[redacted] Flood Control

A HISTORY OF THE SALT RIVER CHANNEL IN THE VICINITY OF TEMPE, ARIZONA 1868-1969

by

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1971

PREFACE

The stream channel of the Salt River in the vicinity of Tempe, Arizona has changed significantly over the period from 1868 and the cadastral surveys of W. H. Ingalls to the present. In the nineteenth century, the river flowed continually and moved unrestricted in its valley. The land area immediately bordering the Salt River near Tempe was described as "... swampy; and populated with cottonwood and mesquite trees, and willow brush." One hundred years later, the area possesses little native vegetation, and a stream channel occupied by urban and industrial development. Only rarely does water flow in the constricted channel. The changes that occurred over the past century have resulted from the forces of nature, and from the interferences of man. This report presents information as it concerns these changes in the alluvial channel of the Salt River.

Paul F. Ruff

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INTRODUCTION

Stream channels and the lands that immediately border them (the flood plain) have traditionally been of major interest and importance to society. In the arid and semiarid regions of the United States, these level lands were first used for irrigation purposes because of their fertility, but more recently the lands are being occupied by industry and urban developments. Prior to the occupancy of these lands, any change in the location of the stream channel or in its geometry was of little consequence. However, with the occupancy of the channels and lands that immediately border them, and change in the channel's location and/or geometry becomes of immediate concern. Such changes affect the water flow characteristics of the region, and may result in losses of life and property.

The natural processes that occur in stream channel systems and the interrelations of the variables that govern these processes are extremely complex. Water flowing in a channel is subjected to both internal and external forces. Two external forces of major importance are gravity, which causes water to move in a downhill direction, and the retarding or frictional force between water that is moving and its channel boundaries. The Manning equation [1]* establishes a relationship between these forces, the channel geometry and (material) composition, and the discharge. The relationship is:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}$$

where Q = volumetric flowrate or discharge, cubic ft per second,
n = retardance factor empirically derived, $ft^{1/6}$,
A = cross-sectional area of the channel, square ft
R = A/P, ft. P = the wetted perimeter of the channel, ft.
S = slope of the channel bed.

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*Numbers in [ ] refer to the references listed at the end of this report.

The behavior of an alluvial stream channel depends on the movement of the water, and on the movement of the sediment load carried by the water. The Manning equation for most situations adequately describes the movement of the water. However, no equation or set of equations have been derived to satisfactorily describe the movement of sediment. The complexity of the problem can be appreciated by the fact that the movement of the water is dependent on the mode of the sediment movement and vice versa. The principal variables to be considered in the analysis of stream flow in alluvial channels are: discharge, sediment load, size(s) of sediment, flow resistance, velocity, channel width, depth, and slope. There is no unique interrelationship among these variables that produces a specific result. That is, more than one combination of these variables may exist to produce a specific result. The variables usually do interact, however, in a manner that creates a long-range state of equilibrium and/or cyclic condition in the stream channel. Nevertheless, it must be recognized that man's time period of observation is too short to accurately evaluate cause and effect relationships of nature [2].

The geology of a region determines the size, character, and amount of sediment transported in a stream. This sediment, in turn, determines the character of the channel (shape) boundaries, and the magnitude of "n" in the Manning equation. The configuration of an alluvial channel bed changes as the flowrate increases. During this period of changing bed forms, the resistance factor "n" is initially increasing, and the depth of flow is increasing with the increasing flowrate. However, a flowrate is reached when the bed configuration is transformed from a plane boundary to one of sand waves; it is at this transition that "n" begins to decrease. The depth of flow then begins to stabilize with the continuing increase in the flowrate [3].

The longitudinal shape of a stream channel is also dependent on the character of the channel material, and it may assume many configurations that include straight, meander, and braided forms. Examples of straight channels are rare. Even in so called "straight channels," the longitudinal path of maximum depth tends to wander back and forth from one bank to the other. Sand bars in these channels are usually distributed from bank to bank, and opposite the path of maximum depth. Straight channels afford less resistance to flow than otherwise comparable braided or meandering channels. While examples of straight channels are not common, the main path of the discharge during large flows is usually in a relatively straight line down the valley.

Braided channels are associated with aggradation, easily eroded (sandy) bank materials, rapid shifting of the bed sediments, and continuous shifting of the flow channels. A braided configuration occurs when any channel is excessively wide for the amount of sediment that is available to be transported by the water. The potential of a stream to transport sediment probably varies as the third or fourth power of the average velocity. A velocity reduction by a factor of two, for example, as caused by a widening of the channel, would decrease the sediment carrying capacity of the flow by eight to sixteen times; and the sediment would be deposited in the wide reach of the channel. The braided channel(s) that carries the largest part of the sediment load will usually aggrade until it carries only a small part of the streamflow, and eventually the channel(s) is abandoned. Fluctuating discharges also contribute to braided channel configurations. Meandering and braiding channels possess many similar characteristics. In general, however, the channels of a braided stream are less sinuous than those of the meandering stream, and braided channels develop on slopes that are steeper than those slopes producing meanders. Many studies have been conducted in the laboratory and in the field to increase the engineer's knowledge of the mechanics of stream channel formation. These studies have not been conclusive. The prediction of stream channel behavior today is more dependent on empiricism than on theoretical analysis.

CHARACTERISTICS OF THE STUDY AREA

The surface area drained by the Salt River is a series of broad, connected desert valleys and plains from which rise hills and isolated mountain ranges. The rocks that underlie the hills, ranges, and valleys are composed of pre-Cambrian metamorphosed granites and volcanics. Small amounts of sedimentary rocks are also present. The valleys and plains are filled with poorly assorted alluvium and coarse sediments interbedded with silt and clay. These materials are deposited in such an irregular manner that boulders, gravel, sand, silt and clay are indiscriminately mixed. The thickness of these sediments is known to exceed scores of feet. These sediments also exist in an ancient flood plain of the Salt River that extends from the City of Mesa southward to Chandler and the Gila River.

The Salt River originates in the mountainous area of eastern Arizona and flows westward to its confluence with the Gila River west of Phoenix. The Verde River is the main tributary of the Salt River which it joins approximately 25 miles upstream from Phoenix. The Salt and Verde Rivers are perennial in their headwaters. However, the construction of irrigation storage dams in the headwaters, and the lowering of the groundwater table in the Central Valley of Arizona, have, for all practical considerations, eliminated flows in the Salt River below the Granite Reef irrigation diversion dam (located about four miles downstream of the Salt and Verde River confluence). The flows that do occur are caused by water released downstream from the dams resulting from excessive rainfall or snowmelt that exceeds the available storage capacity of the reservoirs, or by summer precipitation.

The average slope of the Salt River from the headwaters to the mouth is 25 feet per mile, while the average slope from Granite Reef Dam (located 17 miles upstream from the study area) to the Gila River (located 22 miles downstream from the study area) is approximately nine feet per mile. The slope of the Salt River in the vicinity of Tempe, Arizona is about eight feet per mile.

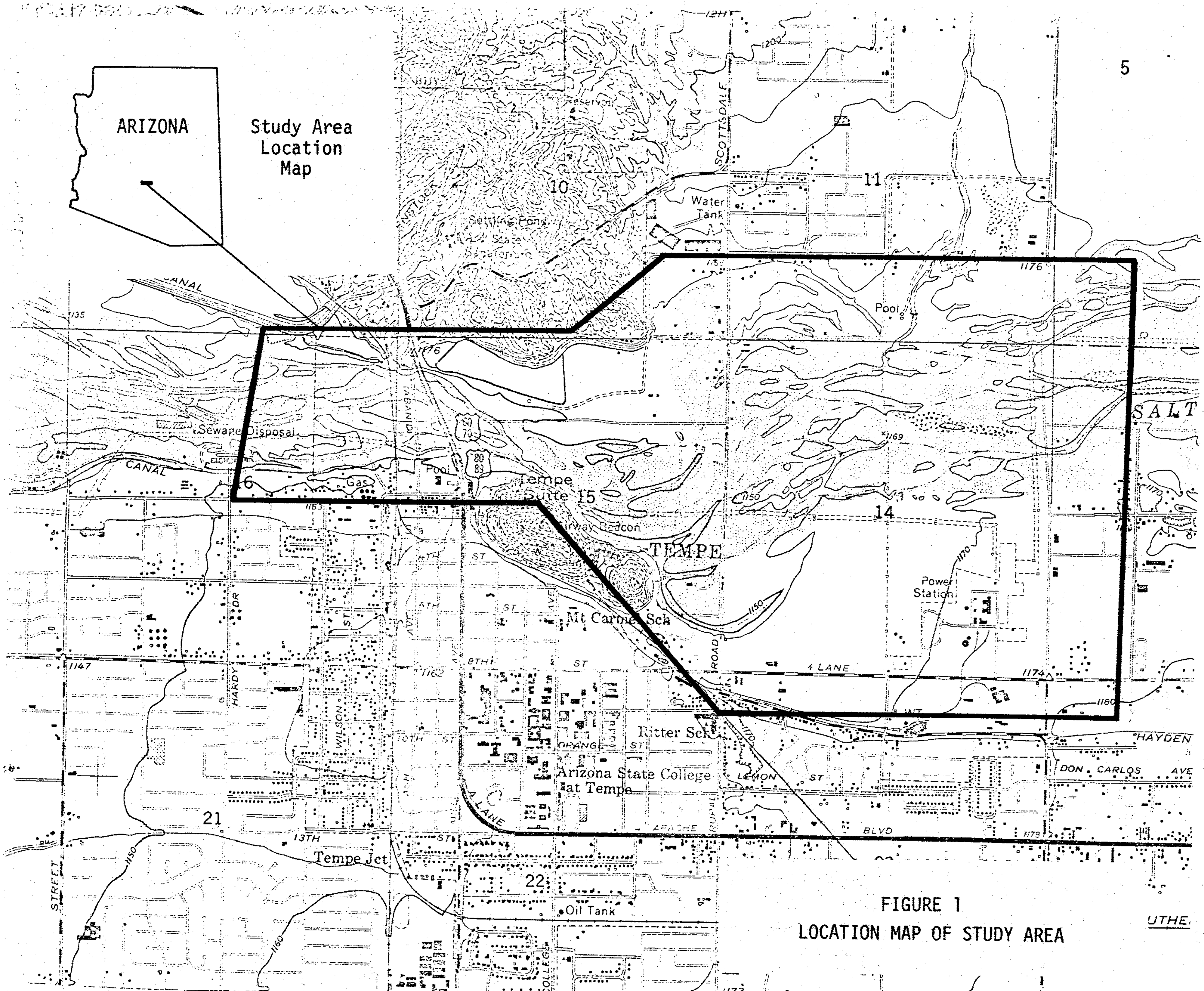

FIGURE 1
LOCATION MAP OF STUDY AREA

Historical reference to flows extends from 1888 to the present. See Appendix C. Flows in excess of 100,000 cubic feet per second (cfs) occurred below the present site of Granite Reef Dam in 1890, 1891, 1893, 1905, 1910, 1919, and 1920. The greatest discharge of record was 300,000 cfs and occurred in February, 1891. Flows of major magnitude result from winter precipitation over the basin. The frequency of large flows has been determined by the Corps of Engineers under the assumption that all existing reservoirs are full. These estimates are based on records of maximum flows for the 68-year period of 1889-1957.

TABLE I. DISCHARGE FREQUENCIES OF THE SALT RIVER AT GRANITE REEF DAM [4]

Number of Times (on the average) That a Flow would be Equaled or Exceeded in 100 Years	Maximum Flow Salt River at Granite Reef Dam Site Cubic Feet per Second
0.6	290,000
1	240,000
2	175,000
5	108,000
10	68,000
15	50,000[1]
20	38,000[2]
25	25,000[2]

[1]Minimum damaging flow. [2]Estimate by others.

SOURCES OF INFORMATION

Cadastral surveys made in 1868 of the study area of this report give some descriptions of the stream channel, the vegetation, and the soil types of the neighboring lands. This information, as well as data from partial resurveys of the area, is in the files of the U.S. Bureau of Land Management, Phoenix, Arizona.

Maps drawn from the cadastral surveys are also in the files of the U.S. Bureau of Land Management. Detailed topographic maps for 1903-04 and 1934-53 were obtained from the Salt River Project, Phoenix, Arizona. U.S. Geological Survey maps are also included in this report.

Early photographs, even prior to 1900, of the Salt River are in existence in private collections, the Arizona Room of the Arizona State University Library, Phoenix newspapers, and the Maricopa County Flood Control District. However, the pictures are generally void of details--scenes of water destruction, ferry boats, and flows of water with no identifying landmarks, and so forth.

Photographs for 1934 through 1949 were made available by the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service. The photographs for the period of 1954 through 1969 were obtained from Landis Aerial Surveys and Don Keller, Phoenix, Arizona. The model study photographs were made by the author.

Stream flow data of discharges at Granite Reef Dam were obtained from the files of the Salt River Project.

The cross sections of the study area (1962) were drawn from detailed maps of the Maricopa County Flood Control District. The cross sections of 1969 were surveyed and drawn by Mr. P. E. Borgo, Professional Land Surveyor, Arizona State University.

THE SALT RIVER, 1868-1969

1868

The Salt River flows on two distinct channels as it crosses the present location of Scottsdale Road (section line between Sections 14 and 15). The south channel, designated as "Indian Slough," is approximately twice the width of the north channel, which is referred to as the "Salt River." Mr. W. H. Ingalls, responsible for the cadastral surveys of the region, describes the area along the boundary between Sections 11 and 14 as, "...low and inclined to be swampy; with timber cottonwood along banks, and mesquite and willow brush." References: Appendix D; Figure A-1.

1891

A flow of about 300,000 cubic feet per second (cfs) occurred--the largest flow to date (1971). The area of land inundated by this flow has been estimated by the U.S. Geological Survey. The banks of the low flow channel(s) of a stream and the general configuration of the water's path are usually not the banks and configurations of large flows. It must be assumed that the geometry of the Salt River channel was materially changed by the 1891 flow. References: Appendix D; Figure A-6.

1903-04

Through the study area, the Salt River divides into two distinct channels farther eastward than in 1868. The location of the south channel, along the boundary of Sections 14 and 15, has not noticeably changed since the Ingall's survey; however, Indian Slough has moved somewhat southward. Along the boundary of Sections 13 and 14 (present location of Hayden Road), Indian Slough now occupies the single stream channel of 1868, while a south channel is located approximately 1/2 section southward of Indian Slough. West of the study area the Salt River becomes a single channel, but in 1868 the river in this region flowed in two widely separated channels. Reference: Figure A-2.

