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March 25, 2003

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 additional materials 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. The materials include:

1. Wendy Bigler, Historic Channel Changes in the Salt River, Arizona 1890-1931; and

2. William L. Graf, The Salt and Gila Rivers in Central Arizona: A Geographic Field Trip Guide (1998);

3. Paul R. Ruff, A History of the Salt River Channel in the Vicinity of Tempe, Arizona, 1868-1959 (1971).

The cover page of the Ruff report is a poor copy, but it was the best quality available. The remainder of that report is more clearly legible. 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/o encls.)
Frederic L. Beeson (w/o encls.)

Maricopa County, Lower Salt River
03-005-NAV
4/7/03
Evidence Item No. 023

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THE SALT AND GILA RIVERS IN CENTRAL ARIZONA

A GEOGRAPHIC FIELD TRIP GUIDE

EDITED BY
WILLIAM L. GRAF

THE SALT AND GILA RIVERS IN CENTRAL ARIZONA

A GEOGRAPHIC FIELD GUIDE

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DEPARTMENT OF GEOGRAPHY PUBLICATION 3
ARIZONA STATE UNIVERSITY

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PREFACE

Sitting on the ruins of the gate house of Jointhead Dam here along the Salt River on a warm autumn afternoon, it is still possible to imagine the flow of natural and human history that gives this river its sense of place. It is at the same time unique and representative. This place is unique because there is no other with the same blend of natural processes and cultural development that produced an oasis here in the northern Sonoran Desert. This place is representative, though, of the history and probable fate of many dryland rivers in other parts of the world where the pressures of economic development portend inevitable changes in even the most fundamental environmental systems. The dam has crumbled and now seems forlorn and forgotten on a dry river bed, but this small structure permitted the beginning of a technological society that has not ceased its efforts to convert the river from a hazard to a resource. The city that stretches to the horizon is testimony to the successes of that effort, while the flood debris littering the channel and the sandy wasteland near the river tell of the failures of the effort.

The purpose of this guidebook is to provide the environmental researcher, resource manager, decision maker, student, and interested citizen with an introduction to the geography of the Salt River in the vicinity of the Phoenix metropolitan area. The first chapter provides a broad contextual overview of the Gila River Basin which contains the Salt River. The second chapter is a road log that guides the user from downtown Phoenix to the eastern end of the Salt River Valley, and then downstream to the western end of the valley. Eleven stops along the way provide the user with the opportunity to leave the automobile behind and to walk short distances to significant sites along the river. The remaining chapters in the book provide maps, photographs, and discussions of the stops. Taken at a leisurely pace, the entire trip requires two days, but for those in need of a quick look, one very long day would suffice.

The need for this intimate introduction to the natural and cultural history of the river is becoming more apparent as the population of the metropolitan area grapples with the problems of economic expansion and environmental management. Further development of areas near the river, management of the water supply, and sweeping plans for coordinated regional investments in the river such as the "Rio Salado Project" require that citizens as well as public policy makers be familiar with the river and why it came to be as it is. This volume, when combined with the field experience, offers knowledge of the river's present processes and recent history, knowledge required by the educated, voting citizen.

The authors generated this volume to serve as a field trip guide for the 84th Annual Meeting of the Association of American Geographers held in Phoenix in April 1988. As Professor of Geography at Arizona State University and one specializing in geomorphology, I had an interest in sharing the story of the Salt River with others, especially my fellow geographers who would attend the meetings. Graduate students in my course in fluvial processes accompanied me on preliminary field trips and wrote the individual site descriptions as part of their course requirements. Judy Haschenburger and Scott Lecce pulled together the final compilation of the volume. Without the help of all of these fine graduate students, the volume would have remained an interesting idea but not a reality.

The Salt River flows past this dam and gate house only during flood periods—usually it is a bed of sand devoid of water, with the sounds of the white-winged dove in the tamarisk the only substitute for the sound of running water. How this came about is a worthwhile lesson in the interactions of society and environment. Hopefully this book will make that lesson an enjoyable one.

William L. Graf

Tempe, Arizona

October 13, 1987

ACKNOWLEDGEMENTS

The authors express their sincere thanks to the following organizations for their generous permission to reprint photographs from organizational archives and holdings.

Arizona Historical Foundation: *Figures 4.4, 13.3, 13.5, 13.6, 13.7*

Arizona Historical Society: *Figure 13.4*

Arizona State University, Hayden Library, Arizona Collection: *Figures 4.3 (bottom), 8.3, 8.5*

Dames and Moore, Inc.: *Figures 9.5, 9.6, 9.7, 9.8*

Landis Aerial Survey: *Figures 8.4, 10.2, 11.6, 11.11, 11.12*

Tempe Historical Foundation: *Figures 7.2, 7.3, 7.5, 7.6, 7.7*

U. S. Army Corps of Engineers: *Figures 4.5 (top), 4.6 (top)*

U. S. Bureau of Reclamation: *Figures 3.3, 3.7*

U. S. Geological Survey: *Figures 11.4, 11.5, 13.8*

The authors also wish to acknowledge the financial support of the Department of Geography (Patricia Gober, Chair), Arizona State University, for supplies and photographic reproductions. The departmental Publications Committee (Robert C. Balling, Chair) reviewed and commented on a draft of the text despite limited available time. Malcolm L. Comeaux was especially helpful in suggesting improvements and correcting errors of historical fact. Publication of the volume would have been impossible without the generous advancement of funds by the Laboratory of Climatology (Anthony J. Brazel, Director), the Association of American Geographers (Robert T. Aangeenbrug, Executive Director), and the Salt River Project (Roger Davis, Manager of Public Affairs and Advertising, through the offices of Martin J. Pasqualetti).

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CHAPTER 1

REGIONAL INTRODUCTION

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Department of Geography
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INTRODUCTION

Dryland rivers are the products of the interaction between geomorphic force and resistance. Geologic materials, shallow soils, and sparse vegetation cover readily yield to climatic and hydrologic processes. Semiarid and arid climatic patterns dictate the discontinuity in fluvial dynamics, which contrast with the continuous operation of humid-region rivers driven by wetter climates.

G. K. Gilbert's perception of a river "as a system of energy, as an engine which performed work" (Pyne, 1980, p. 89) was inspired in part during explorations in the dryland Basin and Range Physiographic Province. Located within this province, the Salt River flowing through the Phoenix metropolitan area has eroded its eastern channel reach and deposited sediment in the western agricultural reach as the result of dramatically increased stream energy levels during recent flood events. Deposition of flood sediment extended downstream of the confluence of the Salt and Gila rivers where increased channel resistance from tamarisk thickets, lessened channel slope, and transmission losses curtailed sediment transportation.

The energy regimes of the Salt and Gila rivers have been modified and managed by human's activity. The first of these changes in the fluvial regime was caused by water diversion canals excavated by the Hohokam Indians, who occupyed the Salt River Valley around 300 B.C. and depended upon irrigated agriculture. The inhabitants that followed, including Mormon settlement parties in the late 1800s, perpetuated river manipulation with the reexcavation of Hohokam canals, the additions to the existing canal system, and the construction of 15 dams to control streamflow on major rivers within the Gila River Basin. Management pressures on the river system have been evident since the organization and expansion of agricultural irrigation districts and other water services areas, and this pressure continues to increase because of extensive and rapid growth of the Phoenix metropolitan area. The success of future waterworks is critically dependent upon appropriate management strategies for dryland rivers.

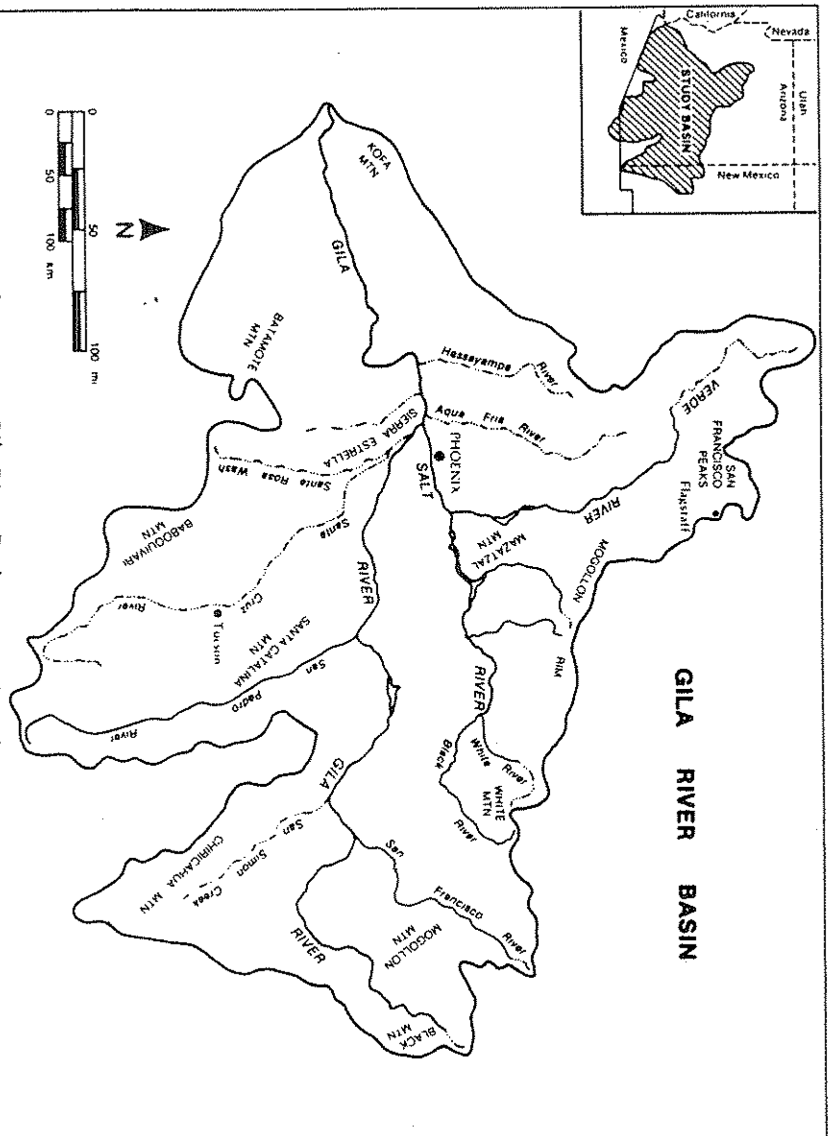

Figure 1.1 Gila River Basin (U.S. Geological Survey, 1970).

This chapter provides a regional context for the Salt and Gila rivers field trip. The physical and human environments are described as well as the general route of the field trip.

PHYSICAL ENVIRONMENT

The Gila River Basin is approximately 57,950 km^2 (22,374 mi^2) in size with the Salt River watershed comprising 38,850 km^2 (14,500 mi^2) (Fig. 1.1). The Verde River, a major tributary to the Salt River, accounts for 17,094 km^2 (6,600 mi^2) of the Salt River drainage area. The large basin produces a wide variety of geologic and climatic settings which produce diversified soil conditions and vegetation types. The key element in understanding the natural diversity is elevation, a theme that recurs throughout the physical environment discussion. The highest basin elevation, Humphreys Peak at 3,862 m (12,670 ft) in the San Francisco Peaks, constrasts sharply with the 43 m (141 ft) elevation of the Gila River mouth and accounts for the significant change within the basin.

Geology

Two major geomorphic provinces encompass the Gila River Basin, the Colorado Plateau and the Basin and Range (Fig 1.2) (Hunt, 1974). A transition zone, identified as the Tonto Section of the Colorado Plateau (also known as the Central Mountain Region) (Nations and Stump, 1981), integrates the two distinctly different geomorphic regions. The Colorado Plateau exhibits horizontal sedimentary rocks, ranging from Precambrian to Cambrian in age which are deeply dissected into canyons and scarps, leaving isolated plateaus (Fig. 1.3). Volcanic activity in the Cenozoic elevated the San Francisco Peaks, headwaters of the Verde River, and the White Mountains, headwaters of the Salt River (Fig. 1.1) (Nations and Stump, 1981).

The Tonto Section, characterized by rugged mountains of igneous, metamorphic, and deformed sedimentary and volcanic rocks (Fig. 1.3), has been a most stable area throughout geologic history. The general absence of Mesozoic and Cenozoic rocks between Precambrian age mountains and erosional remnants of Paleozoic rocks indicates a long period of erosion and/or lack of deposition of sedimentary rocks (Nations and Stump, 1981). The Mazatzal Mountains, the Sierra Ancha, and the Salt River Canyon, located northeast of Phoenix, are dominant features in this area.

The largest portion of the Gila River Basin lies within the Basin and Range Province, which is characterized so distinctively by northwest-southeast trending elongated mountain ranges separated by broad alluvial valleys (Fig. 1.3). The fault block mountains are tilted and often structurally deformed Precambrian, Paleozoic, Mesozoic, and Cenozoic rocks. The Paleozoic and Cretaceous rocks are predominantly marine limestone, shale, and sandstone with Cretaceous carbonates, whereas the Early Mesozoic and Cenozoic rocks are largely volcanic with plutonic rocks in the former age. The structural valleys have subsided thousands of meters and have been filled with Cenozoic volcanics, alluvium, and lacustrine sediments. The majority of the Phoenix basin records alluvium depths greater than 365 m (1,200 ft) (Cooley, 1973) with maximum depths of 6,000 m (19,642 ft).

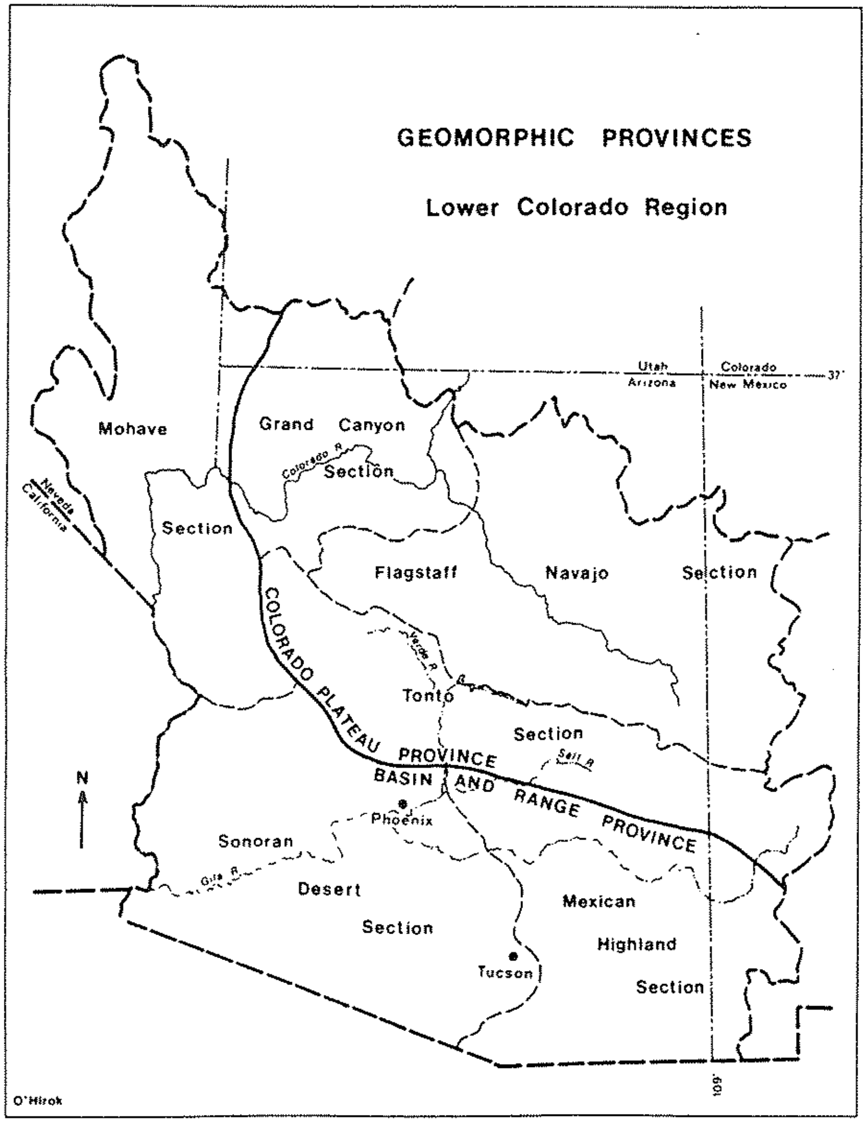

Figure 1.2 Geomorphic provinces, lower Colorado region (Hunt, 1974).

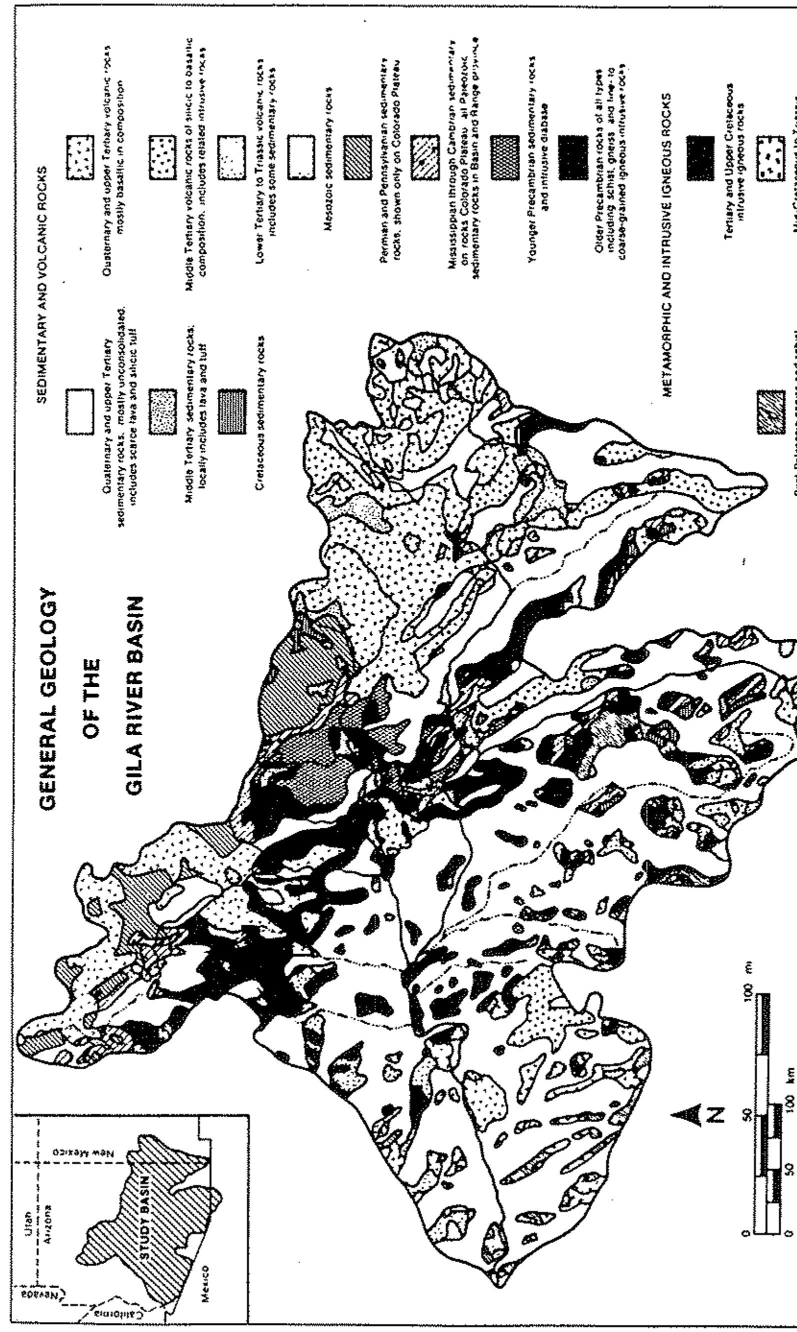

Figure 1.5 Biotic communities in the Gila River Basin (Brown, 1973; Brown and Lowe, 1978).

Climate

The major altitudinal influence on temperature variation is supplemented by a minor latitudinal influence in the portion of the basin in the Colorado Plateau region. January temperatures for the Mogollon and Black Mountains, headwaters of the Gila River, the White Mountains, and the San Francisco Peaks average 11° to 14° C (20° to 25° F), whereas the lower Gila Basin experiences an average 30° C (55° F) winter temperature. In July temperatures in headwater mountain areas average 30° C (55° F) as the lower Gila Basin temperature mounts to 53° C (95° F) (Sellers and others, 1985).

Winter precipitation, occurring from December through March, and summer precipitation, falling in July, August, and September, distinguishes the bimodal nature of moisture delivery. Large scale cyclonic storms moving with prevailing westerlies produce nearly continuous, low to moderate intensity precipitation and widespread cloudiness during the winter. High mountain elevations receive greater than 75% of precipitation as snow, and in the San Francisco Peaks and White Mountains snow depths accumulate between 2.4 to 3.4 m (8 to 11 ft) annually.

During the summer precipitation season, known as the summer monsoon, convective storms deliver localized, higher intensity downpours. Thunderstorms can be frequent as the White Mountains have experienced 80 to 90 storms within two midsummer months (Green and Sellers, 1964). Recurring synoptic patterns in the mid to upper troposphere that dominate southwest summer monsoon reduce moisture variability (Carleton, 1987) as compared to winter storms, which depend on westward displacement of a high pressure ridge in the Pacific Ocean as well as the development of a semipermanent low pressure trough over the western United States. Wet years, therefore, coincide with wet winters (Green and Sellers, 1964).

