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HISTORICAL GEOMORPHOLOGY OF THE GILA RIVER

by

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Introduction

Integral to ascertaining the navigability of the Gila River at time of statehood is an understanding of the river's geomorphology. The Gila River has been the topic of several geomorphologic studies that focused on changes in channel position and form through time (e.g., Burkham, 1972; Graf, 1981; Huckleberry, 1993b; Stevens and others, 1975). Although detailed historical descriptions of the Gila River only extend approximately 120 years, within that short interval of time the river has changed between narrow, meandering and wide, braided conditions (see Leopold and Wolman, 1957 for common channel patterns). Channel changes on the Gila River are driven primarily by changes in the frequency of large floods (Burkham, 1972, Huckleberry, 1993b), however, one cannot ignore the effects of human disturbances (Bahre, 1991). Irrigation diversions, dams, exotic vegetation, and channelization have also undoubtedly affected the hydraulics and hydrology of the channel.

Historical channel changes on the Gila River are not the same along all reaches of the river. Alluvial reaches, i.e., segments not confined by bedrock, are prone to greater changes in channel position and form. Furthermore, because of physiographic variability and a climatic gradient across the Gila River watershed, different reaches have unique hydrologic characteristics (Hirschboeck, 1985), and thus as one might expect, channel transformations along separate reaches are not synchronous or uniform. In addition, dams and irrigation diversions have altered different reaches of the Gila River.

In this study, historical channel changes were reviewed for three primary alluvial reaches of the Gila River (Figure A). The upper Gila River includes two reaches: a larger reach located in the Safford Valley and a smaller reach located between Winkelman and Kelvin. The middle Gila River is an alluvial reach extending from Florence to its confluence with the Salt River. The lower Gila River is a largely alluvial reach extending from the mouth of the Salt River to Yuma (excluding Painted Rock Reservoir). These divisions of the Gila River are partly arbitrary and partly based on hydrologic and physiographic boundaries. The upper Gila River is located within the mountainous Central Highland zone and receives considerable base flow from snowmelt. In contrast, the middle Gila River is located within the Basin and Range physiographic province and is supplied by lower elevation watersheds such as the San Pedro and Santa Cruz river catchment areas. The lower Gila

River is also in the Basin and Range province, but its flow is supplemented by the Salt River which supplies a greater volume of water than the middle and upper Gila River watersheds.

Historical channel positions were plotted for the study reaches onto U.S. Geological Survey 7.5' quadrangles. Archival sources include 1) General Land Office cadastral survey notes and plat maps, 2) historical maps produced by the U.S. Geological Survey, Bureau of Reclamation, and Indian Irrigation Service, 3) historical aerial photography, and 4) U.S. Geological Survey 7.5' orthophotoquads. All photographs and maps were adjusted to 1:24,000 scale and plotted on the quadrangles with a zoom transfer scope. Previous channel reconstructions by Burkham (1972) and Huckleberry (1993b) were utilized to describe historical channel changes. It is clear from this investigation that all three study reaches were experiencing changes in channel form in 1912, and that these changes were driven by a shift from a period of drought to one of the wettest decades in 500 years (Meko and Graybill, 1993).

Evolution of the Gila River

The Gila River is the primary drainage for southern Arizona with a drainage area of approximately 150,000 km^2 (60,000 mi^2) that extends into western New Mexico and northern Sonora. As a major water source in the Sonoran Desert, it has been the locus of cultural activity for at least 2,000 years, but the origin of this river extends back several million years. The ancestral Gila River originated after the landscape of southern and central Arizona had been radically altered into a series of linear mountain ranges and basins approximately 8 to 15 million years ago (Damon and others, 1984). Initially drainage was closed within individual basins. The basins eventually filled and regional drainage became integrated sometime between 3 and 6 million years ago (Menges and Pearthree, 1989; Morrison, 1985; Shafiquallah and others, 1980). As drainage became integrated, the Gila River and its tributaries began to incise into basin deposits forming several strath terraces in the Central Highland zone. In the more tectonically stable Basin and Range province, the Gila River primarily deposited sediment. Here there are few terraces except along the margins of the Phoenix Basin (Huckleberry, 1993a; Péwé, 1978). Radiometric dates from basalt flows intercalated with Gila River gravels indicate that the oldest Gila River landforms in the Basin and Range province are at least 3 million years old (Shafiquallah and others, 1980).

The modern geologic flood plain of the Gila River is incised into early Pleistocene surfaces and contains channel and overbank alluvial deposits. The channel deposits consist primarily of sands, gravels, and cobbles. The overbank deposits consist primarily of sand, silt, and clay and are generally within 3 m (9 ft) of the surface and date to the middle and late Holocene. Although a firm Holocene chronology of climatic variability has yet to be defined, it is clear that secular changes in climate characterized by changes in the intensity and seasonality of precipitation resulted in different periods of flood frequency and magnitude (Ely, 1992; Meko and Graybill, 1993; Nials and others, 1989). This undoubtedly resulted in alternating periods of channel stability and instability, and specifically, changes in channel form (e.g., braided vs. meandering) during the Holocene. Periods of increased large flood frequency are more likely to be associated with wide, braided channel conditions on the Gila River (Burkham, 1972; Huckleberry, 1993b).

Historical Geomorphology

Upper Gila River. The upper Gila River study reach is located in the mountainous region of east-central Arizona and divided into two study reaches: a larger reach in the Safford Valley, a northwest trending basin bounded by the Pinaleños and Gila Mountains, and a smaller reach located in a smaller, unnamed valley located between the Dripping Springs and Tortilla Mountains. This latter reach is herein referred to as the Kearny reach. The segment between the Safford Valley and Kearny reaches is covered by San Carlos Reservoir or confined by bedrock and is not part of this study. The study reaches are characterized by a flood plain of variable width inset into basin fill. The upper Gila River flood plain is widest in the upper part of the Safford Valley where it is approximately 5 km (3 mi) wide; in the lower part of the Safford Valley and in the Kearny reach, the flood plain is approximately 3 km (2 mi) wide. In general, upper Gila River flood-plain alluvium is 7-10 m thick (Culler and others, 1970).

The upper Gila River watershed extends into the Mogollon Highlands of eastern Arizona and western New Mexico; drainage basin area at the mouth of the Safford Valley is approximately 29,800 km^2 (11,500 mi^2). There are no major dams upstream from the Safford Valley; streamflow on the Kearny reach is partially controlled by Coolidge Dam, which was completed in 1928. Mean annual precipitation within the watershed ranges 20-100 cm (8-40 in) and averages approximately 36 cm (14 in). There are two periods of peak flow that are directly linked to two rainy seasons. Summer peak flow occurs between July and October and is predominantly linked to monsoonal, convective storms. Winter peak flow occurs November through June and is supplied largely by frontal storms, snowmelt, and groundwater storage (Burkham, 1970). Segments of the upper Gila River are frequently dry in June and July (Turner, 1974).

Gaged streamflow records on the upper Gila River extend only to 1911 and provide a limited timeframe for analyzing long-term streamflow patterns. However, a recent dendrohydrological study by Meko and Graybill (1993) reconstructs mean annual streamflow for the upper Gila River for the period A.D. 1663-1985 based on statistical relationships between tree-ring width and gaged annual streamflow. The reconstructions are characterized by a series of irregularly spaced, multidecadal peaks and troughs of high and low annual streamflow. Interestingly, the 20th century contains the wettest decade (1906-1915) and the driest decade (1947-1956) within the 322 year reconstruction. Decadal scale changes in climate appear to be stochastic and related to shifts in large-scale ocean-atmospheric circulation patterns. Much of the temporal variability in annual streamflow on the upper Gila River may be linked to El Niño - Southern Oscillation climatic phenomena (Betancourt and Webb, 1992; D'Arrigo and Jacoby, 1991).

