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received
04-01-2003

April 1, 2003

Hand-delivered

Mr. George Mehnert
Arizona Navigable Stream Adjudication Commission
1700 West Washington, Room 304
Phoenix, AZ 85007

Re: In re Determination of Navigability of Lower Salt River

Dear George:

Enclosed are seven copies of the following documents submitted by the Salt River Project Agricultural Improvement and Power District and the Salt River Valley Water Users' Association (collectively, "SRP") for purposes of the April 7 hearing on the Lower Salt River:

1. "Information Regarding Navigability of Selected U.S. Watercourses" (April 2003);

2. Tammy LeRoy, "Salt River Centennial," Phoenix Magazine, at 67-73 (February 2003);

3. Excerpts from Marshall Trimble, Arizona: A Cavalcade of History, at 258-266 (1989);

4. Excerpts from Karen L. Smith, The Magnificent Experiment: Building the Salt River Reclamation Project, 1890-1917, at 70-91, 169-171 (1986); and

5. Excerpts from Earl A. Zarbin, Roosevelt Dam: A History to 1911, at 75-107, 114, 133, 146 (1984).

If you have any questions about these materials, please call me.

Very truly yours,

Salmon, Lewis & Weldon, P.L.C.

By Mark A. McGinnis
Mark A. McGinnis

Encls.

024, 25, ⑳

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March 27, 2003

received
04-02-2003
glm

Mr. George Mehnert
Arizona Navigable Stream Adjudication Commission
1700 West Washington, Room 304
Phoenix, AZ 85007

Re: In re Determination of Navigability of Lower Salt River

Dear George:

Enclosed are seven copies a report prepared by Dr. Stanley Schumm, entitled "Geomorphic Character of the Lower Salt River." This report is submitted by the Salt River Project Agricultural Improvement and Power District and the Salt River Valley Water Users' Association (collectively, "SRP") for purposes of the April 7 hearing on the Lower Salt River.

In addition to Dr. Schumm, SRP intends to provide testimony from Dr. Douglas Littlefield and by Mr. David Roberts, Manager of Water Rights and Contracts at SRP. Dr. Littlefield has testified before the Commission on a variety of occasions in the past, and SRP has previously provided copies of his Salt River report. If you need additional copies, please let me know. Mr. Roberts will not be presenting a written report.

If you have any questions about these materials, please call me.

Very truly yours,

Salmon, Lewis & Weldon, P.L.C.