In the headwater areas of the Gila River basin the annual precipitation averages 493 mm (19.4 in) with isolated mountain peaks receiving greater than 635 mm (25 in). The southwestern portion of the basin receives an average of 198 mm (7.8 in) with Yuma, Arizona, near the mouth of the Gila River receiving less than 76 mm (3 in) annually (Green and Sellers, 1964). The eastern section of the basin receives more precipitation during the summer season while in the western section winter storms deliver the largest percentage of precipitation.

Soils and Vegetation

Aridisols, mineral soils with shallow profile development, blanket the basin (SCS, 1975a). Caliche, a petrocalcic horizon, commonly develops in soil profiles and occassionally forms cemented channel beds, influencing water infiltration and stream transmission losses. Soils exposed to intense sunlight between precipitation events form an upper hardened crust which reduces water infiltration potential (Steila, 1976). Approximately 60% of the soil types comprising soil associations in the basin have moderately high to

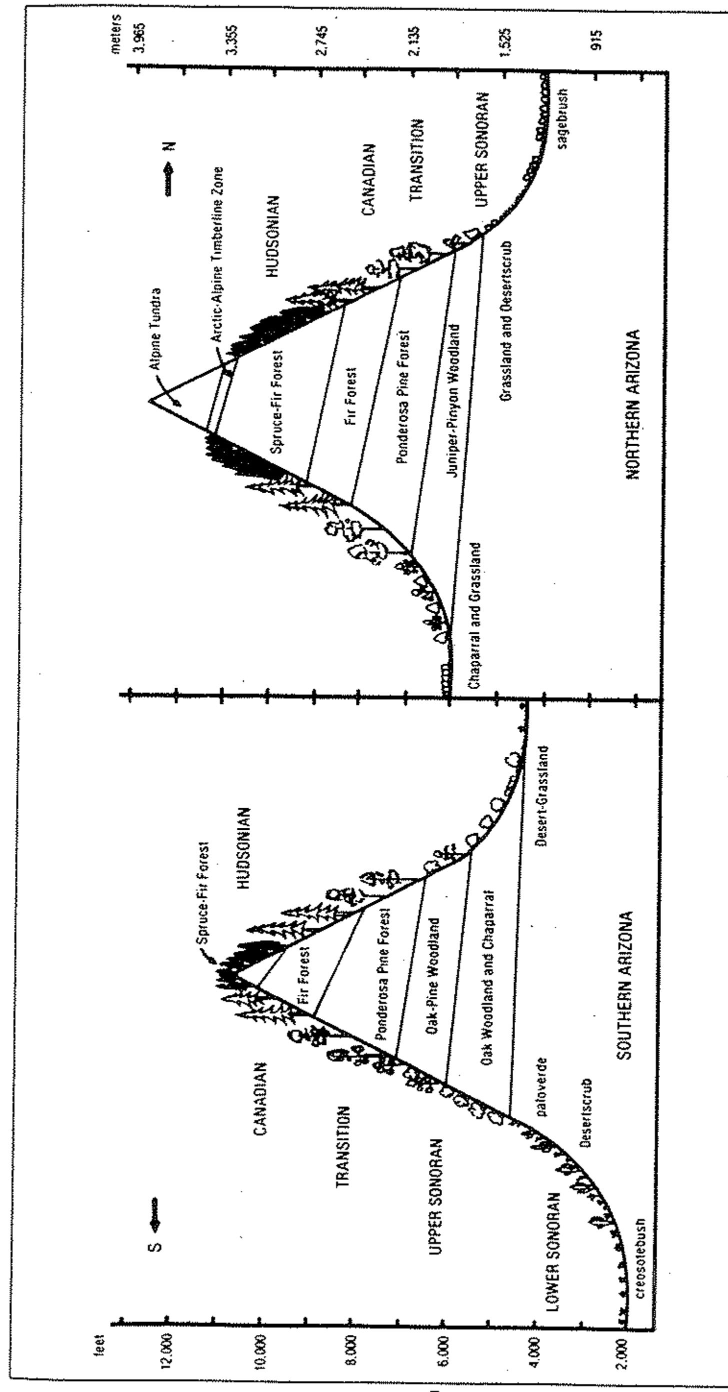

Figure 1.4 Vegetation communities and elevation (Lowe, 1964).

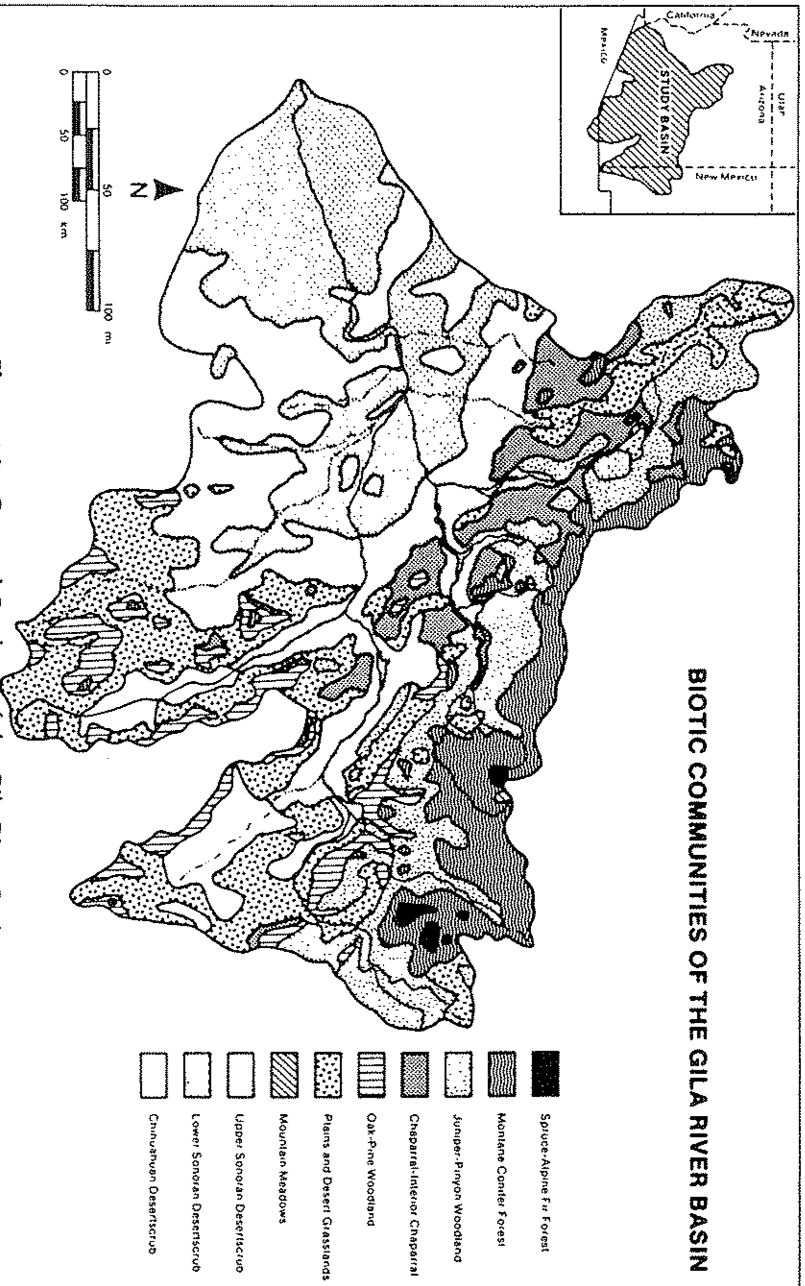

Figure 1.3 General Geology of the Gila River Basin
(American Assoc. of Petroleum Geologists, 1967; Comite de la Carta Geologica de Mexico, 1968; Nations and Stump, 1981).

high runoff potential (SCS, 1975b), a condition which contributes to the flashy hydrologic tendencies of arid rivers.

The basin altitudinal change creates different climate regimes and soil conditions to support the wide variety of plant species (Fig. 1.4; Lowe, 1964). The large diversity of vegetation, although sparse in coverage, ranges from alpine tundra in the San Francisco Peaks to lower sonoran desert vegetation abundant in the lower Gila and Salt River basins (Fig. 1.5; (Turner, 1974; Brown, 1973; Brown and Lowe, 1977). The Phoenix area is covered by the three subtypes of sonoran desert vegetation, desert saltbrush, creosotebush, and paloverde-saquaro communities with the latter community constituting the most spectacular, complex vegetal landscape of foothill paloverde and ironwood trees, creosotebush and bursage shrubs, and the giant saquaro and other cacti species (Fig. 1.4; Shreve and Wiggins, 1964; Benson, 1969).

Deciduous riparian forest communities prevail along streams and in locations of shallow ground-water tables. Species change progressively with altitude, and plant diversity increases through the incorporation of plants from adjacent communities. Near the 1,200 m (3,937 ft) level the riparian vegetation includes walnut, Goodding willow, sycamore, Arizona ash, canyon hackberry, and cottonwood. At lower elevations these species are replaced partially or completely by mesquite, catclaw, desert willow, and blue paloverde (Turner, 1974). Since the 1930s tamarisk (saltcedar) has invaded the Gila River Basin, competing successfully with other riparian species in areas of human disturbance.

Geomorphology

Fluvial theory derived primarily from humid-region river research requires additional consideration when applied to the discontinuous operation of dryland rivers (Rendell and Alexander, 1979). In arid river channels, transmission losses result in downstream decreases in discharge (Schumm, 1977). Total stream power, a function of discharge, therefore decreases downstream, reducing energy available for sediment transport and channel change.

High precipitation in headwater areas produces the perennial flow in the Gila, Salt, and Verde Rivers, although this hydrologic condition is not always evident in urbanized areas. Changes in river morphology occur during large flooding events as ephemeral streams funnel storm runoff, which mobilizes bed sediment, and perennial streams experience increased levels of stream energy for sediment transportation (Leopold and others, 1964). Recent Salt River degradation, resulting from five flood events occurring between March 1978 and February 1980 and posting a maximum peak flow of 5,040 m^3/s (180,000 ft^3/s), clearly demonstrates this aspect of dryland rivers. The precipitation regime is paramount in controlling the seasonal occurrence of floods. Flood frequency at Gillespie Dam (see Table 10.1) is greatest during the winter storm season when flows reach peak magnitudes.

Human Settlement

A long history of human occupation in the Salt and Gila River basins began with Hohokam Indian settlement around 300 B.C. Because the Hohokam culture was agriculturally based, construction of an extensive irrigation canal system for nurturing crops proved critical for desert survival. The Anasazi, a pueblo culture, spread from the Northern Plateau area into the Salt and Gila River valleys by 1200 A.D., interfacing with the Hohokam, the most sophisticated, urban culture in the Southwest (Ambler, 1977). Concentration of modern descendents, such as the Pima Indians of Hohokam lineage (Ambler, 1977), is generally confined to the 12 reservations located within the Gila River Basin (Table 1.1) that encompass 2,763,893 ha (6,826,816 ac) in land area.

TABLE 1.1 INDIAN RESERVATIONS IN THE GILA RIVER BASIN

DATE	NAME	TRIBE	HECTARES (ACRES)	POPULATION
1859	Gila River	Pima-Maricopa	150,645 (372,093)	7,380
1871	Fort Apache	Apache	674,078 (1,664,972)	7,774
1871	San Carlos	Apache	739,851 (1,827,431)	6,104
1914	Camp Verde	Yavapai-Apache	264 (653)	200
1874	San Xavier	Papago	28,783 (71,095)	875
1879	Salt River	Apache-Mojave	19,957 (49,293)	4,089
1882	Gila Bend	Papago	4,185 (10,337)	0
1902	Fort McDowell	Apache-Mojave	9,992 (24,680)	349
1911	Papago	Tohono O'odam	1,112,379 (2,772,277)	7,203
1912	Ak-Chin	Maricopa	8,842 (21,840)	397
1917	Cocopah	Cocopah	718 (1,773)	355
1884	Fort Yuma	Quechan	3,758 (9,282)	2,235
			2,763,452 (6,825,726)	36,961

Source: Walker and Bufkin, 1986; U.S. Bureau of Indian Affairs, 1987.

The Church of Jesus Christ of Latter Day Saints (the Mormons), with the guidance and inspiration of Brigham Young, expanded their settlement area from Salt Lake City to acquire additional agricultural land. Although three settlement areas were inhabited in the Gila River Basin (Walker and Bufkin, 1986), the greatest concentrated effort was in the Salt River Valley. Mormon parties, settling the Lehi townsite in 1877 and the Mesa townsite in 1878 (see Chapter 5 of this volume), quickly reexcavated the abandoned Hohokam canals for irrigation purposes. The city of Mesa, developed from the Mesa townsite, remains a religious stronghold because it is the site of the Mormon Temple.

TABLE 1.2 VALLEY POPULATION

YEAR	CITY OF PHOENIX	MARICOPA COUNTY
1910	11,134	34,488
1920	20,292	89,576
1930	47,950	150,970
1940	65,000	186,193
1950	106,818	331,170
1960	439,170	663,510
1970	581,562	968,487
1980	764,911	1,509,262
1990*	876,000	1,827,000

*Projected figures

Source: Johnson, 1982; U.S. Census of Population, various years; Maricopa Association of Governments, 1978.

After the early settlement period the population in the Salt River Valley expanded rapidly (Table 1.2). The greater Phoenix area population, effectively represented by Maricopa County statistics, experienced the greatest expansion following World War II and the 1970s (Table 1.2) (Johnson, 1982). The 1980 census tallied a population of approximately 1,500,000 persons, while the projected population for 1990 is 1,827,000 (Maricopa Association of Governments, 1978), an increase of 18%. Over 75% of the Arizona population is located within the Gila River Basin in two urban centers, Phoenix and Tucson (Walker and Bufkin, 1986), concentrating the staggering water demand in relatively small geographic areas. The explosive growth and urban expansion may eventually threaten small agricultural towns located in the western valley.

Institutional Structure of Agricultural Water

The Salt River Project (SRP), a quasi-public water and utility organization, has played an important role in administering the most vital resource in the desert, water. Early organization of water delivery was critical to the valley economy, an ecomony controlled dramatically by the availability of water, (Smith, 1972).

Like pre-1900 attempts to divert water with brush dams, the 1902 enactment of the National Irrigation Act initiated formal water use organization in the valley. This law provided federal financing for reclamation projects, the funds raised by the sale of public lands. The federal government, refusing to negotiate reclamation projects with private individuals, forced valley farmers to organize the Water User's Association and pledge farmland for debt repayment. In early 1903 the association was approved as well as a dam site in Tonto Basin, the present-day site of Roosevelt Dam. Construction of Roosevelt Dam, a 85.3-m (280-ft) high stone masonry dam, began in 1906 and was completed in 1911.

To improve the efficiency of water delivery, the existing irrigation canals were purchased and integrated by the federal government. Granite Reef Dam, a diversion dam located below the Salt-Verde confluence (see Chapter 4 of this volume), was constructed between 1902 and 1913 to control irrigation canal flows. Three additional dams, Horse Mesa Dam, Mormon Flat Dam, and Stewart Mountain Dam (Fig. 3.3) constructed on the Salt River below Roosevelt Dam, provided an expanded capacity for water storage and the generation of electrical power.

Barlett Dam, the first dam on the Verde River (Fig. 3.3), was constructed by 1939 as a component of the existing irrigation district. Phelps Dodge, an eastern company involved in copper mining, financed the completion in 1946 of the second structure on the Verde River, Horseshoe Dam (Fig. 3.3). Horseshoe Dam was part of a water exchange program whereby its storage replaced water diverted from the Black River (in the Salt River headwaters) to the company town of Morenci (Smith, 1972).

Irrigated fields quickly required ground-water pumping plants to correct waterlogging problems. This unanticipated complication affected surrounding non-irrigated fields and forced these farmers to join the association to access pumping services. Ground-water wells were constructed in 1928 to supplement surface water supply.

Following the lead of SRP, valley water services have been highly organized to improve water delivery and reliability of supply. The 41 major agricultural water organizations irrigate approximately 297,000 ha (733,000 ac), concentrated in the Salt and Gila River valleys, using about 3,600,000 m^3 (3,000,000 ac-ft) of water annually (Arizona Dept. of Water Resources, 1983).

In 1983 approximately 70% of valley water was supplied by ground-water sources (Maricopa County Department of Planning and Development, 1983) of which 70% was used for agriculture. A history of ground-water mining, which has resulted in land subsidence in areas of concentrated irrigation and urban development, convinced the Arizona legislature to pass the Groundwater Management Act in 1980, acclaimed to be the most innovative and comprehensive law of its kind in the United States (Arizona Department of Water Resources, 1986). Areas of intense ground-water use have been divided into Active Management Areas, where ground-water resources are stringently monitored. The 1980 law requires that the quantity of extracted ground water can not exceed natural and artificial recharge by 2025.

ROUTE

The field trip concentrates on the portion of the Salt and Gila rivers within the greater Phoenix area, which extends from the confluence of the Salt and Verde rivers, near Mount McDowell, to Gillespie Dam, located near Gila Bend (Fig. 1.6). A total of 11 stops were selected for detailed examination, although there is much to observe from the vehicle window and optional stops as interest dictates. Throughout the trip dryland fluvial processes and human adjustment and manipulation of these processes constitute unifying themes.

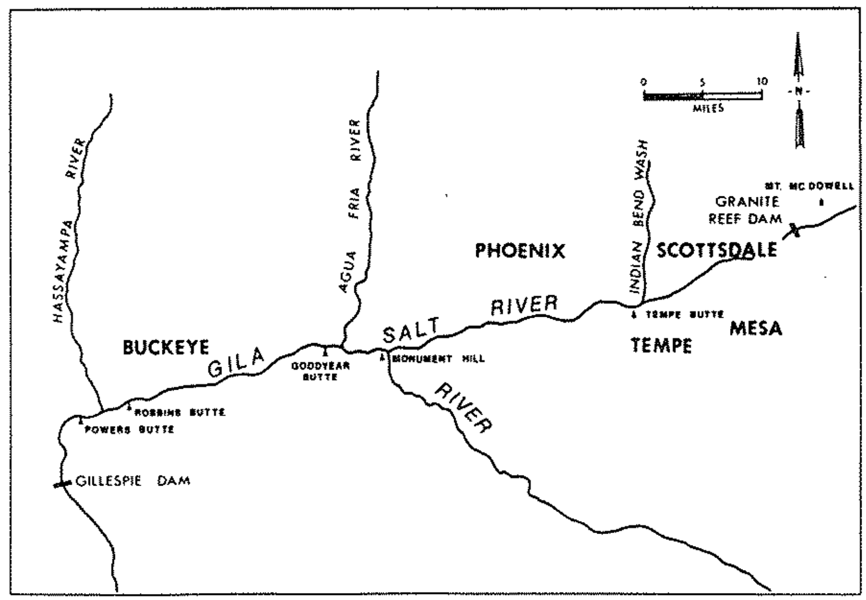

Figure 1.6 General area for the field trip.

The first day focuses on the Salt River channel located in the eastern portion of the metropolitan area, beginning with its junction with the Verde River (stop 1) and ending with the historical river crossing in present-day Tempe (stop 7) (Fig. 1.7). These five stops reveal components of the valley irrigation system and its importance from a historical perspective, channel development of the Indian Bend Wash tributary, pioneer crossings of the Salt River, and channel degradation caused by flooding events.

The second day examines the western section of the Salt River and a portion of the Gila River. The six stops, stops 8 through 13 (Figs. 1.8 and 1.9), highlight the impact of diversion dams, sedimentation and tamarisk, and channel change and instability.

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Figure 1.7 Stop 1 through Stop 6 locations.

Figure 1.8 Stop 7 and Stop 8 locations.

Figure 1.9 Stop 9 through Stop 11 locations.

