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DENVER, COLORADO

UPPER GILA RIVER FLUVIAL GEOMORPHOLOGY STUDY

GEOMORPHIC ANALYSIS ARIZONA

US Department of the Interior
Bureau of Reclamation



DECEMBER 31, 2003

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GRAHAM COUNTY, ARIZONA

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ARIZONA

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EXECUTIVE SUMMARY

The Geomorphic Analysis synthesizes geomorphic information about the Gila River and compares results of the analysis to other tasks performed for the Upper Gila River Fluvial Geomorphology Study. The goal of the geomorphic analysis is to provide an understanding of the fluvial geomorphology and to explain recent geomorphic change on the Gila River in Safford and Duncan Valleys. Methods used for the Geomorphic Analysis include geomorphic mapping, soil descriptions and laboratory analysis. Soil maps developed by Poulson and Youngs (1938) and Poulson and Stromberg (1950) for Safford Valley and Duncan Valley, respectively, provided critical information for developing the Geomorphic Map. In addition to soil surveys, 26 soil/stratigraphic descriptions of bank exposures provide detailed information about areas that are currently being eroded. Laboratory analysis includes both radiocarbon analysis and macrobotanical analysis. Radiocarbon analysis provides quantitative estimates for the age of alluvium, while macrobotanical analysis identifies the charcoal prior to radiocarbon analysis.

In Safford and Duncan Valleys, geomorphic change along the Gila River in recent decades appears to be controlled by changes in human factors such as levees and diversion dams rather than changes in external factors such as runoff and sediment influx. This conclusion is based on several products developed for the Upper Gila River Fluvial Geomorphology Study as well as this analysis. Geomorphic mapping in these valleys indicates that the Gila River has migrated within the Pima Soil boundary for the last several hundred years and within the Geomorphic Limit for at least the last 1,000 years. Areas of lateral instability are indicated by the erosion of soils older than several hundred years mapped as part of the Geomorphic Limit or Pima Soil Boundary. Several reaches were discovered that had significant erosion of property that warranted a detailed discussion of the areas of property loss and factors that contributed to its erosion. These reaches include: Railroad Wash, the cutoff meander upstream of Duncan Bridge, Duncan Bridge, Whitefield Wash, Kaywood Wash, San Jose Diversion, San Jose Wash, Graham Diversion, Smithville Diversion, Watson and Butler Washes, Curtis Diversion, Fort Thomas Diversion, Fort Thomas Bridge, and Geronimo. Together, these reaches constitute 40% of the entire study reach.

The Catalog of Historical Changes and the Geomorphic Map reveal the close correlation between levee construction and subsequent failure and geomorphic change during large floods along the Gila River in Arizona. As the Geomorphic Map was compiled, several factors causing instability emerged as common to multiple reaches. These factors include: (1) levee failure; (2) downstream propagation of erosion; (3) channel straightening; and (4) diversion dam orientation. Vegetation and alluvial fan development may also act in conjunction with these factors in some cases. The Catalog of Historical Changes, among other studies, shows that the majority of erosion occurs during floods. The local factors mentioned above appear to cause minimal geomorphic change during low to moderate flows but are the catalysts of substantial geomorphic change during the large floods of recent decades.

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GEOMORPHIC ANALYSIS

ARIZONA

INTRODUCTION

The Geomorphic Analysis synthesizes a number of geomorphic analyses of the Gila River and compares results to other tasks performed for the Upper Gila River Fluvial Geomorphology Study. The goal of the geomorphic analysis is to provide an understanding of the fluvial geomorphology and to explain recent geomorphic change on the Gila River in Safford and Duncan valleys. Figure 1 illustrates the reach of the river for this analysis, extending from the San Carlos Indian Reservation to the Arizona-New Mexico state line. This reach includes roughly 38 miles (60 km) in Safford Valley and 25 miles (40 km) in the Duncan Valley. The Gila River in this reach flows through two narrow canyons, the longest of which is the Gila Box between Safford and Duncan Valleys. The second is near Apache Peak in the Duncan Valley, between Apache Grove and York, Arizona.

Previous studies document historical change changes (e.g. Burkham, 1972; Hooke, 1996) along the Gila River in downstream reaches of the study area. A comprehensive study, the Gila River Phreatophyte Project, was conducted by the U.S. Geological Survey in the 1970's (Culler and others, 1970). Numerous geologic studies documenting Pleistocene age and older geologic features and processes have also been conducted (e.g., Houser et al. 1985; Davidson, 1961; Fair, 1961; Heindl, 1958; Knechtel, 1938). The Background Information document of this project provides detailed summaries of these studies as well as summaries of other pertinent hydrologic, biologic, and engineering references related to the Gila River. The Catalog of Historical Changes (Klawon, 2001) also provides a summary of historical channel change.

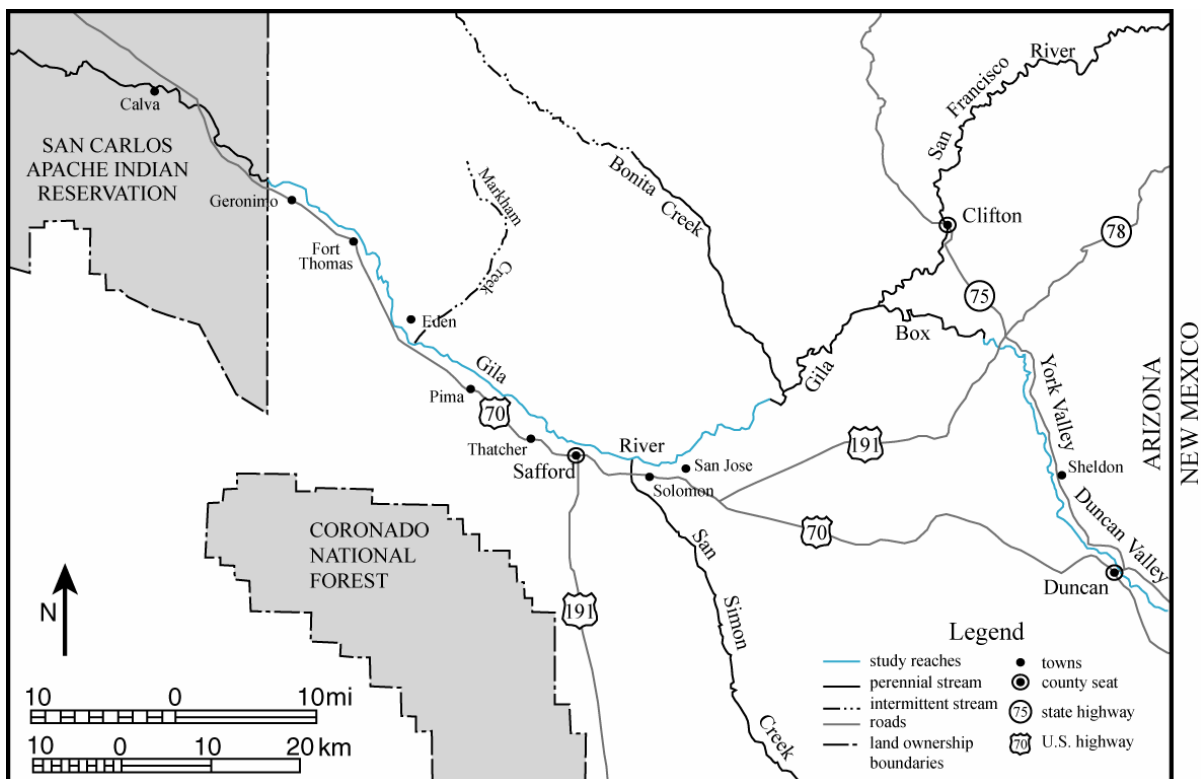


Figure 1. Study area location.

BACKGROUND

Several reports developed prior to the Geomorphic Analysis provide supporting information for this study. The Catalog of Historical Changes documents changes in the Gila River flood channel from 1935 to 2000 (Klawon, 2001). Flood Frequency, Flow Duration, and Trends looks for trends in historical stream flow and rainfall data (England, 2002). The Geomorphic Map documents major historical geomorphic change along the river primarily related to the construction of levees (Klawon, 2003). The Stable Channel Analysis (Wittler and Delcau, and Klawon, 2002) forms a quantitative basis for understanding Gila River sediment transport and channel stability. When combined, these studies cover historical changes in river flood channel, historical trends in hydrology, the causes of major historical geomorphic change along the river, and insight into channel stability and sediment transport.

PURPOSE

The purpose of this analysis is to provide an understanding of the fluvial geomorphology and to explain recent geomorphic change along the Gila River in Safford and Duncan valleys. To accomplish this goal, the Geomorphic Analysis combines data and analyses conducted during the course of the project. Due to the length of the study reach and complexity of historical alteration of the Gila River, the study is broad in scope seeking to understand the major processes that control the observed fluvial geomorphology.

In recent decades, landowners along the Gila River have experienced a substantial amount of property erosion during large floods. Concern arose regarding whether the river was inherently unstable or if conditions in the upper watershed were causing the geomorphic change in Safford and Duncan Valleys. Multiple hypotheses may explain the recent geomorphic changes. The following discussion will explore these hypotheses using the analyses produced for this project, and either invalidate or support each idea.

POSSIBLE CAUSES OF GEOMORPHIC CHANGE

The causation hypotheses for geomorphic changes along the Gila River in Safford and Duncan valleys fall into two categories. The first category includes external factors that influence the recent geomorphic change observed in the Gila River in those valleys. The most important of these external factors are changes in the characteristics of runoff or sediment flux from the upper Gila River drainage basin. The second category includes internal factors that influence the morphology of the Gila River. The most important internal factors include modification of the river through mechanical means such as levees, bridges, and diversion structures.

The candidates for causation hypotheses for the fluvial geomorphology of the Gila River in the Safford and Duncan Valleys are:

1. There is no perceptible geomorphic change in these valleys.
2. A change in the upper Gila River drainage basin characteristics has resulted in increased runoff or a change in runoff characteristics. This change in runoff characteristics has resulted in geomorphic change in these valleys.
3. A change in the upper Gila River drainage basin characteristics has resulted in a change in sediment flux. This change in sediment flux has resulted in geomorphic change in these valleys.
4. Some combination of hypothesis two and three.
5. A change in local characteristics of the river has resulted in geomorphic change. This type of local modification would consist of levee construction and subsequent failure, flow redirection

by levees, reduced sediment transport resulting from levee construction, and encroachment by phreatophyte vegetation in the Gila River channel.

The purpose of this Geomorphic Analysis task, and tasks of a similar project on the Gila River in New Mexico, is to test the above hypotheses. Other project tasks include the Background Information, the Qualitative Assessment of Upper Box, New Mexico, the Catalog of Historical Changes, Flood Frequency, Flow Duration, and Trends, the Geomorphic Map, and the Stable Channel Analysis.

The hypothesis that there is no perceptible geomorphic change along the Gila River in the Safford and Duncan Valleys is easily invalidated. The Background Information, the Catalog of Historical Changes, and the Geomorphic Map all chronicle substantial geomorphic change in the Gila River in these Valleys.

The Flood Frequency, Flow Duration, and Trends analysis documents variations in precipitation and runoff over the past 70 years, but it does not document a positive trend over the past 40 years, when the majority of property erosion has occurred. These multi-decadal variations in flood frequency have been observed in other studies such as Webb and Betancourt (1992). This pattern generally displays episodes of frequent large floods followed by episodes of few large floods. These episodes can be irregular and may differ by geographic area and may last several decades to more than 50 years. It appears that the Gila River has experienced a period of few large floods from the 1930's through the early 1970's bracketed by eras of more frequent large floods, one at the turn of the 20th century and one from the late 1970's through at least the early 1990's. The results of this analysis appear to invalidate the hypothesis that detectable trends runoff resulted in geomorphic change. Over the past several decades, once in an episode of frequent large floods, there is no clear trend in runoff.

The Qualitative Assessment of Upper Box Geomorphology, New Mexico (Levish, 2002) examines the geomorphic history of the Upper Box, just upstream of the Cliff-Gila Valley in New Mexico. The Assessment demonstrates that the Gila River in the Upper Box has been dynamically stable for at least the last several hundred to perhaps the last several thousand years. This conclusion invalidates the hypothesis of historical geomorphic change along the Gila River downstream of the Upper Box invoking change in upper watershed hydrology, and sediment yield as the causative mechanism. The geomorphic record of the Upper Box failed to show any major changes in the upper basin that propagate to the downstream valleys.

The Qualitative Assessment shows that there is a clear record of stability of the geomorphic surfaces that bound the Gila River in the upper box, predating 19th and 20th century land use changes. This record of stability places doubt on the hypothesis that changes in the upstream watershed are a major cause of geomorphic change from the downstream end of the Upper Box to the Arizona State line.

The Qualitative Assessment also invalidates the fourth hypothesis, that geomorphic change is the result of some combination of a change in runoff and a change in sediment flux. The lack of strong trends in runoff over the past four decades along with no apparent change in sediment flux over hundreds of years invalidates the hypothesis of a combination of the two causing geomorphic change.

The hypothesis that local changes in characteristics of the Gila River channel are responsible for the observed geomorphic change in Safford and Duncan Valleys is supported by the available data. Since changes in runoff and sediment flux from the upper Gila River basin can be discounted as causes of geomorphic change, local factors must be responsible for changes in each of the valleys. These factors include levee and diversion dam construction, bank protection, vegetation encroachment, and tributary alluvial fan development. The effects from these factors on the fluvial geomorphology will be explained in detail in the Discussion.

METHODOLOGY

Methods that are important for developing data for the Geomorphic Analysis include geomorphic mapping, soil descriptions and laboratory analysis. Methods used in geomorphic mapping are discussed in detail in the Geomorphic Map Report (Klawon, 2003). Briefly, these methods include a combination of aerial photograph interpretation and field checking in which the physical characteristics of alluvial deposits, such as surface height, surface morphology, soil development, and sedimentology are identified. These characteristics are then correlated from one alluvial deposit to another and grouped into map units. Ground leveling of agricultural fields made some geomorphic features difficult to observe on recent photography and during field mapping. Soil maps developed by Poulson and Youngs (1938) and Poulson and Stromberg (1950) for Safford Valley and Duncan Valley, respectively, provided critical information for developing the Geomorphic Map in obscured areas. The soils for Safford Valley are mapped at a 1:63,360 scale, while the soils of Duncan Valley are mapped at a 1:15,840 scale. Although more recent soil surveys were available (DeWall, 1981; Gelderman, 1970), they did not accurately reflect fluvial geomorphic processes and therefore were not used. In addition to soil surveys, 26 soil/stratigraphic descriptions of bank exposures provide detailed information about areas that are currently being eroded (Appendix A). Soil and sedimentologic characteristics of bank exposures were described following USDA guidelines and standard sedimentary terminology (Tucker, 1981; Soil Survey Staff, 1993; Birkeland, 1999). The degree of soil development provides important information about the relative age of soils developed on alluvial surfaces in the study area. Characteristics such as carbonate and clay accumulations and soil structure develop with time and can be used as indicators of soil age (Gile et al., 1981; Birkeland, 1999; Machette, 1985). Soils that have been studied extensively (e.g., Gile et al., 1981) provide well-documented soil chronosequences but have insufficient age resolution during the Holocene for correlation. For example, the development of stage I carbonate, which is described in many soils along the Gila River in the study area, spans 100 to 7,000 years in non-gravelly soils of southern New Mexico (Gile et al., 1981, p. 68). It is for this reason that soil characteristics are used to indicate relative age while laboratory analysis is intended to provide quantitative age information.

Radiocarbon analysis provides quantitative estimates for the age of alluvium. Radiocarbon analysis relies on the decay rate of radiocarbon that was incorporated into the tissue of a once living organism (Trumbore, 2000). The most common materials found in fluvial sediments that are collected for radiocarbon analysis are charcoal and mollusk shell. There are numerous potential problems associated with ages derived using this methodology. The first kind of problem is related to the incorporation of young or old carbon into the sample material following death of the organism. Rootlets or burrowing that penetrate the sampling area can introduce new carbon into the material and result in an erroneously young age. New carbon may be also introduced to shell material by the recrystallization of aragonite to calcite thereby creating an exchange of modern carbon. Old carbon, or the “hard water effect”, may occur where organisms take up carbon from water rich in carbonate derived from limestone or other inert sources. When dated, these shells may give an erroneously old age that could be off by several thousand years (Bradley, 1985). Another kind of problem is associated with the interpretation of the analysis. Given that the sample is not contaminated by old or young carbon, a sample may give an erroneously old age if a significant amount of time has elapsed prior to its deposition in the sampled profile. For example, charcoal from a forest fire in the upper watershed could have been transported and stored several times before being deposited in the sampled profile. Numerous studies and discussions in the literature address these types of issues.

There are measures that when taken can reduce problems associated with radiocarbon analysis. Samples for this study were floated and identified by species (macrobotanical analysis) so that any rootlets, seeds, or other young material that might contaminate the sample could be discarded. Based on the materials that were identified, materials that could potentially have grown near the site were preferred rather than materials that could have been transported long distances from the upper watershed. Vegetation in the

upland areas includes pinyon pine, juniper, manzanita, shrub live oak, and desert hackberry, among others. Vegetation near the Gila River includes creosotebush, tamarisk, cacti, grasses, mesquite, juniper, yucca, and cottonwood, among others (DeWall, 1981; Gelderman, 1970). The latter list would be the preferred vegetation to date. Other plants such as corn at sites with archaeological materials should also be locally derived. The hard water effect was not accounted for in this study. However, dates from shell appear to be consistent with dates from charcoal and are in stratigraphic order.

OVERVIEW OF GEOMORPHOLOGY

The Gila River in Safford Valley and Duncan Valley flows through alluvial deposits that can be separated into young, intermediate, and older alluvial packages. These packages include the alluvial surfaces and immediately underlying alluvium and for brevity will be jointly referred to as alluvium. Distinctions between alluvium are characterized by soil development and radiocarbon analysis. The Gila alluvium exhibits very weak soil development and commonly has a sandy texture with obvious sedimentary structures. Radiocarbon dates indicate that these soils range in age from historic to several hundred years old (Table 1; Figure 2). Pima alluvium has soils that are moderately developed and have greater percentages of silt and clay when compared to the Gila alluvium. Radiocarbon dates for this alluvium could not be obtained in sufficient quantity to provide a quantitative age for the Pima alluvium. This problem occurred because the samples that were acquired were too small for analysis following macrobotanical identification and pretreatment procedures for radiocarbon analysis. Additional bulk sampling and scouring of exposures for charcoal or shell would be necessary to quantify the age of this alluvium. However, soil development suggests that the Pima alluvium is an intermediate age between the young and old soils and therefore is estimated to range from several hundred to 1,000 years.

Alluvium associated with the Geomorphic Limit of flood evidence consists of older alluvium as well as younger gravelly tributary alluvial fans that are difficult to erode. Soils of older alluvium have greater soil development, reflected in thicker B-horizons, than the Gila or Pima alluvium and have greater percentages of clay in soil profiles. Soils in tributary alluvial fans are typically composed of sand and gravel and are semi-consolidated with carbonate as a cementing agent where they are observed in vertical exposures. Radiocarbon dates of the older alluvium indicate that soils are greater than 1,000 years old. Few radiocarbon dates were obtained on tributary alluvial fans primarily because it is difficult to find charcoal in gravelly deposits.

Table 1. Radiocarbon dates by age of alluvium.

Gila alluvium		Pima alluvium		Geomorphic Limit alluvium	
Sample	14C age	Sample	14C age	Sample	14C age
GRD1-1SA	0	GRS12-1AT	1160 ± 40	GRD3-3ZM	1910 ± 40
GRD2-2PR	260 ± 40	GRS13-1U	160 ± 40	GRD3-3AT	1870 ± 40
GRD2-2SA	340 ± 40			GRD3-3SA	1930 ± 40
GRD5-8SA	160 ± 50			GRD3-4AT	2490 ± 50
GRD5-10FR	220 ± 40			GRD3-5YSU	4110 ± 40
GRD9-6PI	580 ± 40			GRD3-7YSU	3010 ± 40
GRD9-8PR	410 ± 40			GRD7-9AT	80 ± 40
				GRD10-1FR	210 ± 40
				GRD10-9SA	230 ± 40
				GRD12-1AT	3270 ± 40
				GRD12-2ZM	2530 ± 40
				GRD12-3AT	2570 ± 40
				GRS1-2YSU	700 ± 40
				GRS1-3YSU	1050 ± 40

Elevation above the modern Gila River and lateral position in the landscape also characterizes the alluvial surfaces, although moderate variability exists in these factors. For instance, the Gila alluvium is generally the lowest in elevation and closest proximity to the Gila River, while alluvium associated with the Geomorphic Limit is generally the highest in elevation and furthest away from the Gila River. The Pima alluvium is an intermediate surface between the Gila alluvium and Geomorphic Limit alluvium.