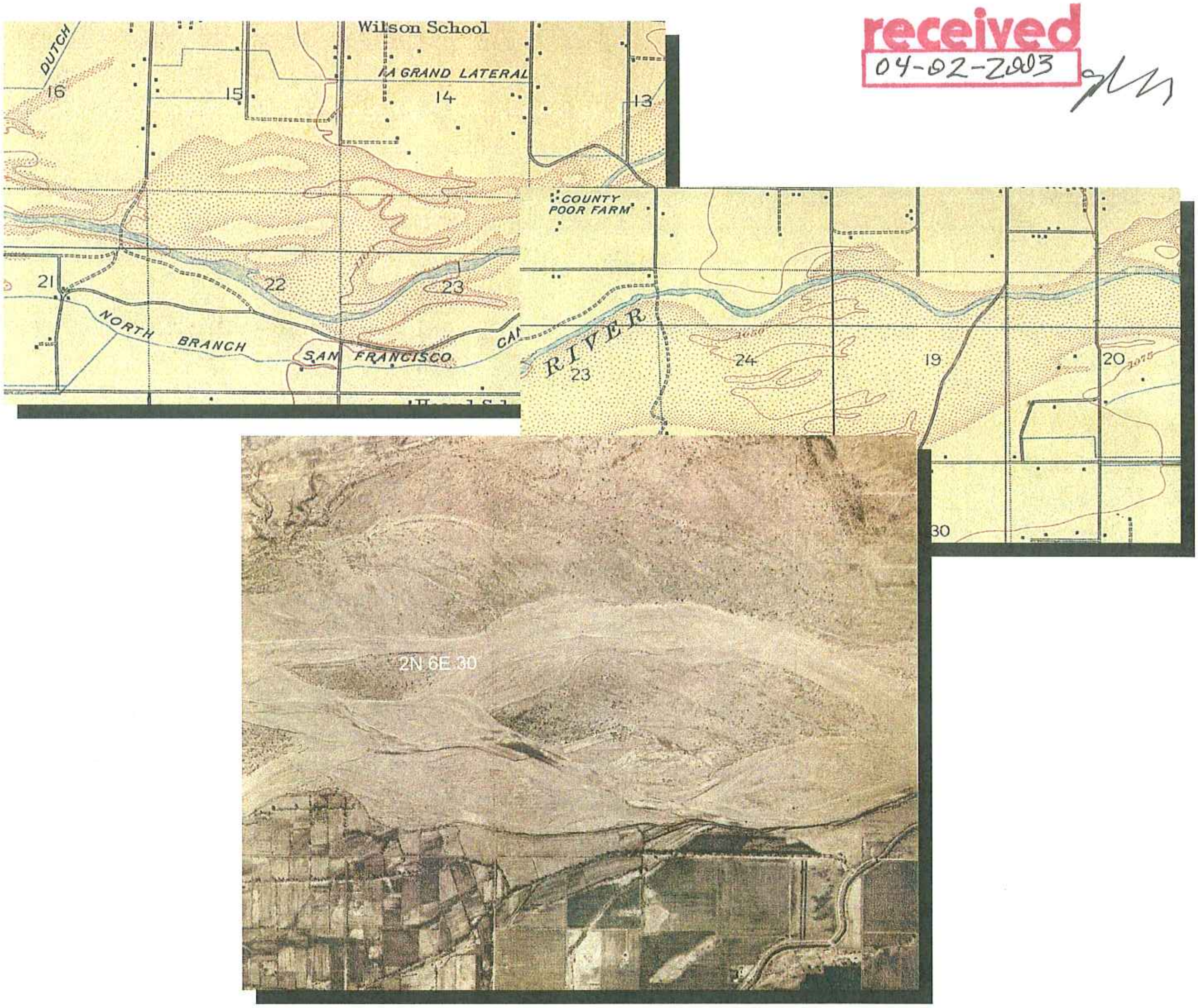
By Mark A. McGinnis
Mark A. McGinnis

Encls.

cc: David C. Roberts (w/ encls.)
Frederic L. Beeson (w/ encls.)

GEOMORPHIC CHARACTER OF THE LOWER SALT RIVER

received
04-02-2003



By: Stanley A. Schumm, Ph.D., P.G.

MUSSETTER ENGINEERING, INC.
1730 S. College Avenue, Suite 100
Fort Collins, Colorado 80525

March 2003

Maricopa County, Lower Salt River
03-005-NAV
4/7/03
Evidence Item No. 026

TABLE OF CONTENTS

Page

1. INTRODUCTION 1
2. RIVER TYPES 1

Pattern 1 1
Pattern 2 2
Pattern 3 2
Pattern 4 2
Pattern 5 2

3. THE SALT RIVER 3
4. DISCUSSION 4
5. REFERENCES 5

LIST OF FIGURES

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) 2

Figure 2. A 1934 aerial photograph of Salt River in Section 30, T2N, R6E (Mesa Quadrangle). Maximum river width is 4,800 feet. Note islands, bars, and low-water channels 5

Figure 3. A 1934 aerial photograph of Salt River in Section 24, T1N, R2E (Phoenix Quadrangle). Note islands, bars, and low-flow channels. Channel is about one mile wide 6

Figure 4. A 2002 aerial photograph of Salt River in Section 25, T2N, R5E. Much of the channel has been modified by gravel mining; however, in the south half of the channel, a large island, bars, and low-water channels remain. Original width of channel was 3,500 feet; 1,600 feet of channel remains 7

Figure 5. A 2002 aerial photograph of Salt River in Section 32, T1N, R1E. Channel is about one-half mile wide. Note vegetated low-water channels, discontinuous low-water channels, bars and floodplain 8

Figure 6. Salt River, as shown on 1903-04, 1913 USGS topographic maps of a portion of the Phoenix Quadrangle, southeast of Phoenix 11

Figure 7. Salt River as shown on 1903-04, 1912 USGS topographic maps of a portion of the Phoenix Quadrangle southwest of Phoenix 11

LIST OF TABLES

Table 1. Classification of stable alluvial channels (after Schumm, 1977)........................... 3

Table 2. Floods greater than 20,000 cfs, 1903-1934, from CH2M Hill (1996)................... 5

1. INTRODUCTION

A study of the Salt River downstream of Granite Reef Dam 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 flight over the river (February 27, 2003), a study of 1902-1903, 1913, 1952, 1955, 1957, and 1962 U.S. Geological Survey topographic maps, a study of 1902-1903 topographic map prepared by the U.S. Geological Survey and Reclamation Service, and study of 1934 and 2002 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.

2. RIVER TYPES

In order to understand the morphologic character and the behavior of the Salt River, it is necessary to consider the range of river types that exist and the Salt 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, peak discharge, sediment size, and sediment load probably 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.

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). It is relatively stable and carries a small load of coarse sediment, which may move through the channel as alternate bars. The thalweg is the deepest part of a channel.

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 Salt River pattern. The 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 channel (Table 1, Figure 1). This is a good description of the Salt River downstream of Granite Reef Dam.

3. THE SALT RIVER

The reach of concern begins at Granite Reef Dam just below the junction of the Salt River with the Verde River, and it ends at the junction of the Salt with the Gila River. Both the Verde and Salt Rivers above their junction are steep with gradients of 0.0027 and 0.002, respectively. Below the junction, the Salt River is confined by bedrock and terraces until the valley widens below the Granite Reef Dam (Granite Reef Dam quadrangle) at about T1N, R6E, Sec 28. Downstream in Sec 30, the river widened to about one mile in 1903-1904, and gradient decreased to about 0.0014. This reach of the river, between T2N, R6E, Sec 29 and T2N R5E, Sec 26, appears to be a reach of deposition, where the sediment loads of the Verde and Salt Rivers are, at least temporarily deposited. A similar situation occurs downstream of the Tempe Butte constriction (T1N, R4E, Sec 15). Sediment flushed through the constriction was temporarily deposited in the reach between Tempe Butte and T1N, R3E, Sec 13 where the river widened to in excess of one mile (Tempe quadrangle). River width in 1903-1904 ranged from about 0.5 to 1.25 miles.