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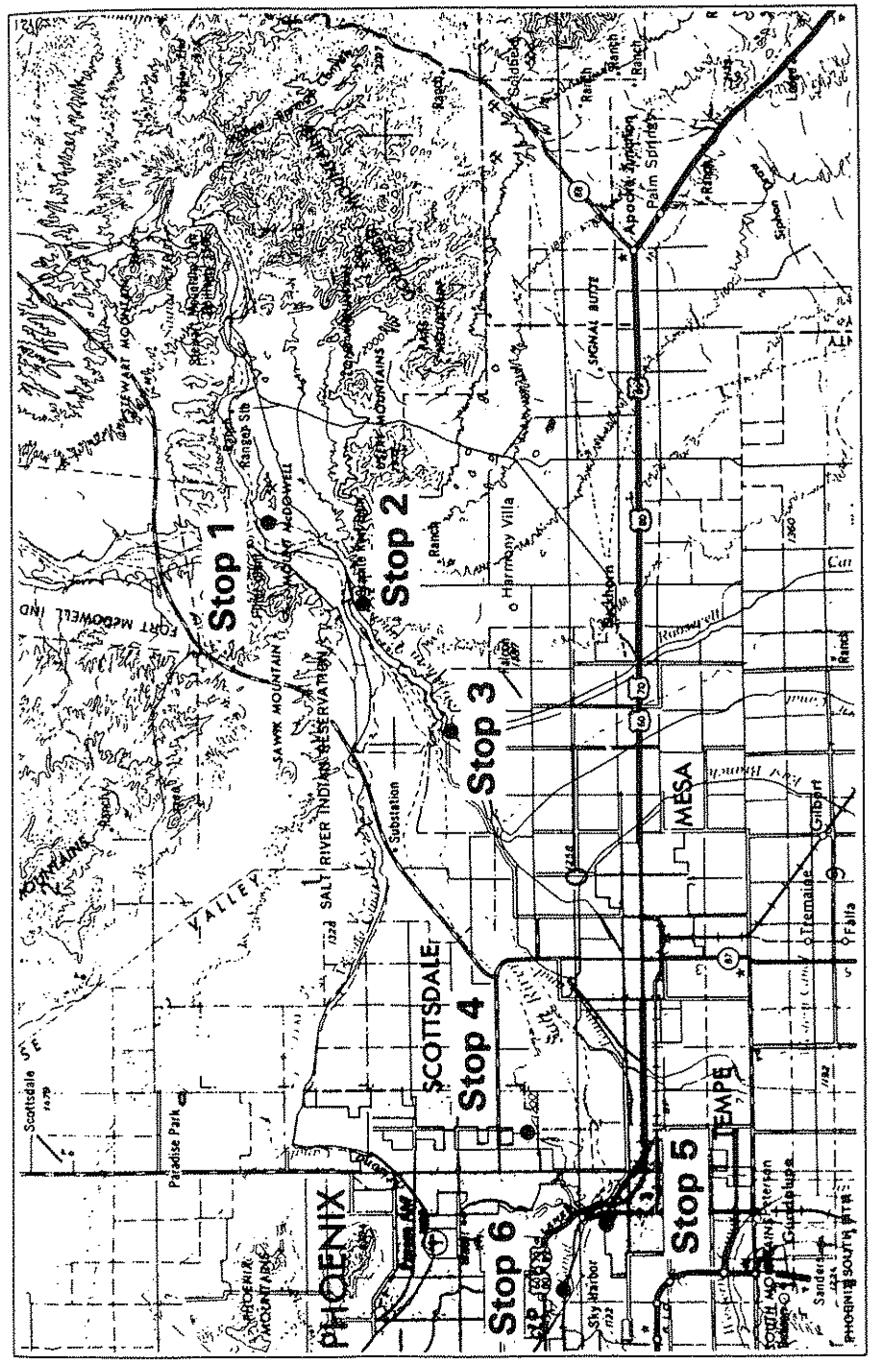

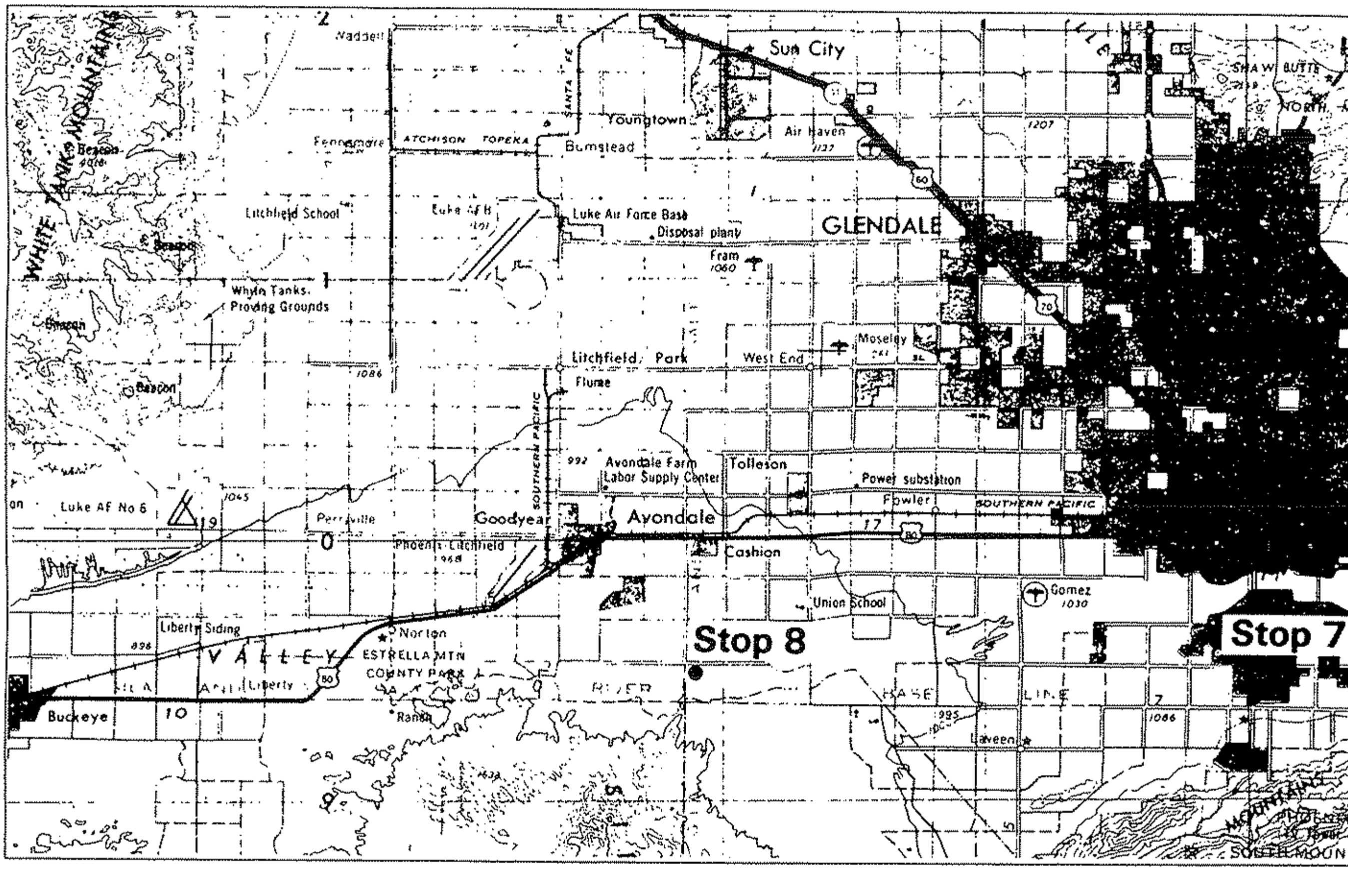
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Stop 8
Sun City
Youngtown
Air Haven
GLENDALE
Luke Air Force Base
Disposal plant
Litchfield School
White Tanks Proving Grounds
WHITE TANK MOUNTAINS
Litchfield Park
West End
Moseley
Avondale Farm Labor Supply Center
Tolleson
Power substation
Fowler
SOUTHERN PACIFIC
Goodyear
Avondale
Cashion
Union School
Gomez
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VALLEY
Buckeye
Laveen
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ATCHISON TOPEKA
Bumstead
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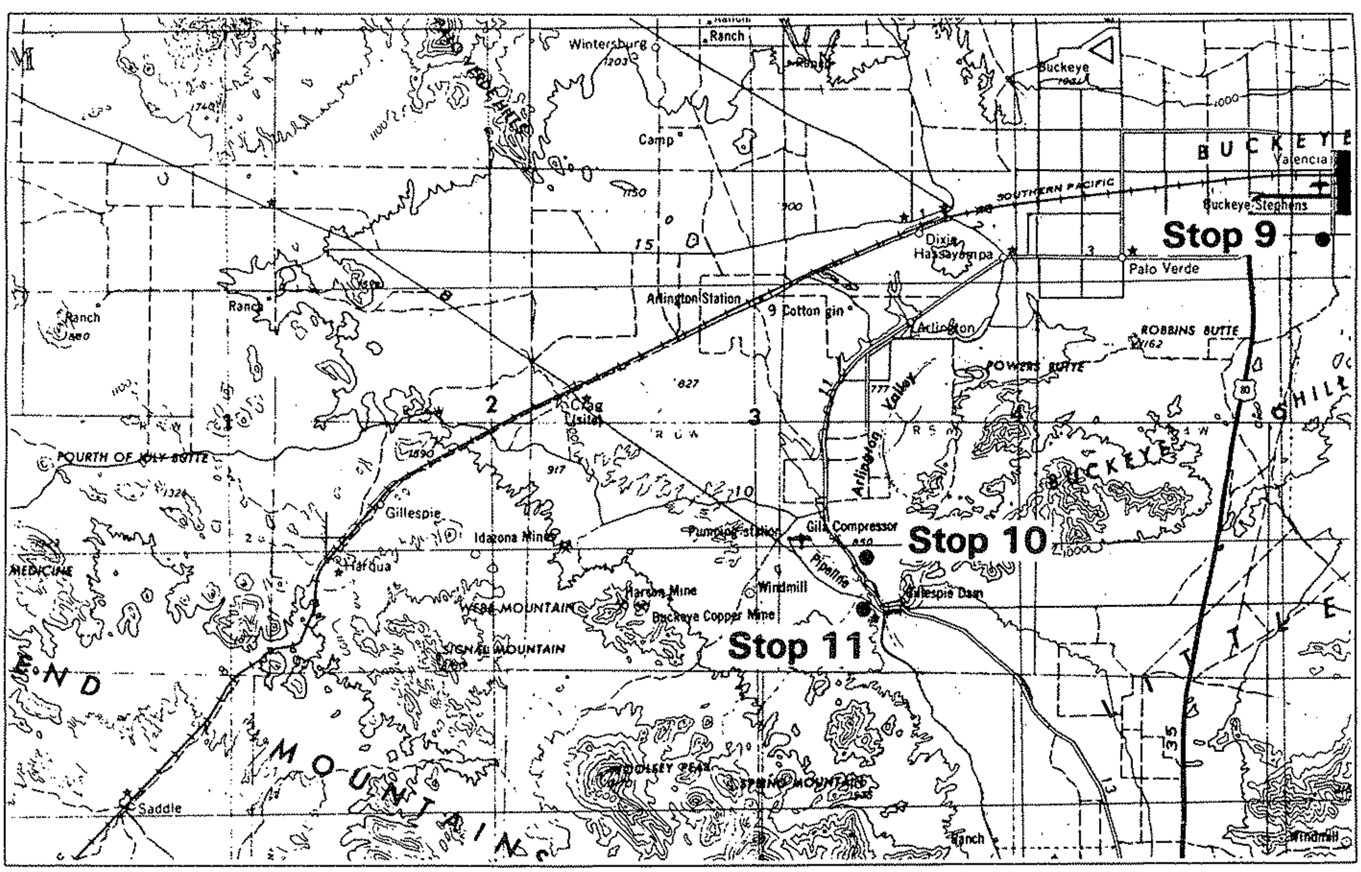
SHAW BUTTE
SOUTH MOUN


Stop 9
Stop 10
Stop 11
Wintersburg
Ranch
Buckeye
BUCKEYE
Valencia
Buckeye-Stephens
SOUTHERN PACIFIC
Palo Verde
Dixie
Hassayampa
Arlington Station
9 Cotton gin
Arlington
ROBBINS BUTTE
POWERS BUTTE
Arlington Valley
FOURTH OF JULY BUTTE
Gillespie
Idazona Mines
Pumping station
Gila Compressor
Pipeline
Windmill
Gillespie Dam
Harquahala
Webb MOUNTAIN
SIGNAL MOUNTAIN
Buckeye Copper Mine
WOOLSEY PEAK
SPRING MOUNTAINS
Saddle
MOUNTAINS
MEDICINE
Camp

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CHAPTER 2

ROAD LOG

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FIRST DAY

(Note: Although most measurements in this guide are in metric, distances in the following log are in miles to permit use of standard odometers on American automobiles).

The starting point for the field trip is the corner of Third and Jefferson Streets near the Phoenix Convention Center. Begin the trip by driving east on Jefferson Street.

0.3 **Seventh Street:** turn right (south), continue south on Seventh Street.

1.6 **Interstate 10 Highway (Maricopa Freeway):** turn left (east), continue east and then south on I-10.

3.5 **Tempe**

In 1871-1872 Charles Trumbull Hayden, a Connecticut immigrant to Arizona, established a flour mill and a ferry at the Salt River at a narrow crossing near here. Hayden and others built systems on the south side of the river to provide water for the fledgling communities of San Pablo and Butte City. Darrel Duppa, an area developer, investor, and gadfly, apparently suggested the name Tempe because the area reminded him of the Vale of Tempe near Mt. Olympus in Greece. The name came to be applied to the combined areas of San Pablo and Butte City. Hayden's Ferry became a significant transportation link between Phoenix and Tucson.

8.9 **Arizona Route 360, (Superstition Freeway):** take the exit for Arizona 360 East, continue east on Arizona 360.

12.3 **McClintock and Arizona Route 360 East (Superstition Freeway):** continue east on the Superstition Freeway.

13.3 **Tempe Canal, Mesa**

The canal is a supplier of irrigation water for much of Tempe and a connector between the Southern and Western canals. The canal serves as the boundary between Tempe and Mesa. Mesa was founded in May 1878 by settlers sent by the Church of Jesus Christ of Latter-Day Saints (the Mormons)from Bear Lake County, Idaho, and from Salt Lake County, Utah. Using their irrigation experience from these northern areas, the settlers quickly developed a canal system to serve municipal and agricultural needs for water from the Salt River. The town, established by T. C. Sirrine, was first named Hayden, in honor of Charles Trumbull Hayden, but in 1888 was named Zenos to honor a prophet in the *Book of Mormon.* In 1888 the name was changed to Mesa, a term in popular use at the time to refer to the town which appeared from the north to occupy a tableland.

20.5 **Consolidated Canal**

The canal supplies irrigation water for the agricultural and municipal areas of Mesa, Gilbert, and Chandler and is a connector between the Southern and Western canals.

22.1 **Eastern Canal**

The canal supplies irrigation water for the agricultural lands east of Gilbert and Chandler and for municipal Mesa from the Southern Canal.

24.4 **Roosevelt Canal**

The canal was constructed by the Roosevelt Water Conservation District to conduct irrigation water from the Southern Canal south to agricultural areas south and east of Gilbert and Chandler. The canal crosses a pediment and fan surface diagonally, so that flood waters from upslope pose a hazard for the canal. Note the long low ridge constructed on the upslope (or east) side of the canal to provide flood protection. A drain channel on the east side of the canal provides additional protection from flood over for the structure by conducting collected flood water southward, where it is emptied into an area near the Gila River.

The flood control facilities in this area also serve an economically important land use function as a golf course location. The golf course allows secondary use of the area near the canal and increases nearby property values, adding to the tax base of the canal district.

25.3 **Power Road Exit from the Superstition Freeway:** take the exit and turn left (north) on Power Road. Continue north on Power Road which will eventually change to Bush Highway.

29.9 **McKellips Road:** turn right (east), continue east on McKellips Road.

30.5 **Central Arizona Project Canal:**

Optional Stop A—Central Arizona Project Canal

The Central Arizona Project Canal conducts water from the Colorado River system at Lake Havasu across central Arizona to Phoenix and then south to Tucson. The canal, with a capacity of 85 m^3/s (3,000 ft^3/s), provides surface water to be used instead of ground water which is now being radically overdrawn. Major users of the Central Arizona Project water are municipalities.

At this location the canal is situated on the Spook Hill Pediment which slopes gently upward toward the Goldfield and Usery mountains to the east. Runoff from this upslope pediment poses a flood hazard for the canal similar to the hazard seen earlier along the Roosevelt Canal. From the crest of the road crossing the view to the east shows suburban development which increases the flood hazard by introducing new impervious surfaces to replace natural soil surfaces. These new surfaces, along with associated drains and gutters, collect and deliver runoff up to four times more rapidly than under natural conditions.

Turn around and proceed west along McKellips Road back toward Bush Highway.

31.3 **Bush Highway:** turn right (north), continue along Bush Highway.

34.9 **Central Arizona Project Canal**

To the left is the syphon that carries the canal under the Salt River; to the right is the collector basin and pump house that starts the water on its way south toward Tucson. Continue north on the Bush Highway.

35.6 **Salt River**

The river at this point includes flow from the Verde River. Note the Mesquite Bosque (forest) and tamarisk thickets along the river on the left and the flood deposits topped by Upper Sonoran vegetation on the right which includes saguaro cactus, palo verde trees, and creosote bush. The riparian vegetation on the left subsists on groundwater that is a few feet below the surface, while the plants on the right are drought resistent and survive on sporatic soil moisture.

Granitic rocks of the Usery Mountains to the right produce through weathering a granular soil with large amounts of grus. Note the spheroidial weathering of the granitic rocks on the mountain slopes above the pediment.

Continue northeast on Bush Highway.

38.2 **Entrance to Phon D. Sutton Recreation Area:** turn left (northwest) and proceed along the entrance road.

39.4 **Parking lot for the Phon D. Sutton Recreation Area:** park at the east end of the lot where a connector road continues northeast into another parking area. From the right (south) side of this paved road, hike up the rutted dirt track that leads up the slope to the top of the terrace. The best view of the area is from the top of the terrace.

Stop 1—Confluence of the Salt and Verde Rivers

For more complete information, maps, and diagrams, see Chapter 3 of this guide.

The mountain watersheds that supply water to the Salt and Verde Rivers are not generally visible from the valley area, but some of the higher precipitation mountain slopes can be seen to the north and east of this location. To the northeast, Four Peaks (2,332 m; 7,645 ft) of the Mazatzal Mountains rise above the general line of the horizon, while to the north the mountainous terrain of the transition zone is visible. The transition zone is a band of rugged terrain separating the Mogollon Rim (the southern edge of the Colorado Plateau) from the Basin and Range Province. Runoff from these high altitude zones supplies water for the valley and the metropolitan area, while precipitation on the valley itself is a tiny fraction of the evapotranspiration.

The terraces along the rivers at this location do not represent the entire sequence of depositional units in the river system, but the Mesa Terrace, on which we are now standing, is especially well-developed. Small cobbles in the terrace have lithology representing much of the complex geologic materials from the Superstition and Goldfield mountains. The terraces grade upslope into pediments that lead to the mountains. Downslope the terraces grade to a presumed past level of the rivers which was higher than at present. No absolute dates are available for the terraces, but Troy Péwé, who has mapped them, estimates their ages to be at least early Pleistocene. Péwé also concluded that tectonic activity created the terraces rather than climate changes (see chapter 3 for citations).

From the early 1900s to the early 1980s, Salt River Valley water managers planned to construct Orme Dam at a location immediately downstream from the confluence of the Salt and Verde Rivers. The dam, with its left abutment at the point where we are now standing and its right abutment at the water filtration plant on the slope of Red or McDowell Mountain across the river, was to be a flood-control structure. Planners turned to alternative proposals when complications arose concerning the inundation of lands on the Salt River and Fort McDowell Indian

reservations and the need to integrate flood control, water storage, and water delivery by the Central Arizona Project.

Stream gages on each river a short distance upstream from their confluence provide the best measure of flow into the Salt River Valley, though gages have existed at other sites on the Salt River below the confluence. Gaging records extend back to the 1890s, but unstable cross sections confused measurements until the upstream gages began operations. Each river supplies roughly the same amount of irrigation water and provides about the same potential for flood hazard. The worst case senario for flooding is the simultaneous peaking of both streams, a circumstance which apparently occurred in 1891 to produce a combined discharge of about 8,496 m^3/s (300,000 ft^3/s).

Return to the Bush Highway via the parking lot entrance road.

40.6 **Bush Highway:** turn right (west) and continue back toward the metropolitan area.

43.5 **Unpaved road on the right with a stop sign at its junction with Bush Highway:** turn right (west) and follow the unpaved road past the gate keeper's house for Granite Reef Dam. Continue on the road until it crosses the Southern Canal and enters the river bed. Park on the bed, but off the road to allow other vehicles to pass. Walk up the river bed, along the south bank to the left abutment of the dam.

Stop 2—Granite Reef Dam

For more complete information, maps, and diagrams, see Chapter 4 of this guide.

Granite Reef is an exposure of older Precambrian granite in the bed of the Salt River that establishes a relatively stable cross section at this location between Red or McDowell Mountain on the north and the Usery Mountains on the south. The mountain, which has religious significance for the Indians on the Salt River and Fort McDowell reservations, is formed by resistant fanglomerates produced by erosion of the mountains to the east. Note that the beds slope gently to the west, away from the source of materials.

This site was used from prehistoric times as a take-out point for irrigation water by means of temporary brush dams. The present structure was completed in 1908 to provide a means of supplying water to the Arizona Canal on the north side of the river and the Southern Canal on the south side. The establishment of Granite Reef Dam preempted other take- out points downstream for irrigation water and allowed the integration of many of the canal systems in the Salt River Valley.

During the floods of 1978-1980 considerable erosion occurred on the channel bed immediately downstream from the dam. During the pre-1978 period the surface of the bed materials was coincidental with the upper surface of the splash apron at the foot of the dam. Erosion has removed material several feet below the original level, exposing bedrock in some places and removing sand and gravel bars in other locations.

The section of river bed immediately downstream from the dam was the site of an extensive, complex riparian vegetation community prior to 1978. Cottonwood, willow, arrowweed, and tamarisk formed a forest-like habitat important for avian populations. Post-1978 erosion destroyed the habitat except for a few small remnants.

A partial explanation for the erosion below the dam is that material removed by floods is not now replaced by new sediment from upstream because that material is now stored behind dams. Granite Reef Dam stores so much sediment that the Salt River Project excavates the material by dredging and sells it as construction material. The sediments behind the dam represent a renewable resource as the river continually transports new material into the location, replacing the mined sediments.

