GEOMORPHIC CHARACTER OF THE VERDE RIVER

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INTRODUCTION

A study of the Verde River upstream of the confluence with the Salt River to Cottonwood 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 To accomplish this, there was a review of published and unpublished reports, a low-level helicopter flight over the river (September 24, 2004), a study of U.S. Geological Survey topographic maps, and 1934 aerial photographs. 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 Verde River, it is necessary to consider the range of river types that exist and the Verde 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) confined, (2) constrained, and (3) alluvial. The confined channel is fixed in position by bedrock or resistant alluvium, 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. The position of the confined and constrained channels is fixed by resistant material. For example, width is limited by valley walls, but the channel can aggrade or degrade except where bedrock forms the floor of the channel.

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. 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.

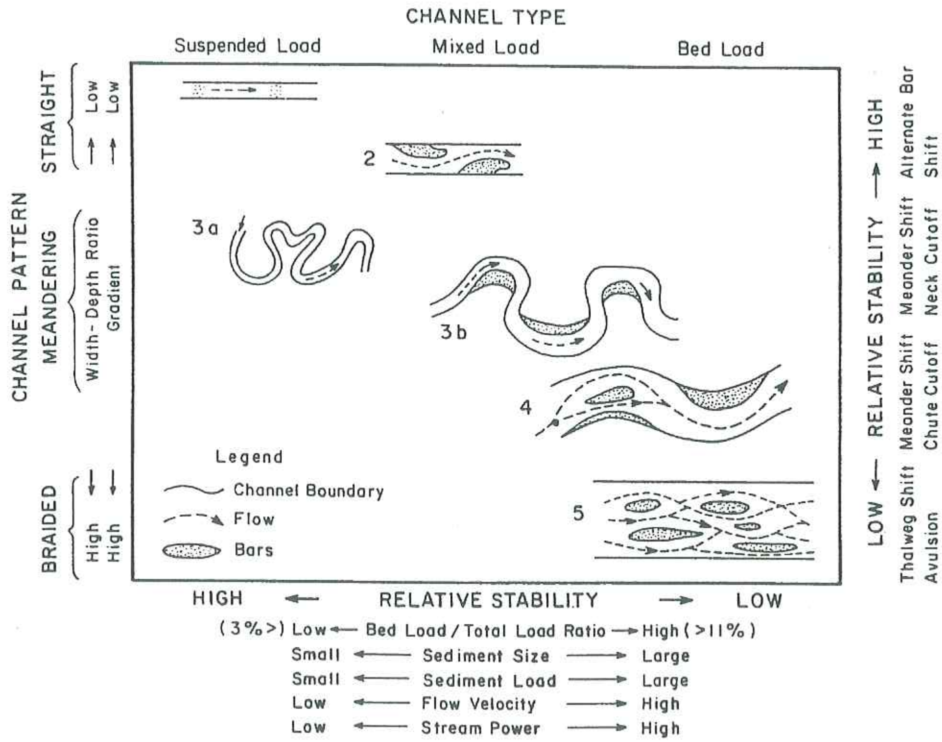

Figure 1. Channel classification based on pattern and type of sediment load, showing types of channels, their relative stability, and some associated variables (after Schumm, 1977).

The braided Pattern 5 is of most interest because it is the Verde 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 good description of the Verde River.

Although bedrock and geologic structures strongly control valley and channel morphology, it is obvious that within the Verde River valley, the channel is braided (**Figures 2 through 4**). However, a cursory glance at aerial photographs of the Verde River could lead to the conclusion that it is a meandering river of Pattern 3, but a more careful study reveals that the valley of the Verde River is sinuous and the river is forced to follow this pattern in a deep valley (**Figure 5**). Elsewhere, the valley is very straight and so is the river (**Figure 6**). This is clearly the result of a geologic control. In addition, valley and channel width is highly variable as a result of the effect of bedrock (Figures 2 through 4). These constrictions significantly affect channel width and depth and flow velocity.