The very different dimensions (gradient and width) of the different reaches makes it difficult to generalize about channel morphology except to note that it was and still is variable. Nevertheless, it is obvious that the Salt River between the junction of the Verde and Gila Rivers in 1903-1904 was a braided river, and the pattern of bars, islands, and low-water channels change through time. At present, the river has been greatly modified by gravel mining and constriction of the channels.

Chuang and Figueredo (1998) provide a description of the Salt River channel in 1935. Using a 1-mile reach of the river between Phoenix (48th Street) and Tempe (Priest Drive), they determined that the channel was composed of the following:

- 14 percent low-water channel
- 54 percent high-water channel
- 32 percent islands and bars

This distribution of islands and bars is typical of a braided channel. The 1934 aerial photographs show that the Salt River was clearly braided (**Figures 2 and 3**), and remnants of the braided pattern persist today (**Figures 4 and 5**).

An indication of the nature of Salt River at the time of Arizona statehood can be obtained from the 1903-1904 topographic maps (**Figures 6 and 7**). On these maps, a single low-water channel is identified by blue color. This channel lies within a stippled pattern that is a symbol for sand and gravel. This pattern suggests a river width often in excess of one mile, but the blue pattern indicates a much narrower low-water channel. When the General Land Office surveys of 1870 are compared with the 1903-1904 maps, it becomes clear that the Salt River occupied all of the width of the stippled pattern, and in contrast to the 1903-1904 maps, the 1870 pattern consisted of multiple channels. The comparison leads to the conclusion that the Salt River, in 1903-1904, was a wide, sandy-gravelly channel. The low-water channels shifted within the main channel and often more than one low-water channel was present.

The question remaining is how similar was the 1912 channel to the 1903-1904 and the 1934 channels? This can be determined by considering the frequency of large floods between 1903 and 1912 and between 1912 and 1935. Between 1902 and 1912, there were six floods well in excess of 20,000 cfs (**Table 2**), which would have maintained a wide braided channel during this 10-year period. The 20,000 cfs is very close to the 21,000 cfs mean annual flood, which is considered by many to be bankfull discharge. Between 1912 and 1934, when the aerial photographs were taken, there were 11 large floods in excess of 20,000 cfs (Table 2). During this 22-year period, these floods would have maintained a channel like that of the 1903-1904 maps. Hence, the 1934 aerial photographs (Figures 2 and 3) and the 1903-1904 topographic maps (Figures 6 and 7) provide a convincing picture of the channel of Salt River on February 14, 1912.

4. DISCUSSION

Figure 1 shows the differences between meandering (Patterns 3 and 4) and braided channels (Pattern 5). If an equal amount of discharge occurred in Pattern 3b and 5, it is obvious that the depth of flow would be much less in Pattern 5. For example, if there was 5 feet of water in the channel at the Granite Reef Dam location, which is 1,200 feet wide, the depth of flow at the 4,200-foot wide downstream reach would be 1.5 feet.

A means of determining flow depths for the Salt River is provided by calculating water depth for the mean annual flood of 21,000 cfs (CH2M Hill, 1996).

If discharge Q is the product of w, depth d and velocity v, then mean depth can be calculated as follows:

$$d = \frac{Q}{wv} \tag{4.1}$$

For a width of 4,200 feet at the wide reach below Granite Reef Dam and a velocity of 3.0 feet per second (CH2M Hill, p. 7.25), the average depth for the mean annual flood is 1.7 feet. This is at a flood stage usually considered to be near bankfull, and it would be a time of bar and low-water channel modification.

Clearly, unless a braided river has abundant perennial flow, it will be too shallow to permit sustained navigation. In addition, a braided river is dynamic in the sense that the multiple channels shift position and are abandoned as new channels form through time. A navigation channel in such a river would require continual maintenance.

The difficulty of maintaining navigation on such a river is exemplified by the Hayden Ferry, which was frequently washed away during high water, but it could be recovered from where it grounded on a downstream bar (CH2M Hill, 1996, p. 3-7).

This wide and shallow Salt River channel, that contained numerous bars and islands, would not be favorable for navigation. Deeper low-water channels existed, but they would be highly variable and usually not continuous. Hence, sustained navigation would not be possible and any attempt to maintain a navigation channel would fail.

Table 2. Floods greater than 20,000 cfs, 1903-1934 (mean daily cfs) (from CH2M Hill, 1996).

Date	Discharge
April 2, 1903	21500
November 27, 1095	199500
March 14, 1906	67000
March 6, 1907	50770
December 16, 1908	63000
January 2, 1910	294000
January 20, 1916	83475
April 18, 1917	27668
March 9, 1918	45375
November 28, 1919	101867
February 23, 1920	108600
September 17, 1925	20000
April 6, 1926	32000
February 17, 1927	70000
April 5, 1929	26000
February 14, 1931	34000
February 9, 1932	53000

5. REFERENCES

American Geological Institute, 1972. Glossary of Geology. Washington, D.C., p. 89.