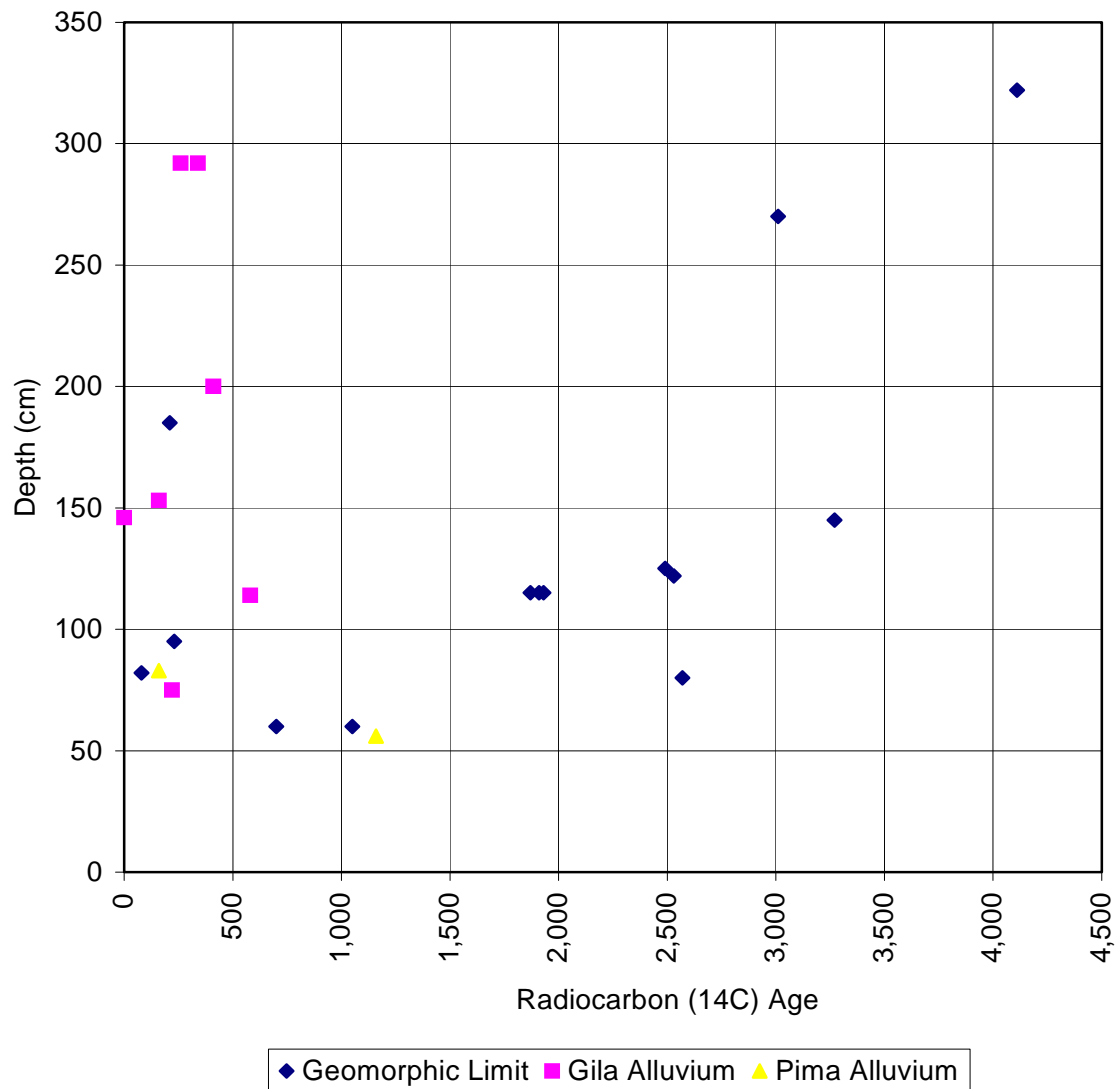


Figure 2. Radiocarbon age versus depth of sample.

Soils developed on the Gila, Pima and Geomorphic Limit alluvium are described in detail below with comparison to soils described in published soil surveys for Duncan Valley and Safford Valley (Poulson and Stromberg, 1950; Poulson and Youngs, 1938).

GEOMORPHIC MAP EXPLANATION

The geomorphic map is a tool for assessing river stability rather than mapping the extent of individual alluvial or bedrock units. The geomorphic map shows two extents of lateral movement for the Gila River. The Pima Soil Boundary is the contact between intermediate alluvium with soils of the Pima Soil Series and young alluvium with soils of the Gila Soil Series. The Geomorphic Limit of flood evidence is the boundary within which the Gila River channel has migrated over at least the past 1,000 years. The Geomorphic Limit is defined by tonal signatures on aerial photography, receding flood waters observed in post-flood aerial photography that show areas of historical flood inundation, and observations of soils that are strongly developed and have not been significantly modified by recent floods. In this way, the Geomorphic limit can be defined both by evidence of floods and well as evidence of stable soils. Although not explicitly mapped on the Geomorphic Map, the Gila alluvium with soils of the Gila Soil Series can be inferred to exist between the modern Gila River and the Pima Soil Boundary. If the Pima Soil Boundary is not present at a given location, then the Gila alluvium extends from the Gila River to the Geomorphic Limit (Figure 3).

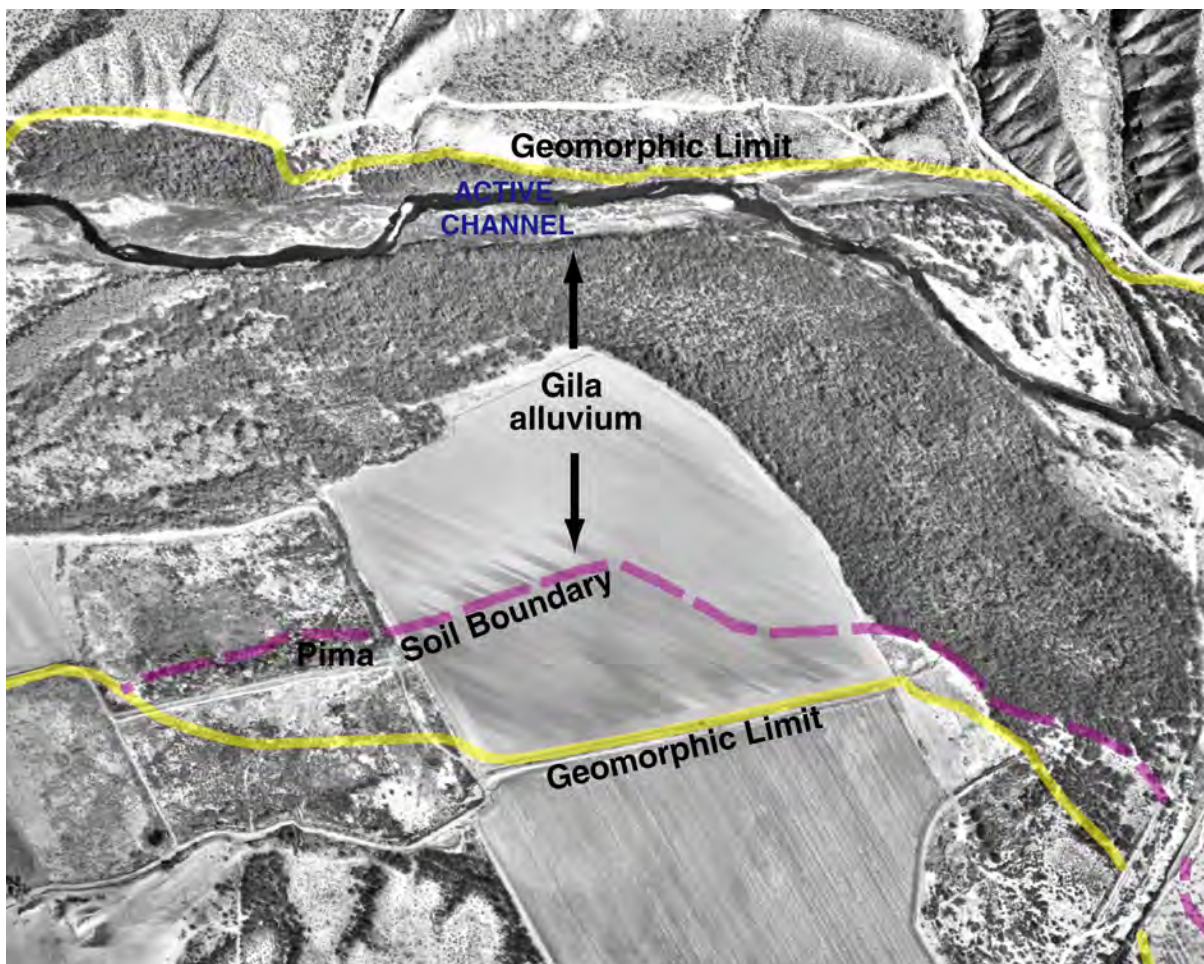


Figure 3. Example showing the lateral extent of the Gila alluvium.

DEFINITION OF MAP UNITS

The map units shown on the Geomorphic Map are described below. These descriptions can also be found in the Geomorphic Map Report, however, additional information for each unit is added here as part of the analysis.

The Gila alluvium is most commonly adjacent to the active channel and is part of the channel migration zone of the past several hundred years (see Figure 3). The Gila alluvium is composed of weakly developed soils with a C-horizon commonly at the surface (Figure 4). Buried soils exist in many cases; some of these soils appear to be truncated with no A-horizon while others consist of an A and C-horizon with no B-horizon development (Figure 5). The texture of the Gila alluvium is typically either a silt loam or sandy loam. The soils generally are formed on point bars, or on floodplain nearest to the river. The Gila Soil Series as described in Poulson and Stromberg (1950) is a clay loam and fine sandy loam formed on level to 2% slopes and is generally adjacent to the low flow channel and subject to frequent overflow. The surface is frequently channelized, or channelized scars are readily apparent on the surface. Both soil profiles are stratified and pale brown to light brownish-gray. Gravelly strata may also exist in the sandy loam. Radiocarbon dates obtained from charcoal samples range in age from 0 to 500 years old (see Table 1 and Figure 2 for further detail).

PIMA SOIL BOUNDARY

The Pima Soil Boundary is important because it provides evidence for the extent of lateral channel migration for at least the past several hundred years. The Pima soil is a cumelic floodplain soil formed on Holocene fluvial sediments deposited by the Gila River. Radiocarbon dates and soil development suggest that the Pima soil has not been subject to channel migration for the past several hundred to 1,000 years, although surfaces with Pima soils may be inundated during flood flows. These soils are currently being eroded along the river in some locations where the active channel is adjacent to the Pima Soil.

Surfaces with the Pima Soil are generally elevated above the active channel by 1.5 to 3 m and appear to be formed on alluvium that is several hundred years old. The Pima Soil Series generally runs parallel to the river and is a deep, dark-colored soil formed on level to 2% slopes. Although there is no salt concentration in any particular layer, the soil is generally rich in salts. Primary depositional stratification is present in the subsoil, which is lighter in color below a depth of 0.5-1 m (Poulson, 1950).

A typical soil consists of 38 cm of brownish gray granular silty clay loam underlain by brownish gray silty clay loam with fine blocky structure to a depth of 60 cm. From 60 to 150 cm, the profile consists of stratified or laminated layers of pale brown to weak brown friable silty clay loam, loam, and clay loam with occasional sandy and silty seams. From 150 to 175 cm, the soil consists of friable stratified pale brown material ranging from fine sandy loam to silty clay loam. Coarser material is present below 175 cm (Poulson and Youngs, 1938). Soil/stratigraphic descriptions in this study compare well with the general soil description provided by Poulson and Youngs (1938). Pima soils at sites described in this project have brown A-horizons with sub-angular blocky structure and textures ranging from silt loam to clay loam. Two B-horizons are typical, either with a B-horizon over a Bk-horizon or with 2 Bk-horizons. The Bk-horizons have stage I carbonate development in fine-grained material. The C-horizon typically has a texture of sandy loam except when there are interbeds of clay and silt. For example, site GRS12 exhibits a 25 cm thick A-horizon, two B-horizons to a depth of 88 cm and several C-horizons described to the base of a 2.0 m exposure (Figure 6).

Atriplex (common name saltbush) obtained from a charcoal-rich contact at 56 cm at site GRS12 yielded a date of 1160 ± 40 . Only two dates were obtained for soils in the Pima Soil Series that define the Pima Soil Boundary. The second date yielded an age of 160 ± 30 from a deeper depth at site GRS13 (Figure 7). The lack of other quantitative information from the Pima Soil precludes definitive estimates for the age of this boundary. However, based on bracketing information from younger and older soils, the Pima alluvium is estimated to be several hundred to 1,000 years old.

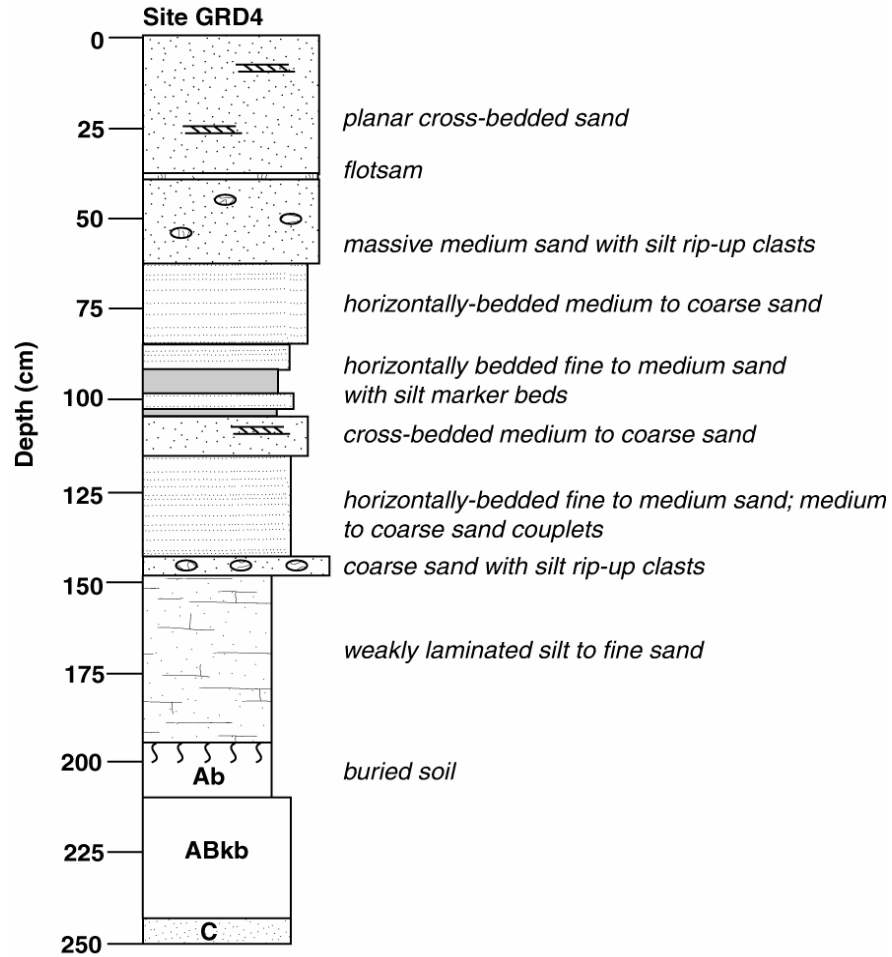


Figure 4. Gila soil profile at site GRD4.

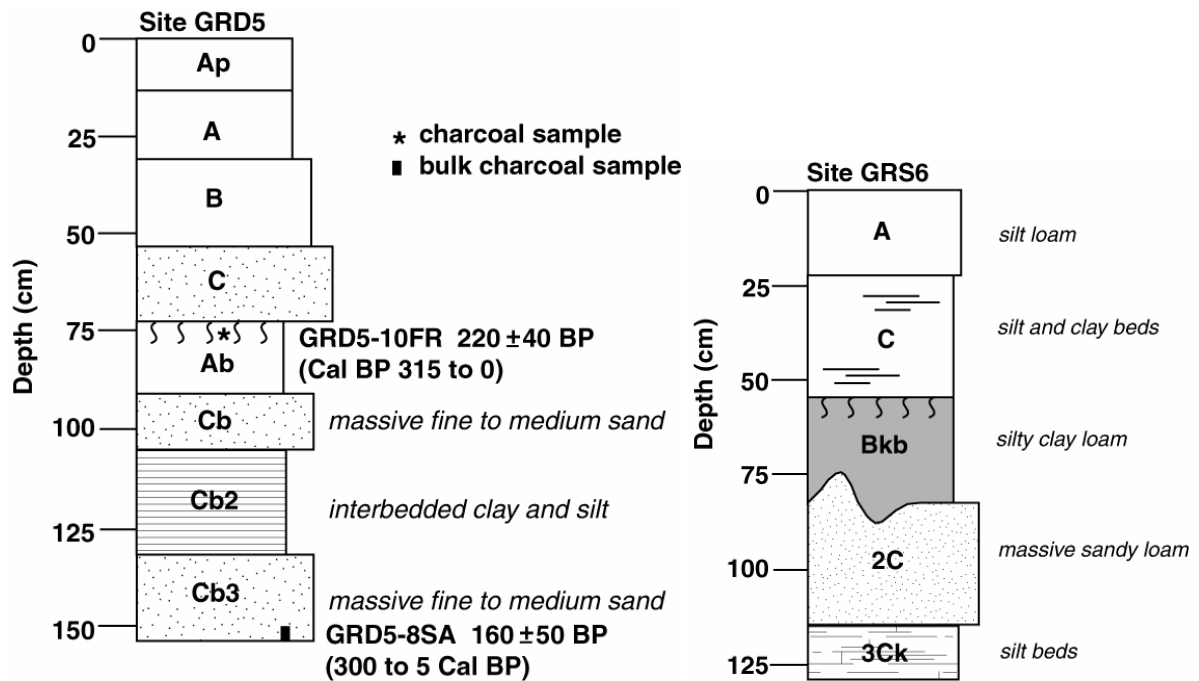


Figure 5. Gila soil profiles at sites GRD5 and GRS6

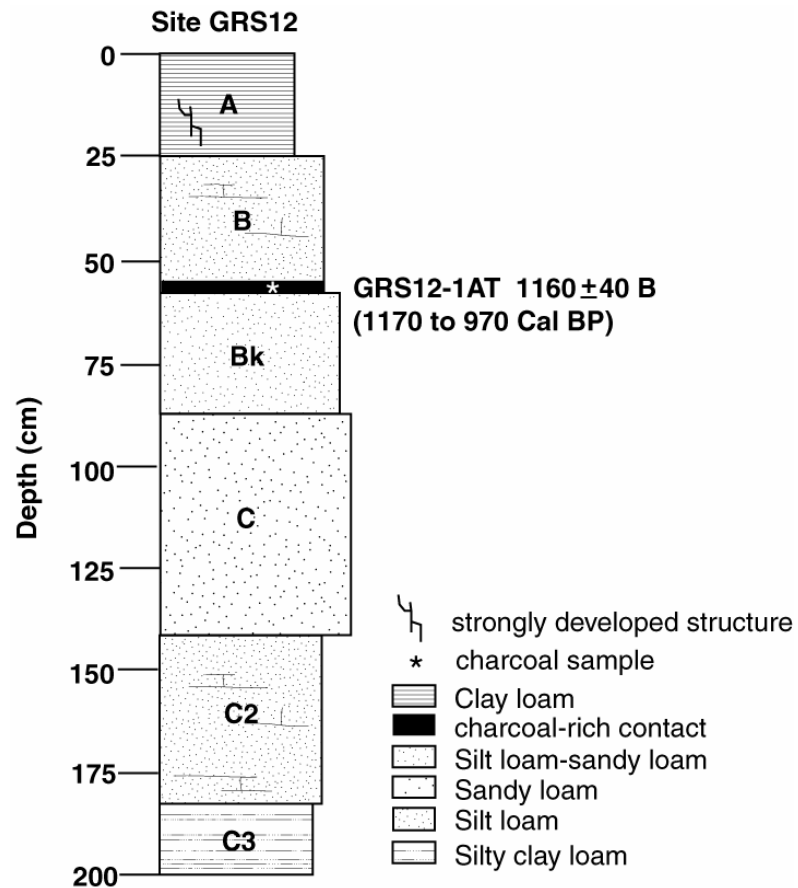


Figure 6. Pima soil profile at site GRS12.

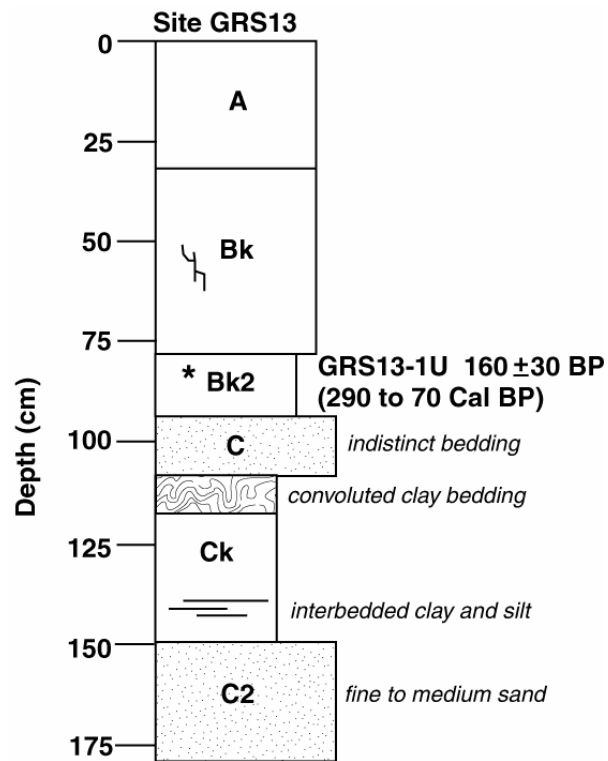


Figure 7. Pima soil profile at site GRS13.

GEOMORPHIC LIMIT OF FLOOD EVIDENCE

The geomorphic limit of flood evidence defines the boundary for surface modification by floods of the Gila River and defines the extent of lateral channel migration for at least the past 1,000 years. Within the geomorphic limit, surfaces are channelized or have tonal signatures on aerial photography that suggest flooding in agricultural fields. Beyond the geomorphic limit, soils may be eroded along bank exposures, but are eroded much slower than other banks due to their consolidated nature. Geomorphic units beyond surfaces with flood evidence include bedrock, colluvium, high stream terraces, alluvial fans derived from a single tributary, and alluvial fan complexes on gently sloping piedmonts. These units provide a limit to lateral movement along the Gila River based both on their age and erodibility. Although several soil series are included in this unit, the alluvial soils generally contain higher percentages of gravel and are more sloping than soils of the Pima Series. The soils also typically have carbonate accumulations in a particular horizon in the form of coatings on gravels in gravelly sediments or nodules and filaments in fine-grained sediments. In many cases, these soils have a greater amount of clay when compared to the Pima soil (Poulson and Youngs, 1938). They are also further removed from the active channel where the Pima soil is present and occupy positions of higher elevation than the Pima soil.

