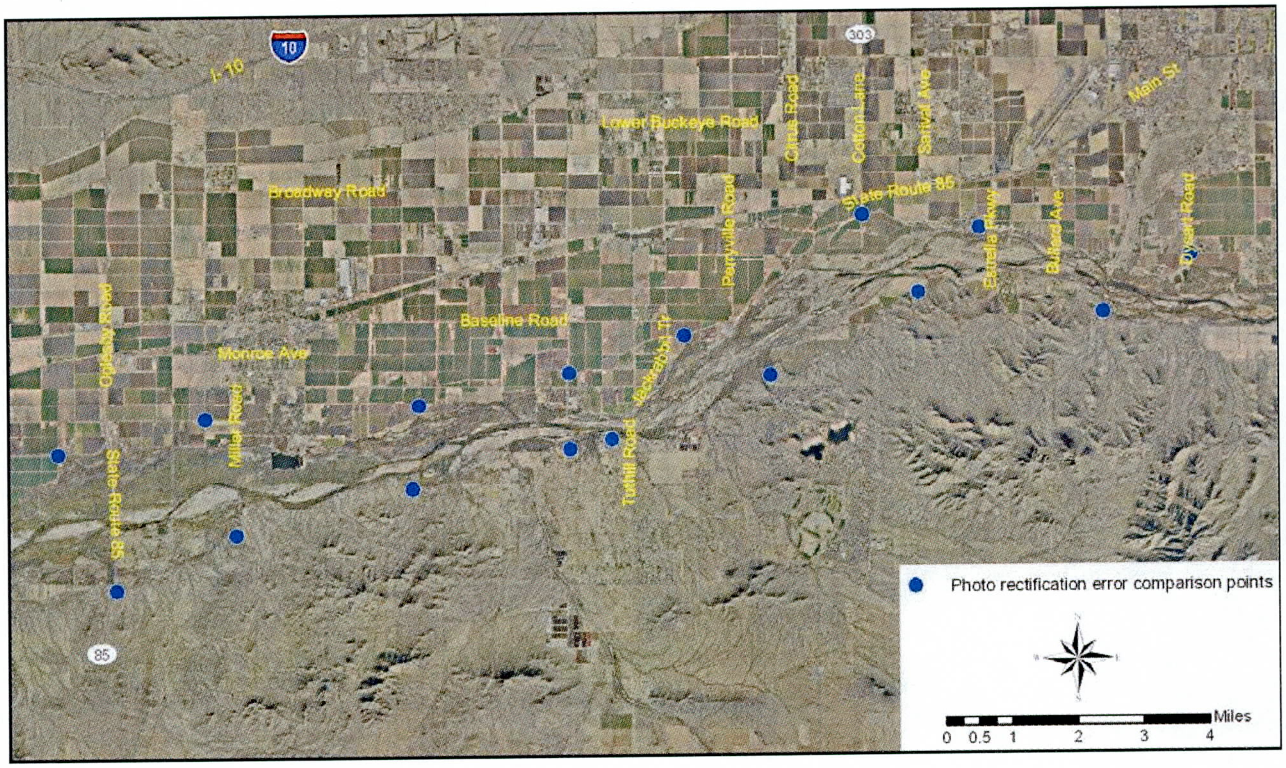


Figure 23. Photo rectification error comparison point locations

Measured bank erosion distances are described later in this Chapter and are graphically depicted in Appendix C. The magnitude of channel change measured from the historical photographs ranges up to more than 3,000 feet over the long term and more than 2,000 feet in response to single floods. The estimates of measurement error shown in Table 7 represent a maximum of 14% error for the worst case scenario, with an average error of about 2%. Given the other uncertainties associated with predicting future river behavior, the measurement error is not significant relative to the magnitude of measured lateral movement.

Table 8. Photo rectification error analysis results			
Photo Year	Mean Photo Rectification Error Within Study Area (ft)	Minimum Photo Rectification Error Within Study Area (ft)	Maximum Photo Rectification Error Within Study Area (ft)
1937	59	19	115
1949	26	3	45
1958	17	5	37
1964	18	6	54
1971	14	5	31
1977	41	2	285
1978	84	15	209
1979	52	10	116
1983	16	2	44
1985/1986	24	4	62
1992	15	6	31
1993	33	4	113
1997	14	2	38

Additional Historical Data

Additional historic data included General Land Office (GLO) survey plat maps from the late nineteenth century. Collected from the Bureau of Land Management (BLM) Phoenix office, these maps were scanned and semi-rectified and are also shown in the accompanying historic photo comparison book. The primary purpose for the GLO surveys was to establish section and subdivision lines, not river position; therefore their accuracy is high at the section boundaries and less accurate in-between, thus providing the general location of the river during the time of the survey.

Additional support data (both digital and hard copy) were collected from the following agencies, and have been cited where appropriate within this Report:

- Arizona Geological Survey (AZGS)
- Arizona State Land Department (ASLD)
- Arizona State University – Geology Department (ASU)
- Flood Control District of Maricopa County (DISTRICT)
- U.S.D.A – Natural Resources Conservation Service (NRCS or SCS)
- U.S. Geological Survey – Water Resources Division (USGS)
- U.S. Geological Survey – EROS Data Center (USGS - EROS)
- U.S. Bureau of Land Management (BLM)

GEOMORPHIC COMPONENTS OF THE GILA RIVER FLOODPLAIN

To facilitate the comparison of historical channel position data, three geomorphic components of the floodplain were compared: the thalweg, active channel, and compound channel (Figure 24). Each of these components was identified on the historic aerial photographs, and changes in the position of each feature were measured.

Thalweg

The thalweg is defined as the line connecting the lowest points along a stream bed or valley (Bates and Jackson, 1984). The thalweg was identified using the following criteria:

1. Flowing water. Low flow areas with flowing water, by definition, include the thalweg. The center of the wetted areas was delineated as the thalweg line.
2. Vegetation corridors. For dry channels, the thalweg was assumed to be located at the midpoint of corridors of bank vegetation, presumably left as remnants of the previous active low-flow channel.

Active Channel

The active channel is defined as the part of the floodplain that conveys low flows and is frequently inundated by small floods. For this study, the active channel corridor is defined as the lateral zone in which the low flow channel migrates. The active channel is subject to the most severe lateral erosion hazards, and may be swept clean of vegetation during small to moderate floods. The active channel banks are often bounded by a well-defined topographic break, a change from aquatic or riparian to terrestrial vegetation, and/or a change in sediment size.

Compound Channel

Compound channels, as defined by Graf (1988), have a low flow, meandering channel occupying a single thread (analogous to the above described thalweg), and wider "braided" high flow channel corridor containing several overbank channels. Graf concluded that compound channels form where the bimodal flow regime is dominated by nearly continuous low flows with a few high-discharge events that completely re-write the floodplain morphology. The compound channel corridor does not include portions of the geologic floodplain that are primarily depositional or subject to very shallow flooding that does not have the capacity to significantly modify the surficial geometry.

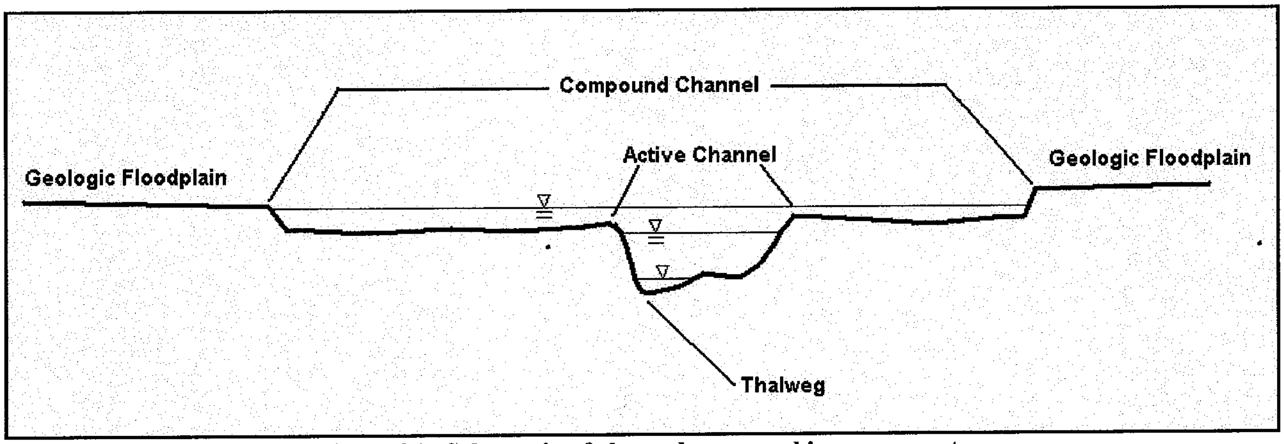


Figure 24. Schematic of channel geomorphic components

LATERAL MIGRATION MEASUREMENT

Historic aerial photography spanning most of the 20th century was used in both the lateral migration and channel width change analyses. The aerial photographs provide valuable insight into the geomorphic changes of the Gila River as well as a means to quantitatively assess lateral channel migration. Each of the three geomorphic components of the Gila River floodplain described above were evaluated independently for this analysis.

Compound/Active Channel Quantitative Analysis

To measure historical channel movement on the semi-rectified aerial photographs, a series of north-south oriented reference line segments (hereafter, "reach line segments") were created to segregate the study reach into 1,000 foot reaches for quantitative analysis. A total of 85 segments were delineated and used as a datum from which lateral channel change for each of the geomorphic components was measured (Figure 25).

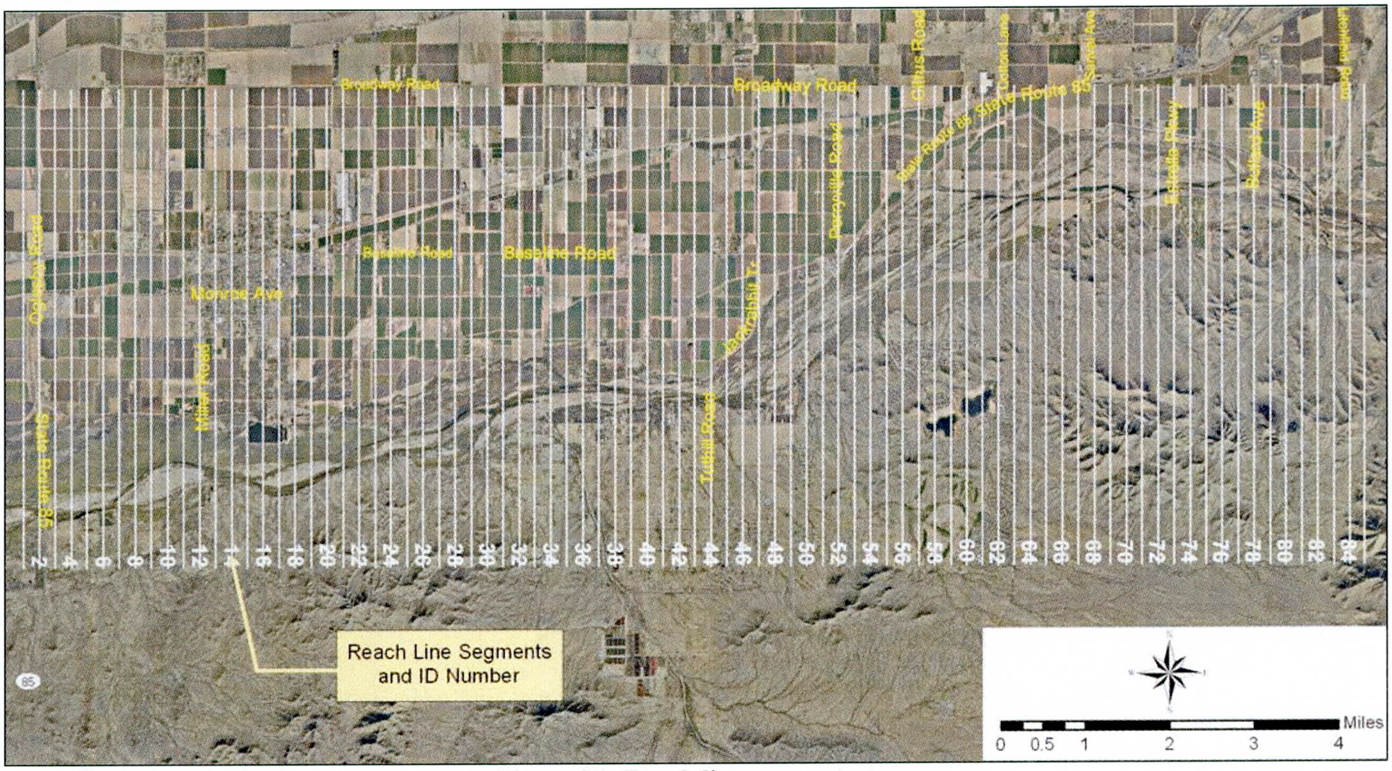


Figure 25. Reach line segments

Channel bank lines for the active and compound channels were delineated in ArcMap on each set of historical aerial photographs. Then a mean flow path line was delineated for both the active and compound channels by displaying the entire chronological set of channel bank delineations and plotting a best-fit mean flow path through the study reach, as illustrated in Figure 26. Separate flow path lines were created for the active and compound channel analysis.

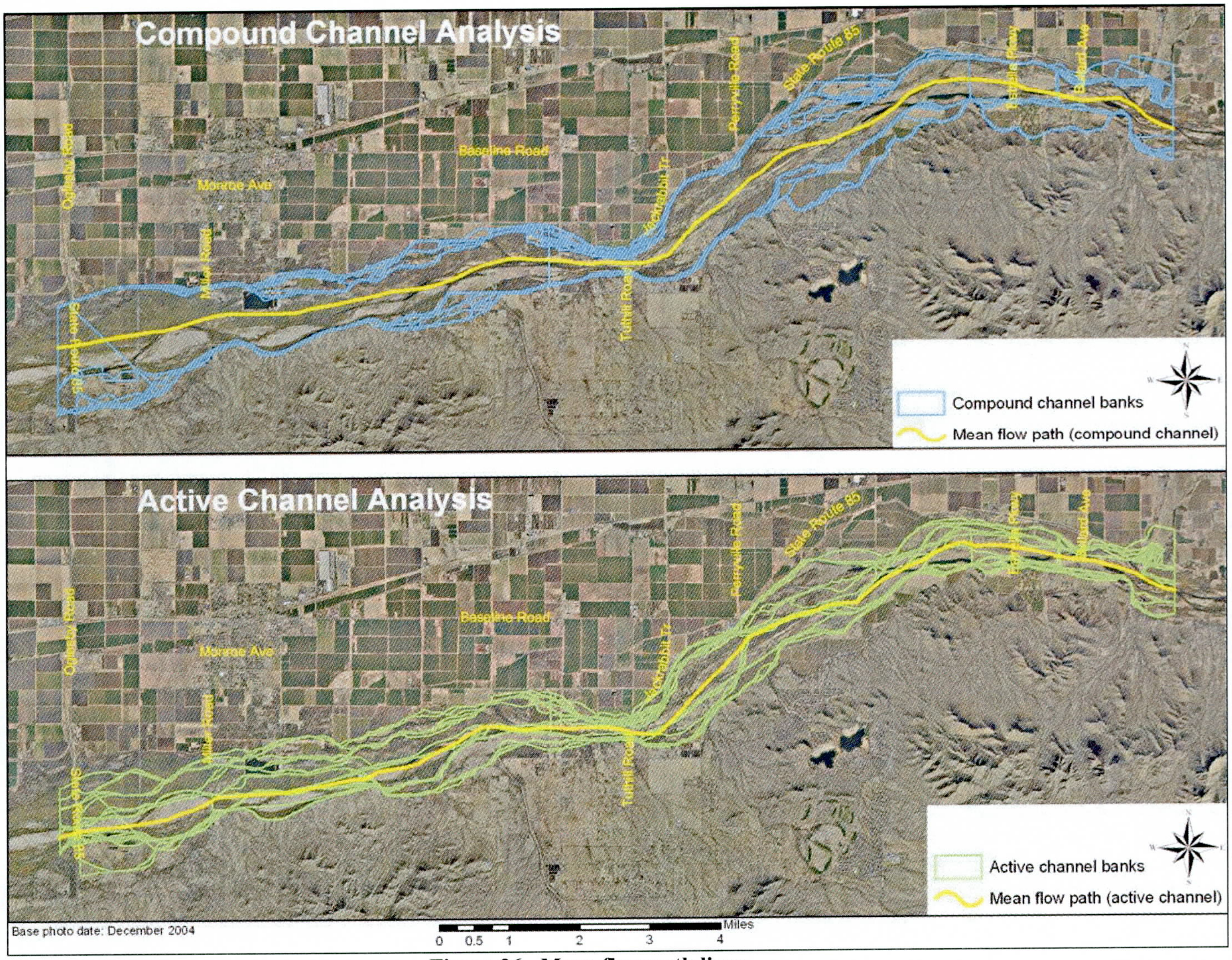


Figure 26. Mean flow path lines

Next, the distance of lateral migration was estimated on each set of historical photographs by measuring the distance at from the bank location to the mean flow path line at each reach line segment. The distance from the mean flow path line to the bank location was measured approximately perpendicular to primary flow direction. Measurements were made for both the left and right banks. This methodology was repeated for each subsequent year of aerial coverage. Figure 27 illustrates this methodology as applied to the 1992 compound channel.

Once the distance from the mean flow path to bank location was measured for each year of aerial coverage, the change in that distance between years of coverage was computed to determine the magnitude of channel movement. A positive change in either the left or right bank distance values indicated movement away from the thalweg. A negative change in the distance values indicated movement toward the thalweg. For example, the compound channel left bank distance at reach line segment #43 is 2,450.7 feet for year

1958 and 792.9 feet for year 1964. Subtracting the distance in 1958 from the distance in 1964 yields a change in distance of 1,657.8 feet, indicating the left channel bank migrated 1,657.8 feet toward the flow path line, or northward. The right bank distance at the same reach line segment is 459.6 feet for 1958 and 521.5 feet for 1964. Subtracting these values results in -61.9 feet, indicating the right bank has migrated away from the flow path line, or northward.

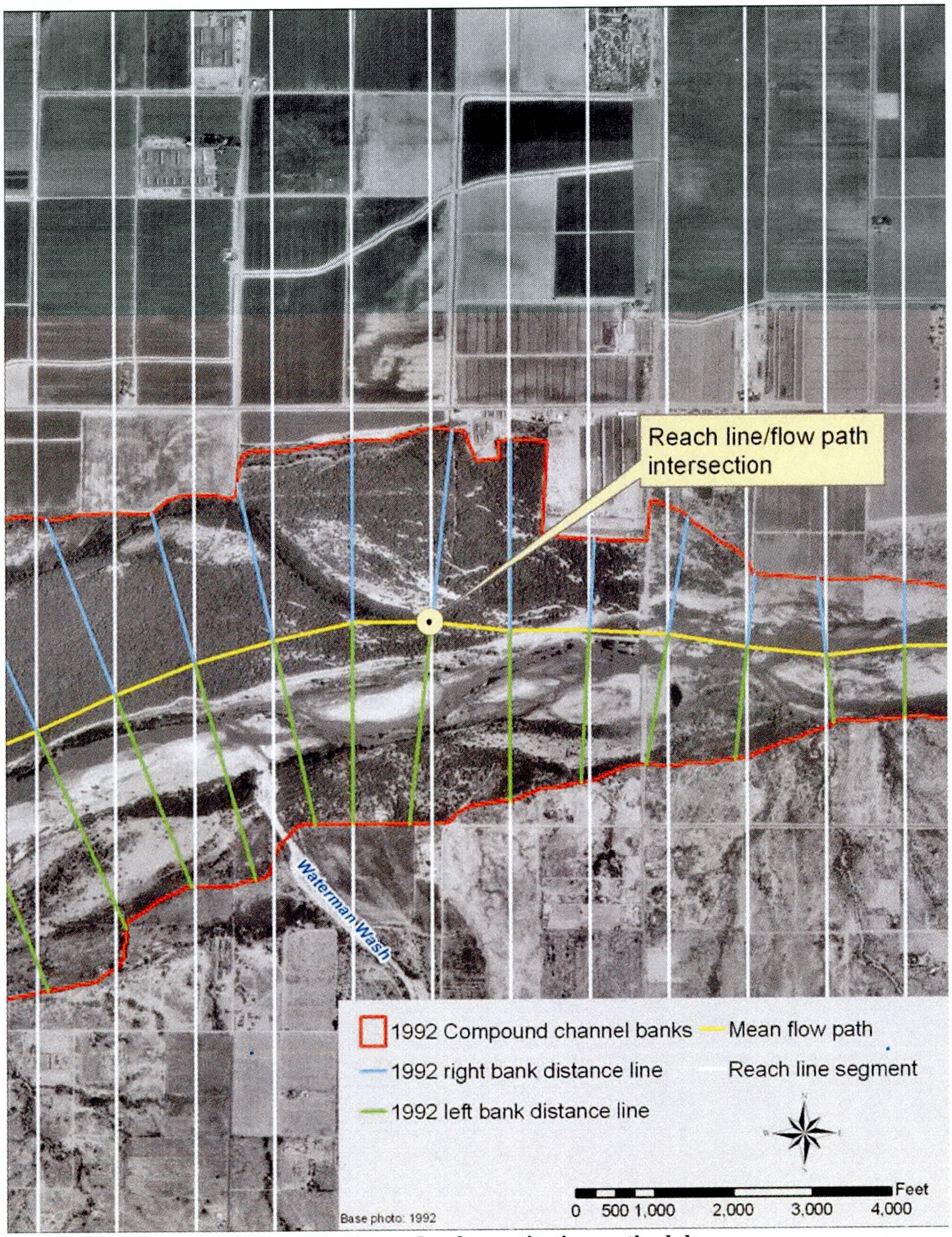


Figure 27. Example of quantitative methodology

Results and Interpretations

The compound/active channel lateral migration analysis results were plotted in a series of bar graphs attached in Appendix C. Sample plots for the compound channel left bank and active channel left bank analyses are shown in Figure 28 and Figure 29, respectively. Each bar plot represents a lateral change in channel bank position (northward, southward, or no change) and the magnitude of that change. Each year of photographic coverage is represented for every reach line segment in the study reach. For plotting purposes, the lateral migration analysis was divided into eight equal length subreaches.

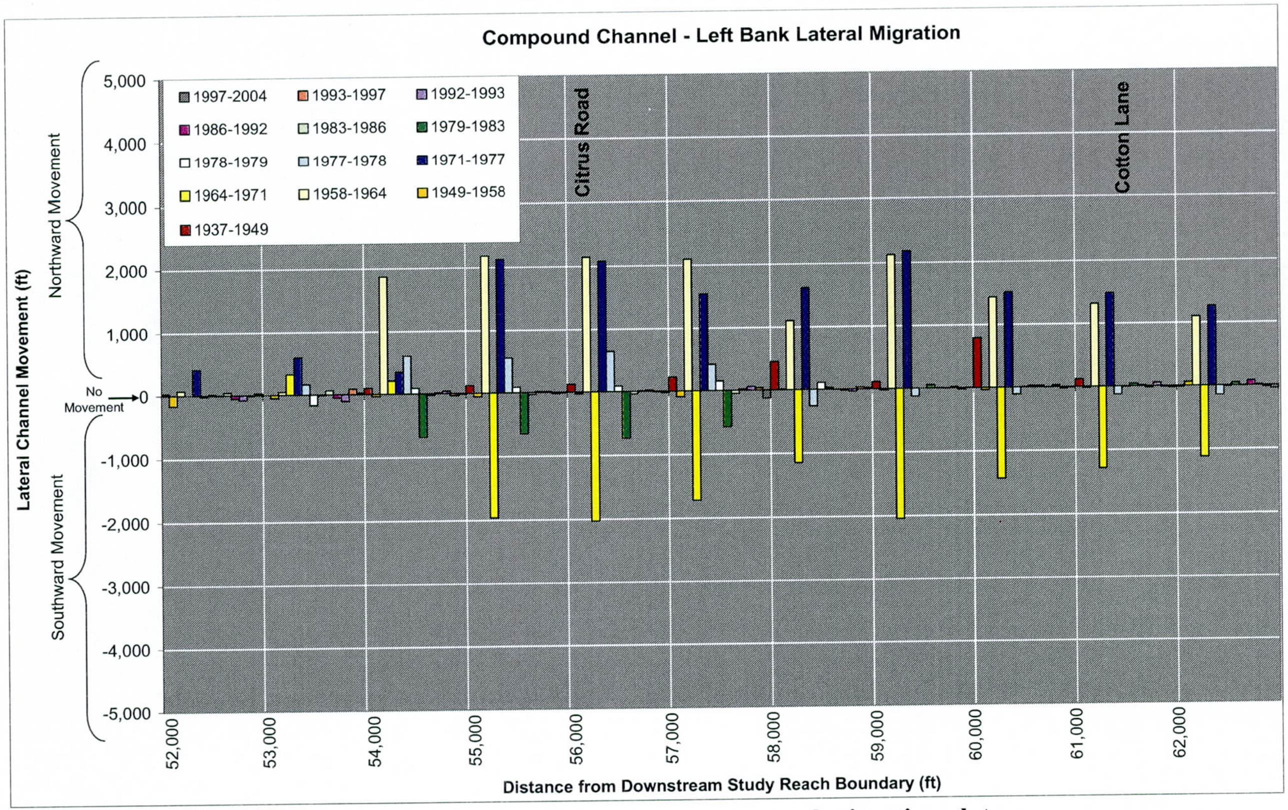


Figure 28. Sample compound channel lateral migration plot

Maximum Single-Event Change

The maximum single-event channel change for each reach line segment was extracted from the lateral migration analysis results for the purpose of identifying areas within the study reach that have experienced significant changes caused by a single flood. The results indicate that at one location the right bank of the compound channel moved more than 2,600 feet during the December 1978 flood. The left bank of the compound channel moved in excess of 3,100 feet during the same event. The maximum single-event lateral change of both the right and left banks of the active channel at a single location also occurred during the 1978 flood and had magnitudes of more than 3,100 feet and 2,900 feet, respectively. These results illustrate the dynamic nature of both the compound and active channels during large magnitude floods and provide insight into potential changes that can be expected during future flood events.

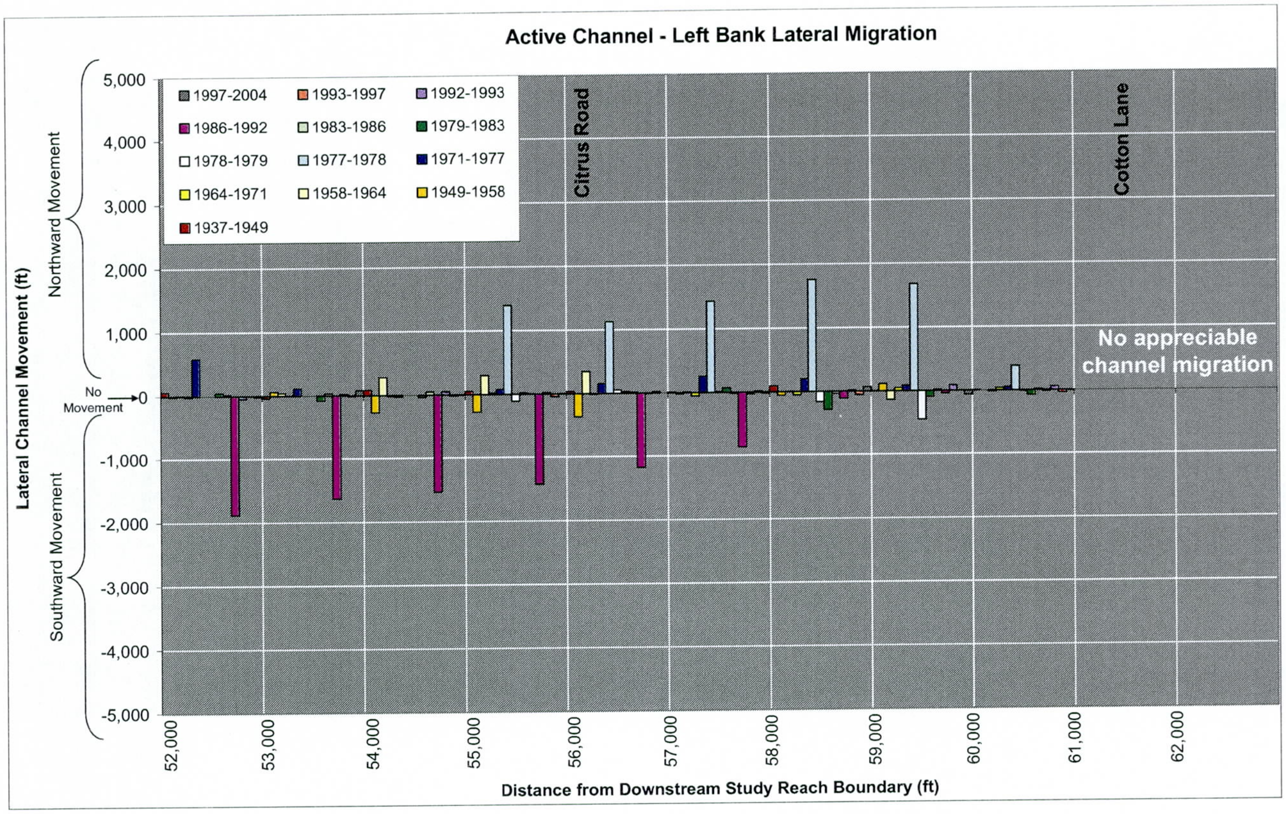


Figure 29. Sample active channel lateral migration plot

Net Channel Change

In addition to the maximum single-event changes in channel banks, the net change over the period of record at each reach line segment was measured for both the compound and active channels. The net channel change was determined by subtracting the distance between the bank location and mean flow path lines for the earliest year of photographic coverage and the most recent year of coverage. The result was the net change in channel position for the entire photographic record. These results aid in determining the long-term trends of channel migration. For example, the average of the net channel change for the entire right bank of the compound channel is approximately 137 feet in the northward direction with the left bank average net change of 515 feet in the southward direction. The average net change for the right and left banks of the active channel is approximately 500 feet in the northward direction and 280 feet southward direction, respectively.

Summary Analysis

The results of the maximum single-event change and the net channel change analyses are illustrated in the Lateral Migration Summary Plots attached in Appendix C. The 1937 aerial photographs only cover the eastern half of the El Rio study reach, therefore the net change analysis was divided into two segments: 1937-2002 and 1949-2002. Three primary causal mechanisms for single event channel changes were identified from aerial photo interpretation: flood events, anthropogenic encroachment, and the District's 1,000 foot corridor clearing project. One of these causal mechanisms was assigned to each maximum single-event based channel change per reach line segment in the Summary Plots. Identification of the causal mechanism of change provides insight into the characteristics of that change and aids in predicting areas of potential future changes. Table 9 summarizes the results of the lateral migration quantitative analysis by reach line segment and Table 10 summarizes the net channel change by reach line segment through the photographic record (1937-2004). Figure 30 and Figure 31 show the lateral migration summary analysis plots for both the active and compound channels for the entire study area. Within these plots, each line segment shows two bar graphs. The left bar shows the magnitude and direction of the net channel change. The bar color indicates the period of record (either 1937-2004 or 1949-2004, depending on the extent of the aerial coverage). The right bar shows the magnitude and direction of the maximum single-event channel change and the bar color indicates the aerial photo coverage set in which the change occurred.

