GEOMORPHIC CHARACTER OF THE LOWER GILA RIVER

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INTRODUCTION

A study of the Lower Gila River downstream of the Salt River confluence was undertaken to determine the character of the river at statehood on February 14, 1912. To accomplish this, there was a review of published and unpublished reports, a low-level helicopter flight over the river (March 31, 2004), a study of U.S. Geological Survey topographic maps, 1934 aerial photographs, and Soil Conservation Service soil surveys of relevant areas. These activities provide a firm basis for the development of conclusions regarding the morphologic character of the river and the dynamics of the channel, both before and after statehood.

RIVER TYPES

In order to understand the morphologic character and the behavior of the Gila River, it is necessary to consider the range of river types that exist and the Gila River's place within the continuum of river types. Depending on the nature of the materials through which a river flows, there are three major categories of stream channels: (1) bedrock, (2) constrained, and (3) alluvial. The bedrock channel is fixed in position, and it is stable over long periods of time. The constrained channel is controlled only locally by bedrock or resistant alluvium. The alluvial channel has bed and banks composed of sediment transported by the stream. Therefore, the alluvial channel is susceptible to major pattern change and to significant shifts in channel position as the alluvium is eroded, transported, and deposited, and as the sediment load and water discharge change.

For simplicity and convenience of discussion, the range of common alluvial channel patterns can be grouped into five basic patterns (**Figure 1**). These five patterns illustrate the overall range of channel patterns to be expected in nature. Figure 1 is more meaningful than a purely descriptive classification of channels because it is based on cause-and-effect relations and illustrates the differences to be expected when the type of sediment load, flow velocity, and stream power differ among rivers. It also explains pattern differences along the same river (Schumm, 1977).

Numerous empirical relations demonstrate that channel dimensions are largely due to water discharge, whereas channel shape and pattern are related to the type and amount of sediment load moved through the channel (**Table 1**). As indicated by Figure 1, when the channel pattern changes from 1 to 5, other morphologic aspects of the channel also change; that is, for a given discharge, both the gradient and the width-depth ratio increase. In addition, sediment size and sediment load increase from Pattern 1 to Pattern 5. With such geomorphic and hydrologic changes, hydraulic differences can be expected, and flow velocity, tractive force, and stream power also increase from Pattern 1 to Pattern 5. Therefore, the stability of a stream decreases from Pattern 1 to Pattern 5, with Patterns 4 and 5 being the least stable. A brief discussion of the five basic patterns is presented as follows.

Pattern 1

The suspended-load channel is straight with a relatively uniform width (Figure 1). It carries a very small load of sand and gravel (Table 1). Gradients are low, and the channel is relatively narrow and deep (low width-depth ratio). The banks are relatively stable because of their high silt-clay content.

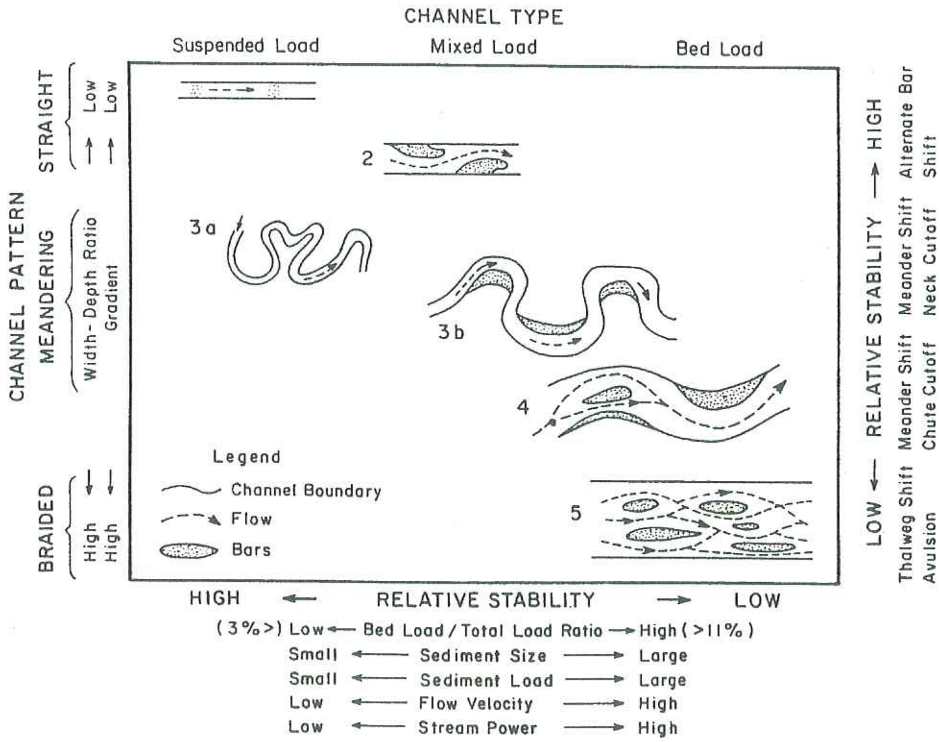

Figure 1. Channel classification based on pattern and type of sediment load, showing types of channels, their relative stability, and some associated variables (after Schumm, 1977).

Table 1. Classification of stable alluvial channels (after Schumm, 1977).