As the volume of streamflow changes in response to secular climatic variability so does river channel geometry as it adjusts to accommodate changing flow regimes. Alluvial rivers adjust their hydraulic parameters (e.g., width, depth, sinuosity, hydraulic roughness, and slope) in response to changing discharge and sediment load (Leopold and Maddock, 1955). Although dryland rivers do not adjust to gradual changes in flow regime as rapidly as rivers in wetter climates (Wolman and Gerson, 1978), dryland streams do respond to low frequency, high magnitude flow events that may accompany secular climatic change (Baker, 1977, Graf, 1988). If changes in annual stream flow correspond with changes in large flood frequency, then one can expect the upper Gila River to have a channel geometry subject to dramatic changes through time at decadal time scales.

A classic study of historical channel changes on the upper Gila River was performed by Burkham (1972) as part of the U.S. Geological Survey's Phreatophyte Study near San Carlos Reservoir (Culler and others, 1970). Burkham utilized historical descriptions, survey notes, maps, and photographs to reconstruct channel width and sinuosity for a segment of the upper Gila River from 1846-1970 (Table A). To summarize, Burkham divides the chronology into three periods. From 1846 to 1904, the upper Gila River contained a relatively deep, narrow, and sinuous channel; from 1905-1917, the channel increased its width over 600 percent and became straighter, whereas from 1918-1970 the channel narrowed and increased its sinuosity (Figure B). These channel changes are clearly correlated to changing flood frequency. Large floods and above average streamflow between 1905 and 1917 resulted in the destruction of large cottonwood groves and the formation of a wide, braided channel (Olmstead, 1919). The largest floods occurred in 1891, 1905, 1906, and 1916. Of all of the hydraulic parameters sensitive to changing hydrologic conditions, channel width seems to have been most responsive to changing flow regimes (Figure B). The period 1918-1970 was a relatively dry period, culminating in the decade of 1947-1956 (Meko and Graybill, 1993), and one with few large floods. During this period, vegetation returned to the flood plain and facilitated sedimentation (Turner, 1974). It took 50 years for the flood plain to return to conditions resembling those before 1905, although introduced exotics like tamarisk (*Tamarix* sp) precluded the return to identical pre-1905 conditions (Graf, 1988b).

No systematic study of historical channel changes exists for the Kearny reach. Cursory inspection of the General Land Office plats (Table C) indicates that the river contained a single, slightly sinuous channel in the 1870's. Photographs of the channel near Riverside reveal a relatively wide sandy channel (Lippincott, 1900: Plate 17). That there was little vegetation in the channel during this period is also suggested by the Florence (1:125,000) quadrangle surveyed in 1900 which shows a road following the course of the river downstream from Kelvin. The Ray (1:62,500) quadrangle was surveyed in 1907-08 after the 1905 floods, and it shows a wide sandy flood plain with several branching channels similar to that described for the Safford Valley reach after 1905. A large flood in September, 1926 on the San Pedro River (see Hereford and Betancourt, 1993) may have helped to maintain wide-braided conditions on this reach until 1930. However, the subsequent period of low flood frequency plus the effect of Coolidge Dam halting large floods from the upper watershed have contributed to a heavily vegetated flood plain with a single, narrow, low flow channel.

Burkham's (1972) detailed study provides a good indication of channel conditions on the upper Gila River at time of statehood, 1912. The transformation from a single-meandering channel to a wide-braided channel began in earnest in 1905 and was largely completed by 1916 (Table A). Channel characteristics presented by Burkham for the year 1914 are a good representation of channel characteristics in 1912. Moreover, the channel boundaries presented by Olmstead (1919) and reproduced by Burkham (1972: Plate 1) for the upper Gila River in 1914-15 can be considered a close approximation of 1912 channel boundaries. The 1914-15 channel boundaries may be a little wider than those of 1912, however, since there were large floods in December, 1914 and January, 1915 that resulted in bank cutting (Olmstead, 1919). Wide-braided channel conditions probably also characterized the Kearny reach in 1912 based on historical records of widespread erosion along the upper Gila River and San Pedro River (Burkham, 1972; Hereford and Betancourt, 1993, Olmstead, 1919; Turner, 1974).

Middle Gila River. As the Gila River splits the gap between North and South Butte east of Florence, it enters the southern margins of the Phoenix Basin (Péwé, 1978) where it begins to flow over deep alluvium and lose much of its flow to infiltration. The middle Gila River study reach extends from the Ashurst-Hayden Diversion Dam to the Salt River (Figure A); most of this reach is located within the Gila River Indian Community. Due to upstream diversions for irrigation agriculture, the middle Gila River flows only during infrequent floods. An exception occurs in the lower part of this reach near the Sierra Estrella Mountains where effluent from irrigation supports a sluggish, narrow stream (Rea, 1983). Of the 150,000 km^2 (60,0000 mi^2) comprising the Gila River drainage basin, 47,400 km^2 (18,960 mi^2) lies above the Ashurst-Hayden Diversion Dam with 33,390 km^2 (13,360 mi^2) located above Coolidge Dam and most of the remaining 14,010 km^2 (5,600 mi^2) located within the San Pedro River system. There are no pristine records of annual streamflow for the middle Gila River; by the time gaging stations were established, water was ready being diverted for irrigation.

Middle Gila River climate is arid and warm. July maximum temperatures at Sacaton average 41° C; January minimum temperatures at Sacaton average 1° C (Sellers and Hill, 1974). There is a slight moisture gradient from west to east; mean annual rainfall ranges from 19 cm at Maricopa to 21 cm at Sacaton and 24 cm at Florence.

Historical descriptions of the Gila River extend back to 1697 when Padre Kino and Captain Juan Manje described a channel with large cottonwoods supporting irrigation agriculture at the Pima Villages (Figure C). Subsequent European visitors passing through the area also described a stable, narrow and relatively deep channel with dense riparian galleries (Huckleberry, 1993b; Rea, 1983). Before Anglo settlement in the 1860's, the middle Gila River would periodically run dry near the Pima Villages during May and June (Rea, 1983). The early cadastral surveys (Table C) also characterize the middle Gila as having a single, narrow channel up until 1891. In 1891, the middle Gila River experienced a large flood that resulted in some channel widening. Beginning in the 1890's, streamflow on the middle Gila River was greatly reduced due to Anglo irrigation diversion, but the river was still susceptible to large flood flows. Beginning in 1905, a series of large floods struck the middle Gila River coinciding with a radical transformation in channel planform and geometry (Figure D). Similar to the upper Gila River (Burkham, 1972), the middle Gila River contained a wide, braided channel between 1905 and 1920 correlating to a period of high large flood frequency with the largest floods occuring in 1905, 1914, and 1916 (Figure C).

After construction of Coolidge Dam in 1928, the middle Gila River became somewhat hydrologically disconnected from the upper Gila River. The middle Gila River above Pima Butte seldom contained streamflow except during rare floods, and most of the floods that did pass through this reach were generated in the San Pedro River watershed (an exception is the flood of January, 1993). Below Pima Butte, effluent from irrigation and naturally shallow water tables have helped to maintain a small stream. Throughout the middle Gila River a low flow channel formed within the former wide braided channel during the 1930's, 40's and 50's, resulting in the formation of a compound channel planform (Graf, 1988a). The channel changed its geometry when the sustained flow of the floods of January, 1993 converted the compound channel above Pima Butte into a single, wide, braided channel.