1910

The Salt River (south channel) is in approximately the location of 1903-04, although major discharges did occur in 1893, 1905, and the early spring of 1910. Reference: Figure A-3.

1934

A plain of sediments that is void of vegetation exists in the central part of the study area. However, the plain is bordered by vegetation that delineates the low flow channel(s). In the 24-year period following the 1910 survey, only three discharges of major size occurred (1919, 1920, and 1927). The channel area is unstable as it fills with sediments carried into the region by relatively small flows of water. The constriction of the Salt River channel as it passes the Tempe Butte and the conglomerate outcropping to the north is the cause of the variability in the channel(s) locations. This constriction in effect produces a gorge, and stream channels above gorges are notoriously unstable. In this region of the Salt River, the flow of water is pooled and the resulting decrease in the water velocity causes the sediments carried by the water to be deposited in the backwater area, and in relatively large volumes. The Salt River does not have the ability to move the sediment continuously through the constriction [5]. A meander loop that has developed into Sections 10 and 11, and along their common boundary of Sections 14 and 15, is restrained from moving downstream by the channel constriction previously mentioned. The slope of the river channel decreases as it approaches the Tempe area. This reduction of slope must result in an increase of water depth, or in a decrease of the resistance factor "n," if the channel is to convey the discharge. In the study region, sediment deposits are the major cause of the channel bed instability, and the "n" value does change resulting from bed form change(s). The discharge moves faster in the regions where the "n" has been decreased; the depth of water in the channel and the bed slope remain relatively unchanged. Reference: Appendix D, Plate 1.

1941

A flow of 46,000 cfs occurred in the spring of 1941. Prior to this discharge there were flows of 95,000 cfs in 1938 and 63,000 cfs in 1937. The meander loop noted in 1934 does not appear to have noticeably changed its location, but the braided channel is more easily recognized than in earlier photographs. The study area of the river is wide and shallow, which is typical of a stream channel that is filling or is in the process of aggradation. As this channel fills, the stream shifts laterally whenever there are no confining walls, and flows to lower adjacent ground. Small channels literally cover the study area, with each channel potentially representing the flow channel for a particular discharge. Any number of factors could disturb this heterogeneous pattern of flow channels--for example, Scottsdale Road which represents a low, compacted earth, and paved obstruction. This roadway cuts off these small channels and becomes a dominant factor in analyzing potential low stream flow configurations; this is not true for large flows. The historical flow channel areas at the extreme north (top of the meander loop) and south, and that lie between Sections 10-11 and 14-15, are mutually exclusive. The meandering channel (north) carries water and is the result of natural forces acting within the Salt River waters and its channel. The configuration to the extreme south is of unknown origin. This area could be the site of a historical meander loop for which no records exist, or the configuration could be the result of high flows entering the Salt River from the Indian Bend Wash. This area does lie in a direct line with the wash as it enters the river. References: Appendix D; Figure A-4; Plate 2.

1949

The river channel is now a filling one with even moderate discharges so infrequent that any local inflows deposit their sediment loads almost immediately as the water infiltrates the channel bed. That is, the inflow is greater than the outflow from the area, and this streamflow depletion does influence the (increased) rate of deposition. It should be noted that no (major) streams enter the

Salt River downstream from Granite Reef Dam. The water that has entered the channel during this time period is primarily from overland flow resulting from local precipitation. Few occupants are located in the channel area. However, an extensive dike system now exists in the northwest corner of Section 15. The potential influence of this system of dikes was determined from a model study of the Salt River. Backwater effects and the displacement of flows southward were observed. Roadways have been constructed in the study area. References: Plate 3; Plates E-1 and -2; Appendix D.

1952-54

Urban dwellers and industry have started to move into the channel area of the river. However, a continual shift of the river channel(s) in an erratic manner is of no concern until this opportunity to move is lost where people have encroached upon the channel area. Gravel mining operations are also in progress. References: Figure A-5; Plate 4.

1957

Urban, industrial, gravel, and roadway developments continue to increase and occupy the river channel. Reference: Plate 5.

1958

"Works of man have been such as to almost completely obliterate the original channel in many areas. ...Sand and gravel companies have operated in the river bottom; subdivisions have encroached upon the old original flood channels; a large sanitary fill has been built; and other types of work by man have tended to constrict or to obliterate the original channel. ...It must be pointed out that the hazards to life and property are great in this area. A narrow low-flow channel should be developed throughout the reach of the river. The channel of two thousand feet in width as delineated in the Corps of Engineers report is considered advisable. At present, there is no defined channel. ...The whole river area should be rigidly zoned." Reference: Report of Flood Protection Improvement Committee (Maricopa County), Phoenix, Arizona, 1958.

1964

The operations and developments that have been noted previously continue to further expand in the channel. A sewage treatment plant lagoon and the accompanying outfall appurtenances have been constructed immediately east of the confluence of the Indian Bend Wash and the Salt River. A comparison of Plates 2 and 6 clearly shows that the treatment plant does indeed lie in the Salt River channel. Reference: Plate 6.

1965-66

A study of Plates 2 through 7 shows the high rate of urban and industrial encroachment and occupancy of the Salt River channel. The Salt River Valley as well as the channel itself are being urbanized and industrialized. The sewage treatment plant facility observed in 1964 has been greatly enlarged and now occupies approximately 50 percent of the area normal to the flow of the entire river channel. This facility also completely blocks any possible flows of the river in its (north) meandering channel. Reference: Plate 7.

In December-January, a discharge of 65,000 cfs occurred on the Salt River below Granite Reef Dam [6]. The damages in the area of inundation were great. During this period of large discharge, and accompanying high water velocities, the water course has been routed to the south part of the river channel plain by the developments in the northern portion of the channel, namely the sewage treatment plant lagoon and appurtenances, and the urban and industrial occupants west of the lagoons. It is also evident that these obstructions have curtailed or stopped the normal flow of the water in both a north and westerly direction. Without these deflectors and obstructions to the flow a greater area of the land in the upper part of Section 15, north of the Tempe Butte, would have been incorporated into the major flow channel. The influence of the sewage lagoons was further examined in a model study. The model studies showed that before the lagoons were constructed the flow in the area was in a west and northwest direction, and after construction the flow was grossly diverted to the south. The high velocity flow during this large discharge is in a channel that lies north of the Tempe Butte and the existing transmission towers. The retarding and inhibiting influence of the developments along Scottsdale Road and the north part of the channel are clearly evident in Plates 8 and 9. The large degree of development--for example, houses, fences, major structures, and so forth--that deflected, in part, the normal course of the flow is shown in Plate 9. Also of interest in this photograph is the geometry of the flow, and the tortuous path it is caused to assume by the developments. These developments are partly responsible for the relatively static body of water that exists in the north part of Section 15. It appears that this area would have been a major flow channel if the discharge had not been diverted to the south as already noted, if this channel area had not been blocked to the east by the sewage treatment plant lagoons and appurtenances. References: Figure A-6; Plates 8 through 12; Plate E-3.

The channel immediately after the 65,000 cfs flow bears slight resemblance to the channel of, say, 1941. Little water has been allowed to flow in its historic channel. It is of interest to note that a large part of Scottsdale Road, north of the channel, was not removed by the discharge but remained an obstruction throughout the flow. A comparison of Plate 7, of the poorly defined channel before the large flow, and Plate 13, of the channel cut by the flow, afford a good study of the man-made encroachments on a stream channel region and the results of the stream's efforts to reclaim its channel. Reference: Plate 13.

1969

The encroachment on the river channel continues unabated. A dike system immediately east of Scottsdale Road, and the interceptor channel and accompanying protective dike for the City of Scottsdale's large storm drain, are potentially dangerous obstructions to a large flow in the river. The Salt River is now restricted to a 40-foot opening through this dike system. A model study of this construction shows the geometry of the severely constricted channel flow [7]. Material has also been placed immediately north of the Arizona State University stadium. The model study of this work has indicated that this material can increase the hydraulic efficiency of the river channel. An increased efficiency is caused by the flow being directed in a straighter path than has previously been possible through the Tempe constriction. References: Plate 14; Plate E-4.

A PICTORIAL STUDY OF THE SALT RIVER

1934-1969

PLATE 1

January, 1934

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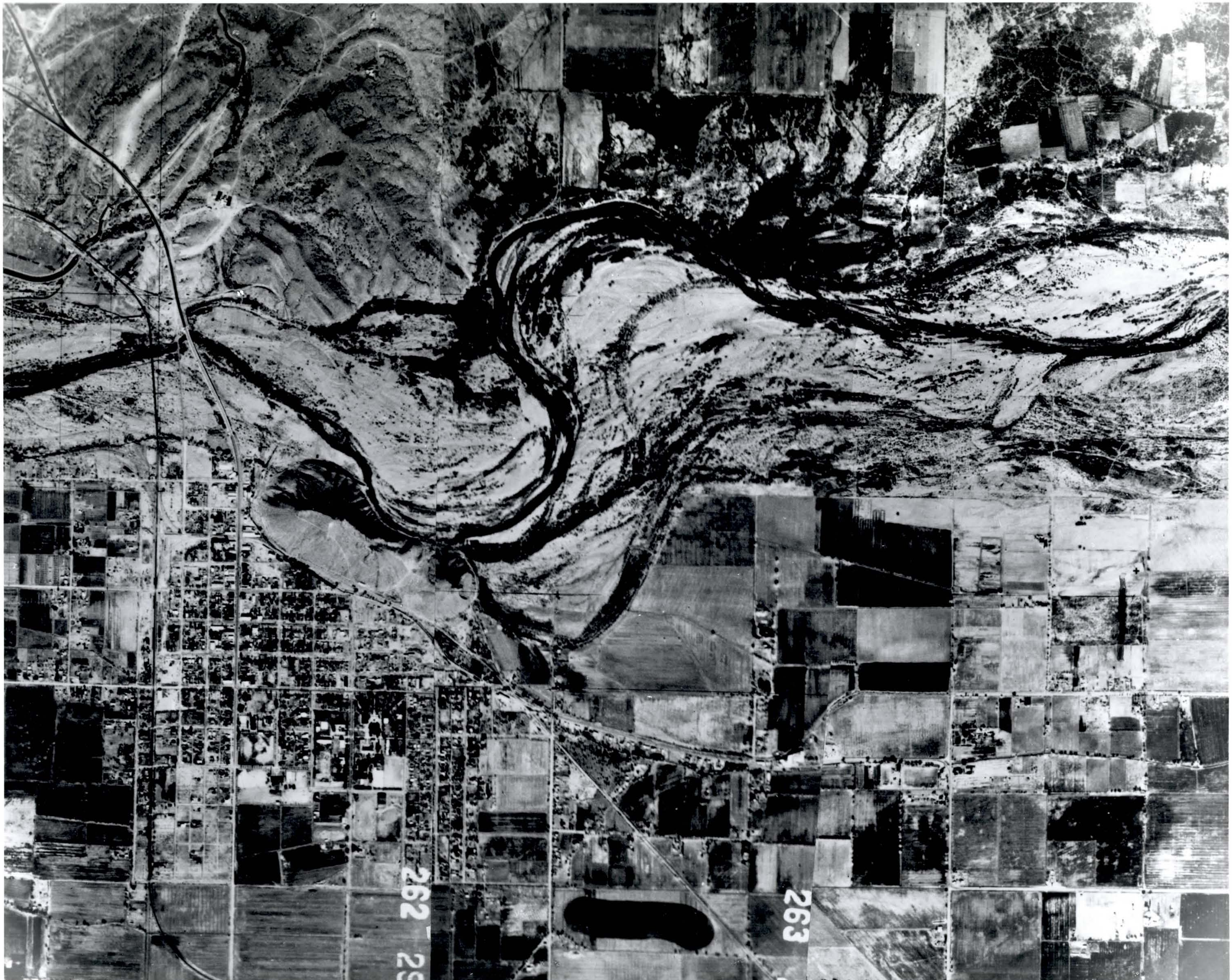
The variability of the location of the Salt River in the Tempe area is primarily the result of the channel constriction formed by the Tempe Butte and the conglomerate outcrop on the north side of the channel. The constriction causes a backwater area to develop. The river does not have the ability to move the waterborne sediments through the Tempe constriction, and the sediments are deposited. Streams that flow in channels filled with large deposits of sediments are notoriously unstable.



262
29
263

PLATE 2

July 26, 1941

A wide and shallow river course is typical of channels that are in a process of filling or aggradation. During this process the channel(s) continually shift and move to lower adjacent topography. Each small channel potentially represents the flow channel for a particular discharge. Large discharges, however, move in a relatively straight path down the valley.

PLATE 3

February 17, 1949

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The water that once flowed continually and unrestrained in the Salt River is now stored in the upstream dams. Periodically, overland flow resulting from local precipitation does enter the river course, but it soon deposits its sediment load as the water infiltrates the already sediment-filled channel bed. The presence of the dike system located north and east of the Tempe bridges significantly reduces the flow passage area of the Tempe constriction.