Type of Channel	Bed Load (Percent of Total Load)	Type of River
Suspended Load	<3	Suspended-load channel; width-depth ratio <10; sinuosity >2.0; gradient relatively gentle
Mixed Load	3-11	Mixed-load channel; width-depth ratio >10, <40; sinuosity <20; gradient moderate; can be braided
Bed Load	>11	Bed-load channel; width-depth ratio >40; sinuosity <1.3; gradient relatively steep; can be braided

Pattern 2

The mixed-load straight channel has a sinuous thalweg (Figure 1). The thalweg is the deepest part of a channel. This river is relatively stable and carries a small load of coarse sediment, which may move through the channel as alternate bars.

Pattern 3

This pattern is represented by two channel patterns. Pattern 3a shows a suspended-load channel (Table 1) that is very sinuous. It carries a small amount of coarse sediment. The channel width is roughly equal and the banks are stable. Pattern 3b shows a less stable type of meandering stream. Mixed-load channels (Table 1) with high bed loads and banks containing low-cohesion sediment will be less stable than the suspended-load channels. The sediment load is large, and coarse sediment is a significant part of the total load. The channel is wider at bends, and point bars are large. The channel is relatively unstable.

Pattern 4

This pattern represents a meander-braided transition (Figure 1). Sediment loads are large, and sand, gravel, and cobbles are a significant fraction of the sediment load. The channel width is variable, but it is relatively large compared with the depth (high width-depth ratio), and the gradient is steep. Chute cutoffs, thalweg and meander shift, and bank erosion are all typical of this pattern.

Pattern 5

This bed-load channel (Table 1) is a typical braided stream (Figure 1). The bars and thalweg shift within the unstable channel, and the sediment load is large. Steep gradients reflect a large bed load. Bank sediments are easily eroded; gravel bars and islands form and migrate through the channel. Therefore, the channel is relatively unstable and the location of bars and low-water channels can shift during floods.

The braided Pattern 5 is of most interest because the braided pattern is the Gila River pattern. A braided river is defined by the American Geological Institute (1972) as a *stream that divides into or follows an interlacing or tangled network, of several, small branching and reuniting shallow channels separated from each other by branch islands or channel bars, resembling in plan the strands of a complex braid.* Braided rivers have a high width-depth ratio and relatively steep gradient, as a result of high bed load and large floods, which produce a relatively unstable pattern and a relatively variable channel in time and location. This is a description of the Gila River (**Figures 2 through 5**). However, human activities have significantly altered the Gila River at many locations, encroachment of salt cedar into the channel has narrowed the channel significantly (**Figure 6**), and there are several locations where bedrock may exert a control.

GENERAL DESCRIPTION

The Gila River is characterized by inherent instability and frequent and destructive channel migration (Chin, 1988; Graf, 1981), and there are reaches of relative stability and instability. For example, during a flood in 1941, the channel shifted 0.5 miles near Buckeye (Chin, 1988). According to Graf et al. (1994, p. 32), the lower Gila River "typified braided streams, variable in

Figure 2. Gila River view downstream toward Gila Bend in March 2004.