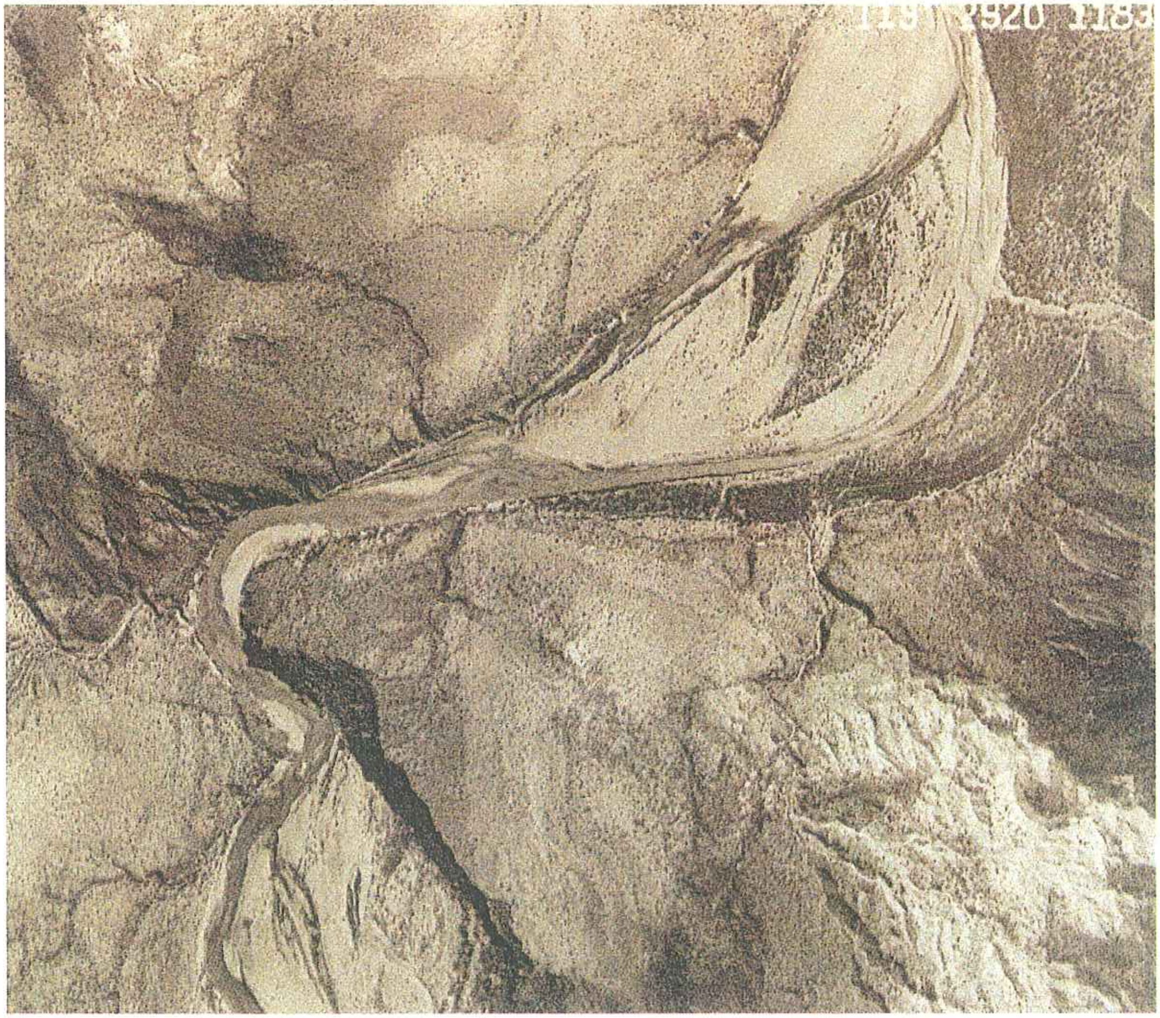

Figure 2. Verde River at Horseshoe Dam site (T7N, R6E, Sec 2). 1934 aerial photograph showing braided channel pattern and constriction, as a result of geologic control. Note that channel occupies entire width of valley.

Figure 3. Verde River at "bottom of Fort McDowell Indian Reservation" (T3N, R7E, Sec 31). 1934 aerial photograph showing braided channel pattern and constriction, as a result of geologic control. Note that the channel occupies the entire width of the valley.

Figure 4. Verde and Salt River confluence (T2N, R7E, Sec 5). 1934 aerial photograph showing braided channel pattern and constriction. Note that large sediment delivery from Verde River forces Salt River channel to south side of valley.