It is clear that the upper and middle Gila Rivers share similar histories (Figure B), but there are some differences. The middle Gila River experienced two catastrophic floods in 1833 and 1868, and anecdotal evidence (see Huckleberry, 1993b) suggests that the magnitude of the 1833 and 1868 floods on the middle Gila River was greater than that of the 1905 flood, which was responsible for dramatic channel changes on the upper and middle Gila River. Burkham (1972) mentioned no floods on the Upper Gila River during these years, and he assumed that none occurred given stable channel conditions throughout most of the 19th century. That the middle Gila River remained stable despite these large floods is contrary to disequilibrium models of arid stream behavior (Graf, 1981; Stevens and others, 1975). Applying the concept of critical discharge for sediment entrainment, catastrophic floods should result in dramatic channel changes

(Graf, 1983). However, as recent floods attest, it is not the peak discharge that is as critical in channel transformations as the duration of those floods. Although the October, 1983 flood had a peak discharge of 2,800 m^3/s (100,000 ft^3/s; measured at Kelvin gage), it did not produce any long lasting changes to channel planform. In contrast, the January, 1993 flood with a peak discharge of 2,080 m^3/s (74,290 ft^3/s) resulted in the most dramatic changes in channel planform since 1905. If flood duration is a more important variable than peak discharge in channel changes, then there is a stronger basis for reconstructing prehistoric channel behavior for the Gila River based on dendrohydrological data than for other streams like the Salt River (Nials and others, 1989).

In 1912, the middle Gila River above Pima Butte contained a wide, shallow, braided, sandy channel. This is supported by several maps drafted during the period 1900-1914 by the U.S. Reclamation Service, Geological Survey, and Indian Irrigation Service (Table C), and terrestial photographs of the river (e.g., Haury, 1976: Figure 8.47). Downstream from Pima Butte, there is less domumentation pertaining to channel geometry, although resurveys of townships T. 1 S., R. 1 E., T. 1 S., R. 2 E., T. 2 S., R. 2 E., T. 2 S., R. 3 E., and T. 3 S., R. 3 E. performed 1910-12 reveal a much wider channel than that surveyed in the 1860's and 1870's.

Lower Gila River. From the confluence of the Salt River near Phoenix, the lower Gila River flows southwestward towards the Colorado River near Yuma (Figure A). Like the middle Gila River, this stretch of the Gila flows mostly over deep alluvium within the Basin and Range physiographic province. In a few places the river is confined by bedrock (e.g., near Arlington and below Painted Rock Dam), but elsewhere the river contains a wide, unconfined flood plain (generally > 3 km (2 mi)). All tributaries along this reach are ephemeral and seldom flow. The climate is arid and hot. Daily maximum temperatures average 31° C (88° F) at both Yuma and Buckeye whereas mean annual precipitation at Yuma and Buckeye is 7 cm (2.8 in) and 18 cm (7.1 in), respectively (Sellers and Hill, 1974).

Before Anglo settlement in the Phoenix Basin, streamflow on the Salt River was greater than that on the middle Gila River. Reinvigorated by the Salt River watershed (38,850 km^2 (6,600 mi^2) in area), most of the lower Gila River was perennial reaching all the way to the Colorado River (Ross, 1923). Spanish explorers during the 1700's described the native peoples living along the lower Gila River as fishermen, and large galleries of cottonwood trees lined the banks as recently as the late 1800's. Also, there were a few successful journeys by boat down the lower Gila River during the 1800's (Ross, 1923; McCroskey, 1988). However, expansion of irrigation systems within the upper watershed during the late 19th century and subsequent construction of large dams during the early 20th century greatly reduced the amount of streamflow reaching the lower Gila River. As a result, there are no pristine records of gaged streamflow for the lower Gila River. Eventually the upstream diversions combined with local groundwater pumping for agriculture converted the lower Gila River into an intermittent stream by 1920 (Brown and others, 1981; Bryan, 1923; Ross, 1923). Except for a segment near Buckeye fed by irrigation and waste water effluent from Phoenix, the lower Gila River flows only after rare, heavy rains.

Unlike the upper and middle Gila River segments, there have been no systematic measures of historic channel width, although Graf (1981) measured changes in low flow channel sinuosity for the reach upstream from Gila Bend. Historical descriptions of the lower Gila River vary somewhat which may reflect not only changes in channel configuration through time but also spatial variability in channel geometry at any one time due to local hydrological conditions. In general, the lower Gila River channel appears to have been braided in historical times. Lieutenant William Emory of the Kearny Expedition in 1846 described the lower Gila River as "about 100 yards wide, and flowing gently along a sandy bottom...". However, a rancher described the river near Powers Butte (between Buckeye and Gillespie Dam) in 1889 as having a well-defined channel with hard, sloping banks lined with cottonwood and bushes. The water was clear, was 5 or 6 feet deep, and contained many fish." (in Ross, 1923:66). The former description implies a braided, sandy stream, whereas the latter suggests a relatively, narrow, deep channel, however, the latter description may be of the main flow channel within an overall braided channel. Discrepancies in descriptions may also be enhanced by observers describing the same reach during different times of the year under different streamflow conditions.

Given that the lower Gila River flood plain is composed mostly of sand and silt (Ross, 1923), the bank material can be easily mobilized by floods of significant magnitude and duration. This results in spatially dynamic low flow channels that shift after large floods (Graf, 1981). Early cadastral surveys plats and U.S. Geological Survey maps reveal considerable shifts in channel position near Yuma and Agua Caliente during the late 1800's and early 1900's. In a detailed study of the lower Gila River between the Salt River and Gila Bend, Graf (1981, 1988b,c) documented shifts in the low flow channel and demonstrated the effects of not only floods but also vegetation in processes of sedimentation and channel avulsion. Reaches that showed the greatest spatial instability included those behind Gillespie Dam (an area of heavy sedimentation) and other areas of dense tamarisk growth.

Given the similar chronologies of channel changes on the upper and middle Gila Rivers (Burkham, 1972; Huckleberry, 1993b), one has to ask whether or not the lower Gila River experienced similar changes. Graf's (1981, 1988b,c) study of the lower Gila River suggests that this reach did not experience dramatic changes in channel configuration near the turn of the century: "Between 1868 and 1929 the channel was braided, and the 1905 flood had no particular geomorphic significance." (Graf, 1988b:233). This stands in contrast to statements made by Ross (1923:64) who noted that the Gila River has "changed materially since it was first seen by white men". Of course, Ross was referring to the entire lower Gila River rather than the reach studied by Graf, but nonetheless there are distinct geomorphological differences in channel descriptions for the entire lower Gila River before and after 1890.

Before 1890, the lower Gila River had a distinct main flow channel within a larger braided, flood-flow channel. Every winter and spring, flow would exceed channel capacity of the main flow channel and extend into the adjacent flood channels. Dramatic changes appear to have occurred during two large floods in 1890 and 1891. A flood in February, 1890 damaged settlements and eroded terraces along the lower Gila River. Erosion was probably enhanced by a large surge in flow that entered the lower Gila River through the Hassayampa River due to the Walnut Grove Dam failure (Dobyns, 1981). The following year, another large flood passed down the lower Gila River. This flood generated the largest estimated peak discharge on the Salt River (8,400 m3/s (300,000 ft3/s)). Ross (1923:67) noted that "The disastrous floods of 1890 and 1891 did much to break down the river's confining banks, partly filled the channel with sediment, and in general interfered with the equilibrium that had been established." Although Dobyns (1981) believes that erosion on the lower Gila River began as early as 1867, it appears that major changes did not occur until after 1890 and that the floods of 1890 and 1891 were the driving force behind the change in channel configuration. During the next 25 years, a braided, sandy flood plain was probably maintained by the flux of sediment and water generated from the upper and middle Gila Rivers during the abnormally wet decade of 1905 to 1915.