Chuang, F.C. and Figueredo, P.H., 1998. 48th Street Crossing, Upper Reach: Priest Drive to 48th Street. In Graf, W.L. et al. (eds), Recent channel changes in the Salt River, Phoenix, Arizona, p. 54-66.

CH2M Hill, 1996. Arizona stream navigability study for the Salt River. Report for the Arizona State Land Department.

Schumm, S.A., 1977. The Fluvial System. John Wiley, New York, 338 p.

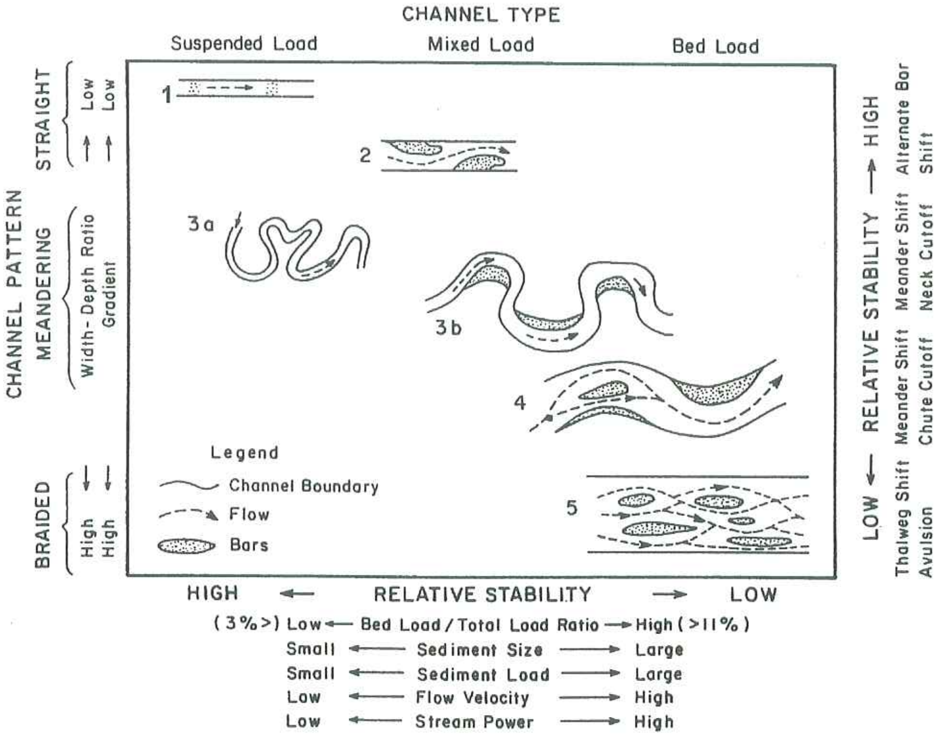


Figure 1. Channel classification based on pattern and type of sediment load, showing types of channels, their relative stability, and some associated variables (after Schumm, 1977).