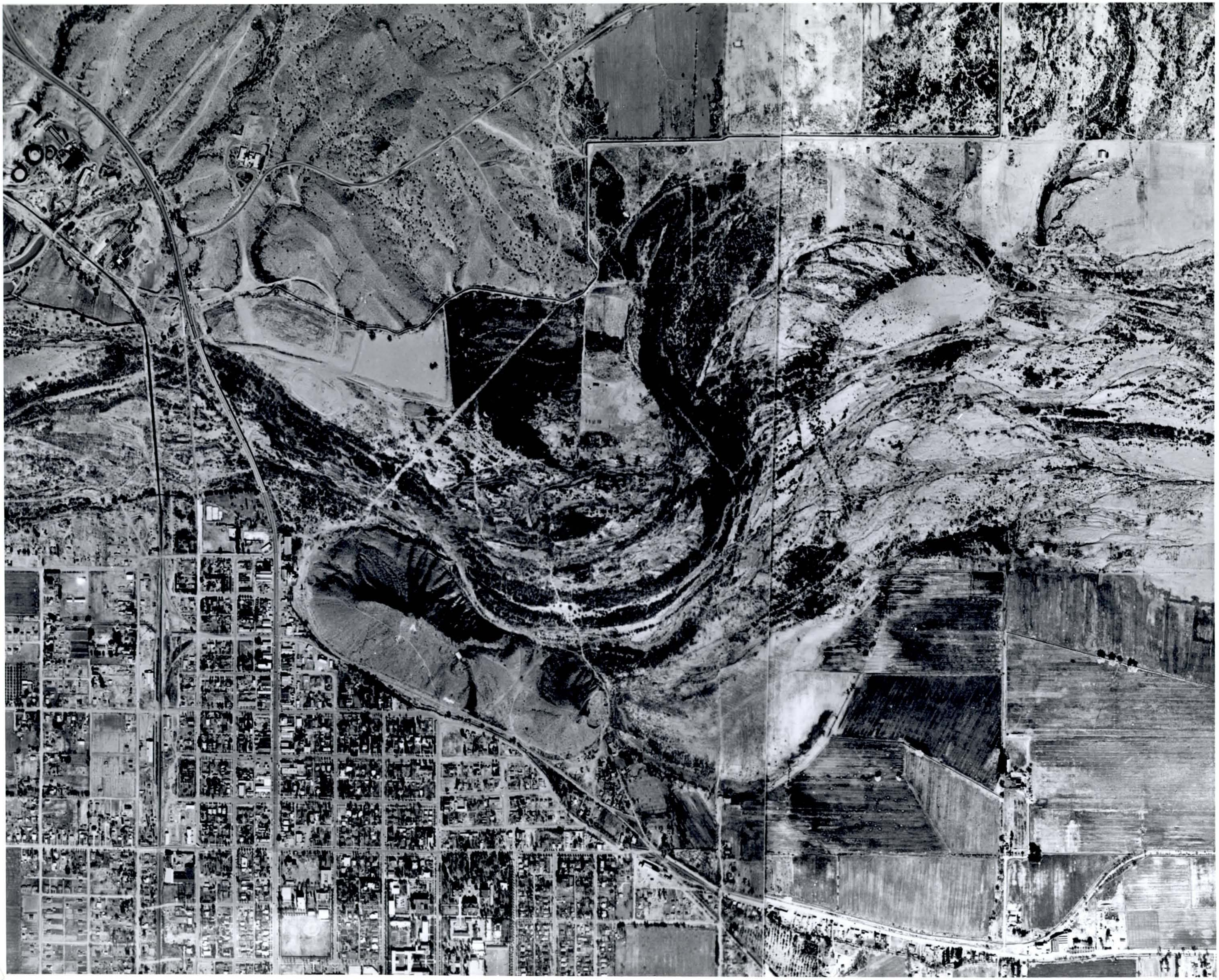

PLATE 4

January 26, 1954

The geometry and the location of a river course changes slowly and in an erratic manner. This change is of little concern to anyone until a large flow assumes possession of its channel, and help is needed to keep the water from the doors of the channel's intruders.

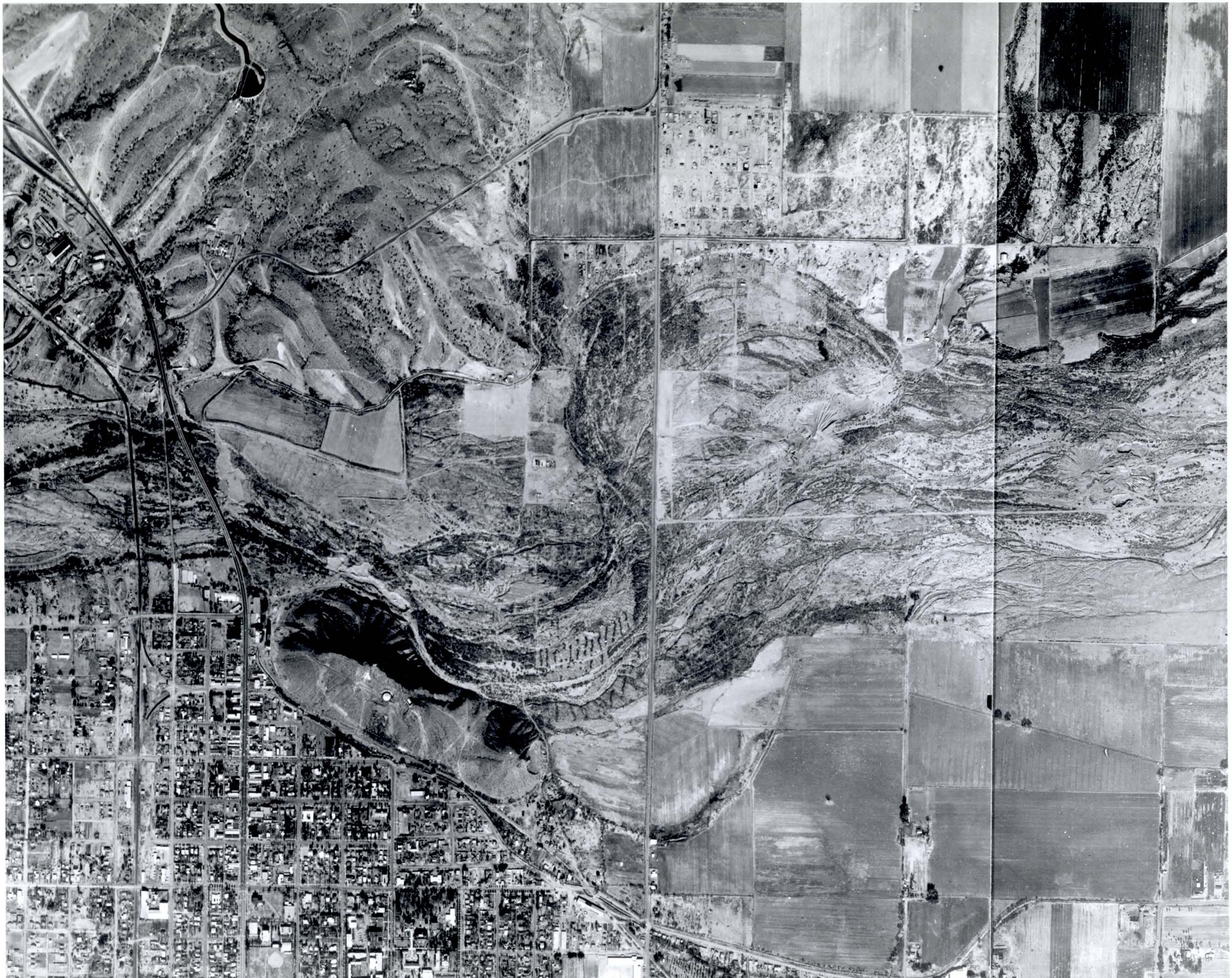

PLATE 5

December 30, 1957

Page 20 →

Roadways, urban development, and gravel operations begin to make the river channel a functioning part of the metropolitan community. The channel is dry; the river has few tributaries in this reach...the drainage area of the Gila River lies very close to the Salt River channel in the Tempe area.

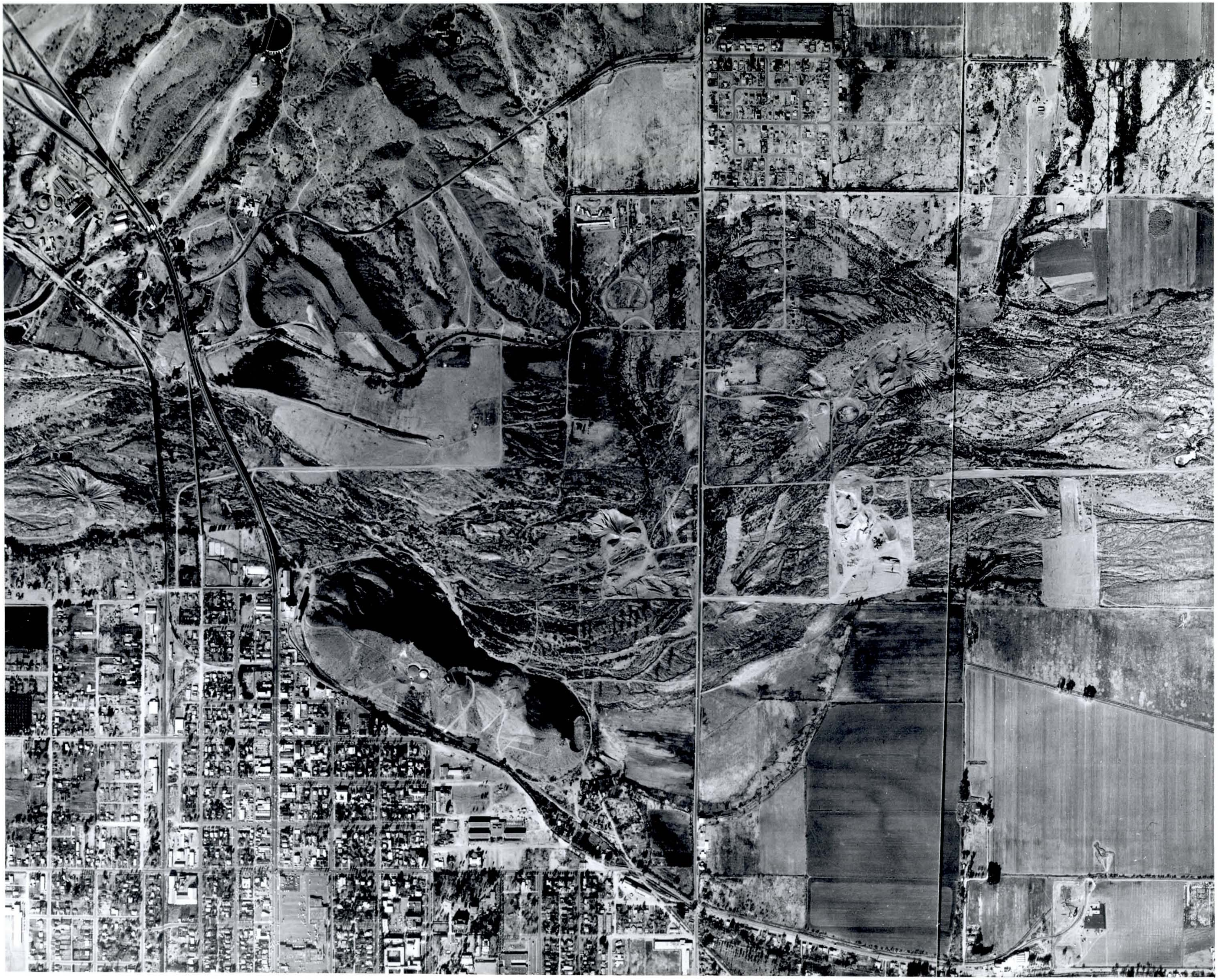

PLATE 6

January 2, 1964

Page 21 →

The potentially active flow areas of the river continue to be occupied; a sewage treatment plant facility now partially occupies the river channel. The natural and historically defined flow channels are being obliterated.

LANDIS AERIAL SURVEYS
1410 N. CENTRAL PH. 252-9746
PHOENIX, ARIZONA 85004
PHOTO DATE 12-30-57
NEGATIVE NO.

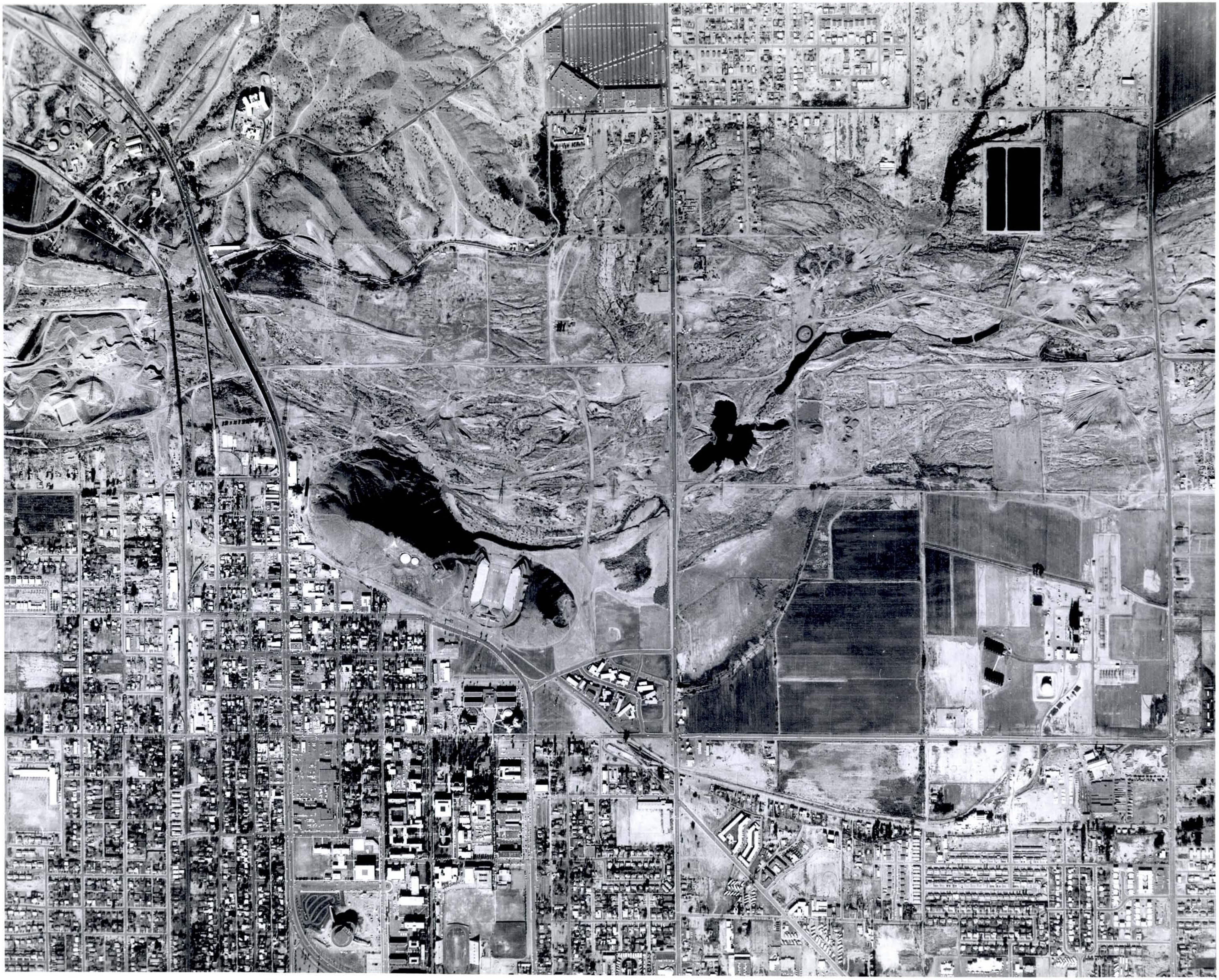

PLATE 7

January 12, 1965

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Urban and industrial development, roadway construction, gravel operations, and so forth, proceed with gross oblivion to the river's priority for its channel. The historic channel area normal to the flow path of the river has been reduced 50 percent by the sewage treatment plant and its appurtenances. Developments and operations in the channel area further reduce the potential efficiency of the river to carry its periodic discharges.