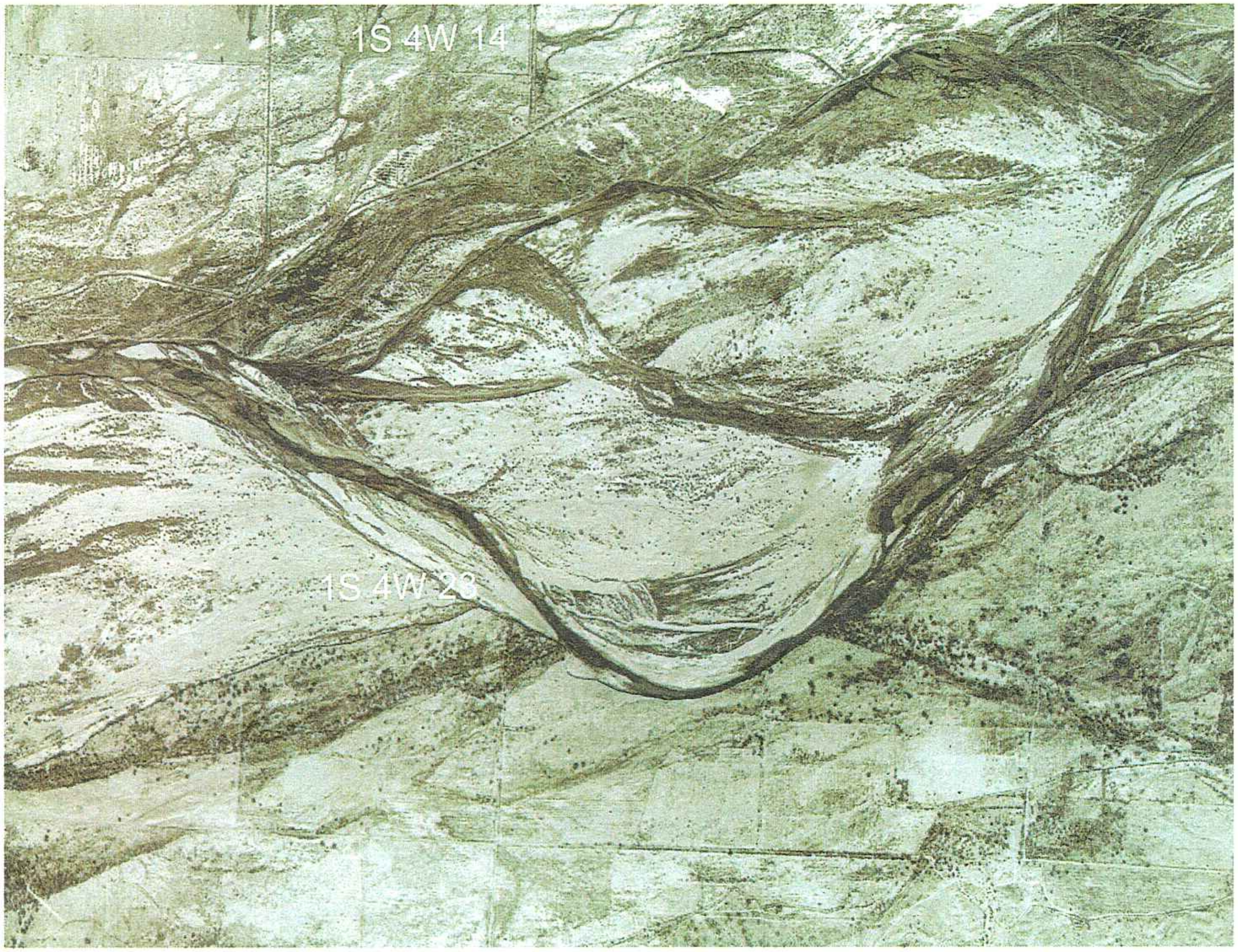

Figure 3. Gila River in T1S, R4W, 1934 aerial photograph. River bed is about one mile wide.

Figure 4. Gila River in T1S, R2W, 1934 aerial photograph. River bed is about one mile wide.

Figure 5. Gila River downstream of Painted Rock Dam. Channel is confined by lava flows east of Aqua Caliente.

Figure 6. Gila River channelized upstream of Yuma. View downstream northwest of Owl.

channel configuration and dimensions..." According to Ross (1923, p. 36), the river in 1917 was an interrupted stream, that is, one that has local reaches of flow while most of the river was dry. Clearly then, the river had intermittent flow. "Gila River below Salt River is a winding stream subject to considerable changes of volume... Between terraces is a floodplain which in most places from one mile to several miles wide, incised into the floodplain and channel one foot to 10 feet or more deep and a few feet to the mile wide. The position, size, and number of channels change with every flood." (Ross, 1923, p. 76)

Huckleberry (1996, p. 16) summarizes the character of the Gila River as follows: "The Gila River is a classic example of a dryland river that seldom seeks an equilibrium form. Unlike rivers in humid regions that have more stable channels that are 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." Clearly, a braided river will respond to hydrologic changes and especially to large floods.

Descriptions of the pre-statehood river that have been compiled by Graf et al. (1994) and Rea (1983) and others generally agree that the river was bordered by willows and cottonwoods. It ranged in width from 240 to 1,300 feet with 450 feet being the most common estimate. Depth ranged from almost 0 to 4 feet, and Cooke (1878) complained that "the river, where I have wanted it as a barrier to the mules, has always been but a few inches deep; here, where I must cross it, it is swimming."

A very different river is described near Powers Butte near Arlington. John Montgomery, a rancher states that "in the summer of 1889, when a boy of 12...the river had a well-defined channel with hard sloping banks lined with cottonwoods and bushes. The water was clear, was 5 or 6 feet deep, and contained many fish." (Ross, 1923, p. 66) If accurate, this is a description of a river that is very different from that described elsewhere, but this variability is expected for most rivers.

CHANNEL CHANGE

According to Darton (1933, p. 228), "The Gila River channel has changed materially in a century or less. When it was originally discovered, there was a well-defined channel with hard banks sustaining cottonwoods and other trees and plants. The current was swift and deep in places, so that the stream could be navigated by flat boats of moderate size, and it contained sufficient fish to be relied upon as food for many Indians... Now (1933), the Gila River is depositing sediment in its lower part and its braided course follows many narrow sand-clogged channels."

As described by earlier travelers, and shown on the early maps, the Gila River was a relatively narrow single channel, but plats surveyed after 1910 show a much wider channel (**Figure 7**).

Studies in the upper and middle Gila River can be used to demonstrate river changes that undoubtedly occurred in the lower Gila River. The U.S. Geological Survey carried out an extensive investigation in the Safford Valley on the impact of phreatophytes on the river. As part of this investigation, Burkham (1972, 1981) studied the impact of floods on the channel characteristics. He found that the changes can be grouped into three periods—1846-1904, 1905-1917, and 1918-1970. From 1846-1904, the stream channel was narrow, and it meandered through a floodplain covered with willow, cottonwood, and mesquite. Only moderate changes occurred in the width and sinuosity of the channel in this period; the maximum width of the channel was 150 feet in 1875 and about 300 feet in 1903.