The best descriptions of the lower Gila River channel near the time of statehood are offered by Ross (1923) who systematically described several segments from Buckeye to Yuma. By 1920, the segment in Buckeye Valley wandered "over a sandy flood plain between cut banks 5 to 15 feet high. The flood plain varies in width but is a mile or more in most places. The water meanders in shifting channels and does not cover more than a small part of its flood plain exept during unusually great floods." (Ross, 1923:68). (Contrast this with the rancher's 1889 description presented above.) Ross characterized the segment in the Arlington Valley as similar to that in the Buckeye Valley. Between Gillespie Dam and Gila Bend, the channel had higher banks but still maintained its wide form. At Gila Bend, a cross-section reveals a wide channel composed of silt and sand. Ross did not describe the reach from Gila Bend to Painted Rock Mountains, however where the river cuts through the Sentinel volcanic field, he described the channel as 10 to 30+ m (30 to 100+ ft) wide between low banks. Between Agua Caliente and Palomas, the channel contained banks over 10 m (30 ft) high and had shifted its position almost a mile. From Palomas to Yuma, Ross (1923:75) described the lower Gila River flood plain as "a desolate expanse of silt and sand dotted with thickets of mesquite..." and the channel as having banks 1 to 3 m (3 to 10 ft) high. These descriptions are probably applicable to channel conditions in 1912 except that at the time of statehood there was probably more water within the braided channel.

Plotting Channel Boundaries

Mapping historical channel positions is a challenging endeavor given the often arbitrary nature of channel boundaries. Whereas channel boundaries are easily defined in bedrock reaches of rivers or in entrenched or channelized alluvial rivers, they are less absolute in braided reaches where channel position frequently varies in space and time. Also, rivers in humid regions usually have easily discernable boundaries where a single channel conveys most of the flow throughout the year. However, dryland rivers are different in that the annual peak flow is considerably larger than the mean annual flow (Graf, 1988a), and thus there are commonly low and high flow channels. This latter situation certainly applies to the Gila River, especially the middle and lower reaches. Borrowing from Burkham (1972) and Minckley and Clark (1984), in this study "channel" is defined as that part of the fluvial system that conveys channelized flow and is scoured of perennial vegetation by flooding.

The earliest scaled maps that show the location of channel boundaries in Arizona are the General Land Office (now the Bureau of Land Management) plat maps. These maps were constructed when the townships were originally surveyed. The first townships along the Gila River were mapped in 1868; most others were mapped by 1900. Many of these townships were resurveyed after 1912. Because the position of the channel is only measured where it crosses township and section boundaries; the channel is sketched between section lines, and thus their mapped position is of questionable accuracy. For example, in several places the channel is plotted outside the flood plain. Subsequent maps by the U.S. Geological Survey are more accurate although lacking the detail of the larger scale General Land Office plats. Aerial photographic coverage of the river begins in the middle and late 1930's; the negatives for these photographs are housed at the National Archives in Washington D.C. In this study, 1930's aerial photography for only the upper and middle reaches of the Gila River was accessed (Tables A and C). The most recent channel boundaries presented in this study are based on orthophotoquads from 1971-72. Comments regarding the plotting of channel positions from each reach are presented below.

Upper Gila River. All of the townships crossed by the study reaches of the upper Gila River were surveyed in the 1870's (Table A) except those located within the San Carlos Apache Indian Reservation. The accuracy of the channel position on the plats is greatest in townships T. 6 S., R. 24 E., T. 6 S., R. 25 E., and T. 7 S., R. 26 E. where sections are subdivided into 1/8 units; elsewhere, channel position is estimated between section lines. During this period, the upper Gila River contained a single flow channel with more definite boundaries.

The upper Gila River was subsequently mapped by Olmstead (1919) and resurveyed by the General Land Office. After 1905, the upper Gila River consisted of a wide braided channel with several smaller branching channels. Channel boundaries mapped during this period include the entire scoured channel formed after the large floods of 1905, 1914-15, and 1916. The earliest systematic aerial photography was flown in 1934 and 1935 by the Soil Conservation Service. By 1934, mesquite and tamarisk had colonized the flood plain (Turner, 1974), and a main flow channel had become discontinuously re-established. The latter defines the channel boundaries plotted in this study.

By 1972, agricultural fields had encroached onto the margins of the former 1914-15 flood channel mapped by Olmstead (1919). Furthermore, several reaches are confined by artificial levees resulted in rectilinear channel boundaries. Several of the photographs were taken after the flood of October, 1972 and show several freshly scoured areas. However, by and large the channel is relatively narrow and comparable to that described by Burkham (1972).

Middle Gila River. All of the original township surveys and associated plats (1868, 1869, and 1876) that cover the middle Gila River include section boundaries except townships T. 3 S., R. 4 E., T. 3 E., R. 5 E., T. 4 S., R. 5 E., T. 4 S., R. 6 E. (Table C). Thus there is good control of channel position along section lines, but between section lines the accuracy is questionable. For example, the segments of the channel are plotted outside the flood plain in townships T. 1 S, R. 1 E., and T. 4 S., R. 10 E. Accurate mapping of the middle Gila River channel begins in 1904 with the U.S. Reclamation Service maps of the Gila River Indian Community (these were incorporated into the U.S. Geological Survey 15' quadrangles of the area). The 1904 maps generally show a single main flow channel with distinct banks although branching channels occur locally.

Channel boundaries on maps produced after 1905 cover a wider portion of the flood plain when the middle Gila River converted to a wide, braided channel. Maps produced in 1914 and 1928 demarcate the channel by steep banks that contained the large floods of 1905, 1914, and 1916. Hence these channel boundaries contrast from earlier boundaries in that they define the limits of flow during infrequent floods. Between these boundaries, a much smaller, low flow channel shifted laterally across the larger flood channel. Aerial photography flown in March, 1936 by the Soil Conservation Service reveals a more stable low flow channel established along most segments. Adjacent bars and islands within the flood plain became covered with phreatophytic vegetation like tamarisk and mesquite (*Prosopsis* sp) and are clearly outside the main channel. The photography shows that much of the middle Gila River is dry except for segments near Blackwater and below Pima Butte.

By 1972, a distinct compound channel configuration is established where a single, narrow low flow channel is inset into a larger flood plain with several overflow channels. Near Florence, the low flow channel was mechanically channelized. Also, many of the phreatophytes formerly present in the flood plain were absent due to groundwater withdrawal and subsequent lowered water tables (Rea, 1983). Because the low flow channel along most reaches is too small to support unregulated streamflow, it is not suitable for defining the middle Gila River channel. However, the overflow channels are difficult to distinguish on the orthophotoquads since they consist of several small distributary channels and lack vegetation along their banks. Consequently, banks on the larger flood channel are used to define the 1972 channel boundary resulting in a relatively wide channel. Locally, the 1936 and 1972 channel boundaries are identical.

Lower Gila River. Most of the first General Land Office plats that include the lower Gila River were surveyed between 1868 and 1890 except for T. 4 S., R. 8 W. (1910), T. 5 S., R. 10 W. (1914), T. 8 S., R. 19 W. (1912), and T. 8 S., R. 20 W. (1916) (Table E). Channel positions before 1890 are sketched between section lines in all of the townships except T. 8 S., R. 21 W. and T. 8 S., R. 22 W. where sections are subdivided into 1/8 units. All subsequent surveys subdivide the sections and provide better accuracy on channel position. The lower Gila River is plotted as a single channel on most of the early plats, although the channel is shown to branch along a few reaches. Plats produced after 1910 tend to show a wider flood channel with a single thread, low flow channel. Fifteen and 30 minute U.S. Geological Survey maps of the lower reach below Agua Caliente are based on surveys made in 1901-02 and 1926-27. These maps are more accurate for plotting channel position but provide little information as to channel configuration. By 1920, streamflow is largely intermittent and most of the alluvial reaches are dry (Ross, 1923).