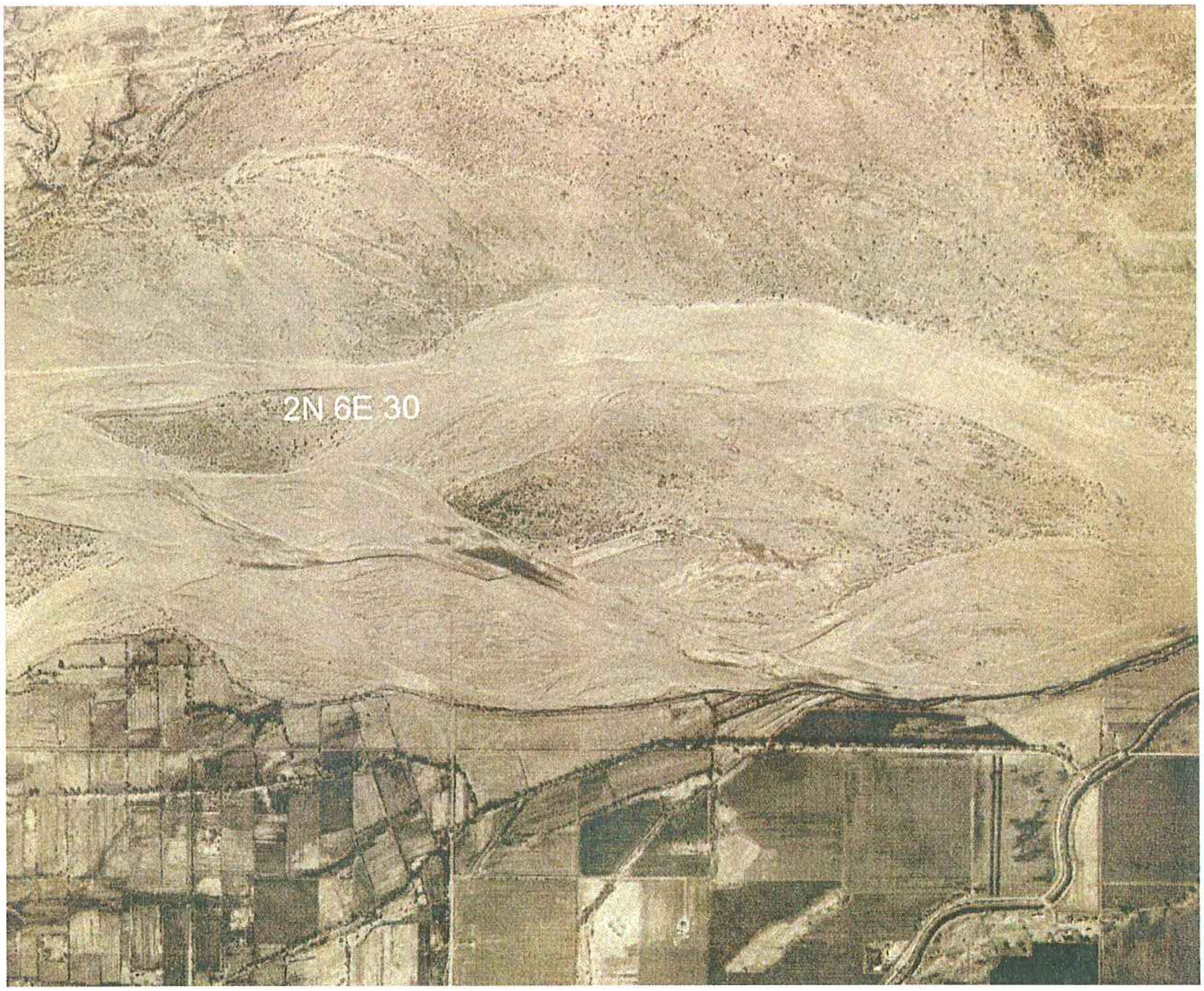


Figure 2. A 1934 aerial photograph of Salt River in Section 30, T2N, R6E (Mesa Quadrangle). Maximum river width is 4,800 feet. Note islands, bars, and low-water channels.