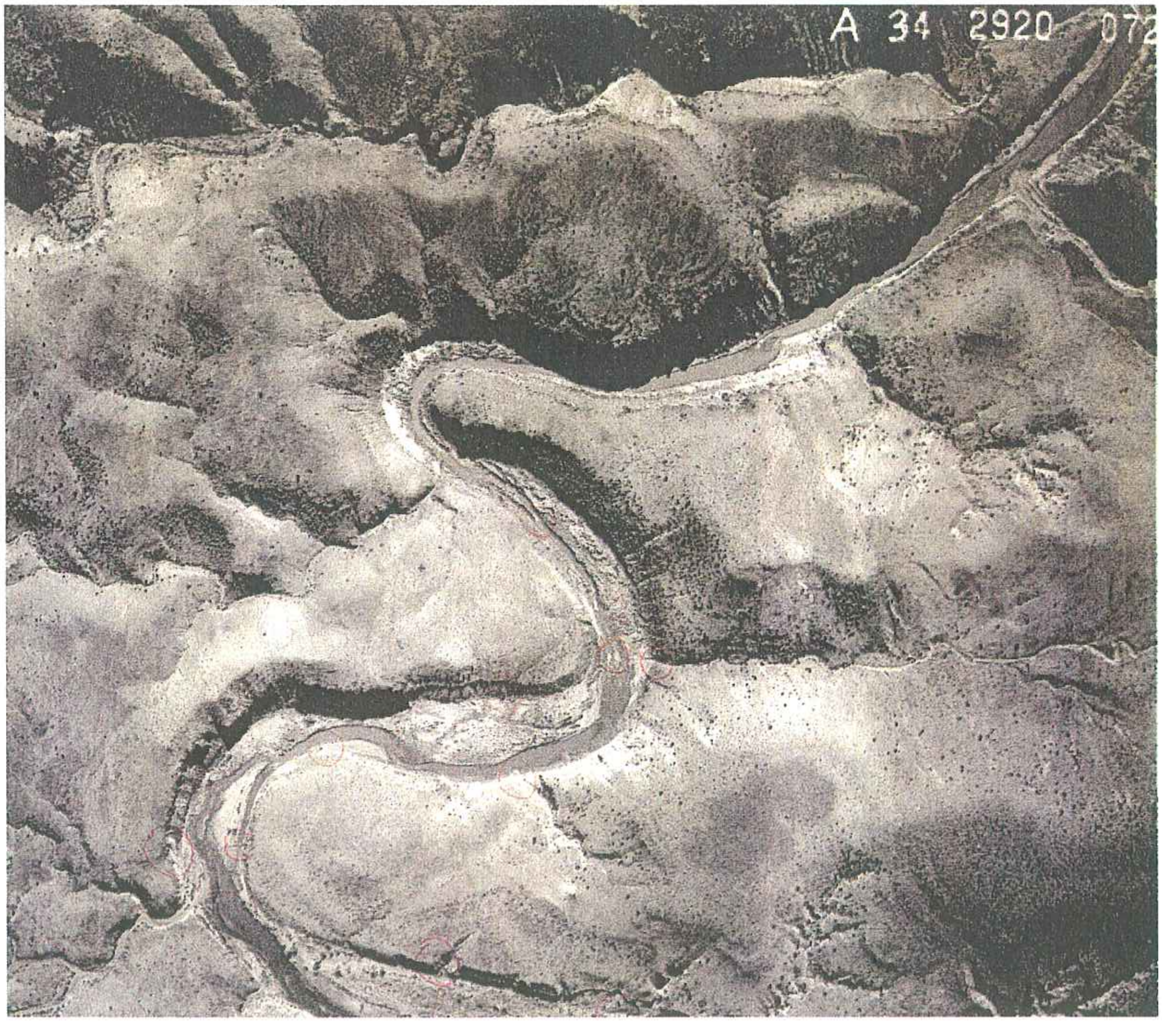

Figure 5. Verde River at Sycamore Canyon (T12N, R5E, Sec 1). 1934 aerial photograph showing sinuous valley, tributary influences constricting channel, and exposed bedrock.

Figure 6. Verde River below Lower Coldwater Creek (T12N, R6E). 1934 aerial photograph of straight reach, a result of a geologic control. Note very narrow valley.

The effect of bedrock on channel and valley characteristics is obvious along many rivers and **Figures 7 and 8** show how valley width and gradient can be controlled by bedrock, tributaries, and rock falls. Outcrops of bedrock in the Verde River channel obviously control local channel width, depth, and gradient.

HISTORICAL VARIABILITY

The lower Verde River today is a cobble- and gravel-bedded channel that flows over shallow or exposed bedrock (CH2M HILL, 1993). In the late 19th century, the river was described as deep, slowly flowing, with many beaver dams and marshy reaches. The marshy conditions were "destroyed around 1890 for as yet unknown reasons" (CH2M HILL, 1993, p. 79). However, large floods preceding statehood reportedly "caused channel erosion, which resulted in channelization of the middle Verde River and elimination of swampy marshland" (CH2M HILL, 1993, p. 92).

It is clear that a dramatic change of the Verde River occurred in the late 19th and early 20th century. A series of high discharge years (1889, 1890, 1891, **Table 1**) appears to have caused major channel erosion, and this was continued by the high discharge years of 1905, 1906, 1907, and 1909 (Table 1).

The 1934 aerial photographs show a Verde River channel that is wide, occupying the entire valley floor (Figures 2 through 4). This undoubtedly was the condition of the channel in 1912, following the series of major floods (Table 1) that significantly widened the Gila River and its tributaries (**Figure 9**), including the Verde River. The GLO surveys of T3N, R7E in 1901-1902 and 1911 support this conclusion (**Figures 10 and 11**).

According to Burkham (1972), the major floods were the cause of the dramatic channel changes along the upper Gila River 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 9a).

Huckleberry (1996) reached the same conclusion regarding the middle Gila River (Figure 9b). 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) 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. During 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, and indeed, the gage at McDowell was washed out during the flood of 1905 (USGS, 1906).

Large floods occurred in the years preceding statehood, which resulted in channelization of the middle Verde River, and elimination of swampy marshland. (CH2M HILL, 1993, p. 92).

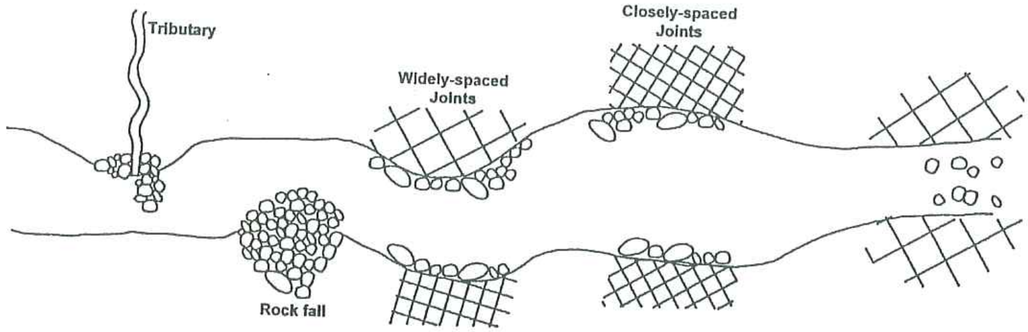

Figure 7. Sketch showing some types of geologic and geomorphic controls (tributary, rockfall, spacing of joints) on valley and channel width.