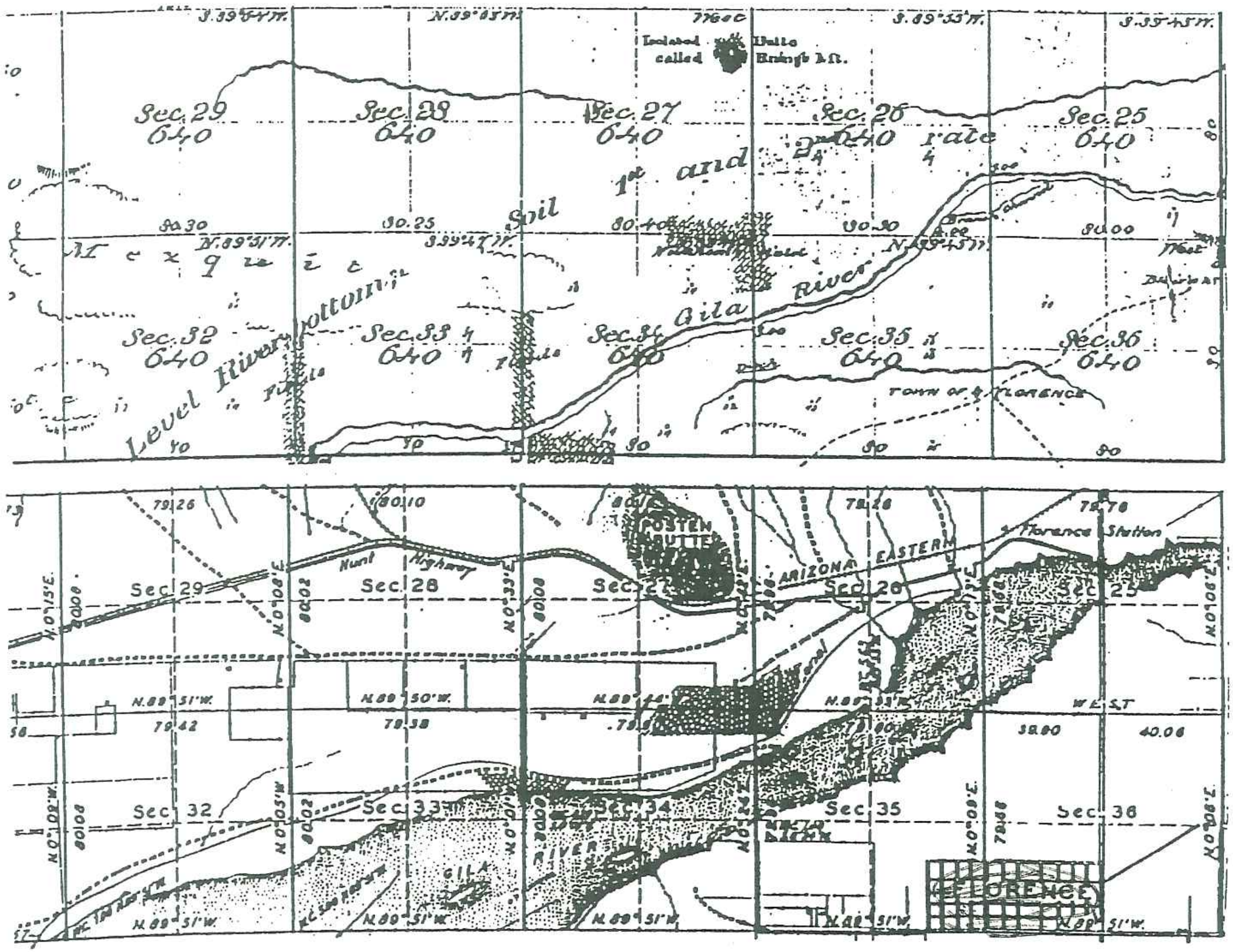

Figure 7. General Land Office plats of T4S, R9E as surveyed in 1869 (above) and 1928 (below). Note change in the width of the Gila River channel.

The average width of the channel of the Gila River increased during 1905-1917 to about 2,000 feet, mainly as a result of large winter floods. The meander pattern of the river and the vegetation in the floodplain were destroyed completely by the floods.

The channel of the Gila River narrowed during 1918-1970 and the maximum width was 200 feet in 1964. The channel developed a meander pattern and the floodplain became densely covered with vegetation.

According to Burkham, the major floods were the causes of the dramatic channel changes prior to statehood. He summarizes the changes by plotting channel area in the reach between San Simon and Pima for the period 1875 to 1970 (**Figure 8**).

Huckleberry (1996) reached the same conclusions regarding the middle Gila River (**Figure 9**). The early surveys showed the middle Gila as a narrow single channel until 1891. In 1891, the middle Gila River experienced a large flood that caused channel widening and large floods in 1905 and 1906 radically transformed the relatively narrow channel to a wide braided channel. Huckleberry (1996, 1994) concluded that major channel changes are related more to the duration of a flood than to its magnitude. Beginning in 1905, the channel experienced great widening as a result of bank cutting during periods of sustained flow. For example, it was reported for U.S. Geological Survey gaging station near Dome that there were "radical changes in channel in 1905 and 1906" (U.S. Geological Survey, 1954, p. 707). During those two years, there were five months of high flow in 1905 and six months of high flow in 1906. Prolonged flow of this magnitude undoubtedly contributed to channel widening.

During the floods of 1905-1906, the Geological Survey had difficulty maintaining their gaging stations. For example, the gage at Dome was established in 1903, but in 1905, the river had shifted one mile north (U.S. Geological Survey, 1906, p. 164). Further description of the river in 1905 revealed that its channel was not amenable to navigation. For example, "The Gila carries an enormous amount of mud and sand. At times, the waves of sand...are so large, the current is so swift, and the stream to [sic] shallow, that the water is broken into a uniform succession of waves two feet high and over. During 1905, there have been 10 floods... At every flood, the channel shifts." (U.S. Geological Survey, 1906, p. 164)

Channel transformation from a meandering to a braided pattern during a period of large and prolonged flooding is not restricted to the Gila River. For example, the Cimarron River in southwestern Kansas was transformed from a narrow sinuous 50-foot wide channel to a 1,200-foot wide braided channel by a series of floods during the 1930s (Schumm and Lichty, 1963).