Several bank exposures and soil pits near the active channel illustrate these characteristics. Site GRD12, located near Railroad Wash in Duncan Valley, exhibits a 25 cm thick plow pan over a 11cm thick A-horizon (Figure 8). Three Bk-horizons are developed to a depth of 135 cm and have silty clay loam to clay textures and strongly developed angular blocky structure. Carbonate development ranges from stage I to stage II- while clay films are prominent to distinct on ped faces. Archaeological features including grinding stones and fire-cracked rock are present in these horizons; no other artifacts were noted. Charcoal collected from these horizons is most likely associated with these artifacts. The charcoal was disseminated throughout the horizons, lacking distinct lenses. Charred *Zea mays* (corn cob) and *Atriplex* (saltbush) charcoal were obtained from the Bk2 and Bk3-horizons and have very similar radiocarbon ages of 2570 ± 40 and 2530 ± 40 . The C-horizon at the base of the profile, described to a depth of 160 cm, has a fine sandy loam texture with coarse sub-angular blocky structure. An additional *Atriplex* charcoal sample collected at a 145 cm depth in the C-horizon has a radiocarbon age of 3270 ± 40 BP.

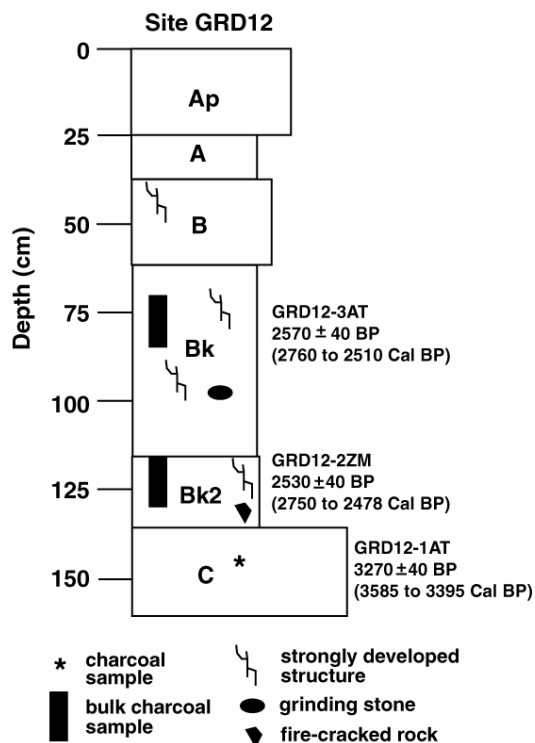


Figure 8. Bank exposure along the Geomorphic Limit, site GRD12.

Site GRD3 is located approximately $\frac{3}{4}$ mile west of the Greenlee County Fairgrounds along the Gila River. The surface soil is buried by approximately 15 cm of laminated fine sand and silt, which are interpreted to be derived from a nearby tributary. These sediments thin downstream with distance from the tributary mouth (Figure 9). Within the C-horizon of this buried soil are several hearths at various depths and charcoal-rich sand. Rounded stones are also observed within this horizon and appear to be grinding stones. Radiocarbon ages obtained from this horizon average 2028 ± 40 BP from three samples identified from a bulk sample at a depth of 115 cm and 2 samples identified from a bulk sample at a depth of 125 cm. Below a depth of 195 cm, 5-10 cm thick beds of silt, clay and fine sand overlie two buried soils with moderate to strongly developed sub-angular blocky structure, silt loam texture and stage I carbonate. Charcoal samples from the two buried soils have radiocarbon ages of 3010 ± 40 BP and 4110 ± 40 BP, respectively.

Site GRD10 is located upstream of Apache Creek and is composed of fine grained and gravelly alluvium that may be associated with Apache Creek or Kaywood Wash. The surface soil extends to a depth of 137 cm and consists of moderately to strongly developed structure with sandy loam texture and approximately 10% gravel in the B-horizons (Figure 10). The C-horizon consists of loosely consolidated rounded gravels with stage I carbonate. An additional soil is buried below the surface soil. No A-horizon is preserved. This soil is moderately developed with sub-angular blocky structure, sandy loam to loamy sand texture and stage I carbonate (Gile et al., 1981). Charcoal material sampled at depths of 95 and 185 cm and have radiocarbon ages of 230 ± 40 BP (420 to 0 Cal BP) and 210 ± 30 BP (305 to 0 Cal BP), which are almost certainly younger than the alluvium. These dates point out one of the problems encountered in radiocarbon dating, where the introduction and contamination of young material into an older profile can be a significant source of uncertainty and consternation in estimating its age.

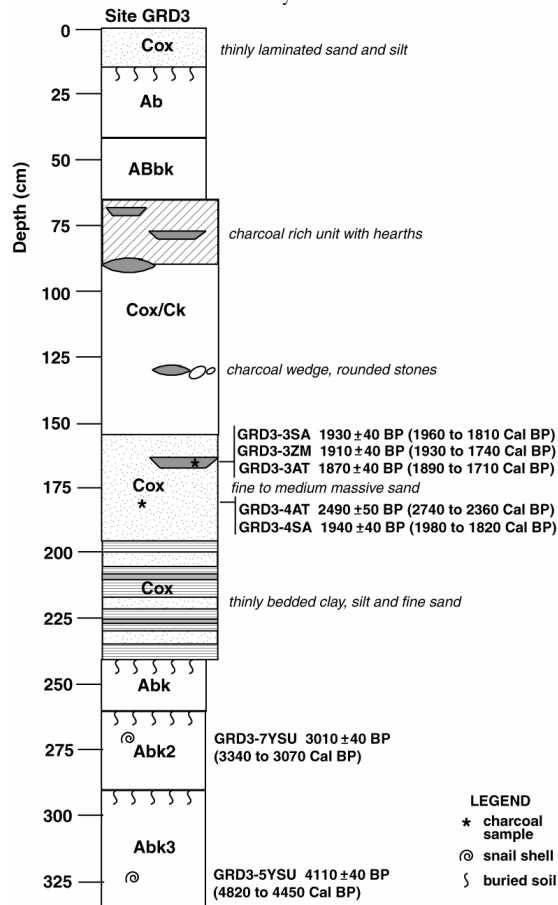


Figure 9. Bank exposure along the Geomorphic Limit, site GRD 3.

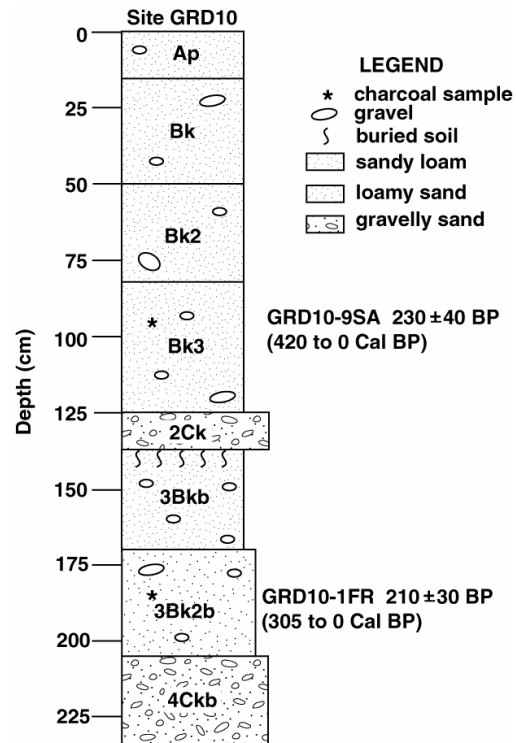


Figure 10. Bank exposure along the Geomorphic Limit, site GRD 10.

Site GRS1 is located near the downstream end of the study area on Doug Hinton's property west of Geronimo. The soil profile has a 10 cm A-horizon, and 5 B-horizons to a depth of 210 cm (Figure 11). The soil is rich in clay, ranging from silty clay to clay texture, with a weak to moderate sub-angular blocky structure. Carbonate accumulations are visible in the lowermost B-horizon with stage I morphology. Snail shell samples have radiocarbon ages of 700 ± 40 and 1050 ± 40 at 60 cm within the B2-horizon.

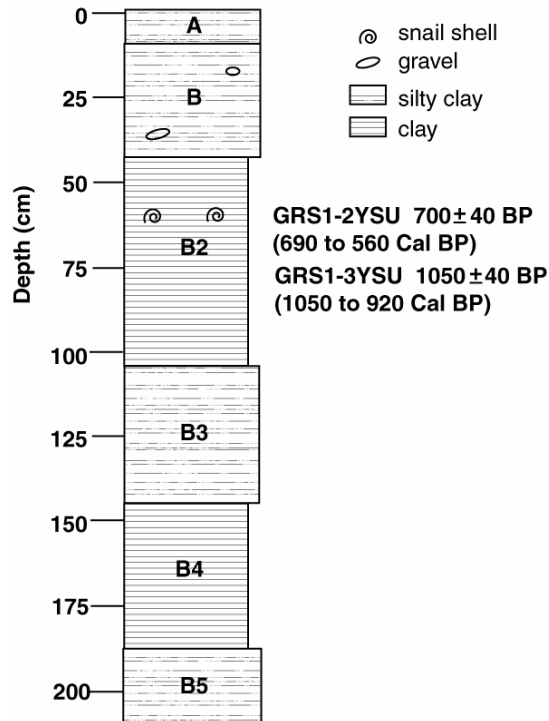


Figure 11. Bank exposure along the Geomorphic Limit, site GRS 1.

LEVEES

Levees from 1953 to 1992 that appeared to be important factors in property loss during large floods were mapped on aerial photography. Many levees have been built that are not portrayed on the Geomorphic Map because they did not appear to be catalysts for channel change on the Gila River. Table 2 lists the aerial photographs that were used in mapping levees. Note that the levees are assigned the year of aerial photography, although they were present prior to photography. For instance, the 1981 levees were built sometime between the 1978 and 1981 aerial photography.

Table 2. Source data for mapped levees.

DATE	SOURCE	SCALE	FILM TYPE
1953	Army Map Service	1:54,000	Black & White
1967	USDA	1:20,000	Black & White
1978	BLM	1:24,000	Color
1981	USGS	1:32,800 to 1:34,000	Color Infrared
1992	USGS	1:40,000	Black & White

PROPERTY LOSS

Property loss is defined as agricultural land eroded during large floods. Aerial photography from 1935-2000 was examined to determine property loss. Since the majority of land in Safford Valley was eroded between 1967 and 2000, 1967 was set as an arbitrary datum. The majority of erosion in Duncan Valley occurred between 1978 and 2000, so that pre-flood 1978 photography was used as the datum. Once the eroded property was identified, it was then outlined on the 2000 aerial photography.

REACH-BASED ANALYSIS

Several reaches had significant erosion of property that warrant a detailed discussion of the areas of property loss and factors that contributed to its erosion. Reaches are discussed from upstream to downstream in order to address in a logical manner the effect of upstream structures and channel changes on downstream channel morphology. Each analysis is accompanied by its portion of the geomorphic map. The yellow lines on each figure represent the geomorphic limit of flood evidence while the purple lines represent the Pima Soil Boundary. Areas shaded blue represent property loss from 1967-2000 in Safford Valley and from 1978-2000 in Duncan Valley. Additional colors represent levees of various construction years and include 1992 (green), 1981 (red), 1978 (coral), 1967 (pink), and 1953 (blue). Features are illustrated on 2000 base photography. Flow is from right to left in the geomorphic map figures. Left are right bank references are in the downstream direction.

RAILROAD WASH

The Railroad Wash reach extends from the left bank near Railroad Wash to the end of the property loss parallel to Lunt Road (Geomorphic Map 30; Figure 12). This reach has experienced erosion of older alluvium along the left bank and young alluvium along the right bank in an area that had been floodplain historically. Levees constructed along the right bank prevented flow from accessing part of the right bank that had been historically flooded during large discharges. Instead, flow was directed at the left bank, eroding the consolidated left bank at site GRD12. The river bend as well as the Railroad Wash alluvial fan appear to have directed floodwaters toward the right bank levee. The breach of the right bank levee accentuated the erosion along this bank, creating asymmetrical meanders related to the levee breach and reentrant flow downstream.



Figure 12. Railroad Wash geomorphic map.

CUTOFF MEANDER

The cutoff meander reach is downstream from the Railroad Wash, and consists of a new channel that was formed during the 1993 and 1995 floods, cutting off a previous meander of the Gila River and effectively reducing the sinuosity of this reach (Geomorphic Map 29; Figure 13). Although it was common for large floods such as the 1978 flood to inundate this part of the floodplain, the main channel had remained in a very similar position throughout the historical period. Following the 1978 flood, extensive levees were constructed in this reach. The inability of the river to access its floodplain along this reach forced the breach of the levee constructed along the right bank and the development of the new channel. Remnants of the 1981 levee can be observed in the 2000 aerial photography. Although the levee appears to have played an important role in this channel avulsion, the erosion occurred within the flood channel and could have been formed naturally as well had the levees not been present.

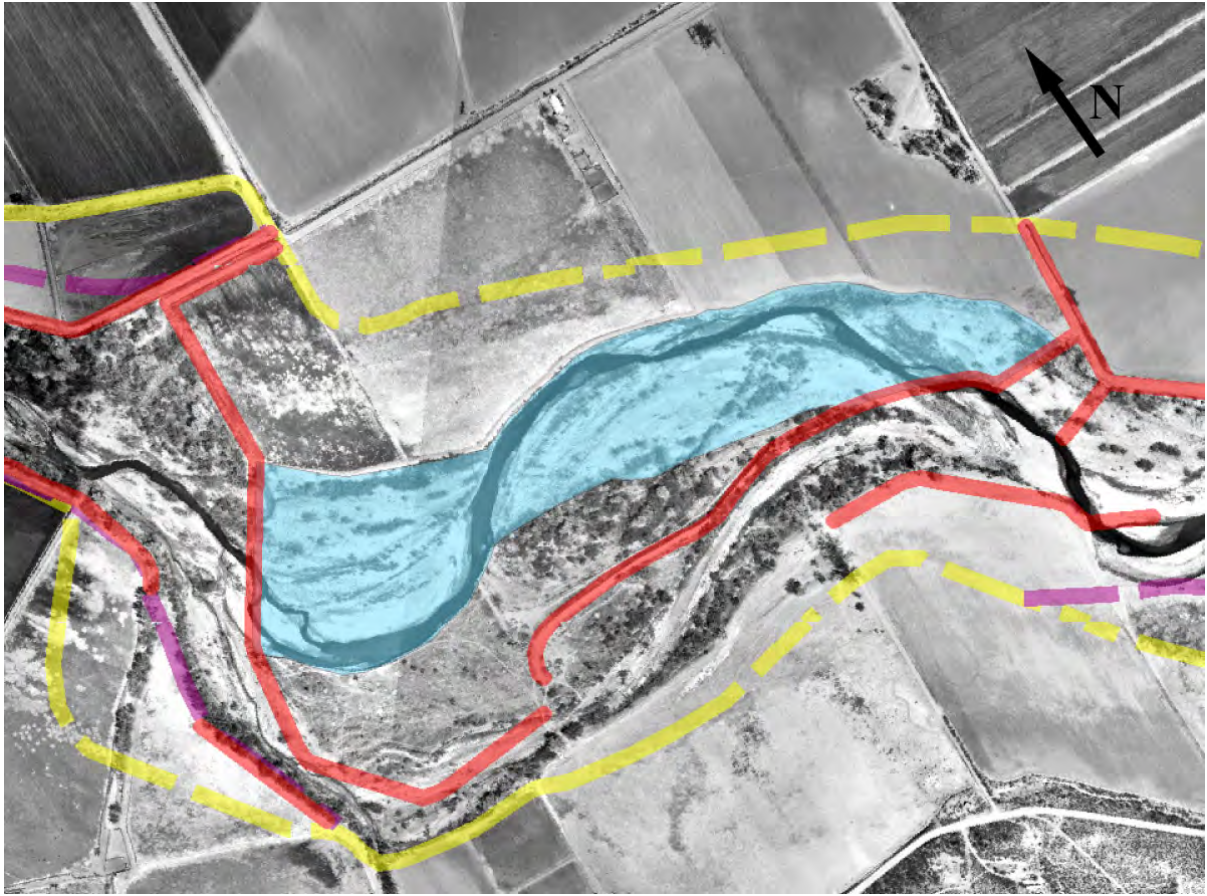


Figure 13. Cutoff meander geomorphic map.

DUNCAN BRIDGE

The Duncan Bridge reach is a short reach located upstream of Duncan Bridge (Map 28 Geomorphic Map; Figure 14). The erosion along the left bank is a result of the propensity of rivers to erode outside bends and exacerbated by extensive levees constructed along the right bank, isolating low channelized surfaces from the main channel. In addition, aggradation in the levied reach has caused repeated breaching of the left bank levee downstream of Duncan Bridge and significant sedimentation over Pima alluvium on the west side of the river.

WHITEFIELD WASH

The Whitefield Wash reach, located just downstream of Duncan Bridge, experienced dramatic channel change between 1992 and 2000 (Geomorphic Map 27; Figure 15). Levees with greater extent following the 1978 flood were constructed presumably in response to inundation of agricultural land. The 1993 and possibly 1994 floods caused erosion of left bank and right bank property as flood flows breached the upstream levee, concentrating flow behind the levee and eroding Gila and Pima alluvium. This erosion created an unusual channel pattern and increased sinuosity. Erosion of levees and minor erosion of land also occurred downstream of this disturbance.

KAYWOOD WASH

The Kaywood Wash reach extends from Kaywood Wash to Apache Creek. Property loss occurred on the right bank, where tributary alluvial fan materials are exposed in vertical banks (Geomorphic Map 23; Figure 16). Before levee construction on the right bank, floods inundated the right overbank of Gila alluvium. The levees directed the river toward the left bank and into the right bank levee downstream.

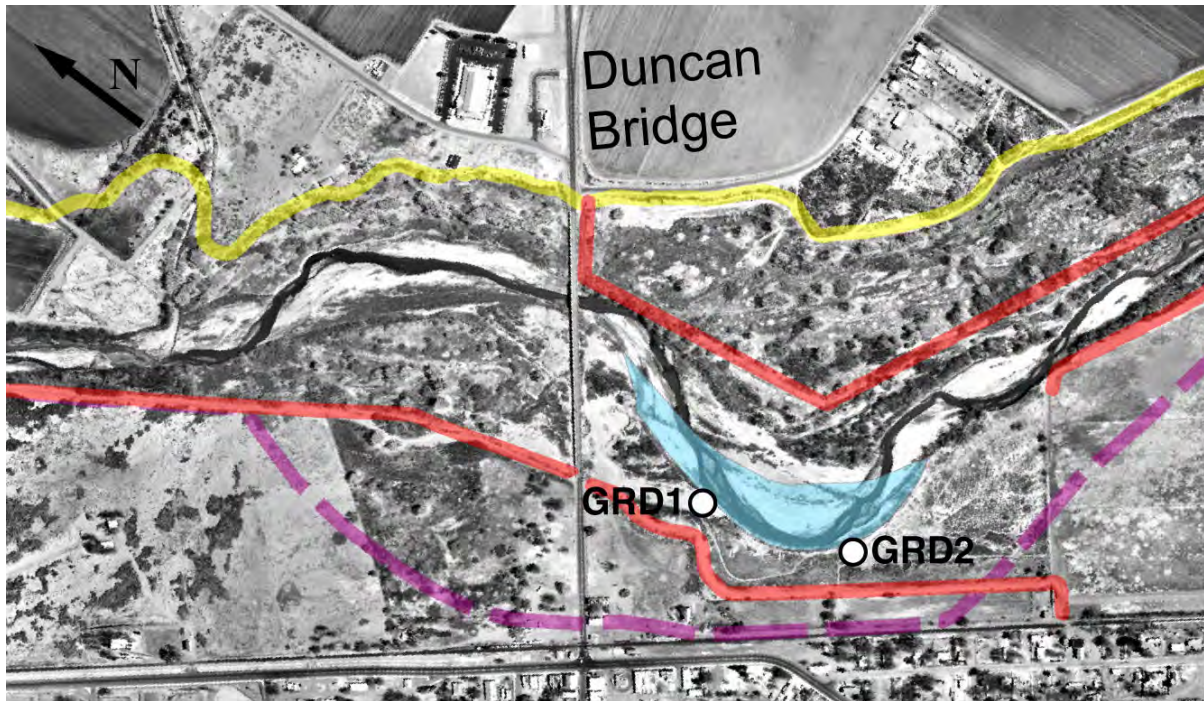


Figure 14. Duncan Bridge geomorphic map.