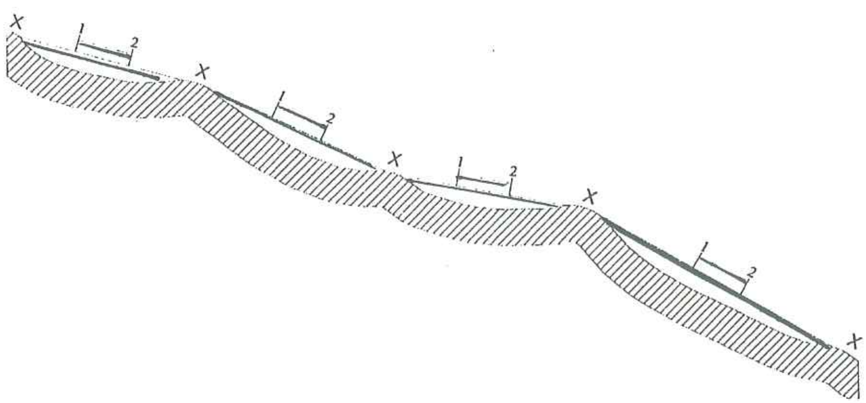

Figure 8. Bedrock outcrops (X) in riverbed determine gradient of reaches. This is very different from condition in alluvial rivers (Figure 1).

Table 1.	Mean annual discharge (cfs) of Verde River below Bartlett Dam (USGS, 1954).
Year	Mean Annual Discharge (cfs)
1889	1,074
1890	1,353
1891	2,401
1892	186
1893	410
1894	266
1895	1,019
1896	420
1897	748
1898	326
1899	274
1900	175
1901	433
1902	292
1903	580
1904	381
1905	2,167
1906	1,246
1907	1,188
1908	628
1909	1,054
1910	655
1911	918
1912	621
1913	523
1914	546
1915	1,202
1916	1,759
1917	1,234
1918	690
1919	749
1920	1,744
1921	428
1922	1,052
1923	742
1924	754
1925	354
1926	708
1927	1,130
1928	432
1929	539
1930	396
1931	557
1932	1,150
1933	303
1934	227
1935	698

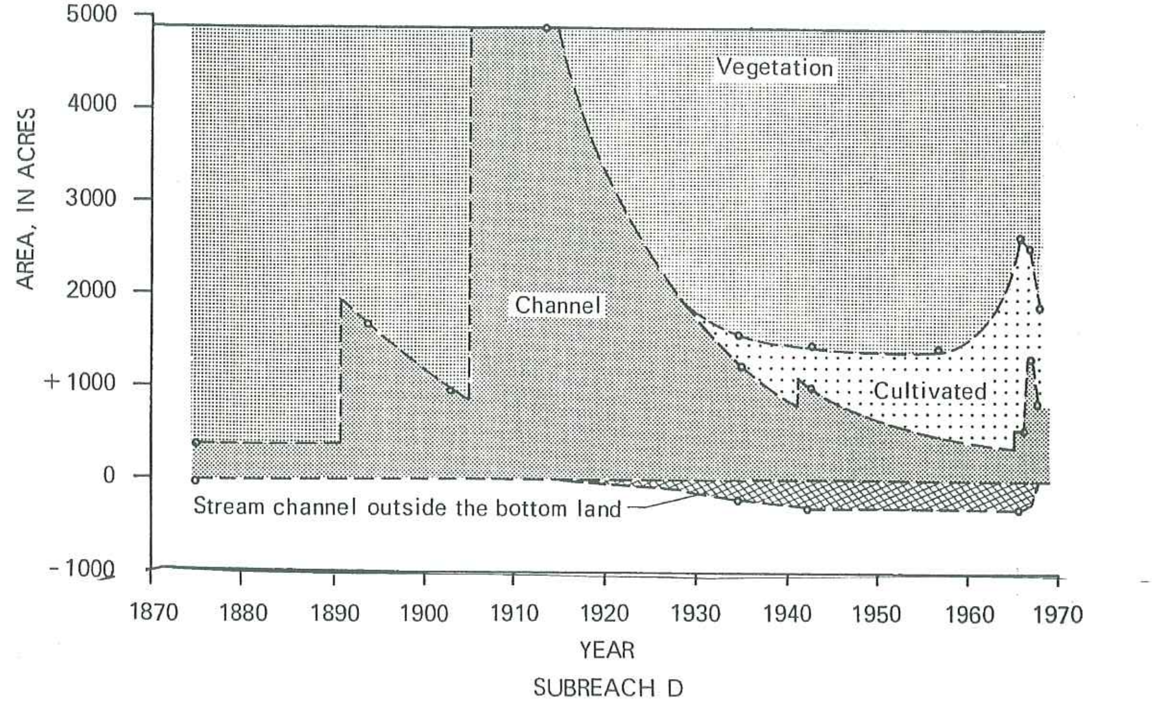

Figure 9a. Historical changes of channel area, upper Gila River, San Simon to Pima (Burkham, 1972).