As an example of the effects of the 1905-1906 floods on the Gila River, the tribulations of Clarence Maddox are impressive. Maddox, on April 19, 1903, filed a homestead entry on Sections 29 and 30, T8S, R22W, east of Yuma. In a June 21, 1909, letter from a special agent of the General Land Office to the Commissioner, the special agent wrote that:

"the only time (the Maddox's) were absent from said land up until June 1908, was at such times as it was unsafe to live thereon by reason of the overflow of the Gila River...Maddox claims that at one time to have had about 40 acres cleared and planted, but that the river washed away all of said cultivation, and that the Gila River has changed its course three or four times during the period he had lived on said land and that at the present time most of said entry is in the bed of said river, there being only about 20 acres left; that his other houses were built on the north side of the Gila River, while his present house is on the south side; that the channel of the river has so changed during the past five or six years that while at the time he made his entry all his entry was on the north side of the river that most of it is now on the south side of the river."

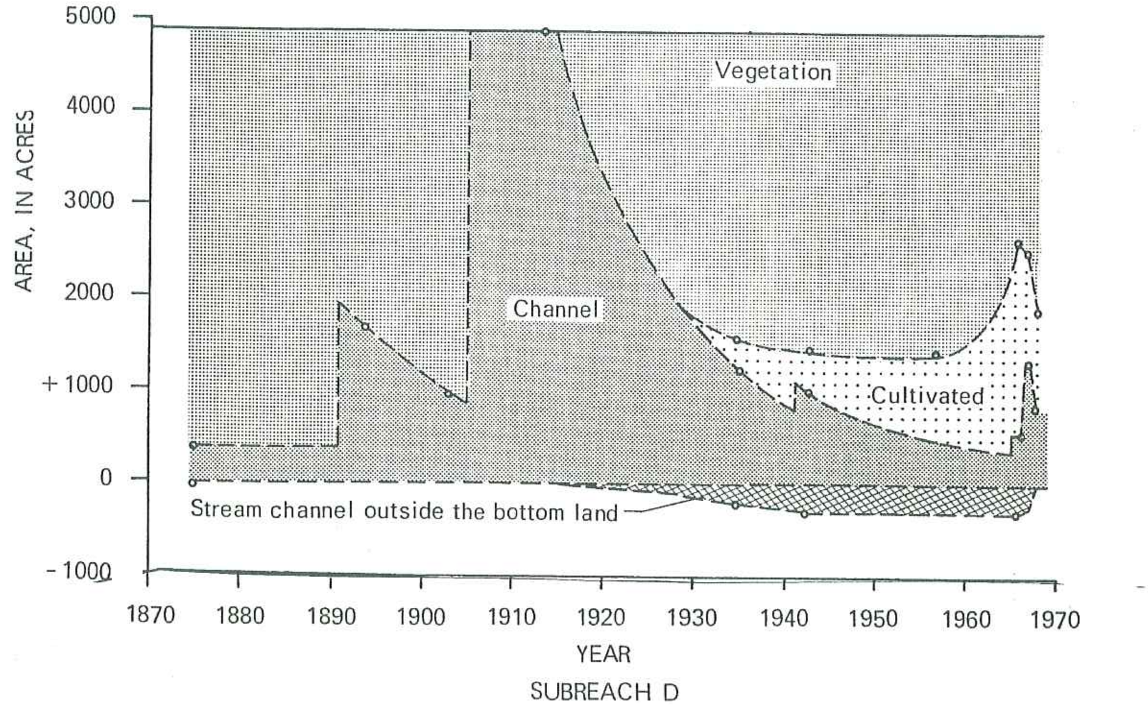

Figure 8. Historical changes in channel area of upper Gila River (San Simon to Pima) (from Burkham, 1972).