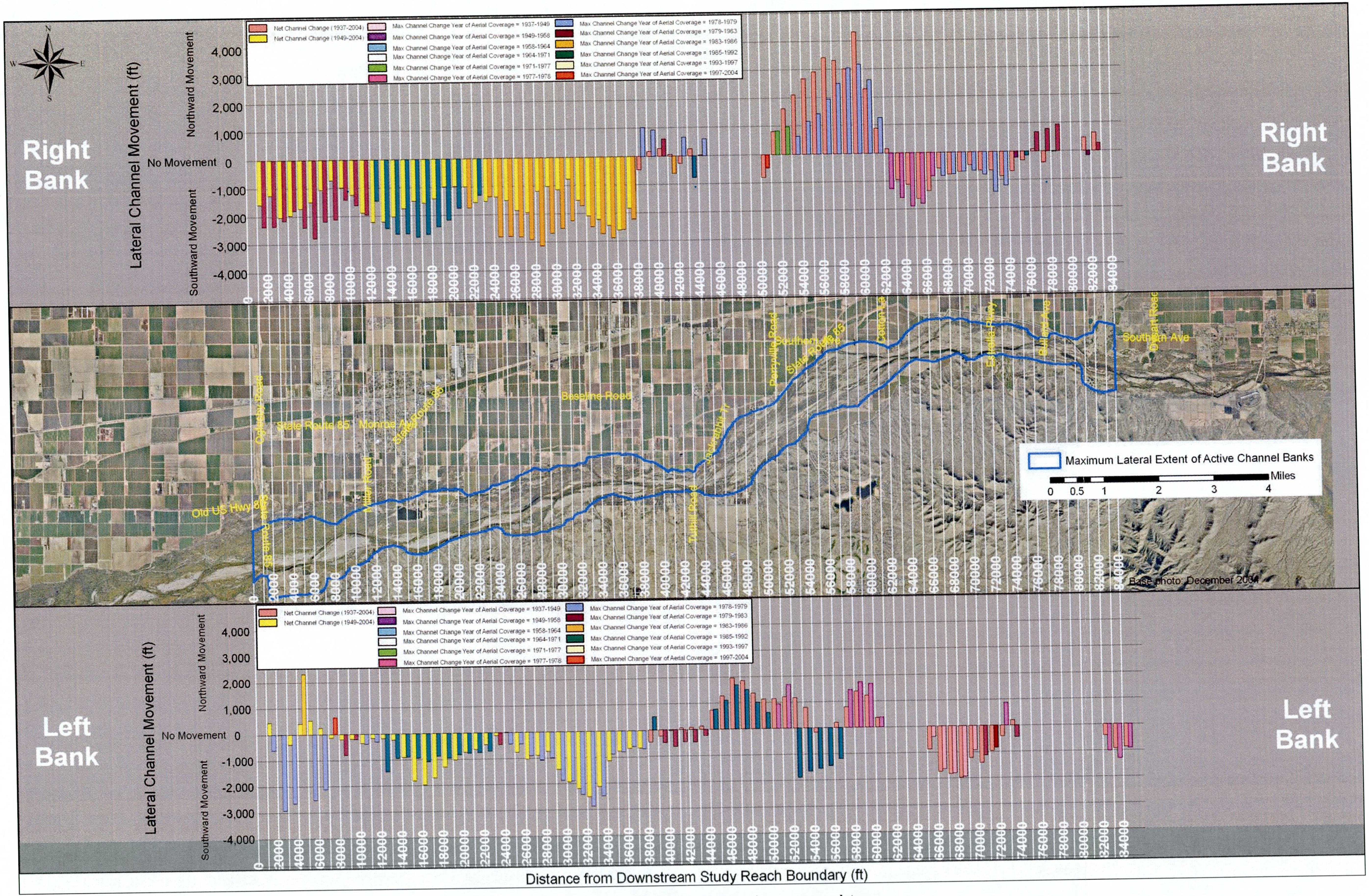


Figure 30. Active channel lateral migration summary plot

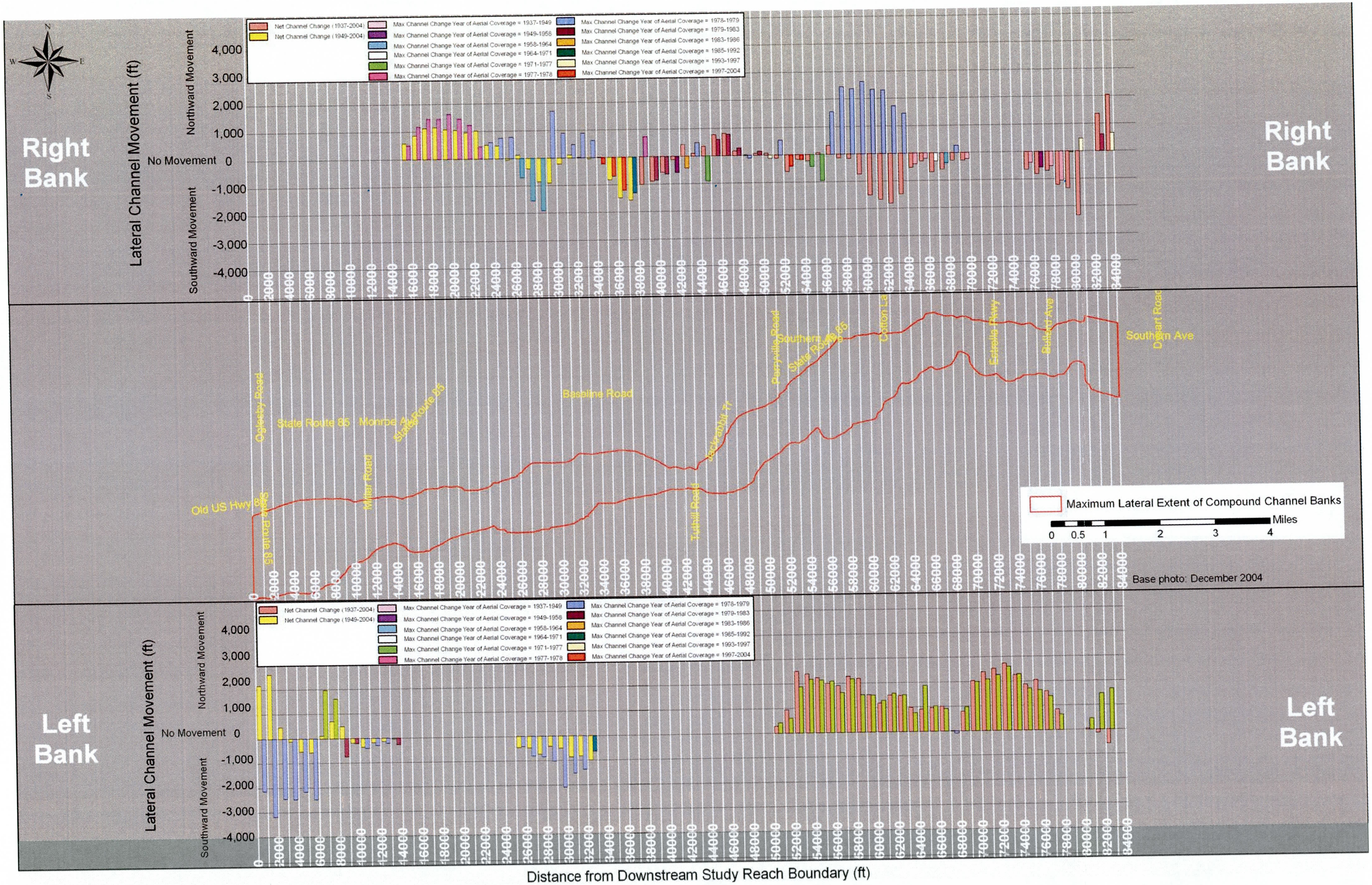


Figure 31. Compound channel lateral migration summary plot

Reach Line Segment (dist. from downstream study limit) (x 1,000 in ft.)	Compound Channel						Active Channel						Thalweg		
	Left Bank Max Movement[1] (ft)	Span of Occurrence (year)	Cause[2]	Right Bank Max Movement[3] (ft)	Span of Occurrence (year)	Cause[2]	Left Bank Max Movement[1] (ft)	Span of Occurrence (year)	Cause[2]	Right Bank Max Movement[3] (ft)	Span of Occurrence (year)	Cause[2]	Thalweg Max Movement[4] (ft)	Span of Occurrence (year)	Cause[2]
84	1660	1971-1977	A	0	-	B	-916	1977-1979	B	0	-	N	-2034	1971-1977	B
83	1463	1971-1977	A	-646	1993-1997	B	-1293	1977-1979	B	-273	1979-1983	B	-2129	1971-1977	B
82	446	1971-1977	A	-600	1979-1983	B	-1013	1977-1979	B	172	1949-1958	A	-2218	1971-1977	B
81 (Agua Fria River Confluence)	Agua Fria River Confluence												-1202	1992-1993	B
80	0	-	N	-462	1993-1997	B	0	-	N	0	-	N	1644	1964-1971	A
79	621	1949-1958	A	30	1985-1992	B	0	-	N	-934	1979-1983	B	2479	1964-1971	A
78	1371	1949-1958	A	1063	1937-1949	A	0	-	N	-784	1979-1983	B	1961	1964-1971	A
77 (Bullard Ave. Bridge)	1625	1949-1958	A	518	1937-1949	A	0	-	N	-675	1979-1983	B	1636	1964-1971	A
76	1704	1949-1958	A	567	1949-1958	A	0	-	N	141	1985-1992	A	1625	1964-1971	A
75	2293	1949-1958	A	388	1937-1949	A	0	-	N	212	1949-1958	A	-1776	1977-1978	B
74	2598	1949-1958	A	0	-	N	0	-	N	1202	1978-1979	B	-2145	1977-1978	B
73	2267	1949-1958	A	0	-	N	-441	1979-1983	B	1415	1978-1979	B	-1575	1977-1978	B
72 (Estrella Pkwy. Bridge)	2095	1949-1958	A	0	-	N	877	1977-1978	B	804	1978-1979	B	-1409	1978-1979	B
71	2002	1949-1958	A	0	-	N	-846	1979-1983	B	654	1978-1979	B	-1304	1978-1979	B
70	974	1949-1958	A	0	-	N	-1114	1979-1983	B	681	1978-1979	B	-1754	1977-1978	B
69	-85	1978-1979	B	226	1937-1949	A	-919	1937-1949	B	778	1978-1979	B	-2597	1977-1978	B
68	909	1971-1977	A	-257	1978-1979	B	-1931	1937-1949	B	836	1978-1979	B	-3133	1977-1978	B
67	1022	1971-1977	A	353	1958-1964	A	-1791	1937-1949	B	840	1977-1978	B	-2761	1977-1978	B
66	1865	1971-1977	A	294	1937-1949	A	-1625	1937-1949	B	1808	1977-1978	B	-1239	1977-1978	B
65	755	1971-1977	A	195	1937-1949	A	-384	1937-1949	B	1898	1977-1978	B	-607	1979-1983	B
64	1492	1971-1977	A	384	1937-1949	A	0	-	N	1586	1977-1978	B	628	1978-1979	B
63	1557	1971-1977	A	-1456	1978-1979	B	0	-	N	1281	1977-1978	B	1179	1978-1979	B
62	1266	1971-1977	A	-1723	1978-1979	B	0	-	N	-1265	1978-1979	B	1978	1978-1979	B
61	1491	1971-1977	A	-2301	1978-1979	B	0	-	N	-2610	1978-1979	B	2693	1978-1979	B
60	1517	1971-1977	A	-2345	1978-1979	B	385	1977-1978	B	-3169	1978-1979	B	2737	1978-1979	B
59	2187	1971-1977	A	-2627	1978-1979	B	1683	1977-1978	B	-3037	1978-1979	B	2724	1978-1979	B
58	1619	1971-1977	A	-2369	1978-1979	B	1761	1977-1978	B	-2481	1978-1979	B	2762	1978-1979	B
57	2097	1958-1964	A	-2449	1978-1979	B	1441	1977-1978	B	-1933	1978-1979	B	3359	1978-1979	B
56	2145	1958-1964	A	-1535	1978-1979	B	-1178	1985-1992	C	-1418	1978-1979	B	3467	1978-1979	B
55	2184	1958-1964	A	954	1971-1977	A	-1445	1985-1992	C	-1163	1978-1979	B	-3577	1985-86-1992	C
54	1867	1958-1964	A	427	1971-1977	A	-1552	1985-1992	C	-629	1978-1979	B	-3873	1985-86-1992	C
53	597	1971-1977	A	181	1997-2002	A	-1647	1985-1992	C	-977	1971-1977	B	-3339	1985-86-1992	C
52	417	1971-1977	A	417	1997-2002	A	-1880	1985-1992	C	-832	1971-1977	B	-2412	1985-86-1992	C
51	0	-	N	-533	1978-1979	B	1683	1977-1978	B	468	1997-2002	A	-2829	1985-86-1992	C
50	0	-	N	122	1993-1997	A	927	1977-1978	B	0	-	N	-2672	1985-86-1992	C
49	0	-	N	-139	1979-1983	B	632	1985-1992	C	0	-	N	2440	1978-1979	B
48	0	-	N	96	1978-1979	A	1009	1985-1992	C	0	-	N	2359	1978-1979	B
47	0	-	N	-265	1979-1983	B	1511	1985-1992	C	0	-	N	-4151	1937-1949	B
46	0	-	N	-770	1979-1983	B	1701	1985-1992	C	0	-	N	-3344	1937-1949	B
45	0	-	N	-593	1979-1983	B	1107	1985-1992	C	-586	1978-1979	B	2215	1979-1983	B
44	0	-	N	911	1971-1977	A	781	1985-1992	C	777	1985-1992	C	1579	1979-1983	B
43 (Tuthill Rd. Bridge)	0	-	N	-491	1978-1979	B	-224	1979-1983	B	-654	1978-1979	B	-860	1992-1993	B
42	0	-	N	427	1985-1992	A	-474	1979-1983	B	616	1983-1986	B	-961	1992-1993	B
41	0	-	N	599	1949-1958	A	-455	1979-1983	B	-596	1979-1983	B	921	1971-1977	B
40	0	-	N	646	1979-1983	A	-633	1979-1983	B	-922	1978-1979	B	705	1971-1977	B
39	0	-	N	862	1979-1983	A	-477	1979-1983	B	-1020	1978-1979	B	-662	1992-1993	B
38	0	-	N	-729	1977-1978	B	523	1985-1992	C	1231	1958-1964	C	930	1971-1977	B
37	0	-	N	1306	1985-1992	A	-682	1978-1979	B	2218	1983-1986	C	-1183	1978-1979	B
36	0	-	N	1213	1997-2002	A	-596	1978-1979	B	2581	1983-1986	C	-2305	1978-1979	B
35	0	-	N	695	1997-2002	A	-800	1978-1979	B	2869	1983-1986	C	-3068	1978-1979	B
34	0	-	N	234	1997-2002	A	-878	1978-1979	B	2720	1983-1986	C	-3160	1978-1979	B

Table 9. Quantitative analysis summary

Reach Line Segment (dist. from downstream study limit) (x 1,000 in ft.)	Compound Channel						Active Channel						Thalweg		
	Left Bank Max Movement[1] (ft)	Span of Occurrence (year)	Cause[2]	Right Bank Max Movement[3] (ft)	Span of Occurrence (year)	Cause[2]	Left Bank Max Movement[1] (ft)	Span of Occurrence (year)	Cause[2]	Right Bank Max Movement[3] (ft)	Span of Occurrence (year)	Cause[2]	Thalweg Max Movement[4] (ft)	Span of Occurrence (year)	Cause[2]
33	0	-	N	-617	1978-1979	B	-2479	1978-1979	B	2466	1983-1986	C	-2702	1978-1979	B
32	-629	1985-1992	B	-889	1978-1979	B	-2873	1978-1979	B	1720	1983-1986	C	-2895	1978-1979	B
31	-1376	1978-1979	B	-484	1978-1979	B	-2413	1978-1979	B	2245	1983-1986	C	-3778	1978-1979	B
30	-1523	1978-1979	B	-894	1978-1979	B	-1886	1978-1979	B	2511	1983-1986	C	-3122	1978-1979	B
29	-2090	1978-1979	B	-1694	1978-1979	B	-1855	1978-1979	B	2687	1983-1986	C	-1386	1978-1979	B
28	-1036	1978-1979	B	1909	1958-1964	A	-989	1978-1979	B	3145	1983-1986	C	1189	1985-86-1992	C
27	-845	1978-1979	B	1539	1958-1964	A	-1069	1978-1979	B	2903	1983-1986	C	1583	1985-86-1992	C
26	-810	1978-1979	B	698	1958-1964	A	-898	1978-1979	B	2798	1983-1986	C	1907	1985-86-1992	C
25	-414	1978-1979	B	-772	1978-1979	B	-430	1978-1979	B	2781	1983-1986	C	1687	1985-86-1992	C
24	0	-	N	-740	1978-1979	B	-429	1978-1979	B	2782	1983-1986	C	-932	1997-2002	B
23	0	-	N	-587	1978-1979	B	-451	1985-1992	C	1353	1983-1986	C	-1418	1985-86-1992	C
22	0	-	N	-441	1977-1978	B	-694	1985-1992	C	1312	1985-1992	C	-1396	1985-86-1992	C
21	0	-	N	-1231	1977-1978	B	-749	1985-1992	C	1745	1983-1986	C	-1761	1985-86-1992	C
20	0	-	N	-1454	1977-1978	B	-770	1985-1992	C	1749	1985-1992	C	-1430	1985-86-1992	C
19	0	-	N	-1633	1977-1978	B	-832	1985-1992	C	2169	1985-1992	C	-1333	1985-86-1992	C
18	0	-	N	-1461	1977-1978	B	-951	1985-1992	C	2403	1985-1992	C	-1469	1985-86-1992	C
17	0	-	N	-1461	1977-1978	B	-873	1992-1993	B	2662	1985-1992	C	-2131	1985-86-1992	C
16	0	-	N	-1184	1977-1978	B	-1073	1992-1993	B	2756	1985-1992	C	-2592	1985-86-1992	C
15	0	-	N	-502	1977-1978	B	-944	1985-1992	C	2638	1985-1992	C	-2616	1985-86-1992	C
14	0	-	N	0	-	N	-890	1985-1992	C	2643	1985-1992	C	-2811	1985-86-1992	C
13	-270	1979-1983	B	0	-	N	-942	1985-1992	C	2441	1985-1992	C	-2526	1985-86-1992	C
12	-202	1978-1979	B	0	-	N	-1448	1985-1992	C	1462	1985-1992	C	-1801	1985-86-1992	C
11	-287	1978-1979	B	0	-	N	-288	1978-1979	B	1950	1979-1983	B	-1972	1978-1979	B
10	-411	1978-1979	B	0	-	N	-377	1978-1979	B	1605	1979-1983	B	-1844	1978-1979	B
9	-204	1979-1983	B	0	-	N	-193	1979-1983	B	1413	1979-1983	B	-1789	1978-1979	B
8	-751	1979-1983	B	0	-	N	-795	1979-1983	B	2111	1979-1983	B	-1667	1977-1978	B
7	1608	1971-1977	A	0	-	N	652	1997-2002	A	2192	1979-1983	B	-2185	1977-1978	B
6	1962	1971-1977	A	0	-	N	-2105	1978-1979	B	2773	1979-1983	B	-2074	1977-1978	B
5	-2475	1978-1979	B	0	-	N	-2512	1978-1979	B	2393	1979-1983	B	-2400	1977-1978	B
4	-2169	1978-1979	B	0	-	N	2327	1983-1986	C	1796	1979-1983	B	-2582	1977-1978	B
3	-2465	1978-1979	B	0	-	N	-2634	1978-1979	B	2149	1979-1983	B	-2305	1977-1978	B
2	-2450	1978-1979	B	0	-	N	-2910	1978-1979	B	2345	1979-1983	B	-1741	1977-1978	B
1 (SR 85 Bridge)	-3183	1978-1979	B	0	-	N	-598	1978-1979	B	2356	1979-1983	B	450	1992-1993	B
0	-2137	1978-1979	B	0	-	N	0	-	N	0	-	N	1316	1979-1983	B

1 Positive value = northward migration
Negative value = southward migration

2 A = Anthropogenic encroachment
B = Flood event
C = FCDMC 1,000 ft. corridor project
N = No appreciable bank movement

3 Positive value = southward migration
Negative value = northward migration

4 Positive value = northward migration
Negative value = southward migration

Table 9. Quantitative analysis summary

Reach Line Segment (dist. from downstream study limit) (x 1,000 in ft.)	Compound Channel		Active Channel		Thalweg
	Left Bank Net Channel Change[1] (1937-2002) (ft)	Right Bank Net Channel Change[2] (1937-2002) (ft)	Left Bank Net Channel Change[1] (1937-2002) (ft)	Right Bank Net Channel Change[2] (1937-2002) (ft)	Thalweg Net Channel Change[1] (1937-2002) (ft)
36	0	1482	-663	2598	-761
35	0	814	-768	2431	-1932
34	0	-5	-1133	2215	-2310
33	0	41	-2116	2082	-2154
32	-994	-18	-2506	1520	-1935
31	-823	-99	-2185	772	-1493
30	-854	215	-1928	1147	-1052
29	-498	902	-1437	1033	170
28	-421	853	-742	1200	884
27	-729	375	-884	1938	600
26	-467	-125	-1031	1865	56
25	-448	51	-758	1501	166
24	0	-464	13	1367	164
23	0	-495	-100	1519	-26
22	0	-1024	-448	1551	-903
21	0	-955	-632	1000	-1033
20	0	-1044	-725	980	-950
19	0	-1073	-1028	989	-1618
18	0	-1149	-1278	1403	-2290
17	0	-1121	-1694	1552	-2435
16	0	-857	-1969	1474	-2607
15	0	-581	-1806	1749	-2511
14	0	0	-901	2029	-2555
13	-32	0	-235	2207	-2392
12	-129	0	-157	2217	-1988
11	-174	0	-156	1882	-1115
10	-350	0	-347	1256	-631
9	-185	0	-166	979	48
8	477	0	-187	730	68
7	684	0	-117	1064	-793
6	111	0	249	1492	-1925
5	-569	0	536	1724	-2645
4	-529	0	413	1965	-2979
3	-111	0	-375	2032	-2910
2	459	0	-3	1260	-2427
1 (SR 85 Bridge)	2618	0	467	1575	-331
0	2169	0	0	0	1311

1 Positive value = northward migration
Negative value = southward migration

2 Positive value = southward migration
Negative value = northward migration

Note: A zero value indicates no net appreciable channel change has occurred in the photographic record (1937-2002)

Table 10. Net channel change summary

Reach Line Segment (dist. from downstream study limit) (x 1,000 in ft.)	Compound Channel		Active Channel		Thalweg
	Left Bank Net Channel Change[1] (1937-2002) (ft)	Right Bank Net Channel Change[2] (1937-2002) (ft)	Left Bank Net Channel Change[1] (1937-2002) (ft)	Right Bank Net Channel Change[2] (1937-2002) (ft)	Thalweg Net Channel Change[1] (1937-2002) (ft)
84	-572	0	-858	0	-119
83	-135	-2037	-921	-630	-95
82	43	-1348	-415	-468	-825
81 (Agua Fria River Confluence)	0	0	0	0	-712
80	0	2324	0	0	5
79	826	1341	0	17	233
78	1569	1215	0	391	1202
77 (Bullard Ave. Bridge)	2042	706	0	-77	1302
76	1857	804	0	309	1433
75	2254	648	0	695	1060
74	2728	0	0	867	548
73	2520	0	210	654	145
72 (Estrella Pkwy. Bridge)	2383	0	-396	657	-605
71	2030	0	-963	449	-1621
70	789	0	-1408	697	-2309
69	8	283	-1202	789	-2680
68	1000	278	-1973	548	-2713
67	952	597	-1826	1354	-2211
66	892	689	-1727	1629	-953
65	965	287	-869	1135	-789
64	1468	506	0	950	-314
63	1487	1472	0	-153	787
62	1167	1807	0	-882	1605
61	1521	1666	0	-2292	1612
60	2196	1504	370	-4301	979
59	2279	737	1222	-2997	187
58	1899	152	1386	-3310	-231
57	1994	138	802	-3409	-117
56	2250	-313	204	-2905	-96
55	2391	-54	8	-2677	-393
54	2499	223	-153	-2117	-479
53	940	166	805	-1617	-1131
52	277	618	1160	-815	-1043
51	0	116	1205	810	-1271
50	0	-62	1133	0	-2354
49	0	-60	1122	0	-3008
48	0	-15	1367	0	-3584
47	0	-166	1861	0	-3490
46	0	-802	1963	0	-2112
45	0	-766	1273	-27	1329
44	0	-337	738	-254	751
43 (Tuthill Rd. Bridge)	0	-97	133	263	-99
42	0	-422	93	-61	-196
41	0	121	78	-269	396
40	0	573	-22	-169	310
39	0	888	-228	463	-256
38	0	1008	-446	1606	-170
37	0	1566	-655	1837	-283

Table 10. Net channel change summary

Thalweg Quantitative Analysis

A channel thalweg lateral migration analysis was also performed using measurements made on aerial photographs. The thalweg movement analysis provides insight into the low flow conditions of a fluvial system. Changes in sediment load, upstream controls, and slope are reflected by changes in the thalweg characteristics.

During several time periods, the Gila River had multiple low flow channels. For the purpose of a lateral migration analysis, it was necessary to identify a single channel as the thalweg. To measure lateral migration of the thalweg, an east-west trending baseline was delineated to serve as the datum. This baseline extended through the study reach and connected the northern endpoints of the 85 reach line segments. Figure 32 illustrates the quantitative analysis used to measure thalweg position for the 1977 aerial photography.

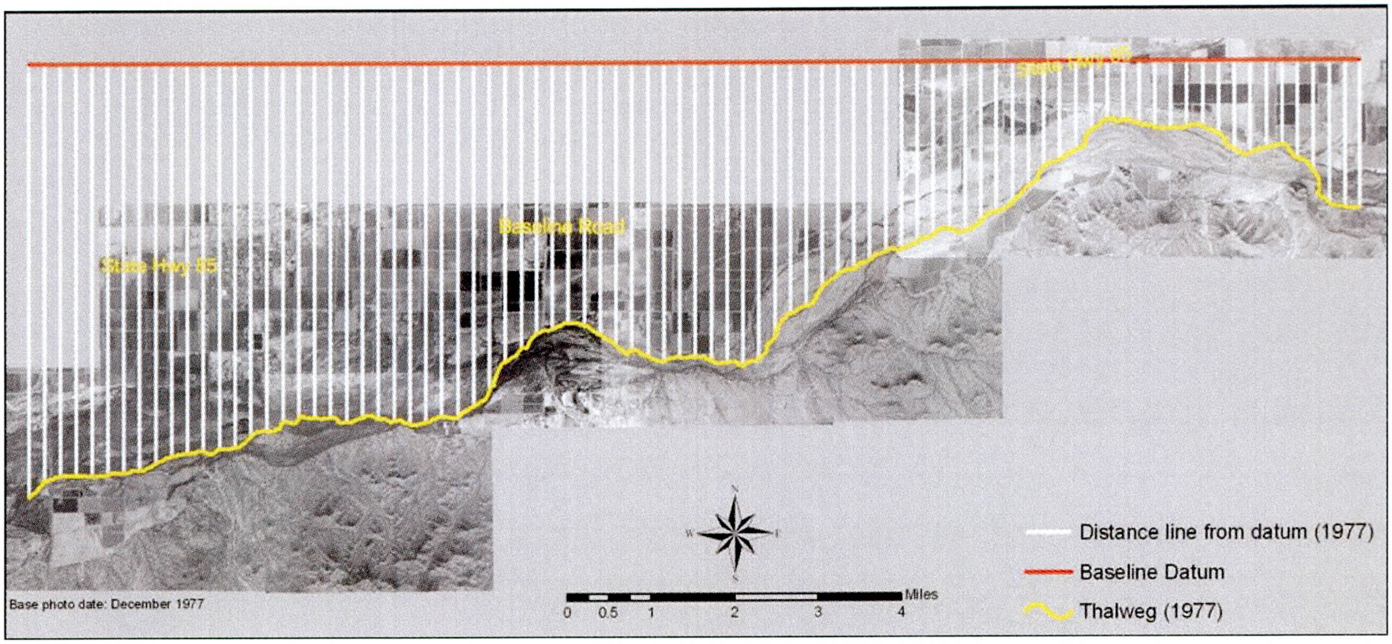


Figure 32. Example of thalweg quantitative analysis

The distance from the baseline along each reach line segment to the intersection of the thalweg line with the reach line segment was measured for each year of coverage. Then, the distance at each reach line segment for a given year was subtracted from the distance for the following year. A positive value indicates the thalweg had migrated northward between the year increments, and a negative value indicated southward migration..

Results and Interpretations

Results of the thalweg lateral migration analysis were plotted as a series of bar graphs similar to the compound/active channel migration plots. A sample plot of the results is shown in Figure 33. The entire plot series is attached in Appendix C.

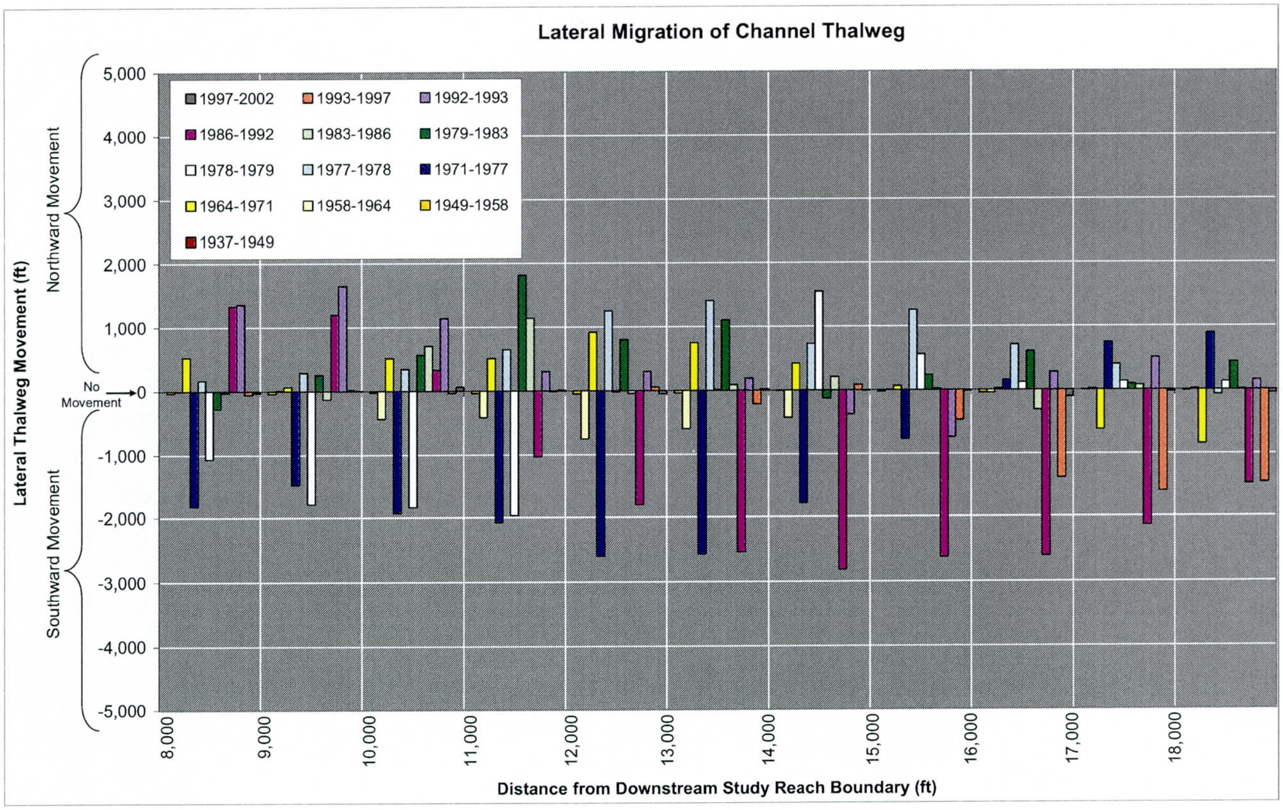


Figure 33. Sample thalweg lateral migration plot

Maximum Single-Event Change

Results of the thalweg movement analysis indicate that the thalweg has experienced dynamic changes throughout the photographic record. The maximum single-event change occurred between 1937 and 1949 with a magnitude of over 4,000 feet in the southerly direction at one location. The average of the single-event maximum changes for each reach line segment is approximately 900 feet in the southerly direction.

Net Channel Change

A net change analysis was also conducted on the thalweg. The results indicate the average net change in thalweg position within the photographic record is approximately 800 feet in the southerly direction. Results suggest that, although the thalweg has migrated significantly both northward and southward, the long-term trend is in the southern direction.

Summary Analysis

Thalweg lateral migration summary plots of the single-event and net thalweg change analyses are included in Appendix C. Causal mechanisms for the single-event change in thalweg position were identified as was done in the compound/active quantitative analysis, and are shown on the summary plots.

CHANNEL WIDTH CHANGE

Changes in channel width can occur independently or in conjunction with lateral migration, may include either widening or narrowing, and can be the results of natural or human (e.g. encroachment, levees, bridges, etc.) processes. Changes in channel width often cause adverse disruptions in sediment continuity. For example, narrowing of a channel due to a bridge construction can increase flow velocities through the structure, and increase abutments and pier scour. Levee construction may cut off natural floodplain storage, thus increasing the unit discharge impacting the opposite bank or downstream reaches, and causing lateral erosion as the channel compensates for the increased stream power. Channel widening at bridge crossings may decrease flow velocities, allowing sediment to drop out and accumulate. Natural channel width change often occurs during large flood events as the river adjusts to the increased discharge, velocity, and stream power. Whether natural or human caused, changes in channel width are a direct reflection of the system adjusting to the imposed water and sediment supply.

Width Change Quantitative Analysis

Channel width change in the El Rio study reach was measured using a similar approach to that used for the thalweg analysis. A datum was established from which distance measurements for all years of coverage could be based for both the compound and active channel widths. Width measurements were taken at the reach line segments from bank to bank for each aerial photo year of coverage. The measured width differs slightly from a true channel width measured perpendicular to the primary flow direction. However, since a consistent datum was used throughout the study reach, the width values measured do reflect actual changes in width. Figure 34 illustrates how the width analysis was conducted, and shows differing widths for the active channel in 1949 and 1958.

Results and Interpretations

Figure 35 and Figure 36 show width comparison result plots for both the compound and active channels. Lines on these Figures that plot close together indicate reaches that have experienced relatively minimal channel width change, while lines that exhibit large gaps between plots indicate a dynamic reach with a history of significant channel width change. The maximum single-event change in active channel width was greater than 4,500 feet and occurred between 1978 and 1979. The average single-event active channel width change for the entire photographic record was approximately 40 feet. The maximum single-event compound channel width change was greater than 5,100 feet and occurred during the January 1978 flood. The period of record average compound channel width change was approximately 100 feet. The discrepancy between single-event and long-term average width change in both the compound and active channels indicates that extensive change occurs during floods, with periods of quiescence between large floods. Therefore, for short periods of observation, a false impression of either stability or instability may be reached, depending the most recent flows.