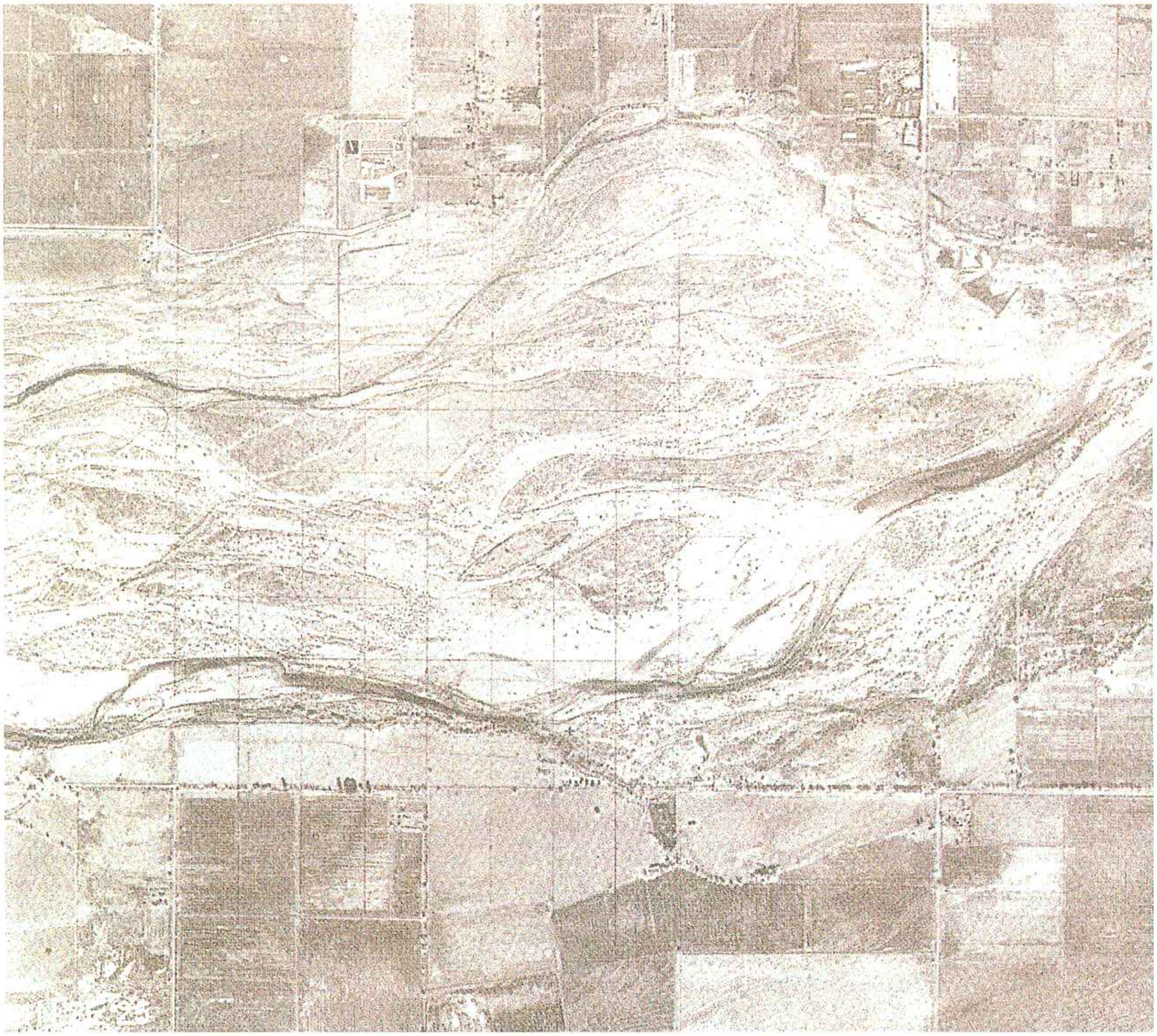


Figure 3. A 1934 aerial photograph of Salt River in Section 24, T1N, R2E (Phoenix Quadrangle). Note islands, bars, and low-flow channels. Channel is about one mile wide.

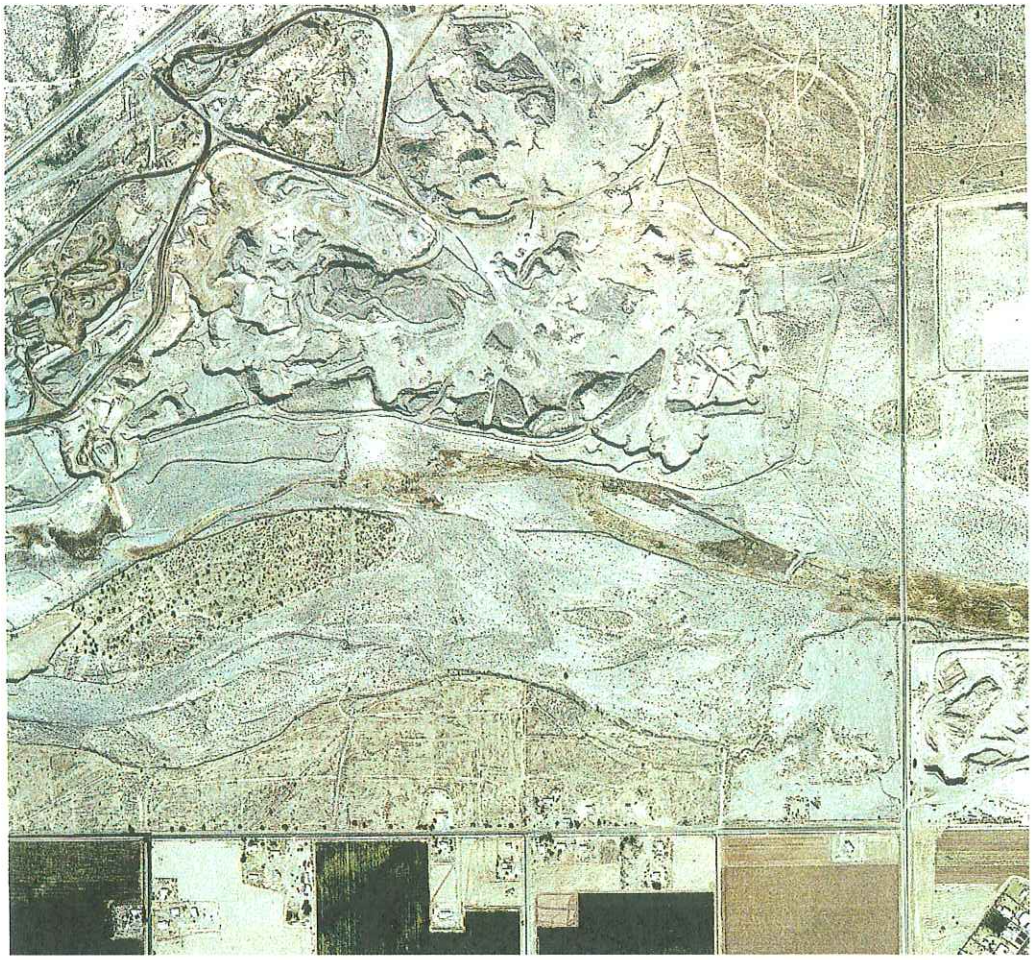


Figure 4. A 2002 aerial photograph of Salt River in Section 25, T2N, R5E. Much of the channel has been modified by gravel mining; however, in the south half of the channel, a large island, bars, and low-water channels remain. Original width of channel was 3,500 feet; 1,600 feet of channel remains.