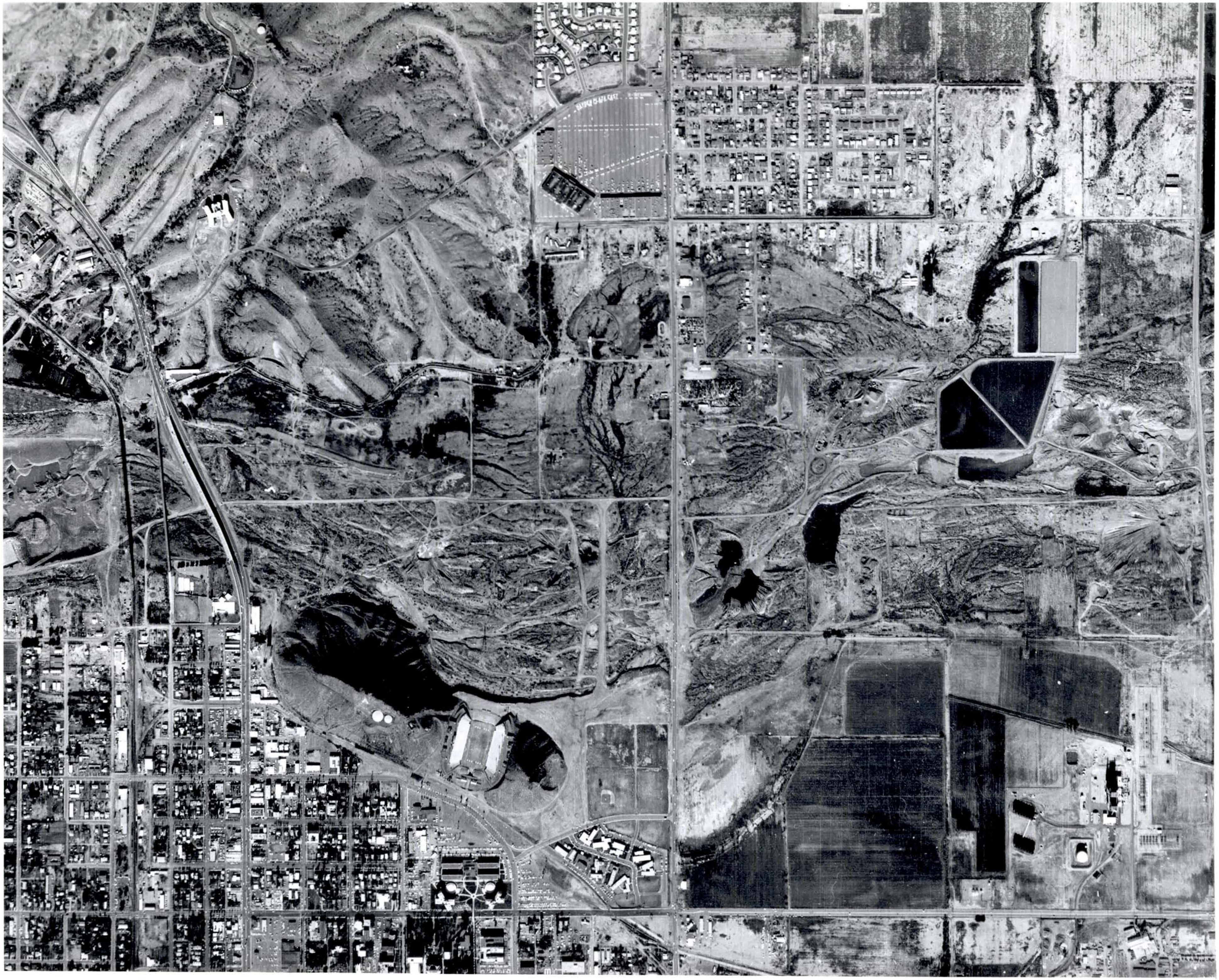

PLATE 8

December 31, 1965

When man occupies a river channel and the area immediately adjacent to it, he can expect that the river, at certain times, will contest his occupancy. This flow of 65,000 cfs can be expected to occur, on the average, once every 12 years. The high flow channel of a river usually does not coincide with the low flow channel(s); during a large discharge the main flow path is in a relatively straight line down the valley. All of the obstructions to the flow of this river in its natural channel, which have been developed over the years, now direct the flow southward. Observe the position of the dike system east of the Tempe bridges and the water that is ponded.

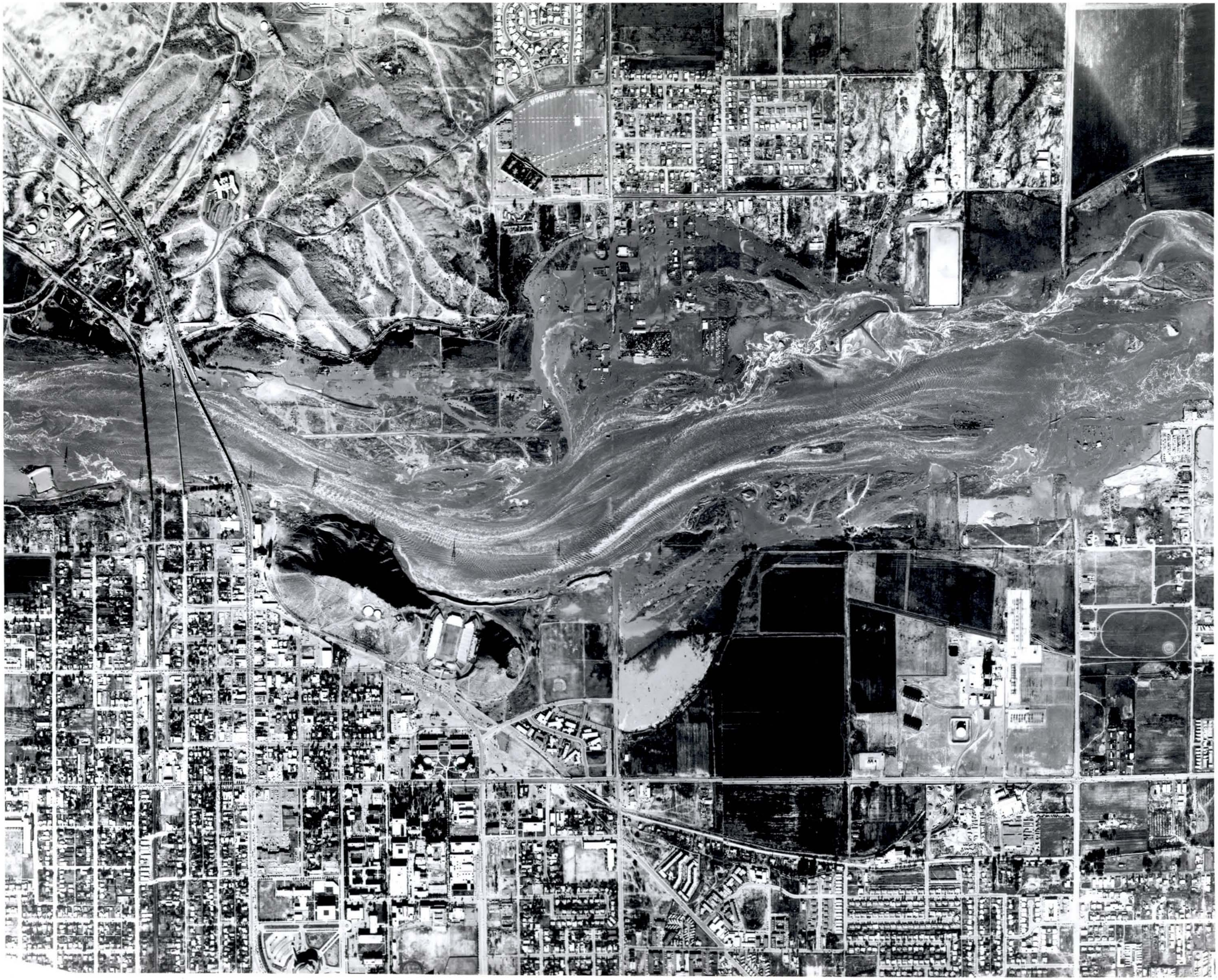

PLATE 9

December 31, 1965

The path of high flowrate and velocity is located in the region of the water surface waves. These waves are caused by sand waves on the bed of the channel, and the resistance to the flow in these regions is relatively low. The large sand bars north of the Tempe Butte would be severely eroded if the discharge had not been diverted southward.

PLATE 10

December 31, 1965

The river does attempt to occupy its historic water course. The white lines (configurations) on the water's surface are indicative of the tortuous path and resistance afforded the water by houses, roadways, fences, and so forth, as it endeavors to flow westward.

PLATE 11

December 31, 1965

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The main route of the discharge is immediately north of the existing electrical transmission towers. Earth work(s) is responsible for the water that is ponded and adjacent to the large sand bars (right-center of picture).

PLATE 12

December 31, 1965

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The lagoons of the sewage treatment plant are visible in the upper left corner of the photograph; their influence on the flow of the river is obvious. Water surface waves and areas of high velocity flow are also evident. The earth work(s) responsible for the water ponded north of the large sand bars is clearly visible.


Don Keller
PHOENIX, ARIZ.

PLATE 13

January 13, 1966

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Extensive erosion results when major flows occur that have low sediment content. Sand bars have developed immediately north of the Arizona State University stadium, north of the electrical transmission towers, and northwest of the Tempe Butte. The sand bars were formed during the falling (stage) discharge of the river.

PLATE 14

January 2, 1969

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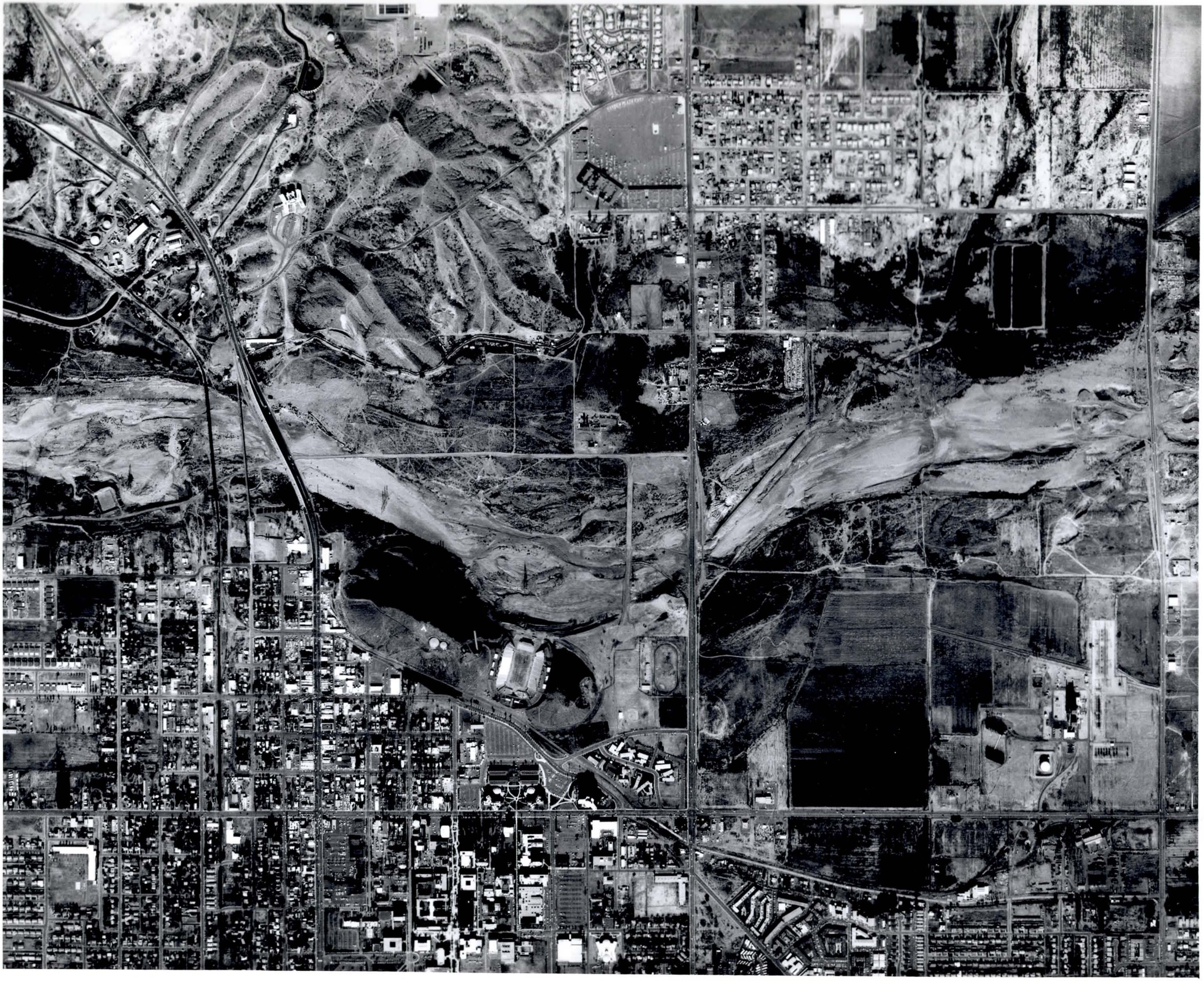
Occupancy of the channel continues with no apparent regard for the value of life or property. The dike system immediately east of Scottsdale Road will pool the flows of the river, and have the potential of directing river discharges into the City of Tempe. The occupants that are now situated in the river channel and west of the dike system have been given a sense of false security by the presence of the dikes.