By the time the lower Gila River is systematically photographed from the air, it is an intermittent stream and most reaches are dry (Ross, 1923). Photography for the orthophotoquads was flown in 1971 and 1972. The orthophotoquads show a distinct break in channel configuration above and below Gillespie Dam. Above the dam, the channel is characterized by a sinuous low flow channel lined with tamarisk within a larger braided flood channel (Graf, 1981, 1988b,c). Similar to the lower reach of the middle Gila River, the outer banks of the braided flood channel are used to define the channel boundaries. In many places, artificial levees encroach upon this boundary. Below Gillespie Dam, there is considerably less flood plain vegetation, and the low flow channel is also braided but contains a slightly sinuous course. This compound form extends to Wellton, but from Wellton to Yuma, the channel is largely channelized by a series of artificial levees.

Summary

The Gila River is a classic example of a dryland river that seldom seeks an equilibrium form (Graf, 1988a; Knighton, 1984; Stevens and others, 1975). Unlike rivers in humid regions that have more stable channels adjusted for more continuous streamflow with less variance in discharge, the dryland rivers are inherently more unstable and more prone to changes in channel configuration. In such unstable fluvial systems, channel configuration depends much upon the history of previous flood events. Periods of high flood frequency are likely to correlate to periods of increased channel instability. In 1912, Arizona was experiencing one of its wettest decades in several centuries (Meko and Graybill, 1993). This was also a period of increased large flood frequency (Ely, 1992), and not surprisingly, many streams within the Gila River watershed were experincing channel changes (Bahre, 1991). Beginning in 1905 on the upper and middle segments of the Gila River, the channel was experiencing tremendous channel widening due to bank cutting during periods of sustained flood flow (Burkham, 1972; Huckleberry, 1993b). In 1912, vegetation had not yet colonized the scoured flood channel, and most alluvial reaches were wide, sandy, and braided. Interestingly, the floods of January, 1993 have resulted in similar channel changes on at least the middle reach of the Gila River.

The chronology of channel dynamics on the lower Gila River are less certain, however it appears that dramatic channel transformations occurred in 1890 and 1891, approximately 15 years earlier than that for the upper and middle reaches. It appears again that two catastrophic floods were instrumental in the destruction of flood plain vegetation and causing dramatic bank erosion (Ross, 1923). Although construction of Roosevelt Dam on the Salt River limited the magnitude of flood flow reaching the lower Gila River after 1911, the lower Gila River was still experiencing excess sediment and water generated from the upper and middle Gila River reaches and possibly other tributaries during the time of statehood. Consequently, channel planform and geometry of the lower Gila River in 1912 can also be characterized as mostly shallow and braided.

Although system instability is believed to have been climatically driven on the Gila River, one cannot ignore anthropogenic mechanisms as well. At the turn of the century, the Gila River watershed was experiencing considerable vegetation change due to cattle grazing and removal of flood-plain vegetation for agricultural purposes (Bahre, 1991). Removal of grass from hillslopes accelerates runoff leading to larger peak discharges in main trunk streams, and removal of flood plain vegetation exposes banks to greater erosion. Because a rare climatic event corresponded in time to considerable landscape degradation near the turn of the century, it is not possible to separate the natural and anthropogenic causes of the channel changes on the Gila River. Obviously both processes play a role. However, a basic premise of this study is that the Gila River responds to secular climatic variability by radical changes in channel configuration, and that periods of increased, large flood frequency correlate with unstable, braided channel conditions.

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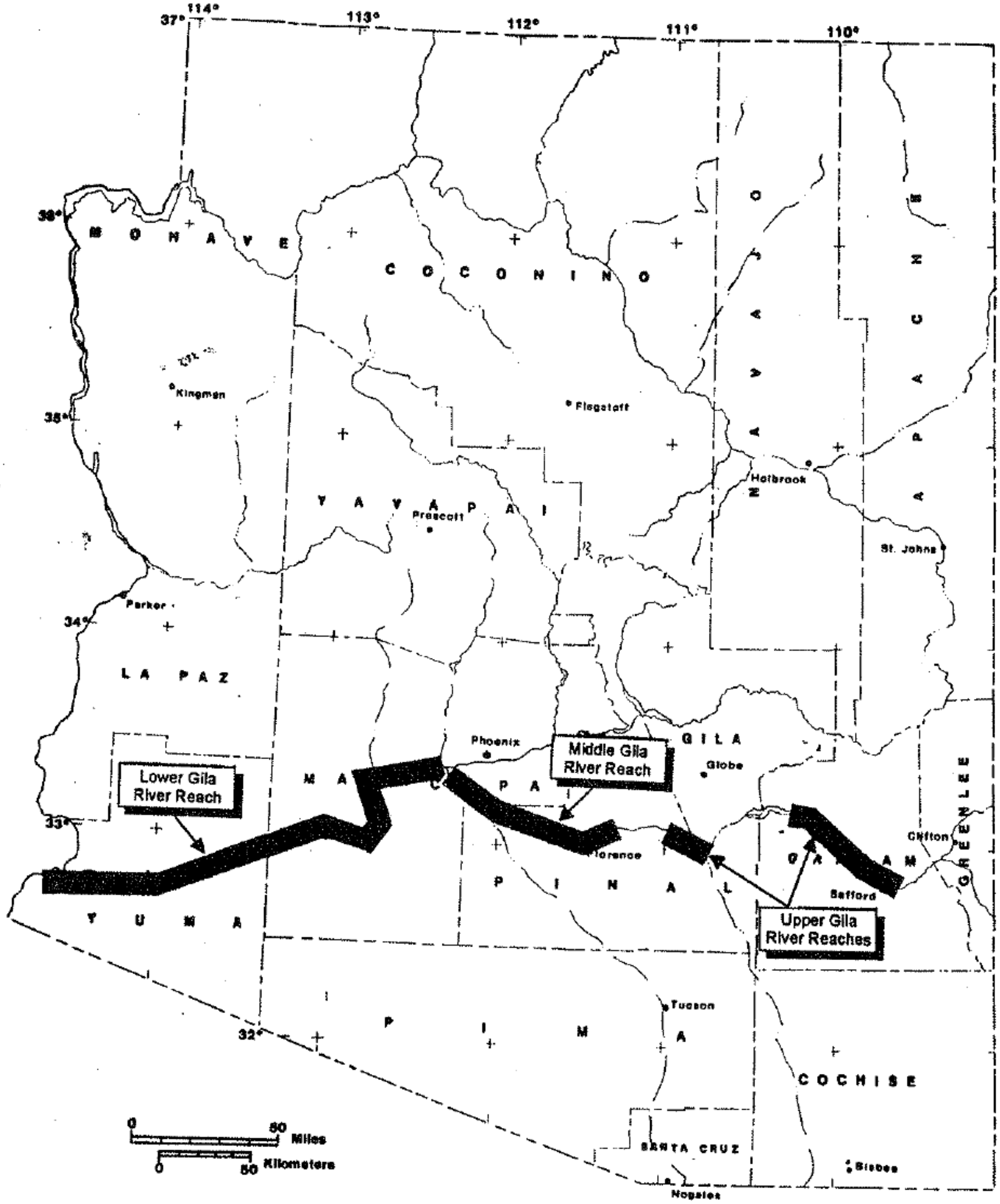
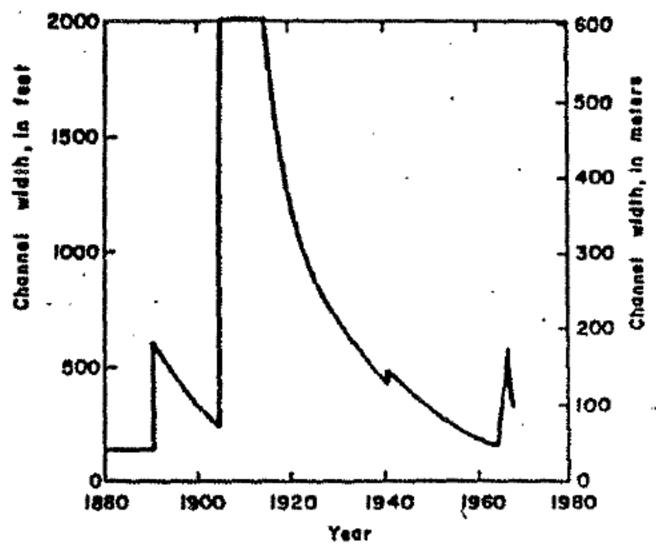