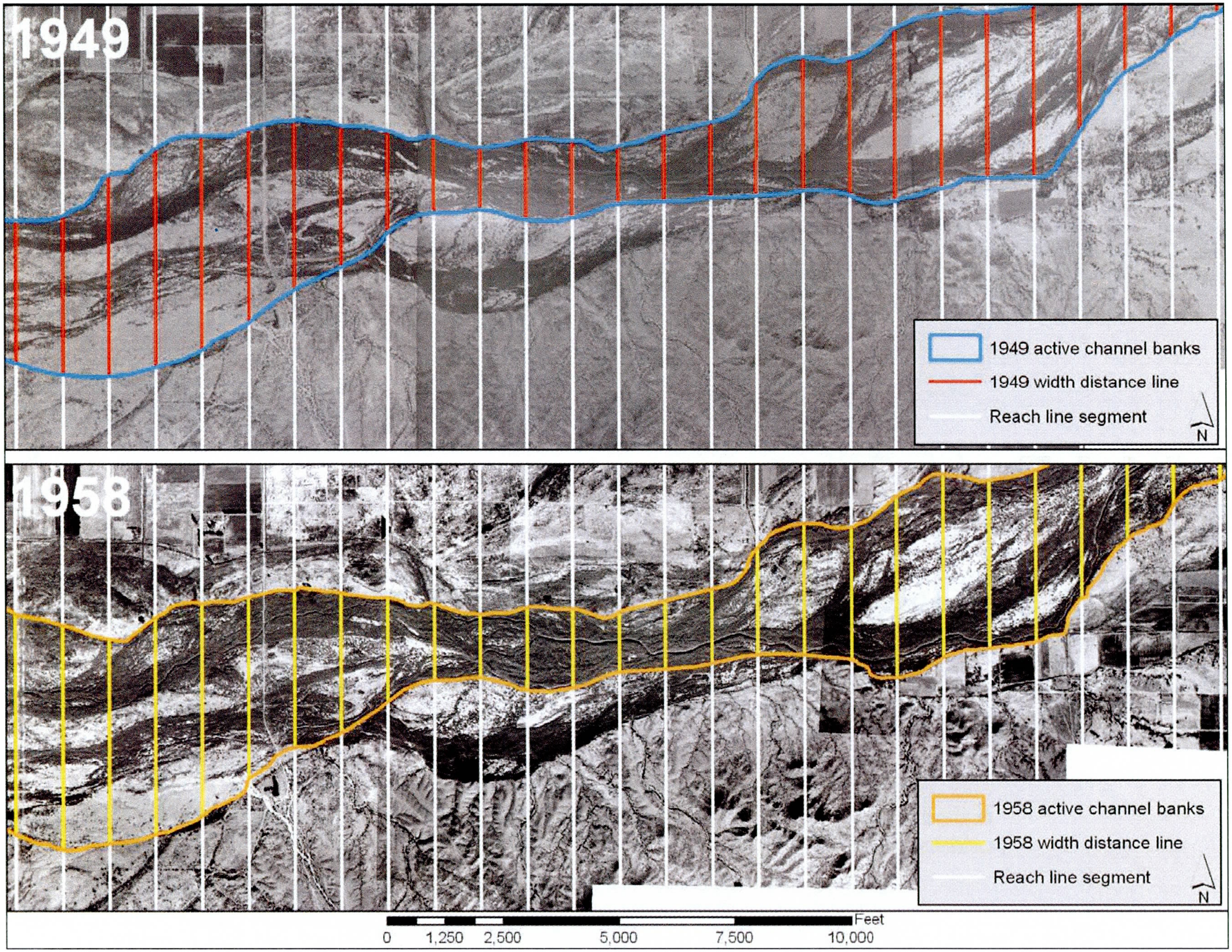


Figure 34. Example of channel width analysis

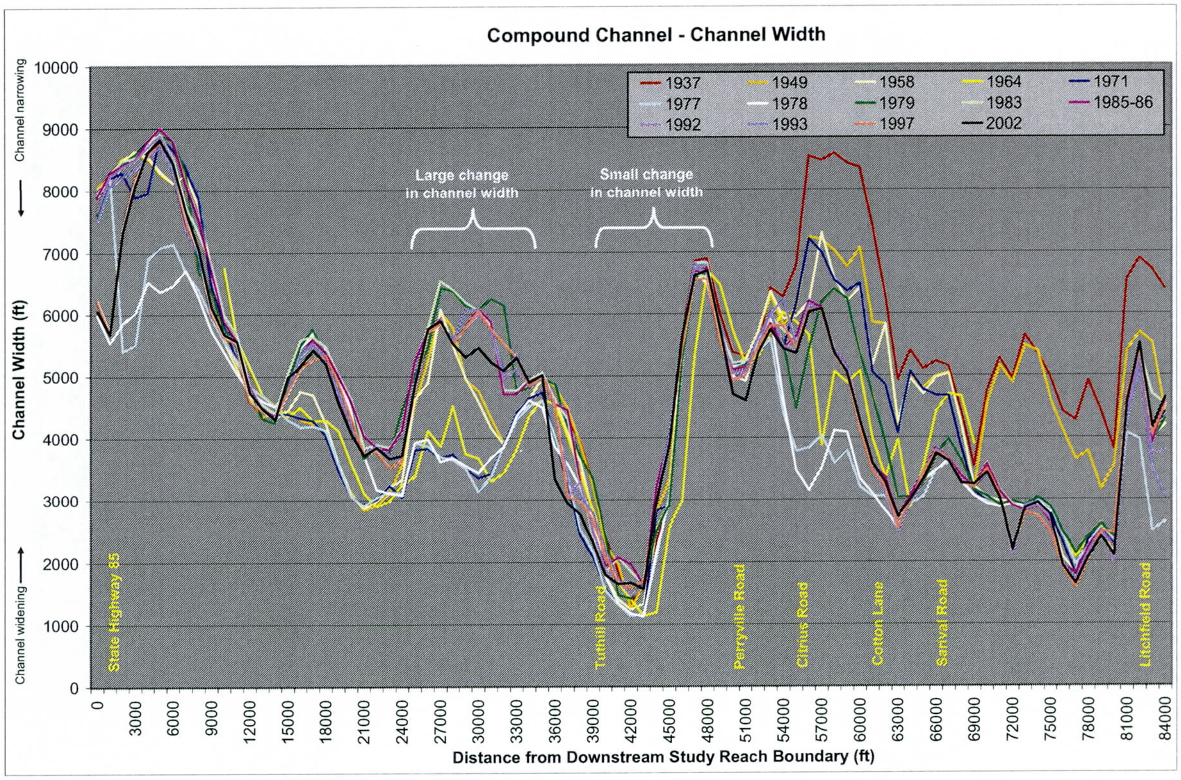


Figure 35. Compound channel width summary plot

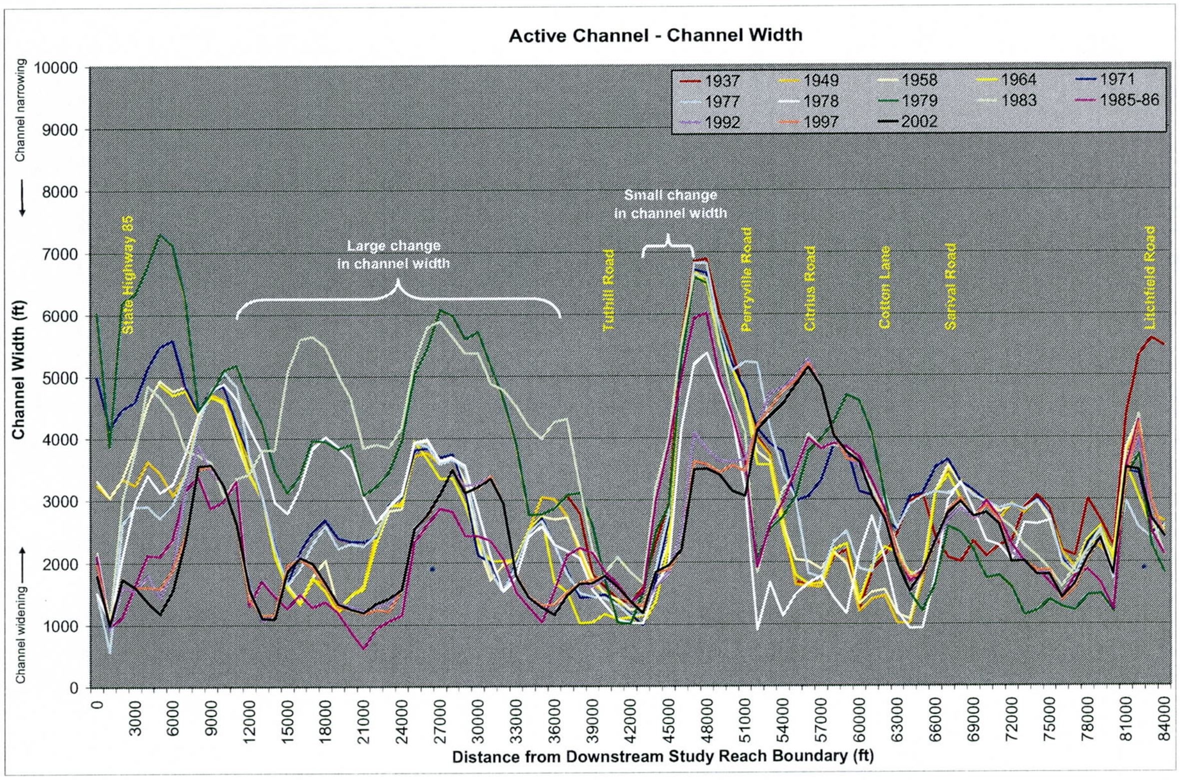


Figure 36. Active channel width summary plot

The results shown in Figure 35 and Figure 36 indicate that the active channel has been very unstable during the period of record, with frequent width adjustments. Near the upstream end of the study reach and at the Tuthill Road Bridge, the active channel is somewhat more stable than the rest of the study reach. The compound channel width has been markedly more consistent than the active channel width. However, the compound channel width experienced more change at the upstream end of the study reach than near the downstream end of the reach. Again, the reach near the Tuthill Road Bridge experienced minimal changes in compound channel width, probably because the channel tends to occupy most of the modern geologic floodplain at this location.

VERTICAL CHANNEL CHANGE

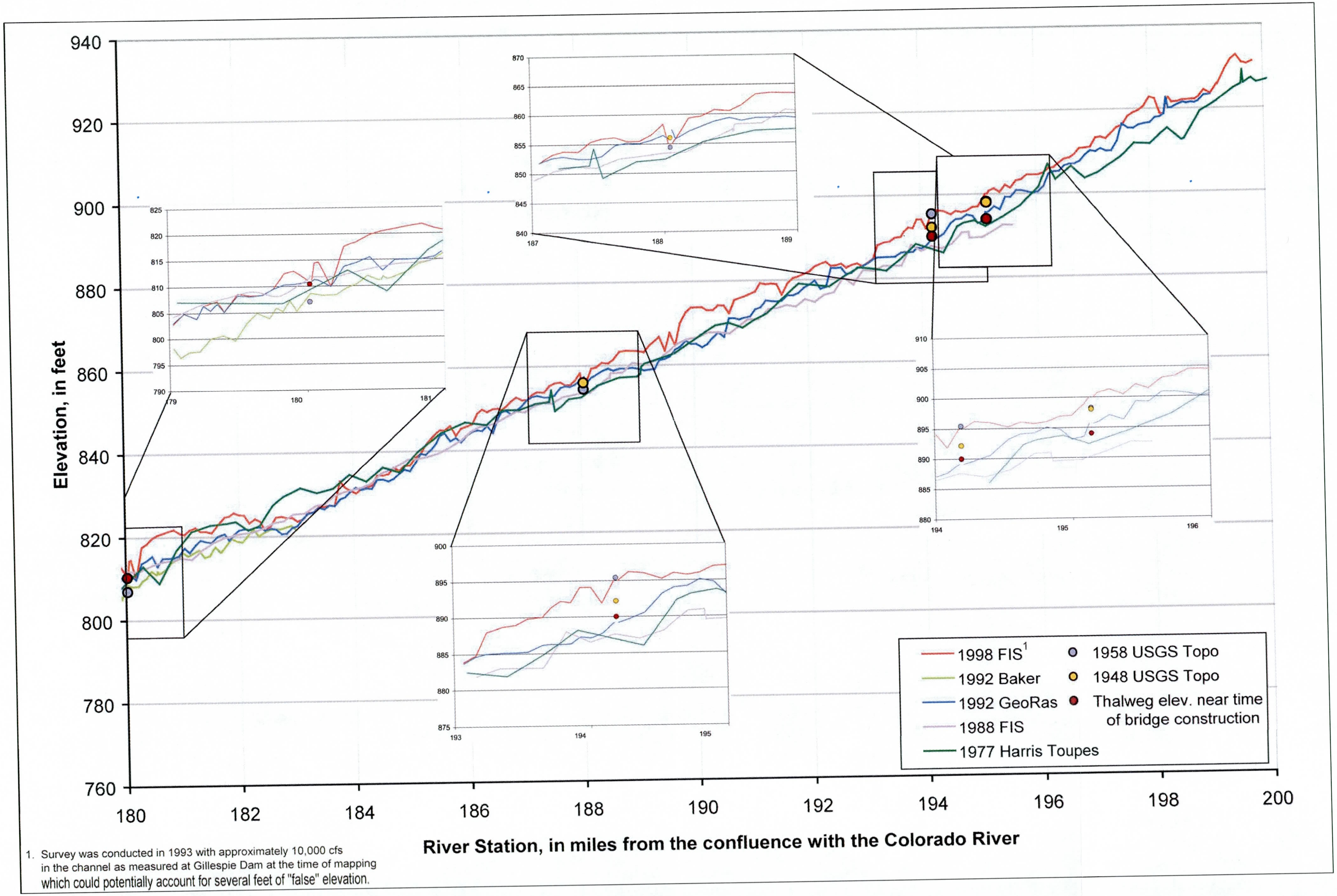
Long-Term Changes

Long-term vertical changes in the Gila River within the El Rio study reach were analyzed using longitudinal profiles developed from topographic data from previous studies and from USGS topographic maps. Table 11 lists the data used in the vertical change analysis. Topographic data from previous studies were provided by Stantec. The vertical datum for all data were referenced and adjusted to NGVD 29 to facilitate comparisons between different mapping sets.

Table 11. Vertical channel change data sources

Date	Source	Extent
1948	USGS Topography	Tuthill Road Bridge to Bullard Avenue Bridge
1958	USGS Topography	SR 85 Bridge to Bullard Avenue Bridge
1977	Harris-Toupes Floodplain Delineation Study	Study reach
1982	Bullard Ave Bridge As-builts, Royden Eng.	At Bridge
1987	Estrella Pkwy Bridge As-builts, A-N West Inc.	At Bridge
1988	Dames & Moore Flood Insurance Study	Gillespie Dam to Bullard Ave Bridge
1990	SR 85 Bridge As-builts ADOT	At bridge
1992	Michael Baker Study	Crest of Gillespie to upstream of SR 85 Bridge
1998	Michael Baker Flood Insurance Study	Study reach

Figure 37 shows the longitudinal profile plot for the entire El Rio study reach with higher detailed views at the bridge locations. The plots indicate the study reach experienced aggradation from 1948 to 1958, followed by general degradation through 1992, and then by aggradation from 1992 to 1998. This oscillation of channel elevation illustrates the dynamic nature of the Gila River and demonstrates the difficulty in predicting future vertical trends from topographic data. Stantec performed HEC-6T sediment transport modeling with the objective of identifying long-term trends in vertical channel movement. The results of the HEC-6T modeling and its implication to vertical channel stability are discussed elsewhere in the El Rio WCMP project documentation (Stantec, in progress). A brief summary of the HEC-6T model results relative to lateral channel stability is provided in the following paragraphs.



1. Survey was conducted in 1993 with approximately 10,000 cfs in the channel as measured at Gillespie Dam at the time of mapping which could potentially account for several feet of "false" elevation.

Figure 37. Gila River longitudinal profiles (1948-1998)

HEC-6T MODELING

HEC-6T modeling of the study reach was prepared by Stantec for the El Rio WMP. The complete model input/output and discussion are described in detail in the *El Rio Sediment Analysis* (Stantec, in progress). For the LMAR, the results of the HEC-6T analysis were compared with lateral migration analysis results to help identify areas of potential channel instability. While HEC-6T does not model lateral channel movement or bank erosion, it can be used to identify reaches with sediment deficits or surpluses that may be more prone to experience lateral erosion (sediment deficit), narrowing, or widening due to imbalances in sediment supply compared to transport capacity.

Figure 38 shows comparison plots of vertical bed change results from the HEC-6T analysis with both channel width and lateral migration change results for the compound channel. The comparison indicates that there is some correlation of HEC-6T results and observed historical changes. For example, for a reach located midway between Tuthill Road Bridge and Estrella Parkway Bridge (between River Station 191 and 193), the HEC-6T minimum and maximum bed change results indicate large magnitudes of both degradation and aggradation. The historical aerial photograph comparisons similarly record large magnitudes of change in channel width and bank locations, which reflect the sediment incontinuities predicted using HEC-6T. These results may indicate that during large magnitude flood events, sediment is being supplied to the system from both the channel banks and overbank areas in this reach. One of the assumptions of the HEC-6T model is that there are only two potential sources of sediment; inflowing water and the movable portion of the stream bed (USACOE, 1993). If sediment was being supplied from the banks causing lateral changes as reflected in Figure 38, the HEC-6T analysis would not account for this influx and therefore could overestimate bed elevation change.

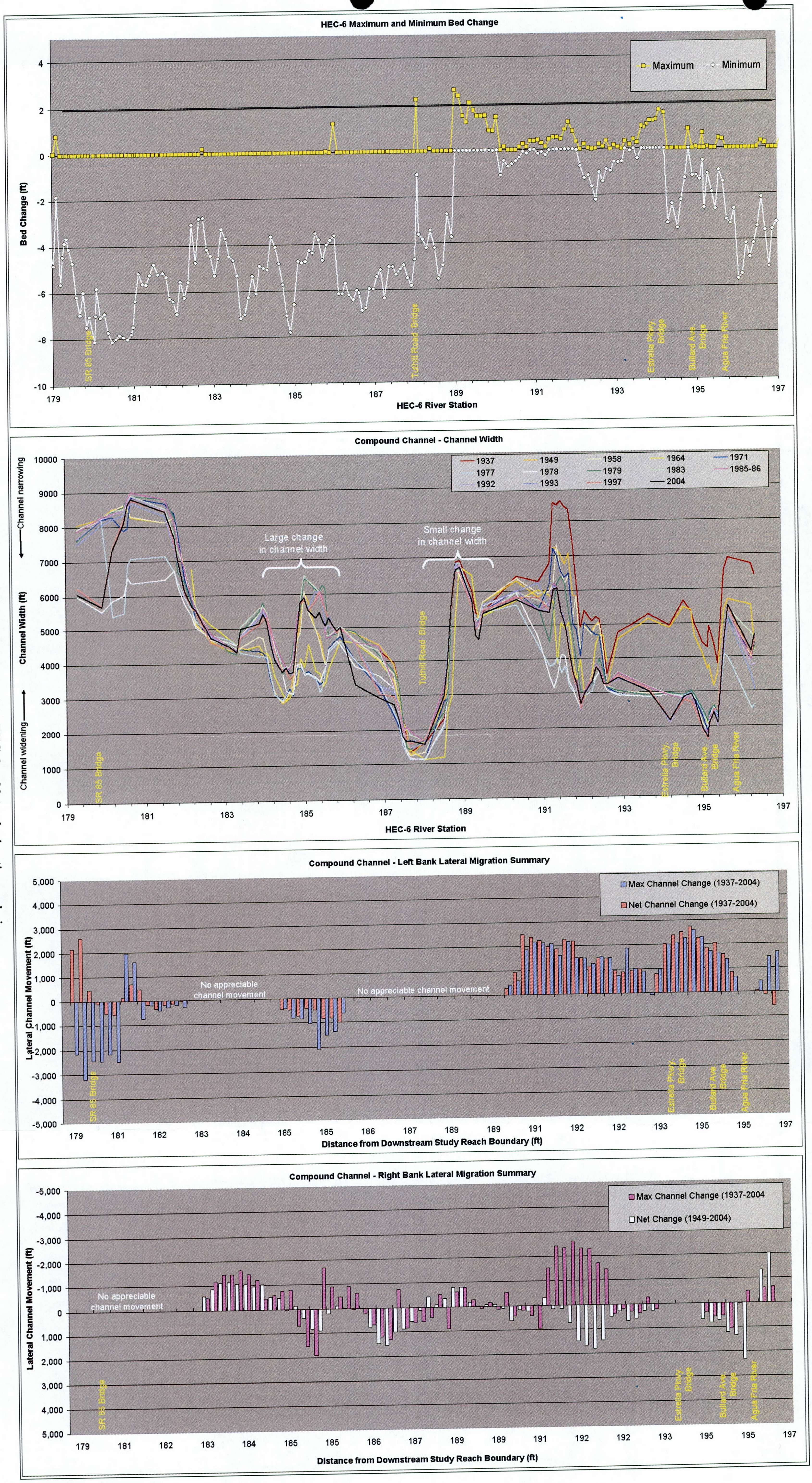


Figure 38. Results comparison of the HEC-6 and lateral migration analysis

SUMMARY

Historical aerial photographs dating from 1937 were used to observe and quantify changes in channel width and location within the El Rio WCMP study reach. From these historical data sets, the following results were obtained:

- The primary cause of lateral channel movement and widening was large floods. A secondary cause was human actions in the floodplain such as encroachment by expansion of agricultural lands or channel narrowing for bridge construction.

- Channel movement and widening has occurred in the study reach in an episodic manner, with moderately long periods of stability interrupted by extreme and dramatic channel change during floods.

- The maximum single-event channel changes were measured as follows:
  - Compound Channel:
    - Right bank: > 2,600 feet (1978)
    - Left bank: > 3,100 feet (1978)
    - Channnel width: > 5,100 feet (1978)
  - Active Channel:
    - Right bank: > 3,100 feet (1978)
    - Left bank: > 2,900 feet (1978)
    - Channel width: > 4,500 feet (1978)
  - Thalweg: > 4,000 feet (1937-1949)

- The maximum long-term channel changes were measured as follows:
  - Compound Channel:
    - Right bank: 137 feet northward
    - Left bank: 515 feet southward
    - Channel width: > 5,000 feet
  - Active Channel:
    - Right bank: 500 feet northward
    - Left bank: 280 feet southward
    - Channel width: > 6,000 feet
  - Thalweg: 800 feet southward

- Longitudinal profile analysis indicates the study reach has experienced alternating periods of thalweg.degradation and aggradation since 1948.

- HEC-6T modeling results are roughly correlative with historical observations with respect to identified reaches of instability.

CONCLUSIONS

Results of the quantitative analysis of both the lateral migration and width change analysis indicate the Gila River throughout much of the El Rio study reach is a dynamic, fluvial system that has experienced significant lateral migration and channel width changes since 1937. Results also indicate areas of localized control where minimal channel change, either laterally or in width, has occurred within the years of aerial coverage. This quantitative approach to lateral channel migration provides a solid foundation, in conjunction with regional geologic data and field observations, from which an Erosion Hazard Zone can be delineated.

CHAPTER 4: FIELD DATA

Field inspection is a critical component in applied fluvial geomorphology. Although landform interpretations based on aerial photography are extremely useful, without field verification, they can be subject to misinterpretation. Ideally, a lateral migration studies and erosion hazard delineations involve comprehensive field investigations covering the entire study reach, including channel banks, overbank floodplains, channel beds, and tributaries. This level of detailed field inspection was not authorized for the El Rio LMAR. Therefore, an alternate approach to field data collection was employed. Analysis of aerial photography spanning 1937 to 2002, in addition to the quantitative lateral migration analyses described in Chapter 3 identified specific key geographic areas of interest that appeared to demonstrated examples of both lateral channel stability and instability. These areas were identified, observed in the field, and used to interpret areas excluded from direct field visits.

FIELD METHODS

Approximately 64 locations were identified for field investigation in the El Rio study reach, most of which were visited. Access to some areas was hampered by private property and vegetation density. Several field visits were conducted between February 11, 2003 and September 16, 2003, and then again in August 2005. Field crews visited identified locations noting general channel conditions, photographing key elements, and mapping key features observed. The objectives of the field visits included the following:

- Document channel bank conditions
- Identify evidence of recent or historical lateral erosion
- Identify evidence of recent or historical degradation or aggradation
- Identify evidence of lateral erosion within recent geologic time
- Identify stream responses to human impacts or structures
- Identify geologic/anthropogenic controls on lateral channel stability
- Identify and document historic channel positions

DATA COLLECTED

The following types of characteristics that have bearing on lateral erosion and channel stability were observed and recorded in the field:

- Cutbanks – location, heights, characteristics
- Bedrock – location, outcrops
- Caliche – location, degree of development
- Particle sizes – channel bed, bank materials, floodplains
- Armoring
- Vegetation – channel, banks, floodplain
- Evidence of Previous Floods – avulsions
- Evidence of Active Lateral Erosion
- Flood Control Structures – bridges, levees, bank protection measures
- Major Tributaries

The remainder of this Chapter summarizes field observations relevant to the lateral stability assessment. Additional field photos and locations are provided in Appendix D.

Cutbanks

A cutbank is a stream bank that has been eroded (cut) to a steep, vertical or overhanging slope and generally is evidence of active lateral erosive processes. Field observations in the study reach and elsewhere in central Arizona indicate that vertical banks are inherently unstable, although the time scale over which instability is expressed varies with the degree of erosivity and resistance of the local bank characteristics. The location and dimensions of cutbanks observed in the field were recorded in the field at key locations. Cutbanks observed in the study reach were generally composed of unconsolidated fine-grained (floodplain) sediment, unconsolidated (channel) cobbles and gravel, weakly cemented (with $CaCO_3$) sediment and/or cobbles, or some combination of each. Bank and overbank vegetation appeared to increase the stability of the bank soils, but did not prevent lateral erosion or the formation of cutbanks. The presence of cutbanks indicates that active lateral erosion occurs within the stream system in the study area, regardless of bank vegetation, soil lithology, and soil composition. Figure 39 through Figure 44 show cutbanks observed in the field. Figure 43 and Figure 44 show evidence of structure damage due to active lateral erosion of cutbanks.

Figure 39. Cutbank composed of weakly cemented cobbles capped by fine overbank sediment

Figure 40. Cutbank located within active channel corridor and composed of overbank, floodplain sediment

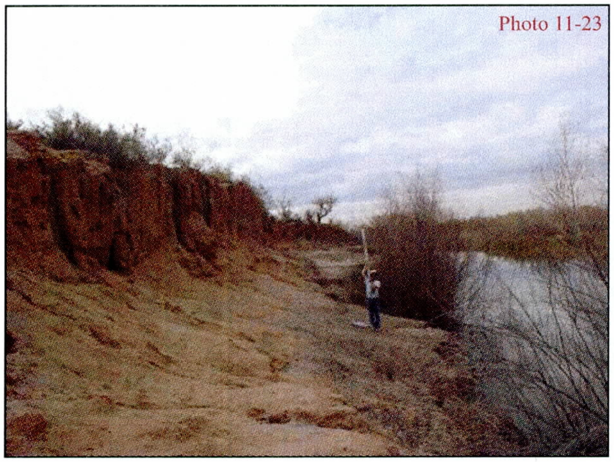


Figure 41. High relief cutbank near thalweg

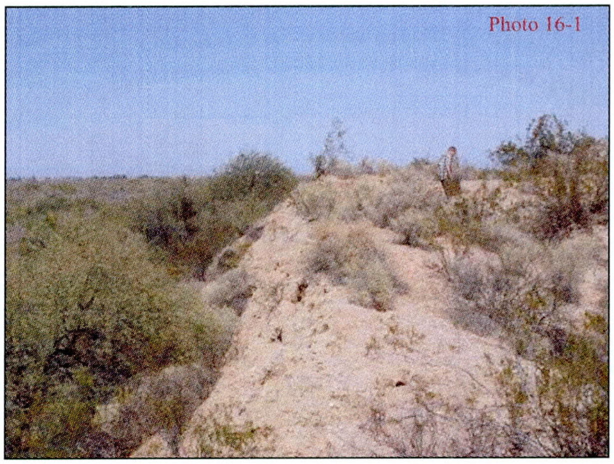


Figure 42. Soft sediment cutbank upstream of Tuthill Road Bridge

Figure 43. Structure succumbs to lateral erosion. Photo is looking upstream along the right bank of the compound channel. Building is collapsed over the cutbank

Figure 44. Well head and casing exposed by lateral erosion along the right bank of the compound channel. Cutbank is located approximately 60 feet behind wellhead

Bedrock

Bedrock provides control from both vertical and lateral channel movement. On a regional scale, the Gila River alluvial valley through much of the El Rio study reach is bounded on the south by the Buckeye Hills and Sierra Estrella mountains. A significant portion of the present left bank of the active channel is flanked by bedrock outcrops from these mountains. However, some significant areas of alluvial floodplains between mountain fronts and the active river banks that represent potential lateral erosion hazards. Areas of bedrock control observed during field visits were identified and recorded. Figure 45 through Figure 47 illustrates a few of these areas. No exposed bedrock was observed along the right bank boundary of the study reach, nor is any identified on the AZGS geology maps. A few isolated outcrops of bedrock are exposed in the channel bed near the south bank of the river corridor. The previous operator of the Alleco sand and gravel mine claimed to have mined to bedrock on the north side of the river, but this claim was later refuted by operators of proposed mines on adjacent parcels.

Figure 45. Bedrock near Estrella Mtn. Park

Figure 46. Bedrock upstream of Estrella Mtn. Park

Figure 47. Bedrock downstream of Waterman Wash tributary

Caliche

Calcium carbonate rich soil (caliche) is common in the semi-arid climate of southern Arizona. The degree of caliche development increases with time, making it a valuable indicator of soil age and thus, landform stability. Early stage development may include imperceptible, disseminated calcium carbonate ($CaCO_3$) within the sediment matrix. A more advanced state will include visible $CaCO_3$ coatings on gravels and cobbles. Advanced state development includes conglomeritic sediments well cemented by $CaCO_3$, often forming thick, resistant layers resembling bedrock. The advanced stage development may provide significant resistance to lateral erosion. Field investigations of the El Rio study reach did not yield locations of advanced stages of caliche development. Early to moderate caliche development was observed in a few cutbanks. The most notable caliche development was found just downstream of the Tuthill Bridge along the left bank. Narrowing of the river corridor in this area has resulted in degradation of the active channel, exposing moderate stage caliche (Figure 49).

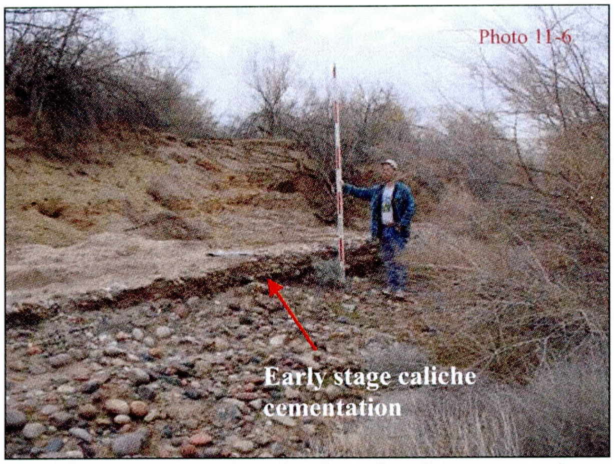


Figure 48. Moderately developed caliche exposed near the right bank of the active channel boundary

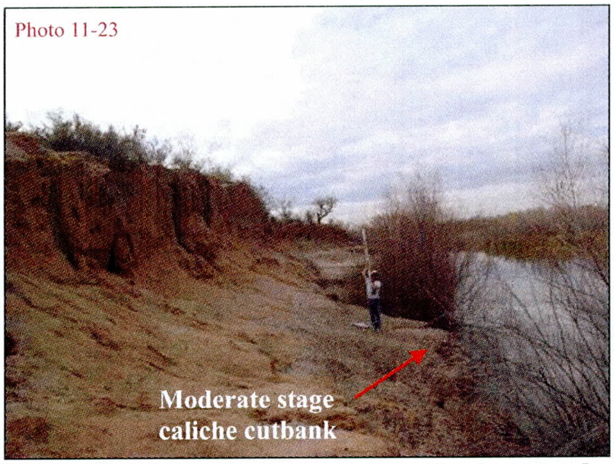


Figure 49. Moderate stage caliche cutbank exposed downstream of Tuthill Bridge

Particle Size

The natural bed load of the Gila River above the Salt River confluence is characterized by fine to coarse sand with some cobbles. The cobble dominated bed load of the Salt River is dramatically different than that of the Gila River. This influx of coarser bed load material to the Gila River downstream of the Salt River affects its geomorphic character. The result is the formation of large cobble bars and islands surrounded by sandy bottom channels (Figure 50 and Figure 51). High frequency, low magnitude flows are constrained to the sand dominated channels transporting and reworking this material. Historic aerial photography evidence suggests the cobble size material is only transported during large magnitude, low frequency flood events. Overbank and floodplain sediments are generally characterized by fine to coarse sands and silts with little to no cobbles present (Figure 52 and Figure 53), which can be clearly distinguished from channel sediments.