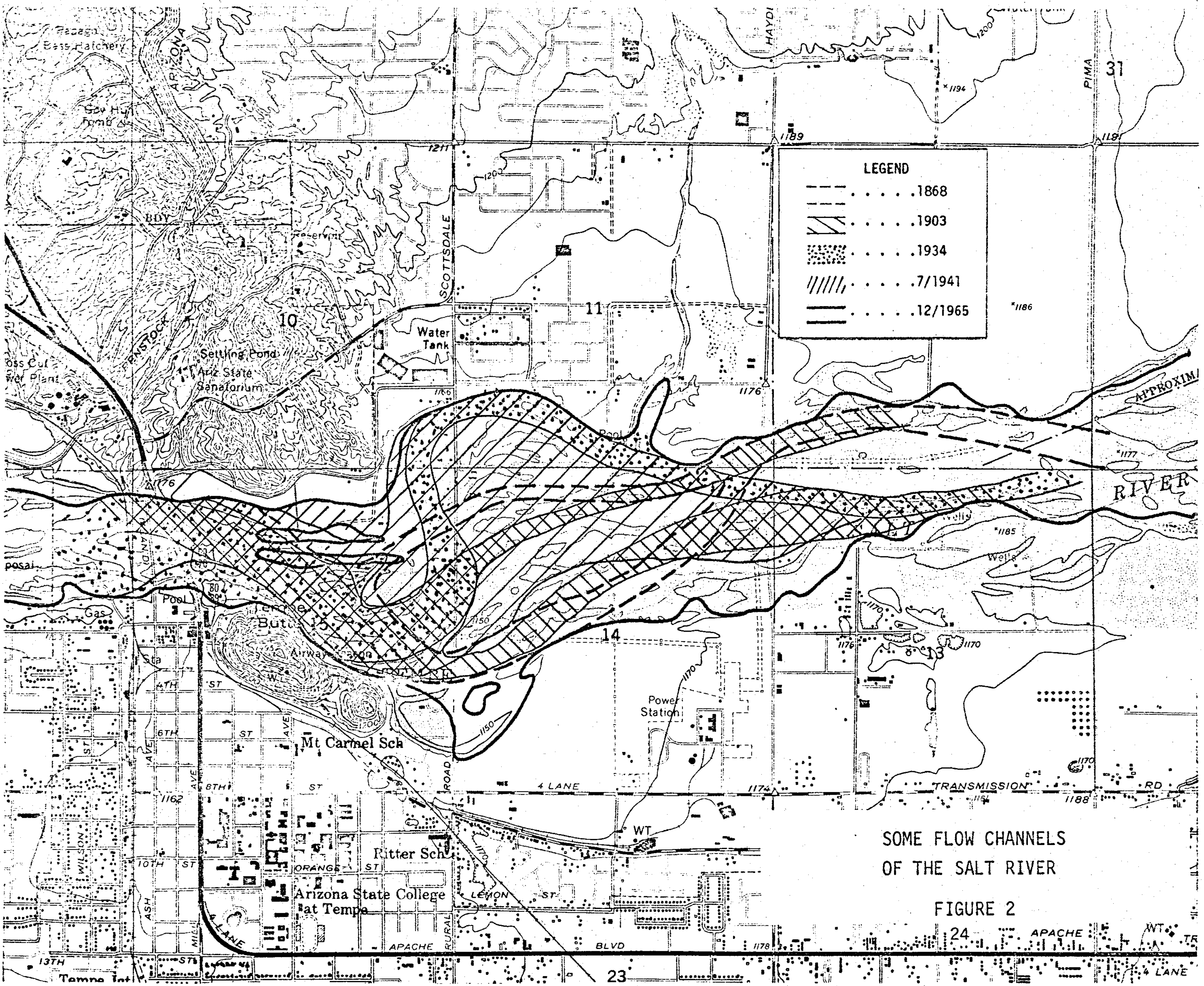
SUMMARY

The available survey records, maps, and photographs of the Salt River in the vicinity of Tempe, Arizona all demonstrate the continually changing disposition of the river's channel. These changes have historically resulted from the forces of nature, which are only incompletely understood by man, as they cause the river's flowing water to carve a channel and transport debris. Recent history, however, has recorded that man is contesting the right-of-way of the flows of the Salt River.

Prior to man's attempted dominance of the Salt River, the location of the river's channel assumed a myriad of positions. See Figure 2. It may be assumed that the short-range limits of potential channel locations are the extreme north and south boundaries of the area inundated by the 65,000 cfs flow in 1965. The long-range limits can be assumed as the inundated area of the 1891 discharge.

Man has now placed severe constraints on the river's channel configuration and location. Houses, fences, industrial structures, roadways, gravel pits, and dikes all attempt to enforce man's dominance; this dominance will prevail--until at certain times nature does contest his occupancy. Man can and has controlled the location and geometry of the channel of the low discharges of the river, but at the present he can offer only little control and resistance to large flows.

Planned development of the Salt River channel and its adjacent lands must soon become a reality. Legislation, zoning, water control structures, bridges, and so forth must be recognized as an integral part of any plan for the total development of the Salt River area.



SOME FLOW CHANNELS OF THE SALT RIVER

FIGURE 2

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5. Personal communication with Mr. Thomas Maddock, Jr., Research Hydrologist, United States Geological Survey, Tucson, Arizona.

6. Aldridge, B. N., "Floods of November 1965 to January 1966 in the Gila River Basin, Arizona and New Mexico, and Adjacent Basins in Arizona," Geological Survey Water-Supply Paper 1850-C, 1970.

7. Ruff, P. F., "A Study of the Flow of the Salt River, Tempe, Arizona," July, 1970, Arizona State University, Tempe, Arizona.

ACKNOWLEDGEMENTS

This investigation was sponsored by the Office of the Vice President for Business Affairs, Arizona State University, Tempe, Arizona. Many organizations and individuals were consulted during the course of the study and are listed below. In many instances, the organizations and/or individuals could supply no data for the study, but did suggest additional sources of information. Under no circumstances is the reader to imply that any of the listings below find agreement with all or any of the contents of this report.

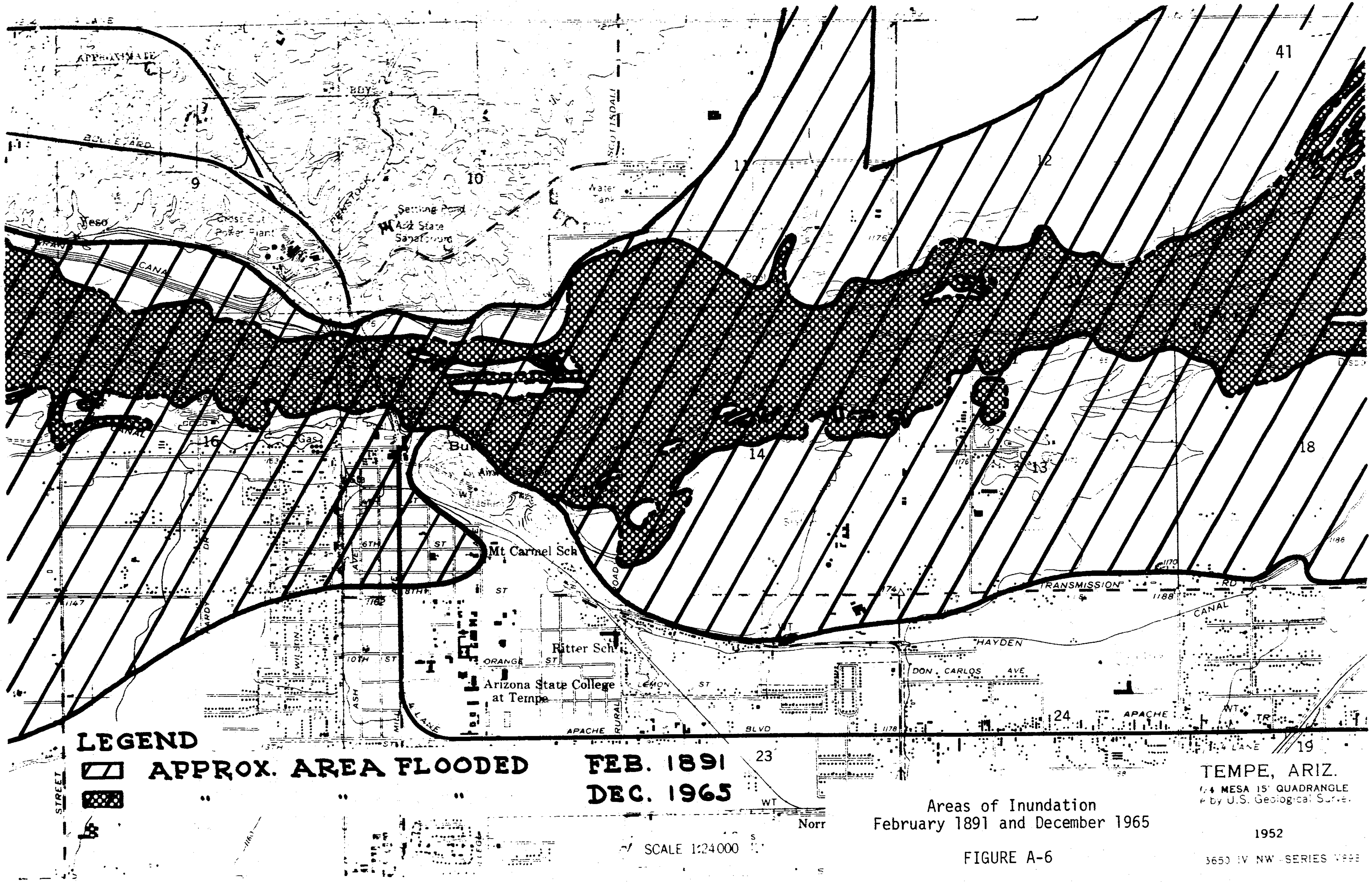
Arizona State Highway Department
Arizona State University Library
City of Tempe, Arizona
Department of Geology, Arizona State University
Keller Photo Services
Landis Air Surveys
Maricopa County Flood Control District
Maricopa County Highway Department
Maricopa County Library
Salt River Project
Soil Conservation Service
U.S. Bureau of Land Management
U.S. Department of Agriculture
United States Geological Survey

The writer is indebted to Mrs. Carolyn Brown for her capable secretarial and editorial assistance.