Figure A. Study reaches of the Gila River



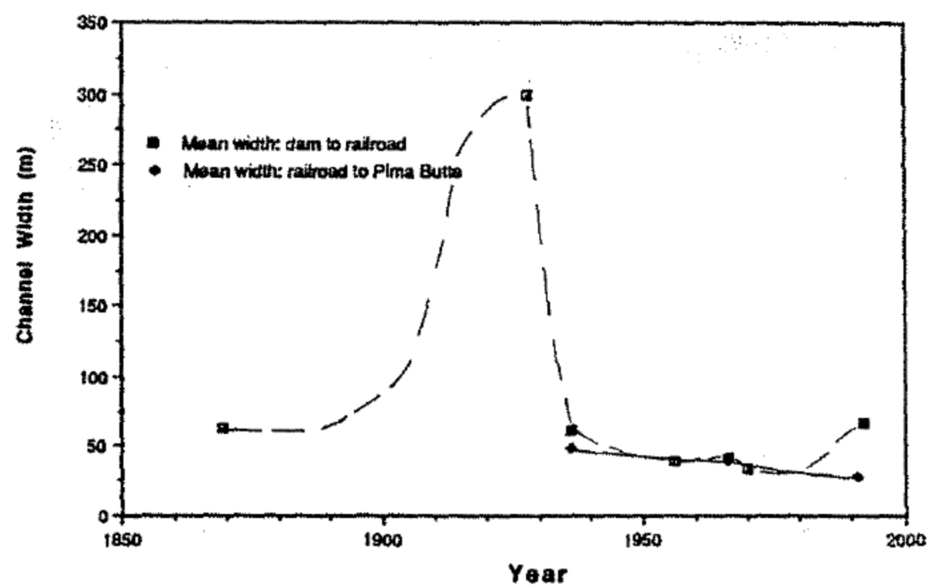


Figure 13. Changes in channel width for the upper (top) and middle (below) segments of the Gila River. Data for upper Gila River from Burkham (1972: Plate 3). Data for middle Gila River from Huckleberry, 1993: Figure 19).

AD1700

1697: Kino mentions large cottonwood groves along MGR

1763: Pfeffercorn notes that Piman fields are easily irrigated by canals implying MGR channel stability

1768-1775: Garces describes riparian vegetation along MGR

1797: Bringas comments that water can be easily diverted from MGR for irrigation and that channels and banks are covered with cottonwood and willow.

1800

1833: Winter flood recorded by Piman calendar stick; reported to have extended across Holocene flood plain

1846: Turner notes flood debris located 9-12 m above the river in canyons upstream from Florence

1868: September flood extends across Holocene flood plain and destroys 3 Pima villages.

1869: First cadastral surveys by G.L.O; MGR channel width ranges 43-82 m; dense undergrowth noted

1891: February flood estimated at 2800 cms at Florence; large trees uprooted

1900: Photographs of Gila River upstream from Florence show no mature cottonwood or willow

1900

1905: Largest recorded flood for MGR occurs in Nov.; peak discharge estimated at 5380 cms at Florence; MGR has a wide, braided channel; riparian communities destroyed

1914: December flood erodes farmland near Florence

1916: January flood estimated at 3740 cms at Kelvin

1928: Resurvey of cadastral lines; MGR channel width ranges 151-517 m; Coolidge Dam constructed

1928-present: MGR flows only during rare wet years; tamarisk invades flood plain; narrow main flow channel becomes re-established

1983: October flood estimated at 1730 cms at Florence

1993: January flood with peak discharge of 2080 cms at Kelvin

2000

Figure 6. Historical descriptions of the middle Gila River (Huckleberry, 1993: Figure 18)