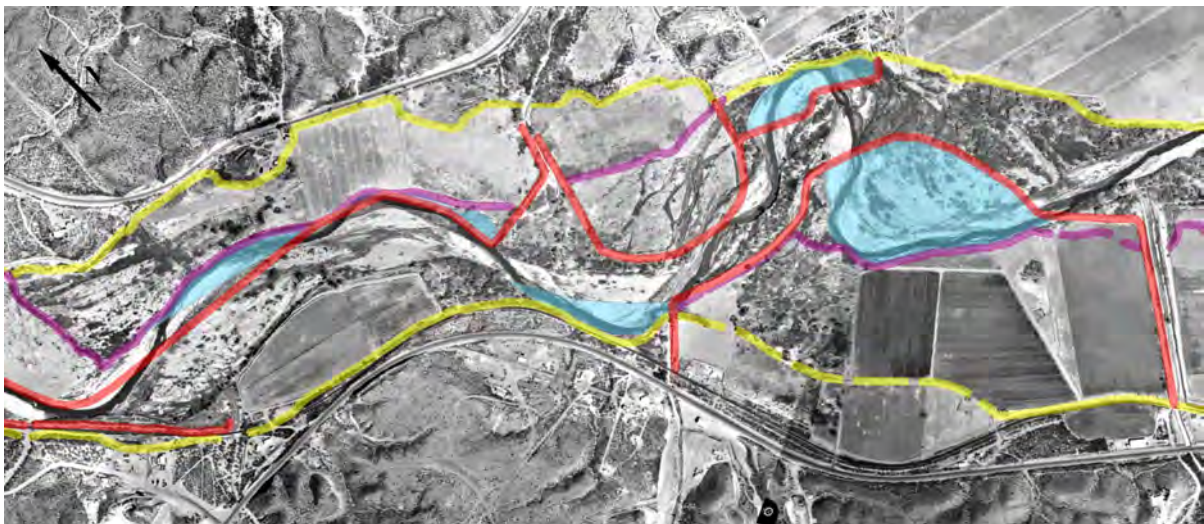


Figure 15. Whitefield Wash geomorphic map.

The natural constriction created by the Apache Creek alluvial fan (far left in Figure 16) may have also played a role in creating a backwater zone and increased water surface elevation sufficient to overtop and breach the right bank levee in this location. While portions of this levee were eroded during the flood, the majority of the levee remained intact. Vegetation on the left bank appears to be important in the active channel position in 2000 and may have also played a minor role in property loss from 1992-2000.

SAN JOSE DIVERSION

Property loss associated with San Jose Diversion extends for two miles downstream of the structure. Considerable erosion of Gila alluvium occurs both upstream and downstream of the diversion (Geomorphic Map 17-18; Figure 17). Erosion of Pima alluvium is restricted to downstream of San Jose Diversion. Although some of the erosion, especially upstream of San Jose diversion, can be attributed to natural channel widening from floods, San Jose Diversion also acts as a catalyst to property loss by

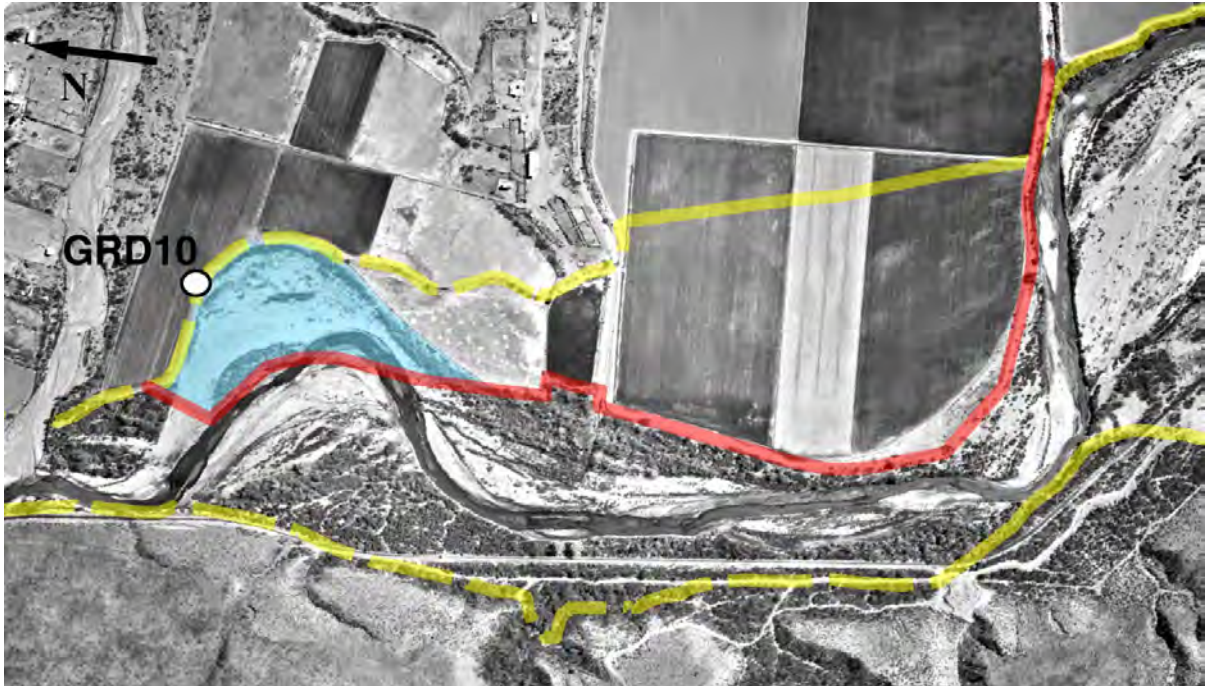


Figure 16. Kaywood Wash geomorphic map.



Figure 17. San Jose Diversion geomorphic map.

directing flood flows into the right bank directly downstream of the structure. This bend sets up the erosion of meanders downstream. During floods in recent decades the river has increased in sinuosity, eroding both right and left banks as the meander propagated downstream.

SAN JOSE WASH

This reach is located near San Jose Wash, where numerous levees were constructed following the 1978 flood (Geomorphic Map 15-16; Figure 18). Some of these levees were constructed along farmland while others were constructed in the channel. The majority of property loss occurred before the construction of these levees and was presumably caused by the flood of 1978. 1981 levees were eroded in the following decades during large floods. It thus appears that in this reach, property loss is mostly related to natural processes of channel widening.

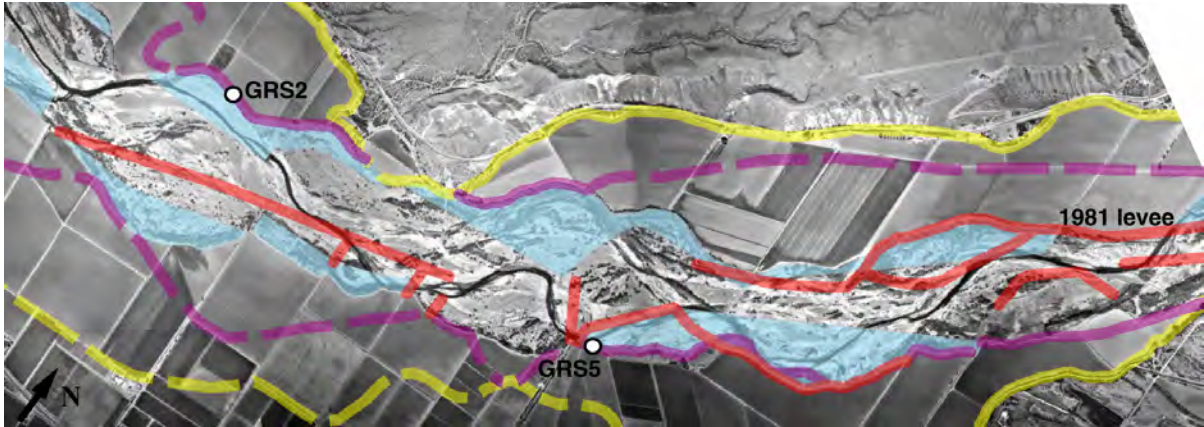


Figure 18. San Jose Wash geomorphic map.

GRAHAM DIVERSION

Levees were constructed upstream of Graham Diversion to direct flow over the diversion dam. During large floods, water overtopped this levee, which directed it toward the left bank, causing the erosion of farmland near the ditch between Safford and Hollywood (Geomorphic Map 14; Figure 19). A levee constructed along this property was not successful in preventing the erosion. Further upstream, channel morphology has the appearance of many generations of similar failure due to aggradation behind the diversion and lateral migration. This area has experienced repeated erosion, as much of the mapped property loss was part of the channel in 1935 (Figure 20).

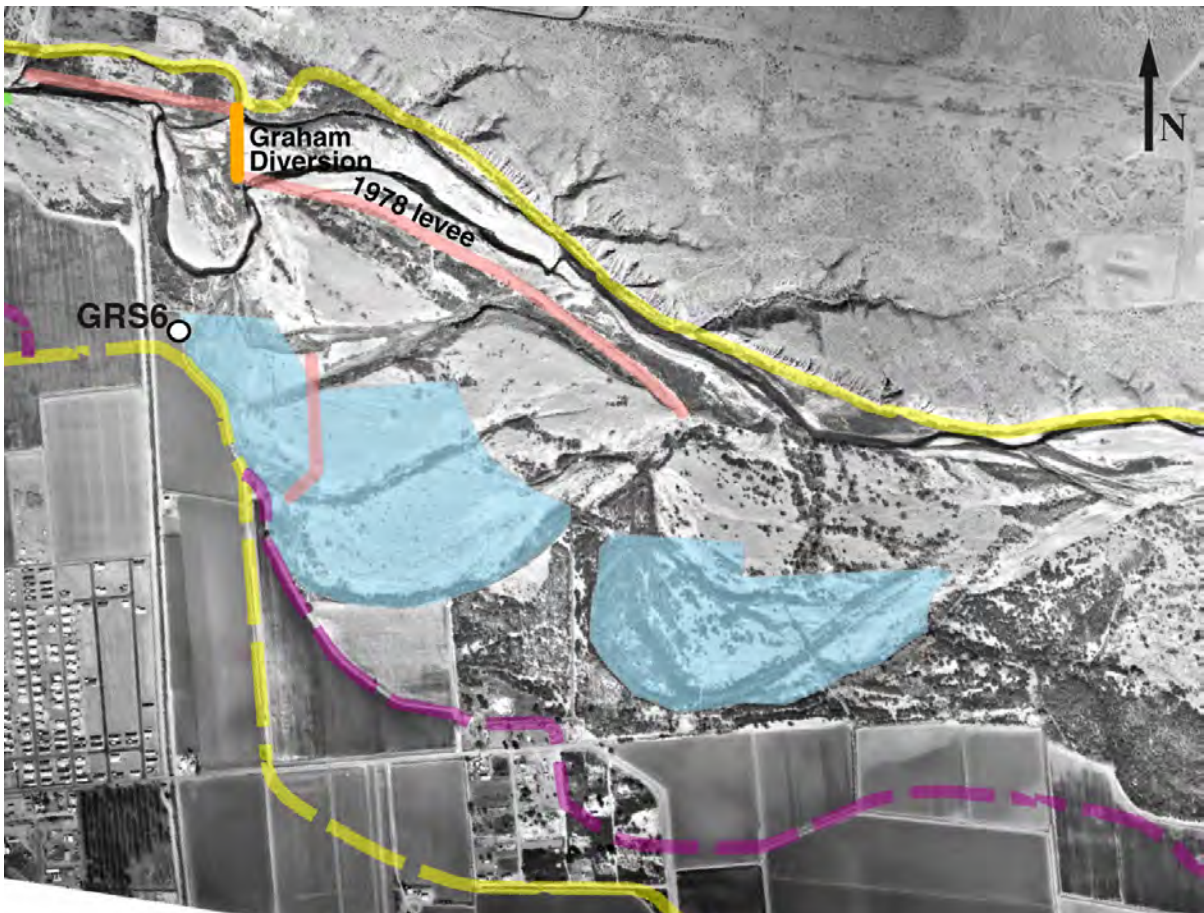


Figure 19. Graham Diversion geomorphic map.

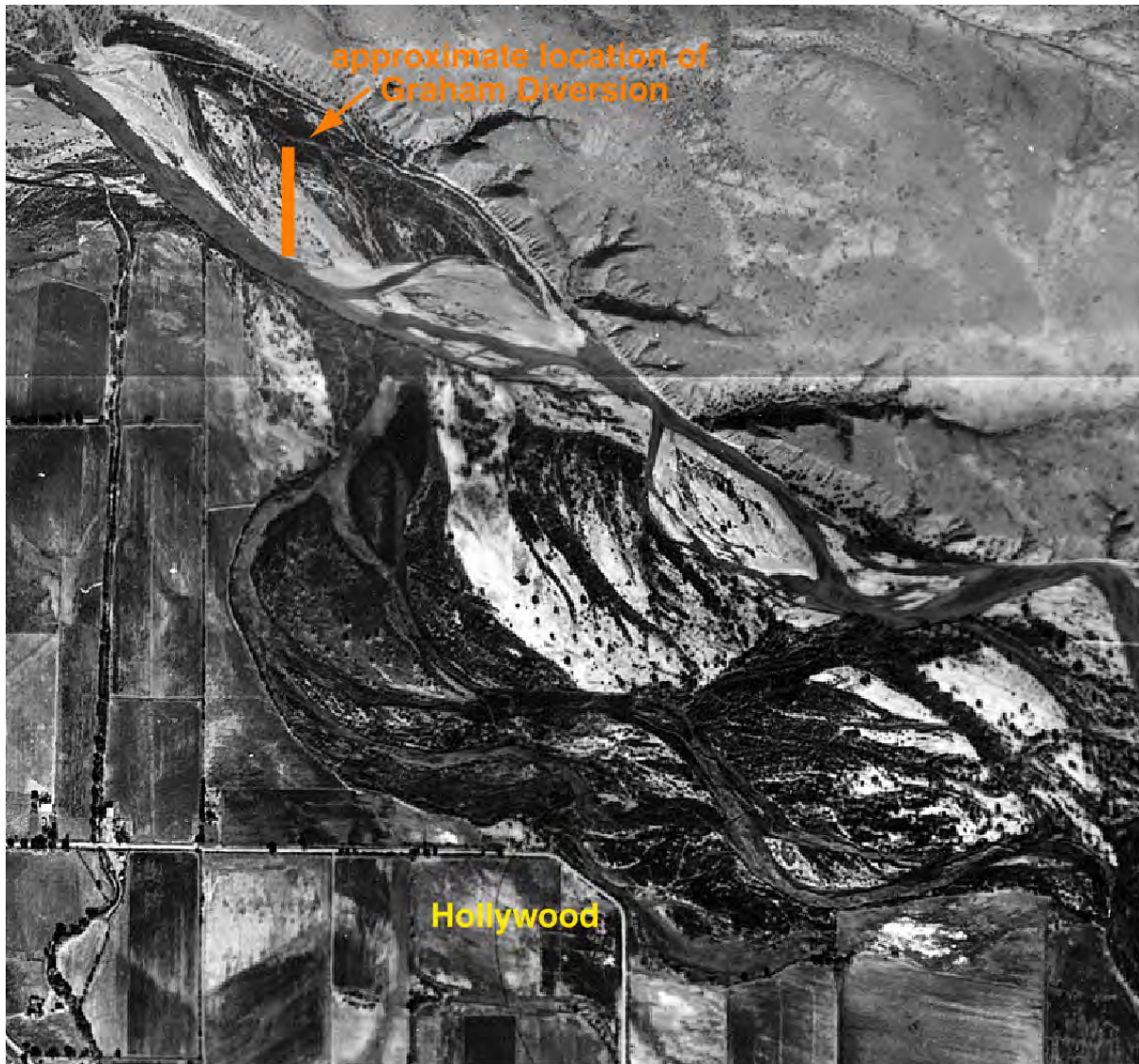


Figure 20. 1935 aerial photograph of Graham Diversion.

SMITHVILLE DIVERSION-TALLEY WASH

The Smithville Diversion reach is located between Safford and Thatcher (Geomorphic Map 12; Figure 21). The river is dredged and lined with unconsolidated levees upstream of the Smithville diversion. The apparent intention of the levees is to direct flow over the diversion. Flood flow during the 1980's and 1990's was redirected toward the banks, eroding Gila alluvium and the margins of Pima Soil on both sides of the river. Flow over Smithville Diversion directed floods toward the right bank downstream due to the orientation of the diversion and levee on the left bank, which eroded Pima Soil near Talley Wash. Alluvium at the downstream end of the left bank levee to Thatcher Bridge was also eroded during floods along with part of the levee. The area near the 1992 levees is one of repeated erosion and land leveling during the historical period (1935-2000).

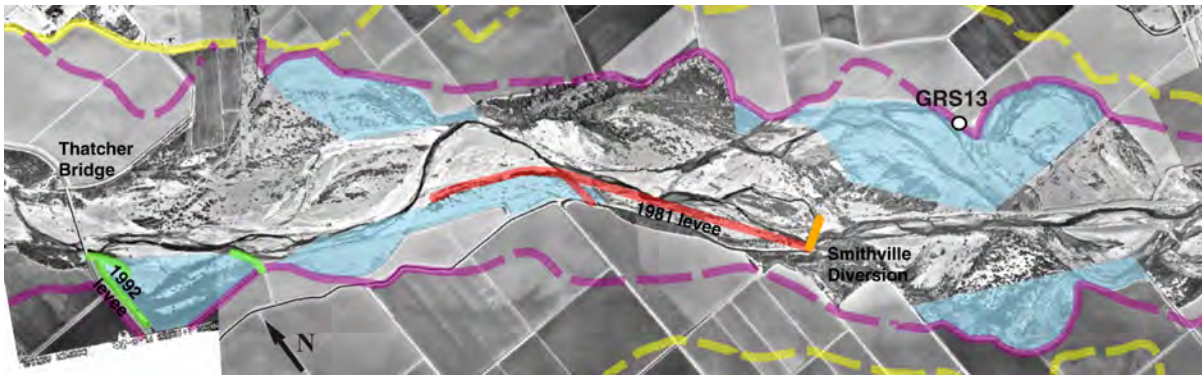


Figure 21. Smithville Diversion-Talley Wash geomorphic map.

WATSON AND BUTLER WASHES

The Watson and Butler reach extends from Watson and Butler washes to the first southwest corner of Safford-Bryce Road near the Gila River (Geomorphic Map 10-11; Figure 22). A levee constructed following the 1978 flood between Watson and Butler washes on the right bank, caused erosion of the left bank immediately downstream and propagation of a new meander train. The exaggerated meanders continued downstream for approximately two miles, eroding some banks that are several hundred to thousands of years old.

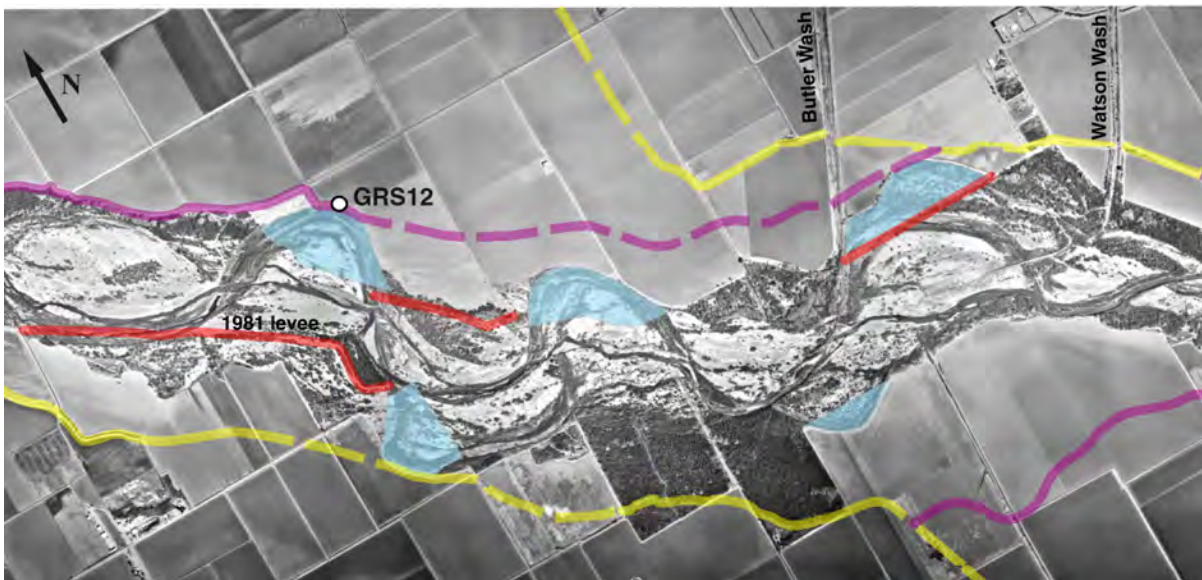


Figure 22. Watson and Butler Wash geomorphic map.

CURTIS DIVERSION

Erosion from Curtis Diversion to Markham Wash appears to be related to channel straightening during the 1970's (Geomorphic Map 8-9; Figure 23 and Figure 24). Following the initial channel straightening in the 1970's a new meander pattern was established as the river abandoned the artificial channel. This pattern developed through time as subsequent floods created new channel morphology. Thick vegetation in this reach was important in establishing the new channel morphology. Near the downstream end of the reach, flow repeatedly overtopped the embankments of the channel and flowed perpendicular to the overall flow direction, creating large loop-shaped erosion scars.



Figure 23. Channel straightening downstream of Curtis Diversion.

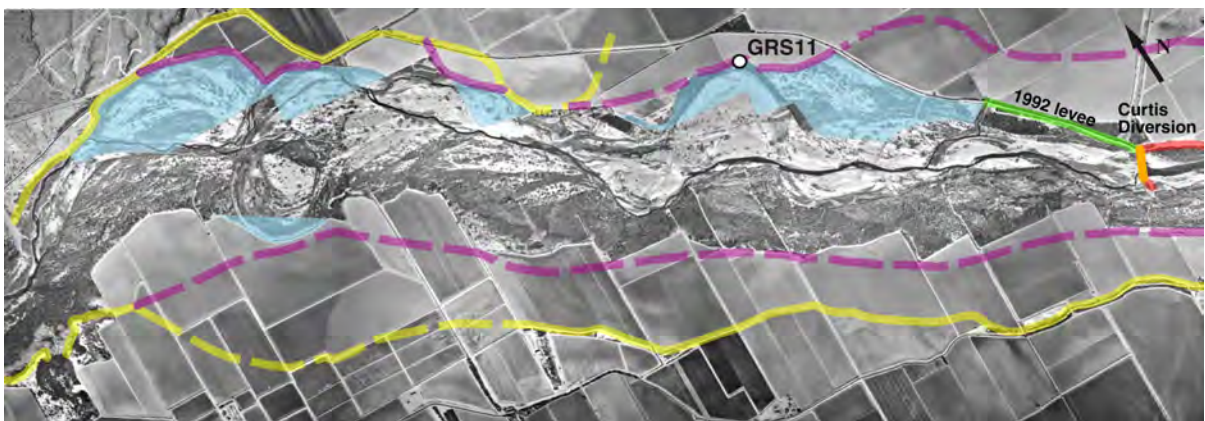


Figure 24. Curtis Diversion geomorphic map.