Figure 50. Cobbles bar sediments

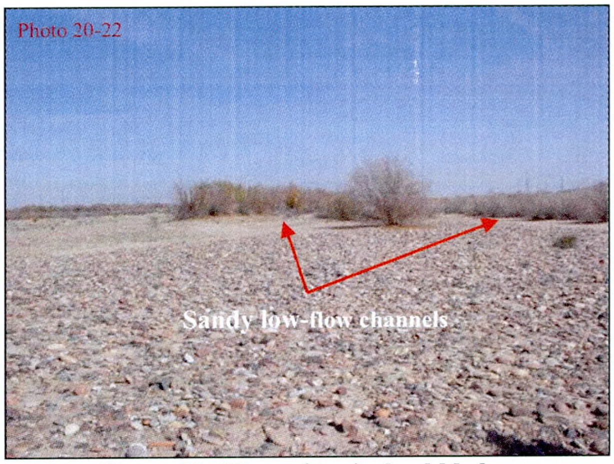


Figure 51. View of typical cobble bar

Figure 52. Exposed floodplain sediments outside of compound channel bank boundaries

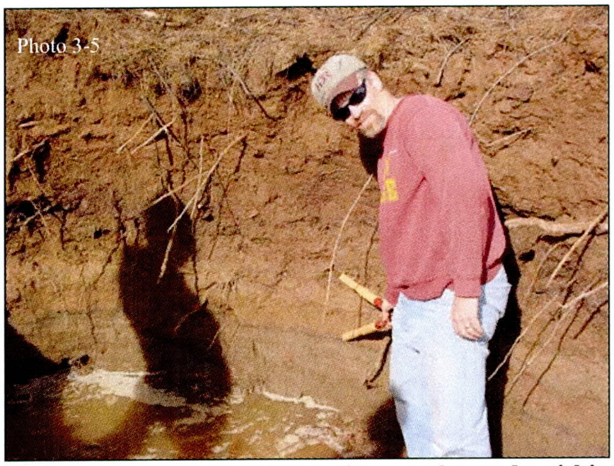


Figure 53. Floodplain sediments located within compound channel boundaries

Armoring

Armoring occurs when a layer of sediment too large for transport by the stream covers the channel bottom and prevents bed scour. The armor layer forms by selective transport of smaller particles, leaving behind the larger particles too big to be transported. To function as an armor layer, it must be at least as thick as two times the armoring size (2 x d_{50}) and extensive enough to completely cover the active channel. Field observations indicate that the numerous cobble bars found throughout the study reach contain large enough clasts to armor the bed, at least during moderate sized floods, but that the bars are laterally discontinuous, and would therefore be easily flanked and rendered ineffective during large floods. Field evidence suggests that the Gila River is not sufficiently armored to prevent long-term scour.

Field observations of a trench excavated by Stantec in March 2003 confirmed that no armor layer was present, and that, in fact a similar distribution of sediment sizes occurred at depths up to six feet as at the surface (Figure 54). Field observations of sediments exposed in sand and gravel mine pits upstream of the SR85 Bridge similarly confirmed that no effective armor layer is present in the study reach (Figure 55). These exposures had large cobble lenses buried by accumulations of floodplain sediment. The coarse grained lenses may represent historic, discontinuous cobble bars similar to those found presently within the active channel.

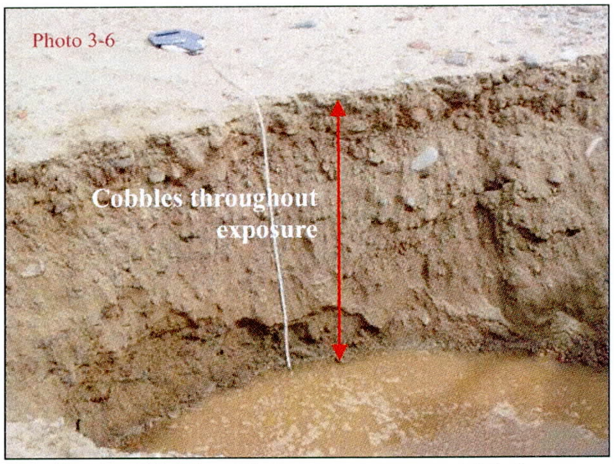


Figure 54. Trench exposure near cobble bar

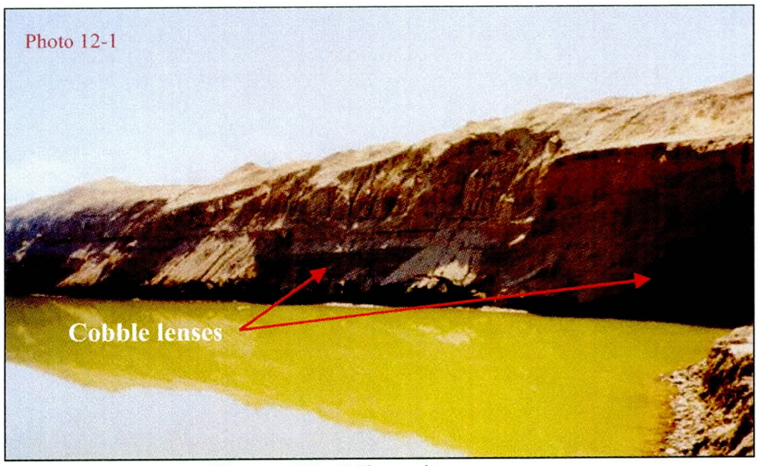


Figure 55. Mine-pit exposure

Vegetation

Bank Vegetation

The presence of dense, deeply rooted channel bank vegetation can enhance bank stability and reduce rates of lateral erosion. Root material binds soil material and increases resistance to stream erosion. Vegetative litter produces a mat that reduces water to soil contact. Plant stems, branches, and leaves increase roughness, resulting in decreased flow velocities, all of which contribute to reduced lateral erosion potential. Interpretations of channel bank vegetation densities were made on aerial photographs and were field verified during field visits, and were used to aid in the determination of the bank's lateral erosion potential for both the active and compound channels. Figure 56 to Figure 59 illustrate varying channel bank vegetation conditions throughout the study reach.

Figure 56. Sparse vegetation on the right bank active channel

Figure 57. Right bank active channel showing dense Tamarix vegetation growth

Figure 58. Moderate to dense vegetation along the right bank compound channel

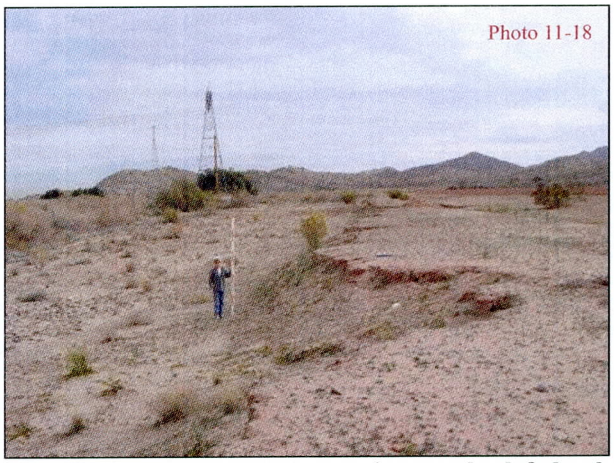


Figure 59. Very sparse vegetation on the left bank active channel

Variations by Surface

Vegetation characteristics vary by geomorphic surface, soil substrate, water availability, frequency of flood inundation, and human influence. Generally, in the study reach, vegetation within the active channel boundary is dominated by Tamarix, which is distributed both as dense forests and sparse clusters. Tamarix has invaded or eradicated many native plant habitats within the active channel corridor (Figure 60). Field observations indicated that the preferential growing conditions for the Tamarix are within the sand dominated low-flow channels. Tamarix growth on the cobble bars is very sparse to non-existent (Figure 61). The dominant vegetation on many overbank and floodplain areas differs from that of the active channel in much of the study reach. These surfaces are generally dominated by more native vegetation such as mesquite and ironwood trees, creosote brush, and an occasional cottonwood tree (Figure 62 and Figure 63). In areas of active channel cutbanks, the Tamarix is present up to and often on the cutbank with a transition to native vegetation on the upslope surface.

Figure 60. Dense Tamarix forest between active and compound channel banks

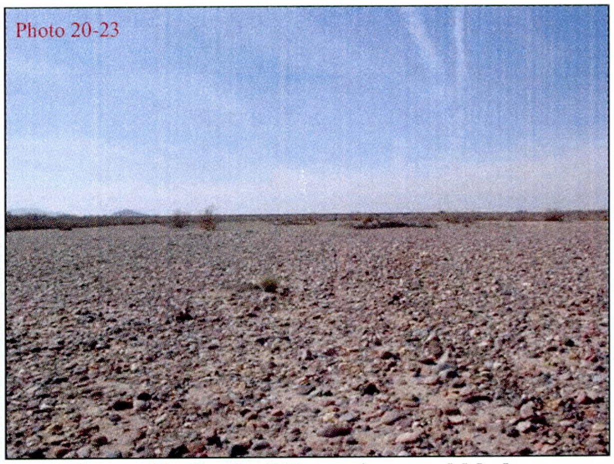


Figure 61. Lack of Tamarix on cobble bars

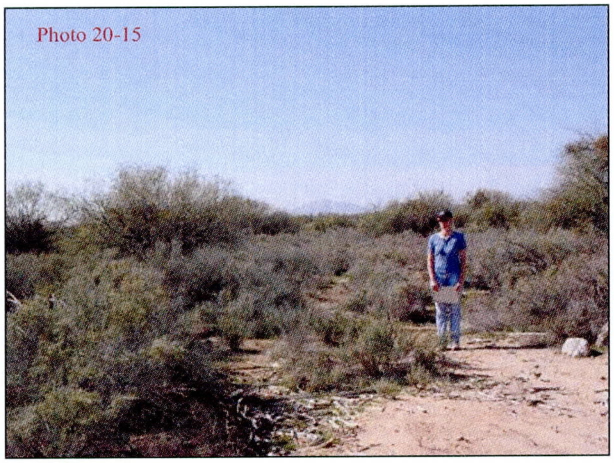


Figure 62. Example of surface dominated by dense native vegetation

Figure 63. Example of surfaces dominated by moderate to sparse native vegetation

Evidence of Previous Floods

Avulsions

An avulsion is the formation of a channel in a portion of the floodplain not previously occupied by a channel. Avulsions are responsible for some of the most significant lateral channel movement on the large stream systems in central Arizona. Generally formed during flood events, avulsions can be responsible for dramatic changes in river course orientation, causing flooding and erosion hazards in parts of the floodplain that were previously free from such hazards. Incipient and current channels were observed at multiple locations within the study reach. These locations represent high potential for future lateral erosion hazards (Figure 64 through Figure 67).

Figure 64. Right-bank avulsive channel just downstream of Agua Fria confluence

Figure 65. Right-bank avulsive channels downstream of Estrella Bridge

Figure 66. Right-bank avulsive channel downstream of Estrella Bridge (*note cobbles*)

Figure 67. Left-bank avulsive channels near State Highway 85 Bridge

Evidence of Active Lateral Channel Erosion

Active lateral erosion processes were observed throughout the study reach within both the active and compound channel boundaries. Evidence such as cutbanks and gullying were identified and photographed, and are described below.

Cutbanks

Cutbanks were described previously in this Chapter. Cutbanks are evidence of recent or on-going lateral erosion. Banks no longer subject to active erosion tend to become flatter sloped and well vegetated.

Gullying

Gullying is the formation of a steep-walled channel by rapid downcutting produced by running water. In the study reach gullies have formed by overland flow over unconsolidated floodplain soil. The gullies in these areas are often oriented perpendicular to adjacent cutbanks and are probably genetically related. Gully processes combined piping can significantly increase the rate of lateral erosion by reducing soil cohesion. Gullying along the study reach was observed in areas of little to no bank vegetation, or where bank and floodplain vegetation had been removed. Figure 68 through Figure 70 show examples of both active gullying and piping processes.

Figure 68. Active gullying in de-vegetated surface

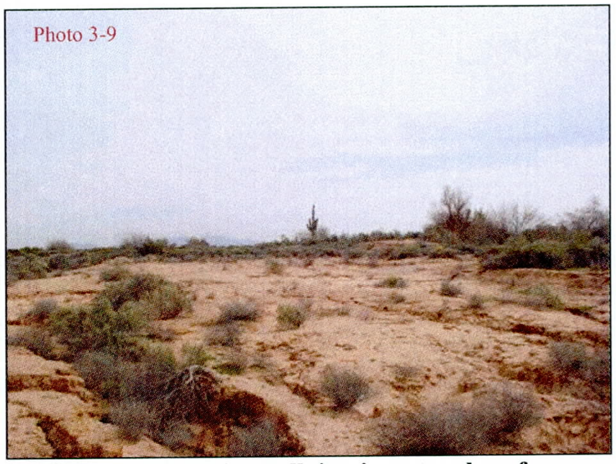
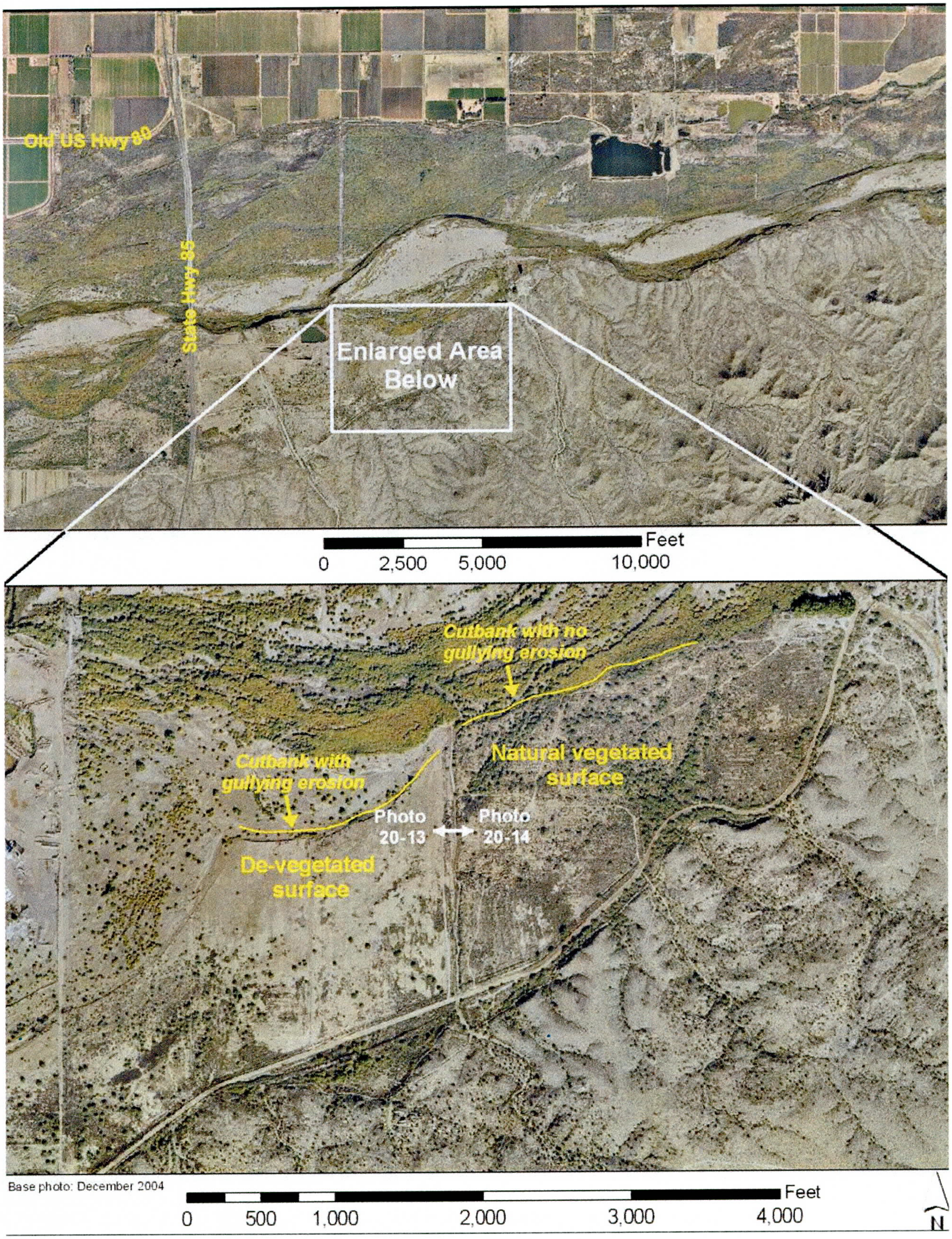


Figure 69. Active gullying in natural surface

Figure 70. Piping in de-vegetated surface

Gullying of overbank terraces was most severe on cutbank and floodplain surfaces with little to no vegetation. These processes were specifically observed along the left bank just upstream of the State Highway 85 Bridge. The left-overbank floodplain along this reach had historically been used as agricultural land, with the natural vegetation cleared and the soil tilled. An equivalent geomorphic floodplain surface exists adjacent to the cleared surface, and has more undisturbed natural vegetation. Gullying processes are nearly non-existent on the undisturbed surface, while severe gullying is present on the developed land. Figure 71 shows an aerial view of these surfaces with Figure 72 and Figure 73 illustrating the vegetation contrast. This evidence suggests that lateral erosion may be accelerated if floodplain areas are cleared or developed without regard to control of increased surface runoff.



Old US Hwy 80
State Hwy 85
Enlarged Area Below
Feet
0
2,500
5,000
10,000
Cutbank with no gullying erosion
Cutbank with gullying erosion
Natural vegetated surface
Photo 20-13
Photo 20-14
De-vegetated surface
Base photo: December 2004
Feet
0
500
1,000
2,000
3,000
4,000
N

Figure 71. Example of gullying caused by de-vegetation

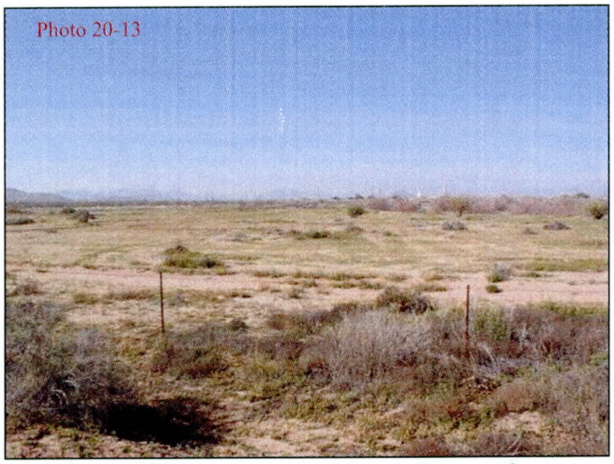


Figure 72. De-vegetated floodplain surface

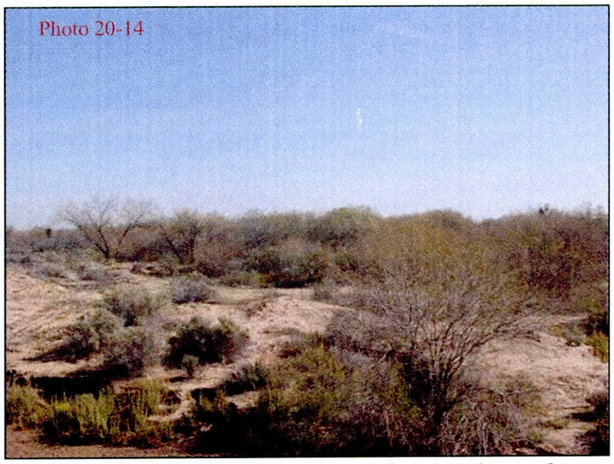


Figure 73. Naturally vegetated floodplain surface

Flood Control Structures

In general, the potential for vertical erosion increases near structures due to flow acceleration through constrictions or over concrete surfaces, disruption of sediment continuity, and/or removal of bank vegetation and placement of fill material, while lateral erosion is often reduced due to engineered protection. Furthermore, manmade structures offer a fixed reference point from which to measure vertical and lateral channel changes. The location, condition, and potential impacts from structures observed in the study reach were documented and are summarized below.

Bridges

Four bridges cross the Gila River in the El Rio study reach. These locations were analyzed using historic aerial photography and field verification to determine the effect of the structure on the lateral stability. Each bridge is discussed below, from upstream to downstream.

<u>Bullard Avenue Bridge</u>
The Bullard Avenue Bridge (span approx. 1,850 feet) was completed in 1982 and was nearly immediately subjected to flooding conditions during the January 1983 event. Historic aerial photographic analysis indicates the active channel banks have remained relatively stable both upstream and downstream of the bridge since its completion. The 1983 flood appears to have widened the active channel boundaries to the width of the bridge. Figure 74 and Figure 75 show field photographs of the left bank approach of the bridge. Figure 76 shows the active channel bank comparison for the photographic record both before and after construction of the bridge.

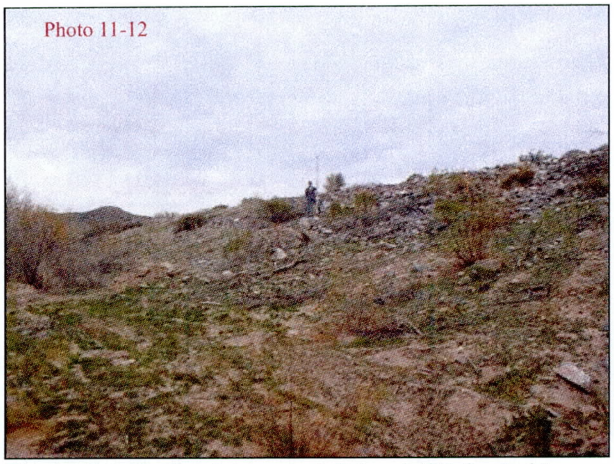


Figure 74. Bullard Avenue left bank fill for bridge approach, looking upstream.

Figure 75. Downstream extent of fill for the left bank bridge approach, looking upstream.

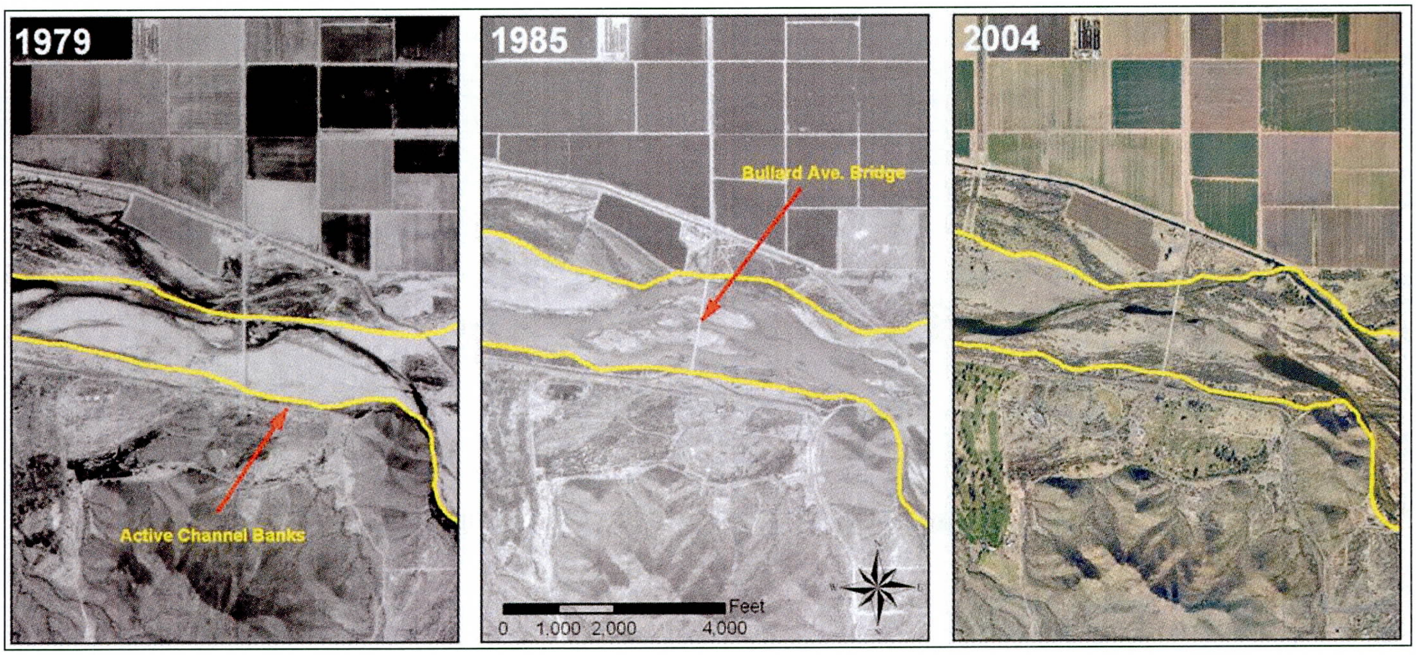


Figure 76. Active channel bank comparison at Bullard Avenue Bridge

Estrella Parkway Bridge

Completed in 1987, the Estrella Parkway Bridge span measures approximately 2,200 feet. Photographic analysis indicates the channel banks have remained stable near the bridge. The condition of the left bank bridge approach was field inspected to determine the stability and potential for lateral erosion. The approach fill material was armored with boulder-sized rip-rap. The channel banks upstream of the approach appeared stable and showed no signs of lateral erosion. The right bank approach appeared in the same condition with no apparent bank stability problems. Figure 77 and Figure 78 are field photos of the left bank both upstream and downstream of the bridge. Figure 79 is the historic photo comparison of the active channel banks.

Figure 77. Estrella Parkway Bridge left bank engineered fill with protection, looking downstream across river

Figure 78. Left bank levee protecting the King Ranch property directly downstream of Estrella Parkway Bridge, looking upstream

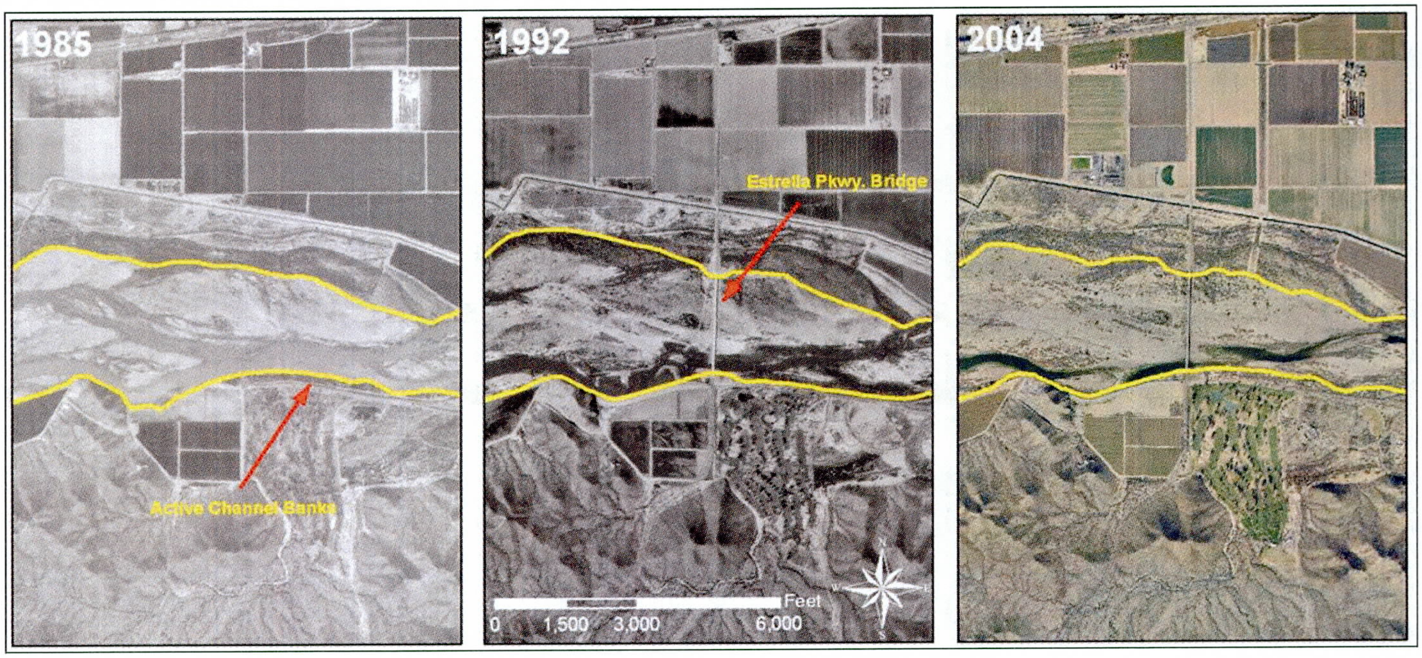


Figure 79. Active channel bank comparison at Estrella Parkway Bridge

<u>Tuthill Road Bridge</u>

The Tuthill Road Bridge was completed in 1981 and has the shortest span of all the bridges in the study reach (approx. 1,770 feet). The photographic record indicates this segment of the study reach has historically been the narrowest of the entire reach, but is also one of the more laterally stable reaches. Field investigation revealed a significant cutbank along the left bank both upstream and downstream of the bridge. Pre-bridge photographs do not show the cutbank present, indicating degradation of the thalweg caused by channel narrowing potentially due to the presence of the bridge (see Figure

41). Figure 80 shows the pre- and post-bridge construction aerial photos for this reach. The right bank both upstream and downstream of the bridge has been one of the most stable reaches within all of the El Rio study reach. Both the quantitative lateral migration and channel width analysis indicated very little lateral movement of either the left or right banks within this reach of the Gila.

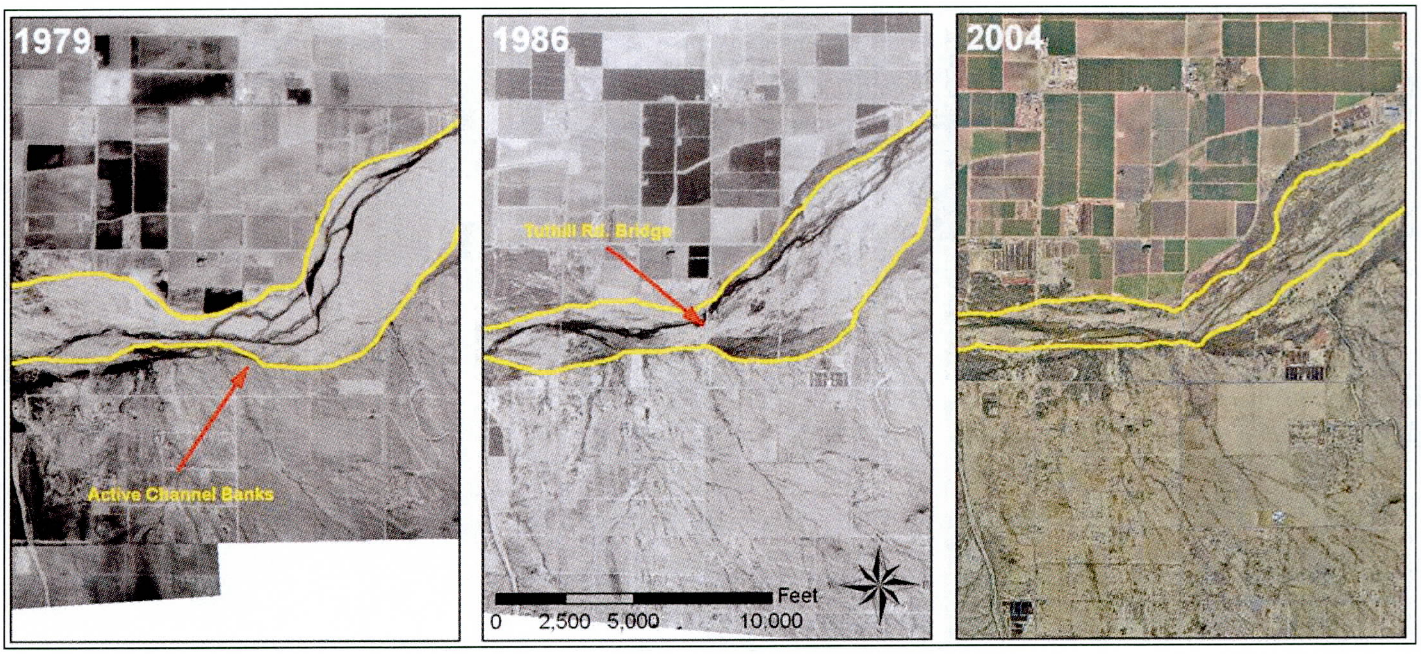


Figure 80. Active channel bank comparison at Tuthill Road Bridge

State Route 85 Bridge

The State Route 85 Bridge was originally completed in 1969 with a span of less than 500 feet. The channel constriction at the bridge caused significant ponding upstream during the December 1978 flood, resulting in considerable lateral erosion of the active channel left bank, as indicated by aerial photographs. Between 1979 and 1983 the bridge was expanded to a width of approximately 800 feet. After the January 1993 flood the bridge was closed. Between 1993 and 1997 a double lane, single-roadway bridge spanning approximately 3,600 feet was constructed. By 2002 a split-roadway, four-lane bridge approximately 3,600 feet in width was in place. Figure 81 and Figure 82 are field photos near the bridge. Since the 3,600 feet expansion of the bridge, the active channel banks have been relatively stable upstream of the bridge as shown by the photo comparison in Figure 83.