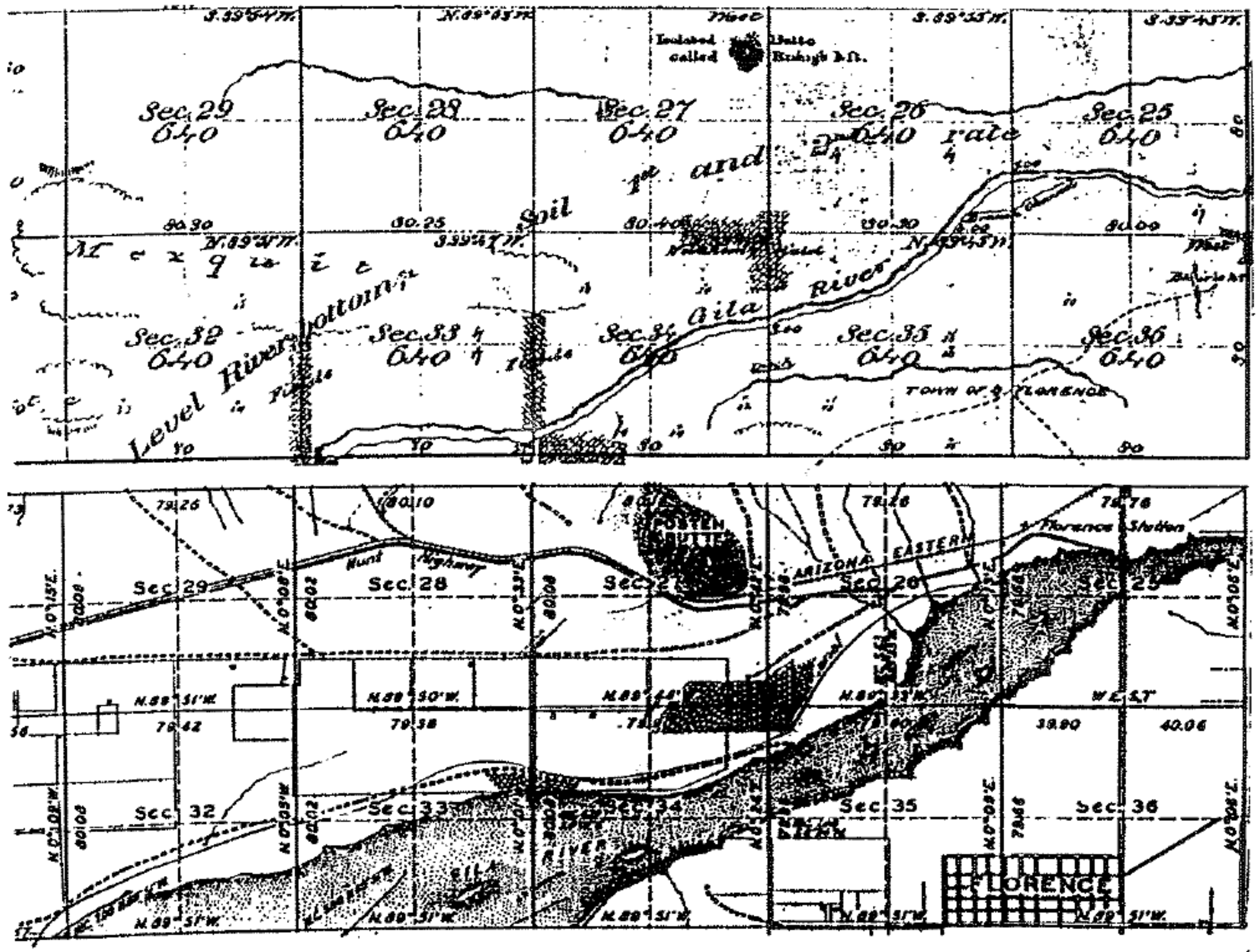


Figure D. General Land Office plats of township T. 4 S., R. 9 E. surveyed in 1869 (above) and 1928 (below). Note change in the width of the Gila River channel.

Table A. Maps and Aerial Photographs Utilized in Plotting Upper Gila River Channel.

USGS 7.5' Quadrangles (year of photography)	Orthophotoquads (year of photography)	Aerial Photography[1] (year)	Other Historical Maps[2] (year)	Cadastral Surveys (year and township)
Kearny (1962)	Kearny (1972)	1934		1879 (T4S, R14E)
Hayden (1962)	Hayden (1972)	1934		1877 (T5S, R14E) 1877 (T5S, R15E)
Winkelman (1947)	Winkelman (1972)	1934		1877 (T5S, R15E)
Dewey Flat (1959)	San Carlos Reservoir NE (1972)			
Calva (1957)	Bylas NW (1972)		1914-1915	
Bylas (1957)	Bylas NE (1972)	1935	1914-1915	
Geronimo (1957)	Bylas SE (1972)	1935, 1952	1914-1915	1875 (T4S, R23E)
Fort Thomas (1957)	Fort Thomas SW (1972)	1935, 1952	1914-1915	1875 (T4S, R23E) 1875 (T5S, R23E) 1875 (T5S, R24E)
Eden (1957)	Thatcher NW (1972)	1935, 1952	1914-1915	1875 (T5S, R24E) 1875, 1916 (T6S, R24E)
Pima (1957)	Thatcher NE (1972)	1935, 1952	1914-1915	1875, 1916 (T6S, R24E) 1875 (T6S, R25E)
Thatcher (1957)	Thatcher SE (1972)	1935, 1952	1914-1915	1875 (T6S, R25E)
Safford (1957)	Safford SW (1972)	1935, 1952	1914-1915	1875 (T6S, R25E) 1875 (T7S, R25E) 1875 (T7S, R26E)

[1] 1934 SCS photography on file at the Arizona Geological Survey; 1935 SCS photography on file at the Bureau of Land Managment, Safford; 1952 SCS photography in Gelderman, 1970)

[2] 1914-1915 channel position in Burkham, 1972:Plate 1, originally from Olmstead, 1919.

Table B. Upper Gila River Channel Characteristics (Adapted from Burkham, 1972: Table 1).

Year	Total Area ha (acres)	Length km (miles)	Average Width m (ft)	Sinuosity m/m
Subreach A: Near Solomon to Pima Bridge (See Burkham 1972: Plate 1)				
1875	116 (290)	24.54 (15.34)	48 (160)	1.20
1903	176 (441)	22.88 (14.30)	75 (250)	1.12
1914	1,192 (2,980)	20.38 (12.74)	579 (1,930)	1.00
1935	334 (836)	22.11 (13.82)	150 (500)	1.08
1957	224 (560)	23.07 (14.42)	96 (320)	1.13
1966	428 (1,070)	20.54 (12.84)	207 (690)	1.01
1967	464 (1,160)	20.64 (12.90)	222 (740)	1.01
1968	332 (830)	20.48 (12.80)	159 (530)	1.01
Subreach B: Pima Bridge to Near Geronimo (See Burkham 1972: Plate 1)				
1875	152 (380)	36.64 (22.90) [1]	41 (137)	---
1894	180 (450) [2]	11.90 (7.44) [2]	150 (500) [2]	1.12
1903	179 (448) [2]	22.2 (13.9) [2]	81 (270) [2]	1.16
1914	360 (900)	32.3 (20.2)	600 (2,000)	1.00
1935	580 (1,450)	36.1 (22.6)	159 (530)	1.12
1942	516 (1,290)	36.9 (23.1)	138 (460)	1.14
1957	236 (590)	38.5 (24.1)	60 (200)	1.19
1966	324 (810)	36.6 (22.9)	87 (290)	1.13
1967	632 (1,580)	36.8 (23.0)	171 (570)	1.13
1968	360 (900)	36.4 (22.8)	99 (330)	1.13
Subreach D: Near Bylas to Near Calva (See Burkham 1972: Plate 1)				
1914	201 (503)	9.74 (6.09)	272 (907)	1.09
1935	128 (320)	10.06 (6.29)	126 (420)	1.12
1942	90 (225)	10.50 (6.56)	84 (280)	1.17
1947	28 (70)	11.06 (6.91)	24 (80)	1.24
1954	24 (59)	11.28 (7.05)	21 (70)	1.26
1964	28 (70)	11.71 (7.32)	24 (80)	1.31
1967	49 (122)	10.88 (6.80)	45 (150)	1.22
1968	95 (238)	10.88 (6.80)	87 (290)	1.22

[1] Stream length was not measured in 1875; the length was "sketched in" by the field party.

[2] Map covered only part of reach.

Table C. Maps and Photography Utilized in Plotting the Middle Gila River Channel Positions.

USGS 7.5' Quadrangles (year of photography[1])	**USGS 15' Quadrangles (year of photography or survey)**	**Orthophotoquads (year of photography)**	**Aerial Photography (year)[2]**	**Other Historical Maps[3] (year)**	**Historical Cadastral Surveys (year and township)**
Florence SE (1963)		Florence SE (1972)	1936	1914	1869, 1928 (T4S, R10E)
Florence (1963, *1978*)		Florence (1972)	1936	1914	1869, 1928 (T4S, R9E) 1869, 1928 (T5S, R9E) 1869, 1928 (T5S, R8E)
Blackwater (1963, *1978*)	Sacaton (1904-1906)	Blackwater (1971)	1936	1914	1869, 1928 (T5S, R8E) 1876 (T4S, R8E) 1876 (T4S, R7E)
Sacaton (1963, *1978*)	Sacaton (1904-1906)	Sacaton (1971)	1936		1876 (T4S, R7E)
Gila Butte SE (1951, *1978*)	Gila Butte (1903-1904)	Gila Butte SE (1971)	1936		
Gila Butte (1951, *1978*)	Gila Butte (1903-1904)	Gila Butte (1971)	1936		
Gila Butte NW (1951, *1978*)	Gila Butte (1903-1904)	Gila Butte NW (1971)	1936		
Pima Butte (1951, *1967*)	Maricopa (1903-1904)	Pima Butte (1971)	1936		1876 (T3S, R3E) 1876 (T2S, R3E) 1868 (T2S, R2E)
Montezuma Peak (1951,*1967*)	Maricopa (1903-1904)	Montezuma Peak (1971)	1936		1868 (T2S, R2E)
Laveen (1951, *1973*)	Phoenix (1903-1904)	Laveen (1971)	1936		1868 (T2S, R2E) 1868 (T1S, R2E) 1868 (T1S, R1E)
Avondale SE (1954, *1971*)		Avondale SE (1971)	1936		1868 (T1S, R1E)

[1] Year of revision photography in intalics.
[2] Soil Conservation Photography on file at the Cartographic Division, National Archives, Washington D.C.
[3] Map of Florence District, U.S. Indian Irrigation Service, on file at the Bureau of Indian Affairs, Phoenix.