FORT THOMAS DIVERSION

At Fort Thomas Diversion, erosion of the right bank is most likely associated with breach of a levee constructed after the 1978 flood (Geomorphic Map 7-8; Figure 25). The bank today is heavily rip rapped; mapping and site investigation indicates that Pima alluvium previously occupied the eroded area.

EDEN BRIDGE

North of Eden Bridge, the Geomorphic Limit is adjacent to the active channel on the left bank. A levee built in 1967 effectively isolated a narrow band of Gila alluvium that was accessed during floods (Geomorphic Map 5-6; Figure 26). During floods in the 1970's, 80's and 90's, the left bank was eroded

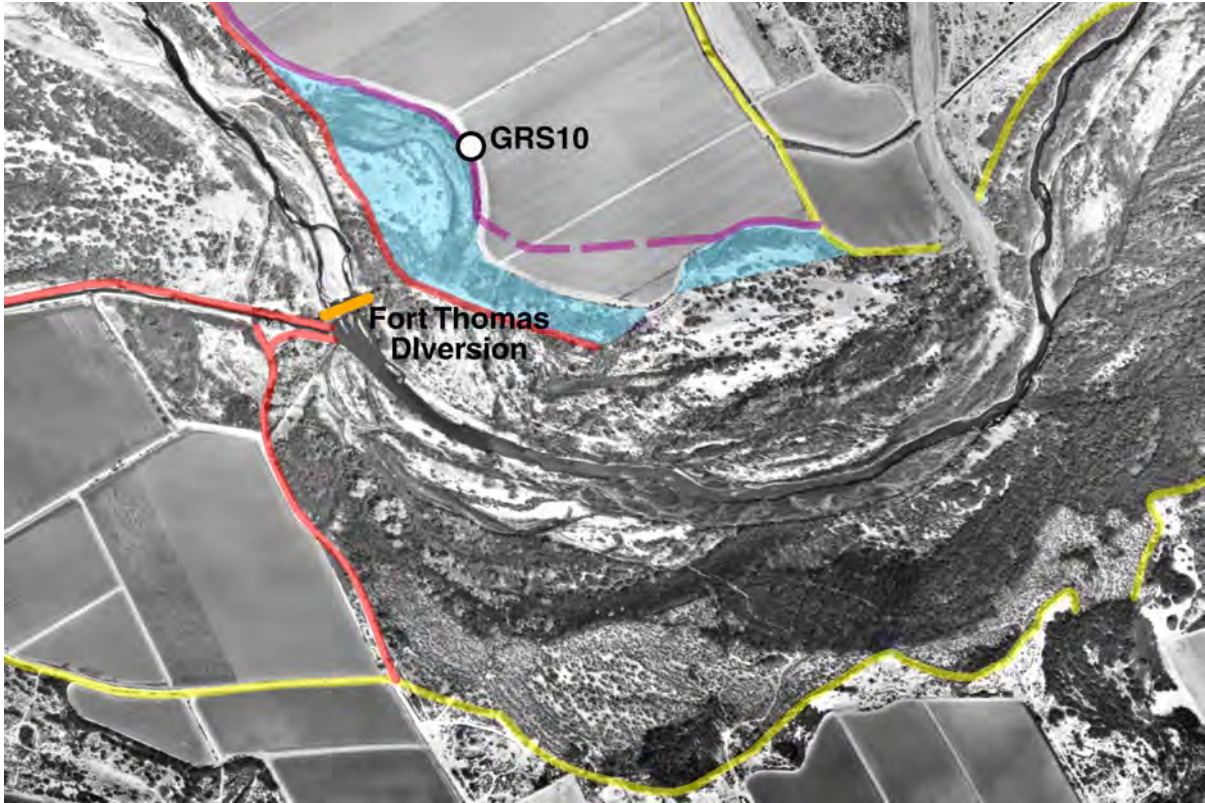


Figure 25. Fort Thomas Diversion geomorphic map.

downstream of the levee. The new large amplitude meander breached the 1981 levee on the right bank. Although the levee breach did not erode old alluvium, the active channel is presently adjacent to the Geomorphic Limit on the right bank. Previous channel positions, which breached the 1953 levee were most likely important in the new channel formation as well.

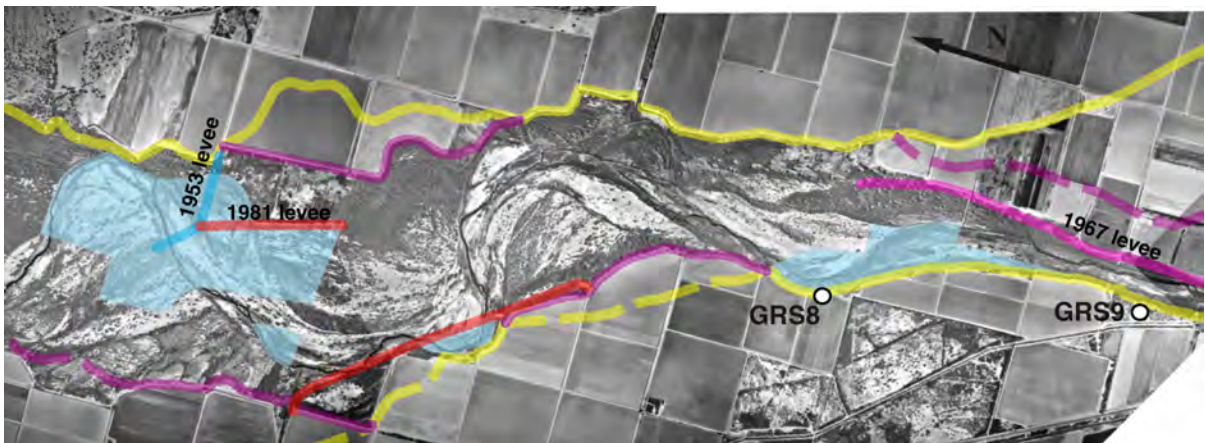


Figure 26. Eden Bridge geomorphic map.

FORT THOMAS BRIDGE

The Fort Thomas reach extends from Fort Thomas Bridge to Goodwin Wash (Geomorphic Map 2-3; Figure 27). Property loss in this reach is associated with levees constructed in the 1990's. Although the 1983 flood caused extensive damage to agricultural fields by breaching the right bank levee upstream of Fort Thomas Bridge, it did not cause extensive channel change (Figure 28). Construction of a new levee in a similar location upstream of Fort Thomas Bridge prevented a breach during subsequent floods.

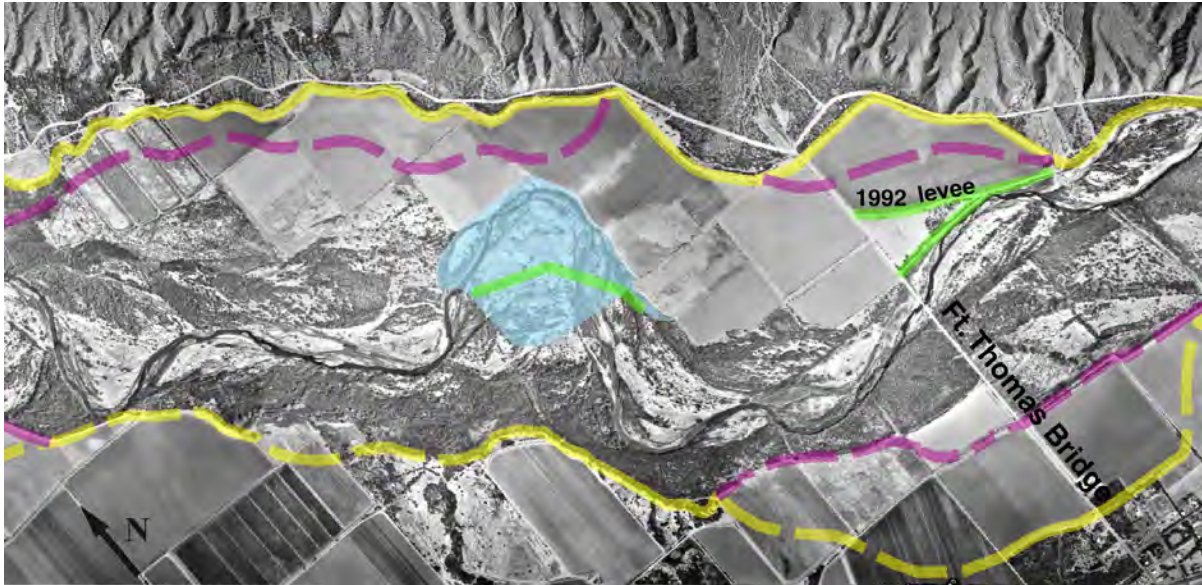


Figure 27. Fort Thomas Bridge geomorphic map.

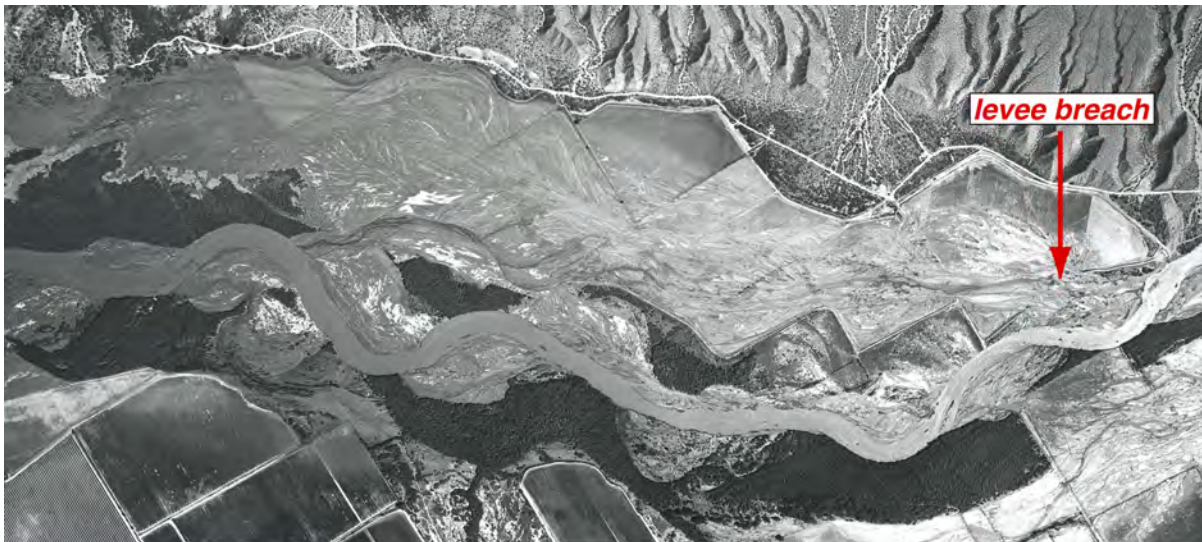


Figure 28. Receding floodwaters, Fort Thomas Bridge, October 7, 1983.

Instead, floods breached the right bank levee downstream, eroding property and creating new channel bottom. The location of the breach was most likely controlled by thick vegetation as well as alluvial fan material from Fine wash on the left bank. Additional erosion occurred downstream from the area and is mainly controlled by thick vegetation and the location of alluvial fans such as Day Mine Wash.

GERONIMO

The Geronimo reach is located near Geronimo and extends downstream to the San Carlos Indian Reservation boundary (Geomorphic Map 1; Figure 29). In this reach, levees on the right bank appear to be most problematic; erosion of these levees during the 1980's and 1990's accentuated the outside bend at this location and directed the river toward the left bank where banks older than 700-1000 years were eroded (see site GRS1). The effect on channel morphology has been a historical increase in sinuosity and a channel with 90 degree bends unlike that of 1935 (Figure 30). Overbank channel splays in farmland on the north side of the river are also evident and caused substantial damage to farmland.



Figure 29. Geronimo geomorphic map.

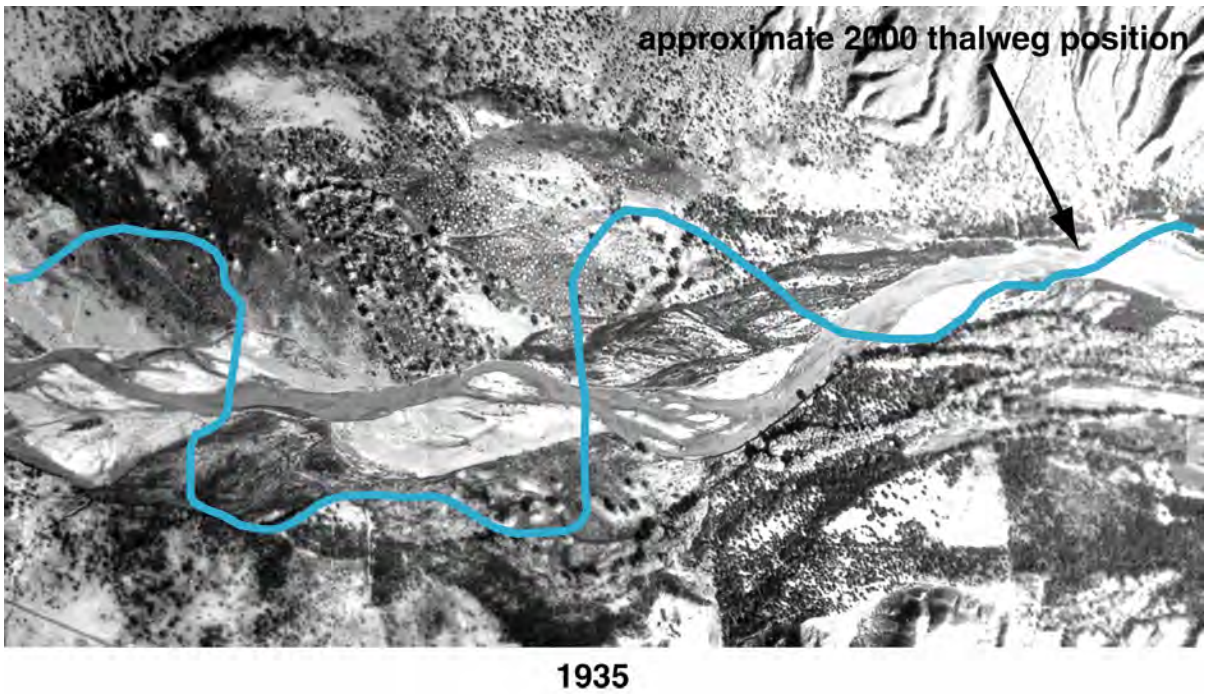


Figure 30. Comparison between 1935 and 2000 channel near Geronimo, AZ.

DISCUSSION

The geomorphic map provides evidence for lateral migration and instability along the Gila River. Understanding the age of alluvial deposits that bound a river helps provide long-term constraints on the lateral stability of the channel. The typical pattern that would be expected along a river in the southwest is a progression in age of deposits away from the active river channel. The older the deposits the less likely it should be that they would be actively eroding. That is not to say that rivers do not migrate laterally and erode older deposits. However, if a river is eroding laterally in many locations and eroding older deposits, that is not a condition with a high probability and generally indicates some form of imposed instability. The Geomorphic Limit of Flood Evidence is against bedrock and piedmont alluvium in some places, while in other areas the alluvium appears to be related to the Gila River. This soil found in these banks has been developing for at least 1,000 years. Surfaces with the Pima Soil have been developing for at least several hundred years. Although floods from the Gila River may occasionally inundate these surfaces, flood sediment is incorporated into the developing soil based on stratigraphy of bank exposures in which the soil is not buried by young sediments. A major exception to this statement occurs upstream of the Duncan Bridge constriction where aggradation within the levees has resulted in breaching of the left bank levee downstream of Duncan Bridge and substantial sedimentation over the Pima Soil. In comparing Safford Valley and Duncan Valley, the Geomorphic Limit is much closer to the active channel in Duncan Valley when compared to the Geomorphic Limit in Safford Valley. This seems logical since the size of the river is much smaller in Duncan Valley, whereas the San Francisco River greatly increases the size of peak discharges and therefore the width of the Gila River flood channel in Safford Valley. The Pima Soil is only preserved in wider reaches of Duncan Valley, where floods do not occupy the entire width within the Geomorphic Limit. In Safford Valley, the Pima Soil is more prevalent, paralleling the Gila River for the majority of its length in the study reach.

Tributary alluvial fans appear to play an important role in channel position and recent geomorphic change. In some cases, deposition of alluvial material in the active channel redirects the channel toward the opposite bank (i.e., Railroad Wash). In other cases, the position of old fans exerts a long-term control on channel position, where channel geometry is clearly related to the alluvial fan. Examples of this scenario occur in Duncan Valley near Apache Peak and Kaywood Wash. In Safford Valley, Day Mine Wash and Markham Wash are two fans that exert important controls on channel geometries. Other authors have attributed similar importance to the capacity of alluvial fans to influence channel geometries on the Gila River (i.e., Burkham, 1972; Levish, 2003).

Recent vegetation encroachment in the floodplain from Pima to the San Carlos Indian Reservation also appears to be an important control on active channel morphology and in geomorphic change during floods. As a barrier to flow, thick vegetation may cause erosion of banks with less vegetation during floods. Thick vegetation may increase the likelihood of levee breaches or avulsions by allowing a smaller volume of water to flow through the main channel, (see Figure 28; Hooke, 1996; Burkham, 1976).

COMPARISON TO CATALOG OF HISTORICAL CHANGES

The geomorphic analysis compares well with the Catalog of Historical Changes (Task 7A) in identifying reaches of channel change. The majority of reaches are the same; however, the Geomorphic Analysis identified additional areas in both valleys (Figure 31; Table 3). The differences can be partly attributed to differences in the methodologies used for each analysis. The Catalog of Historical Changes identifies areas where there has been the greatest variation in channel width from 1935 to 2000. The Geomorphic Analysis documents property loss from 1965 to 2000 in Safford Valley and from 1978 to 2000 in Duncan Valley (Figure 32). This difference in arbitrary datums may be important in explaining differences since land leveling and repeated property loss in the flood channel occurred throughout the historical period. Case Study 4A, downstream of Solomon Bridge, shows an example of substantial historical channel change due to land leveling for agriculture (Figure 33).

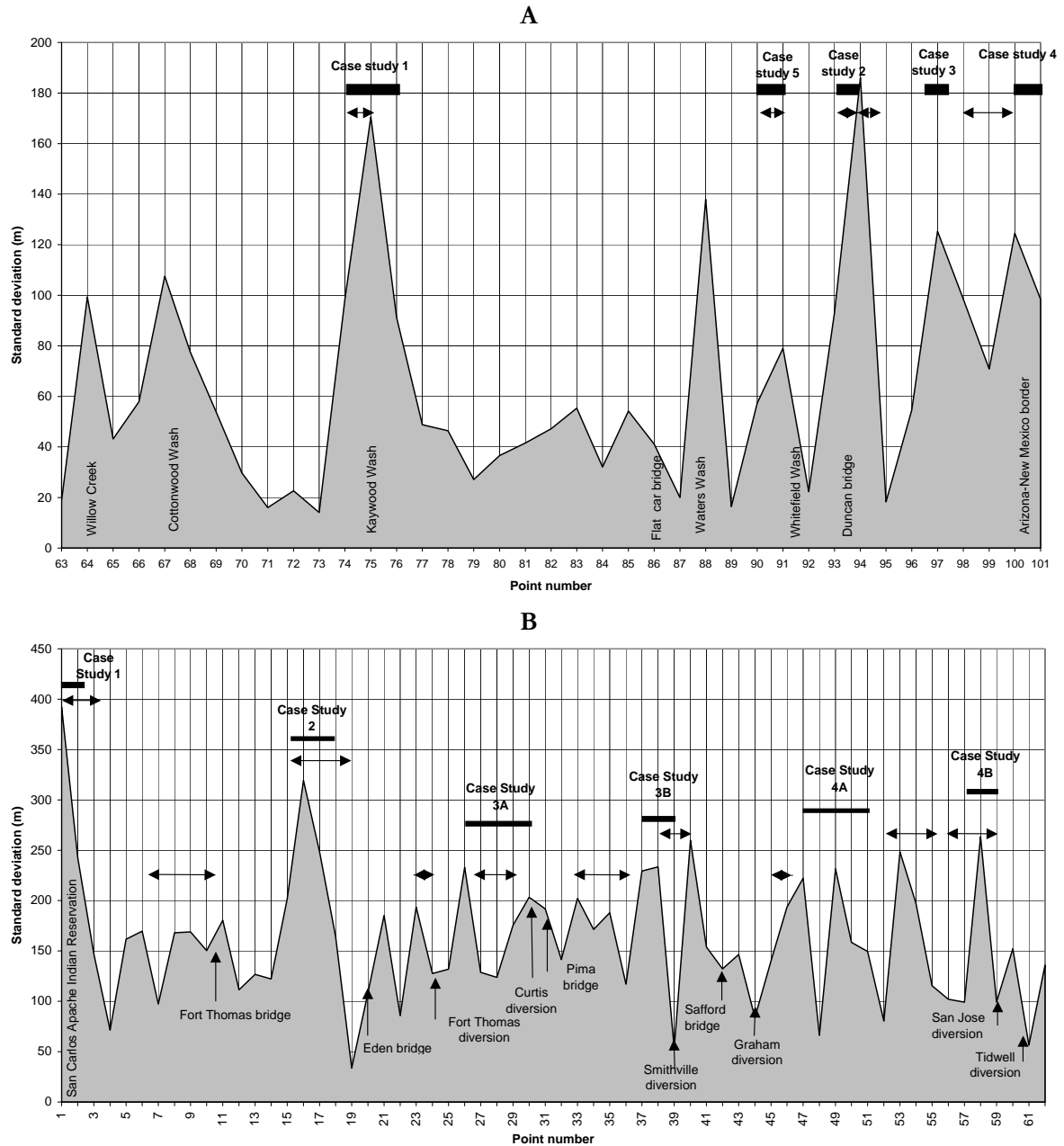
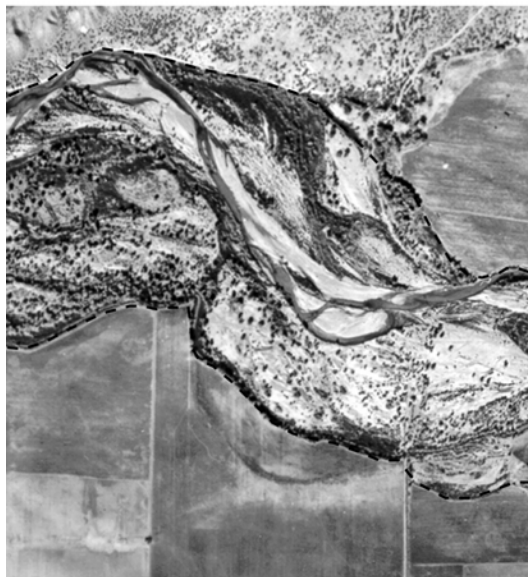


Figure 31. Reach comparison between this analysis and the Catalog of Historical Changes. Case studies refer to reaches in the Catalog while arrows define reached identified in this study.