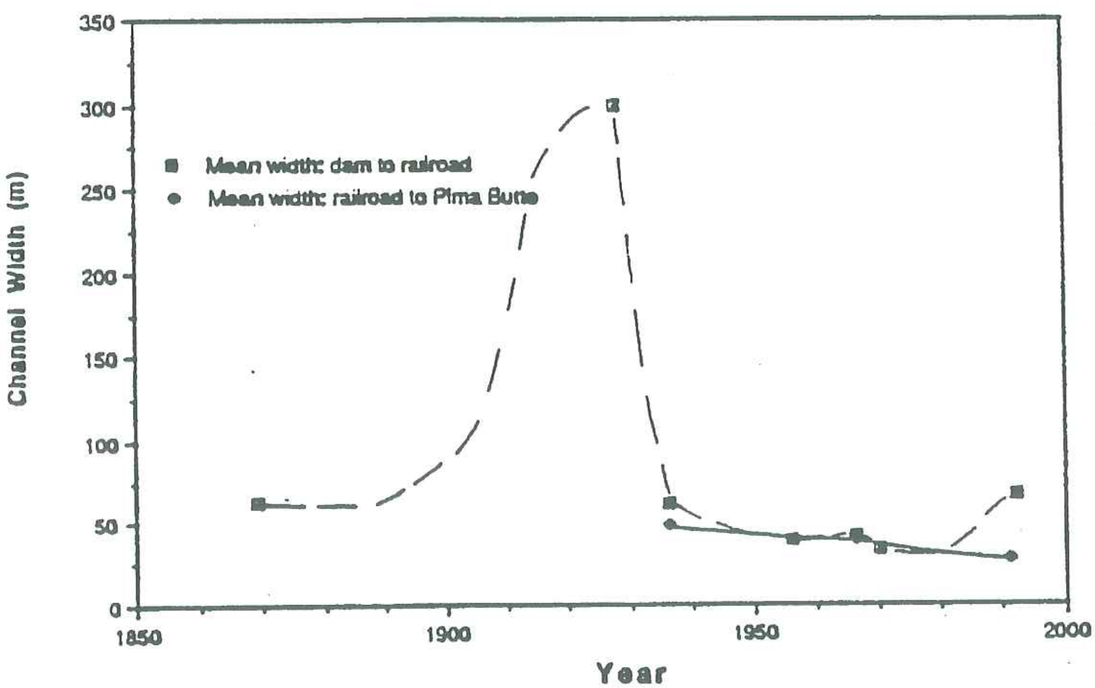

Figure 9b. Historical changes of channel width, middle Gila River (Huckleberry, 1993).

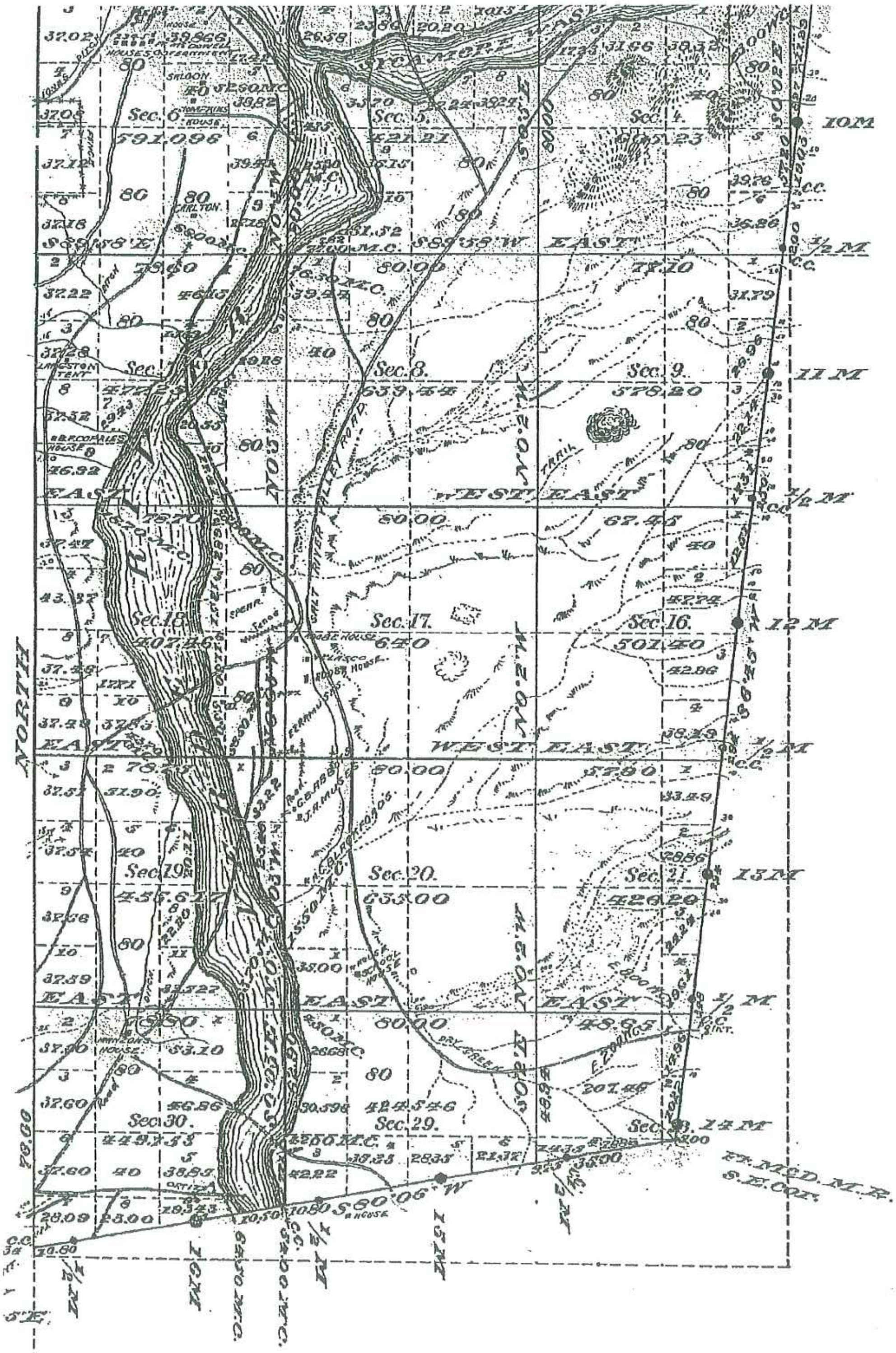

Figure 10. General Land Office map of T3N, R7E, showing a very wide Verde River channel in 1901-1902.