The Central Arizona Project Canal crosses the Salt River immediately downstream from Granite Reef by means of a syphon. Water from the open canal approaches the river from the north side, enters two large pipes which conduct it down the slope, under the river, and up the slope on the south side where it is emptied into an open canal again. A similar crossing for the canal occurs on the Gila River.

Return to the Bush Highway by the same route used to approach this stop.

44.5 **Bush Highway:** turn right (south) and continue south on Bush Highway.

47.6 **McDowell Road:** turn right (west) and continue west on McDowell Road.

The view directly ahead shows the gentle slope of the pediment away from the Usery Mountains (directly behind the vehicle to the east) toward the valley to the west. The road surface flattens as it crosses from the surface of the pediment onto the surface of the deep valley fill of unconsolidated material.

51.1 **Roosevelt Canal**

The Roosevelt Canal conducts water southward from the Southern Canal. In this area the water irrigates extensive citrus groves that are slowly being supplanted by suburban development. Citrus, which grows well in the sandy, well-drained soils of the Mesa Terrace, includes oranges, grapefruit, tangerines, and tangeloes.

51.7 **Val Vista Drive:** turn right (north), continue north on Val Vista Drive.

52.1 **Edge of the Mesa Terrace:** note that the road dips down over the north edge of the Mesa Terrace and descends to the Lehi Terrace.

52.2 **Southern Canal**

The Southern Canal, like many prehistoric canals, follows the edge of the terrace at a relatively high level so that laterals may distribute water by gravity flow to fields on the lower terrace. To the right (east) is the pump or lift that raises water from the level of the Southern Canal to the top of the Mesa Terrace for distribution through the Roosevelt Canal.

52.7 **Lehi Road:** turn left (west) and continue west on Lehi Road.

53.1 **McDowell Crossing Trailhead:** park in the small drive-out in front of wooden sign, and walk along the marked trail to the river bank.

Stop 3—McDowell Crossing

For more complete information, maps, and diagrams, see Chapter 5 of this guide.

McDowell Crossing (named after Fort McDowell that was located north of the river in the late 1800s) was one of the few crossing points on the river for horses and wagons because in the 1800s the river was wide and shallow. The bed was covered with coarse particles which aided in trafficability, unlike many other reaches dominated by fine sand. In March, 1877, a party of settlers from the Church of Jesus Christ of Latter Day Saints (the Mormons) crossed the river at this point and established a camp on the south side. They established the communities of Mesa and Lehi and began irrigated agriculture by clearing sediment from the prehistoric canals already excavated here. The town of Mesa received its name because from the north side of the river the terrace on which the city established appears to be a low, wide mesa.

McDowell Crossing was also a major take-out point for irrigation water for use on the south side of the river. The low flow channel of the river directs water to the south bank at this location, and even prehistoric Hohokam Indians used the site as a canal heading. Two canals still exist at the site. The Consolidated Canal was designed to conduct water from the river to nearby fields and was excavated in 1878. Its use was eventually preempted by irrigation waters from the Southern Canal taken from the river upstream at Granite Reef Dam. The Spite Ditch was excavated in 1912 to take water out of the river a few feet upstream from the Consolidated Canal as part of a water rights dispute (hence the name, Spite). The issue was resolved and the second ditch never carried water.

The canals were designed to take water from the river at the point where they intersect the stream, but at present withdrawal of water would be impossible because the bed of the stream is nearly 6 m (20 ft) below the beds of the canals. When the canals were built, however, the bed of the river was at a much higher level, and only in recent decades has erosion lowered the bed of the river. This remarkable downcutting of the channel extends from Granite Reef Dam to at least the Mill Avenue Crossing, almost 28 km (17 mi) downstream. The width of the deepest erosion averages about 91 m (300 ft), but its depth is most clearly indicated at this location.

The south bank of the river exposes a stratigraphic sequence common along rivers in and near the Salt River Valley. At the upper surface fine-grained materials, probably from overbank flooding, are widespread and frequently contain artifacts from the Hohokam Culture that flourished in the area until about 1250 A.D. Beneath the fine-grained layer are cobbles deposited by channel processes. The cobble layer often has caliche development in its upper portions. Beneath the cobble layer, alternating lenses of fine and coarse particles indicate a switching of fluvial processes from channel-related deposition to overbank processes. In the eastern part of the Salt River Valley, alluvial materials are several hundred feet thick.

The cobbles in the bank of the river are of about the same size as cobbles on the bed of the present river, indicating that the ancient and modern Salt rivers have about the same competence for sediment transport. Apparently hydraulic conditions over the past several thousand years have not been radically different than those observed over the past one hundred years. Though flow conditions have been changeable, they have changed through about the same range of conditions.

Between 1941 and 1965 the river channel was dry except for minor local runoff. All the discharge of the river was stored in upstream reservoirs and diverted by the canal system. The bed of the river became like the rest of the valley floor in the sense that it came to be owned and developed for a variety of purposes. In addition to private individuals and companies, parts of the river bed are owned by cities, counties, the state, the federal government, and various Indian Tribes. Immediately downstream from this site, a large gravel mining operation extracts materials from the bed of the river for construction activities in east Mesa. The pit created by mining activities was excavated before the 1978 floods which refilled them with sand and gravel. The owners again mined materials and created large pits, which partially refilled in subsequent floods.

Return to the parking area, and continue driving west on Lehi Road which will curve to the left and trend southwest.

54.7 **McDowell Road:** turn right (west) and continue west on McDowell Road.

At the Lehi and McDowell roads intersection, three terrace levels are visible. The lowest level is the Lehi Terrace, corresponding to the surface on which the last stop is situated. Lehi Road followed the boundary between the Lehi Terrace on the northwest and a small area of the Blue Point Terrace on the southeast about two meters higher than the lowest surface. The Mesa Terrace is the highest level in this area and is the location of the intersection.

Immediately southeast of the intersection is the Consolidated Canal which conducts water from the Southern Canal to Mesa, Gilbert, and Chandler. The Eastern Canal diverges from the Consolidated at this point, conducting water to areas that are immediately upslope from the remainder of the Consolidated. The small structure associated with the canal is an electrical generating facility that takes advantage of the fall in the Consolidated Canal from the level of the Mesa Terrace down to almost the level of the Lehi Terrace.

During the drive along McDowell Road, notice the radical differences in land use between the two sides of the road. The agricultural area on the north side of the road is part of the Salt River Indian Reservation, while the land use on the south side typifies the semi-rural style of many Anglo residents of Mesa.

57.1 **Mesa Drive:** turn left (south) and continue south on Mesa Drive.

57.6 **Townsite of Lehi**

Lehi was established in March 1877 by Daniel W. Jones, a member of the Mormon group that first settled the east Salt River Valley. Residents first called the settlement Jonesville, while others in the region referred to it as Bottom City because of its location near the Salt River. In 1884 the town was recognized by its post office name, Lehi, which derived from the name of a prophet in the *Book of Mormon.* The agricultural area stimulated the development of a series of increasingly sophisticated ditches to carry water from the Salt River.

58.1 **McKellips Road:** turn right (west) and continue west on McKellips Road.

Those field trip participants wishing to break for lunch may find that this is a convenient point to do so. Two and one half miles south on McKellips Road is Main Street in Mesa. A left turn on Main Street brings the traveler to several restaurants within about one mile. After lunch, return to Mesa Drive-McKellips Road intersection, turn west, and continue with the field trip.

Alternatively for those who wish to remain on the field trip route with a minimum of delay, a fast food restaurant is located one mile west of the Mesa Drive-McKellips Road intersection on McKellips Road at its junction with Country Club Drive.

59.7 **Bed of the Salt River**

The Salt River channel has an artificial form at this cross section in order to protect gravel mining operations on the left bank and to stabilize the channel as it approaches a major bridge. The McKellips Road crossing is built on the floor of the channel and is closed whenever flow occurs. In Arizona this type of crossing is sometimes called a "Wyoming" crossing (in Wyoming it is sometimes called an "Arizona" crossing), language apparently used by sheep herders.

62.8 **Scottsdale**

Scottsdale was named after Major Winfield Scott, an army chaplain who homesteaded the area in 1891. By 1896, when the name became official, the area was primarily agricultural and depended on irrigation water from the Salt River.

63.3 **Hayden Road:** turn right (north) on Hayden Road and continue north.

64.3 **McDowell Road:** turn left (west) and continue west on McDowell Road.

64.7 **Indian Bend Wash**

The wash is a tributary of the Salt River that originally drained the southwestern slopes of the McDowell Mountains (visible to the northeast) and the fan-pediment slopes near the mountains. Development in the area has beheaded much of the drainage from upstream areas but urban surfaces have increased the local runoff into the stream. Joint projects by the city of Scottsdale and the U.S. Army Corps of Engineers have converted the original braided stream into the artificial channel that exists here now.

64.7 **Miller Road:** turn right (north) and continue north on Miller Road.

65.0 **Eldorado Park:** turn right (east) into El Dorado Park, and park in the general parking area or in the picnic area. Walk south along the foot paths to the McDowell Road bridge over the wash, cross the wash to the obelisk play area, walk north up the wash on the opposite side, and return to the vehicle by walking around the lake.

Stop 4—Indian Bend Wash

For more complete information, maps, and diagrams, see Chapter 6 of this guide.

The original natural channel of Indian Bend Wash was braided, laterally unstable, and prone to overbank flooding in some reaches. As the city of Scottsdale expanded rapidly after World War II, the wash became a serious hazard to urban development as construction activities closed in on the channel. In a combined project, the city of Scottsdale

and the U.S. Army Corps of Engineers designed a channel and near-channel environment to stabilize the stream system and to prevent damaging flooding. About 11 km (7 mi) of the channel have been altered at a cost of about $85 million, with some work on the southern portion of the system still incomplete. The project has eliminated the hazards, increased property values in the area, and represents one of the most successful projects of its type in the country.

On the loop walk through Indian Bend Wash, several structural strategies for dealing with channel instability and flooding are visible. The design of the wash is such that it can conduct low flows of only a few tenths of a m^3/s or it can accommodate flood flow of more than 283 m^3/s (10,000 ft^3/s). The low flow channel is hardened so that it is locationally stable, and in some cases it has a decorative function: in this area it provides an excuse for a small foot bridge and supplies flow for a small waterfall.

The design of the wash accommodates intermediate flows by employing several channels. In this area, flood waters flow through the parking lots on either side of the channel, and are also conducted along walkways. After floods, minimal clean-up is required. At high flows, water is spread over the entire cross section of the wash by the sills formed by walkways across the wash and by other dual-purpose structures such as the open-air concert area west of the obelisk and the cement esplanade.

Part of the problem of management of flood waters is the management of energy. Drop structures along low and medium flow channels dissipate energy that otherwise might be expended for erosion. Steps and benches that serve human use purposes in non-flood periods also dissipate energy in flood flows.

Bridge protection is a major feature of the Indian Bend Wash design. Where the wash flows under bridges, the object of the design has been to accelerate flows so that water moves through the constrictions without clogging. Channel gradients beneath bridges and along bridge approaches are steeper than elsewhere along the stream to accelerate flows, and channel floors are hardened under the bridges to protect piers from scour. During dry periods the hardened areas serve as bicycle paths, roller skating rinks, and skate-board areas.

Between bridges, small dams retard the downstream flow to form ponds and small lakes. These retention structures slow the movement of water downstream and allow it to percolate into the subsurface as a means of ground-water recharge. The lakes also serve recreational functions.

Return to the vehicle, and exit El Dorado Park by the Miller Road access. Turn left (south) onto Miller Road and continue south.

65.3 **McDowell Road:** turn right (west) and continue west on McDowell Road.

66.4 **68th Street:** turn left (south) and continue south on 68th Street.

67.5 **Tempe Canal Park**

The Arizona Crosscut Canal extends through the park on the right. The crosscut canal connects the Arizona Canal on the north (which heads at the right abutment of Granite Reef Dam) with the Grand Canal on the south. The crosscut canal integrates the canal system because originally the Grand Canal headed nearby, several miles downstream from Granite Reef.

The Papago Buttes in the park are erosional remnants of Older Precambrian Mazatzal Quartzite and Cretaceous sandstones that project through the Tertiary alluvial fill of the Salt River Valley.

68.2 **Curry Road:** turn right (west) and continue west along Curry Road.

68.9 **Mill Avenue:** turn left (south) and continue south along Mill Avenue across the Salt River on the Mill Avenue Bridge.

69.6 **1st Avenue:** immediately after crossing the bridge, turn right (west) onto 1st Avenue at Tempe Beach Park. Turn right into the parking area and park in the northwest corner of the area. Walk west past the softball diamond and tennis courts to the risers on the approach for the Ash Avenue Bridge. Climb the risers and walk to the base of the pylon for the electric lines on the level of the old street that approached the now abandoned bridge.

Stop 5—Hayden's Ferry Crossing

For more complete information, maps, and diagrams, see Chapter 7 of this guide.

Hayden's Ferry was a flat-bottomed raft attached to a cable that crossed the river at about this location. Beginning in the 1870s the ferry provided a connection between the agricultural areas north of the river in the area that is now Phoenix and the road south to Tucson. Another similar ferry provided a crossing on the Gila River south of what is now Tempe. Although the river could be forded at times of low water, the ferry provided a reliable crossing of the stream because during some years it did not decline below about 23 m^3/s (800 ft^3/s). The bed of the river for several miles above and below the crossing were sandy and not suitable for wagons or general traffic. Even after the completion of the railroad bridge, the ferry served local traffic.

Charles Trumbull Hayden lived in a small adobe house, a portion of which is now Monti's Restaurant, across 1st Street from the Tempe Beach Park. He operated the ferry and constructed a flour mill which served as the basis for the Hayden Mill, the large white structure on the south bank of the river. The mill processed wheat grown in parts of the

Salt River Valley and shipped it south to connect with the Southern Pacific Railroad at Tucson.

The bridges at this crossing are more stable than other bridges across the Salt River in the reaches of the alluvial valley because they are built in an area where bedrock prevents lateral channel migration. The Papago Hills on the north side (with Cretaceous conglomerates close to river level) and Tempe Butte on the south side (with Tertiary andesite) are highly resistant. The present rail bridge was built in 1912, while the Ash Avenue Bridge (now unused) was completed in 1911. The Mill Avenue Bridge, with its neo- Gothic decoration and spanning concrete arches, was a WPA project completed in the early 1930s. The latter bridges are anchored on bedrock below the channel floor, unlike other bridges across the Salt River in the Valley which are constructed only on alluvium.

Beginning with the floods of 1978, the channel in this reach has degraded about 5 m (15 ft), a downstream extension of the erosion seen at the McDowell Crossing (Stop 3). The cross section had dense phreatophyte vegetation in the 1930s and 1940s, but reduction of the ground-water level through pumping produced a river bed mostly devoid of vegetation. Erosive floods (with sediments stored behind dams) and lack of resistance without the vegetation resulted in the removal of large amounts of material. Indications of previous surfaces of the bed of the river are visible on the black pylons supporting the rail bridge. For reference, the bed level during the 1940s was approximately at the level where the metal cross pieces join to form the center of an X between each pair of pylons.

This stop concludes the first day of the field trip. Hotel accommodations and restaurants are available in downtown Tempe. The second day of the field trip begins by proceeding north on Mill Avenue at the Mill Avenue Bridge.

SECOND DAY

The second day of the field trip continues where the first day ended by continuing north on Mill Avenue at the Mill Avenue Bridge.

0.0 **Bed of the Salt River.**

The north-bound lanes of traffic cross the bed of the river while south-bound lanes use the bridge. During times of flow, all traffic uses the bridge. Bed materials visible from the road are mostly large cobbles that are mobilized in flows of about 425 m^3/s (5,000 ft^3/s).

0.8 **Washington Street Turnoff:** move to the left lane and follow Washington Street to the left as it turns to the west.

1.0 Project Drive.

Optional Stop B—Salt River Project Headquarters

Salt River Project is a quasi-public organization that operates as a water and power utility. Its shareholders are property owners in the Salt River Project (SRP) irrigation area that includes about 60,725 ha (150,000 ac) and 42 m (138 mi) of canals in the Valley. SRP operates like a public utility company but has some aspects of a governmental entity, especially in the voting representation of those it serves. The project organization grew out of the need to provide a negotiating group to deal with the newly formed U.S. Bureau of Reclamation in 1902. The Salt River Valley Water Users Association absorbed other groups and individuals to plan and pay for the development of control structures built by the Bureau on the river. SRP represents a cooperative effort, partly private enterprise and partly government agency, that closely approximates the vision of John Wesley Powell for the development of the arid and semiarid western United States.

SRP headquarters buildings include administrative, planning, and control facilities. A museum and library are available. Visitors are welcome.

1.2 **Enter Phoenix.**

The name Phoenix was the suggestion of "Lord" Darrell Duppa, an Englishman who helped organize the Swilling Irrigation Canal Company in 1867. He proposed the name, officially adopted in 1869, in recognition of a new city rising out of the ashes of a previous one that had used the ancient canals. Parts of the city were previously known as Smith's Station and Pumpkinville, while additional suggested names included Stonewall and Salina. Residents decided that the name Phoenix would be more likely to inspire investors.

2.1 **Tovrea Castle on the right (north) side of Washington Street.**

Edward A. Tovrea occupied the castle in the early 1900s. Born in Illinois, experienced as a freighter and canal builder, he assembled a cattle-based business empire, one of the largest in the American West. His operations included properties in five states and Mexico, while his cattle feeding and trans-shipping facility in Phoenix, located between the mansion and the Salt River in this locality, accommodated 50,000 cattle. He later sold his meat-packing plant to Cudahy.

By the 1950s all that remained of the operation were the mansion, the Cudahy plant, and a much reduced area of cattle pens that included some feedlot operations on the river bed. The channel was a useful location for a noxious industry because the river carried no water between 1941 and 1965 and it was not near residential or commercial areas. The instability of the channel location did not become apparent until the 1960s and 1970s.

2.5 **48th Street:** turn left (south) on 48th Street and continue south toward the Salt River.

2.9 **Grand Canal:** cross the canal on the small bridge and immediately turn left (east). Continue east on the unpaved road on the canal bank.

3.2 **Gate House for Jointhead Dam:** on the right (south) side of the canal bank. Park on the open space near the canal bank and walk down onto the channel bed and to the crest of the dam.

Stop 6—Jointhead Dam

For more complete information, maps, and diagrams, see Chapter 8 of this guide.

This was the site of numerous temporary brush dams until the construction of Jointhead Dam in 1886. The dam diverted water from the lowest flow channel into the Grand Canal that trended generally west and northwest from this point and that watered much of the early Anglo agriculture in the Phoenix area. The site was used for similar purposes by the Hohokam Indians for their agricultural and urban culture until about 1300 A.D. Jointhead Dam is a simple concrete sill anchored on the south side by a concrete and stone revetment partially buried by a large sand bar. The right abutment on the north side includes the space once occupied by headgates and the lead-in for the Grand Canal. This outtake canal is now mostly buried by debris on the north bank.

Bedrock occurs at or near the surface at this cross section, unlike most others between the Mill Avenue Crossing (Stop 5) and Gillespie Dam (Stop 11). Small outcrops of Tovrea Granite occur in the channel (at times, deposition covers them), and a small outcrop of the Tovrea Granite is visible at the gate house of the dam.

With the development of Granite Reef Dam (Stop 2), low flows in this lower reach of the river were preempted, and Jointhead Dam lost much of its usefulness. A cross-cut canal connected the higher Arizona Canal (with its headgate at Granite Reef) to the lower Grand Canal and the system became integrated. Two cross-cut canals now exist: an older one about 1.5 km west of 48th Street and the modern one near Papago Buttes in Tempe and Scottsdale.

The Salt River in this reach is unlike the river at the Mill Avenue Crossing where it is a single, well-defined channel. Here the stream is braided and has four subchannels. The northern-most channel is the lowest flow channel and has been since at least 1868, the date of the earliest maps of the area. During low flows the dam efficiently diverted water, while during flood periods the second, third, and fourth canals carried "overflows." During the floods which began in 1978, flows deepened the other channels more than this first low flow channel, partly because of the diversion of water by gravel mines upstream from this location. The channel with Jointhead Dam remains the lowest channel at this cross section.

During flood periods the material eroded from the channel of the river upstream (as seen in previous stops) moves through this cross section and in part across the top of the dam. Notice the erosion of the parapet of the dam on the upstream side, where particles have abraded the originally rectangular crest into an irregular form.

Return to the vehicle by way of the gate house. Drive back to 48th Street, turn right (north) on 48th, and return to its intersection with Washington Street.

3.9 **Washington Street:** turn left (west) on Washington Street and continue west.

4.4 **Entrance to Pueblo Grande**

Optional Stop C—Pueblo Grande Ruins and Museum

Pueblo Grande was one of seven major towns in the Salt River Valley built by the Hohokam people sometime before 1450 A.D. The towns and their surrounding fields survived on water brought from the Salt River by an extensive canal system. The canal system survived largely intact until Anglo-American settlement in the late 1860s, when the newcomers simply cleaned the old canals and reused them. Pueblo Grande was first excavated by Frank Hamilton Cushing and a team of Harvard archeologists in 1887, but archeological work continues to the present, in part stimulated by archeological salvage efforts related to modern freeway construction.