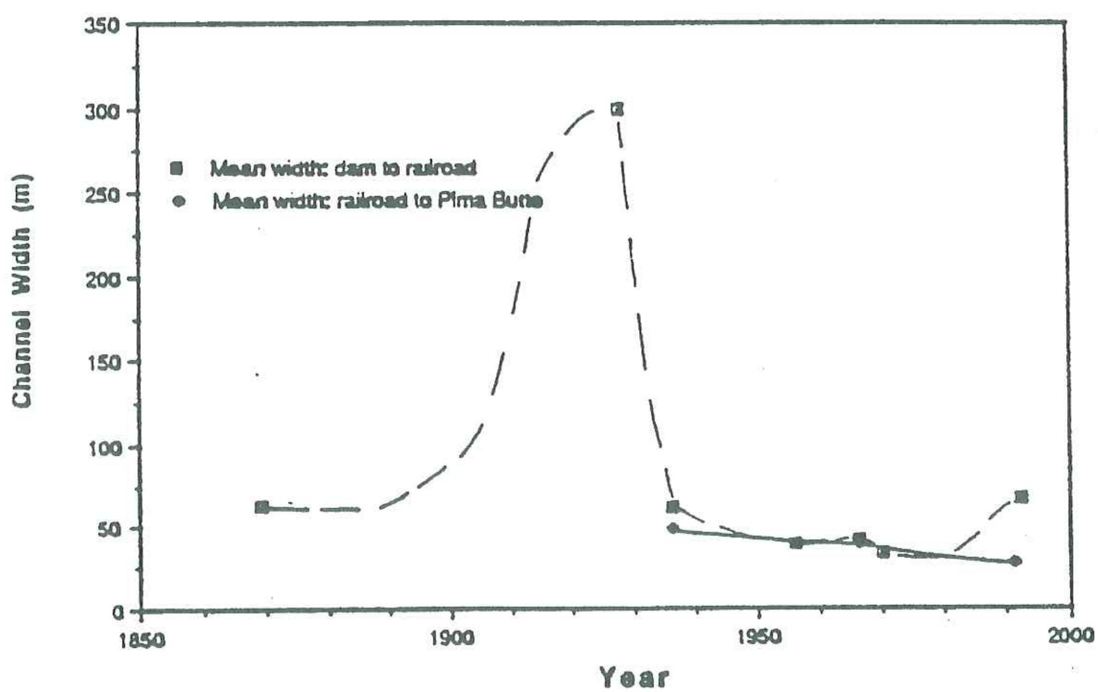

Figure 9. Changes in channel width for the middle Gila River (from Huckleberry, 1993).

(Homestead Entry Patent File for 1034203, 1903, Serial Land Patents, Record Group 49, U.S. General Land Office, U.S. National Archives, Washington, D.C., LRA Box/File 28/21)

Another document in Maddox's file, written by his wife on February 21, 1912, stated that:

"the first big flood came about a year after establishing residence. The Gila River overflowed its natural course and washed over our land...We returned to the land about three months subsequent thereto and again lived in the house, until about a year when the Gila and Colorado Rivers again overflowed and drove us from the land, absolutely destroying the adobe house, pumps and all traces of our residence. About six months thereafter we built a small house, and continuously resided therein until a couple of months afterward when the river again rose, washed away out second house, and driving us from the land...I have exercised the utmost good faith in endeavoring to maintain residence on the land during the above period often-times at the risk of my life, and that of my child, the river oftertimes [sic] rising to a depth of seven or eight feet and forming a stream a mile wide in a single night." (Homestead Entry Patent File for 1034203, 1903, Serial Land Patents, Record Group 49, U.S. General Land Office, U.S. National Archives, Washington, D.C., LRA Box/File 28/21)

If the homestead entry was filed in April 1903 and the first big flood occurred "about a year after establishing residence," it probably was the large long-duration flood of 1905. About a year later, the 1906 flood destroyed their house. The loss of agricultural land indicates major bank erosion and widening of the river during the 1905-1906 floods.

Further evidence of the great impact of these floods is the statement that: "There was no historical evidence identified for this study that any profitable commercial enterprises were conducted using the Gila River for trade and travel as of the time of statehood. However, there is historical evidence that profitable commercial enterprises were conducted barely seven years prior to statehood." (Arizona State land Dept., 1996) Of course, seven years before statehood is 1905.

In addition to the preceding evidence of major lower Gila River channel changes, as a result of 1905-1906 floods, a comparison of pre- and post 1905 General Land Office surveys provides convincing information. **Figure 10** shows a significant widening of the Gila River in T1N, R1W between 1867 and 1915. Note also the shift in position in all sections. This is true of a short reach of the river in T1N, R2W (1883-1907, **Figure 11**). Although there is no comparable pre-1905 map for T8S, L9W, **Figure 12** shows that the Gila River was up to 2,500 feet wide and the width was highly variable in 1912. All of the evidence indicates that the 1905-1906 floods dramatically widened the Gila River and rendered it unfit for navigation.

Finally, not only was the morphology of the river not conducive to navigation, but also hydrology prevented it. According to the U.S. Geological Survey gaging station record at Dome, the river in February 1912 was dry (U.S. Geological Survey, 1954). In fact, the discharge record shows that the Gila River had no discharge during the months of December 1911, January 1912, and February 1912. Therefore navigation was impossible during those months.

CONCLUSIONS

1. The lower Gila River before the floods of 1891, 1905, and 1906 had a relatively narrow and deep channel that was bordered by trees and brush. It appeared to be relatively stable.