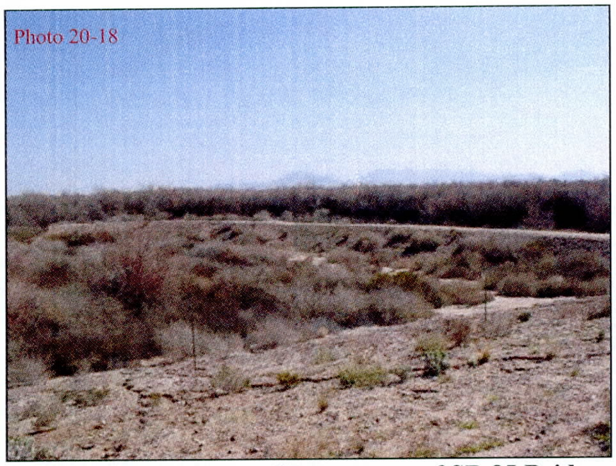


Figure 81. Right bank fill upstream of SR 85 Bridge, looking upstream

Figure 82. Left bank raised roadway to bridge approach with low-flow culvert, looking downstream direction

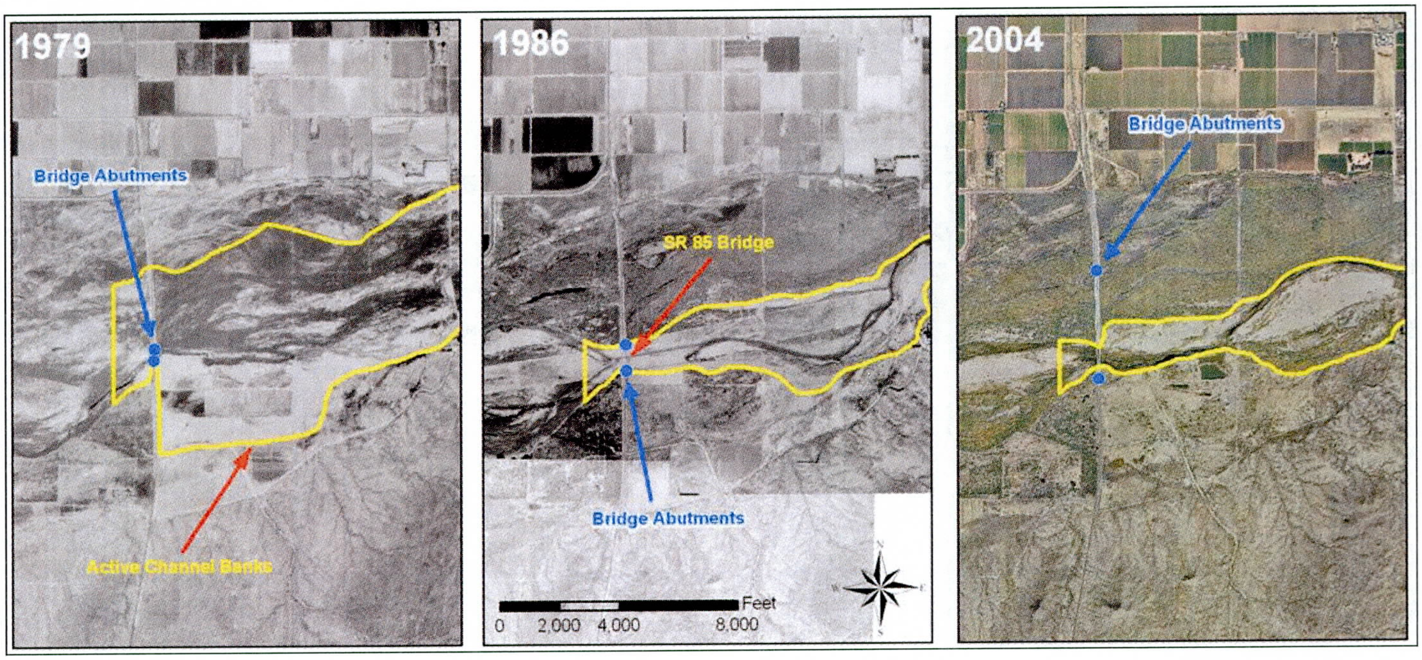


Figure 83. Active channel bank comparison at State Route 85 Bridge

Levees

Levees were identified, recorded, and photographed when encountered in the field. When properly engineered, levees can provide adequate lateral stability for channel banks. Locations of levees were taken into consideration for the erosion hazard delineation analysis. Samples of levees identified are illustrated in Figure 84 through Figure 87.

Figure 84. Left-bank levee just downstream of Estrella Parkway Bridge, looking upstream

Figure 85. Right-bank levee under construction, looking upstream direction

Figure 86. Left-bank levee along W. Vineyard Avenue (Estrella Mtn. Park), looking upstream

Figure 87. Left-bank levee just upstream of Estrella Parkway Bridge, looking upstream

Major Tributaries

Major tributaries entering the Gila River were located, observed, and documented. Of interest to the erosion hazard assessment is the elevation of the tributary channel invert relative to the Gila channel elevation. "Hanging" tributaries, tributaries with channel inverts above the main channel, indicate rapid or recent incision on the main channel. Conversely, significant deposition or delta formation near the confluence may suggest that the tributary is delivering sediment to the main channel more frequently or in greater quantities than the main channel can carry it away, which could result in narrowing or lateral instability of the main channel. In the case of a wide stream like the Gila River, the main channel may be pushed away from the tributary confluence delta toward the opposite bank, causing lateral erosion, if the tributary delivers large quantities of sediment. In addition, with the construction of upstream dams and loss of the small floods to upstream storage, frequent flows are no longer able to flush the influx of sediment from the tributaries on a recurrent basis. Although many small tributaries enter the Gila River within the study reach, the two of primary focus for the LMAR were the two largest streams, the Agua Fria River and Waterman Wash (Figure 88).

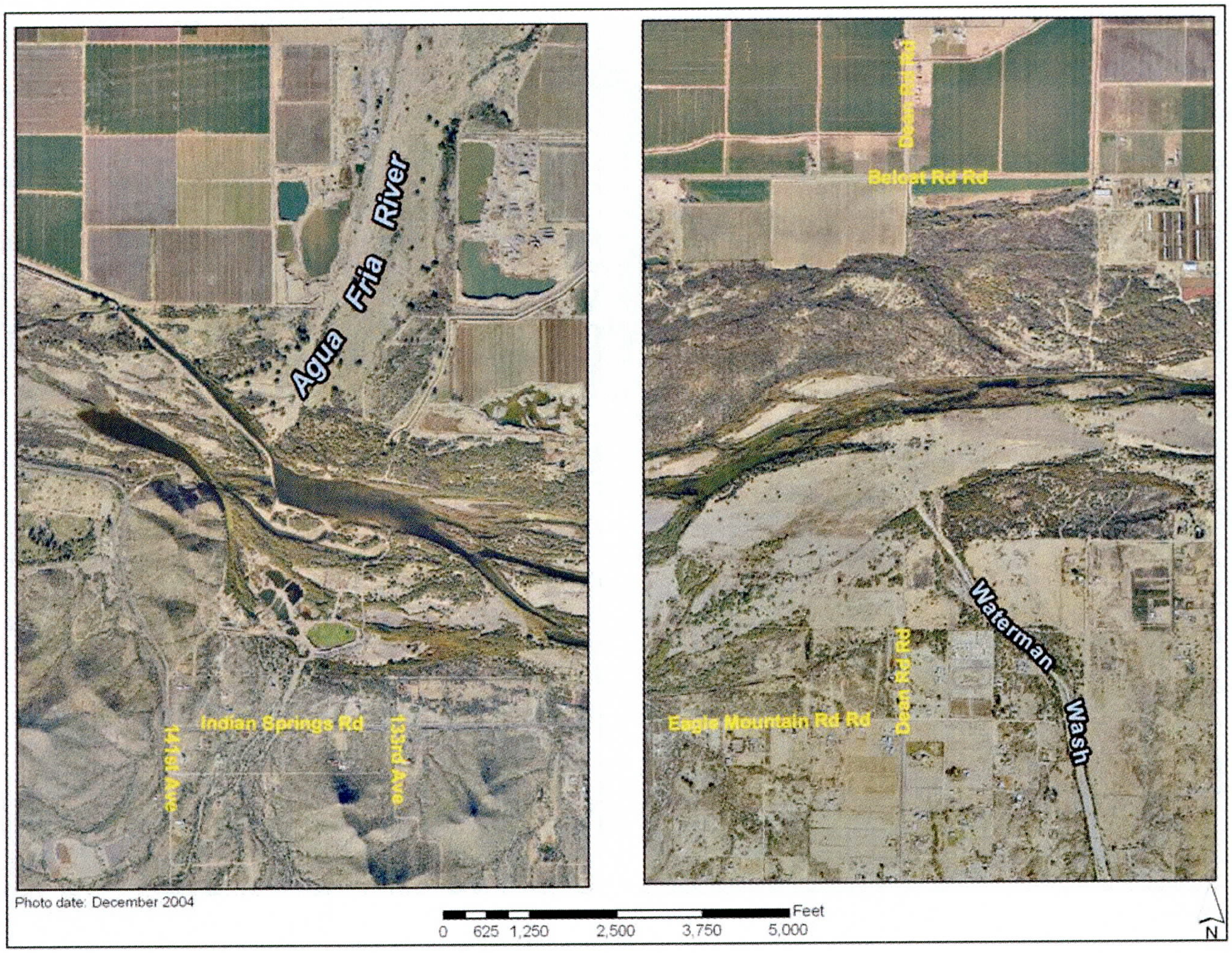


Figure 88. Major tributaries within the El Rio study reach

Agua Fria River

The Agua Fria River drains approximately 2,700 square miles of rugged central Arizona terrain, and empties into the Gila River at the upstream end of the El Rio study reach. The Prescott, Bradshaw, Wickenburg, Hieroglyphic and White Tank Mountains bound the western edge of the drainage basin, while the eastern margin is loosely defined by the Black Hills, New River, and Phoenix Mountains (Figure 89).

The Agua Fria Watercourse Master Plan Lateral Migration Report (AFWMP LMR; JEF, 2001) concluded that significant changes of sediment delivery from the Agua Fria River have occurred as a result of the construction of Waddell Dam in 1927 and New Waddell Dam in 1992, in-stream mining, and urbanization. Additionally, in-stream sand and gravel mining has lowered the bed elevations up to 40 feet within mined reaches along the Agua Fria River, resulting in depletion of sediment supplied to the Gila River. The reduction of sediment supply from the Agua Fria River could have a direct impact on channel stability of the Gila River in the El Rio study reach. In general, a reduction in sediment supply would result in either long-term channel degradation, channel widening, or a combination of both. However, in this case, sediment supplied from the Agua Fria River represents only a small portion of the Gila River sediment budget. Therefore, the historical decrease in sediment & water supply from the Agua Fria River will impact the Gila River at most directly within the confluence area.

Figure 89. Agua Fria River watershed

Waterman Wash

The drainage area of Waterman Wash is approximately 420 square miles. Historic aerial photographs show moderate to low sediment volume influxes into the Gila River, which are easily entrained during large magnitude flood events, as illustrated in Figure 90. The drainage area of Waterman Wash is less than 1 percent of the Gila River drainage area upstream of the study reach, suggesting minimal impact on the Gila system outside of the delta area.

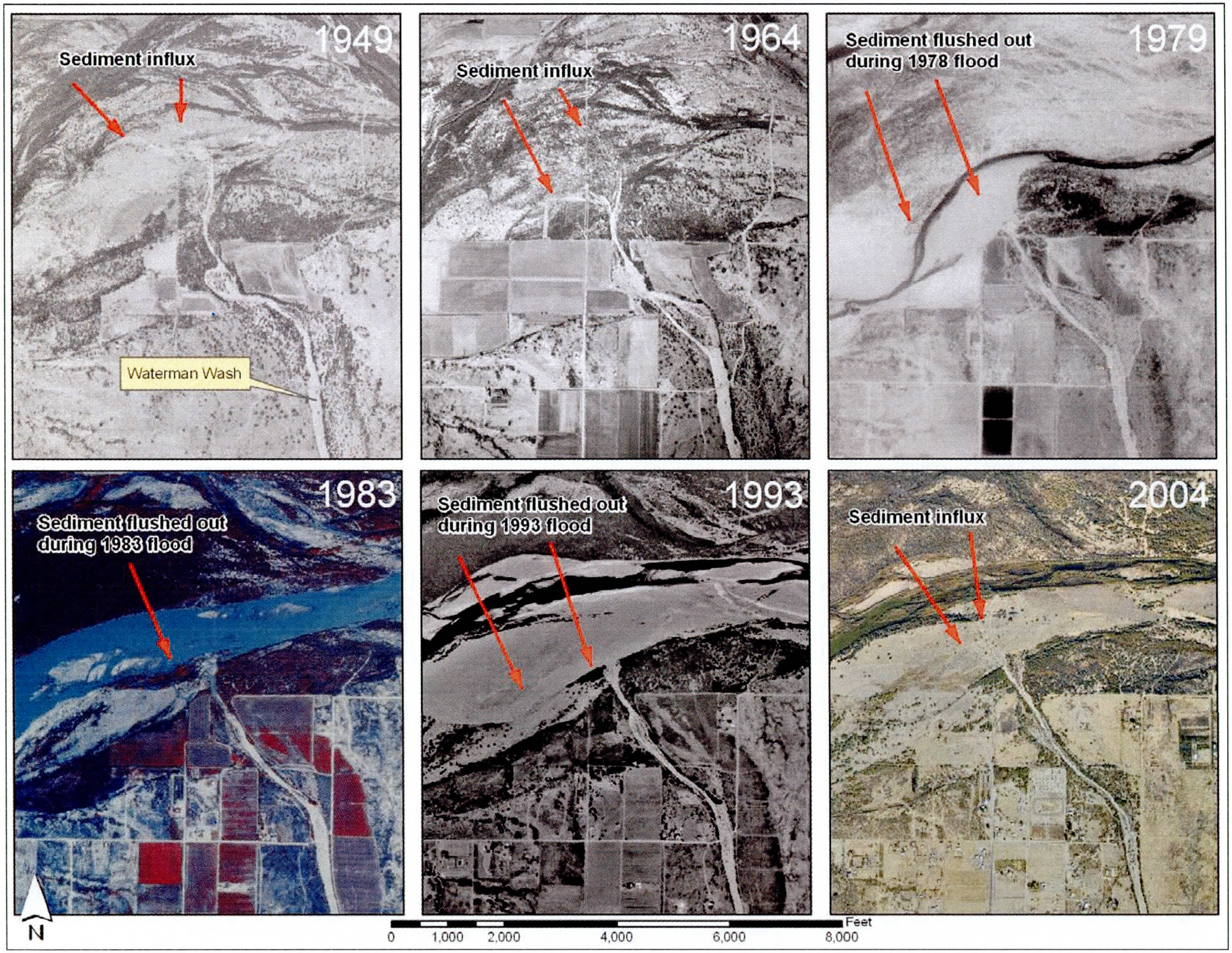


Figure 90. Historic photo comparison of Waterman Wash confluence

SUMMARY

Field data were collected to verify landform interpretations made from aerial photographs and to observe existing conditions within the El Rio study reach. Field data suggest the following:

- Cutbanks observed in multiple locations are evidence that active lateral erosion occurs in the study reach.
- Bedrock crops out and limits lateral erosion on the south side of the river corridor. Bedrock does not crop out along the right bank.
- Carbonate cementation was not observed to be a significant factor for bank stability within the study reach.
- Limited coarse sediments on the river bed are not sufficient to armor it againt long-term or local scour.
- Bank vegetation was not found to be a significant factor for limiting lateral channel erosion, although dense tamarix stands undoubtedly impact the channel morphology within the erosion corridor.
- Flood scars, flood debris, and other evidence of past floods was identified within the floodplain and indicates the expected wide area of inundation and erosion during future floods.
- The two largest tributaries, the Agua Fria River and Waterman Wash, provide sediment that has short-term impacts on local floodplain and channel morphology, but does not significantly impact the overall reach or potential lateral erosion.

CONCLUSIONS

The field methods described previously were employed to aid in the determination of the lateral stability of the Gila River within the El Rio study reach. Interpretations of channel conditions, historic flood evidence, surface characteristics, and areas of general active lateral erosion drawn from aerial photography were field checked to verify accuracy. Data collected in the field were used to interpret areas of the reach not specifically field checked. The summary of field data collected for the study reach indicates that although segments of the study reach are laterally stable, much of the reach is subject to future, active lateral erosion during moderate to large magnitude flood events.

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CHAPTER 5: EROSION HAZARD ZONE DELINEATION

INTRODUCTION

The Erosion Hazard Zone (EHZ) is a management tool used by the District to protecting the health, safety, and welfare of landowners and users of the river corridor. An EHZ was delineated based on the results of the analyses described in Chapters 2 to 4 of this Report, which was based on the following types of information and methodologies:

- Geology/Soils Data
  - Surficial and Bedrock Geologic Mapping
  - Soils Mapping
  - Geomorphic Surfaces
- Historical Analysis
  - Archeological Information
  - Historical Channel Movement Measurements
  - Geomorphic Components
- Field Data
  - Engineered Structures
  - Levees and Existing Bank Protection
- Hydraulic Analysis
  - HEC-6T Analysis
  - Floodplain/Floodway Location
  - HEC-RAS Analysis

A brief overview of how each of these data sets and methodologies were used to determine the EHZ for the El Rio WCMP study area is provided in this Chapter. Specific locations mentioned in the descriptions refer to the reach line segments described in Chapter 3 historical lateral migration discussion, and shown in Figure 25.

METHODOLOGY

Geology/Soils

Aerial photographs, field observations, surficial soil characteristics, channel and floodplain topography, and published surficial soils and geologic mapping were used to identify areas subject to riverine erosion. These data were used to estimate the relative age of the fluvial surfaces in the study reach, and to distinguish geologically recent geomorphic surfaces (0-1,000 years old) from older, more stable surfaces (1,000 – 700,000 years old). Relative geomorphic age data were useful for distinguishing areas of active and inactive channel movement.

Surficial Geology

The AZGS geologic map shown in Figure 3 provided a preliminary starting point for the EHZ delineation. Initially, the EHZ was delineated at the Holocene/Pleistocene (Qy/Qm) geologic unit contact based on the assumption that the Holocene units represent the active

Gila River and the maximum potential lateral extent of the riverine erosion hazard. AZGS mapping was also used to identify areas of bedrock outcrop, based on the assumption that bedrock is inherently resistant to riverine erosion. Although further analysis using other lines of evidence shifted the final position of the EHZ from this initial location, the geologic information provided a first cut at the EHZ. In no case is the EHZ intended to be located outside of the bedrock contract line.

Soils

Soils data were used to refine landform interpretations made from the AZGS mapping and interpretation of aerial photographs. The primary purpose for the soils analysis was to identify surfaces based on their soil characteristics that have been subject to active fluvial processes in recent geologic history. The soils information was most useful along the north (right bank) side of the El Rio study reach where no bedrock crops out and AZGS mapping did not distinguish between Holocene landforms. The landform designations interpreted from the soil descriptions illustrated in Figure 8 provided enough detail to segregate the Holocene (Qy) geologic unit into floodplain, terrace, or valley plain surfaces. Figure 8 shows a general corridor of floodplain soils for the right bank of the study reach suggesting active fluvial processes in recent geologic history, thus a maximum extent of potential lateral erosion (EHZ).

Historical Analysis

Historical data such as archaeological records and measurement of channel changes on historical aerial photographs were used identify areas subject to riverine erosion in the recent past and to calibrate estimates of potential future lateral migration of the river.

Archeological Analysis

Limited archeological data were available in isolated portions of the study reach. Areas where prehistoric sites were undisturbed by lateral erosion for up to 800 years are evidence of a limit on past lateral movement, thus extending the photographic record for those areas. Burial of these archaeological sites by fine-grained sediment is evidence that portions of the floodplain have been subject to periodic shallow inundation.

Historical Lateral Movement

The measurement of historical lateral movement and width from semi-rectified historical aerial photographs represents quantified evidence of the scale and extent of historic channel change. Delineation of the compound and active channel banks for each set of aerial photographs dating back to 1937 provided valuable information as to the maximum extent of active river processes within the past 65 years. Maximum single-event and long-term width and channel bank measurements were applied to the existing channel position to determine the EHZ boundary, except where geologic or manmade features would physically prevent erosion. Where a physical boundary such as bedrock was overlapped by the projected EHZ line, it was trimmed to the location of the physical barrier.

The lack of geologic control and the anthropogenic disturbance of geomorphic surfaces flanking the north side of the river corridor necessitated reliance on historical lateral movement analysis combined with engineering judgment for the EHZ delineation. The rationale is that the maximum lateral distance that the compound channel has moved during a single flood event can potentially reoccur unless prevented by either a natural or manmade control. A detailed analysis at each reach line segment was performed using the aerial photographs for the entire right bank of the study reach. Table 12 and Table 13 summarize the rationale used for EHZ determination along the south (left bank) and north (right bank) portions of the river corridor.

Hydraulic Analysis

Location of Floodplain and Floodway

In general, the EHZ delineation is independent of effective FEMA floodplain and floodway delineations, since erosion hazards are not created exclusively by the regulatory (100-year) flood and may extend well outside the 500-year floodplain (FEMA, 1999). The EHZ is intended to identify areas subject to erosion damage from regardless of whether a property is located within the 100-year floodplain (JEF, 2001). A consistent relationship between the floodplain/floodway and the EHZ does not exist. The EHZ is located both outside and inside the floodplain limits. In general, the Erosion Hazard Zone is located outside the floodway. The one exception where the EHZ is inside the floodway is along the right bank downstream of the Tuthill Road Bridge between reach line segments 41 and 47. The historical analysis determined this reach to be laterally stable throughout the photographic record. Both historic and field analysis indicated the EHZ should not be located outside the floodway, and thus was delineated as illustrated in Appendix E.

HEC-RAS Analysis

The HEC-RAS 100-year hydraulic model from the effective Floodplain Delineation Study (Baker, 1992) was employed to estimate erosion potential using bankfull discharges, as well as flow velocities along compound channel margins and overbank areas where both aerial photo interpretation and field investigations were inconclusive. This methodology was used primarily along the right bank in shallow sloping, overbank areas, such as the area on the right bank reach downstream of the Tuthill Road Bridge. This area has been relatively laterally stable within the photographic record, and bank movement has been caused primarily by encroachment. The overbank terrain is extremely flat. The HEC-RAS model shows right-bank, 100-year flood inundation up to 3,000 feet away from the channel thalweg. The hydraulic model shows overbank velocities in this reach between 3 and 5 feet per second with depths between 4 to 6 feet. When plotting these values on a Hjulström (1939) diagram and considering the sediment size of the overbank material, lateral erosion is probable (Figure 91). The results of the hydraulic analyses were incorporated onto the final EHZ line.

Table 12. Left bank EHZ rationale

Reach Line Segment Span	EHZ Rationale
85-82	The EHZ ties into the Agua Fria lateral migration Erosion Hazard Zone on the upstream-most end of the study reach. Lateral change in this reach has ranged from 200' to more than 500'. A significant area of agricultural land developed between 1964 and 1977 was reclaimed in the 1978 flood. The EHZ is set outside the maximum compound channel line.
82-70	Estrella Mtn Park has historically been a part of the compound channel and has been inundated by floods within the photographic record. Vineyard Avenue is raised with bank protection; however, information regarding specific lateral erosion control engineering of the embankment has not been verified. The EHZ is generally set at the bedrock contact.
70-56	The King Ranch property has historically been a part of the compound channel. The existing King Ranch levee located downstream of the Estrella Parkway Bridge, although bank protected, is not FEMA certified (Baker, 1999), therefore is placed inside the EHZ. The distance from the present compound channel bank to the Pleistocene contact is approximately 1,000 and 3,000 ft in this reach; therefore, EHZ is generally set at Pleistocene-Holocene contact with no buffer into the Pleistocene surface.
56-51	Compound channel bank has migrated a maximum of approximately 600 feet in this reach historically. The present compound channel bank is in contact with the Pleistocene surface; therefore the EHZ is set 100 feet back from Pleistocene-Holocene contact except at bedrock between line segments 52 and 51.
51-28	The compound channel bank has been relatively stable and remained at the Pleistocene-Holocene contact. The characteristics of the Pleistocene surface as described in the LMAR report indicate it is highly erosive forming cutbanks up to 50 feet in height. Severe gullying and piping of the Pleistocene surface at the contact result in significant instability near the cutbanks. In these areas, the EHZ is set 320 feet back from the Pleistocene-Holocene contact as determined from analyses of historic movement of the compound channel banks in addition to engineering judgment.
28-14	Bedrock.
14-2	Significant historic changes in compound channel banks in this reach indicate lateral migration potential is high. There is presently no structural control preventing the channel from migrating as it has done historically. The EHZ is located at the Pleistocene-Holocene contact.

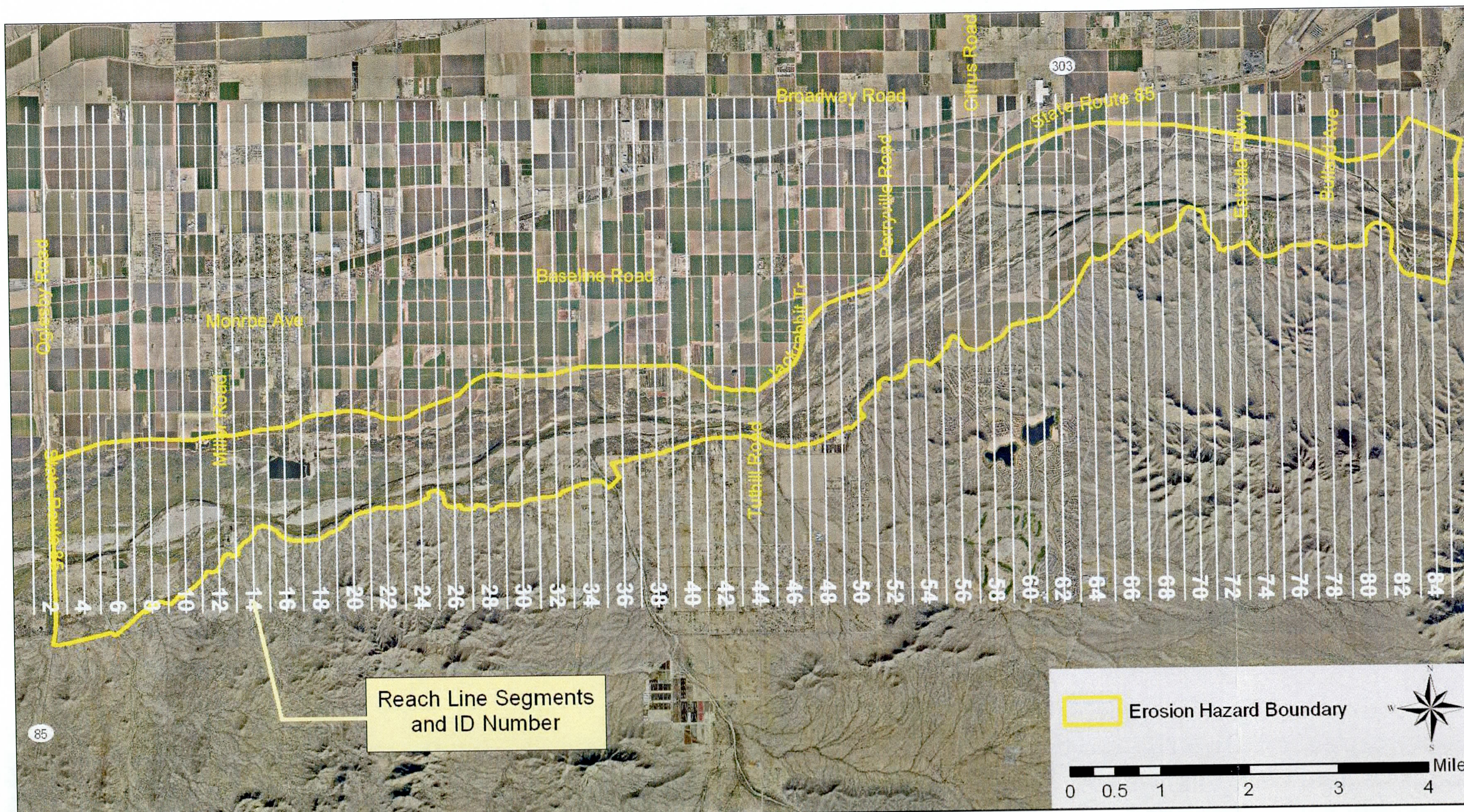
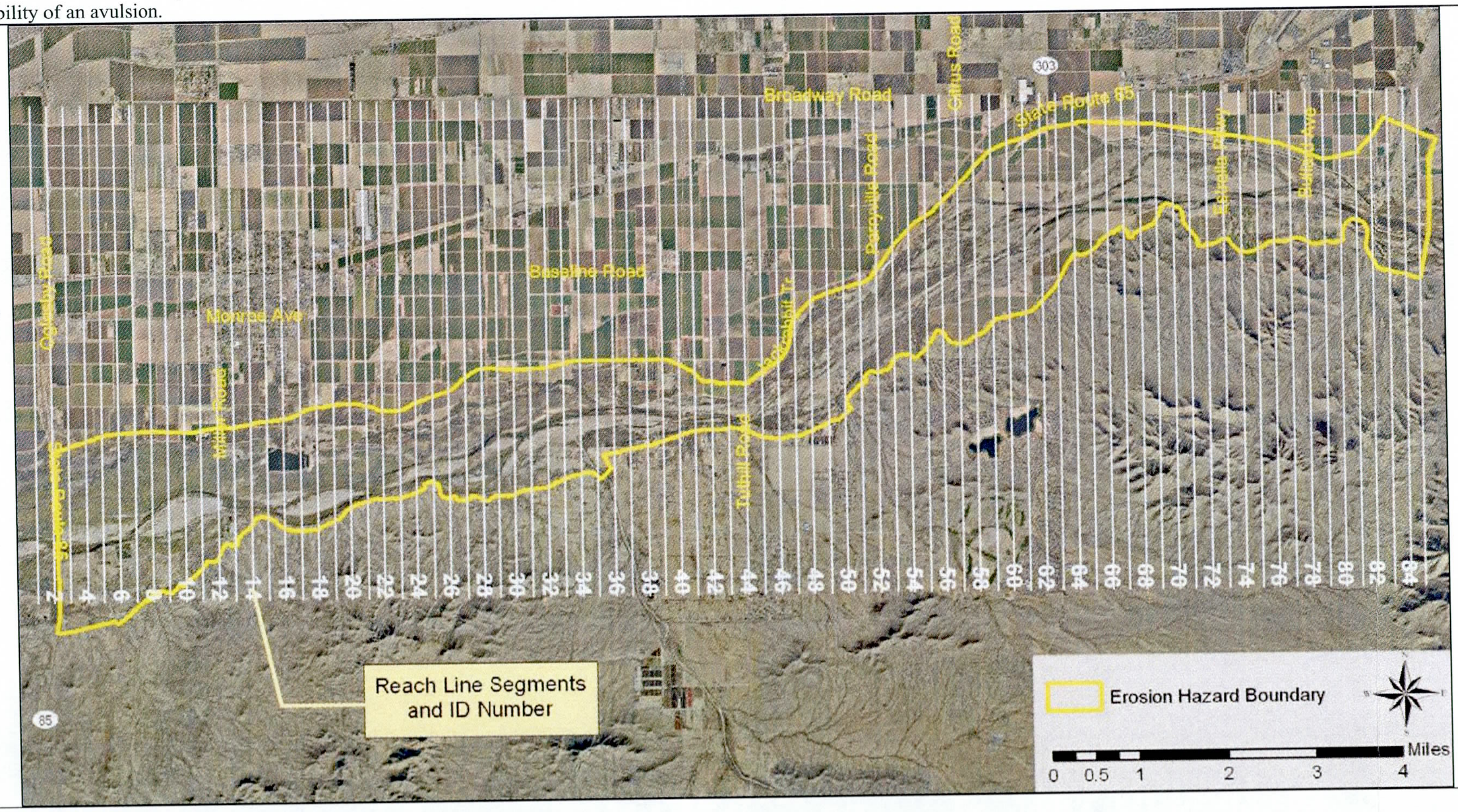


Table 13. Right bank EHZ rationale

Reach Line Segment Span	EHZ Rationale
85-80	Incorporation of the lateral migration Erosion Hazard Zone from the Agua Fria Watercourse Master Plan
80-69	Encroachment has been the dominant process in channel bank location changes. Lateral migration of the compound channel has been minimal in this reach; however, there are no structural controls present to prevent lateral migration. The Buckeye Canal may provide some minor control on lateral erosion, but is not specifically engineered to do so. The EHZ is set at a 500 feet buffer from the north bank of the canal.
69-64	Transition to the Buckeye Canal near reach line segment 64
64-57	Significant lateral change has occurred throughout this reach. The 1978 flood saw significant inundation and was the cause of maximum single event change. Field investigation of this area showed overbank avulsive channels up to the present agricultural field boundaries. No engineered structures are present to prevent lateral erosion. The maximum channel change distance is over 2,600 feet measured from the 2002 compound channel boundary. This puts the EHZ between the 2002 channel boundary and the canal. Therefore, it seems more logical to follow the canal in this reach. The EHZ is set on the northern bank of the canal, no buffer from the canal bank was applied.
57-47	The primary bank movement in this reach comes from encroachment. The maximum bank position has not changed significantly since 1937. Both the 1978 and 1983 floods saw active flows up to the maximum boundary. The reach geometry is relatively straight and just downstream of a bend. The 500 feet buffer from the compound channel bank was applied for the EHZ.
47-44	Historically the channel has been stable in this reach. No evidence suggests flood inundation has occurred west of the Jackrabbit Trail roadway alignment since 1937. A 6 feet-8 feet high cutbank is present near the roadway, but the downslope side is heavily vegetated with Tamarix creating low velocities. The roadway embankment is protected with dumped rip-rap. The EHZ is set outside the roadway embankment.
44-41	The compound channel has been historically stable. There is presently no structural control to protect from lateral erosion. Flow expansion from the bridge could potentially cause lateral migration of the bank. The 500 feet buffer from the maximum compound channel bank was used for the EHZ.
41-39	Channel has had historic movement. Maximum movement of 728 feet occurred in 1978 flood. No present-day structures would prevent another major movement. EHZ line is 728 feet offset from maximum compound channel boundary to northern roadway embankment.
39-35	Area is currently developed, historically has been active. Evidence of 1978 flood indicates significant erosion in this reach. Placement of Tuthill Bridge may limit extent of future floods; however no present-day structures appear to be sufficient to prevent erosion. Historic maximum movements of bank have been caused by encroachment. EHZ follows northern roadway embankment.
35-30	This reach has seen significant inundation from the 1978 flood. Currently there is a 10 feet-12 feet cutbank in this reach. No engineered structures to prevent erosion are present. 890 feet is the value of the maximum single event channel change. The EHZ is at a 890feet buffer outside the maximum compound channel boundary in this reach.
30-21	This reach saw significant overbank flooding in 1978. Currently a 10 feet-20 feet cutbank is present with structural indicators of lateral channel migration (well-head exposed, toppled shack). The value of the maximum flood-caused channel change in this reach was 1,700 feet during the 1978 event but was generally constrained at the agricultural development contact. No engineered structural control is in place to prevent lateral migration. The average compound channel movement in this reach is 910 feet. Engineering judgment suggests 910 feet from the maximum compound channel bank is adequate for the EHZ.
21-13	Significant overbank flooding occurred in 1978 and was less severe, but present, in 1983. Field visits were done in this area north of the S&G operation. No avulsive channels were present. The vegetation is a very dense Tamarix forest. The large gravel pit (probably 40 feet to 60 feet in depth) is within both the FP and the FW. The effects of this pit on lateral erosion during a flood would most likely be significant. Presently no erosion control engineered structure(s) exist in this reach. The maximum channel change value for this reach is 1,600 feet, which occurred between 1977 and 1978 but was within the maximum compound channel limits. Due to the proximity of the sand and gravel mine, the EHZ is set at 1,000 feet from the maximum compound channel bank.
13-2	This has been the most stable right-bank reach throughout all of El Rio. No appreciable compound channel movement has occurred since 1949. By 1949 the floodplain was already a thick forest of Tamarix. The 1978 floods appear to have inundated the northern-most boundary of this area, but did not extend north of the irrigation canal. The 1983 and 1993 floods were focused primarily toward the left bank to bypass the Tamarix. The floodplain area up to the canal was field checked. 5 ft.-6 ft. avulsion channels were present in this area, but appear relatively cu t off from the active system due to the dense vegetation. The channels probably serve as the transport system for local runoff. Capture of the sand and gravel pit upstream could create an avulsion that would bypass the Tamarix along the northern boundary. The EHZ is set back 500 ft. from the northern canal bank to account for the possibility of an avulsion.