The Pueblo Grande Ruins and Museum are open daily and include a self-guiding trail from which visitors can view the remains of canals and dwellings. The museum contains relics and exhibits explaining the Hohokam culture.

4.6 **Grand Canal.**

Originally designed to withdraw water from the Salt River at Jointhead Dam (Stop 6), now the canal receives water from the Arizona Canal by way of the Cross Cut Canal. The Grand Canal originally supplied mostly agricultural needs, but now supplies mostly urban requirements.

6.9 **24th Street:** turn left (south) and continue south on 24th Street.

8.6 **University Avenue:** turn left (east) and follow University Avenue as it approaches the Interstate Highway 10 grade, and as it turns to the right (south).

9.0 **Magnolia Street:** turn right (west) and park on the south side of the

industrial building (containing offices of the DHL Express Company) on the southwest corner of the intersection of Magnolia Street and University Avenue. Walk east and south to the river from the parking area by following the the unpaved road or track near the parking area.

Stop 7—Interstate-10 Bridge Crossing

For more complete information, maps, and diagrams, see Chapter 9 of this guide.

The Interstate-10 highway bridge illustrates construction and management problems associated with unstable dryland rivers. The bridge crosses the river in a previously unstable reach where the single channel migrated laterally before construction. The bridge rests on piers and concrete pads set about 12 m (40 ft) below the bed of the channel. Bridge abutments on either side of the channel with associated rip-rap wings have prevented lateral instability. By concentrating the flow in a restricted cross section, however, the bridge caused deep, erosive flows that excavated the channel under the bridge and destabilized one of its piers. Partial collapse occurred and led to efforts to prevent excessive scour.

Part of the engineering efforts at stabilization of the river in the reach of the bridge crossing has been the construction of sediment dams. These concrete sills cross the river a short distance downstream from the bridge. They prevent deep scour and retain sediment even though its general transport eventually is in the downstream direction. The sills set up eddies and hydraulic jumps that threaten increased bank erosion, however, so that rip-rap linings and levees are required on both sides of the stream.

Unlike some of the reaches of the stream we have visited previously, the reach in the Phoenix area has fine materials on its surface. Photographs from the 1890s show that almost a century ago the river flowed on sandy materials in this reach, and though the river has entrenched itself through channel erosion (a process promoted by channelization efforts and mining operations), sand-sized sediment is still common.

The channelization of this reach along with the downcutting of the channel has converted what was once a flood plain to an elevated terrace. The surface between the channel and the parking area was the flood plain of the river for several centuries. It contains remnants of Hohokam canals, overbank deposits, and typical flood-plain vegetation (except for phreatophytes). It now lies over 9 m (30 ft) above the channel.

Return to the parking area and continue west on Magnolia Street.

9.6 **24th Street:** turn left (south) and continue south on 24th Street.

9.9 **Salt River.**

Sand and gravel mining has been so extensive in this reach of the river that the channel is completely artificial. Mining operations have excavated flood-plain areas near the channel as well, leaving extensive open pits. The state of Arizona may create a special taxation and planning district with the ultimate objective of redesigning the channel and near-channel areas into parks, residential and commercial developments, and recreation areas including small lakes. The proposed project, known as Rio Salado, would be an effort similar to the developments on Indian Bend Wash, but on a grand scale. The feasibility of the project remains unproven.

10.7 **Broadway Road:** turn right (west) and continue west on Broadway Road.

12.9 **South Phoenix.**

South Phoenix neighborhoods would be disrupted and displaced by the developments associated with the proposed Rio Salado project. Space for lower-income residents in the city is an issue in the project because although the development would "improve" neighborhoods such as this one, increased property values would probably force out the present residents who would then have few alternatives for residential location.

14.8 **19th Avenue (not 19th Street):** turn right (north) and continue north on 19th Avenue.

15.0 **Salt River.**

Sand and gravel mines have created a completely artificial channel in this reach. Riparian vegetation survives on surface runoff from the surrounding city and a perched water table. The species represent remnants of a once extensive community that included tamarisk (salt cedar), cottonwood, and arrowweed.

15.8 **Lower Buckeye Road:** turn left (west) and continue west on Lower Buckeye Road.

16.9 **City of Phoenix Landfill.**

The landfill operation on the left (south) side of Lower Buckeye Road represents a common use of the near-channel environment—as a dumping ground. The operation may affect water quality in the river as a result of seepage which contains chromium and other heavy metals. Groundwater contamination may also be an issue because the water-table mounds near the channel, bringing it closer to the surface than in many other locations.

21.1 **Vista to the Left (South).**

Two mountain masses are visible to the south. On the left (east) is South Mountain, an uplifted block of Older Precambrian granite and

schist split by a transverse fault and injected with Cretaceous granites. On the right is the higher and more rugged Sierra Estrella (Spanish for Mountains of the Stars) formed by an uplifted block of Older Precambrian granite. The highest point is Montezuma Peak (1,323 m; 4,337 ft). Both blocks are flanked by pediments and alluvial fans. The Gila River flows through the pass between the two mountain masses.

22.0 **Santa Maria.**

Centered on the junction of Lower Buckeye Road and 67th Avenue, the Hispanic community of Santa Maria is a cultural manifestation of irrigation agriculture. The town developed as migrant workers settled in the valley on a permanent basis to work the surrounding irrigated fields watered by the Salt River Project.

24.9 **91st Avenue.**

Optional Stop D—Phoenix Waste Water Treatment Plant

The 91st Avenue Waste Water Treatment Plant, located about 2 km (1.7 mi) south of the intersection of Lower Buckeye Road and 91st Avenue, processes almost all of the waste water for the metropolitan area. The facility returns treated water to the channel providing a continuous flow downstream. The water is later withdrawn for irrigation purposes in the Buckeye Irrigation District. Some of the water will also be used by the Palo Verde Nuclear Generating Station as a coolant.

25.1 **Lateral Canals.**

In this area small lateral canals distribute water originating in the Grand Canal which is upslope (north and east). Common crops include grains, cotton, and some vegetable farming. Pecan trees line the canals. The general landscape image in this area is representative of the appearance of much of the agricultural portion of the Valley in the early 1900s. Later, many of the trees were removed because it was assumed that they "wasted" too much water from the canals by transpiration. It is not clear, however, how much water was salvaged by the tree removal effort because of increased evaporation from water surfaces no longer shaded by the trees.

27.8 **115th Avenue:** turn left (south) and continue south on 115th Avenue.

28.6 **Canal.**

Decend from an upper terrace to a lower one that also is the flood plain in some areas. The canal at the terrace edge is a drain for fields upslope (north and east) and a means of redistribution of the water to fields downslope (south and west). The drain eventually ends at the Agua Fria River.

30.2 Salt River.

Continue across the river bed on 115th Avenue and turn left (east) off the road onto the unpaved parking area next to the river channel. Walk along the south side of the river to the end of the open, unpaved area to the confluence of the Gila River, a small stream entering the south side of the Salt River. Walk about 0.5 km (0.3 mi) along the unpaved road that leads directly south, away from the Salt River. Follow the curving road until it ends at the Gila River.

Stop 8—Confluence of the Salt and Gila Rivers

For more complete information, maps, and diagrams, see Chapter 10 of this guide.

The flow of the Salt River in this reach is entirely from the 91st Avenue Waste Water Treatment Plant except during brief flood periods. The flow is consistent, so that recharge of the ground-water supplies occurs and the watertable is close to the surface. The consistent flow also fosters the dense growth of phreatophytes including tamarisk and cottonwood.

The smaller flow from the Gila River, easily contained between the levees except during flood periods, represents irrigation return or drain water from fields upstream. In some cases the water has been used several times for irrigation with concentration of dissolved minerals or salts increasing with each use because of evapotranspiration. Over the last several decades, as use of the water has increased, the amount of dissolved solids has also increased. Although federal limits for drinking water and irrigation water for salt content are well below 1,000 ppm, shallow ground water in this area may have over 3,000 ppm disssolved solids. For further use it must be mixed with supplies with lower salt content: either deep ground water or irrigation water from the Salt River.

The difference in sediment content between the two streams is usually apparent at their confluence. The Salt River is relatively clear because the flow is from the waste water treatment plant and it has passed over bed materials that have particles too large to be entrained by the low flows. The Gila River carries drain water from fields in fine-grained materials, and the river flows over fine sands and silts near the confluence with the Salt River. The result is that much material is in suspension in the flow of the Gila. Downstream from the confluence the water from the two streams mixes only slowly, with the brown plume of Gila River water evident at least to the road crossing.

Along the walk on the unpaved road, a tamarisk thicket shows the nature and impact of riparian vegetation on fluvial processes. On the south side of the road, the thicket consists of tamarisk trees several decades old. Their wispy, scale-like leaves and lavender blossoms (in

spring) form a major avian habitat, especially for white-winged dove, which use the thicket for cover and the nearby grain fields for food.

The dense root systems of the trees in the thicket act as efficient sediment traps, causing turbulence in flood flows and producing deposition of fine sediments in streamlined mounds around the plants. This sediment would probably not be deposited here if the surface were occupied by grasses rather than trees and shrubs. Eventually this accelerated sedimentation process restricts channel widths and enhances overbank flood hazards. In the thicket where the road ends at the Gila River, flood debris is piled 1-2 m deep against the tree trunks.

The small hill south of the parking area and west of the unpaved road is known as Monument Butte. Formed as an erosion remnant of Older Precambrian Granite, the hill is capped by a surveyor's monument that is the point of origin for the Township and Range Survey System for the state of Arizona. The monument is the intersection of the Gila and Salt River Base Line (trending east-west) and the Gila and Salt River Meridian (trending north-south). The General Land Office established the monument in 1868.

Return to the vehicle and return north on 115th Avenue to the intersection with Lower Buckeye Road.

32.9 **Lower Buckeye Road:** turn left (west) and continue west on Lower Buckeye Road.

34.5 **Agua Fria River.**

The Agua Fria River has its headwaters in the Bradshaw Mountains north and west of Phoenix. Its waters are impounded behind Waddell Dam and distributed by the Maricopa County Water Conservation District Number 1 canal system. As with the Salt River, all the water in the Agua Fria is impounded and distributed except during flood periods. At this location the channel is therefore usually dry.

Unlike the lower Salt River, the lower Agua Fria River is aggrading and maintains a braided characteristic throughout most of its lower reaches. The flood plain is less than 1 m (3 ft) above the floor of the channel where Lower Buckeye Road crosses the river.

35.1 **Avondale.**

Avondale began life as a wagon freight station on the west bank of the Agua Fria River. It was known as Coldwater in the 1890s because of a well there that produced clear, cold water, and because of the English translation of the Spanish "Agua Fria." The arrival of the railroad and a post office required a formal name, and Avondale, the name of a nearby ranch, was adopted.

At the Avondale exit of Interstate Highway 10 are several restaurants offering lunch.

36.2 **U.S. Route 80:** turn left (west) and continue west on U.S. Route 80.

41.2 **Buckeye Canal.**

The Buckeye Irrigation District Canal takes its water from the Salt River and distributes it on the north side of the main stream, mostly for agricultural purposes.

44.2 **Liberty.**

Liberty was originally known as Toothaker (after the first postmistress Harriet Toothaker) and later Altamount before assuming its present name. The town owes its existence to the nearby cotton gin which serves the area farmers. The long-staple cotton grown here commands a high price because of the fine, strong weave it produces. Irrigation insures dependable production.

49.0 **Buckeye.**

In the mid-1880s M. M. Jackson built the Buckeye Canal which he named in honor of his home state of Ohio. Thomas Clanton donated a quarter section for a townsite in the midst of the lands to be irrigated by the new canal and named the town Sidney, in honor of his hometown of Sidney, Ohio. Informal usage referred to the place as Buckeye, however, and in 1931 formal incorporation made the name Buckeye official.

50.7 **1st Street:** turn left (south) and continue south on 1st Street.

53.2 **End of the 1st Street** (also known as Miller Road).

Park the vehicle and walk directly south from the end of the road, past the gravel mine and through the tamarisk thicket along the line of telephone/power poles to the Gila River.

Stop 9—Buckeye Crossing

For more complete information, maps, and diagrams, see Chapter 11 of this guide.

Until the late 1970s, Miller Road extended across the Gila River and continued on the south side of the channel. The floods of 1978 and subsequent years eroded the central part of the braided channel where it crossed the road, the low flow channel migrated northward, and extensive sedimentation buried the road on the north side of the channel in a flood-plain area. The tamarisk thicket has been present since the 1930s and has undergone little change because ground water is close to the surface and the channel usually carries water resulting from discharges from the 91st Avenue Waste Water Treatment Plant and from irrigation return waters in the Gila system.

The end of the road provides a useful indicator of the depth of sedimentation on the flood plain since early 1978. In February 1978 the road surface was the level of the flood plain, but beyond the end of the road (which is the southern limit of the area cleared of sediment by bull dozers and scrapers) the surface of the flood plain is about 2 meters higher. The general path of the now buried road is still visible as a path of less dense tamarisk growth extending from the end of the present road to the river. Excavations of the flood-plain sediments near the tamarisk trees show that the trees are rooted and began their growth at the level of the road. The lower 2 meters of their trunks are now buried.

The thicket influenced sedimentation rates by introducing increased hydraulic roughness to the flood-plain surface, causing turbulence in the flow of flood waters and accelerating sedimentation. Many of the trees have elongated mounds of sediment around them that rise above the general level of the flood plain. In 1987, most of the streamlined mounds along the old road trend from northeast to southwest, indicating the direction of flow during the last flood.

The present path that follows the trend of the original road descends from the level of the flood plain into an abandoned channel. The bank separating the flood plain from the channel illustrates typical vertical accretion deposits of fine sand in several beds. In some places the bank reveals lag deposits of fine gravels that identify zones of concentrated energy or deeper flows than those which deposited the other fine beds. The abandoned channel was occupied by water until flows in 1984 resulted in a locational adjustment that moved the channel in this reach to the south. The present channel is separated from the abandoned channel by a bar containing fine sands from the Gila system and cobbles from the Salt system.

An excavation into the flood-plain sediments immediately east of the end of the cleared road and associated with the gravel mining operation shows depositional structures in the flood-plain materials. Horizontal beds are vertical accretion deposits, but some arched deposits in fine sands also occur. The arched structures represent materials deposited around or downstream from obstructions such as tree trunks. Lag deposits of fine gravels and marker horizons of flood debris (bottles, plastic, and other artifacts) subdivide the accumulation. On the west side of the excavation is an extensive channel deposit of gravels inset into the finer materials.

Walk to the vehicle and return to U.S. Route 80 by driving north on 1st Avenue (Miller Road).

55.7 **U.S. Route 80 in Buckeye:** turn left (west) and continue west on U.S. Route 80.

57.7 Access **Road to Interstate 10, Arizona Route 85:** turn left (south) and continue south on U.S. Route 80 and Arizona Route 85.

57.0 **Palo Verde Road (also known as Old U.S. Route 80):** turn right (west) and continue west on Palo Verde Road.

60.0 **Palo Verde.**

Palo Verde is named after the palo verde trees that once grew along a near-by wash (palo verde is Spanish for "green stick"). Early settlers included Milis Benson from Denmark. The post office was established in 1910 to serve irrigation farmers in the western end of the Buckeye Irrigation District.

61.7 **Descend from one terrace level to another along the Hassayampa River.** The low level terrace may be a correlative of the Lehi Terrace along the upper Salt River, but little research is available. Terrace levels in this area are also confused by the development of leveled fields which irrigators created to distribute efficiently irrigation water from the Buckeye Canal.

62.6 Hassayampa River.

The name Hassayampa is from the Mohave Indian language and means "place of the big rocks water," probably referring to the boulder and cobble reaches of the river in its headwaters on the western slopes of the Bradshaw Mountains. In the reach of the Palo Verde Road crossing, the stream has generally aggraded in recent decades, in part as a response to extensive hydraulic mining for gold during the past century that mobilized near-channel sediments in upstream reaches. In the lower reaches near the Gila River and at the road crossing the channel form is mostly artificial in an effort to stabilize channel location and to protect the leveled fields.

62.8 **Hassayampa Store Junction:** take the left fork and continue southwest on Old U.S. Route 80.

65.0 **Viewpoint.**

The view to the right includes the containment vessels of the Palo Verde Nuclear Generating Station. The station is the largest nuclear generating facility not located at the edge of a lake, sea, or ocean. In order to obtain cooling water, the facility has purchased rights to the effluent of the 91st Avenue Waste Water Treatment Plant on the Salt River. The water flows down the Salt River to the Gila and then to the Buckeye Heading. Eventually, a pipeline will make the connection more efficient. Public policy debates about the arrangement include the propriety of using water in an arid climate for nuclear power plant cooling and questions about pricing structures. Some cities and agricultural users contend that the price paid by the owners of the nuclear station was unrealistically low.

The nuclear generating station occupies an especially stable location relatively free of geologic faults. The viewpoint is at the edge of an older Quaternary basalt flow. Quaternary basalt also makes up the Palo Verde hills to the northwest and the eastern part of the Gila Bend Mountains to the southwest. The western part of the Gila Bend Mountains and Saddleback Mountain (note its distinctive erosional shape) to the northwest are eroded sections of Cretaceous andesite.

65.3 **Road Cut,** exposure on the right (northwest) side.

The road cut illustrates the relationship between Gila River terraces and the older Quaternary basalt flow. The flow occupies the top of the section and is about 2.2 million years old. Below the basalt is a layer of terrace gravels associated with the river and indurated by the heat of the basalt. The lowest layer of finer materials is Gila River alluvium.

65.5 **Arlington.**

The Arlington Canal takes water from the Gila River west of the Buckeye Canal Heading and irrigates land from the townsite south to Gillespie Dam. Mrs. Moses Clanton, wife of an early settler from Missouri, named the town in 1899 for no particular reason other than she liked the sound of it.

67.7 **Terrace gravels** in cuts along the road represent the first well defined terrace above the channel level and may be correlative to either the Lehi or Mesa terraces along the upper Salt River.

72.8 **Barrow Pit** on the right (west) side of the road.

Optional Stop E—Basalt and Alluvium Barrow Pit

Alluvial deposits in Quaternary terraces of the Gila River are visible in the wall of the pit. Alternating layers of fine and coarse materials illustrate what may be overbank deposits from a braided channel (fines) with intervening deposits from braided channels (course). The basalt which tops the entire sequence is about 3.3 million years old, providing a minimum date for the sequence. This arrangement suggests that the terraces are not Holocene despite their relatively young appearance away from the basalt flow.

A short walk to the back of the pit and then up to the upper surface of the flow provides an opportunity to view a typical Upper Sonoran vegetation community, with Saguaro cactus, palo verde and iron wood trees, and a variety of smaller forms. Caliche is strongly developed on the partially weathered upper surface of the basalt flow.

73.3 **Top of the younger Quaternary basalt flow:** turn left (east) onto the dirt track leading away from the road and follow it to the end. Park and walk to the eastern edge of the flow overlooking the river.

Stop 10—Arlington Valley Overlook

For more complete information, maps, and diagrams, see Chapter 12 of this guide.

Gillespie Dam is visible to the south where the highway bridge and pipeline bridge cross the river. The dam is a diversion work about 8 m (25 ft) high constructed in 1925. Within two years it had filled with sediment, and a wedge of sediment now extends about 11 km (7 mi) upstream from the dam. The view from the edge of the basalt flow shows the extent of the reservoir deposits which lead to increased channel instability in the course of the Gila River. Overbank flooding and erosion hazards are more likely in this area because of the dam, but these problems undoubtedly existed before the installation of the dam.

The bedrock sill across the valley formed by the volcanic rocks associated with the Gila Bend Mountains on the west and the Buckeye Hills on the east provide a natural constriction in the valley which forces ground water to the surface. Marshy conditions in the reservoir delta area are common, even during dry periods because of this ground water which is augmented by irrigation seepage.

The abundant ground water close to the surface supports a dense growth of tamarisk which clogs channel areas. In an effort to prevent overbank flooding that might result from the reduced channel capacity, Maricopa County cleared a strip of vegetation on a generally straight course across the delta area to the dam. Floods in 1978 and subsequent years did not maintain a straight channel, however, and the clearing efforts did not appear to affect river processes. Later, local land owners again cleared a straight reach and excavated a "training channel" to guide flood waters, but regrowth of vegetation has mostly eliminated evidence of the effort.

Locational channel instability has been common in the area visible from the overlook. Photographs from 1940 show that the channel was in the middle of the valley but lineations in the phreatophyte forest immediately north of the overlook point indicate that in the 1920s or 1930s the channel may have been on the west side of the valley. In the 1960s the channel was on the eastern side of the valley. During the 1980 flood, the channel migrated to the far western side of the valley, and evidence of its erosional activity is still visible in the form of abandoned channels. In the mid-1980s local land owners mechanically relocated the channel to the eastern side of the valley again.

About 1981, local land owners sued the owners of the dam, charging that the sedimentation processes behind the dam increased

flood hazards and endangered irrigated farm properties. The case was settled out of court, in part because it was impossible to disentangle the various causes of instability in the river channel. Sedimentation may contribute to the problem, but the problem would have occurred without the dam because of the unstable nature of the river and the invasion of tamarisk which enhanced sedimentation processes.

Return to the vehicle and drive back to the paved highway. Turn left (south), and continue south on Old U.S. Route 80.