APPENDICES

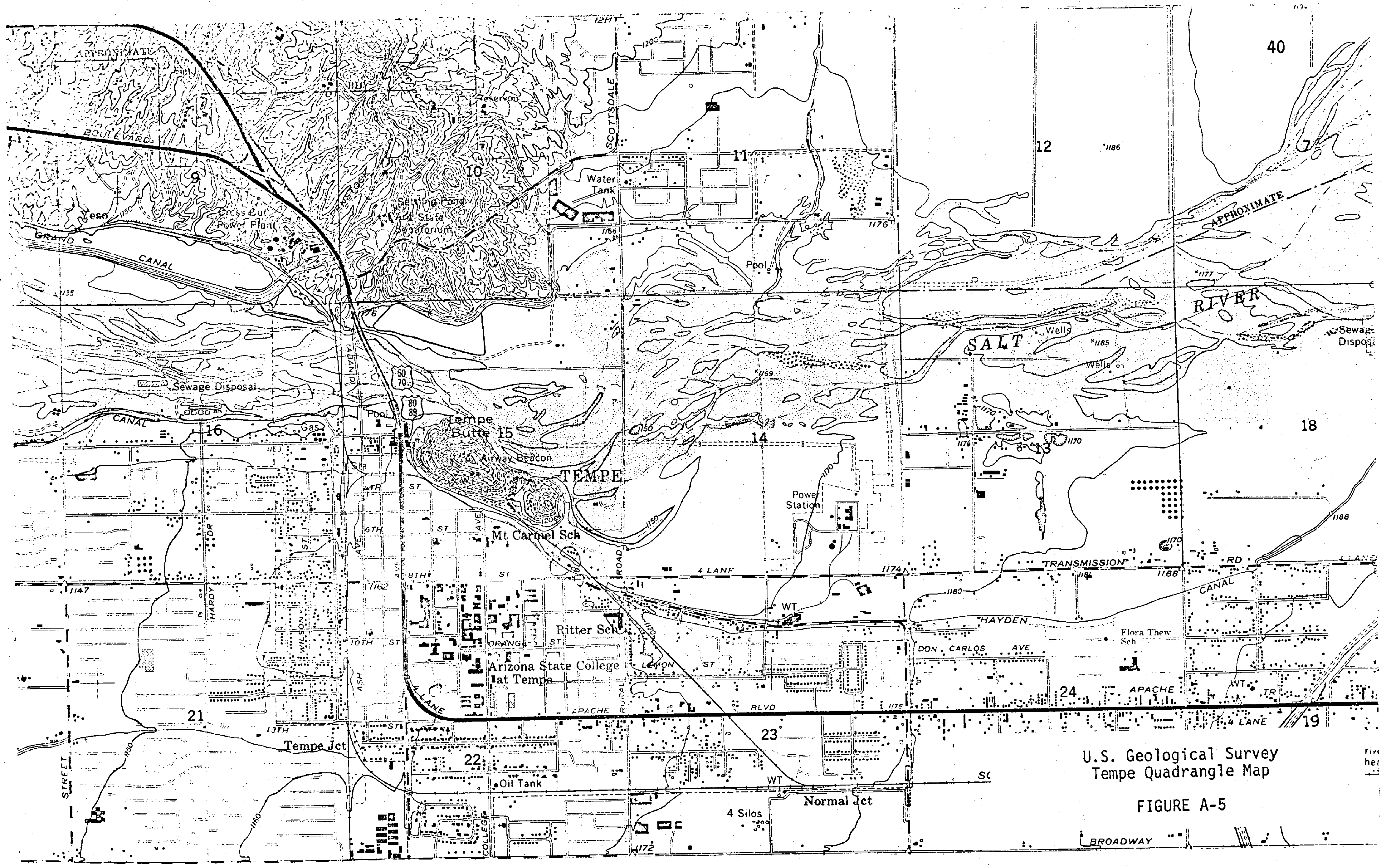
APPENDIX A

MAPS OF THE SALT RIVER, TEMPE, ARIZONA



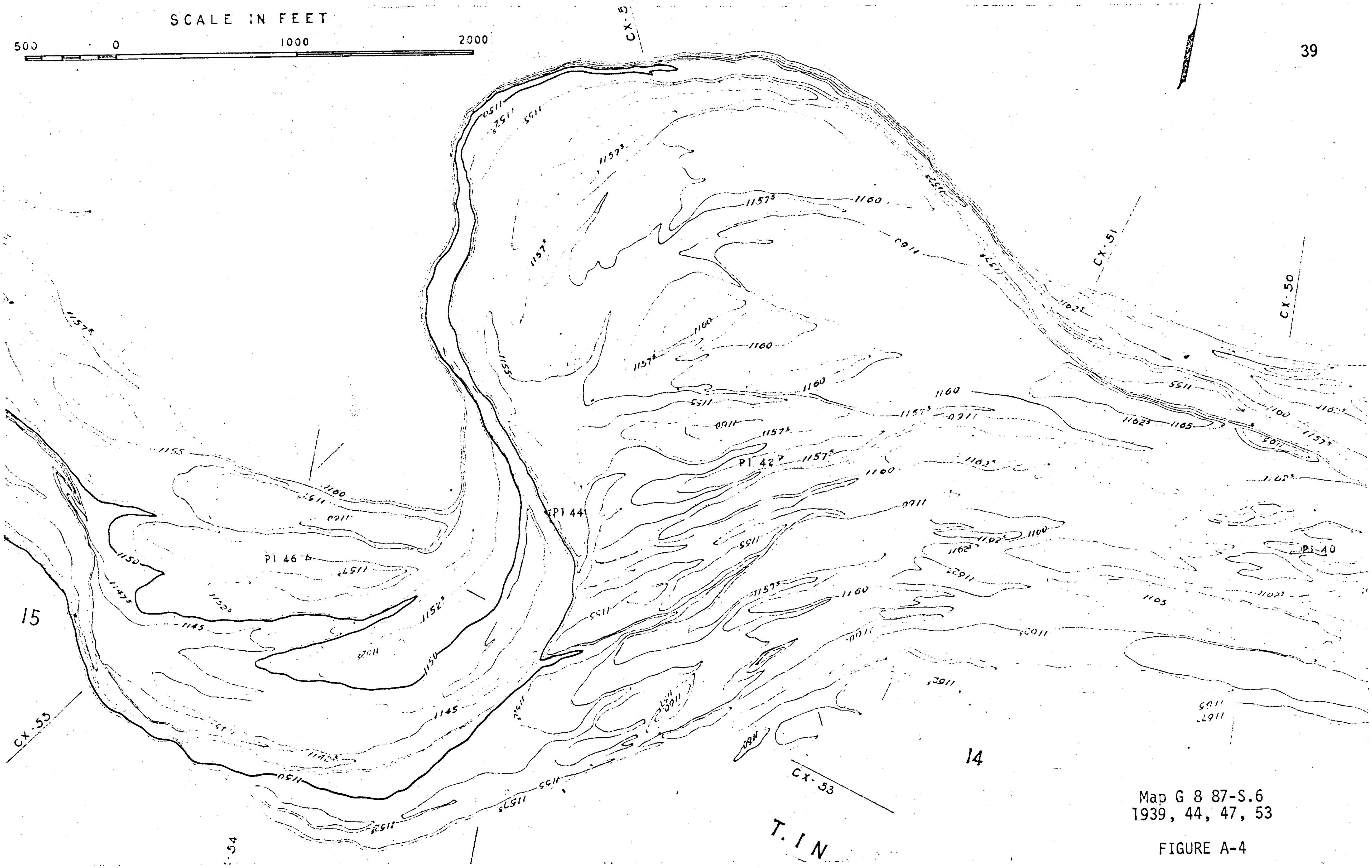
Areas of Inundation
February 1891 and December 1965

FIGURE A-6



U.S. Geological Survey
Tempe Quadrangle Map

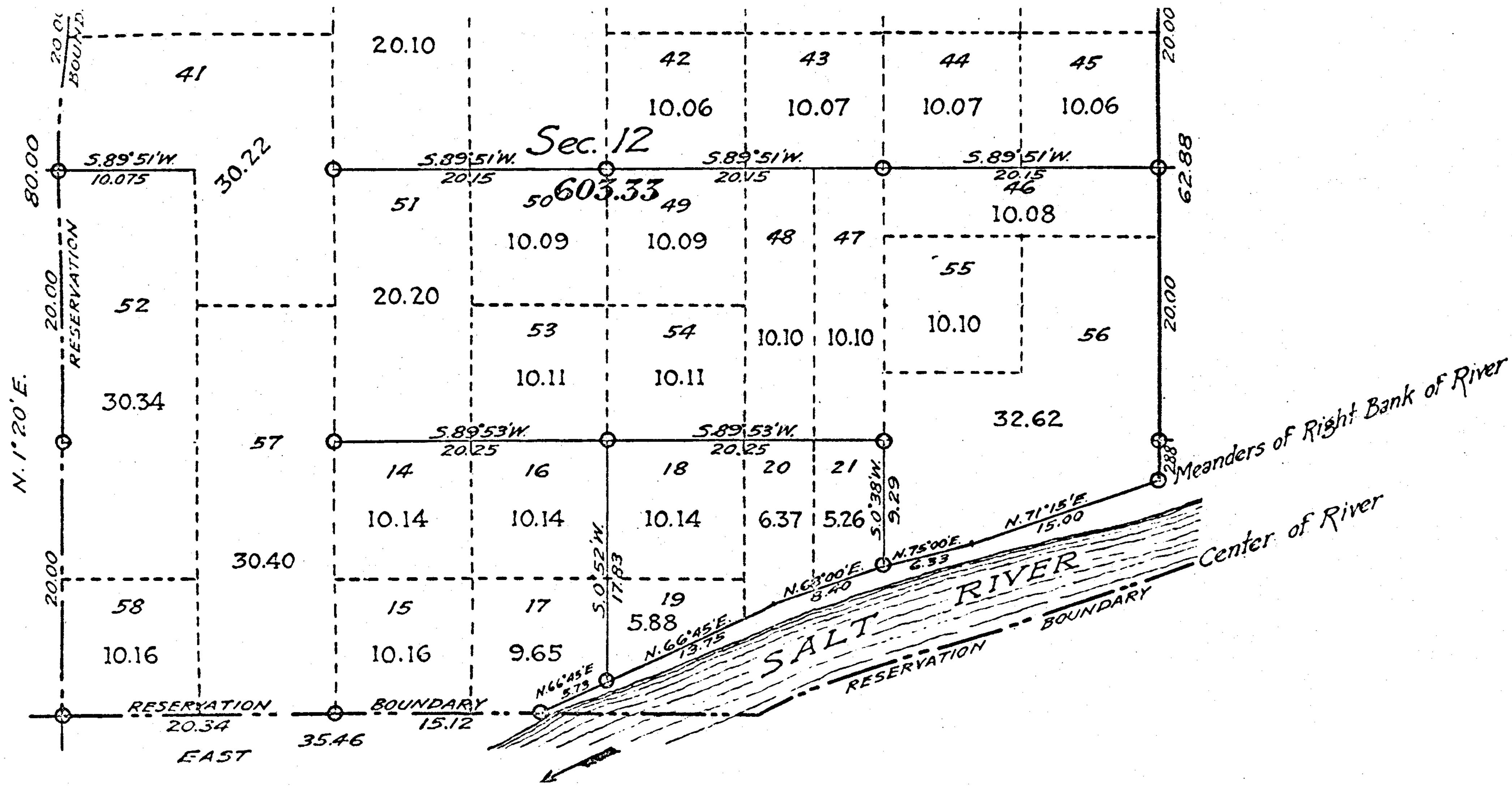
FIGURE A-5



Map G 8 87-S.6
1939, 44, 47, 53

FIGURE A-4

SUPPLEMENTAL PLAT OF THAT PART OF SEC. 12, T.1N.,R.4E.,G. & S.R.B. & M., ARIZ.
SITUATED WITHIN THE SALT RIVER INDIAN RESERVATION



This plat is prepared in strict compliance with instructions contained in G.L.O.letter "E" dated July 11, 1924, for the purpose of providing legal designation and area for Indian allotments within said section.

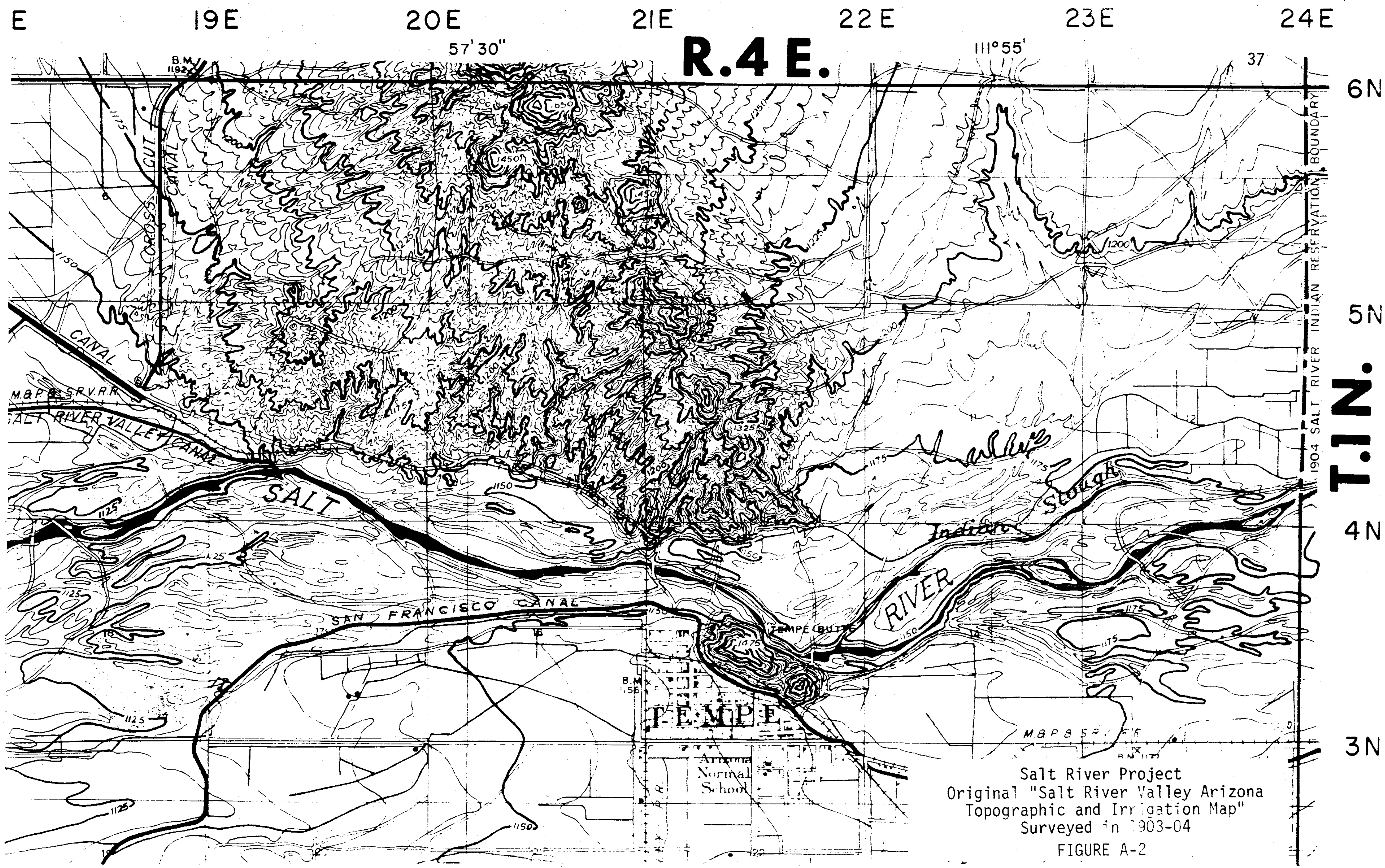
o Indicates corner monuments consisting of iron posts with brass caps set in 1910 by R.A.Farmer. U.S.Topographer.

This supplemental plat of that part of Section 12, of Township 1 North, Range 4 East of the Gila and Salt River Base and Meridian, Arizona, which is situated within the Salt River Indian Reservation, presents an amended subdivision of said section and supersedes those previously shown on the plats of said township approved October 21, 1868 and March 29, 1913, and is strictly conformable to the field notes of the resurvey thereof executed in 1910 which have been examined, approved and filed in this office.

Office of U.S.Surveyor General.
Phoenix, Ariz. [illegible], 1924.