HEC-6 Analysis

A HEC-6T sediment transport model was developed for the El Rio Watercourse Master Plan by Stantec Consulting, Inc. Results of the HEC-6T model were reviewed and compared with the lateral migration analysis results as discussed in Chapter 3. Reaches in which the sediment model predicted significant vertical changes generally exhibited significant lateral change.

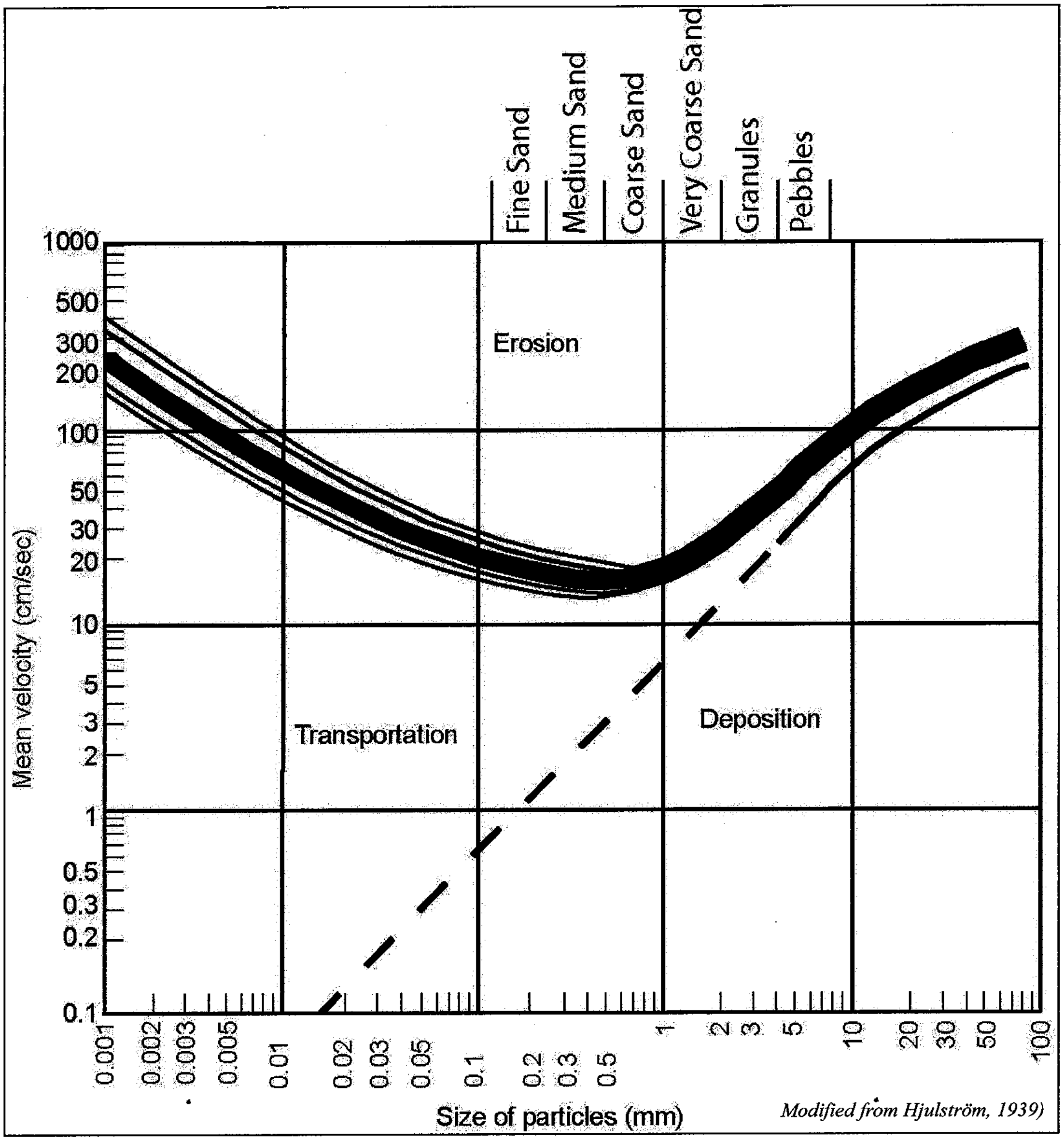


Figure 91. Hjulström diagram

Field Data

As discussed in Chapter 4 of this Report, field data were used to further refine the EHZ line where warranted. Reaches that were not directly observed in the field were interpreted based upon similar characteristics observed on aerial photos. Almost without exception, field observations took precedence over previous interpretations.

Engineered Structures

Manmade structures, whether engineered or not, have the potential to alter the natural lateral erosion hazard along a river, either by creating more erosive conditions or by inhibiting erosion. The influence of manmade structures identified during the LMAR study process was considered as part of the EHZ delineation process.

Levees and Bank Protection

Engineered structures such as levees, channel bank protection, and protected roadway embankments were considered for the EHZ delineation. In general, if existing structures were determined to be adequately designed for lateral erosion protection, then their location would take precedence over any previous EHZ interpretation, and the EHZ would be delineated at the top of the structure.

Figure 92. W. Vineyard Avenue roadway embankment, looking upstream direction

Figure 93. King Ranch Levee just downstream of Estrella Mtn. Regional Park, looking upstream direction

The two structures of primary interest were the West Vineyard Avenue roadway embankment and the King Ranch levee downstream of Estrella Parkway Bridge. The West Vineyard Avenue roadway embankment is raised and bank protected with angular rip-rap (Figure 92). Specific engineering for lateral erosion protection was not readily verifiable; therefore the embankment was assumed to be susceptible to lateral erosion. The revised Salt/Gila FDS (Baker, 1999) modeled Vineyard Avenue both to fail during the 100-year design event and to function as a levee. In either situation, the roadway was overtopped. The combination of this information resulted in the roadway being placed inside the EHZ. The King Ranch levee is approximately 10-12 feet in height and bank protected with large, angular rip-rap (Figure 93). This structure does not currently hold a FEMA approved certification (Baker, 1999), and therefore is located within the EHZ. If evidence of sufficient engineering protection of Vineyard Avenue from lateral erosion can be demonstrated, and/or if a FEMA certification of the King Ranch levee is later designated, a re-evaluation of the EHZ would be warranted.

SUMMARY

An erosion hazard zone was delineated for the El Rio WCMP study reach using a variety of geomorphic and engineering methodologies.

Figure 94 shows the EHZ for the entire El Rio study reach. More detailed figures showing the EHZ delineation by subreach are provided in Appendix E. Appendix F includes a large format plate map showing the entire EHZ.

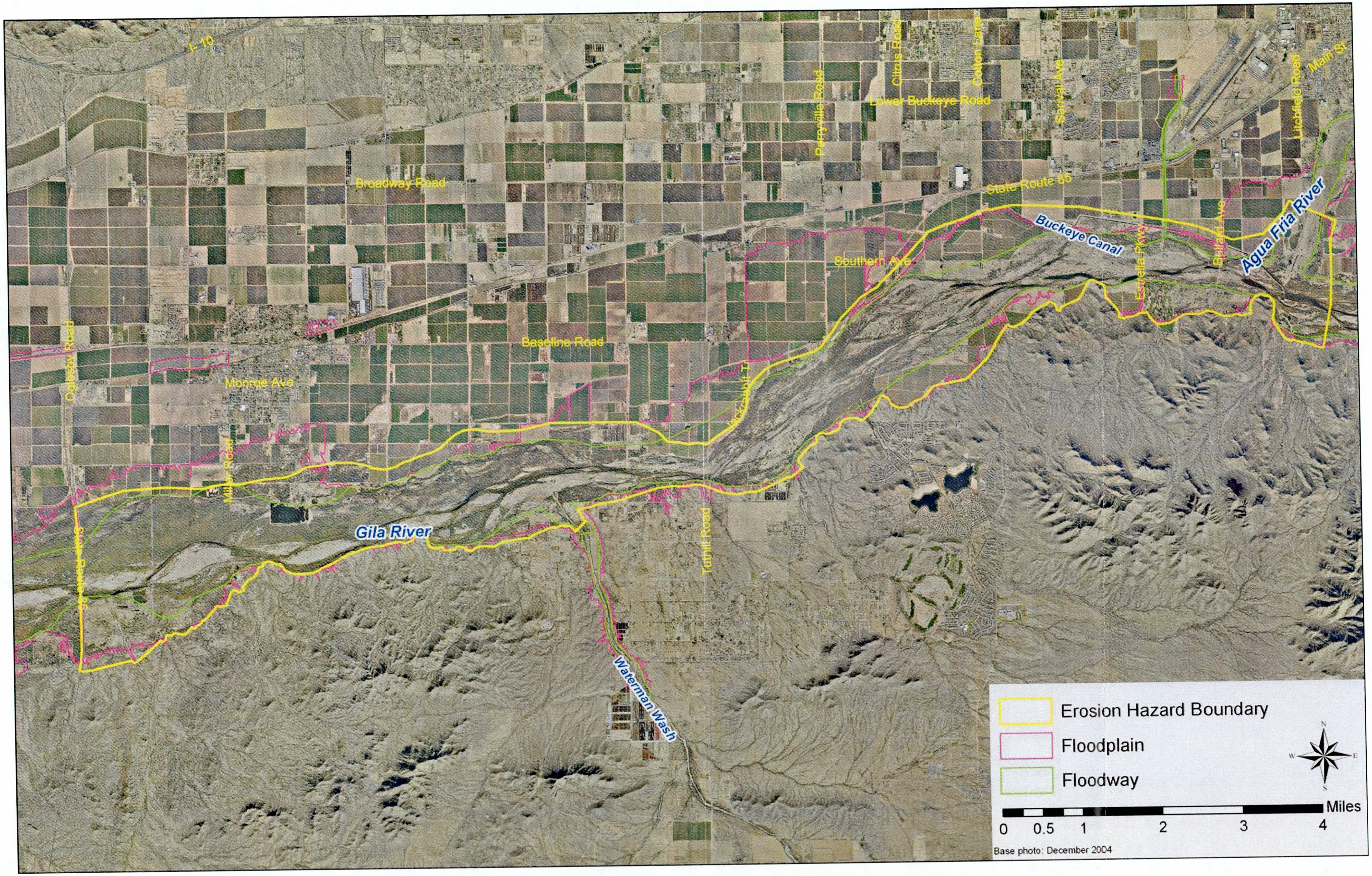


Figure 94. El Rio Erosion Hazard Boundary

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

A variety of methodologies and information types were used to assess the potential for future lateral migration of the Gila River with the El Rio WCMP study reach. Regional geologic and soils information provided a base context from which the general history of active river processes was interpreted for the Quaternary and Holocene Periods. From these date, it is known that within the past 10,000 years, the Gila River occupied a corridor between 14,000 feet and 17,000 feet in width. More recently, the active river corridor ranges in width from approximately 2,000 feet to more than 10,000 feet. Bedrock flanks portions of the south side of the river throughout the project area and provides lateral stability and locally constrains future channel bank movement. No mapped geologic constraints exist along the north side of the river corridor through the study reach, and none were encountered during the field investigation.

Historical information on lateral channel movement was derived from comparison of semi-rectified aerial photographs. These data indicate that the magnitude of channel change that has occurred within the photographic record (1937-2002) is significant, both as response to single flood events or over the entire period of record. The maximum, single-event lateral movement for the compound channel area was more than 3,100 feet. All of the maximum measured single-event channel movements can be attributed to the December 1978 flood, which had an estimated peak discharge of about 125,000 cfs at Gillespie Dam, and was significantly less than the estimate 100-year peak discharge for the study reach.

Although specific reaches within the study area have been relatively stable over the 65 year period of record, the channel width change analysis indicated that a compound channel maximum change of more than 5,000 feet has occurred, with a maximum active channel change of more than 4,500 feet. The locations of the most substantial historic channel change are not presently protected by engineered channel stabilization. Future large magnitude floods similar to those experienced in the photographic record would be expected to cause significant channel change. Although the magnitude and frequency of flood discharges has been greatly reduced by the upstream dams, large floods are still possible. These relatively infrequent, large floods are capable of causing the same types of significant changes in channel bank locations as has been experienced in the past.

The Erosion Hazard Zone delineated for the El Rio WCMP is intended for use in floodplain management of the Gila River, and for development of watercourse master plan alternatives and is recommended for adoption as the regulatory Erosion Hazard Zone for the final watercourse master plan.

RECOMMENDATIONS

The historic and geologic records indicate that the Gila River within the El Rio study reach is vulnerable to extreme rates of lateral channel movement. Within the past 65 years, several large floods have occurred, resulting in lateral erosion within the study area. Population growth in the north Phoenix corridor has increased the pressure to develop flood and erosion prone lands along the major stream corridors. The purpose of the Lateral Migration Analysis Report section of the El Rio Watercourse Master Plan was to identify and delineate an Erosion Hazard Zone, which when regulated, will preserve the natural function of the river. The regulatory Erosion Hazard Zone presented in this report represents present-day river conditions and does not reflect any proposed engineering modifications to the river. Any manmade changes to channel banks, floodplain conditions, vegetation conditions, and general channel morphology will directly impact the erosion hazard boundaries presented herein. Should any of these changes occur, a reevaluation of the Erosion Hazard Zone is recommended. In addition, the following management recommendations are proposed for adoption with the recommended watercourse master plan:

1. Adopt the recommended Erosion Hazard Zone for floodplain management purposes.

2. Regulate all new development within the Erosion Hazard Zone by requiring a special use permit. To obtain a permit, the development within the corridor must do the following:

    - Meet the National Flood Insurance Program (NFIP) requirements for development within a floodplain.
    - Provide an engineering and geomorphic study certifying that the proposed development will not be affected by erosion over a 60-year planning period.
    - Demonstrate that any proposed bank stabilization will not deleteriously affect reaches or development upstream and downstream.
    - Demonstrate the stability of any proposed bank stabilization. Local scour, long-term degradation, channel movement, and bank erosion shall be explicitly addressed in the design reports for any proposed bank protection.
    - Hold the Flood Control District of Maricopa County and Maricopa County harmless from any and all claims resulting from erosion or any other flood related damage due to development within the erosion corridor.
    - Provide for perpetual maintenance of bank stabilization at no cost to any public agency. Provide for maintenance and access easement adjacent to any bank stabilization.
    - Obtain necessary floodplain, wetlands (404), and water quality (401) permits or approvals for any construction activities at no cost to any public agency.

3. Vegetation Management. Within the Erosion Hazard Zone, the following requirements are recommended for all future development:

    - Establish a no-build zone close to banks. Habitable structures should be set back a minimum distance from the top of the bank.
    - Vegetation on and near banks should not be disturbed, or should be replaced where disturbed by construction activities.
    - Where vegetation is disturbed, provisions for temporary bank stabilization should be made that protect the bank from erosion and allow for re-establishment of vegetation.

- Any proposed modifications of the floodway and active channel should include a detailed geomorphic and engineering study of the potential impacts on adjacent reaches.
- The channel should be allowed the freedom to erode its banks and move within the floodplain.

4. Regulation of In-Stream Sand and Gravel Mining. Sand and gravel mining is likely to result in channel degradation and increase bank erosion if it is not properly engineered and managed. Any proposed sand and gravel mining should be required to conform to the Flood Control District of Maricopa County Sand and Gravel Mining – Floodplain Use Permit Application Guidelines (JEF, 2003a).

5. Future Monitoring. Channel stability should be monitored periodically to assess impacts of floods, to determine whether the Erosion Hazard Zone should be updated, and to document continued channel change for application to other stream systems in Maricopa County.

RECOMMENDED FUTURE INVESTIGATIONS

Task 5.10.1.3 requires that the study team identify and recommend areas for further detailed studies within the El Rio study reach. The following areas of more detailed evaluation are recommended:

1. Sand and Gravel Mining Impacts. As discussed in the Human Impacts section of this report, sand and gravel mining has occurred on the Gila River within the El Rio study reach since the 1940s. Population growth patterns projected for Maricopa County indicate that the El Rio corridor is likely to experience rapid growth within the next twenty years, which will dramatically increase the demand for rock products. Assessing the impact of future mining activity was not authorized in the original scope of services for the LMAR. Therefore, we recommend that detailed analyses of cumulative and individual sand and gravel mining impacts be conducted, and a reach-specific cohesive sand and gravel mining policy be established as part of the Watercourse Master Plan.

2. Detailed Field Analyses. Detailed field investigations were not authorized for the El Rio LMAR. Therefore, additional field investigation should be authorized when the Erosion Hazard Zone intersects future construction or planning elements proposed as part of the El Rio Watercourse Master Plan. We recommend that prior to future development that may encroach on the EHZ, detailed field investigations be conducted to determine channel stability.

3. Detailed Geomorphic Mapping of the Study Reach. Geomorphic mapping of the overbank floodplain surfaces, in addition to the areas within the compound and active channels, provide an increased level of understanding of the historic behavior of the Gila River within the study reach. Detailed mapping can provide a higher level of certainty in EHZ delineation.

4. Mathematical Analysis. Application of certain mathematical modeling techniques for assessing and predicting channel behavior used in previously completed watercourse master plan geomorphic assessments were not authorized for the El Rio LMAR. In addition, certain engineering methodologies such as computation of scour depths, equilibrium slope, and armoring to be completed by other team members were not available at the time the LMAR was prepared. It is recommended that mathematical methods be employed to aid in quantifying the erosion hazard potential within the study reach. The types of mathematical analyses recommended include:
    - Comprehensive sediment size estimation throughout study reach – sieve analyses and field estimates
    - Geomorphic methods – bankfull discharge and hydraulic geometry relationships
    - Engineering methods – allowable velocity, equilibrium slope, armoring, scour, and Lane's relation

5. New Hydrologic Regime. Modifications to Roosevelt Dam on the Salt River were initiated in 1991 which raised the height of the dam by 77 feet. These modifications significantly increased the potential storage volume behind the dam. Occurring coincidently with the modifications of Roosevelt Dam was the construction of the New Waddell Dam on the Agua Fria River. Like the modifications to Roosevelt Dam, these improvements significantly increased the potential storage volume behind the dam. Changes to the flood flow frequency of the Salt and Agua Fria Rivers affect the Gila River within the El Rio study reach. Future responses of the Gila River to the new conditions are uncertain. Potential long term changes in both the compound and active channel limits should be investigated.

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http://www.maricopa.gov/parks/estrella	(accessed 8/11/03)
http://www.arizonan.com/Buckeye	(accessed 8/11/03)
http://www.adwr.state.az.us	(accessed 8/12/03)

APPENDIX A

Temporal Chronology

EL RIO WATERCOURSE MASTER PLAN
LATERAL MIGRATION ANALYSIS REPORT

Decade	FLOODS[1]	LAND USE[2, 3, 4, 5]	BRIDGES AND OTHER CONSTRUCTED WORKS[6]	DAMS & DIVERSIONS[5, 7]
1820s		1824: Anglos began trapping beaver along Lower Gila		
1840s		-1846: Kearny's "Army of the West" conducted 1st systematic exploration of the Gila River		
1850s		-1857: Anglo farming began on lower Gila near Wellton -1859: Gila River Indian Reservation established		
1860s		-1868 Ingall's Survey		
1870s		-1872: Cattle grazing in Gila River Valley -1872: Copper Mountain Mining District -Late 1870s: S.P. Railroad		
1880s		-1888: Buckeye Post Office Established		-Mid-1880s: Earliest reports of agricultural diversions -1888: Buckeye Canal
1890s	-Feb 1891: 250,000 cfs	-1892: 10,000 acres were being farmed in Buckeye Valley		
1900s				-1908: Granite Reef Dam (Salt River) -1911: Roosevelt Dam (Salt River)
1910s		-1915: salt cedar introduction in the Safford area		-1911: Roosevelt Dam (Salt River) -1916: Ashurst-Hayden diversion works authorized
1920s	-Jan 4, 1922: 32,700 cfs -Dec 28, 1923: 85,000 cfs -Sep 28, 1926: 38,300 cfs -Feb 18, 1927: 67,300 cfs	-Late 1920s: Cotton becomes dominant crop in Buckeye Valley		-1921: Gillespie Dam (Gila R.) -1923: Ashurst-Hayden Dam (Gila R.) -1926: Mormon Flat Dam (Salt R.) -1927: Pleasant Dam (Salt R.) -1927: Horse Mesa Dam (Salt R.) -1928: Coolidge Dam (Gila R.)
1930s	-Feb 11, 1932: 44,500 cfs -Feb 9, 1937: 45,800 cfs -Mar 5, 1938: 60,000 cfs			-1930: Stewart Mtn. Dam (Salt River) -1939: Bartlett Dam (Verde River)
1940s	-Mar 16, 1941: 45,800 cfs	1949: First sand and gravel mining evidence from aerial photography		-1946: Horseshoe Dam (Verde River)
1950s		-1953: Estrella Mtn. Regional Park established		-1959 Painted Rock Dam
1960s	-Jan 2, 1966: 64,200 cfs		-1969: original State Route 85 Bridge	
1970s	-Mar 3, 1978: 92,900 cfs -Dec 20, 1978: 125,000 cfs			
1980s	-Feb 16, 1980: 178,000 cfs -Feb 10, 1983: 39,800 cfs -Oct 5, 1983: 95,200 cfs		-Early 1980s: FCDMC 1000 ft. corridor clearing project -1981: Tuthill Road Bridge -1982: Bullard Ave. Bridge -1987: Estrella Pkwy. Bridge	
1990s	-Jan 9, 1993: 130,000 cfs -Feb 16, 1995: 50,000 cfs		-1995: State Route 85 Bridge	-1992: New Waddell Dam (Agua Fria River) -1993 Gillespie Dam breached during flood
2000s				

Historic and modern agriculture within the Buckeye Valley (1870s–2000s)

Sand and gravel mining within the Buckeye Valley (1940s–2000s)

1 Source: Annual peak discharge values, USGS Gage #09519500 below Gillespie Dam
2 Source: Tellman, et al. (1997)
3 Source: Rogers (2002)
4 Source: Arizona Stream Navigability Study for the Upper Gila and San Fransisco Rivers (ASLD, 1997)
5 Source: Arizona Stream Navigability Study for the Gila River: Colorado River confluence to the Town of Safford (ASLD, 2003)
6 Source: As-Built and Plan Engineering Documents
7 U.S.G.S. Water Supply Paper Number 1313, p. 595

Temporal Chronology

APPENDIX B

Historic Photo Comparison Exhibit Book

(SEPARATE VOLUME)

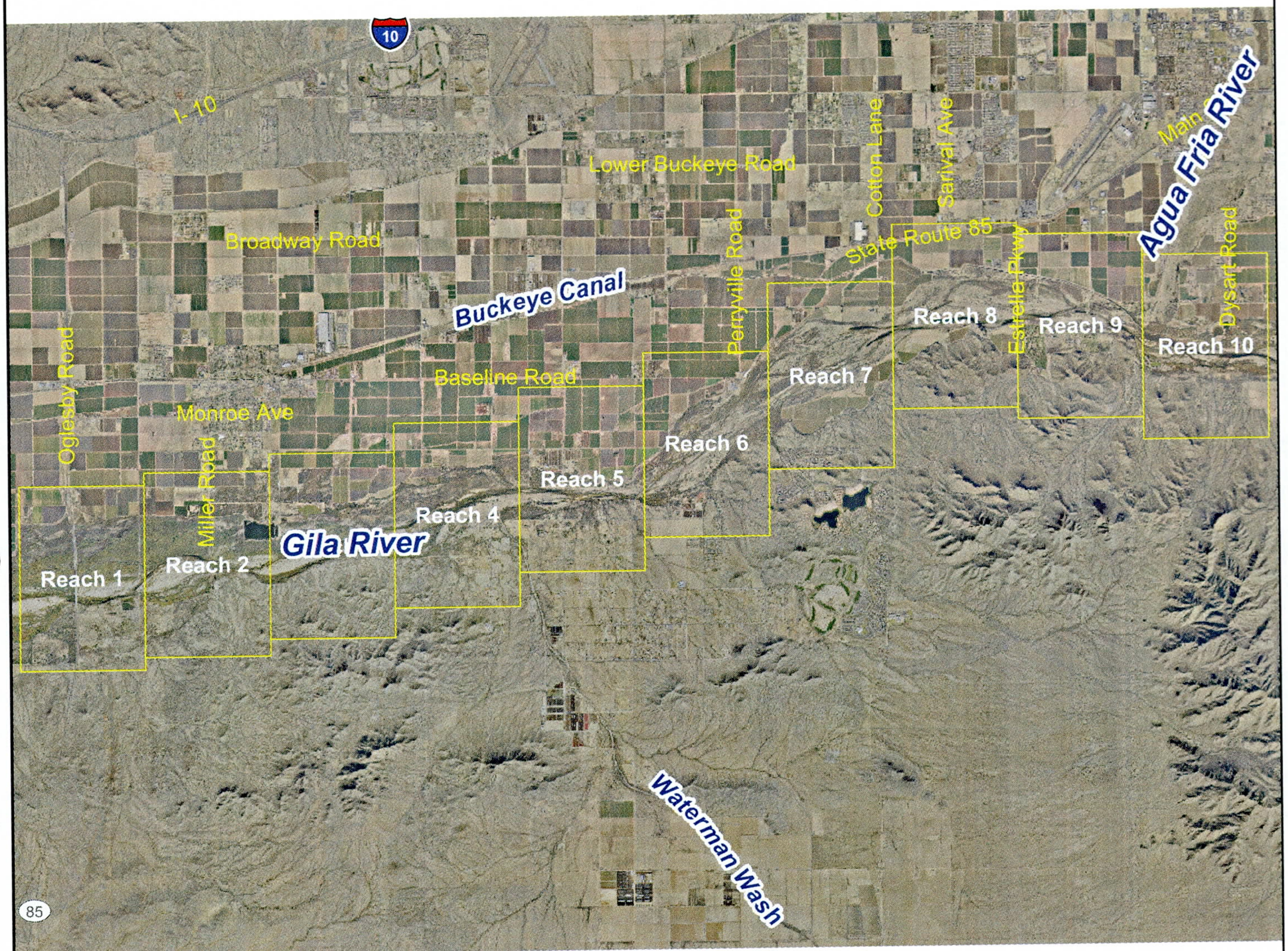
APPENDIX C

Quantitative Lateral Migration Analysis Plots

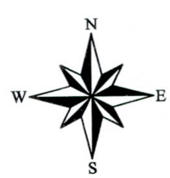
(SEPARATE VOLUME)