73.8 **Gila River.**

Park on the right side of the road without crossing the bridge and walk across the road and along the west bank of the river to Gillespie Dam.

Stop 11—Gillespie Dam

For more complete information, maps, and diagrams, see Chapter 13 of this guide.

The constriction at the lower end of Arlington Valley caused by the younger Quaternary Basalt flow from the Gila Bend Mountains to the west and the older Precambrian Granite of the Buckeye Hills to the east is an optimal location for a diversion dam. In 1886 brush and rock dams diverted water into the Enterprise Canal that irrigated fields downstream from this point on the west side of the Gila River. By 1892 Peoria Dam, a wood and rock structure, offered a more permanent diversion. Settlers from Peoria, Illinois, who had developed the western Salt River Valley named the structure and Peoria, Arizona, after their home town. In 1900 a flood destroyed Peoria Dam, but the owners of the Enterprise Canal system constructed a replacement in 1906. In 1921 Frank A. Gillespie, who had moved to Arizona from Oklahoma, constructed the present concrete spanning arch dam, in part to divert water to irrigate his holdings along the Gila Bend Canal on the east side of the river. The Gillespie holdings, now owned by investment companies in eastern states, include more than 32,000 ha (80,000 ac) in the Gila Bend area.

An embryonic community once existed on the west bank of the river immediately downstream from the dam, and a post office was here from 1925 to 1927. The footings of some of the buildings are still visible on the west bank slope.

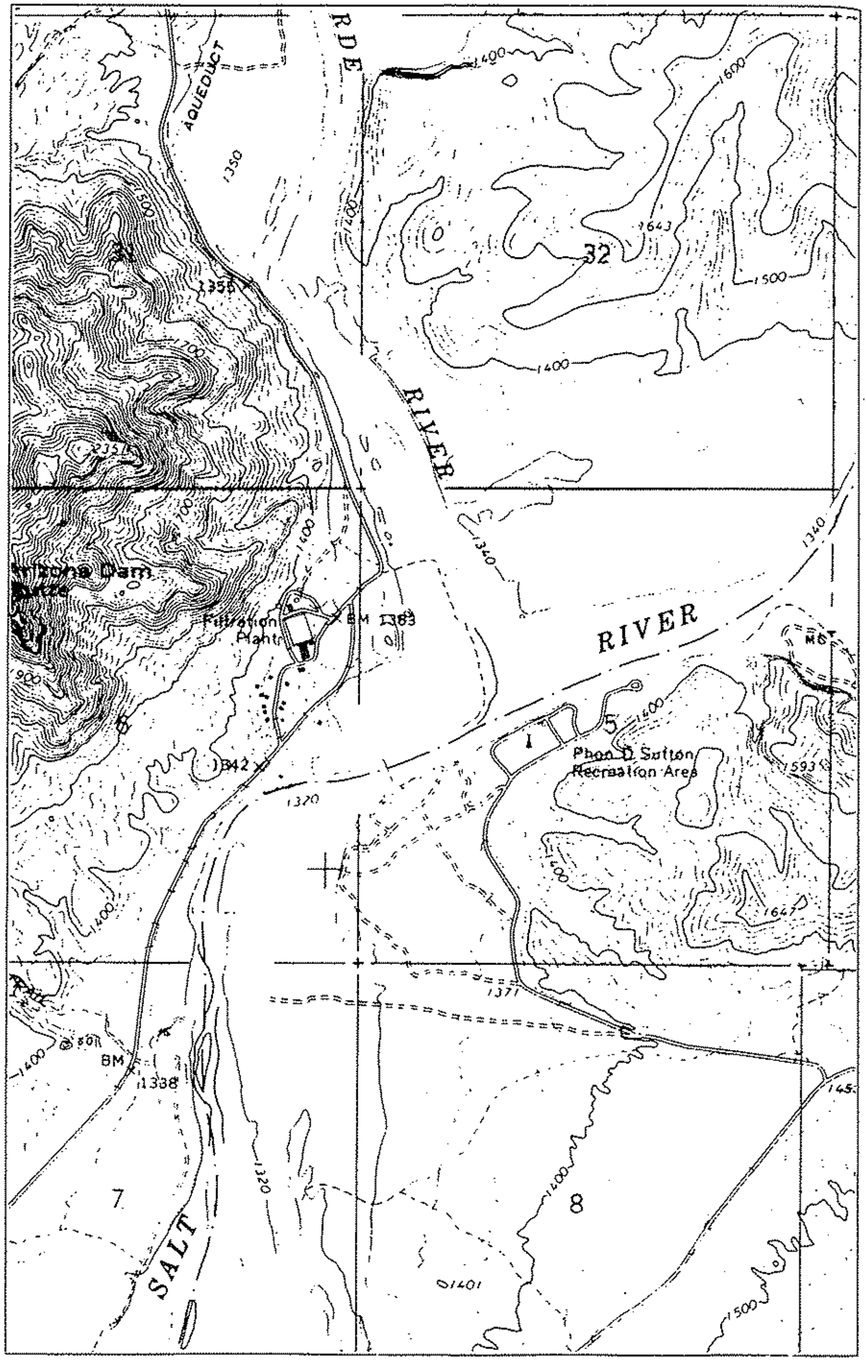
Sedimentation behind the structure extends 11 km (7 mi) upstream and to a height slightly higher than the crest of the dam. The anchoring effect of the tamarisk and accumulation of flood debris on the crest of the dam have caused high-elevation deposits. Maintenance of canal intakes is required. The sediment adds weight to the tops of the spanning arches which extend beneath the material, however, and thus adds stability to the structure which is attached to bedrock.

The area immediately behind the dam is an important wildlife habitat because it represents a wetland area. Ground and surface waters keep the area partly inundated even in drought periods. White winged dove and water fowl use the area as a nesting site, and nearby grain fields provide a food source. Maintenance of cleared channels enfringes on this management objective and represents a significant landuse conflict.

The dam, reservoir, canals, and associate environment are typical of diversion works in the American Southwest. They represent stable points in an unstable fluvial system wherein migrating channels, sedimentation, and erosion change over time. The water resource management objective of a dependable supply of water over a variety of hydroclimatic conditions is made more difficult because of the instability, which in some cases (such as sedimentation behind the dam) is enhanced by the structures.

This stop represents one of the resting places of materials eroded from the Salt River channel. During the first day of the field excursion, we saw erosion dominating the channel environment. Today we saw a different section of the system that is performing a different function, that of temporary storage through deposition. Eventually, floods transport the materials over Gillespie Dam and then take them a few miles further downstream were they are stored behind Painted Rock Dam, below Gila Bend. Painted Rock Dam is a massive flood-control structure constructed by the U.S. Army Corps of Engineers. Unlike diversion dams, Painted Rock stores huge quantities of water and sediment and represents the stopping place for sediments coming down the system, at least for the next several centuries.

This stop is the end of the field excursion. The return distance to Phoenix by way of Old U.S. Route 80, U.S. Route 80, Arizona Route 85, and Interstate 10 is 85.3 km (53 mi). Alternative routes include continuing back through Buckeye on U.S. Route 80, and retracing the path of the trip westward by using Lower Buckeye Road.



CHAPTER 3

CONFLUENCE OF THE SALT AND VERDE RIVERS

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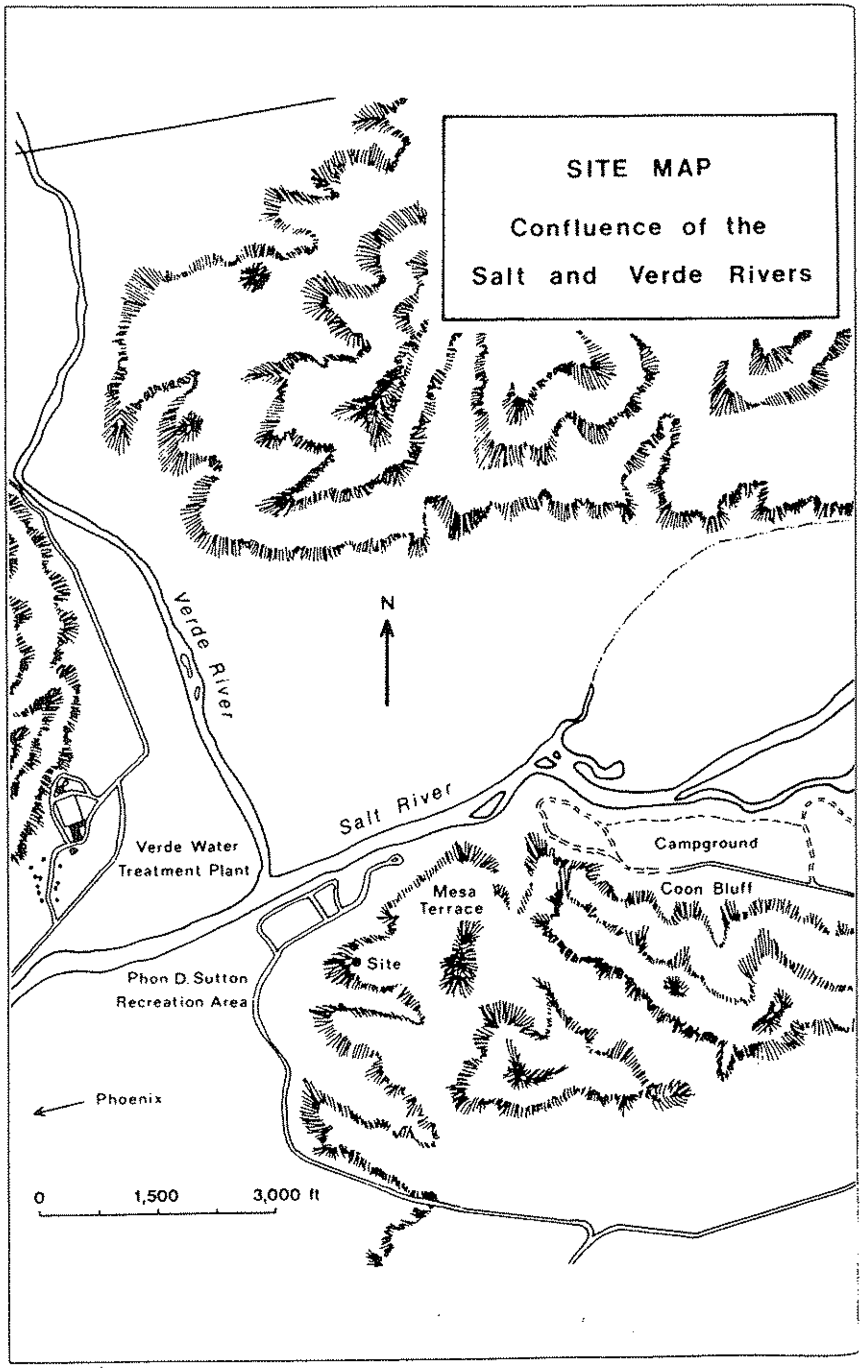
INTRODUCTION

The confluence of the Salt and Gila Rivers is situated within McDowell Basin, a structural depression which is located about 40 km (25 mi) northeast of Phoenix in Maricopa County, Arizona (Figs. 3.1, 3.2 and 3.3). The purpose of this chapter is to describe both the physical and cultural environments of this region, as well as the proposed construction of Orme Dam across the confluence, and the ensuing controversy surrounding this project. The physical environment of the confluence includes the drainage basin, geology, climate, hydrology, geomorphology, vegetation, and wildlife. The cultural environment describes the human occupation and land use in this area.

THE CONFLUENCE

The Salt and Verde rivers confluence lies within McDowell Basin, the transition zone between the Sonoran Desert and Mexican Highlands Section of the Basin and Range Physiographic Province (Fig. 1.2). The Basin and Range Province is characterized by northwest-southeast trending mountain ranges with intervening structural basins filled with alluvium (Hunt, 1974). The Salt River is the largest tributary of the Gila River; the two rivers join south of Phoenix. The Salt River originates in the rugged White Mountains to the east, the northern part of the Gila Basin, and drains 33,342 km^2 (12,873 mi^2)(Fig. 3.4). The river flows through mainly mountainous terrain formed by granitic and volcanic rocks until it joins the Verde River (Corps of Engineers, 1983).

Figure 1.1 Confluence of the Salt and Verde Rivers located on the Granite Reef Quadrangle, U.S. Geological Survey.



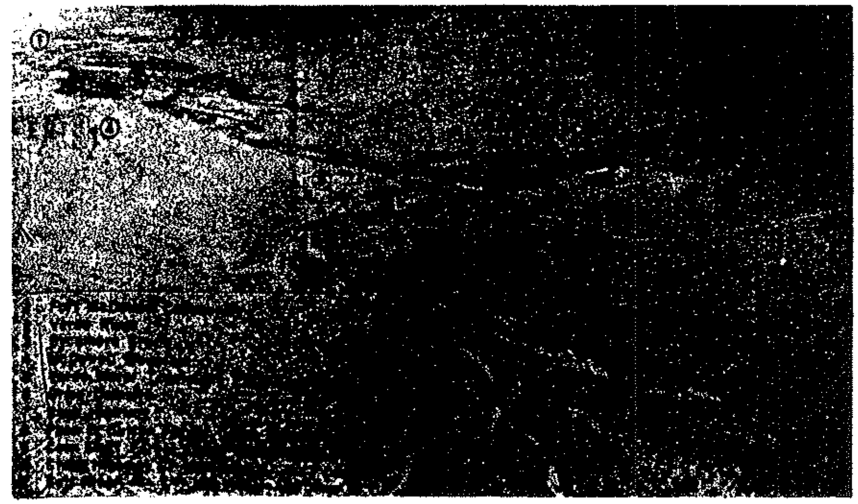


Figure 3.3 McDowell Basin and the confluence of the Sale and Verde rivers (U.S. Bureau of Reclamation, 1976).

The Verde River is the largest tributary of the Salt River and drains 17,094 km^2 (6,600 mi^2) of central Arizona. The Verde River watershed lies within the Colorado Plateau and Basin and Range physiographic province (Fig. 1.2) Its headwaters originate near Flagstaff. Most of its course is cut into basin fill and lake deposits. Other tributaries of the Salt River include Tonto, Cherry, Canyon, Cibeque, and Carrizo creeks (U. S. Bureau of Reclamation, 1976; U. S. Army Corps of Engineers, 1983).

The topography near the confluence is characterized by the narrow flood plains of the Salt and Verde rivers (Figs. 3.1 and 3.3). At this location the rivers have eroded 30-60 m (100-200 ft) below the surface of Mesa terrace, one of the four terraces of the Salt River in the Phoenix region Péwé, 1978) (refer to Chapter 5 in this volume). Other small hills and knobs protrude within this region.

To the west of the confluence lies Arizona Dam Butte, part of the granitic McDowell Mountains. The low terrace of Coon Bluff (Mesa) forms the eastern boundary of the confluence. The terrace is composed of granitic conglomerate interbedded with sandstone and volcanics such as tuff and basalt. This conglomerate also underlies the channel and flood plain at shallow depths. Volcanic tuff forms the resistant knobs protruding from the bed of the channel at the confluence and provides a good marker for noting channel changes (Figs. 3.5 and 3.6) (McDonald and Padgett, 1945). The terrace is capped by large gravels that exhibit well developed impact scars, the results of large boulders saltating along the bottom under high velocity flows of the stream (Péwé, 1978).

Figure 3.2 Site map of Confluence of the Salt and Verde Rivers stop.

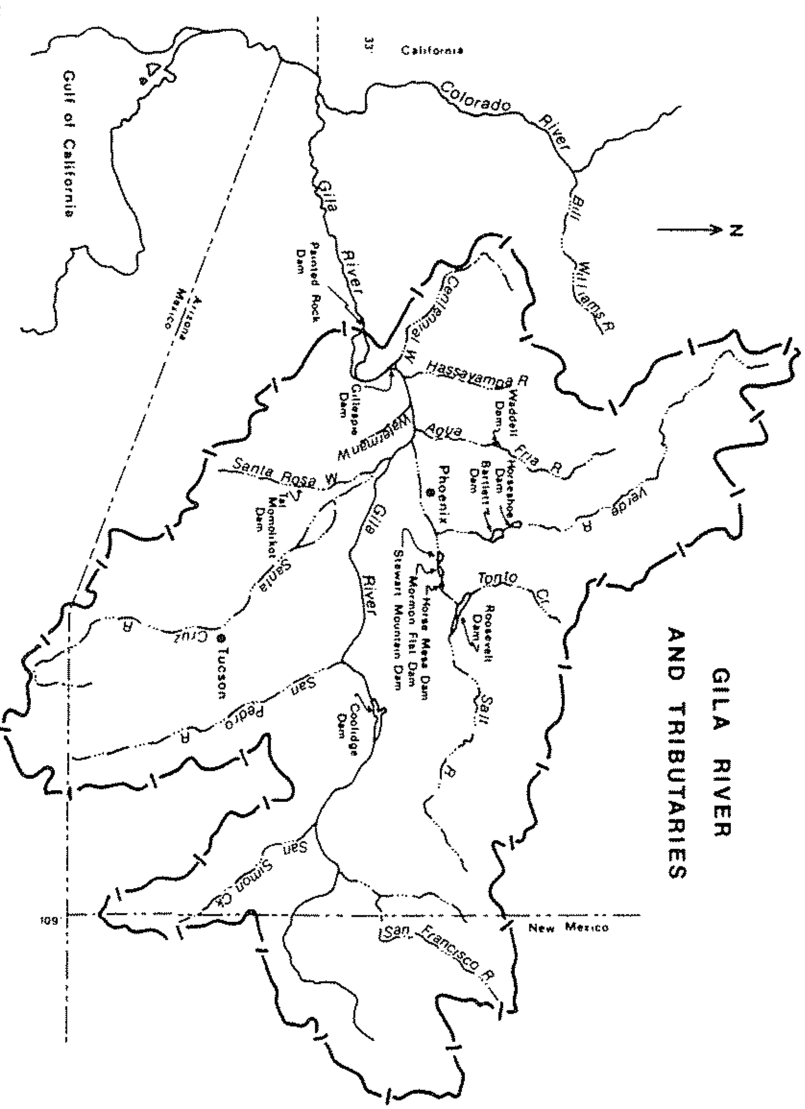


Figure 3.4 The drainage basins of the Gila River (Corps of Engineers, 1983).

Surface flow from the Salt and Verde rivers has historically influenced life in the Salt River Valley. To maintain adequate water storage and flood protection in an area characterized by periods of drought and years of flooding, the flows of the Salt and Verde rivers are largely controlled and sustained by upstream storage reservoirs operated by the Salt River Project (SRP) (SRP, 1972). The storage reservoirs reduce flood peaks by increasing

terraces along river

Figure 3.5 Salt and Verde Rivers confluence, 1949 (U.S. Bureau of Reclamation, 1976).

changes do to flooding

Figure 3.6 Salt and Verde Rivers confluence, 1986 (Photo by author).

lag times. There are presently four dams on the Salt River above its confluence with the Verde River. Starting upstream they include Roosevelt Dam (1911), Horse Mesa Dam (1927), Mormon Flat Dam (1926) and Stewart Mountain Dam (1930). The Verde River is controlled by two dams, Horseshoe Dam (1946) and Bartlett Dam (1939). In 1880, the Arizona Dam, a diversion structure, was built 1.6 km (1 mi) below the Salt and Verde rivers confluence. It was destroyed during the 1903 flood. The site was relocated downstream to Granite Reef Dam (refer to Chapter 4). A description of the dams, their reservoirs and purpose is provided in Table 3.1 (Davis, 1903; U. S. Bureau of Reclamation, 1976).

TABLE 3.1. MAJOR STORAGE AND DIVERSION STRUCTURES AFFECTING FLOWS OF THE SALT AND VERDE RIVERS

STRUCTURE	YEAR	CAPACITY m^3x10^3 (acre-feet)	PURPOSE	STREAM	PRESENT STATUS
Arizona Dam	1903	———	Diversion	Salt	Destroyed
Roosevelt	1911	1,703,488 (1,381,580)	Storage Power	Salt	USBR, SRP
Horse Mesa	1927	302,255 (245,138)	Storage Power	Salt	USBR, SRP
Morman Flat	1926	71,332 (57,852)	Storage Power	Salt	USBR, SRP
Stewart Mtn.	1930	86,020 (69,765)	Storage Power	Salt	USBR, SRP
Horseshoe	1946	171,680 (139,238)	Storage	Verde	USBR, SRP
Bartlett	1939	220,062 (178,477)	Storage	Verde	USBR, SRP

USBR: U.S. Bureau of Reclamation
SRP: Salt River Project

Source: U.S. Bureau of Reclamation, 1976.

FLOODING AT THE CONFLUENCE

The longest runoff record for the Gila Basin is for the Verde River below Bartlett Dam which dates back to 1888 and has had continuous flow since 1903. Hydrologic records indicate that the greatest floods on the Salt and Verde rivers have resulted from winter storms. Major flooding during the critical flood months from December to March is due to saturated ground, capacity-filled upstream reservoirs, snowmelt, and precipitation that covers a large area and lasts for several days (U. S. Army Corps of Engineers, 1983).