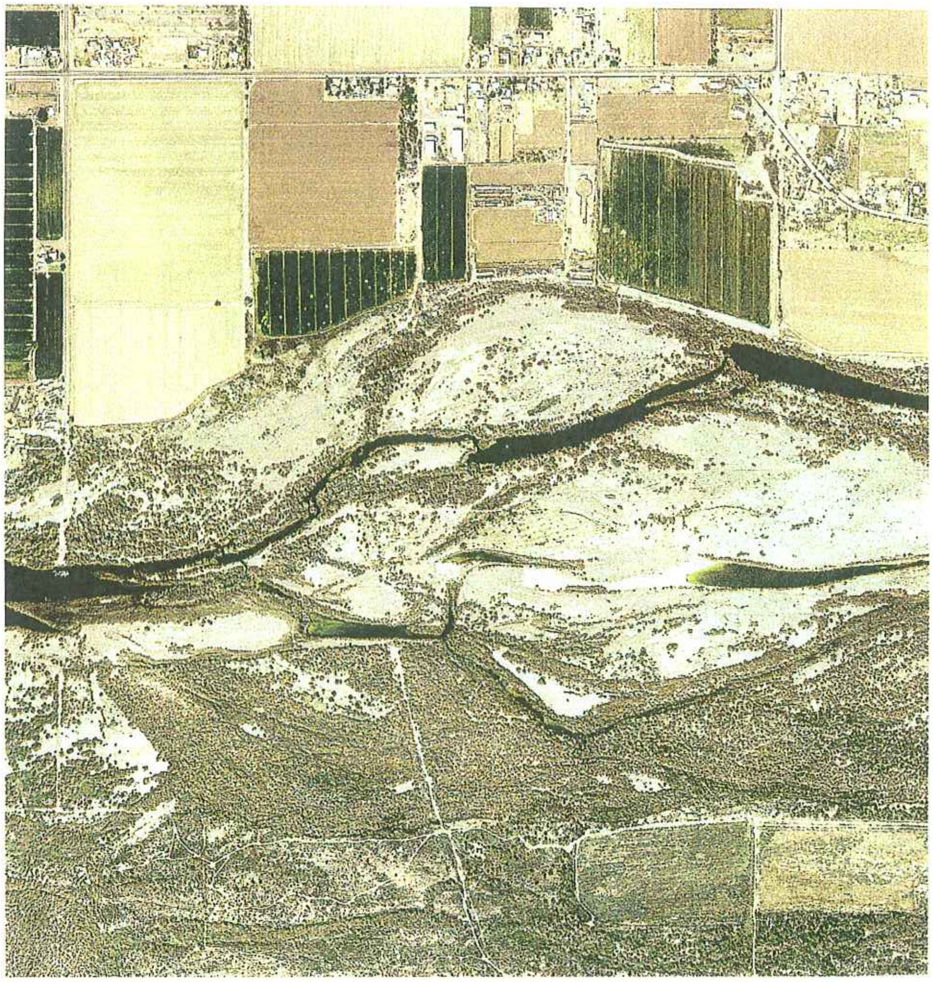


Figure 5. A 2002 aerial photograph of Salt River in Section 32, T1N, R1E. Channel is about one-half mile wide. Note vegetated low-water channels, discontinuous low-water channels, bars and floodplain.

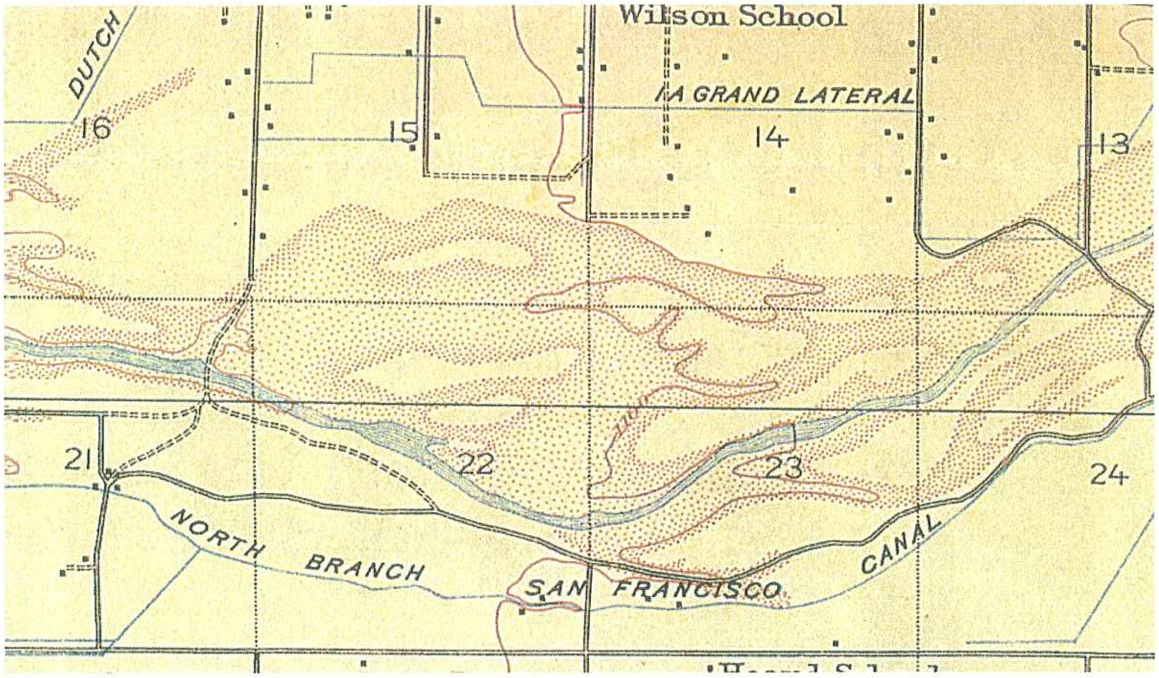


Figure 6. Salt River, as shown on 1903-04, 1912 USGS topographic maps of a portion of the Phoenix Quadrangle, southeast of Phoenix.