APPENDIX D

Field Photos and Locations

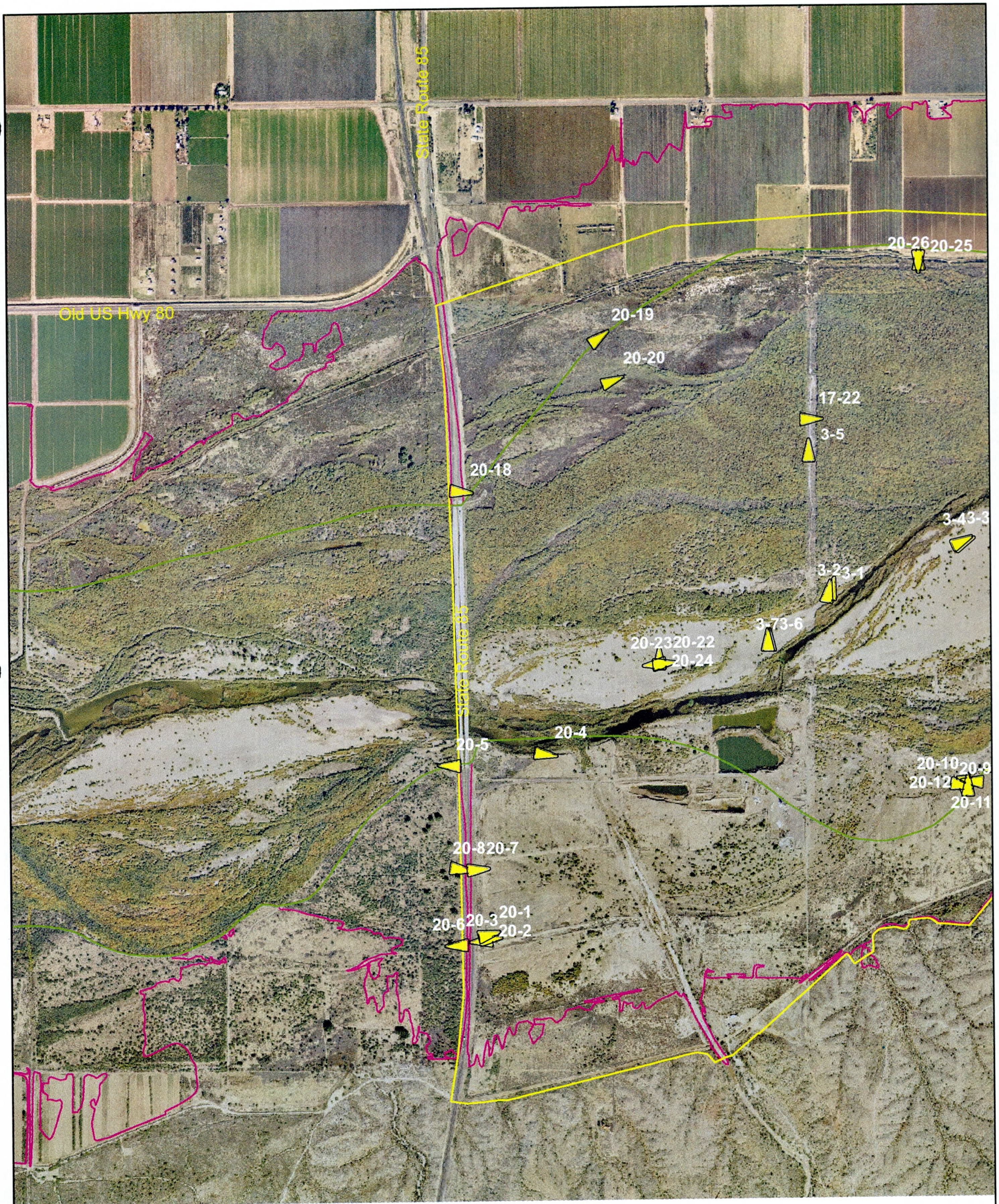


Field Photo Locations
Reach Key Map



Miles

0 1 2 4 6 8



Base photo: December 2004

N
W
E
S

0 500 1,000 2,000 3,000 4,000 Feet

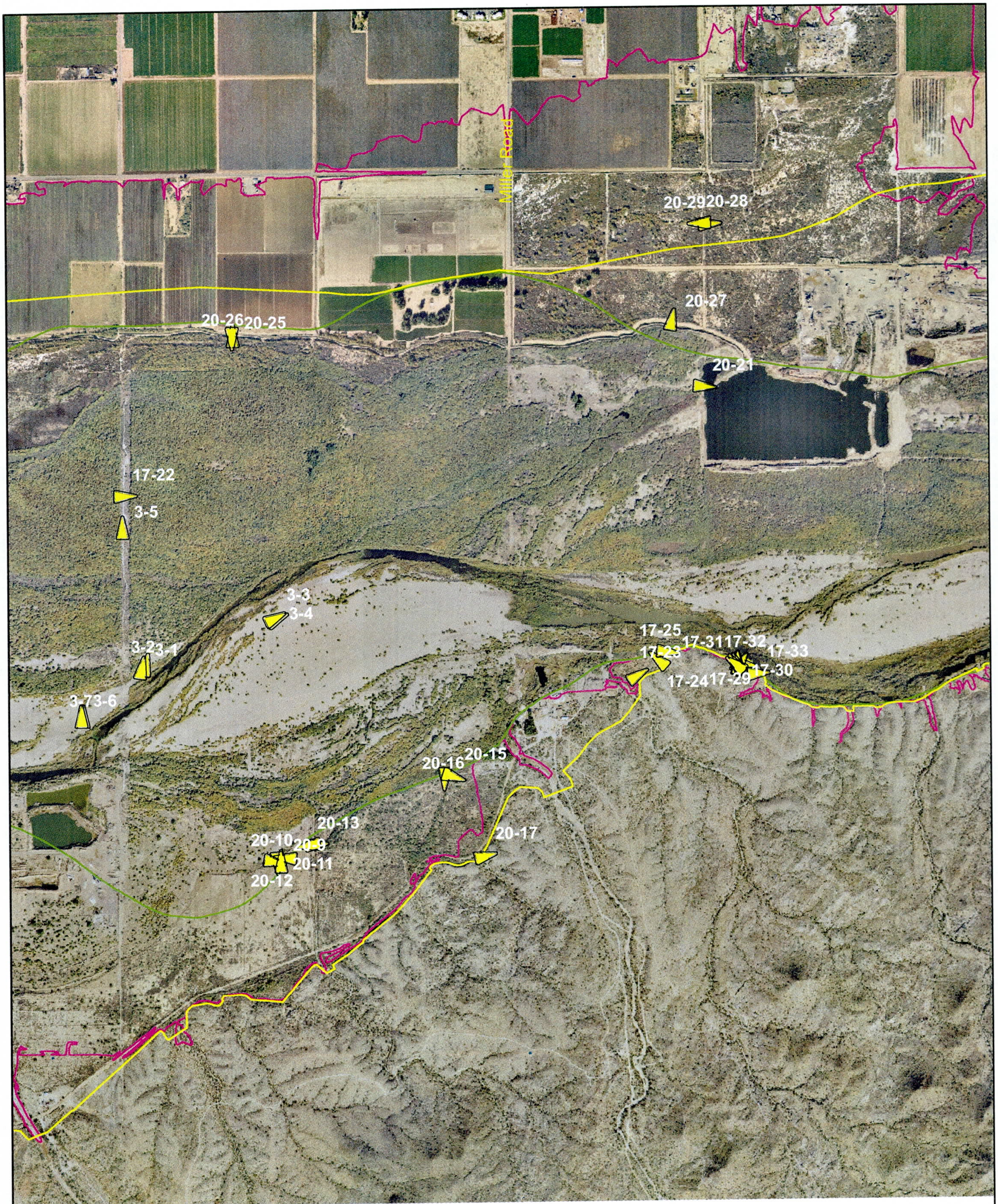
Field Photo Locations
Reach 1

Erosion Hazard Boundary

Floodway

Floodplain

Field photo locations and ID



Base photo: December 2004

Field Photo Locations Reach 2

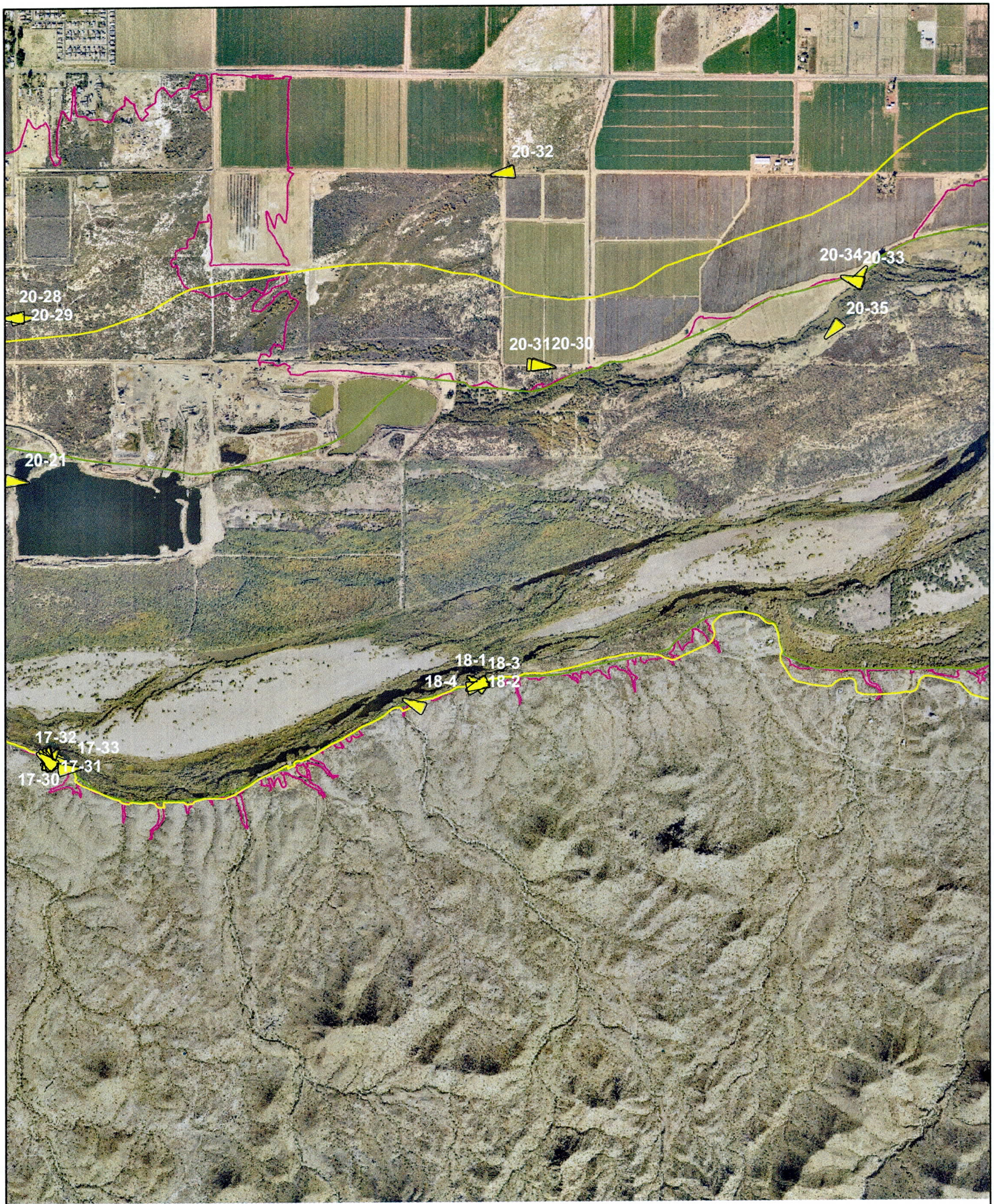
0 500 1,000 2,000 3,000 4,000 Feet

Erosion Hazard Boundary

Floodway

Floodplain

Field photo locations and ID



Base photo: December 2004

N
W
E
S

0 500 1,000 2,000 3,000 4,000 Feet

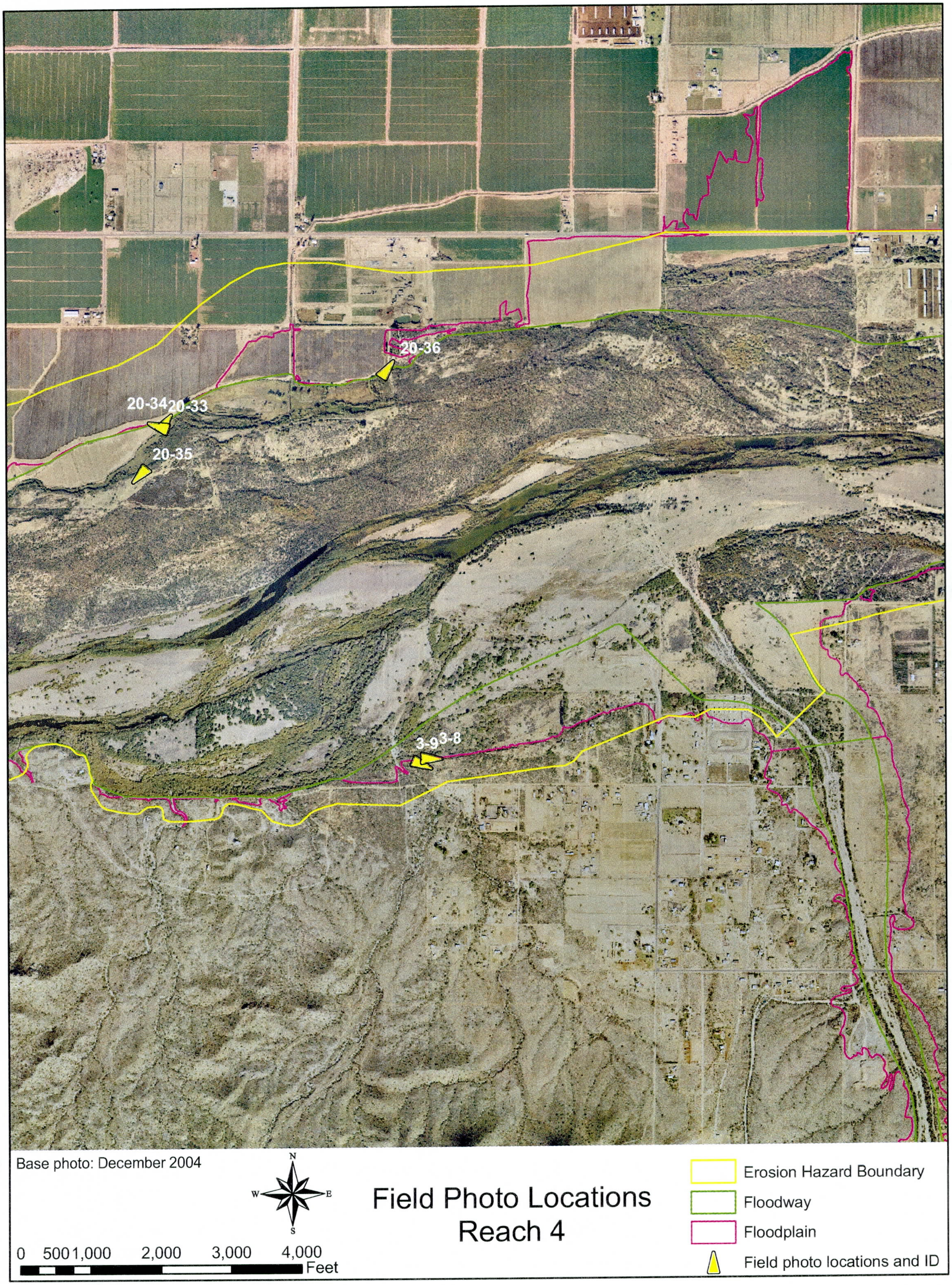
Field Photo Locations
Reach 3

Erosion Hazard Boundary

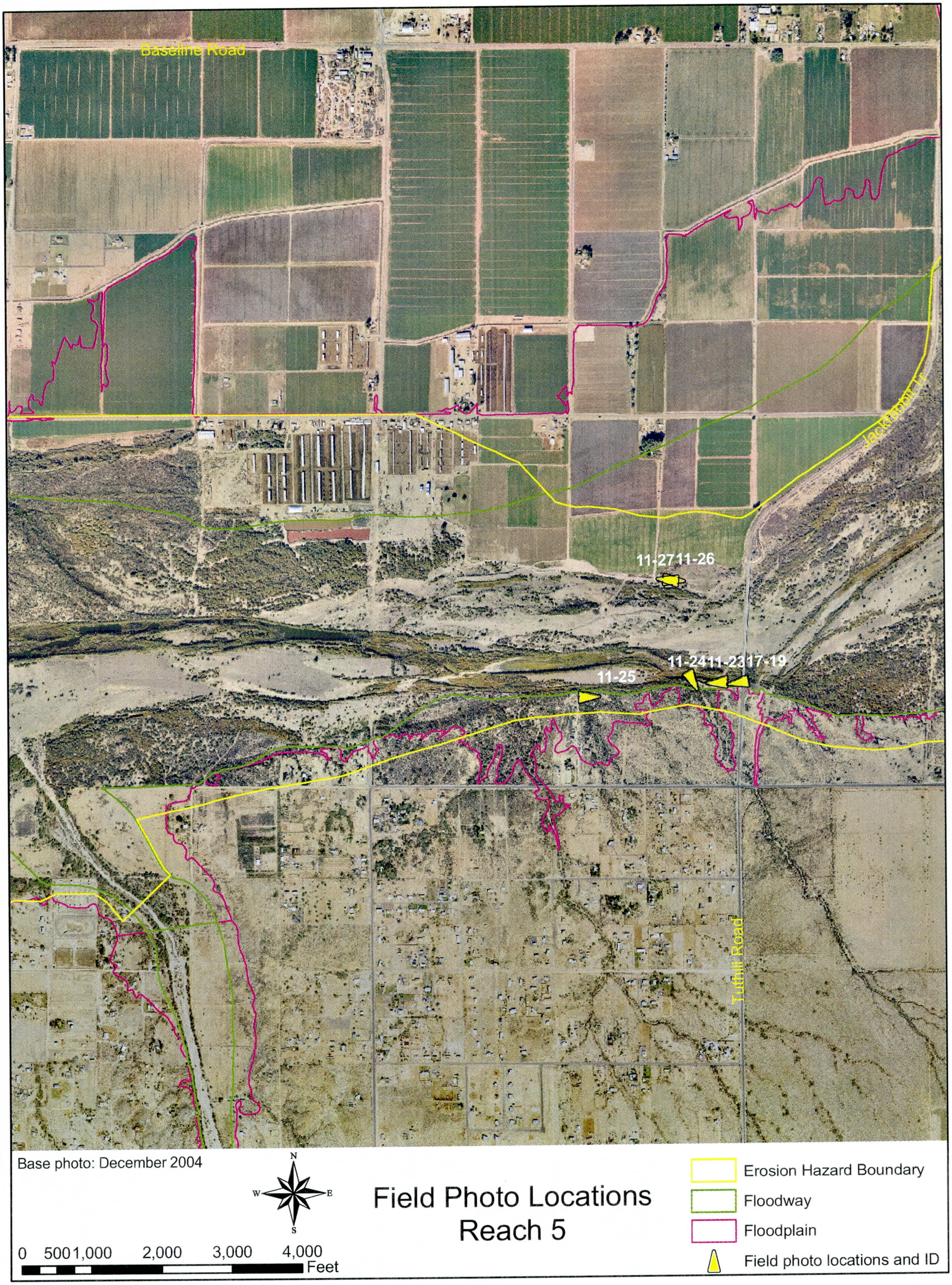
Floodway

Floodplain

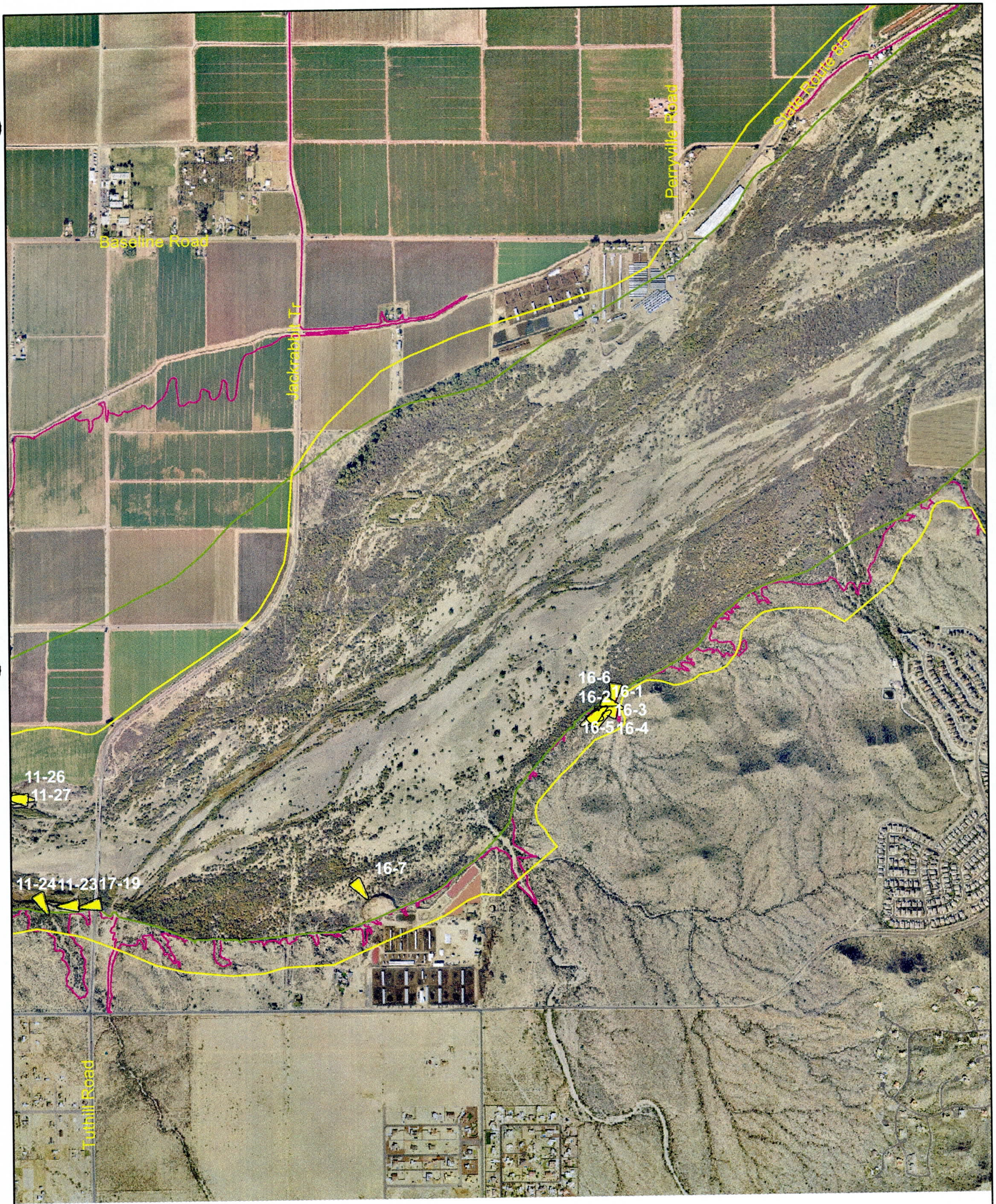
Field photo locations and ID



Field Photo Locations
Reach 4



Baseline Road
Jackrabbit Tr
Tuthill Road
11-27
11-26
11-24
11-23
17-19
11-25
Base photo: December 2004
N
S
E
W
0 500 1,000 2,000 3,000 4,000
Feet
Field Photo Locations
Reach 5
Erosion Hazard Boundary
Floodway
Floodplain
Field photo locations and ID



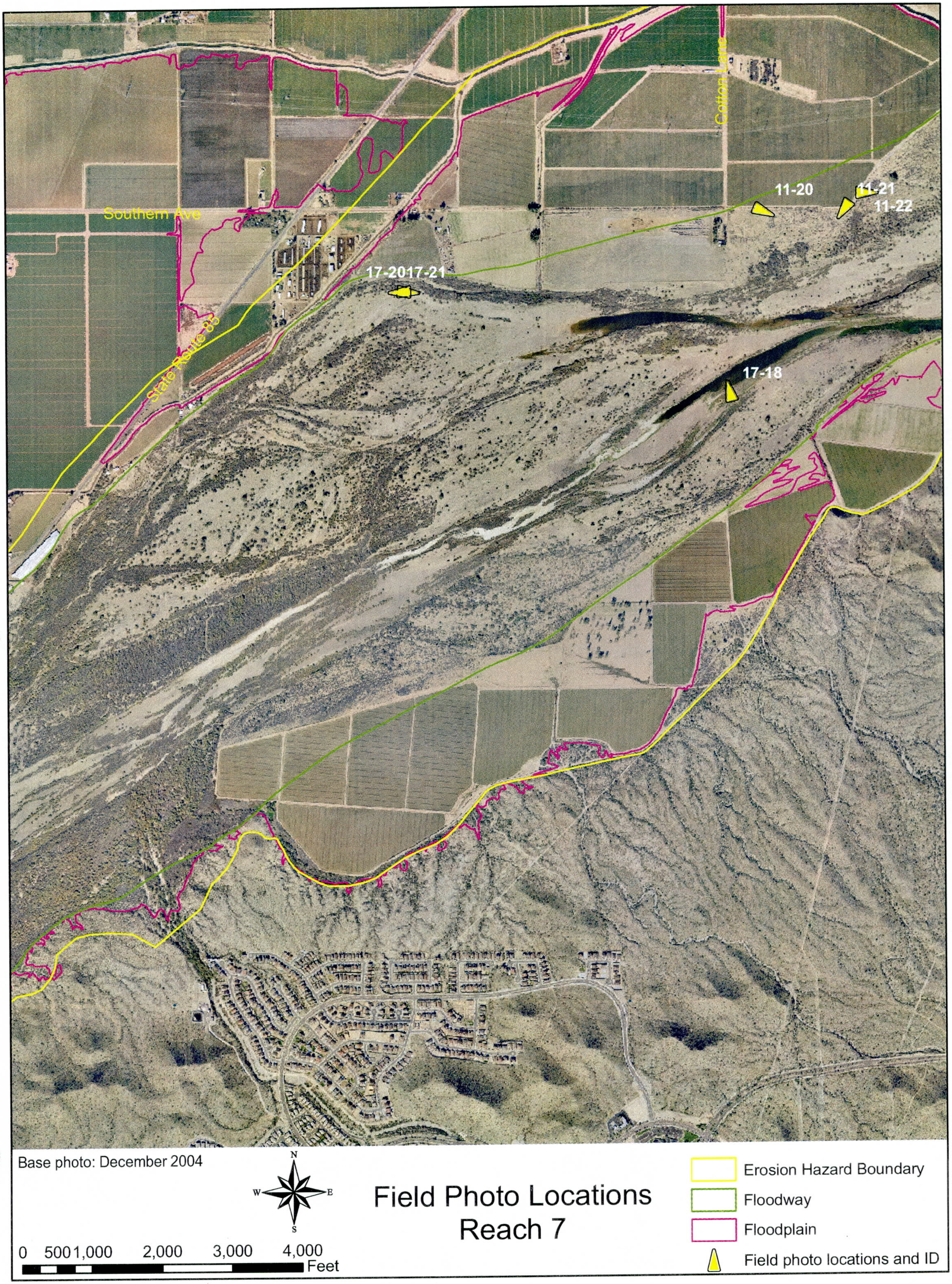
Base photo: December 2004

N
W
E
S

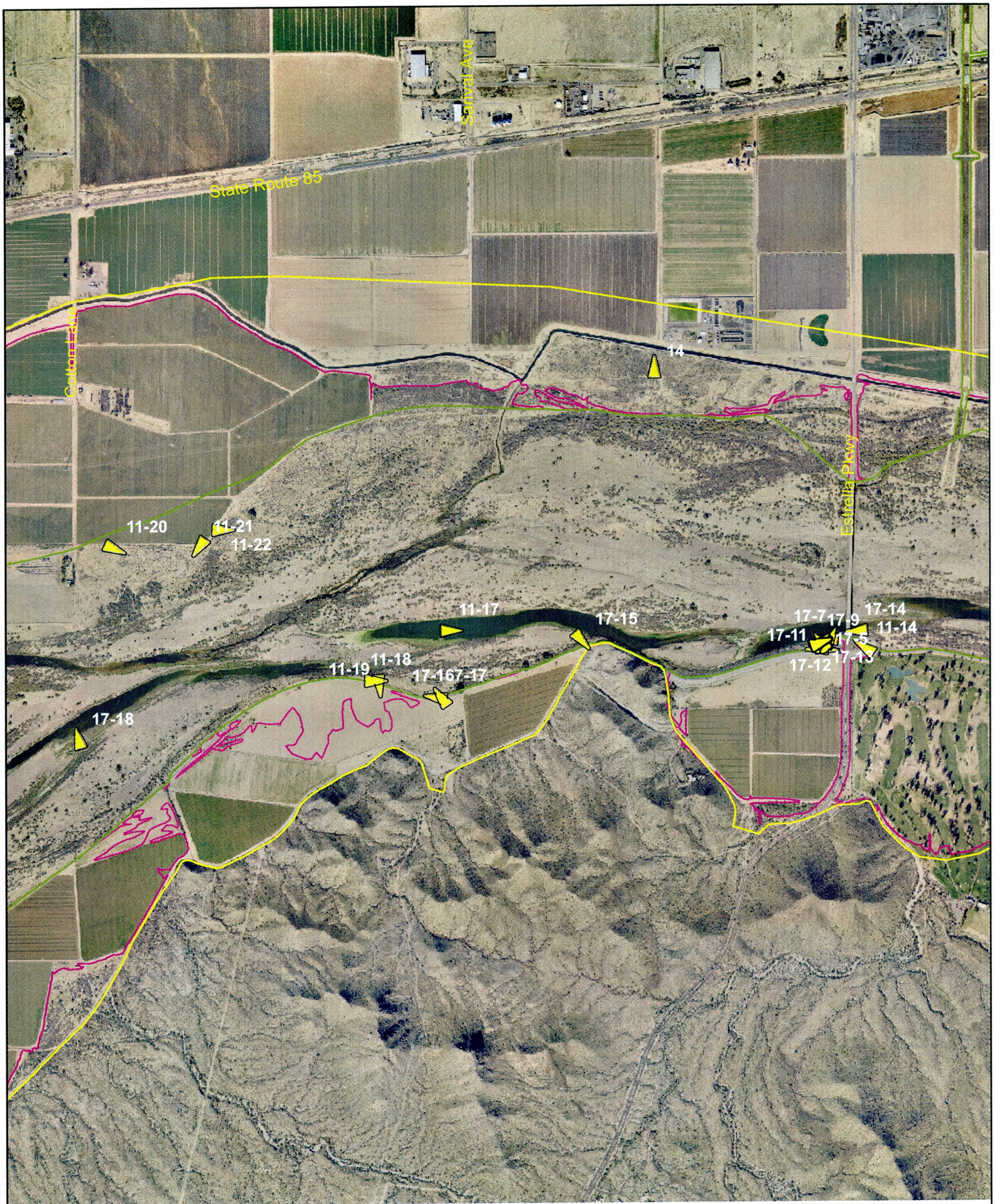
0 500 1,000 2,000 3,000 4,000 Feet

Field Photo Locations
Reach 6

(yellow)	Erosion Hazard Boundary
(green)	Floodway
(pink)	Floodplain
(yellow triangle)	Field photo locations and ID