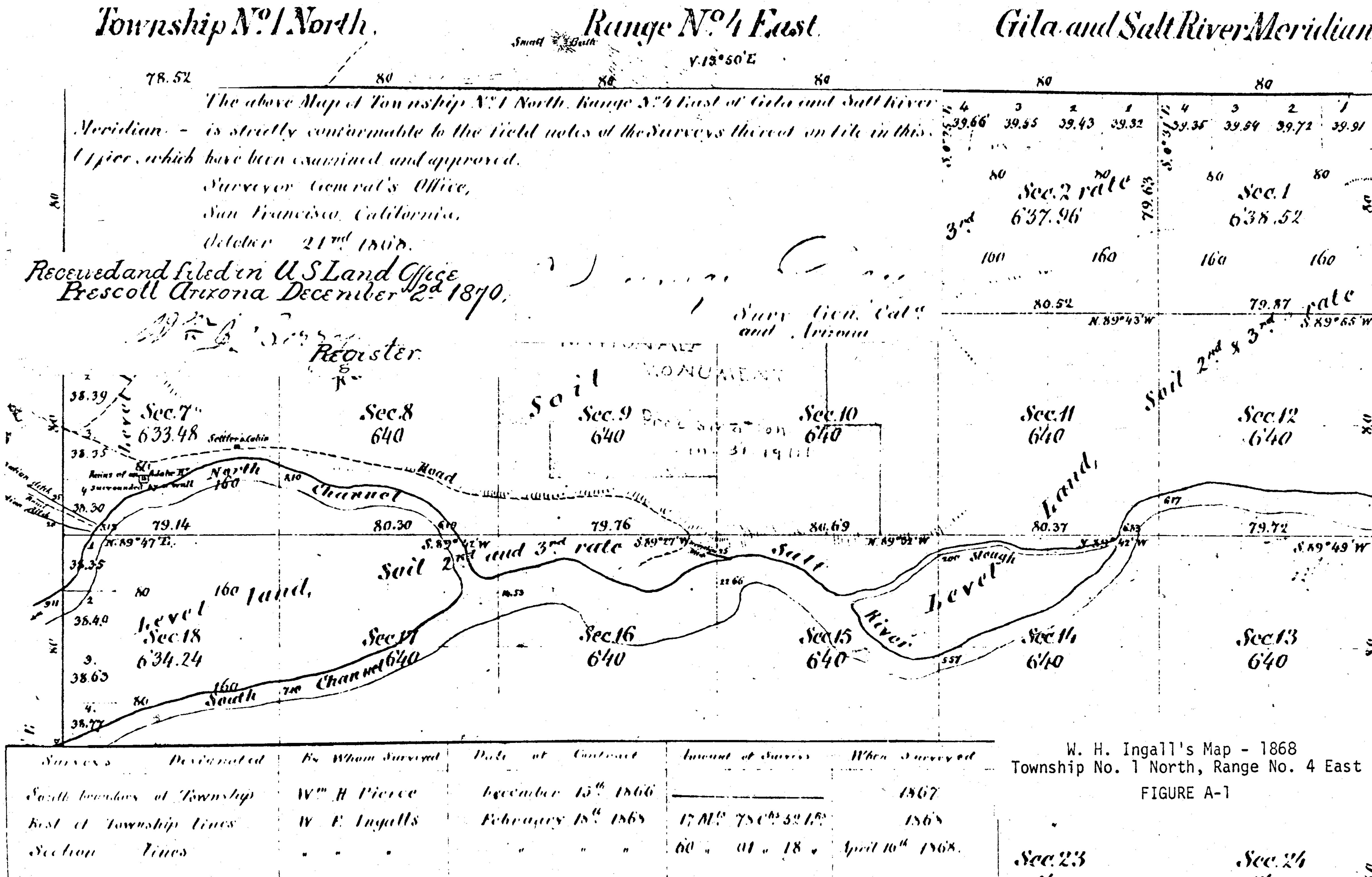
Charles M. Donaldson
U.S.Surveyor General.

FIGURE A-3



Salt River Project
Original "Salt River Valley Arizona
Topographic and Irrigation Map"
Surveyed in 1903-04

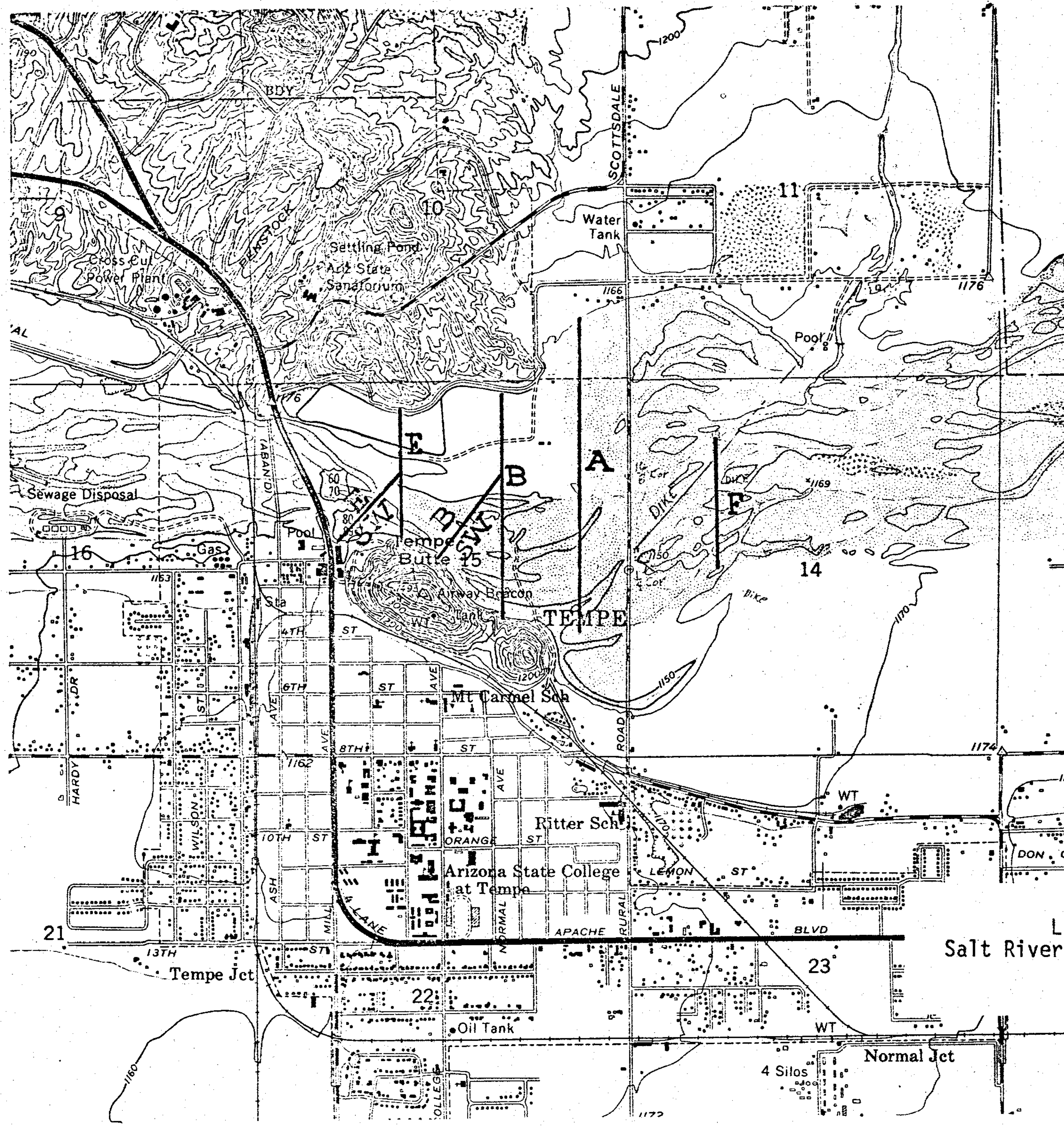
FIGURE A-2



W. H. Ingall's Map - 1868
Township No. 1 North, Range No. 4 East
FIGURE A-1

APPENDIX B

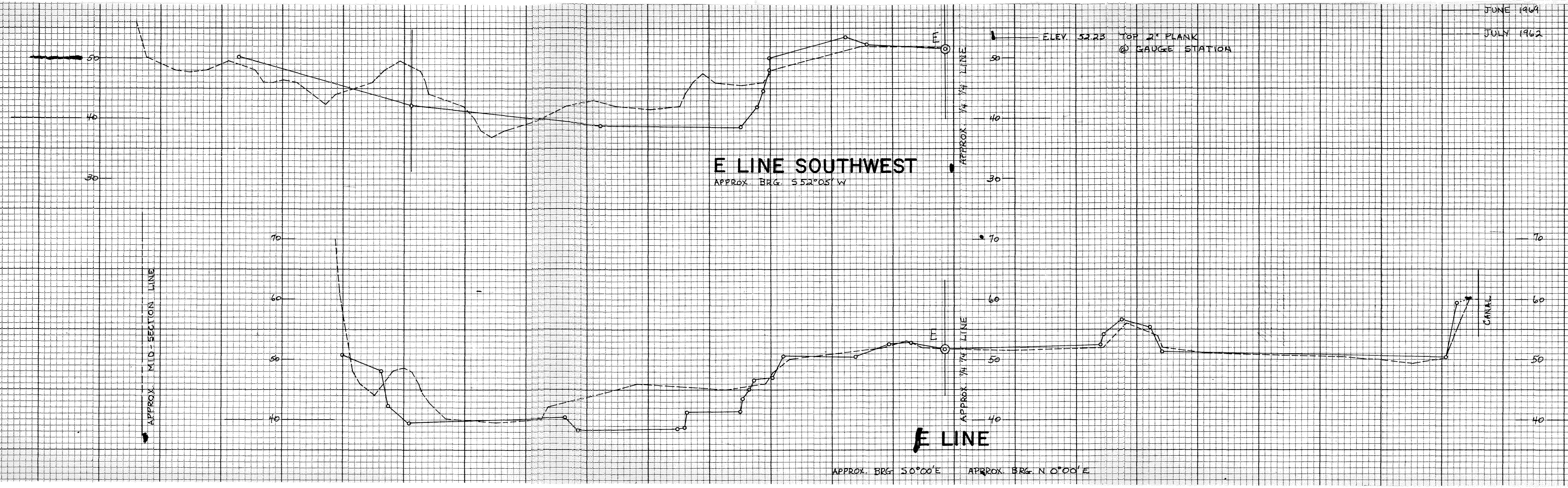
CROSS SECTIONS OF THE SALT RIVER
TEMPE, ARIZONA



Location Map of
Salt River Channel Cross Sections

FIGURE B-1

Cross Sections A and F
FIGURE B-4



Cross Sections E
FIGURE B-2

Cross Sections B
FIGURE B-3

APPENDIX C

FLOWS OF THE SALT RIVER AT GRANITE REEF DAM

FORM 12-28

AVOID VERBAL ORDERS

Date June 29, 1956

FROM L. C. Goldsmith, Supv. - Hydrographic Dept.

TO E. L. Wilson, Supt. - Irrigation Operations

SUBJECT: Maximum Flows - Granite Reef Dam

Listed below are maximum flows at Granite Reef as obtained from records from this office above 20,000 cfs.

The amounts from 1888 to 1901 are from U.S.G.S. Water Supply and Irrigation Paper No. 73 and are maximum average daily flows in second feet.

The amounts from 1901 to 1921 are from a report by Bailhache, Water Users' Chief Hydrographer, given in a testimony on the case of Blasingame vs. County of Maricopa, March, 1921. These amounts also, I feel, are average daily second foot flows.

The amounts from 1921 to date are momentary maximums of the Verde River at Camp Creek or below Bartlett. These quanitities were obtained from U.S.G.S. Water Supply and Irrigation Paper No. 1313. The flows of the Salt above the junction of the Verde were not considered since they were practically zero at these times.

Date	Discharge - CFS
1888	41,315
Mar. 17, 1889	33,794
Feb. 22, 1890	143,288
1891	285,000
March 1893	351,514
Jan. 18, 1895	82,994
Jan. 1897	35,109
Apr. 2, 1903	21,500'
Nov. 27, 1905	199,500
Mar. 14, 1906	67,000
Mar. 6, 1907	50,770
Dec. 16, 1908	63,000
Jan. 2, 1910	294,000
Mar. 7, 1911	56,748
Jan. 31, 1915	25,200
Jan. 20, 1916	83,475
Apr. 18, 1917	27,668
Mar. 9, 1918	45,375
Nov. 28, 1919	101,867
Feb. 23, 1920	108,600

Date	Discharge - CFS
Sept. 17, 1925	20,000
Apr. 6, 1926	32,000
Feb. 17, 1927	70,000
Apr. 5, 1929	26,000
Feb. 14, 1931	34,000
Feb. 9, 1932	53,000
Feb. 7, 1937	63,000
Mar. 4, 1938	95,000
Mar. 15, 1941	45,800

TABLE C-1

LCG/rf

L. C. Goldsmith

AVOID VERBAL ORDERS Date July 6, 1956

. Goldsmith, Hydrographic Supervisor

L. Wilson, Superintendent Irrigation Operations

SUBJ... lt River Accounted for at Granite Reef 1942-55 Inclusive.

(Maximum Day in Average cfs.)

June 26, 1942	2,590	Sept. 8, 1949	2,530
Sept. 11, 1943	2,417	Sept. 2, 1950	2,220
Mar. 29, 1944	2,673	Aug. 28, 1951	5,023
Sept. 14, 1945	3,007	Aug. 8, 1952	2,718
Sept. 7, 1946	2,580	Aug. 14, 1953	2,537
Dec. 29, 1947	2,550	Apr. 10, 1954	2,657
Mar. 25, 1948	1,909	Aug. 24, 1955	2,612

L. C. Goldsmith
Hydrographic Supervisor

LCG/br

TABLE C-2

MEAN DAILY DISCHARGE IN SECOND FEET OF
SALT RIVER BELOW GRANITE REEF DAM +
INDIAN BEND WASTEWAY*

1935	Jan.	12	1070
		13	1430
		16	530
		17	1030
	Feb.	7	2250
		8	6830
		9	5270
		10	4550
		11	850
		15	1690
		16	1040
	Mar.	3	340
		4	3100
		5	710
		14	380
		15	2880
		16	3250
		17	700
	Apr.	10	3680
		11	520
1936	Feb.	25	3400
		26	120
	Aug.	18	440
1937	Feb.	7	30150
		8	36890
		9	9600
		10	3340
		11	960
		12	230
		15	20190
		16	16660
		17	7360
		18	4680
		19	2810
		20	2050
		21	1000
	Mar.	10	330
		11	250
		12	740
		13	2370
		14	5670
		15	3230
		16	2640
		17	23500
		18	15060
		19	7070
		20	3810
		21	2370
		22	770
1938	Mar.	1	7660
		2	6480
		3	12710
		4	59040
		5	11560
		6	3380
		7	1480
		8	920
		13	1330
		14	1920
1939	Aug.	7	450
	Sept.	4	1630
		5	1540
		11	550
		12	210
1940	Dec.	25	1480
		30	3780
		31	2880
1941	Feb.	7	300
		8	1340
		9	1430
		13	1030
		14	1440
		17	3140
1941 (continued)	Feb.	18	920
		19	880
		20	1380
		21	7240
		22	9010
		23	5770
		24	3020
		25	5570
		26	5600
		27	2760
		28	690
	Mar.	1	1110
		2	9080
		3	8500
		4	3710
		5	4150
		6	3300
		7	2750
		8	880
		9	210
		13	1230
		14	19280
		15	32210
		16	13130
		17	5050

*From the data records of the Salt River Project, Phoenix, Arizona.