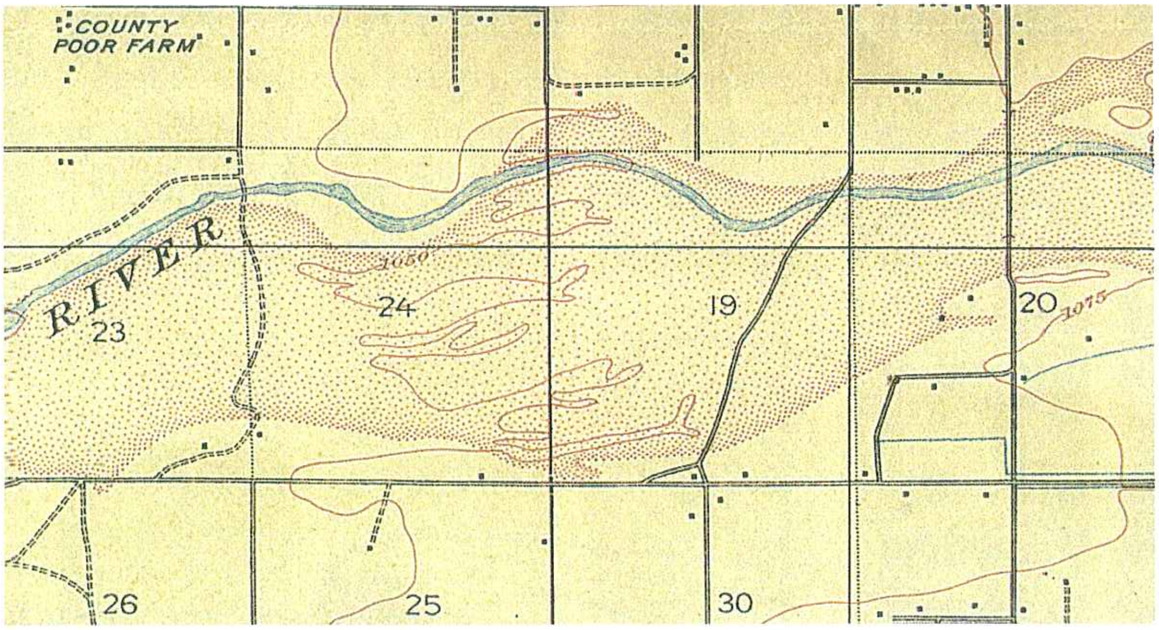


Figure 7. Salt River as shown on 1903-04, 1912 USGS topographic maps of a portion of the Phoenix Quadrangle southwest of Phoenix.

STANLEY A. SCHUMM

Principal Geomorphologist

EDUCATION:

B.A.	Geology with minor in Chemistry, Upsala College	1950
Ph.D.	Geomorphology, Columbia University	1955

PROFESSIONAL REGISTRATION:

Professional Geologist - Wyoming

PROFESSIONAL SOCIETIES:

- American Geophysical Union
- American Association Advancement of Science
- Association of American Geographers
- Geological Society of America
- American Quaternary Association
- American Society of Civil Engineers
- British Geomorphological Research Group
- Japanese Geomorphological Union

EXPERIENCE:

Dr. Schumm is an internationally recognized geomorphologist who has published over 150 papers and authored numerous books. His primary experience has been in the investigation and analysis of fluvial systems. He has applied the concepts of geomorphology, fluvial hydraulics and geology to analyze alluvial river form and shape, sediment transport and effects of man-induced changes on river systems through the United States, including the upper Midwest and in numerous foreign countries.

Dr. Schumm's experience includes research and application of geomorphic principles to riverbank erosion and avulsion, gully erosion and incised channel formation, long-term stability of mine tailings storage sites, and sedimentology and geomorphology of fan deltas. He worked from 1954-1967 as a geologist with the United States Geological Survey and taught at Colorado State University from 1967 to 1997. Dr. Schumm is recognized by professional groups for his outstanding work in geomorphic analysis of erosional processes. He is a past Chairman of the Geomorphology Division of the Geological Society of America, has served on other technical and advisory committees of the National Research Council, Geological Society of America, American Geophysical Union, International Geographical Union, American Society of Civil Engineers, U.S. Forest Service, U.S. National Park Service, the National Science Foundation and NASA. He has performed research, lectured and advised government agencies in Australia, New Zealand, Japan, Taiwan, South Africa, Canada, United Kingdom, Poland, Israel, Venezuela, Colombia and the Peoples Republic of China.

During his career, Dr. Schumm has collaborated on a wide variety of projects involving channel stabilization issues. His extensive training and experience provides a diverse, but complimentary, perspective on channel dynamics issues, and thus provides an unparalleled capability for evaluating channel erosion and instability problems and identifying appropriate restoration methods for disturbed channels.