Field Photo Locations
Reach 7



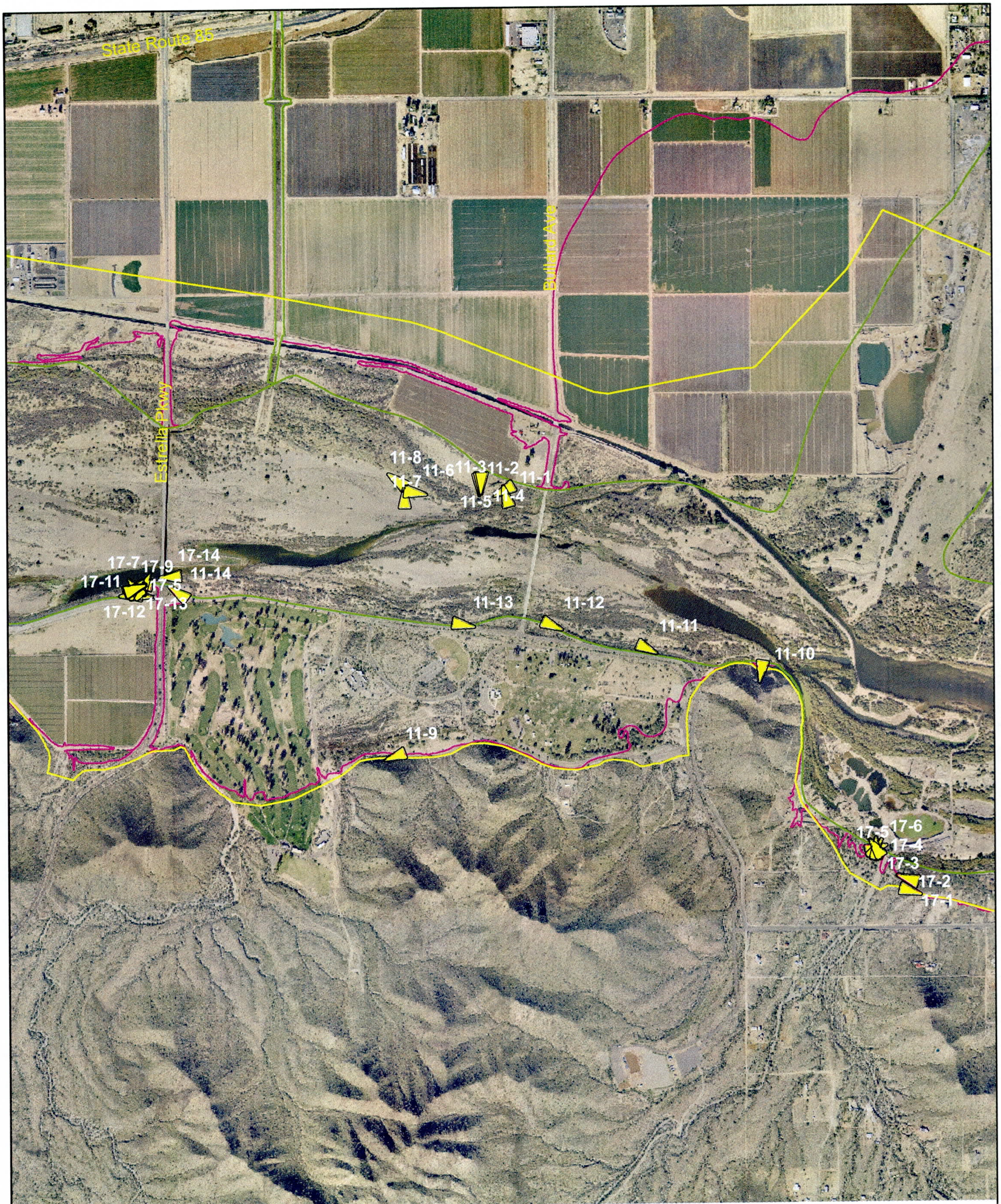
Base photo: December 2004

N
W
E
S

0 500 1,000 2,000 3,000 4,000 Feet

Field Photo Locations Reach 8

- Erosion Hazard Boundary
- Floodway
- Floodplain
- Field photo locations and ID



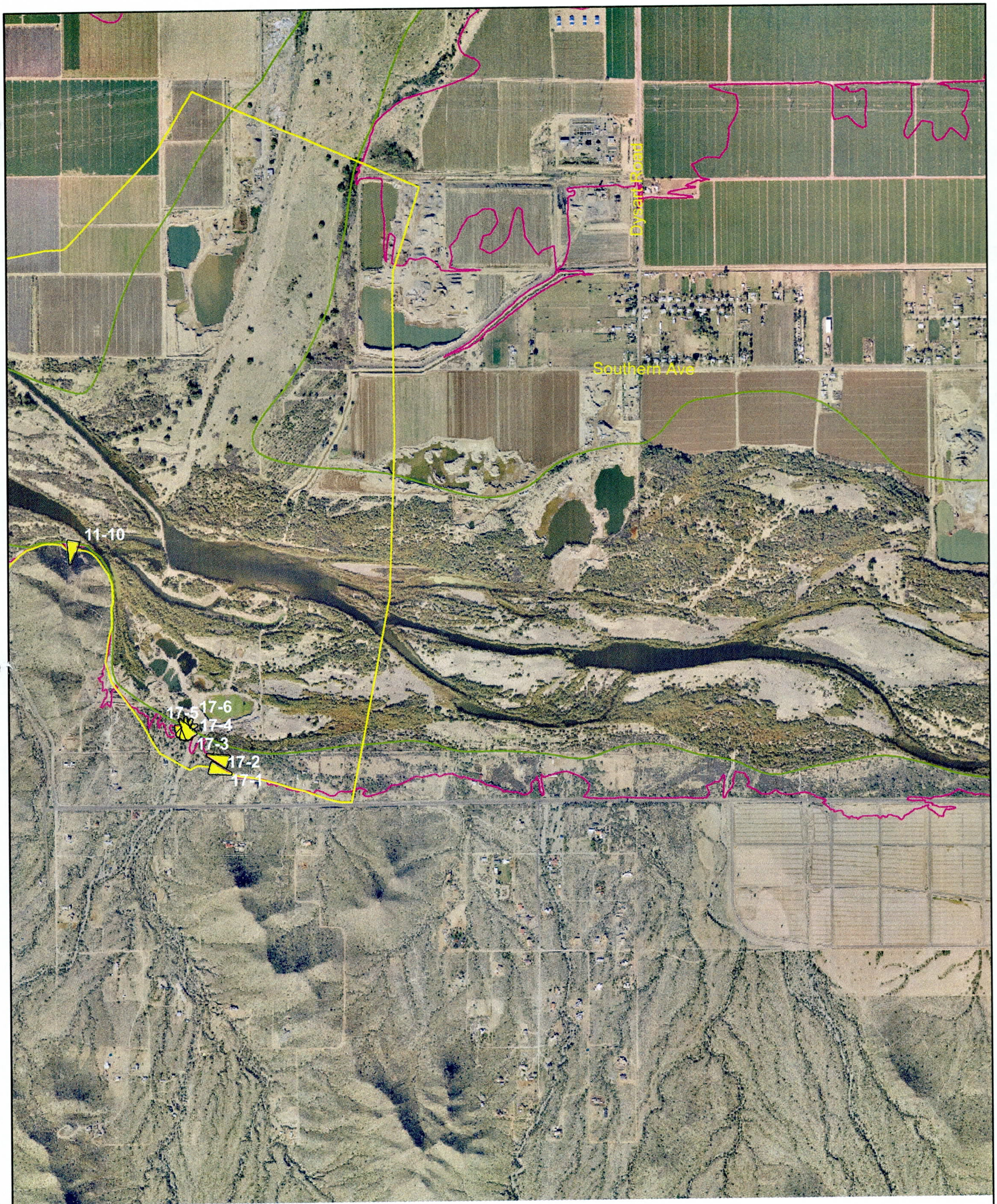
Base photo: December 2004

N S E W

Field Photo Locations
Reach 9

0 500 1,000 2,000 3,000 4,000
Feet

Erosion Hazard Boundary
Floodway
Floodplain
Field photo locations and ID



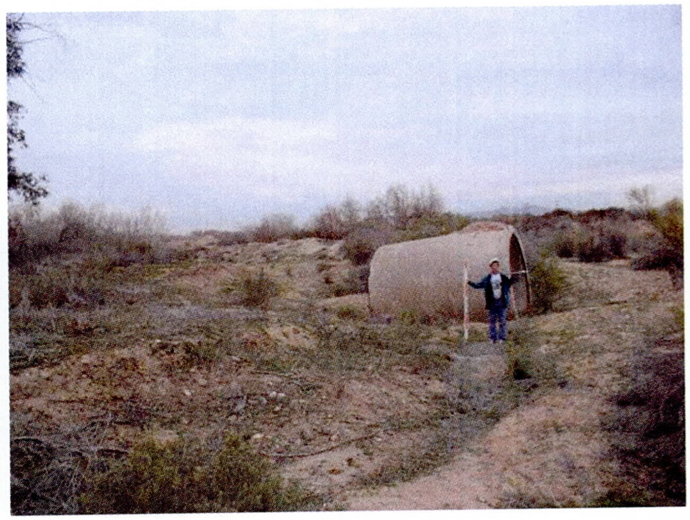
Base photo: December 2004

Field Photo Locations
Reach 10

Erosion Hazard Boundary
Floodway
Floodplain
Field photo locations and ID

0 500 1,000 2,000 3,000 4,000 Feet

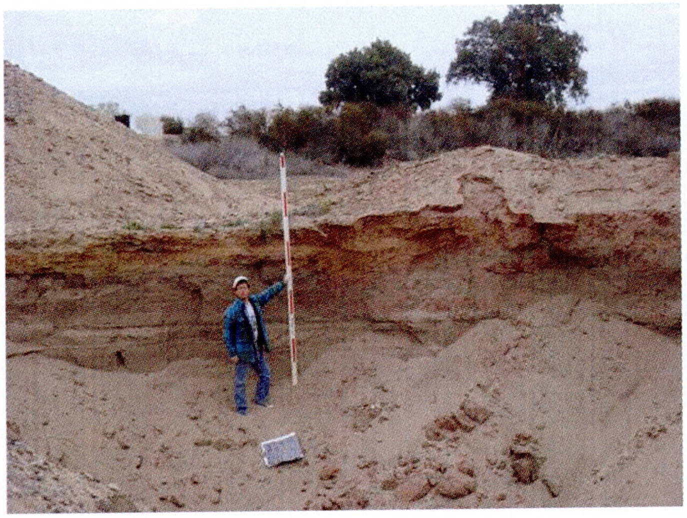
11-27.JPG



11-02.JPG

11-03.JPG

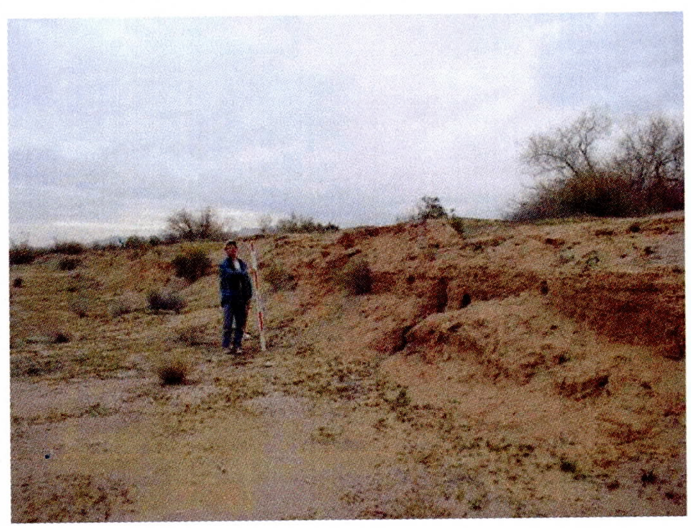
11-04.JPG



11-05.JPG

11-06.JPG

11-07.JPG



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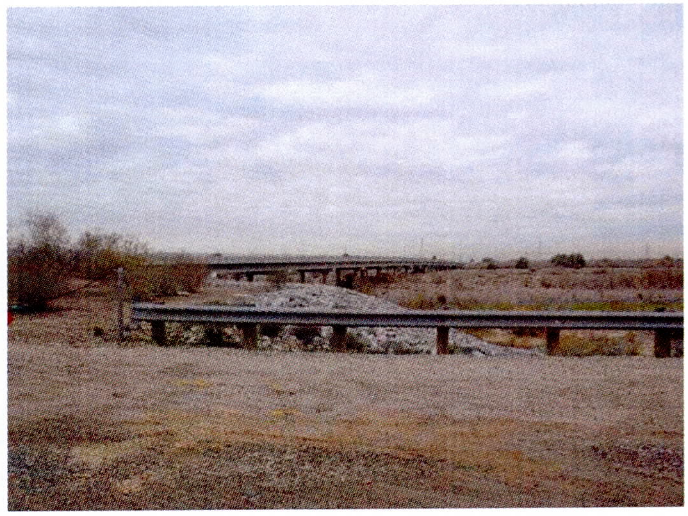
11-09.JPG

11-10.JPG

11-11.JPG

11-12.JPG

11-13.JPG



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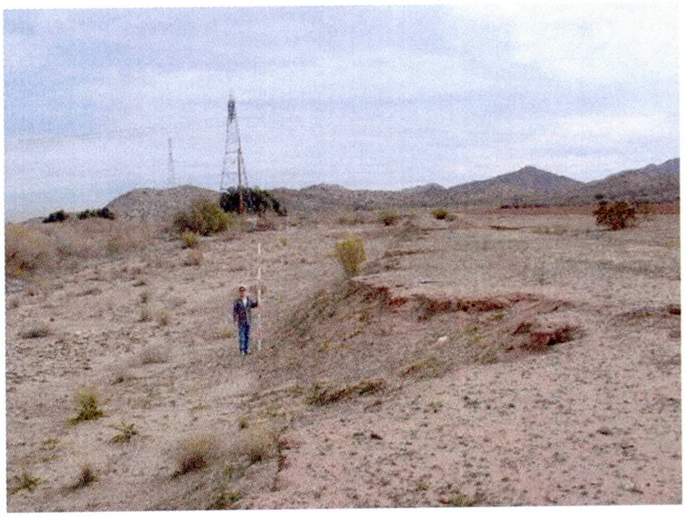
11-15.JPG

11-16.JPG


11-17.JPG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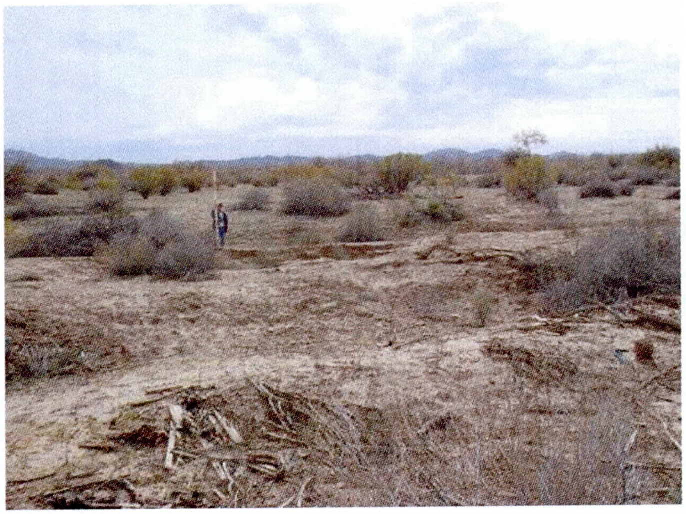
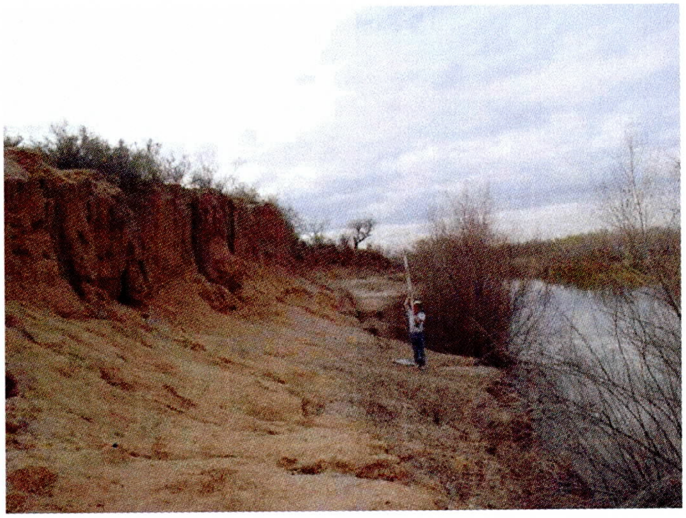
11-19.JPG


11-20.JPG



11-21.JPG

11-22.JPG



11-23.JPG

11-24.JPG

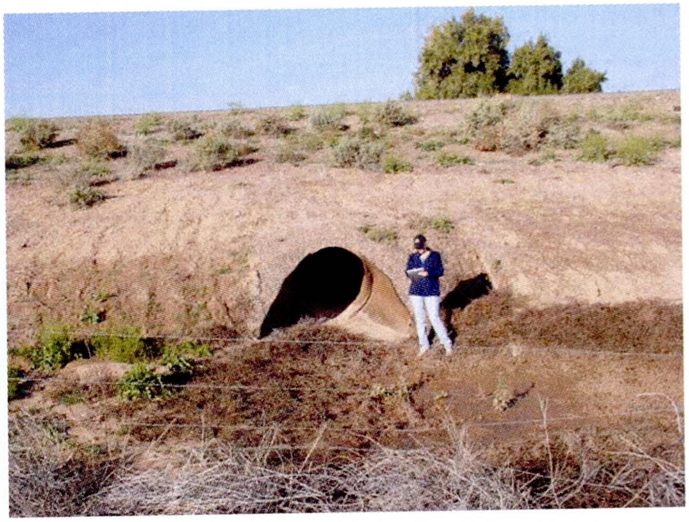
11-25.JPG

11-01.JPG

11-26.JPG

20-36.JPG

20-02.JPG



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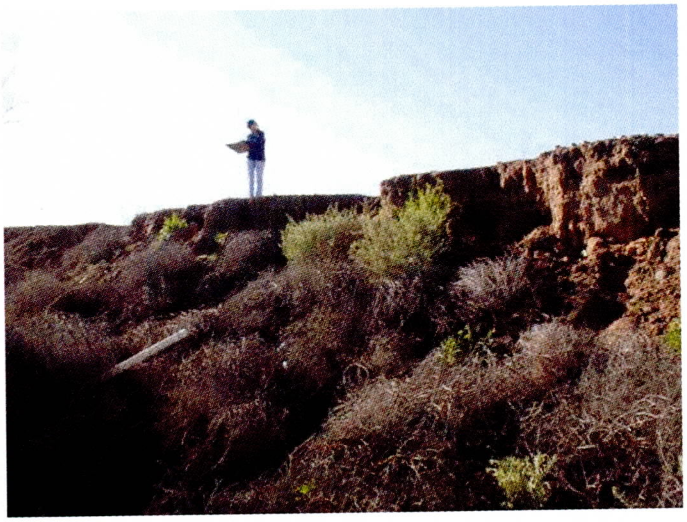

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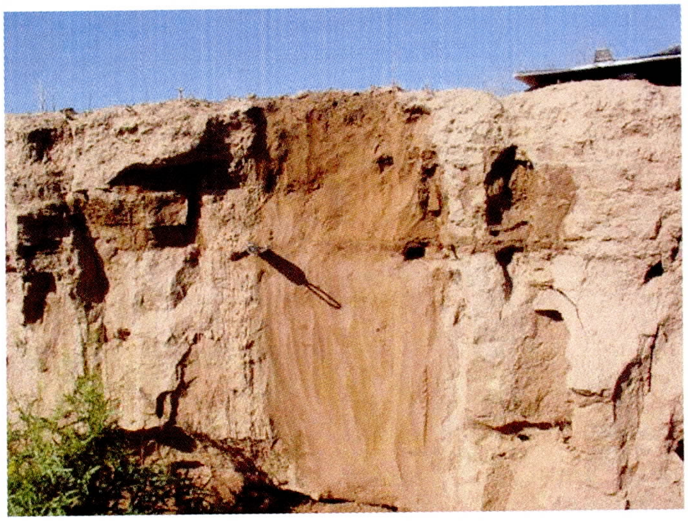
20-05.JPG

20-06.JPG

20-07.JPG

20-08.JPG



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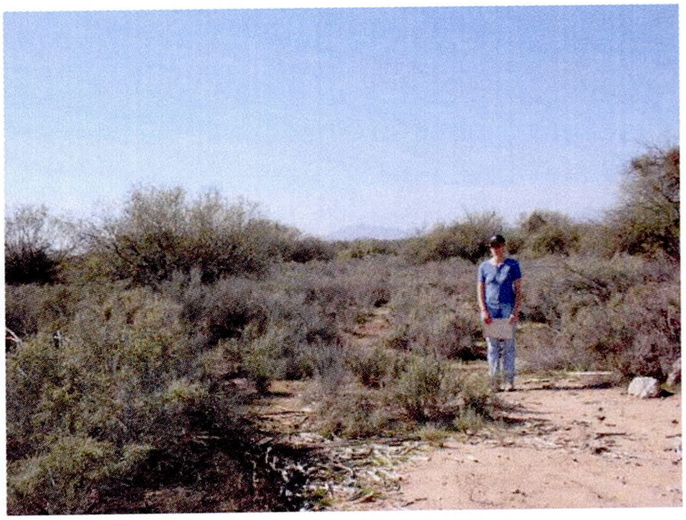
20-11.JPG


20-12.JPG


20-13.JPG

20-14.JPG



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20-22.JPG


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20-25.JPG


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20-27.JPG

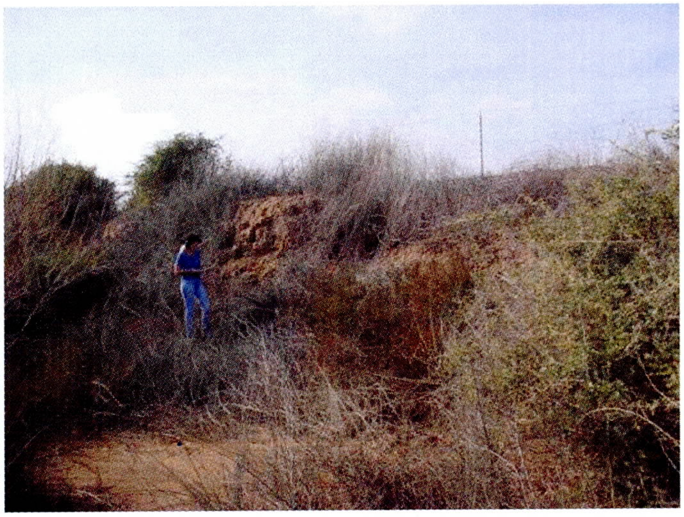

20-28.JPG


20-29.JPG

20-30.JPG

20-31.JPG

20-32.JPG



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20-34.JPG


20-01.JPG

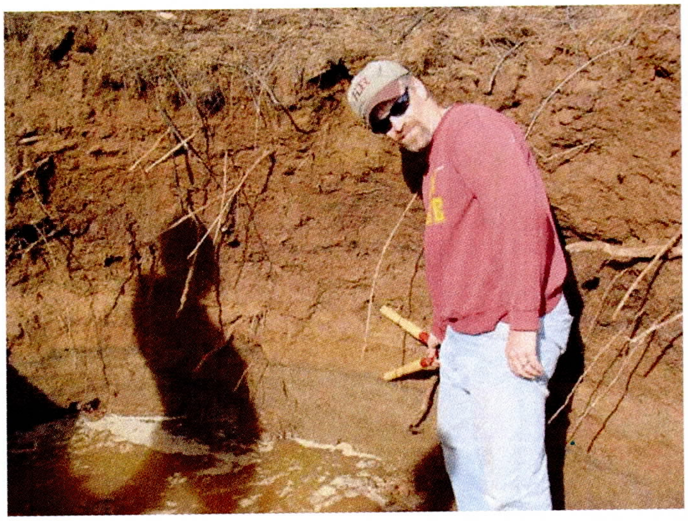

20-35.JPG


3-9.JPG


3-2.JPG


3-3.JPG


3-4.JPG


3-5.JPG


3-6.JPG


3-7.JPG


3-8.JPG


3-1.JPG

16-07.JPG

16-02.JPG

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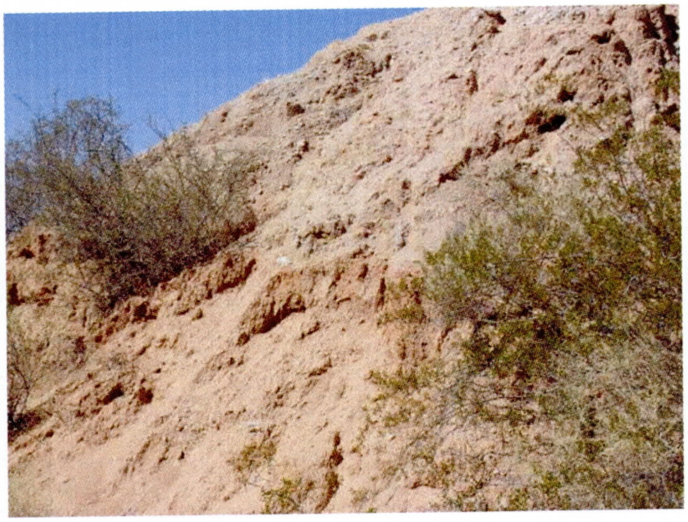
16-04.JPG



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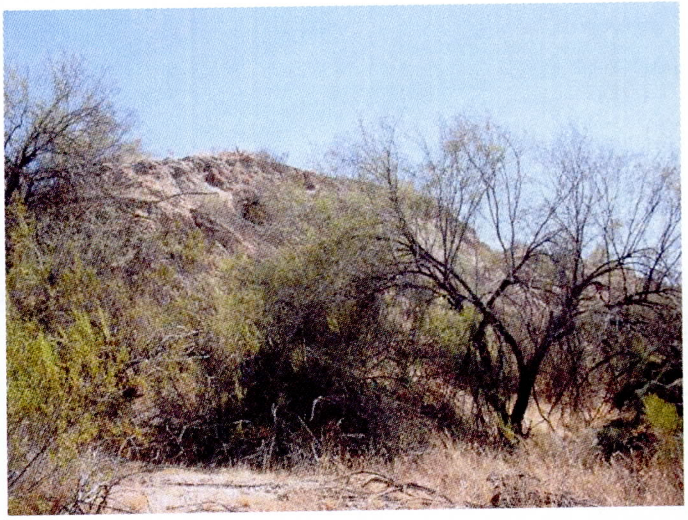
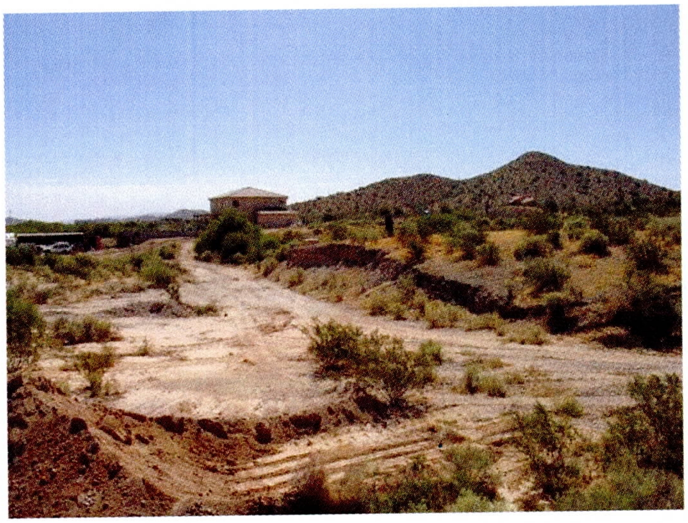


16-06.JPG

16-01.JPG



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17-3.jpg


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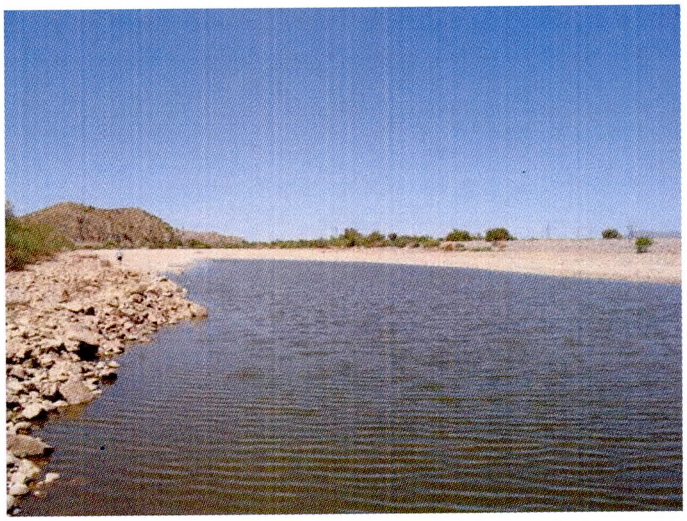
17-5.jpg

17-6.jpg

17-7.jpg



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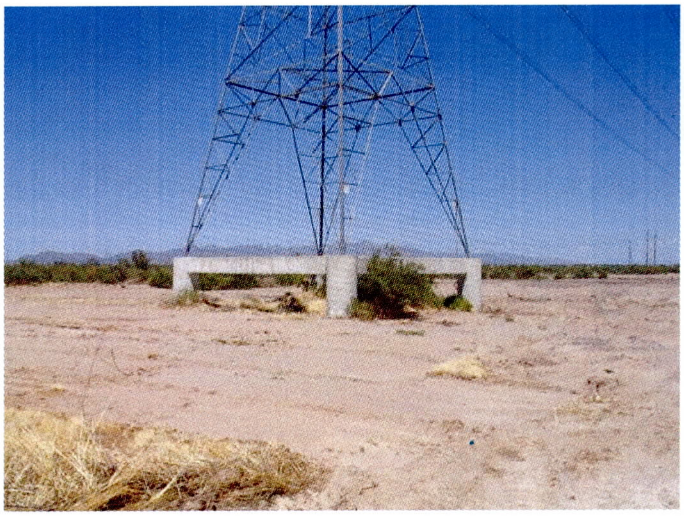

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17-30.jpg


17-31.jpg


17-32.jpg


17-33.jpg


18-1.jpg


18-2.jpg


18-3.jpg


18-4.jpg

APPENDIX E

Detailed Erosion Hazard Zone Maps

(SEPARATE VOLUME)

APPENDIX F

Plate Map: Erosion Hazard Zone

El Rio Watercourse Master Plan

Lateral Migration Analysis Report

Plate 1

Erosion Hazard Boundary

- Erosion Hazard Boundary
- Compound Channel Corridor
- Active Channel Corridor
- Floodway
- Floodplain

N
W E
S

Feet
0 2,500 5,000 10,000

0 0.5 1 2
Miles

Base photo: December 2004

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.

www.jefuller.com

APPENDIX G

Response to Report Comments

Memorandum JE Fuller/ Hydrology & Geomorphology, Inc.

DATE: September 22, 2005

TO: John Hathaway, P.E./FCDMC

FROM: Jon Fuller, PE, PH, RG, CFM

RE: El Rio Watercourse Master Plan: Lateral Migration Analysis Report Response to District Review Comments

CC: Scot S. Schlund, P.E. - Stantec Consulting, Inc.

This memorandum presents responses to review comments provided in a memorandum dated November 12, 2004 from Bing Zhao of the Flood Control District of Maricopa County (FCDMC) Engineering Division - Hydrology and Hydraulics Branch. The District comments are shown below in italics. JE Fuller/Hydrology & Geomorphology, Inc. thanks the District review for his thoughtful comments.

4. Lateral Migration Analysis Report -- El Rio Watercourse Master Plan and Area Drainage Master Plan, Draft, Contract FCD 2001C024, Stantec and JE Fuller, October 2004.

Background: JE Fuller, a sub-consultant of Stantec performed a thorough channel lateral migration analysis from geomorphologic point of view. An erosion hazard boundary was developed by using the geologic data, historical aerial photos, field data, and engineering judgment.

Comment (4.A). Historical aerial photos are essential to this lateral migration analysis. Photos were collected from several sources. An aerial photo-based quantitative analysis was performed to study how the channel laterally migrated in the past by comparing two consecutive time periods. Photos were semi-rectified in order to achieve the accuracy since the photos need to be at the same GIS coordinates for comparison. Since the photos are old and are from difference sources, it must have been very challenging to rectify them. It may be impossible to rectify some of them. A further discussion on the accuracy/error for the semi-rectified photos should be provided since the errors may be in hundreds of feet. The lateral migration plot (Figure 33) shows that many historical migrations are in hundreds of feet. Therefore, a few hundred of feet of error can be significant.

> **<u>JEF Response</u>: The semi-rectification process is not difficult using ESRI ArcMap tools, and has been used for a large number of previous District studies. An analysis of rectification error has been added to the report, and indicates that the estimated error ranges from a minimum of 2 feet to a maximum of 285 feet, with a mean error of 32 feet. Error depends primarily on the photo scale, but also the photography, camera and conditions. Measured historical channel movement is on the order of thousands of feet, rather than tens or hundreds of feet. Therefore, any uncertainties in rectification are minor relative to the distances measured.**

Comment (4.B). An erosion hazard boundary was developed for the El Rio based on geologic information, historical aerial photos, field data, and engineering judgment. The rationale for the erosion hazard boundary on the north and south banks are well documented in Table 10 and Table 11 in the report. As can be seen in the tables, the determination of some segments of such boundaries can be very subjective, especially the buffer zone selection. Two different geomorphologists may give very different explanation about how the boundaries are selected. Generally speaking, the erosion hazard boundaries tend to be conservative, giving a kind of safety factor. It can also be less conservative since it did not happen in the past does not mean it will not happen in the near future. However, the erosion hazard boundaries still give engineers the historical information about what happened in the past.

> **JEF Response: No response needed. The topic of subjectivity is discussed in the response to comment 4E below. My experience in reviewing river mechanics analyses submitted to the District in support of sand & gravel mining permits is that use of mathematical techniques does not guarantee consistent conclusions from engineers.**

Comment (4.C). The geomorphology-based channel lateral migration analysis provides useful historical insights about the river. It will be challenging to use such information for the proposed elements in the corridor.

> **JEF Response: The District, the State of Arizona, FEMA, and practitioners throughout the world routinely use geomorphology-based lateral stability assessment in river planning studies. In fact, consideration of river morphology is the standard of practice defined in numerous textbooks and engineering manuals. We have not found use of geomorphology-based analyses to be challenging.**

Comment (4.D). The lateral migration analysis used in the study is based on geomorphology. A comprehensive analysis for lateral migration involves not only geomorphology but also computational fluid mechanics modeling and geotechnical analysis. The computational fluid mechanics modeling involves the numerical solution to equation of motions, fluid continuity equation, sediment continuity equation, turbulence flow equation, secondary currents equation, and sinuosity analysis. The numerical modeling can show how the river banks respond to a particular flood or a series of floods. A variety of such modeling methods are available in the literature. The geotechnical analysis involves bank stability analysis. Nevertheless, the geomorphology-based lateral migration analysis still provides a good understanding about the history of the river and the results can be used for future fluid mechanics numerical modeling.

> **JEF Response: We agree that computation fluid mechanics modeling and geotechnical analysis could provide insight into possible river responses. However, we point out that ASCE Committee on Sedimentation and FEMA's Riverine Erosion Hazard Area Study (not to mention the District's *Sand & Gravel Floodplain Use Permit Guidelines* and *Erosion Hazard Zone Delineation & Development Guidelines*) reached a different conclusion than the reviewer about the ability to mathematically predict changes in river**

width and pattern. Even if one were able to completely know and be able to precisely model every aspect of river and soil mechanics, one will never know the future flood series, watershed changes, changes in groundwater conditions, changes in sediment supply, or even land use/vegetation changes within the river corridor itself. We further note that the District chose not to fund most of the empirical geomorphic analyses used in other lateral stability studies completed for watercourse master plans.

Comment (4.E). Considering the determination of the erosion hazard boundary is subjective and subject to huge uncertainties, it may be necessary to also estimate the uncertainties associated with the estimated boundary, i.e., the probability associated with the boundary. The probabilities computed for the erosion hazard boundary will make the procedure more defensible.

JEF Response. Although the process of determining the location of the erosion hazard zone boundary (EHZ) may appear to be highly subjective because it does not rely solely on mathematically-derived procedures, erosion hazard delineation is firmly grounded on quantitative methodologies and physical geologic properties that include the following:

- **Soils– physical properties of soils that indicate whether they have been subject to active riverine processes.**
- **Geology – mapped and exposed bedrock that provide effective erosion resistance resulting is channel stability.**
- **Quantitative measurements of changes in river corridor position; both single event measurements and cumulative measurements over the period of historical record.**

Assigning a probability the EHZ at any given location is an intriguing idea that could be applied in future EHZ delineations. Unfortunately, the District has not authorized or funded such analyses for the El Rio WCMP.

APPENDIX H

Data Disc