Table Da. Channel widths (meters) of selected cross-sections in upper reach of middle Gila River.

Township & Range	Sections	Surveyed Cross-section	Year: 1869	1892	1928	1936	1954-57	1966	1969-70	1992
T4S, R10E	11&12	1	70		275	85	-	61	-	-
T4S, R10E	10&11	2	70		-	73	-	61	-	70
T4S, R10E	15&16	3	50		269	58	30	41	36	
T4S, R10E	20&21	4	57		220	43	40	45	31	30
T4S, R10E	19&30		50	140	340	-	-	-	-	-
T4S, R9E	25&30		-		151	58	34	-	-	-
T4S, R9E	25&26		60		-	58	40	31	44	
T4S, R9E	26&35	5	57		225	57	-	31		30
T4S, R9E	34&35	6	43		339	58	48	41	29	-
T4S, R9E	33&34		53		278	65	-	-	-	-
T5S, R9E	5&4	7	-		383	50	54	66	36	85
T5S, R9E	6&7		71		-	-	-	-	-	-
T5S, R9E	12&7	8	82		424	65	26	15	26	60
T5S, R8E	11&12	9	81		172	58	23	41	31	105
T5S, R8E	10&11	10	70		517	72	55	36	36	95
average			62.6		299.4	61.5	38.9	42.6	33.6	67.9
standard deviation			12.3		106.7	10.7	11.7	15.2	5.6	29.8
median			62.5		334.0	64.0	39.0	40.5	35.0	67.5

1869, 1892, and 1928 values are determined from survey notes.
1936, 1954-1957, and 1969-1970 values measured from aerial photographs.
1966 values measured from Florence SE and Florence quadrangles (1:24,000).
1992 values measured with electronic station; low flow channel.

Table Db. Channel widths (meters) of selected cross-sections in lower reach of middle Gila River.

Township & Range	Sections	Surveyed Cross-Section	1876	1903	1914	1928	1936	1966	1991
T5S, R8E	3&4	11				247	36	40	56
T4S, R8E	31&32	12	20				28	40	35
T4S, R8E	22&27	13					69	38	29
T4S, R6,7E	7&12	14					57	34	41
T4S, R6E	9	15					56	48	36
T4S, R6E	6	16					63		23
T3S, R5E	21	17			92		49		16
T3S, R5E	18&19	18			145		56		20
T3S, R4E	14	19		65			35		17
T3S, R4E	19&20	20		49			42		10
average							49.1	40.0	28.3
standard deviation							13.3869754	5.10	13.920808
median							48.5	43.0	33.0

1876 and 1928 values determined from survey notes.
1903 values measured from U.S. Indian Service Map (1:32,000).
1914 values measured from U.S. Indian Service Map (1:12,000).
1936 values measured from aerial photography.
1966 values measured from Blackwater and Sacaton quadrangles (1:24,000).
1991 values measured with electronic station; low flow channel.

Table E. Maps and Photography Utilized in Plotting Lower Gila River Channel Position.

USGS 7.5' Quadrangles (year of photography[1])	USGS 15' Quadrangles (year of photography or survey)	Orthophotoquads (year of photography)	Aerial Photography[2] (year)	Historical Cadastral Surveys (year and township)
Tolleson (1954, *1978*)		Tolleson (1971)		1868 (T1N, R1W)
Perryville (1954, *1978*)		Perryville (1971)		1868 (T1N, R1W) 1883 (T1N, R2W)
Avondale SW (1957, *1971*)		Avondale SW (1971)		1883 (T1S, R2W)
Buckeye (1958, *1971*)		Buckeye (1972)		1883 (T1S, R3W)
Hassayampa (1958, *1971*)		Hassayampa (1972)		1883 (T1S, R4W) 1882 (T1S, R5W)
Arlington (1960, *1981*)		Arlington SE (1972)		1882 (T1S, R5W) 1882 (T2S, R5W)
Spring Mt. (1972)		Spring Mt (1972)		1882 (T2S, R5W)
Cotton Center NW (1972)		Cotton Center NW (1972)		1882 (T3S, R5W) 1871 (T3S, R4W)
Cotton Center (1972)		Cotton Center SW (1972)		1871 (T4S, R4W) 1871 (T5S, R4W)
Gila Bend (1972)		Gila Bend NW (1972)		
Dendora Valley (1979)		Dendora Valley SE (1972)		1910 (T4S, R8W) 1914 (T5S, R8W)
Oatman Mt. (1979)		Dendora Valley SW (1972)	1953	1877 (T5S, R9W) 1877 (T5S, R10W)
Sentinel Peak (1979)		Sentinel Peak (1972)	1953	1877 (T5S, R10W)
Hyder SE (1963, *1980*)	Hyder (1927)	Hyder SE (1972)	1953	
Agua Caliente (1962, *1982*)	Aztec (1926-27)	Agua Caliente (1972)	1953	1877 (T5S, R10W) 1877 (T5S, R11W)
Aztec NW (1963, *1980*)	Aztec (1926-27)	Aztec NW (1972)		1877 (T6S, R11W) 1877 (T6S, R12W)
Horn (1962-63)	Stoval (1927)	Horn (1972)		1877 (T6S, R12W) 1877 (T6S, R13W)
Dateland (1962-62; *1980*)	Stoval (1927)	Dateland (1972)		1877 (T6S, R13W) 1877 (T7S, R13W)
Texas Hill (1963, *1980*)	Stoval (1927)	Texas Hill (1972)	1953	1877 (T6S, R13W) 1877 (T7S, R14W)
Growler (1953, *1980*)	Norton (1926)	Growler (1972)	1953	1877 (T7S, R15W) 1878 (T7S, R16W)
Roll (1953, *1980*)	Norton (1926)	Roll (1972)	1953	1878 (T7S, R16W) 1878 (T8S, R16W)
Tacna (1962, *1980*)	Mohawk (1926)	Tacna (1972)		1878 (T8S, R16W) 1878 (T8S, R17W)
Wellton Mesa (1962)	Wellton (1926)	Wellton Mesa (1972)		1878 (T8S, R17W) 1878 (T8S, R18W)

Wellton (1962)	Wellton (1926)	Wellton (1972)		1878 (T8S, R18W) 1912 (T8S, R19W)
Ligurta (1962)	Fortuna (1902-03; 1925-26)	Ligurta (1972)		1916 (T8S, R20W)
Dome (1953, *1985*)	Laguna (1902-03; 1925-26)	Dome (1972)		1890 (T8S, R21W)
Laguna Dam (1953, *1976*)	Laguna (1902-03; 1925-26)	Laguna Dam (1972)		1890 (T8S, R21W)
Fortuna (1962-62, *1976*)	Fortuna (1902-03; 1925-26)	Fortuna (1972)		1890 (T8S, R21W) 1874 (T8S, R22W)
Yuma East (1948, *1976*)	Yuma (1902-03)	Yuma East (1973)		1874 (T8S, R22W)

[1] Year of revision photography in intalics.
[2] 1953 photography on file at the Arizona Geological Survey