Other reaches identified in the Geomorphic Analysis that are not identified in the Catalog of Historical Changes do not rank high enough in historical variation in width to be identified as areas of substantial change. A few areas such as between Safford Bridge and Smithville Diversion were not identified because they were simply not selected as case studies. There is also a potential for the methods used in the Catalog to completely miss a short reach of geomorphic change. This is illustrated in the case of the cutoff meander upstream of Duncan Bridge (between measurement points 95 and 96 in the Catalog of Historical Changes). This reach fell in between width measurements and therefore was not identified.

Table 3. Reach comparison, this analysis versus the Catalog of Historical Changes (Klawon, 2001).

Reach Name (Geomorphic Analysis)	Corresponding Case Study Reach (Catalog of Historical Changes)
Railroad Wash	3 (Duncan Valley)
Cutoff meander	none
Duncan Bridge	2 (Duncan Valley)
Whitefield Wash	5 (Duncan Valley)
Kaywood Wash	1 (Duncan Valley)
San Jose Diversion	4B (Safford Valley)
San Jose Wash	none
Graham Diversion	none
Smithville Diversion/Talley Wash	none/3B (Safford Valley)
Watson and Butler Washes	none
Curtis Diversion	3A (Safford Valley)
Fort Thomas Diversion	none
Eden Bridge	2 (Safford Valley)
Fort Thomas Bridge	Reach of Intermediate Variability (Safford Valley)
Geronimo	1 (Safford Valley)



1935



1973

Figure 32. Land leveling near Solomon Bridge.

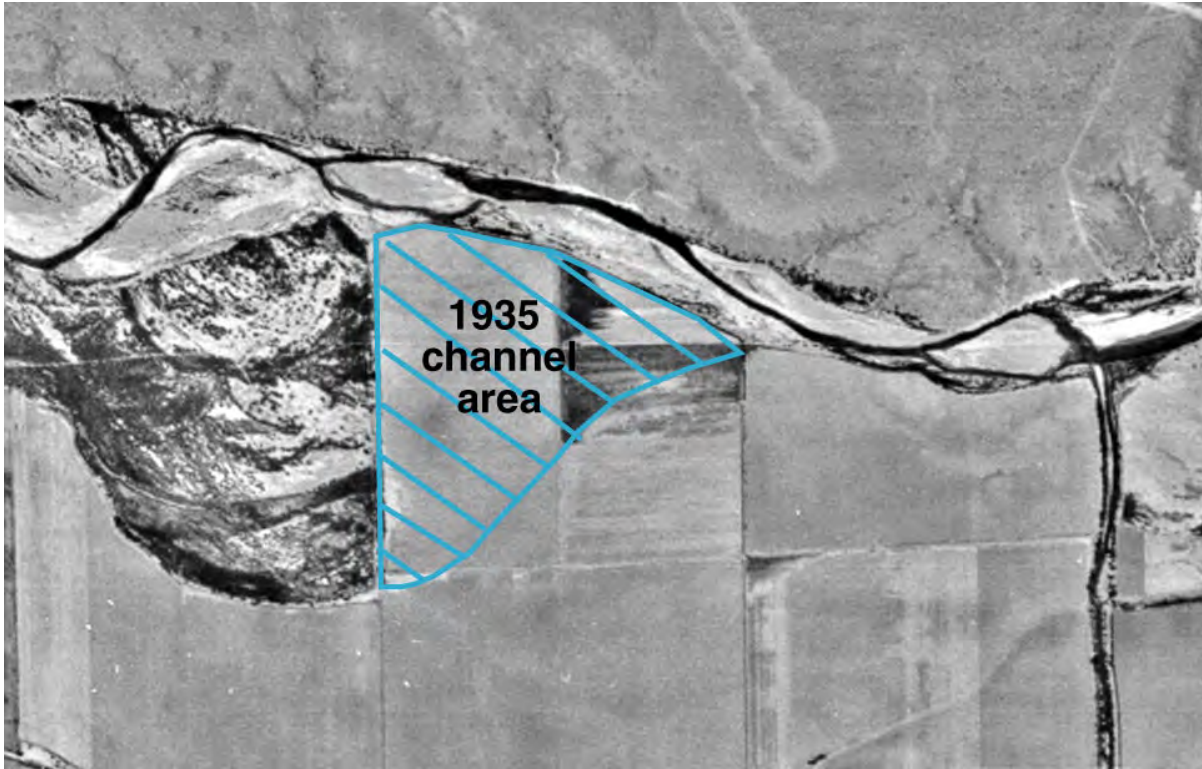


Figure 33. Land leveling downstream of Solomon Bridge.

Common Patterns Of Lateral Instability

The Catalog of Historical Changes and the Geomorphic Map reveal the close correlation between levee construction and subsequent failure and geomorphic change along the Gila River in Arizona. As the Geomorphic Map was compiled, several factors causing instability emerged as common to multiple reaches (Table 4). These factors include: (1) levee failure; (2) downstream propagation of erosion; (3) channel straightening; (4) diversion dam orientation. Levee failure causes catastrophic property loss because failure results in water flowing nearly perpendicular to the former flood channel. The reduction of flood plain storage and the decrease in flood channel sinuosity results in higher flood velocities. Since the levees artificially raise the stage of the floodwater, the water flowing from a levee breach generally has tremendous energy compared to normal overbank flows. Once behind the levee, the water must find a return path to the main channel. This return path also acts as an effective flow redirection and can propagate erosion and levee failure downstream. Examples of this pattern are the cutoff meander upstream of Duncan Bridge and Whitefield Wash downstream of Duncan Bridge. These reaches were confined by levees following the 1978 flood. Once the levees were breached, considerable erosion ensued behind the levees. Much of the floodplain that had previously been inundated during large floods became river channel and was lost to future agriculture. Erosion continued until flow reentered the river downstream. Remnants of levees and the previous main channel can be viewed in the 2000 aerial photography.

Table 4. Agents of geomorphic change in Safford and Duncan Valleys.

Reach Name	Alluvium of eroded banks	Pattern
Railroad Wash	Gila GL	Levee breach
Cutoff meander	Gila	Levee breach
Duncan Bridge	Gila	Channel straightening
Whitefield Wash	Pima GL	Levee failure
Kaywood Wash	GL	Levee failure
San Jose Diversion	Gila Pima	Diversion dam orientation/DS Propagation
San Jose Wash	Gila Pima	Natural channel widening
Graham Diversion	Gila Pima	Diversion dam orientation and levee failure
Smithville Diversion/Talley Wash	Gila Pima	Channel straightening DS Propagation
Watson and Butler Washes	Gila Pima GL	DS Propagation
Curtis Diversion	Gila Pima	Channel straightening
Fort Thomas Diversion	Gila Pima	Levee failure
Fort Thomas Bridge	Gila Pima	DS Propagation
Geronimo	Gila GL	DS Propagation

In downstream propagation of erosion, an initial perturbation such as a levee or diversion dam redirects flow toward the opposite bank causing erosion; the process continues downstream so that alternating banks are eroded. In Safford Valley, this wave of propagation generally appears to dissipate within two miles of the initial perturbation. Examples of this pattern include San Jose Diversion and Watson and Butler Washes. While the initial perturbations were different, the effects appear very similar. Both reaches show erosion of alternating banks due to structures which redirected flow into opposing banks.

A similar process occurs when channels are straightened. This channel modification also decreases flood channel sinuosity, decreases sediment transport where the channel is narrowed resulting in aggradation within the levees and redirects flow when floodwaters reach a stage high enough to breach levees. In the case of Curtis Diversion, it appears that relatively unconsolidated levees were constructed from the dredged sediments of the straightened reach. Once the river breached these levees, it was directed toward the banks and began to scour large loop-shaped patterns into the surrounding flood plain (Figure 34). This process recurred as the channel was straightened repeatedly and large floods breached the levees. When channels are straightened upstream of diversion dams, the dams may also contribute to local aggradation which results in lateral instability (i.e., Smithville Diversion).

Diversion dam orientation may also cause erosion of opposing banks. This is an isolated case of factor (2), where erosion of the opposing bank does not initiate a propagation of erosion downstream. As water flows over the diversion, it is directed perpendicular to the diversion's orientation. If that direction points toward the opposite bank, then erosion most likely will occur during large floods. A chronology of photos shows progressive erosion of the opposite bank downstream of San Jose Diversion dam inferred



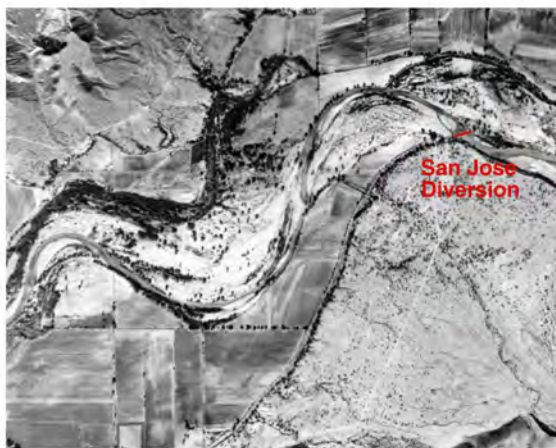
Figure 34. Effects of channel straightening near Curtis Diversion.

to occur during large floods between the years of the aerial photographs (Figure 35). This erosion eventually forced erosion to propagate downstream into older alluvium.

Vertical Changes

A detailed analysis was not performed to assess vertical changes in Safford and Duncan Valleys. Qualitative observations, however, of soils and elevations above the active channel can be used to provide some insight on these types of fluctuations. In general, observations suggest that the Gila River is not currently undergoing widespread aggradation or degradation in Safford and Duncan Valleys. This is based on the absence of young sediments overlying older soils associated with the Pima Soil Boundary and Geomorphic Limit. Multiple buried soils in units such as the Pima alluvium are part of natural floodplain formation, where the vertical accretion of sediment is a normal process. If substantial degradation had occurred, rivers would not be able to access their floodplains. This is not the case in areas where there is substantial modification and in areas where there are few human modifications to the river and its floodplain.

A few areas of localized vertical changes should be noted. In the vicinity of Duncan Bridge, qualitative observations indicate that there has been aggradation in this reach. Young sediment overlies an older soil in the Gila alluvium on the left bank upstream of Duncan Bridge (Figure 36). This package of sediment appears to thin upstream and thus would be interpreted as a wedge of sediment associated with the construction of Duncan Bridge. Downstream of Duncan Bridge, sediment deposition associated with levee breaches on the left bank over the Pima alluvium is caused by elevated water surface within the levees. Recent channel changes, however, have caused some of the banks of Gila alluvium to be 2 meters or more above the active channel. These high banks are located on outer bends and appear to be localized areas of incision since other areas of Gila alluvium in the vicinity are less than one meter above the active channel. Between Waters Wash and Sheldon, young alluvium is incised but still is experiencing deposition on its surfaces during floods. It is possible that these fluctuations are caused by natural constrictions such as alluvial fans and bedrock, and by the process of vertical accretion. A few areas on



1935



1967



1981



1992



1997

Figure 35. San Jose historical channel changes.

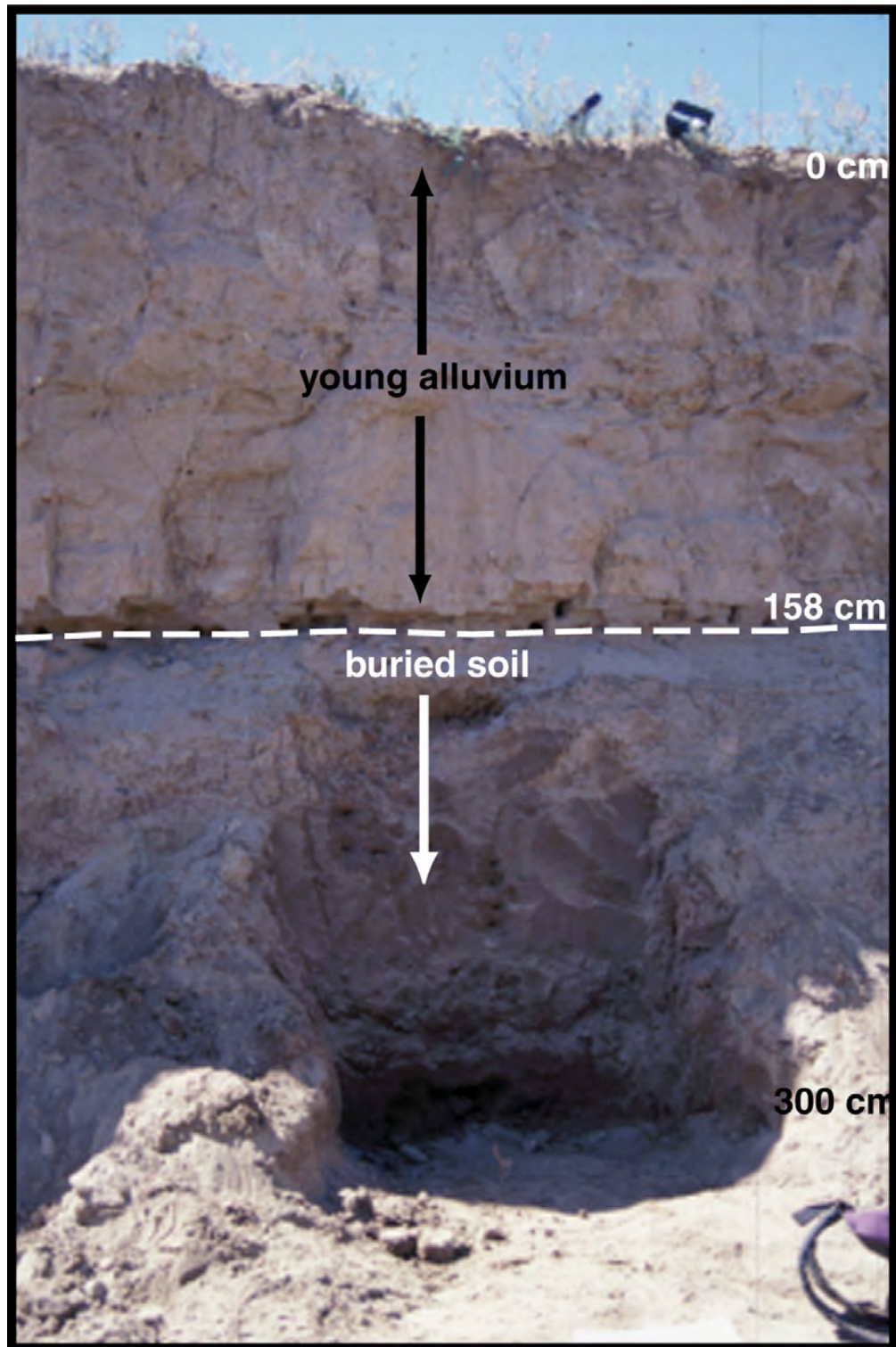


Figure 36. Aggradation at Duncan Bridge.

the left bank near Safford appear to be aggraded. These areas of aggradation are most likely caused by local bank protection and levees. One such area is located on the left bank downstream of Safford Bridge, where approximately 0.5 to 1 m of sediment overlies bank protection. Although many observations were made in Safford and Duncan Valleys during field work, there may be other short reaches that were not field checked that have similar characteristics.

CONCLUSIONS

In Safford and Duncan Valleys, geomorphic change along the Gila River in recent decades appears to be controlled by changes in human factors such as levees and diversion dams rather than changes in external factors such as runoff and sediment influx. This conclusion is based on several products developed for the Upper Gila River Fluvial Geomorphology Study as well as this analysis. Using soil/stratigraphic information and lab analyses, geomorphic mapping in these valleys indicates that the Gila River has migrated within the Pima Soil boundary for the last several hundred years and within the Geomorphic Limit for at least the last 1,000 years. Areas of lateral instability are indicated by property loss in which stable soils mapped as part of the Geomorphic Limit or Pima Soil Boundary are eroded.

Fourteen specific reaches with substantial property loss are described ranging from 0.5 to 3.5 miles in length. Together, these reaches constitute approximately 40% of the entire study reach. For each valley, the described reaches constitute 50% of the entire reach in Safford Valley and 24% of the entire reach in Duncan Valley. The majority of property loss has occurred in areas of young alluvium, which is part of the active channel migration zone. Within this zone, lateral migration is common and it is not unusual for large areas to be eroded during large floods. Several areas with unusual channel geometries and erosion of banks older than several hundred years are clues that other factors are important in creating the current (year 2000) channel morphology. Human factors that cause lateral instability include: (1) levee failure; (2) downstream propagation of erosion; (3) channel straightening; and (4) diversion dam orientation. Vegetation and alluvial fan development may also act as controls on channel position in these reaches. The Catalog of Historical Changes, among other studies, shows that the majority of erosion occurs during high flow events such as the flood of October 2-3, 1983, and that channel widening is a natural geomorphic response to large floods. The local factors mentioned above appear to cause minimal geomorphic change during low to moderate flows but are the catalysts of substantial geomorphic change during the large floods of recent decades.

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APPENDIX A

SOIL DESCRIPTIONS

Table 5. List of sites by category of alluvium

Gila Alluvium		Pima Alluvium		Geomorphic Limit	
Site Number	Site Name	Site Number	Site Name	Site Number	Site Name
GRD1	Duncan Bridge I	GRS2	Solomon Bridge	GRD3	Fairgrounds
GRD2	Duncan Bridge II	GRS3	Head Canyon	GRD7	Ash Peak Canyon
GRD4	Waters Wash	GRS5	San Jose Wash	GRD8	Ash Peak Canyon
GRD5	Burma Road Bridge	GRS10	Fort Thomas Diversion	GRD10	Apache Creek
GRD6	Apache Peak Canyon	GRS11	Curtis Diversion	GRD12	Railroad Wash
GRD9	Two Cottonwoods	GRS12	Safford-Bryce Road	GRS1	Hinton bank
GRD11	York Valley	GRS13	Smithville Diversion	GRS8	Eden Bridge North
GRS4	San Jose Diversion			GRS9	Eden Bridge
GRS6	Hollywood Canal				
GRS7	Day Mine Wash				

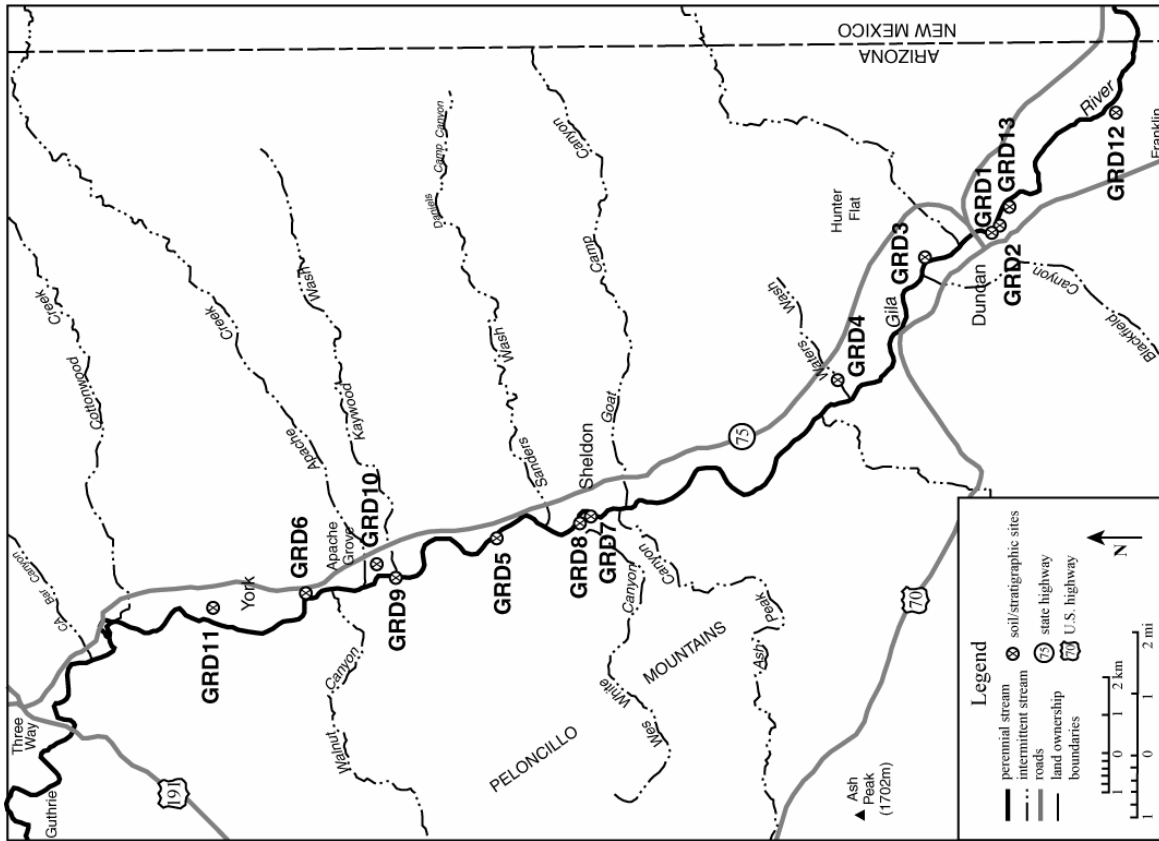


Figure 37. Duncan Valley Site Map.