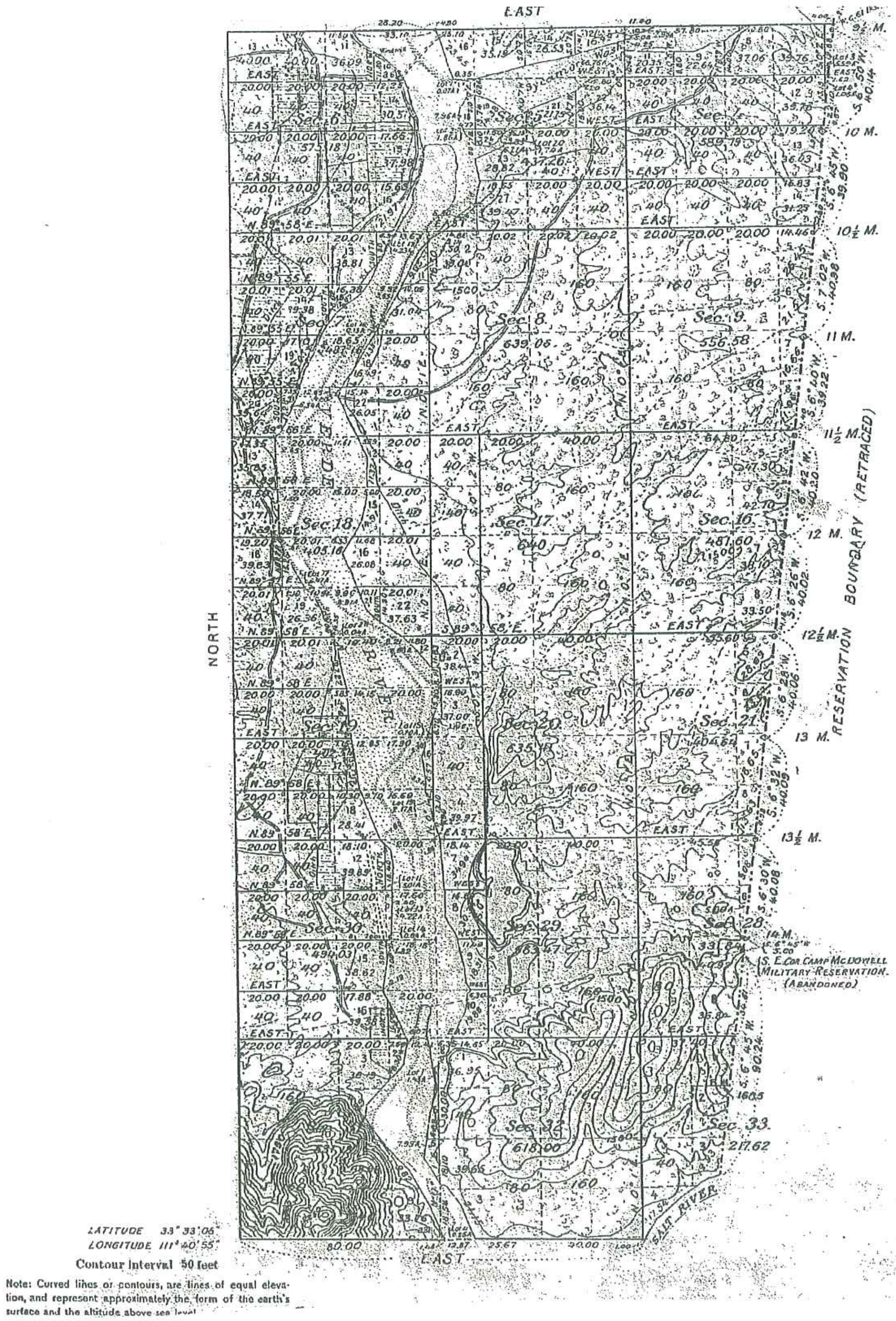

Figure 11. General Land Office map of T3N, R7E, showing a very wide Verde River channel in 1911.

PRESENT VARIABILITY

Not only did the character of the Verde River vary through time, but the aerial photographs and a longitudinal profile show that the channel is variable as a result of tributary influences (Figures 2 and 3), and lithologic-geologic controls (Figures 2 through 5). The long profile (**Figure 12**) shows great irregularity as a result of bedrock (e.g., Needle Rock, Sta 100,000, **Figure 13**), and tributary effects.

A study by Mussetter Engineering, Inc. (2004) of riparian vegetation provides evidence of Verde River variability. Three sites were selected for detailed study (Figure 12) in wide reaches of the valley, where alluvium is stored and riparian vegetation is present.

Site 1 is located upstream of Horseshoe Dam (Figure 12). At this location, the valley is 600 feet wide and river gradient is 14 feet per mile.

Site 2 is located downstream of Horseshoe Dam (Figure 12). At this location, the valley is 2,000 feet wide and river gradient is 25 feet per mile.

Site 3 is located downstream of Bartlett Dam (Figure 12) where the valley is 4,000 feet wide and channel gradient is 12 feet per mile.