The largest floods at the confluence result from simultaneous floods in the Verde and Salt systems. The nature of floods within each river systems depend partly on basin and storm characteristics (Arizona Republic, 1986). Due to the nature of basin topography, shape, and orientation, the Verde River exhibits a flashier hydrograph than the Salt River (Heinert, 1986). A front moving from west to east over the narrow north-south trending basin

of the Verde River is likely to release its moisture over the basin at one time. A similar front moving across the east-west trending Salt River basin, however, releases its moisture over only part of the basin at one time, thus increasing the lag time and reducing the peak flow. Peak flow of the Verde River usually precedes that of the Salt River. If by chance both peaks flow through the confluence at the same time it would produce coincident flooding (Corps of Engineers, 1983).

Calculating the timing of peak discharges and coincident flooding is problematic when predicting flood frequency. Table 3.2 presents a comparison of recorded and simulated floods. Simulated flows represent present conditions with the moderating influence of the six upstream dams. Table 3.3 provides discharge-frequency values for existing conditions below the confluence of the Salt and Verde rivers. The largest flow occurred in February 1891 with an estimated peak discharge of 8,496 m^3/s (300,000 ft^3/s). It is suggested in the frequency analysis that this was the 200-year flood. The storm of 1980 produced a peak discharge of 5,692 m^3/s (201,000 ft^3/s), a return period of approximately 75 years (U. S. Army Corps of Engineers, 1983).

TABLE 3.2 COMPARISON OF FLOODS OF RECORD: SIMULATED VS NATURAL RESULTS

Salt River Below Confluence With Verde River			
WATER YEAR	MONTH	SIMULATED EXISTING CONDITIONS m^3/s (ft^3/s)	NATURAL CONDITIONS m^3/s (ft^3/s)
1891	Feb	7,675 (271,000)	8,496 (300,000[a])
1905	Apr	3,200 (113,000)	3,257 (115,000[b])
1906	Nov	3,795 (134,000)	6,230 (220,000[b])
1916	Jan	4,106 (145,000)	4,644 (164,000[b])
1920	Feb	3,908 (138,000)	4,390 (155,000[b])
1927	Feb	2,322 (82,000)	3,483 (123,000[b])
1932	Feb	2,435 (86,000)	3,313 (117,000[b])
1938	Mar	2,180 (77,000)	3,257 (115,000[a])
1941	Mar	3,738 (132,000)	4,814 (170,000[a])
1966	Dec	1,331 (47,000)	2,407 (85,000[a,c])
1978	Mar	3,370 (119,000)	7,363 (260,000[a])
1979	Dec	4,446 (157,000)	6,655 (235,000[b])
1980	Feb	5,692 (201,000)	6,825 (241,000[b])

[a] U.S. Geological Survey
[b] U.S. Army Corps of Engineers
[c] This value is for the Dec.31 peak; peak which would have occurred without reservoirs for the previous flood, Dec.23, was 3,313 m^3/s (117,000 ft^3/s).

Source: U.S. Army Corps of Engineers, 1983.

TABLE 3.3 DISCHARGE FREQUENCY VALUES FOR THE SALT RIVER BELOW THE CONFLUENCE WITH THE VERDE RIVER

Existing Conditions	
RETURN PERIOD YEAR	DISCHARGE m^3/s (ft^3/s)
5	1,274 (45,000)
10	2,889 (102,000)
20	3,993 (141,000)
50	4,956 (175,000)
100	6,938 (245,000)
200	8,213 (290,000)
500	10,195 (360,000)

Source: U.S. Army Corps of Engineers, 1983.

The Standard Project Flood (SPF) represents the flood that could result from the most severe combination of meteorological and hydrological conditions characteristic of the region. For the Salt-Verde river confluence the SPF would be generated by a storm centered critically over the entire basin to produce maximum runoff. Assuming no upstream dams, the SPF is calculated as 9,912 m^3/s (350,000 ft^3/s, 1,416 m^3/s (50,000 ft^3/s) larger than the uncontrolled flood of 1891. Modified for existing conditions, the SPF would be 8,354 m^3/s (295,000 ft^3/s), comparable to the 1891 flood (U. S. Army Corps of Engineers, 1983). Recent investigations by Baker (1987) into the paleohydrology of the Salt River suggest that a large flood occurred about 1,000 years ago. The result of coincident peak discharges produced a combined peak discharge of 12,461 m^3/s (440,000 ft^3/s) at the confluence, with 6,797 m^3/s (240,000 ft^3/s) down the Salt River and nearly 5,664 m^3/s (200,000 ft^3/s) down the Verde River. The Probable Maximum Flood (PMF) is defined as the flood that would result if the probable maximum precipitation would occur when ground conditions were conducive to maximum runoff. The PMF is a measure of the upper bound of flood potential in a watershed and is used for designing dam spillways. The PMF as predicted by the Bureau of Reclamation is 40,243 m^3/s (1,421,000 ft^3/s; U. S. Army Corps of Engineers, 1983). For perspective, a flood of this size would fill Roosevelt Lake twice or the other five reservoirs four times. The flow would cover Phoenix to a depth of 3.8 m (12.5 ft).

The Salt River has a compound channel pattern, at low flow it is meandering and at higher flows it is braided. The Verde River also meanders and exhibits a series of pools and riffles. The flow and sediment contributed by the Salt and Verde rivers at the confluence tend to remain separate for several hundred feet downstream. This is due to differences in flow densities and in part, to the helicoidal circulation pattern set in motion when the two flows collide at the confluence (Mosley, 1976). Historic flooding has caused changes in the location and geomorphology of the Salt and Verde rivers confluence. The confluence has migrated 152 m (500 ft) downstream since 1949 (Figs. 3.5 and 3.6). This is illustrated by the changing relative location of the tuff bedrock knobs protruding from the channel bed. The change most likely occurred between the 1966 and 1980 storms. The storms of 1980 caused the Verde River to slightly alter its meandering course by creating a larger sweeping bend upstream of the confluence. This was due to the higher velocities associated with flood flows which resulted in increased bank cutting (Heinert, 1986).

An inventory of the vegetation and wildlife to assess the potential impact caused by the construction of Orme Dam was prepared for the lands bordering the Salt and Verde rivers from their confluence to Bartlett Dam on the Verde River and Stewart Mountain Dam on the Salt River (Fig. 3.7) (Ohmart, 1972; Patten, 1972; Horejsi, 1976). The present vegetal environment of the study area is not pristine. The occupation of man for at least a thousand years, economic development at Fort McDowell, agricultural,

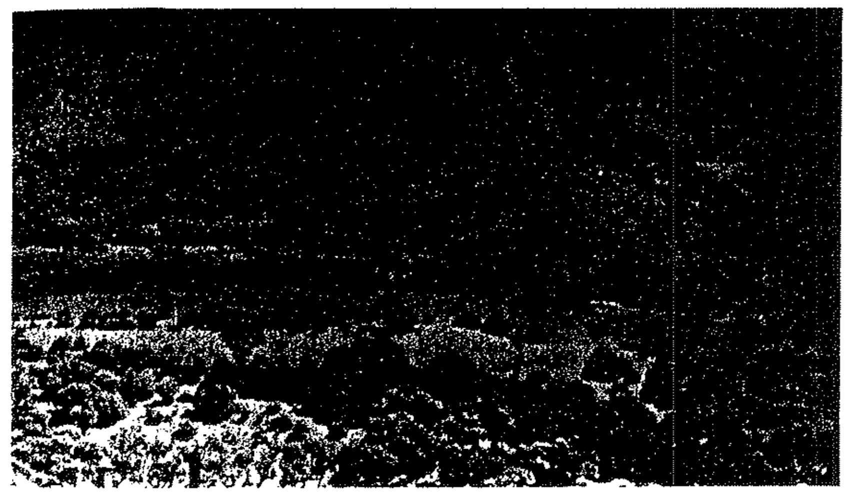


Figure 3.7 . Aerial view east toward Stewart Mountain showing the following vegetation communities: (1) cottonwood-willow, (2) saltcedar-arrowweed, (3) mesquite, and (4) desert scrub (U.S. Bureau of Reclamation photo # P344-300-01715NA, 1976).

grazing, and recreational uses of the area have resulted in vegetation changes and the introduction of nonnative species. The construction of upstream dams has regulated the natural flow regime, preventing large floods which cut new channels, destroy some of the vegetation, and maintain the necessary process of plant succession. The dams have altered species composition and vegetation now grows in areas within the river that under natural flow regimes would be barren (Patten, 1972).

Based on topography, soils and dominant plant species, the vegetation communities can be divided into riparian and desert plant communities (Kearny and Peebles, 1960). Riparian communities, which occupy only 7% of the 50,108 ha (124,000 ac) study area, can be separated into four main groups in which one or two species predominate. These are cottonwood-willow, mesquite, saltcedar, and a mixed community found on sand deposits composed primarily of baccharis (seep-willow). These plant species are hydrophytes and mesophytes, with many assuming phreatophyte characteristics. As a result of agricultural and grazing practices several dominant nonnative plant species have been introduced into the riparian habitat. These include saltcedar, bermuda grass, and alfileria (Patten, 1972).

Within the center of the channels lie relatively unstable sand bars which are dominated by seep-willow and giant reed (Fig. 3.7). Saltcedar mixed with seep-willow dominate the higher more stable sand bars located along the edge of the active channel. Reeds can be found in a few areas of low flow velocity and rock shorelines. Adjacent to the channel edge are low sandy terraces which are occasionally flooded and are characterized by mesquite, arrowweed, seep-willow, and paloverde. Bermuda grass, desert-broom, and mesquite occur in more gravelly areas. During wet winters a rich variety of annual grasses grow. Occasionally, pricklypear may be found on the low terraces, likely the result of heavy grazing. Isolated galleries of old cottonwoods occur on the slightly higher terraces. These terraces, which have a finer soil, form at the edges of the old channel. At the confluence of the Salt and Verde rivers, dense stands of cottonwood, willow, mesquite, saltcedar, and seep-willow grow in limited areas (Fig. 3.7; Patten, 1972). Most of these cottonwoods are older than 50 years, suggesting that successful reproduction has not occurred. This is probably the result of flow regulation and overgrazing (U. S. Bureau of Reclamation, 1976). Slightly above and surrounding the cottonwoods lie bosques of mesquite. These often occur with a seasonal grass understory and in association with apolappus and pricklypear.

Above these terraces, the mesquite grades into desert vegetation. Desert vegetation is primarily composed of xeric shrubs and trees ranging from several centimeters to 5 m (15 ft) in height. Vegetation density and species diversity increases with proximity to the river. There are two desert scrub vegetation communities: creosote bush and paloverde-saguaro. Creosote bush communities which prefer finer textured soils of lower slopes are characterized mainly by creosote bush, bursage and cactus. The paloverde-saguaro community includes paloverde, saguaro, creosote bush, cholla, barrel, pricklypear and hedgehog cacti along with bursage, ironwood, and brittlebrush (Patten, 1972).

Large mammals inhabiting the study site include mule, deer, coyote, javalina, bobcat, and mountain lion. Small mammals include jackrabbit, cottontail, pocket mice and gopher, kangaroo rat, chipmunk, shrew, and bats (Ohmart, 1972; Horejsi, 1976).

Common larger birds residing in the area are great blue heron, Cooper's hawk, Harris hawk, redtailed hawk, great horned owl, and road runner. Smaller birds include the towhee, Gila woodpecker, quail, killdeer, cardinal, and black-throated sparrow (Ohmart, 1972). The endangered Yuma clapper rail has been observed downstream from the dam site (U.S. Fish and Wildlife, 1970). One pair of Bald Eagles nest in a tree on the Verde River upstream from the confluence. A total of seven pair are known in Arizona and all are located in the Salt and Verde river drainage basins (Grewe and Frenzel, 1976).

Fish species native to the area that have adapted to extreme fluctuations in waterflow, high turbidity, and high mineral content include squawfish, minnows, and suckers. The dominant species are the introduced carp and catfish (Minckley, 1972).

CULTURAL ENVIRONMENT OF THE CONFLUENCE

The McDowell Basin has been occupied by man for many centuries with evidence from cultures dating between 300 B.C. to 1,200 A.D. The native cultures that used this area include Hohokam, Salado, Sinagua, and Hakataya. More recently, the basin has been periodically inhabited by the Yavapai and Pima Indians (Gladwin, 1957). The Yavapai people have been divided into three groups by territorial regions: the Western, the Northeastern, and the Southeastern (Fig. 3.8). Distinction between subtribes, bands, and clans was obscured however, when the Yavapai were moved from Fort McDowell, Camp Verde, and Verde Valley to San Carlos reservation in 1875 (Arizona State Museum, 1975).

In 1865, the Camp McDowell military post was established (Brandes, 1959). At that time the McDowell Basin was virtually a no-man's-land with only occasional usage by the Yavapai, Pima, and Maricopa tribes for gathering cactus fruit and mesquite beans. Some Yavapai acted as scouts for the post. In 1873, Camp McDowell was established as a temporary Indian reserve and was mainly occupied by Southeastern Yavapai. Northeastern and Western Yavapai were concentrated at Camp Verde. In 1875, they were all relocated to San Carlos. Unrest between the Yavapai and Apache forced the return of some Yavapai to their original territory in the McDowell Basin (Arizona State Museum, 1975). With abandonment of Fort McDowell in 1890, many Yavapai settled at the Fort in small, agricultural communities. Anglos and Mexicans also settled in the lower Verde Valley and lower Salt River Canyon. Conflict ensued between the Indians and non-Indian settlers until establishment of the Camp McDowell reservation in 1903. A 1904 legislation act authorized purchase of settler's lands which led to the creation of a "completely Indian enclave." Settlers of the lower Salt River Canyon were able to keep their lands. The Fort McDowell community has more than 300 residents, with a tribal roll of more than 500 for the reservation.

The Pima Indians originally occupied the Gila River region. As a result of water shortages on the Gila caused by non-Indian settlements in the mid-1870s, the Pima and Maricopa who settled among them relocated to the Salt River Valley. Plentiful water enabled them to establish an irrigated culture. In 1879, the Salt River Reservation was set aside for the Pima and Maricopa Indians (Arizona State Museum, 1975).

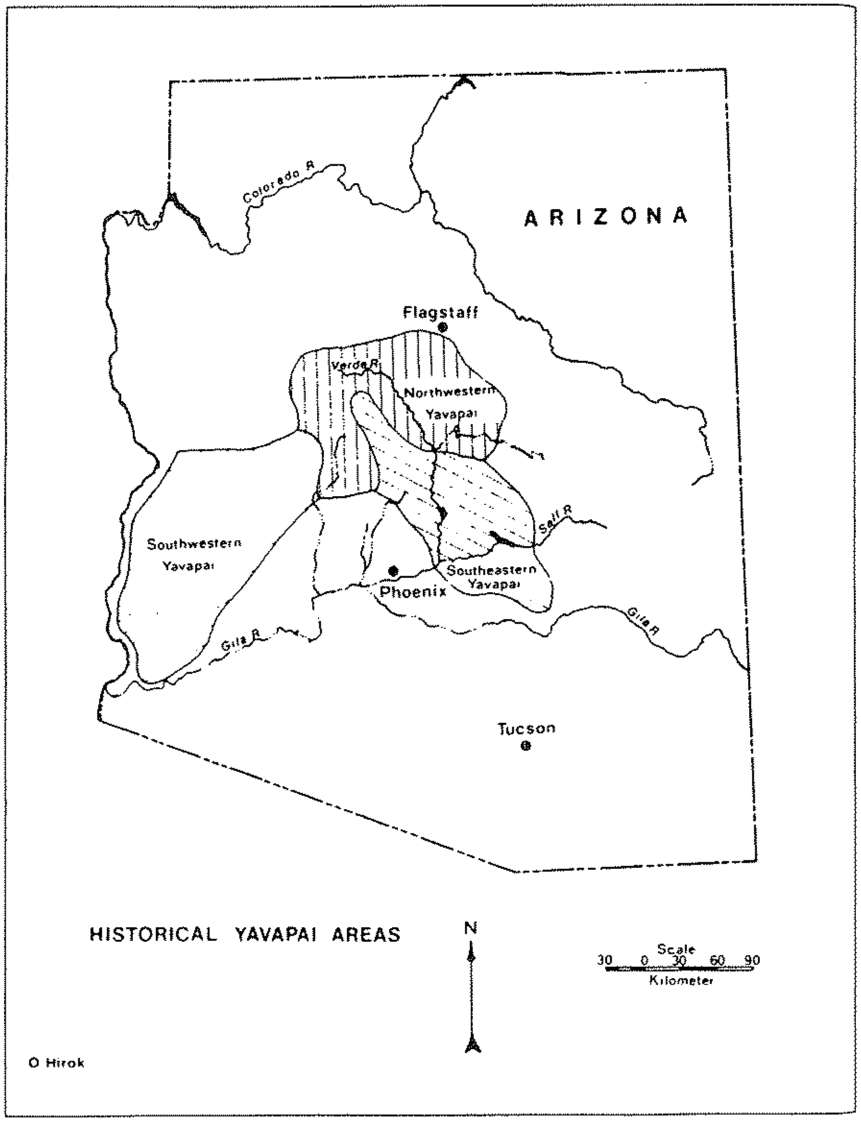


Figure 3.8 Yavapai Indian territories (U.S. Bureau of Reclamation, 1976).

Other types of land use in the McDowell Basin include works of the Salt River Project, the U.S. Forest Service Phon D. Sutton Picnic Ground and Coon Bluff Campground, the Saguaro and Goldfield ranches, and the Verde Water Treatment Plant located at the confluence of the Salt and Verde rivers (Figs. 3.1, 3.2 and 3.3; U. S. Bureau of Reclamation, 1976).

ORME DAM

Construction of Orme Dam at the confluence of the Salt and Verde rivers was proposed by the Bureau of Reclamation in 1966 as part of the Central Arizona Project (CAP; Fig. 3.9). CAP provides a conveyance system of canals, tunnels and dams designed to bring water from the Colorado River into central and southern Arizona. The purpose of the earthfill dam was 1) to provide storage of Colorado River water in the 4.6×10^8 m^3 (376,000 ac-ft) reservoir formed behind the dam to be distributed when needed to Maricopa, Pima, and Pinal counties, 2) to ensure flood protection and sediment control for Metropolitan Phoenix, 3) to develop hydroelectric power, 4) to create water-based recreational facilities, and 5) to enhance fish and wildlife habitat. The reservoir would inundate a total of 3,927 ha (9,700 ac) and extend upstream from the confluence 16.4 km (10.2 mi) up the Salt River and 16.7 km (10.4 mi) up the Verde River (U. S. Bureau of Reclamation, 1976).

Much controversy surrounds the proposed Orme Dam. Proponents of the project claimed that the benefits provided by Orme Dam not only included those as specified in the purpose of the project, such as storage and flood control, but also provided increased property values by encouraging shoreline development, and employment for the Indians who would

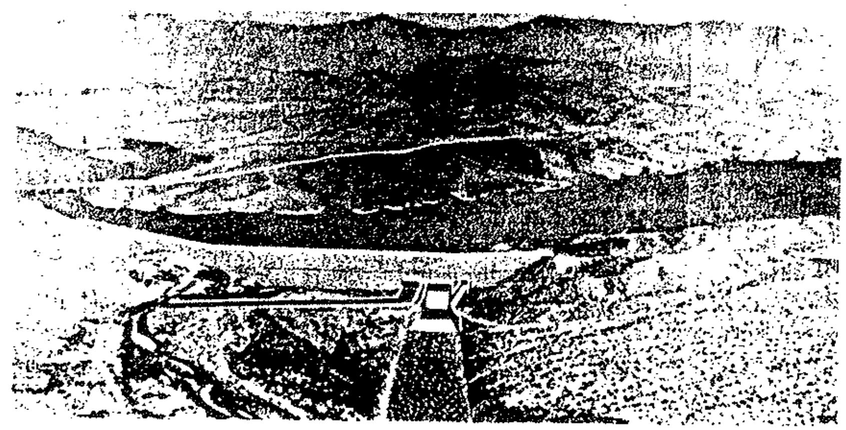


Figure 3.9 Artist's concept of Orme Dam and Reservoir (U.S. Bureau of Reclamation, 1976).

have the concession rights for the lake, boating, and fishing (Arizona Republic, 1976a-d; Tempe Daily News, 1979; Audubon Society Newsletter, 1980). Many proponents also argued that the Indians were offered just compensation for their land when considering that a much larger number of non-Indians suffered great losses as a result of the floods of 1979 and 1980 (Arizona Republic, 1980a-e). In response to those floods, construction of the dam gained further support as a flood control measure (Arizona Republic, 1978; U. S. Bureau of Reclamation, 1976). Orme Dam was designed to reduce the Standard Project Flood of 8,354 m^3/s to 1,416 m^3/s (295,000 ft^3/s to 50,000 ft^3/s).

Those in opposition to the project cited many reasons for their concerns but focused primarily on the exhorbitant cost of construction of the dam in lieu of the alternatives, the questionable safety of the dam, the inundation of Indian land and the loss of "Home," the destruction of vegetation and wildlife habitat, and the loss of recreational benefits such as tubing and bird watching (Arizona Republic, 1976, 1980d, 1981). In 1980, Orme Dam would have cost $485 million (Arizona Republic, 1980a). Many also claimed that the reservoir designed to contain 4.5×10^8 m^3 (367,000 ac-ft) of water would not be able to provide adequate flood protection and contended that the floods of 1980 with a maximum discharge of 5,692 m^3/s (201,000 ft^3/s) still would have occurred even if Orme Dam had been constructed (Arizona Republic, 1980a-e). As a storage and flood control reservoir, Orme Dam would not have been able to limit the flow to 1,416 m^3/s (50,000 ft^3/s). Several suggested that the flood hazard could be reduced for less than $40 million. Schulz, the Federal Water and Power Resources Service and others maintained that increasing the height of Roosevelt Dam, constructing a new dam at Cliff on the Verde River, building more "secure" bridges and channelizing the Salt River around Sky Harbor Airport would be better investments (Arizona Republic, 1980b).