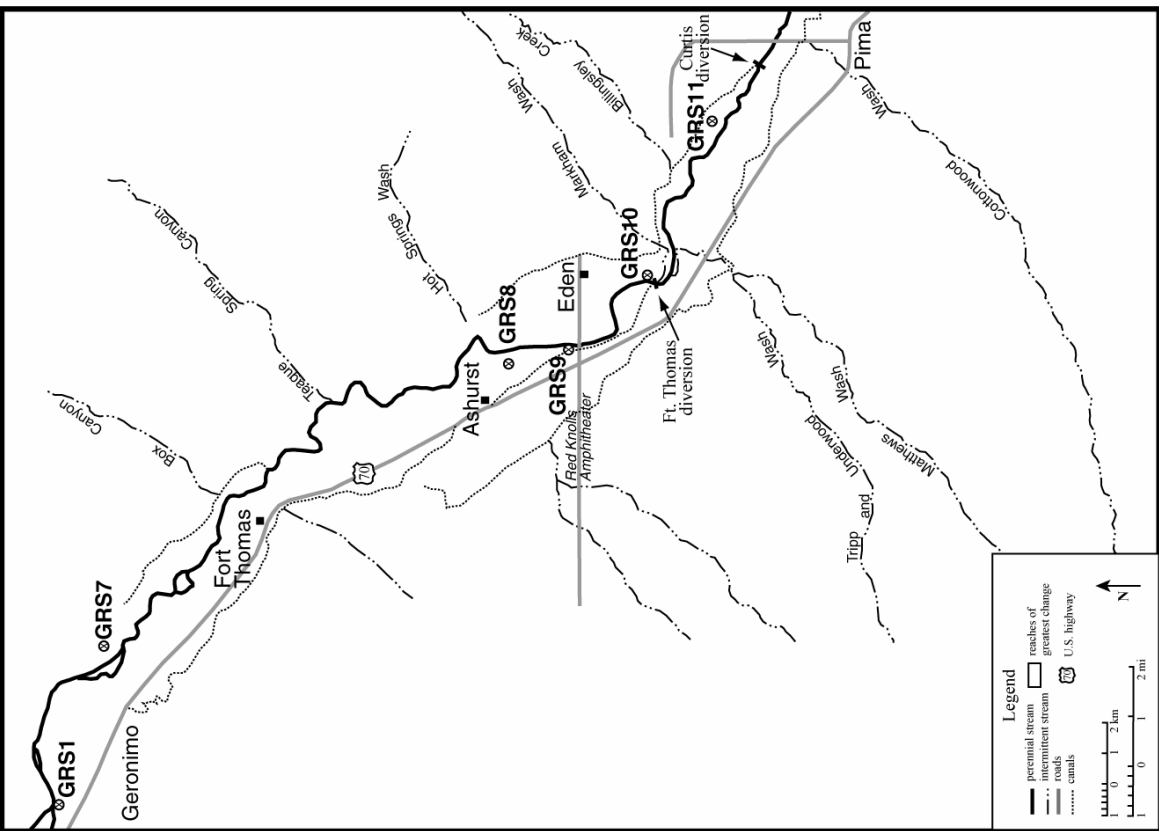


Figure 38. Safford Valley Site Map: Pima to San Carlos Indian Reservation.

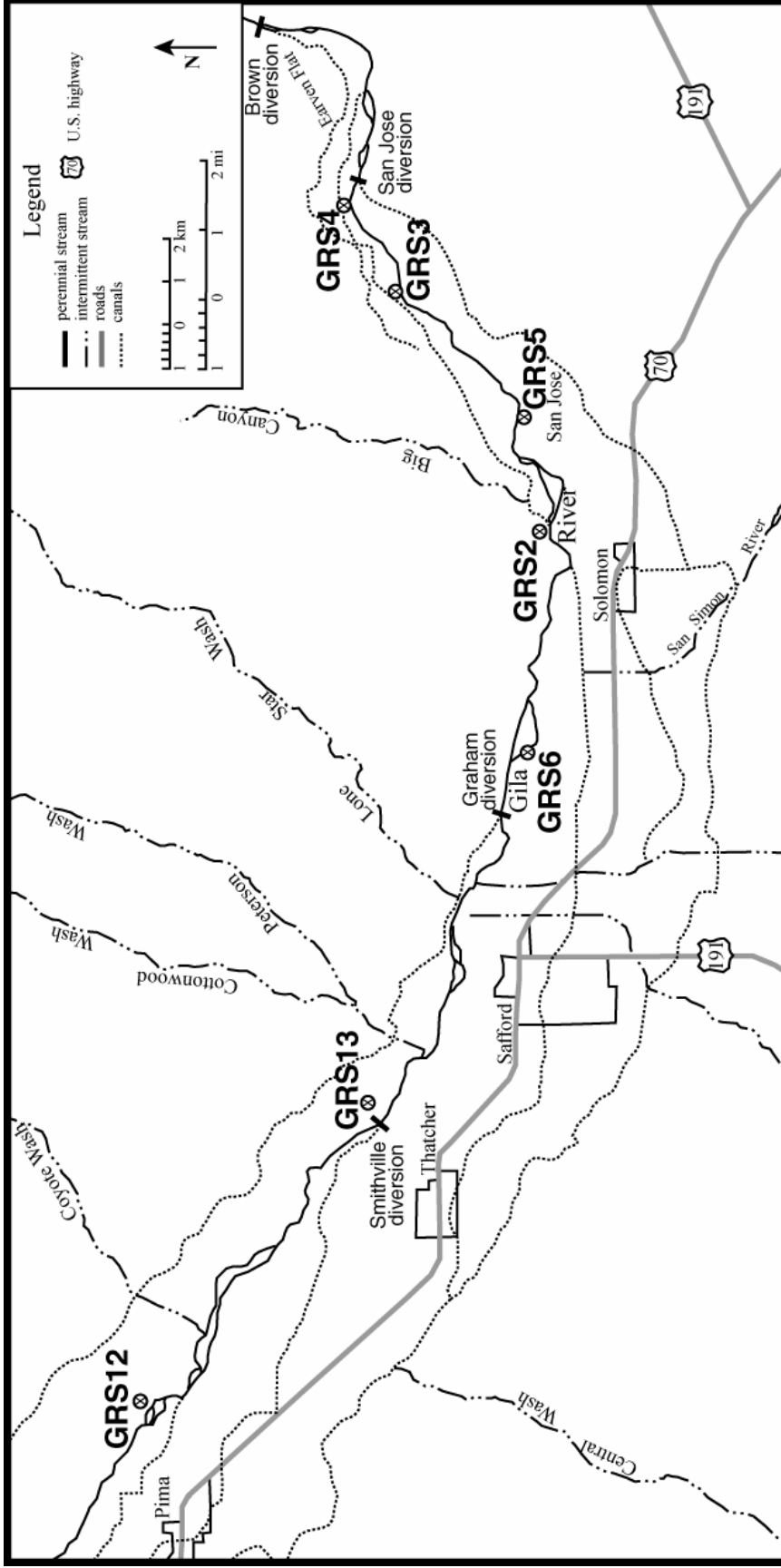
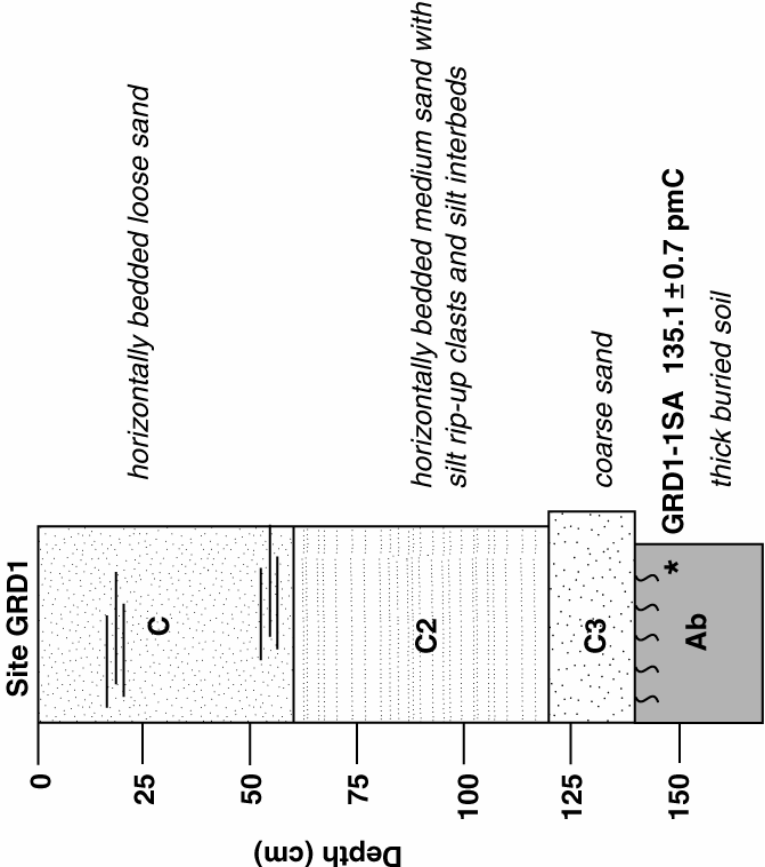


Figure 39. Safford Valley Site Map: Head of Safford Valley to Pima.

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD1 Described by Jeanne Klawon, Dan Levish Date 2/07/2001 Slope Vertical Aspect East
Map Unit Gila alluvium Parent Material fine-grained alluvium
Location N32°43'04", W109°05'59"; left bank inside levee upstream of Duncan Bridge
Quadrangle Duncan 7.5' USGS Township/Range T8S R32E Section 20 SW1/4 Elevation 3650 ft
This profile was developed during the reconnaissance phase of the study. A detailed soil profile was not described; however, a general description was made and follows:



FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD2 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/28/2001 **Slope** Vertical **Aspect** East
Map Unit Gila alluvium **Parent Material** fine-grained alluvium
Location N32°43'04", W109°05'59"; left bank inside levee upstream of Duncan Bridge
Quadrangle Duncan 7.5' USGS **Township/Range** T8S R32E **Section** 20 SW1/4 **Elevation** 3650 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-10 (10)	cw	2f-mpl	mSL	none	so	po	sh	0	none (none)	10YR4/3M 10YR6/3D
Cb	10-158 (148)	as	m-sg	mS	none	so	po	lo-so	0-75	none (es)	10YR4/3M 10YR6/2D
Ab	158-183 (25)	cs	3mgr	SiL	none	ss	ps	sh	0	I- (es)	10YR4/3M 10YR6/3D
ABkb2	183-260 (77)	cs	2csbk	SiL	none	ss	ps	h	0	none (es)	10YR4/3M 10YR5/3D
Cb2	260-270 (10)	--	m	fLS	none	so	po	so	0	none (es)	10YR4/3M 10YR6/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD3 **Described by** Jeanne Klawon, Dan Levish **Date** 3/04/2001 **Slope** Vertical **Aspect** Southwest
Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium
Location right bank exposure, approximately ¾ miles west from fairgrounds in Duncan, AZ
Quadrangle Duncan 7.5' USGS **Township/Range** T8S R32E **Section** 18 NE1/4NE1/4 **Elevation** 3540 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence		Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity			
Cox	0-15 (15)									
laminated fine sand and silt										
Ab	15-42 (27)	cw	2f-msbk	fSL-SiL	none	ss	ps	sh	0	10YR4/2M 10YR5/3D
ABk	42-65 (23)	cw	2m-csbk	fSL-SiL	none	ss	ps	sh	0	10YR4/2M 10YR6/2D
Cox/Ck	65-240 (175)									
massive fine to medium sand underlain by thinly bedded (5-10 cm) silts, clays and fine sand.										
Abk	240-260 (20)	cw	2m-csbk	SiL	none	ss	ps-p	h	0	10YR4/2M 10YR6/2D
Abk2	260-290 (30)	as	3f-msbk	SiL	none	ss	ps-p	h	0	7.5YR4/3M 7.5YR6/3D
Cox	290-295 (5)									
fine sand										
Abk3	295-335+ (40)	--	2csbk	SiL	none	ss	ps	h	0	7.5YR4/3M 7.5YR5/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD4 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/29/2001 **Slope** Vertical **Aspect** Southeast
Map Unit Gila alluvium **Parent Material** fine-grained alluvium
Location N32°45'09", W109°08'39"; approximately 215 feet from the mouth of Waters Wash
Quadrangle Sheldon 7.5' USGS **Township/Range** T8S R31E **Section** 11 NW1/4SW1/4 **Elevation** 3600 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence		Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity			
C	0-195 (195)									
Ab	195-210 (15)	gi	2mabk	fSiL	none	ss	ps	0	none (es)	7.5YR4/3M 7.5YR6/3D
ABkb	210-243 (33)	aw	1msbk	fSL	none	ss	ps	0	I (es)	7.5YR4/3M 7.5YR6/3D
Cb	243-250+ (7)	--	sg-m	fLS	none	so	po	0	none (e)	7.5YR4/3M 7.5YR6/3D

interbedded silt and sand with sedimentary structures

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD5 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/27/2001 **Slope** Vertical **Aspect** Northeast
Map Unit Gila alluvium **Parent Material** fine-grained alluvium
Location N32°50'08", W109°11'07"; left bank downstream of washed out bridge
Quadrangle Sheldon 7.5' USGS **Township/Range** T7S R31E **Section** 9 SW1/4SW1/4 **Elevation** 3540 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
Ap	0-14 (14)	as	2mpl-gr ¹	SiL	none	ss	ps	h	0	none (e)	10YR3/3M 10YR5/3D
A	14-31 (17)	as	2f-msbk	SiL	none	s	ps-p	h	0	none (e)	10YR3/2M 10YR4/3D
B	31-54 (23)	cw	1c-vcsbk	mSL	none	so	ps	h	0	I (e)	10YR3/3M 10YR5/3D
C	54-73 (19)	as	1msbk	mLS	none	so	po	sh	0	none (none)	10YR3/3M 10YR6/3D
Ab	73-86 (13)	cs	1csbk	SiCL	none	vs	?	sh	0	none	10YR3/2M
Cb	86-106 (20)	as	1msbk	f-mSL	none	so	po	so	0	(e) none	10YR5/3D 10YR?
Cb2	106-133 (27)	as								(e)	10YR5/3D
Cb3	133-154 (21)	--									

massive sand

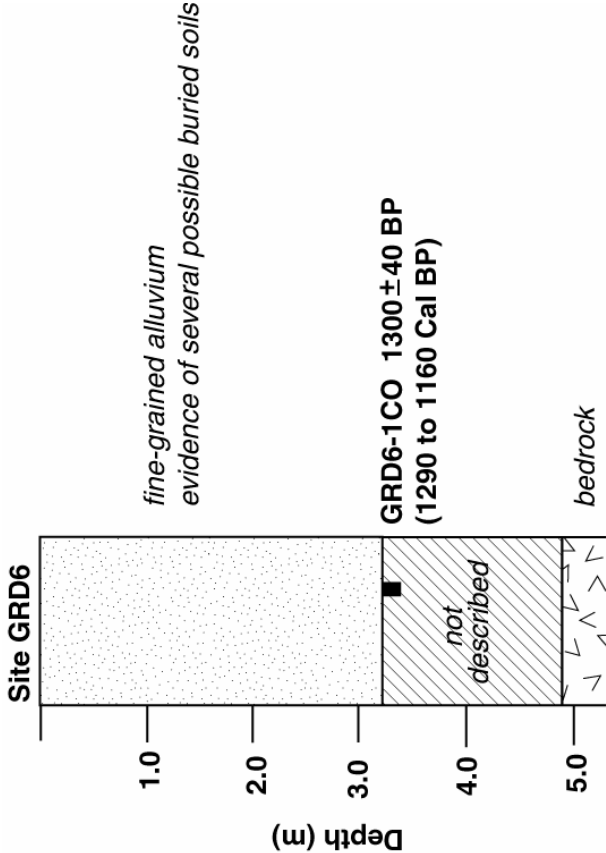
thinly bedded clay and silt over massive sand

¹ Play structure extends from 0-4cm; granular structure extends from 4-14 cm.

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD6 Described by Jeanne Klawon, Dan Levish Date 2/07/2001 Slope Vertical Aspect West
Map Unit Slackwater deposit (Gila alluvium) Parent Material fine-grained alluvium
Location N", W"; right bank, Apache Peak Canyon between Apache Grove and York
Quadrangle York 7.5' USGS Township/Range T6S R31E Section 29SW1/4NW1/4 Elevation 3500 ft

This profile was developed during the reconnaissance phase of the study. A detailed soil profile was not described; however, a general description was made and follows:



FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD7 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/27/2001 **Slope** Vertical **Aspect** East
Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium
Location N32°48'50", W109°10'42"; downstream of Ash Peak Canyon
Quadrangle Sheldon 7.5' USGS **Township/Range** T7S R31E **Section** 21 NW1/4NE1/4 **Elevation** 3560 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-3 (3)	as	2mpl	fSL	none	so	po	so	0	none (es)	10YR3/3M 10YR5/4M
AB	3-14 (11)	cw	1m-csbk	fSL	none	so	po	sh	<10	none (es)	10YR3/3M 10YR5/3D
Bk	14-47 (33)	cw	2cabk- 1vcpr	vfSL	none	so	ps	sh	0	I (es)	7.5YR3/3M 7.5YR5/3D
Ck	47-75 (28)	aw	sg-1f- msbk	mSL	none	so	po	lo-so	0	none (none)	10YR3/3- 7.5YR3/4M 10YR6/3- 7.5YR5/4D
Ab	75-90 (15)	cw	2m-csbk	vfSiL	none	ss	ps	sh	0	none (e-es)	10YR3/3M 10YR5/3D
Cb	90-101 (11)	cw	1f-msbk	fSL	none	so	po	sh	0	none (es)	10YR3/3M 10YR6/3D
Cb2	101-109 (8)	cw	sg	cLS	none	so	po	lo	0	none (none)	10YR3/3M 10YR5/3D
Ab2	109-122 (13)	cw-as	1csbk	fSL	none	so	po-ps	sh	0	I- (c)	10YR3/2M 10YR5/2D
Ab3	122-145 (23)	ce	1csbk	fSL	none	so	po	so	0	I- (c)	10YR3/2M 10YR5/2D
Cb3	145+	--	sg	mS	none	so	po	lo-so	<10	none (c)	10YR4/3M 10YR5/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD8 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/27/2001 **Slope** Vertical **Aspect** Northeast
Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium
Location N32°48'55", W109°10'51"; downstream from Ash Peak Canyon
Quadrangle Sheldon 7.5' USGS **Township/Range** T7S R31E **Section** 16 SW1/4SW1/4 **Elevation** 3560 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-4 (4)	as	m-cpl	fSL	none	ss	po	so	0	none (es)	7.5YR3/3M 7.5YR5/3D
AB	4-16 (12)	aw	1msbk	fSL	none	ss	po	sh	0	none (e)	7.5YR3/3M 7.5YR5/4D
Bk	16-80 (64)	cw	2csbk- vcabk	fSL	none	ss	ps	h	0	I- (e)	7.5YR3/2M 7.5YR5/4D
Ck	80-120 (40)	--	1m-csbk	mSL	none	so	po	so	0	I- (es)	7.5YR3/2M 10YR6/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD9 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/28/2001 **Slope** Vertical **Aspect** East
Map Unit Gila alluvium **Parent Material** fine-grained alluvium
Location N32°51'28", W109°11'42"; left bank across from Kaywood Wash
Quadrangle Sheldon 7.5' USGS **Township/Range** T7S R31E **Section** 5 NW1/4NE1/4 **Elevation** 3520 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
Cox ²	0-15 (15)	cw	m- 1msbk	mLS	none	so	po	so	0	none (c)	10YR4/3M 10YR5.5/3D
Ab	15-18 (3)	cw	2cgr	fSL	none	so	po	sh	0	none (es)	10YR3/3M 10YR5/3D
Cox	18-32 (14)	as	m	mLS	none	so	po	so	0	none (c)	10YR4/3M 10YR5/3D
Ab	32-40 (8)	cw	2cgr- 1msbk	f-mSL	none	ss	po	sh	0	none (c)	10YR3/3M 10YR5/3D
C	40-123 (93)	as	m	fLS	none	so	po	so	0	I- (c)	10YR3/3M 10YR5/3D
C2	123-136 (13)	as	1f-msbk	fSL	none	ss	ps	so	0	none (es)	10YR4/2.5M 10YR6/3D
C3	136-144 (8)	aw	1f-msbk	fSL	none	ss	po	sh	0	none (es)	10YR4/3M 10YR5.5/3D
Ab2	144-206 (62)	as	1-2m- csbk	SiL	none	vs	?	sh	0	I- (c)	10YR3/3M 10YR5/3D
Cb	206-216 (10)	cw	m	mLS	none	so	?	lo	0	none (c)	10YR4/3M 10YR5/3D
Cb2	216+	--				rounded gravels and sand					

² 1 cm organic mat on surface

This profile is a composite of two locations along the bank exposure; the break in the description occurs at 40 cm.