a

b

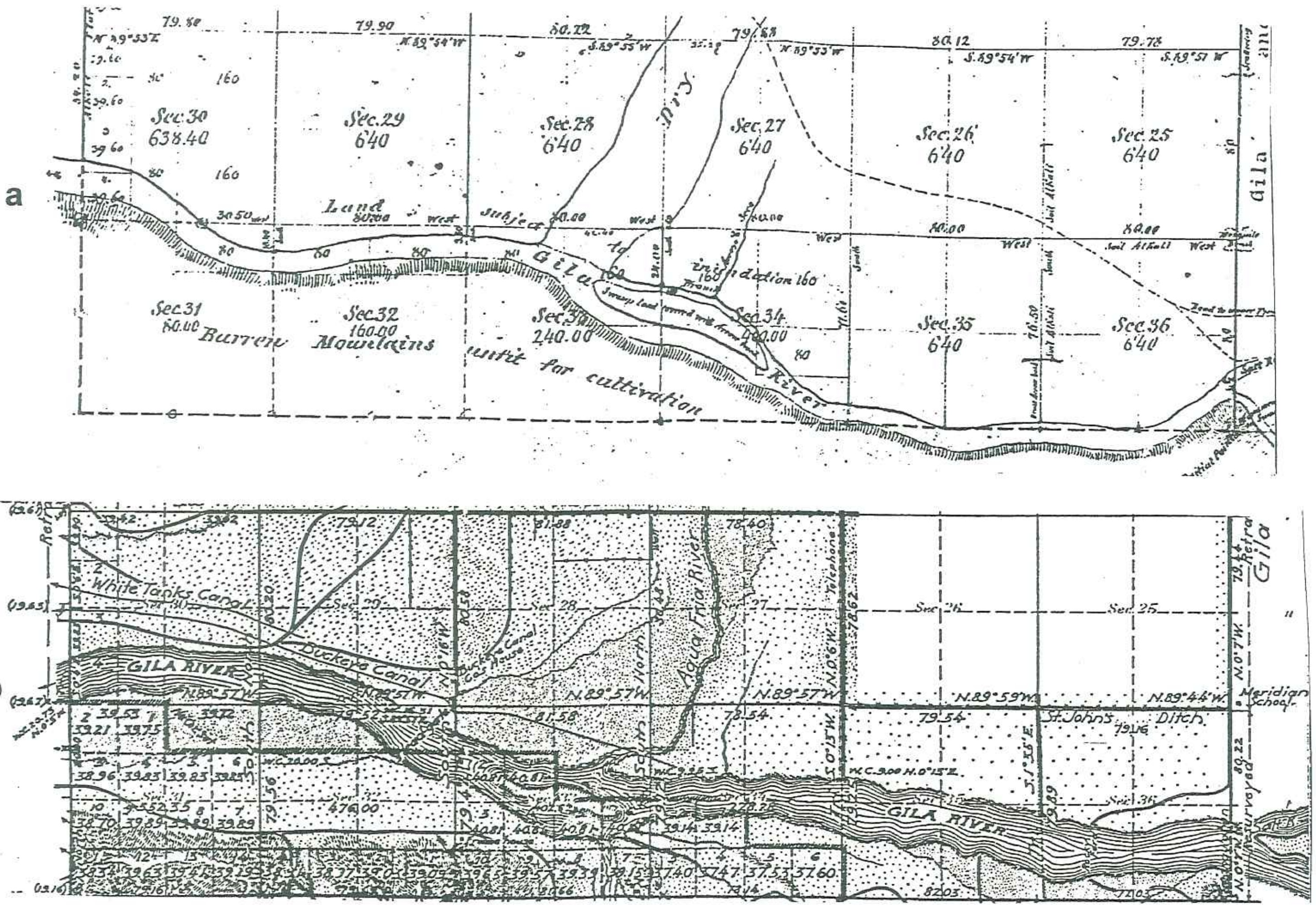

Figure 10. Gila River below Salt River confluence in a) 1867 and b) 1915.