Obviously, there are great differences among the three reaches, and this is characteristic of the Verde River. The effect of bedrock on the channel is described by the Forest Service (1997). For example, there are 14 rapids between the upper limit of Horseshoe Reservoir and Camp Verde, a distance of 61 miles ((**Figure 14**, **Table 2**), and the gradient varies from 16 to 22 ft/mile, which is consistent with the MEI data (12 to 25 ft/mile). Furthermore, bedrock at the confluence of the Verde and Salt Rivers clearly prevents navigation on the Verde and Salt Rivers (**Figure 15**).

CONCLUSIONS

Braided rivers are wide, shallow, and steep, a condition not conducive to navigation. The marked changes of valley width cause dramatic alterations of water depth and velocity (Figures 2 through 5), which would make navigation hazardous. The numerous rapids (Table 3) clearly prevent navigation, and the bedrock that controls the Verde and Salt Rivers at their confluence prevents navigation upstream on both rivers (Figure 15).

Obviously, the numerous rapids and bedrock impacts on the river prevent navigation, but even more important are the very steep gradients ranging from 12 to 25 ft/mile. These gradients are significant because Captain John A. Mellon, with over 40 years experience on the Colorado River (Lingenfelter, 1978, p. 51), stated in a letter to the Bureau of Corporations (1907) that, "I have come to the conclusion that any river that has over 4 feet fall to the mile can not compete with a railroad for freight or passengers" (Littlefield, 1997; Commissioner of Corporations, 1909). If at 4 feet per mile, commercial navigation is inhibited, certainly at 10 to 25 feet per mile, the gradients measured on the Verde River, navigation would be impossible.

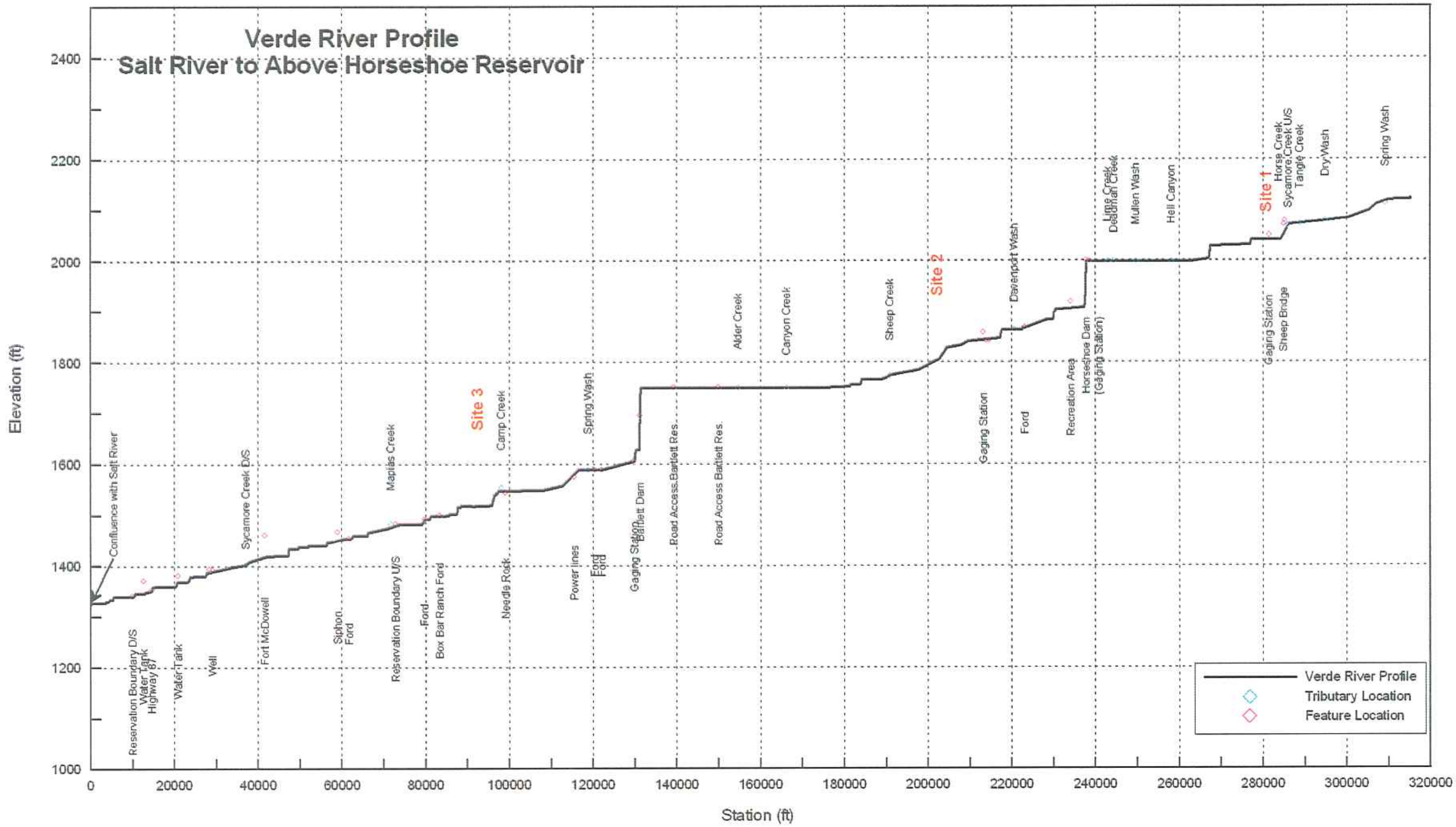

Figure 12. Longitudinal profile of Verde River. The profile shows great irregularity as a result of bedrock and tributary effects. Note location of Mussetter Engineering field sites.

Figure 13. Bedrock in Verde River channel at Needle Rock.