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD10 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/28/2001 **Slope** Vertical **Aspect** West

Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium and gravelly alluvium

Location N32°51'51", W109°11'53"; right bank upstream from Apache Creek

Quadrangle Chiloquin 7.5' USGS **Township/Range** T35S R7E **Section** 11 SE1/4NW1/4 **Elevation** 4200 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
Ap	0-15 (15)	cs	2msbk	fSL	none	so	po	h	<10	none (es)	10YR3.5/3M 10YR5/3D
Bk	15-50 (35)	cs	3msbk	fSL	none	so	po	vh	10	I- (es)	10YR3/3M 10YR5/3D
Bk2	50-82 (32)	cw	2msbk	mSL	none	so	po	h	10	I (es)	10YR3/3M 10YR5/3D
Bk3	82-125 (43)	cw	1msbk	fSL	none	so	po	sh	10	I (es)	10YR3/3M 10YR5/3D
2Ck	125-137 (12)	aw	sg	vcS	none	so	po	lo	75	I (es)	10YR3/3M 10YR5/3D
3Bkb	137-170 (33)	cw	1msbk	fSL	none	ss	ps	sh	10	I (es)	10YR3/3M 10YR5/3D
3Bk2b	170-205 (35)	ci	?	mLS	none	so	po	sh	10	I- (es)	10YR3/3M 10YR5/3D
4Ck	205-235 (30)	--									
rounded gravel											

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD11 Described by Jeanne Klawon, Ralph Klinger Date 3/28/2001 Slope Vertical Aspect West

Map Unit Gila alluvium Parent Material fine-grained alluvium and gravelly alluvium

Location N32°53'59", W109°12'17"

Quadrangle York 7.5' USGS Township/Range T6S R31E Section 11 SE1/4NW1/4 Elevation 3510 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-15 (15)	as	1mpl- sbk	mLS	none	so	po	so	0	none (es)	10YR3/3M 10YR5/3D
B	15-37 (22)	aw	1m-csbk	mLS	none	so	po	sh	<10	none (es)	10YR3/3M 10YR5/3D
C	37-112 (75)	cw	m	S	none	so	po	so	0	none (e-es)	10YR4/3M 10YR5/3-2D
C2	112-125 (13)	aw	m	fS	none	so	po	so	0	none (es)	10YR4.5/3M 10YR5/3D
C3	125-160 (35)	--	sg	mS	none	so	po	lo	0	none (c)	10YR4.5/3M 10YR5/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRD12 **Described by** Jeanne Klawon, Ralph Klinger **Date** 3/29/2001 **Slope** Vertical **Aspect** Southeast
Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium
Location N32°41'24", W109°03'56"; left bank across from the end of Lunt Road
Quadrangle Duncan 7.5' USGS **Township/Range** T8S R32E **Section** 33 SE1/4NE1/4 **Elevation** 3660 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
Ap	0-25 (25)	cw	2fgr, 2mpl	L	none	ss	ps	sh	10-25	none (es)	10YR3/3M 10YR5/3D
A	25-36 (11)	aw	2m-cgr	CL	2ppf	s	p	sh	10-25	I (ev)	10YR3/3M 10YR5/2.5D
B	36-62 (26)	gs	3cabk	C	2ppf	vs	vp	vh	0	I (ev)	10YR4/3M 10YR5/2D
Bk	62-115 (53)	cs	3m-cabk	SiCL	2ppf	s	p	vh	0	II- (ev)	10YR3/3M 10YR6/3D
Bk2	115-135 (20)	cw	3f-mabk	C	2dpf	vs	p	h	0	I+ (ev)	7.5YR4/3M 10YR6/2.5D
C	135-160 (25)	--	1csbk	fSL	none	ss	ps	sh	0	none (e)	7.5YR3/2M 10YR6/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS1 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** Vertical **Aspect** North
Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium
Location N33°05'17.3" , W 110°03'00"; left bank of Doug Hinton Property near Geronimo, Arizona
Quadrangle Geronimo 7.5' USGS **Township/Range** T4S R22E **Section** 13 NW1/4NW1/4 **Elevation** 2660 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence		Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity			
A	0-10 (10)	as	2fgr	SiC	none	vs	p-vp	0	none (es)	10YR4/4M 10YR5/3D
B	10-43 (33)	cs	2msbk	SiC-C	none	vs	vp	<10	none (ev)	10YR4/4M 10YR6/3D
B2	43-105 (62)	cs	1csbk	C	none	vs	vp	0	none (e)	7.5YR 4/3M 7.5YR5/3D
B3	105-145 (40)	cs	2csbk	SiC	none	vs	vp	0	none (e)	10YR4/3M 7.5 YR5/3D
B4	145-188 (43)	cs	2csbk	C	none	vs	p-vp	0	none (e)	7.5YR4/3M 7.5YR5.5/3D
B5	188-210+ (32)	--	1csbk	SiC	none	vs	vp	0	I (e-es)	7.5YR4/3M 7.5YR5/3.5D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS2 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/27/2003 **Slope** Vertical **Aspect** South

Map Unit Pima alluvium **Parent Material** fine-grained alluvium

Location right bank, north side upstream from Solomon Bridge

Quadrangle San Jose 7.5' USGS **Township/Range** T7S R27E **Section** 18 NW1/4SE1/4 **Elevation** 2960 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
Ap	0-40 (40)	as	--	--	--	--	--	--	--	--	--
Ab	40-68 (28)	as	2msbk	SiCL	none	ss-s	ps-p	h	0	I- (e)	10YR3/3M 10YR5/3D
Ck	68-125 (57)	--	1msbk	mLS	none	so	po	lo-so	0	I- (es)	10YR3/3M 10YR5/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS3 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/27/2003 **Slope** Vertical **Aspect** South

Map Unit Pima alluvium **Parent Material** fine-grained alluvium and gravelly alluvium

Location N32°51'17", W109°34'11.7"; Head Canyon fan, north side of Gila River

Quadrangle Chiloquin 7.5' USGS **Township/Range** T35S R7E **Section** 11 SE1/4NW1/4 **Elevation** 4200 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
C	0-56 (56)	aw	--	--	--	--	--	--	--	--	--
Bb	56-81 (25)	cw	2msbk	SiL	none	s	ps-p	h	<10	I- (es-cv)	10YR3/4M 10YR5/4D
Bkb	81-120 (39)	--	2-3csbk	SiL	none	ss	ps	h	<10	I (es)	10YR3/4M 10YR5/4D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS4 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/27/2003 **Slope** Vertical **Aspect** South

Map Unit San Jose Diversion **Parent Material** fine-grained alluvium

Location N32°51'50.5", W109°32'57.1"; access road west of Sanchez property

Quadrangle Chiloquin 7.5' USGS **Township/Range** T35S R7E **Section** 11 SE1/4NW1/4 **Elevation** 4200 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
Ap	0-37 (37)	as	--	--	--	--			--	--	--
C	37-63 (26)	as	m	SL	none	so	po	lo- so	<10	none	--
Bb	63-113 (50)	as	2vcsbk	SiL	none	ss	ps	h	<10	none (e)	10YR3/4M 10YR5/3D
Bkb	113-123+ (10)	--	2-3csbk	fSL-L	none	ss	ps	h	0	I (e)	10YR3.5/3M 10YR5/3.5D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS5 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/27/2003 **Slope** Vertical **Aspect** North

Map Unit Pima alluvium **Parent Material** fine-grained alluvium

Location N32°49'44.7"; W109°35'42.5"; left bank, east side of San Jose Wash

Quadrangle San Jose 7.5' USGS **Township/Range** T7S R27E **Section** 9 SW1/4SW1/4 **Elevation** 2990 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence		Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity			
A	0-28 (28)	as	1mcsbk	SiCL	none	s	p	<10	none (e)	7.5 YR4/3M 7.5YR5/3D
Bk1	28-125 (97)	as	3vcabk- pr	SiC	1fpf	vs	p-vp	0	I- (e)	7.5YR3.5/3M 7.5YR5/3D
Bk2	125-190+ (65)	--	2vcsbk	CL	none	s	p	0	I- (es)	10YR3/4M 10YR5/4D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS6 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/27/2003 **Slope** Vertical **Aspect** Southeast
Map Unit Gila alluvium **Parent Material** fine-grained alluvium
Location N32°50'22.3", W109°41'26.5"; access along canal from Hollywood Road
Quadrangle Safford 7.5' USGS **Township/Range** T7S R26E **Section** 11 SW1/4SW1/4 **Elevation** 2930 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-22 (22)	aw	2cgr	SiL	none	s	ps	h	0	none (e)	10YR3/4M 10YR5/4D
C	22-55 (33)	as	m	SiCL	none	s	p	h	0	none (es)	10YR3/4M 10YR5/4D
Bkb	55-83 (28)	ai	1f-msbk	SiCL	none	s	p	sh-h	0	I (es)	10YR3/4M 10YR5/3.5D
2C	83-115 (32)	as	m	SL	none	so	po	lo- so	0	none (none)	10YR3/4M 10YR5/4D
3Ck	115-130+ (15)	--	1m-csbk	SiL	none	ss	ps	sh	0	I (--)	10YR3/4M 10YR5/3.5D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS7 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** 0-3° **Aspect** South
Map Unit Gila alluvium **Parent Material** fine-grained alluvium
Location N33°04'28.1", W110°00'12.7"; fallow field west of Day Mine alluvial fan
Quadrangle Geronimo 7.5' USGS **Township/Range** T4S R23E **Section** 20 NE1/4NE1/4 **Elevation** 2650 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
C	0-12 (12)	aw	sg	SL	none	so	po	lo	0	none (e)	10YR3/3M 10YR5/3D
Ab	12-18 (6)	as	1mgr	vf-fSL	none	so-ss	ps	so	0	none (e)	10YR3/3M 10YR5.5/3D
Cb	18-34 (16)	as	m	vf-fSL	none	ss	ps	so	0	none (e-es)	10YR3/3M 10YR5.5/3D
Ab2	34-42 (8)	as	2fgr	SiL	none	ss	po	sh	<10	none (es)	10YR4/3M 10YR5.5/3D
Bb	42-70+ (28)	--	1f-msbk	SL	none	so	po	sh	0	none (e)	10YR3/3M 10YR5/4D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS8 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** Vertical **Aspect** East
Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium
Location N32°58'36.8", W109°55'07.3"; left bank exposure downstream from Eden Bridge
Quadrangle Eden 7.5' USGS **Township/Range** T5S R24E **Section** 19 SE1/4SE1/4 **Elevation** 2730 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-10 (10)	aw	2fsbk- 2cgr	CL	none	s	p	h	0	none (es)	10YR4/3M 10YR5.5/3D
B	10-56 (46)	as	2csbk	C	none	s-vs	vp	h- vh	0	none (es)	10YR3/3M 10YR4.5/2D
Bk	56-82 (26)	as	3csbk	C	2dpf,po	s-vs	p-vp	vh	0	I (es)	10YR3.5/3M 10YR5/3D
C	82-100 (16)	--	m	SiL- SiCL	none	s	ps-p	sh- h	0	none (ev)	10YR5/4M 10YR6/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS9 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** 0-3° **Aspect** East
Map Unit Geomorphic Limit alluvium **Parent Material** fine-grained alluvium
Location N32°57'52.1", W109°54'57.3"; west side of river north of Eden Bridge (bee boxes)
Quadrangle Eden 7.5' USGS **Township/Range** T5S R24E **Section** 30 SE1/4SE1/4 **Elevation** 2740 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-15 (15)	aw	2mgr-pl	SiCL	none	s	ps-p	sh	0	none (es-ev)	10YR4/3M 10YR5/4D
Bk	15-40 (25)	aw	1-2msbk	SiCL	2dpf,po	s	ps-p	so- sh	0	I+ (es)	10YR4/3M 10YR5/4D*
Bk2	40-50+ (10)	--	2msbk	SiC	2dpf,po	s-vs	p	so- sh	0	I+ (es)	10YR4/4M 10YR4/4D ³

³ Soils were slightly moist for dry coloring

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS10 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** Vertical **Aspect** West

Map Unit Pima alluvium **Parent Material** fine-grained alluvium

Location N32°56'40", W109°53'35"; right bank downstream of Fort Thomas Diversion

Quadrangle Eden 7.5' USGS **Township/Range** T6S R24E **Section** 4 NE1/4NW1/4 **Elevation** 2740 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-13 (13)	aw	2fsbk	CL	none	s	p	sh-h	0	none (e)	10YR4/3M 10YR5/3D
Bk	13-38 (25)	cw	2f-msbk	SiCL	none	s	p	h	0	I- (e)	10YR3/3M 10YR4.5/2D
Bk2	38-58 (20)	aw	1m-csbk	SL	2dpf	so	ps	sh	0	I (e)	10YR3/3M 10YR5/3D
2C	58-130 (72)	--	sg	SL	none	so	po	lo- so	0	none (e-es)	10YR3/3M 10YR5/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS11 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** Vertical **Aspect** South

Map Unit Pima alluvium **Parent Material** fine-grained alluvium

Location N32°55'51.4", W109°50'56.5"; right bank along Curtis Canal

Quadrangle Pima 7.5' USGS **Township/Range** T6S R24E **Section** 12 NW1/4NW1/4 **Elevation** 2780 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence		Gravel %	CaCO3 Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity			
A	0-20 (20)	aw	2fsbk	SiL	none	ss-s	ps	0	none (e)	10YR4/3.5M 7.5-10YR5/3D
B	20-65 (45)	cs	2msbk	SiCL	none	s	p	0	none (es)	10YR4/3M 10YR5/3.5D
Bk	65-155 (90)	aw	2msbk	CL	1fpf, 2dpo	s	p	0	I (es)	7.5YR4/3M 10YR5.5/3D
Ck	155-180 (35)	as	m	SL	none	so	ps	0	I (e-es)	10YR4/3M 10YR5/3D
Btb	180-210 (30)	--	3vcsbk	C	2ppf,po	vs	vp	0	none (es)	7.5YR4/4M 7.5YR5/4D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS12 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** Vertical **Aspect** South
Map Unit Pima alluvium **Parent Material** fine-grained alluvium
Location N32°54'08.7", W109°48'00"; corner of Safford-Bryce Road
Quadrangle Pima 7.5' USGS **Township/Range** T6S R25E **Section** 21 NW1/4NW1/4 **Elevation** 2820 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence			Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity	Dry			
A	0-25 (25)	as	2-3f- msbk	CL	none	s	p	sh-h	0	none (e)	7.5YR4/3M 7.5YR5/3D
B	24-54 (29)	as	1csbk	SiL	none	ss	ps	sh	0	none (es)	7.5-10YR4/3M 7.5-10YR5/3D
Bk	54-88 (34)	gs	1csbk	SL-SiL	none	so	ps	sh	0	I (es)	10YR3/3M 10YR6/3D
C	88-142 (54)	cs	m-sg	SL	none	so	ps	so	0	none (e)	10YR4/3M 10YR5.5/3D
C2	142-183 (41)	cs	m	SiL	none	ss	ps	sh	0	none (es)	10YR3/3M 10YR5/3D
C3	183-200 (17)	--	1f-msbk	SiCL	none	s	p	sh	0	I (es)	10YR4/3M 10YR6/3D

FIELD DESCRIPTIONS OF SOIL PROPERTIES

Profile No. GRS13 **Described by** Jeanne Klawon, Ralph Klinger **Date** 8/28/2003 **Slope** Vertical **Aspect** Northwest
Map Unit Pima alluvium **Parent Material** fine-grained alluvium
Location N32°51'34.4", W109°44'02.9"; right bank upstream of Smithville Diversion
Quadrangle Safford 7.5' USGS **Township/Range** T6S R25E **Section** 36 SE1/4SW1/4 **Elevation** 2870 ft

Horizon	Depth (Thickness) cm	Boundaries	Structure	Texture	Clay Films	Consistence		Gravel %	CaCO ₃ Morphology (effervescence)	Color (moist/dry)
						Stickiness	Plasticity			
A	0-32 (32)	as	2f-msbk	SiL	none	ss	ps	0	none (es)	10YR4/3M 10YR5/4D
Bk	32-78 (46)	as	1-2m- csbk-abk	SiL	none	ss	ps	0	I (e-es)	10YR4/3M 10YR5/3D
Bk2	78-94 (16)	as	2csbk	SiCL	v1fpf	s	ps-p	0	I (es)	10YR4/3M 10YR5/4D
C	94-108 (14)	as	m	fSL	none	so	po	0	I- (e-)	10YR4/3M 10YR6/3.5D
Ck	108-150 (42)	as	m	SiC	none	s-vs	p	0	I (e)	10YR4/3M 10YR5/3D
C2	150-180 (30)	--	sg	SL	none	so	po	0	I- (e-)	10YR4/4M 10YR5/4D

APPENDIX B

RADIOCARBON ANALYSIS

Table 6. Upper Gila River Geomorphic Analysis - Radiocarbon Ages.

Sample No. (Lab No.)	Depth (cm)	Type of Material	Sample Weight (g)	Age (¹⁴ C yrs. B.P. ⁴)	Calibrated Age (cal yrs. B.P. ⁵)
GRD1-1SA Beta-154511	146	Salicaceae Populus charcoal	0.250	135.1 ± 0.7 pmC ⁶	
GRD2-2PR Beta-154512	285-300	Prosopis charcoal	0.018	260 ± 40	430-360 330-280 180-150 10-0
GRD2-2SA Beta-154513	285-300	Salicaceae charcoal	0.026	340 ± 40	500-300
GRD3-3ZM Beta-154514	115 ⁷	Zea Mays cupules (charred)	0.292	1910 ± 40	1930-1740
GRD3-3AT Beta-154515	115 ⁷	Atriplex charcoal	0.098	1870 ± 40	1890-1710
GRD3-3SA Beta-154516	115 ⁷	Salicaceae charcoal	0.018	1930 ± 40	1960-1810
GRD3-4AT Beta-154517	125 ⁷	Atriplex charcoal	0.033	2490 ± 50	2740-2360
GRD3-4SA Beta-154518	125 ⁷	Salicaceae charcoal	0.157	1940 ± 40	1980-1820
GRD3-5YSU Beta-154519	322	Succinea spp. snail shell	--	4110 ± 40	4820-4520 4470-4450
GRD3-7YSU Beta-154520	270	Succinea spp. snail shell	--	3010 ± 40	3340-3070
GRD5-8SA Beta-182011	152-155	Salicaceae charcoal	0.018	160 ± 50	300-5
GRD5-10FR Beta-182012	75	Fraxinus charcoal	0.018	220 ± 40	315-265 140-25 25-0
GRD6-1CO Beta-154521	320-340	Conifer charcoal (rounded)	0.008	1300 ± 40	1290-1160
GRD7-9AT Beta-182014	75-90	Atriplex charcoal	0.009	80 ± 30	265-215 140-25 25-0
GRD9-6PI Beta-182015	114	Pinus charcoal	2.507	580 ± 50	655-520
GRD9-8PR Beta-182016	195-205	Prosopis charcoal	0.006	410 ± 40	525-430 375-325

⁴ Conventional radiocarbon age in years before present with present being 1950 A.D.

⁵ Calibrated radiocarbon age in years before present derived from computer calibration program Oxcal v. 3.5 (see Bronk, 1995).

⁶ Percent of modern carbon

⁷ Sample was collected along the exposure from a location other than the soil profile description. The original sampling depth is recorded here; however, the corresponding depth in the site's soil profile may be different.

Sample No. (Lab No.)	Depth (cm)	Type of Material	Sample Weight (g)	Age (¹⁴ C yrs. B.P. ⁴)	Calibrated Age (cal yrs. B.P. ⁵)
GRD10-1FR Beta-182017	185	Fraxinus charcoal	0.315	210 ± 30	305-270 210-145 20-0
GRD10-9SA Beta-182018	95	Salicaceae charcoal	0.047	230 ± 40	420-405 315-270 210-145 20-0
GRD12-1AT Beta-182019	145	Atriplex charcoal	0.006	3270 ± 40	3585-3395
GRD12-2ZM Beta-182020	115-130	Zea mays cob (charred)	0.112	2530 ± 40	2750-2475
GRD12-3AT Beta-182021	70-90	Atriplex charcoal	0.130	2570 ± 40	2760-2710 2585-2510
GRD13-1AS Beta-154522	?	Asteraceae charcoal	0.015	121.1 ± 0.6pMC ⁶	
GRS1-2YSU Beta-154523	60	Succinea spp. snail shell	--	700 ± 40	690-640 590-560
GRS1-3YSU Beta-154524	60	Succinea spp. snail shell	--	1050 ± 40	1050-920
GRS12-1AT	56	Atriplex charcoal	0.743	1160 ± 40	1170-970
GRS13-1U	83	unidentified hardwood charcoal	0.002	160 ± 30	290-240 230-70

APPENDIX C

MACROBOTANICAL ANALYSES AND MOLLUSK IDENTIFICATIONS

CONTENTS

Puseman, K., 2002. Examination of bulk soil and detrital charcoal from the Duncan Valley, Upper Gila River, Arizona: Paleo Research Institute Technical Report 01-37, 41 pp.

Puseman, K., 2003. Examination of detrital charcoal from along the Upper Gila River, Arizona: Paleo Research Institute Technical Report 03-73, 9 pp.

Evanoff, Emmett, 2001. Letter dated March 21, 2001 regarding taxonomic identification of mollusk samples, 1 pp.