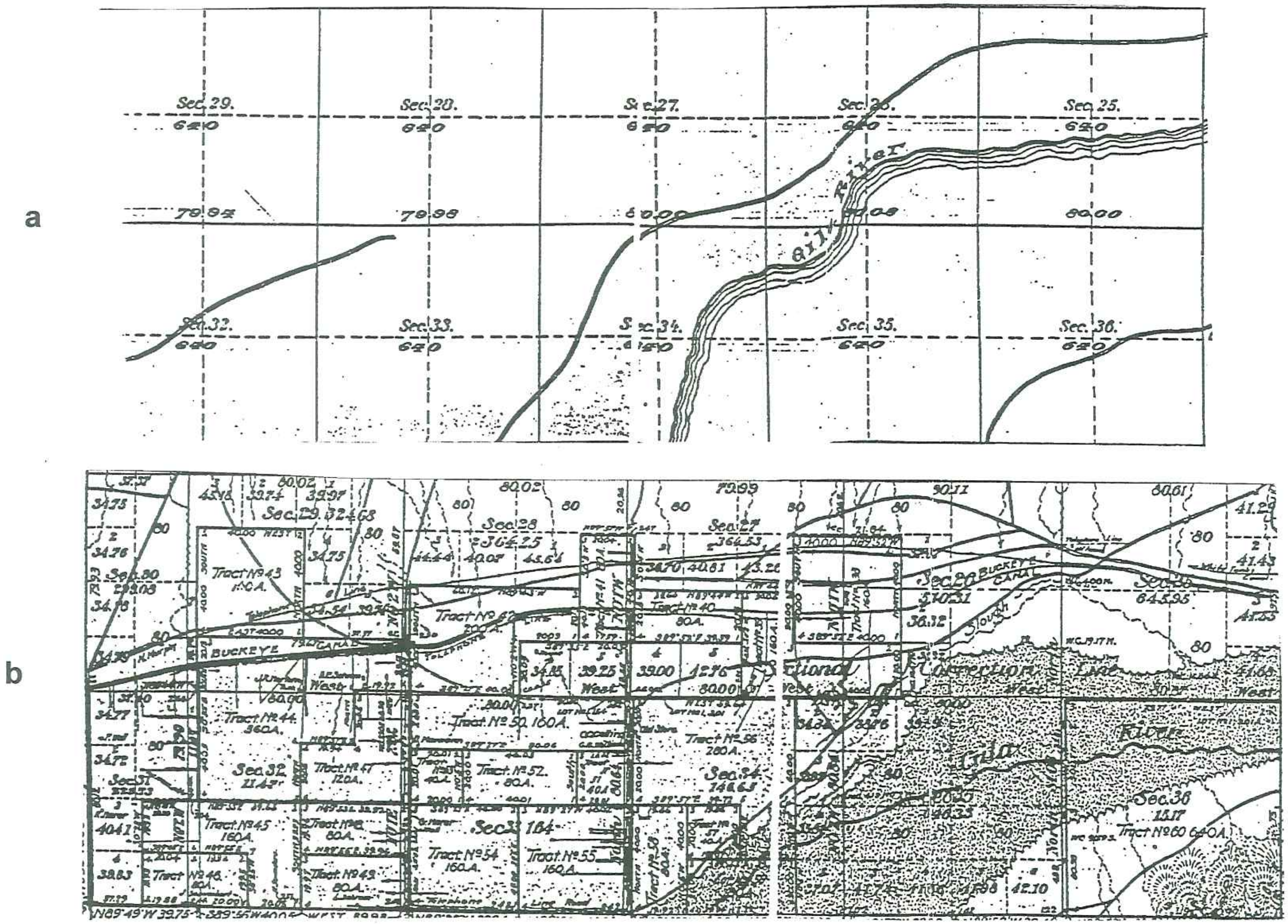

Figure 11. Gila River in T1N, R2W in a) 1883 and b) 1907.

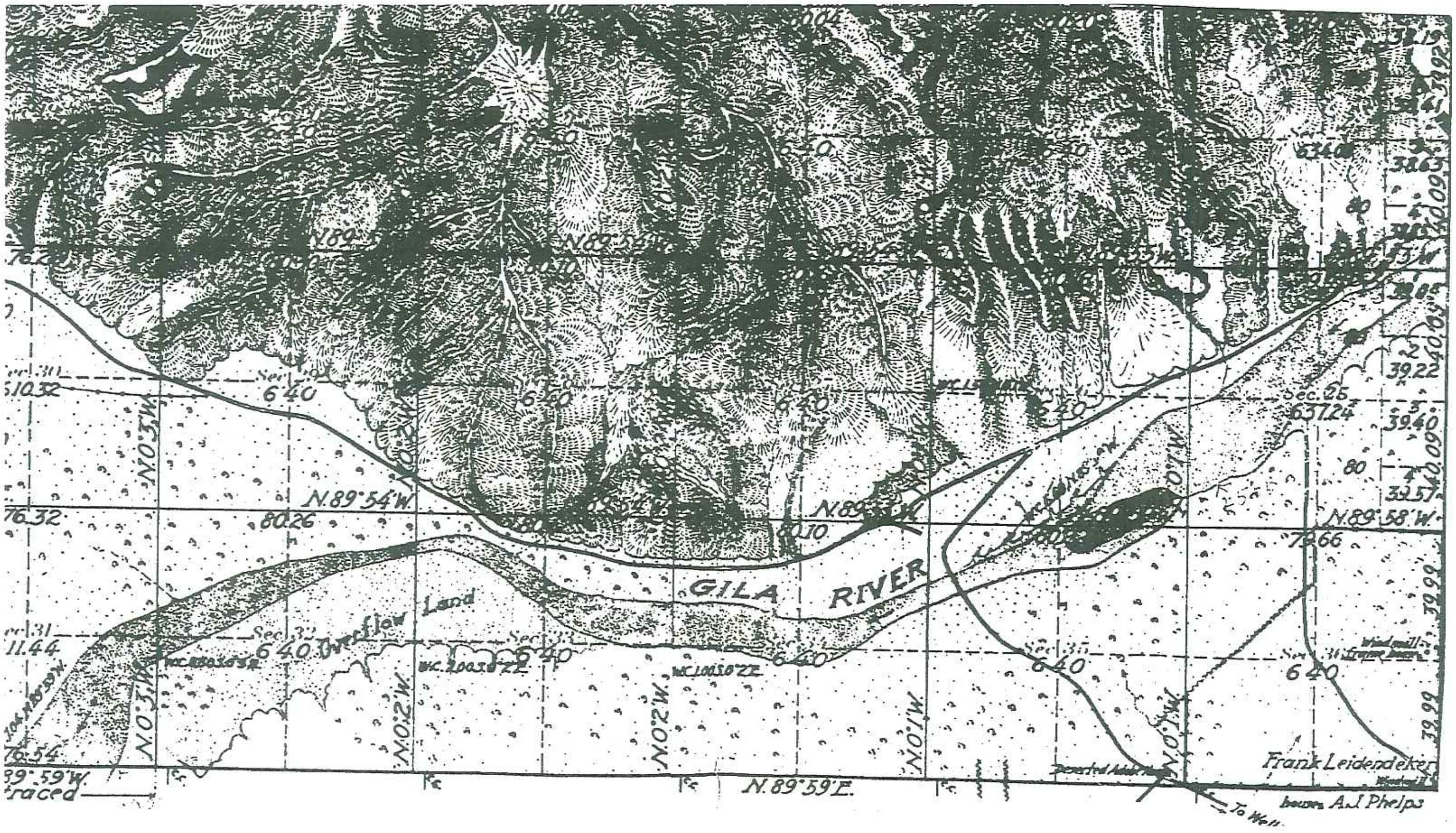

Figure 12. Gila River in T8S, R9W in 1912.

2. The large, long-duration floods, especially those of 1905 and 1906 converted the relatively stable lower Gila River into a braided channel that was wide and shallow and unsuitable for navigation.

3. The General Land Office surveys pre- and post-statehood, where available, reveal the dramatic alteration of the channel.

4. The fact that the Dome gaging station recorded no flow in February 1912 further supports the conclusion of non-navigability in 1912.

5. Geomorphic and hydrologic evidence demonstrates that on February 14, 1912, the lower Gila River was not navigable.

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