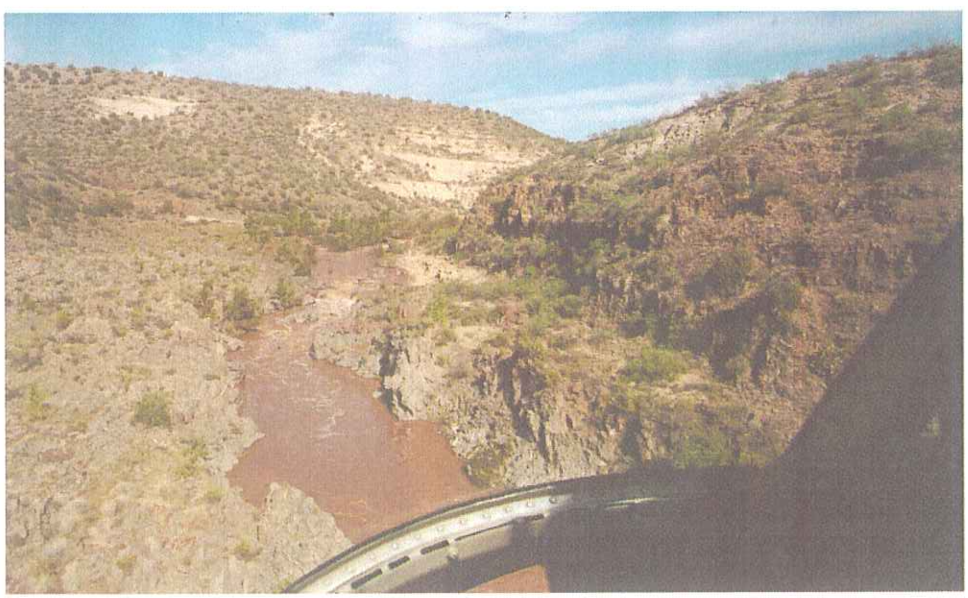

Figure 14. Verde Falls. Bedrock forms bed and banks of channel.

Table 2. Verde River Forest Service Guide (1997).	
River Mile	Description
8	Upper limit Horseshoe Reservoir
9.75	Scouting recommended
10.6-11	Slow water
12	Honey Chute
13-14	Slow water
15.5-15.8	Nice ride
18.7	Wet As rapid
19.7	Red Creek Rapid, watch for rocks
20.7	Mellofa Hess Rapid, trees blocking channel
29-30	Slow water
32.2	Red Wall Rapid, river drops 17 feet per mile for next 11 miles downstream
33.5	Very rocky
36.6	Watch for rock in center
38-38.5	Narrow rocky channels
38.7	Nasty little dog-leg, use caution
41.6	Baby Snaggle-tooth, rock in center
42.2	River drops 20 feet per mile for next 10 miles downstream
42.5	Childs-play Rapid
43.5	Rocky channels
46.8	Boulder field
48.5	Trees, rocks
49.4	White Flash Rapids
50.1	Black Hole Rapids
51.1	Bushman Rapid
51.5	River drops 22 feet per mile for next 9 miles downstream
52.5	Turkey Gobbler Rapid
54.5	Kisit Goud-by Rapid
55	Rock garden at low water
56.8	Verde Falls, use extreme caution--do not accidentally run these falls
57.1	Pre-fall Rapid, some nasty drops
57.7	Off-the-wall Rapid, river drops 17 feet per mile for next 6 miles downstream
59.5	Do not run beyond this point unless you know what you are doing
69	Camp Verde

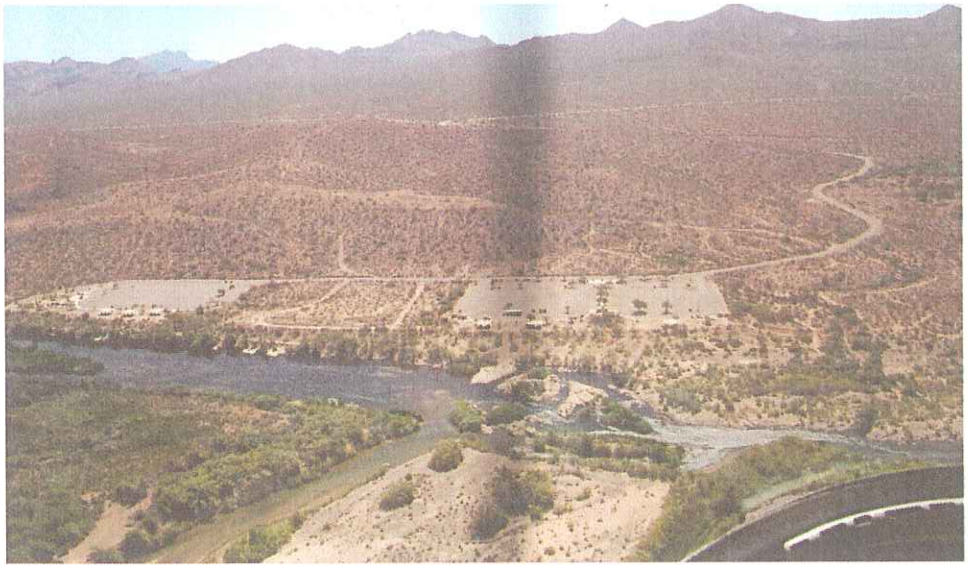

Figure 15. Confluence of Verde and Salt Rivers. Bedrock controls entrance to Verde River channel.

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