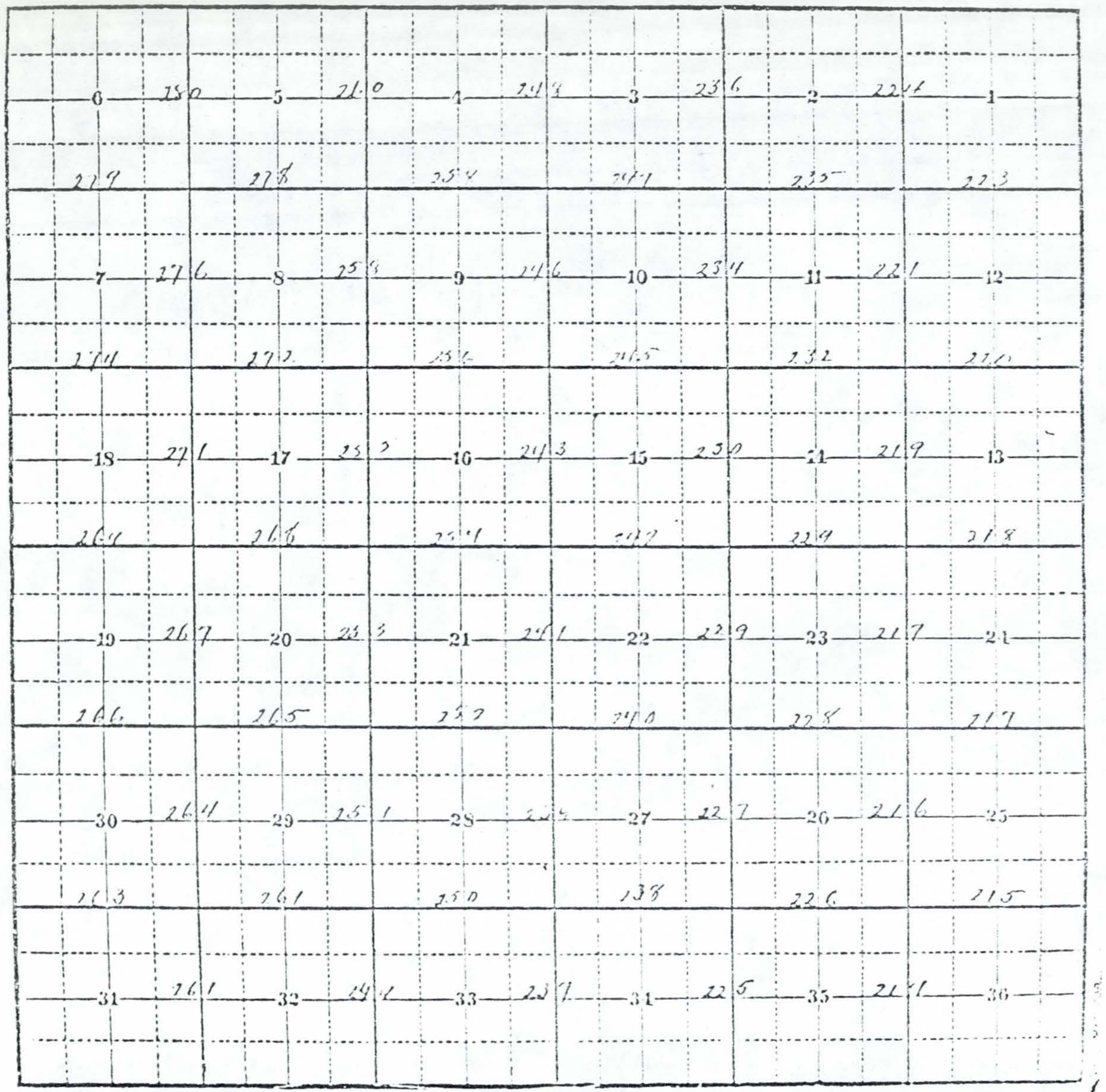
1941 (continued)			
	Mar.	18	3770
		19	2320
		20	1730
		21	1760
		22	910
		23	380
		24	310
	Apr.	2	1060
		3	5410
		4	2850
		5	2360
		6	1770
		7	790
		8	120
		12	5600
		13	15670
		14	17000
		15	17820
		16	22080
		17	15620
		18	7010
		19	7380
		20	5760
		21	3840
		22	3260
		23	2960
		24	2900
		25	2320
		26	1920
		27	3740
		28	5140
		29	4770
		30	2670
1941 (continued)			
	May	1	5080
		2	8110
		3	10630
		4	10240
		5	8290
		6	9560
		7	10000
		8	10280
		9	9890
		10	6780
		11	5810
		12	6290
		13	3080
		14	5030
		15	3370
		16	2320
		17	1260
		18	1210
		19	100
	July	23	210
1943	Aug.	2	130
		3	2550
		15	250
1945	July	8	285
1946	Sept.	17	90
		18	90
		19	540
1949	Aug.	6	360
	Sept.	13	340
1950	July	8	420
	Aug.	5	200
1951	Aug.	27	2050
		28	4860
		29	2190
		30	370
1952	Jan.	18	730
		19	210
	June	21	370
1954	Aug.	19	720
	Sept.	24	960
1955	July	23	630
		24	520
		25	2320
1957	Jan.	27	440
1958	Sept.	12	480
1959	Oct.	29	2700
		30	1630
	Dec.	14	240
		25	1770
		26	2110
1960	Jan.	12	430
		13	380
		14	750
		15	370
		16	570
1964	Aug.	1	2820
		26	430
		27	520
1965	Apr.	20	3590
		21	2320
		22	3360
		23	800
	Dec.	22	1900
		23	6900
		24	4300
		25	2300
		26	2100
		27	990
		30	6100
		31	64000
1966	Jan.	1	53000
		2	17000
		3	11000
		4	12000
		5	12000
		6	13000
		7	13000
		8	13000
		9	12000
		10	11000
		11	1000
	Feb.	12	240
		13	560
		14	520
		15	380
		16	200
		17	160
		18	110
		19	390

Year	Month	Day	Value
1966 (continued)			
	Feb.	20	1080
		21	1590
		22	2280
		23	2310
		24	1840
		25	1390
		26	1380
		27	1450
		28	1470
	Mar.	1	1330
		2	1230
		3	1240
		4	320
	Sept.	13	2450
1967	Dec.	15	500
		19	2510
		20	3170
1968	Feb.	14	1630
		15	3700
		16	3470
		17	3440
		18	3410
		19	1360
		25	1570
		26	2960
		27	2603
		28	2540
		29	2510
1968 (continued)			
	Mar.	1	1130
		9	230
		10	1060
		11	1070
		12	1820
		13	3320
		14	2630
		15	760
	Apr.	11	290
		12	330
		13	490
		14	640
		15	970
		16	1480
		17	1520
		18	1450
		19	1350
		20	1260
		21	1240
		22	840

APPENDIX D

SOME SURVEY NOTES OF W. H. INGALLS

Township No. 1 N, Range No. 4 E, G&SRB&M.



Clay ... to sec 3 ... any of ...

North line ... East Bn

4020 Sera ... as per

8020 ... 25.26.35 ... as ... Bound ... measured

T 1 N Range 4 E
Gila & Salt River Meridian

31.50	To left bank of Salt River 10 ft high — runs S 80 W
	I now caused a flag to be set on the right bank and on the line bet secs 14 & 15 and from the point on line on left bank I run a base East 4.24 chs to a point from which the flag on right bank bears N 87½ W which gives for the distance across the river on the line bet secs 14 & 15 5.57 chs to which add 31.50 chs distance south of river makes
37.07	To flag on right bank of river
40.00	Set a post for ¼ sec cor with mound and pits as per instructions
73.17	A slough from river 2.00 chs wide runs SW

BOOK 2		BOOK 2
..ge 4 E		Tp 1 N Range 4 E
..er Meridian		Gila and Salt River Meridian
..of Salt River co. ft	80.00	Set a post for cor to secs
..s 880 W		10, 11, 14 & 14 with mound and
..ed a flag to be set		pits as per instructions
..bank and on the		Land level - South of river 1st rate
..s 14 & 15 and from		North of river level - rather 2-3d rate
..line on left bank		Mesquite and sage brush south of
..ace East 4.24 chs		river
.. from which the		Cottonwood on river banks
..ht bank bears		
..which gives for		East on a random line bet
..ce across the river		secs 11 & 14
..ne bet secs 14 & 15		Va 13°35' E
..to which add 31.50 chs		
..th of river makes	40.00	Set a post for temporary 1/4 sec cor
..ght bank of river		
..for 1/4 sec cor with	65.70	To right bank of Salt River runs S75 W
..d pits as per		I now caused a flag to be
..s		set on the left bank and on
..ing river 2.00 chs		the line bet secs 11 & 14 and
..s S W		from the ... on left right bank

Tp 17 N Range 4 E
Gila & Salt River Meridian

Chs	
	and on line bet said secs
	Thence North 5.00 chs to a point
	thence East on an offset line
	6.83 chs to a point from which
	the flag on left bank of river
	bears South which gives for
	the distance across river on line
	bet secs 11 & 14 — 6.83 chs to
	which add 65.70 " dist
	~~West~~ of river makes
72.53	To flag on left bank of river
80.37	Intersect N. line 42 lks North of cor to secs 11, 12, 13 & 14 From which cor I run
	N 89°42' W on a true line bet secs 11 & 14 Va 13°35' E
40.18	Set a post for 1/4 sec cor

uge 4 E
River Meridian

ine bet said sec^s
th 5.00 chs to a point
st on an offset line
a point from which
left bank of river
t which gives for
across river on line
1 & 4 – 6.83 chs to
c 65.70 " dist
to makes
left bank of river

f line 42 chs North
s 11, 12, 13 & 14
the cor I run

na true line
11 & 14
13°35' E

For ¼ sec cor

BOOK 2

Tp 1 N Range 4 E
Gila and Salt River Meridian

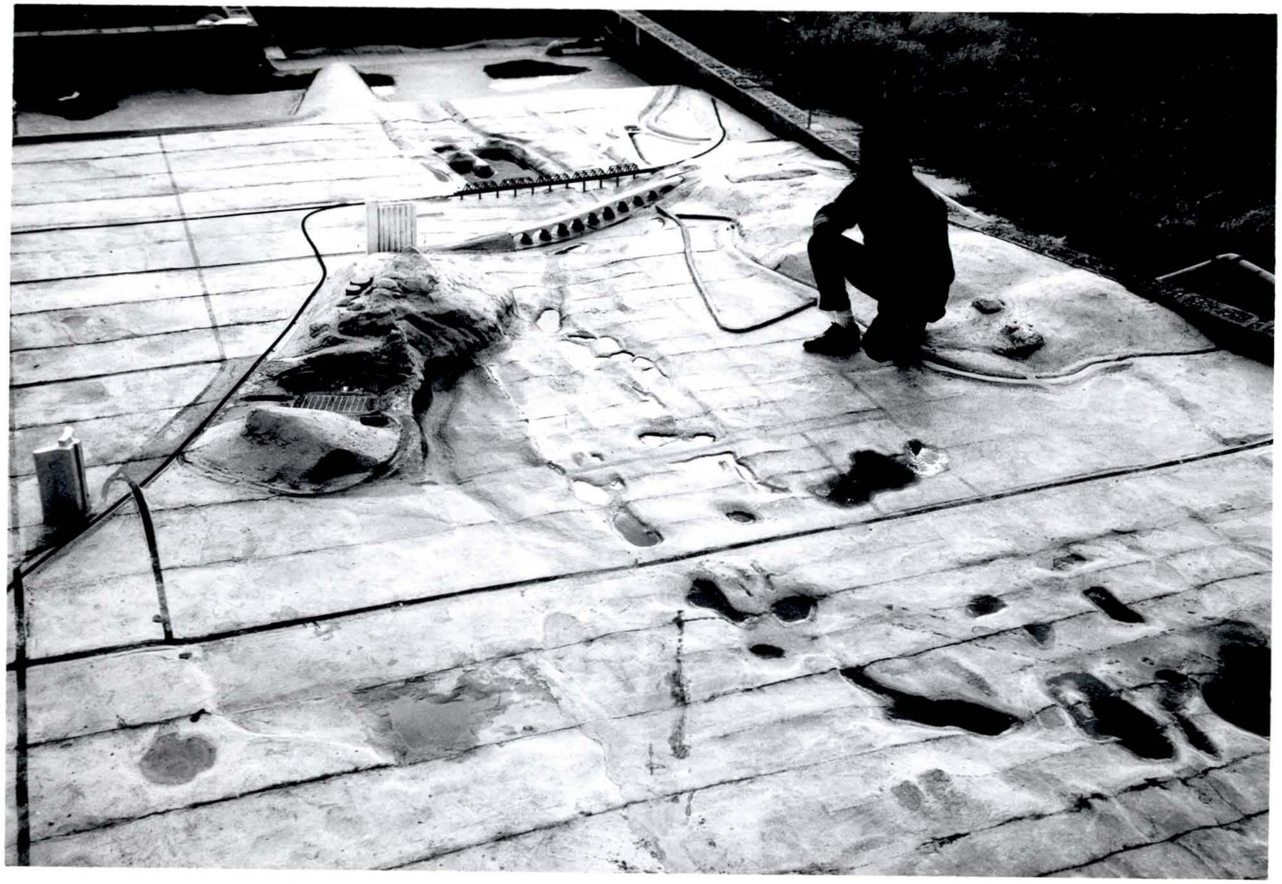
also	with mound and pits as
	per instructions
80.87	The cor to secs 10, 11, 14 & 15
	Land level – East of river 1st rate
	" West of river 2nd and inclined to be
	swampy
	Timber Cottonwood along river
	banks
	Mesquite and willow brush

North bet secs 10 & 11
Va 13°35' E

40.00	Set a post for ¼ sec cor with
	mound and pits as per
	instructions
80.00	Set a post for cor to secs 2, 3,
	10 & 11 with mound and pits

APPENDIX E

PHOTOGRAPHS OF A HYDRAULIC MODEL STUDY
SALT RIVER AT TEMPE, ARIZONA



North

Scottsdale Road

PLATE E-1

General View
Hydraulic Model of the Salt River
Tempe, Arizona

Direction of

Flow

PLATE E-2

Model Study of the Salt River Dike System East of Tempe Bridges

Direction of ← Flow

PLATE E-3

Model Study of the
Sewage Treatment Plant Facility
East of Scottsdale Road

Direction of

Flow

PLATE E-4

Model Study of the
Salt River Dike System
Immediately East of Scottsdale Road