Arizona Bureau of Mines was concerned that the geologic faults on either side of the proposed dam site would threaten the safety of Orme Dam (Arizona Republic, 1980a). Additionally, the seepage from the reservoir could potentially affect the safety of Stewart Mountain Dam located 8 km (5 mi) upstream from the Orme Dam site (Arizona Republic, 1976a).

Yavapai Indians of the Fort McDowell Community have been strongly opposed to the construction of Orme Dam. The reservoir would inundate approximately 70% of the Yavapai reservation including the town of Fort McDowell and a sacred burial ground (Bureau of Reclamation, 1976). This would cause forced relocation and the Indians have stated that they intend to preserve their land, their culture, and their way of life (CAWCS Newsletter, 1980). Their land represents stability associated with historical, religious, and economic significance. The Yavapai felt that the 1978 offer of $15-30 million was not a fair settlement and that the land was worth $300 million (Arizona Republic, 1980e). Furthermore, the Indian community was insensed that the

United States government, would, once again, not stand by its word to leave the Indian community alone as promised (Arizona Republic, 1969).

Environmentalists, the Audubon Society, the U.S. Forest Service, and Wildlife Federation maintained that the reservoir would destroy valuable stands of riparian vegetation and threaten a number of endangered species including the Bald Eagle, Peregrine Falcon, and Yuma Clapper Rail. The U.S. Forest Service contended that construction of Orme Dam would adversely affect the eagle habitat (Arizona Republic, 1976e; Phoenix Gazette, 1976; Audubon Society Newsletter, 1977; CAWCS Newsletter, 1980, 1981).

By 1980, the economic, social and environmental costs associated with the construction of Orme Dam had become prohibitive and alternatives for Orme Dam were requested by the Bureau of Reclamation (Phoenix Gazette, 1979). The issues of Orme Dam, alternatives, flood protection, and completion of the CAP distribution system are still unresolved. Major studies such as the Central Arizona Water Control Study (CAWCS) are presently addressing the issues of determining the discharge frequency relationships, predicting the SPF and MPF, and evaluating flow attenuation and the effects on upstream and downstream dams (Corps of Engineers, 1983).

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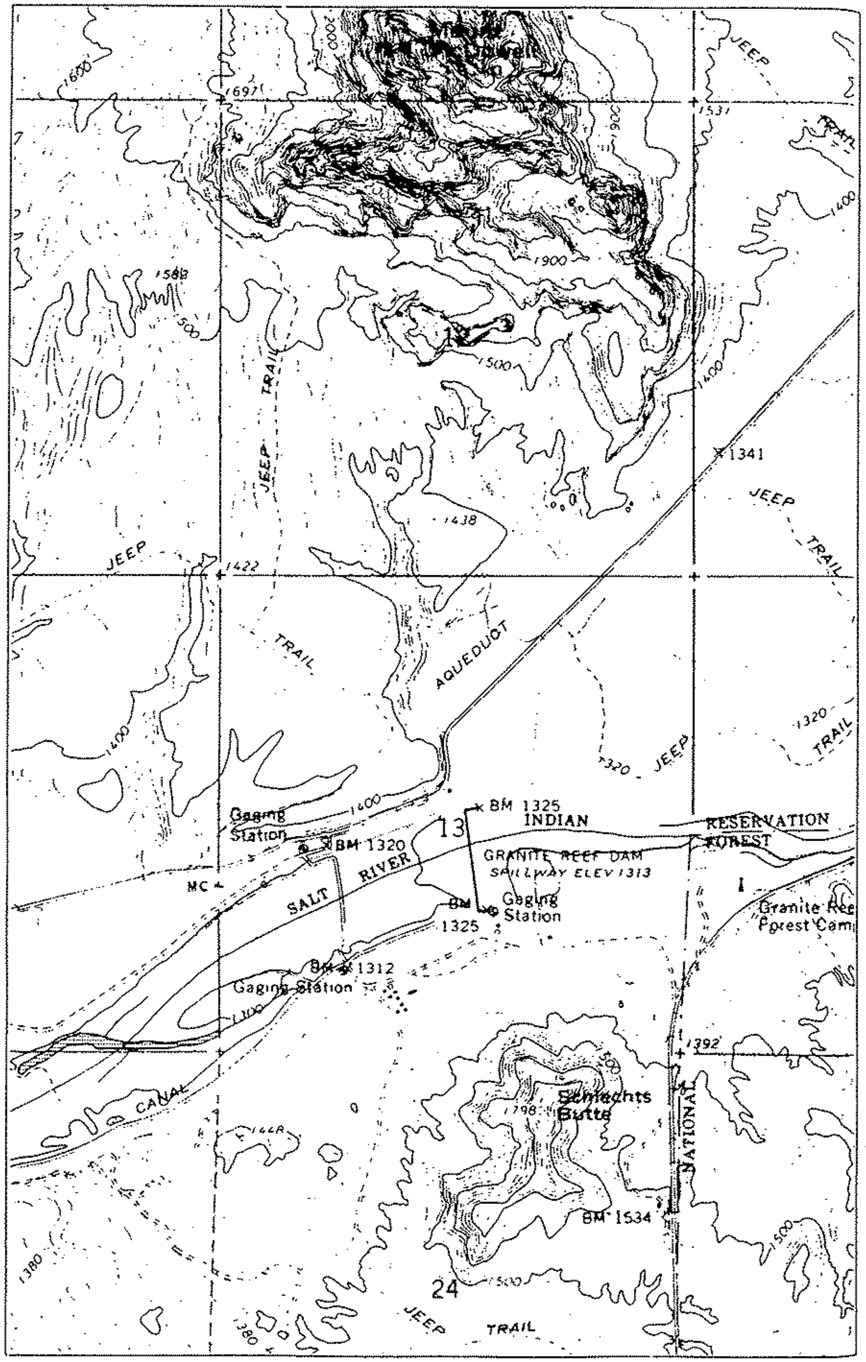

CHAPTER 4

GRANITE REEF DAM

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INTRODUCTION

The history of the Salt River Valley is in fact a history of reclamation. Since prehistoric Indians occupied the region, humans have survived by diverting Salt River water for use in irrigation. Granite Reef Dam is a diversion structure and principle take-out point for all Salt River irrigation water used in the Phoenix area (Figs. 4.1 and 4.2).

The geology of the area makes it an ideal location for a diversion dam. Red Mountain to the north is composed of Cretaceous fanglomerate materials eroded from the Goldfield Mountains to the east. Bracketing the river channel is a reef of Precambrian granite to which the dam is anchored (Arizona Bureau of Mines, 1957). An outcrop of this granite can be seen in the river channel at the downstream side of the splash apron.

Granite Reef Dam diverts water via two main canals: the Arizona Canal to the north and the Southern Canal to the south. These two canals feed a series of other canals on both sides of the river.

In addition to providing an excellent dam site, the granite reef has been exploited as the site of a stable crossing for the Central Arizona Project Canal. The Central Arizona Project is a federally funded effort to bring Colorado River water to central and southeastern Arizona. The canal starts at Lake Havasu on the Arizona-Colorado border and flows 317 km (190 mi) via the Granite Reef Aqueduct to this point where it flows under the Salt River in two 6.4 m (21 ft) diameter, 2.7 km (1.6 mi) long siphons. Just south of the siphons, the water is raised into the Salt-Gila Aqueduct for its 230 km (138 mi) trip to Tucson (U. S. Bureau of Reclamation, 1983).

Figure 4.1 Granite Reef Damsite located on the Granite Reef Quadrangle, U.S. Geological Survey.

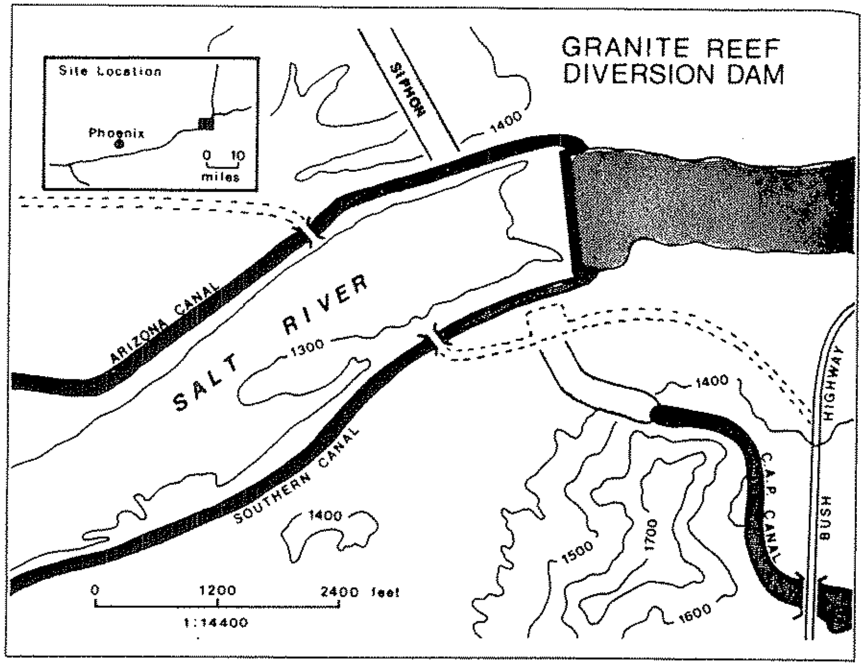

Figure 4.2 Site map of the Granite Reef Dam stop.

HISTORY OF GRANITE REEF DAM

In the modern era, diversion of Salt River water began in 1868 when Jack Swilling constructed a brush-diversion dam as a take out for his canal known as Swilling's Ditch (Smith, 1972). Subsequently, numerous canals were constructed in the valley, each with their own diversion points. In 1885, consolidation of the canal systems began with the incorporation of the Arizona Canal Company.

The Arizona Canal Company set out with $500,000 to build the Arizona Canal and its take-out point, the Arizona Dam (located just downstream from the present Granite Reef Dam). In 1887, the main canal line was completed, and in the following four years, the Arizona Canal Company began its consolidation of the water distribution system by purchasing the Grand, Maricopa, and Salt River Valley canals. The take outs for these three canals were abandoned and the Crosscut Canal was constructed near Scottsdale to feed these canals from the main Arizona Canal (USGS, 1893).

February of 1891 saw the largest recorded flood on record strike the Salt River Valley, when a discharge of 8,400 m^3/s (300,000 ft^3/s), destroyed the Arizona Dam, and damaged the head of the Arizona Canal. A new stronger dam was built in the same location that year (USGS, 1891b, 1893).

Despite the consolidation of the canal system, delivery of water to irrigation users varied with the flow of the river. As early as 1889, the search for a storage dam site was conducted and an ideal site upstream on the Salt was found at the present-day site of Roosevelt Dam. During the late 1800s, however, there was a water surplus and the notion of a storage reservoir was abandoned (Smith, 1972).

Drought struck the Salt River Valley in 1898 to 1904, and valley farmers resurrected the movement for a storage reservoir. Their efforts coincided with the passage of the National Irrigation Act of June 17, 1902 which was designed to help finance reclamation activities. The federal government was ready to help the valley farmers, but the law prohibited the National Reclamation Association from dealing with individuals, so in late 1902, a movement was begun to form the Salt River Valley Water Users Association. An uphill battle ensued trying to convince skeptical farmers to join the organization, but finally in the early summer of 1903, the organizers prevailed, the Association was incorporated, and construction of Roosevelt Dam was begun (Smith, 1972).

In addition to the construction of Roosevelt Dam, the federal government realized that the water distribution system in the Salt River Valley needed to be improved. To this end, the Reclamation Service began buying all of the canals in the valley in 1905, and the following year the construction of the current Granite Reef Dam was started. Granite Reef Dam was completed by 1913.

Today, control of the distribution of irrigation water lies with the Salt River Project which combines the original Salt River Valley Water Users Association and an electric power cooperative (Smith, 1972).

STREAM GAGING AND THE IRRIGATION SURVEY

On October 2, 1888, Congress approved $100,000 for a survey of potentially irrigable lands in the Western United States. Charge of the survey was given to John Wesley Powell as director of the Geological Survey. Powell assigned Professor A. H. Thompson to start topographic work, and Clarence Dutton to start engineering and hydraulic work on the survey (USGS, 1890).

In the first report of the irrigation survey, Dutton discussed his work on the Salt and Gila rivers, and commented that the two rivers posed the greatest difficulties of any river studied that year. In particular he pointed to the "peculiar character of stream beds which afford no good cross-sections for measurements," as the focus of the difficulties in establishing gaging sites (USGS, 1890). After a great amount of difficulty, one of Dutton's assistants, W. A. Farish, was able to establish a gage on the Salt just upstream from the confluence with the Verde (USGS, 1890). This site also proved unstable for use and the gage was abandoned during the winter of 1889-90. The following spring, the gage was moved upstream into the Salt River Canyon (USGS, 1891a).

In their quest for obtaining discharge measurements on the Salt River, Dutton and his men discovered that Samuel A. Davidson, the engineer for the Arizona Canal Company, had been collecting discharge data at the Arizona Dam since 1888. Davidson had measured the first recorded flood on the river on February 21, 1890 when discharge jumped from 28 m³/s (1,000 ft³/s) to over 4,004 m³/s (143,000 ft³/s) (USGS, 1891a).

A year later during February 1891, Davidson recorded the largest measured flood (Table 4.1) to date on the river when discharge peaked at 8,400 m³/s (300,000 ft³/s). According to Dutton, this flood raised water in front of the Arizona Canal headgates 5.6 m (18.5 ft), and changed the channel so radically that the initial rating curve for the river had to be abandoned (USGS, 1891b, 1893).

TABLE 4.1 FLOODS ON THE SALT RIVER, ARIZONA

YEAR	PEAK DISCHARGE m³/s (ft³/s)
Feb. 1890	4,004(143,000)
Feb. 1891	8,400(300,000)
Apr. 1895	3,200(115,000)
Apr. 1905	3,200(115,000)
Nov. 1905	5,600(200,000)
Jan. 1916	3,360(120,000)
Jan. 1916	2,940(105,000)
Feb. 1920	3,640(130,000)
Feb. 1927	1,960 (70,000)
Mar. 1938	2,380 (85,000)
Mar. 1941	1,120 (40,000)
Jan. 1966	1,876 (67,000)
Feb. 1973	616 (22,000)
Mar. 1978	3,416(122,000)
Dec. 1978	3,920(140,000)
Jan. 1979	2,464 (88,000)
Mar. 1979	1,887 (67,400)
Feb. 1980	5,040(180,000)

Source: Graf (1983).

Note how these data differ from those in Tables 3.2 and 10.2.

The current stream gage is located at the south end of Granite Reef Dam. Two other gages record the discharge of diverted water in the Arizona and Southern canals.

HISTORY OF CHANNEL CHANGE

In addition to being the start of the irrigation works for the Salt River Valley, Granite Reef Dam marks the beginning point of channel downcutting. From this point downstream to the confluence with the Gila River, the channel has gone through numerous changes since the 1880s.

As demonstrated by Graf (1983), channel changes in the Salt River occur

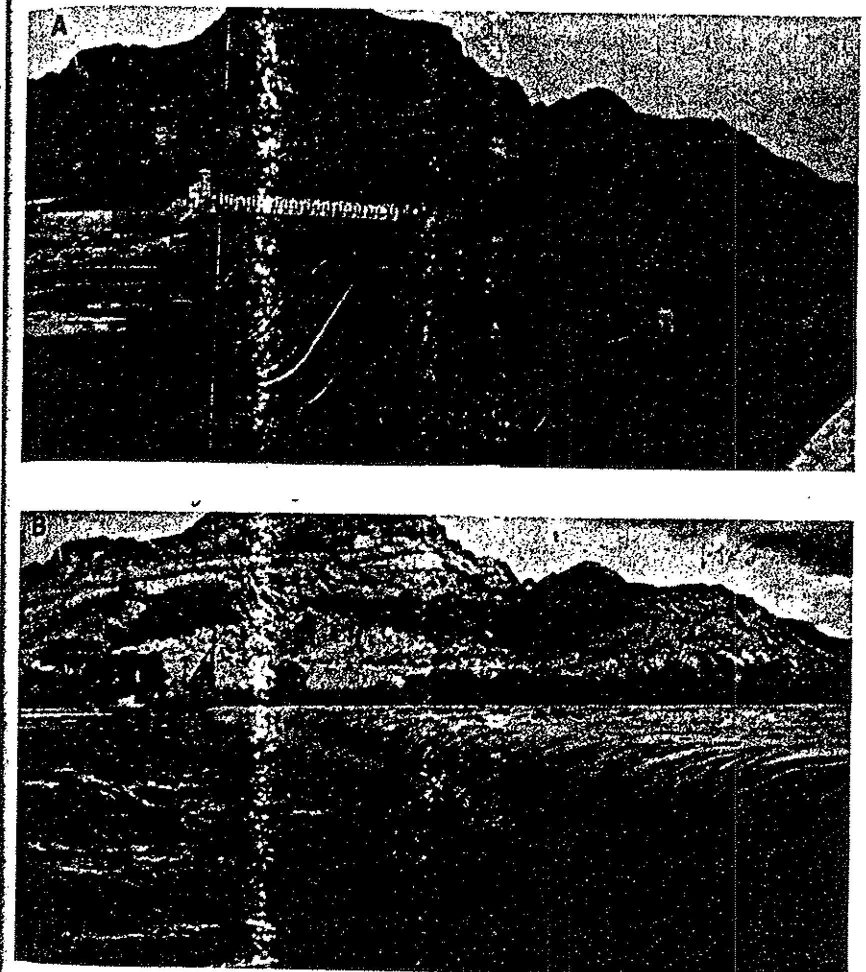

Figure 4.3 Comparison of the Salt River channel at Granite Reef Dam under normal and flood conditions. Photo A shows a typical dry channel, November 1986 (photo by author). Photo B was taken on March 4, 1938 and contained the note that the water was five feet over the weir (photo courtesy of the Arizona Collection, Arizona State University, Gertrude Muir Collection. GM01055).

only during flood events due to control by upstream dams. Figure 4.3 shows a comparison of the channel at Granite Reef Dam in its normally dry state to the channel during a flood event.

When the dam was completed in 1908, the dam's splash apron was level with the bed of the channel. During the flood of February 1920, the channel was downcut and a portion of the splash apron was removed (Fig. 4.4). Although three more floods followed between 1920 and 1949, by September 1949 the channel aggraded, the splash apron was covered with sediments, and a healthy phreatophyte growth had formed in the channel (Figs. 4.5a and 4.6a). Overall, however, the Salt River channel bed elevation changed little from the 1880s to 1965 (Graf, 1983).

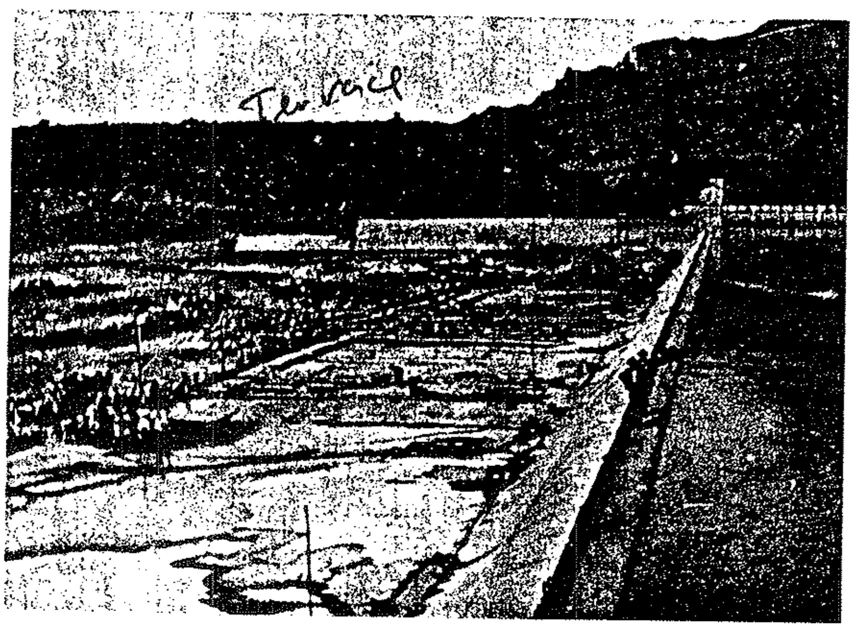

Figure 4.4 Reconstruction of the Granite Reef Dam splash apron after it was removed during the 1920 flood. The photo was taken on February 2, 1920 (photograph courtesy of the Arizona Historical Foundation, Arizona State University, Gregory Collection, QD-50 1990).

Since 1965, there have been a series of floods on the Salt River causing its channel to entrench as much as 6 m (19.7 ft) in some areas. Most of the downcutting occurred during the 1978 flood (Graf, 1983). Figures 4.5 and 4.6 show the amount of downcutting evident near Granite Reef Dam. Particularly clear is the downcutting near the dam's splash apron, and the removal of phreatophytic vegetation in the channel.

A

B

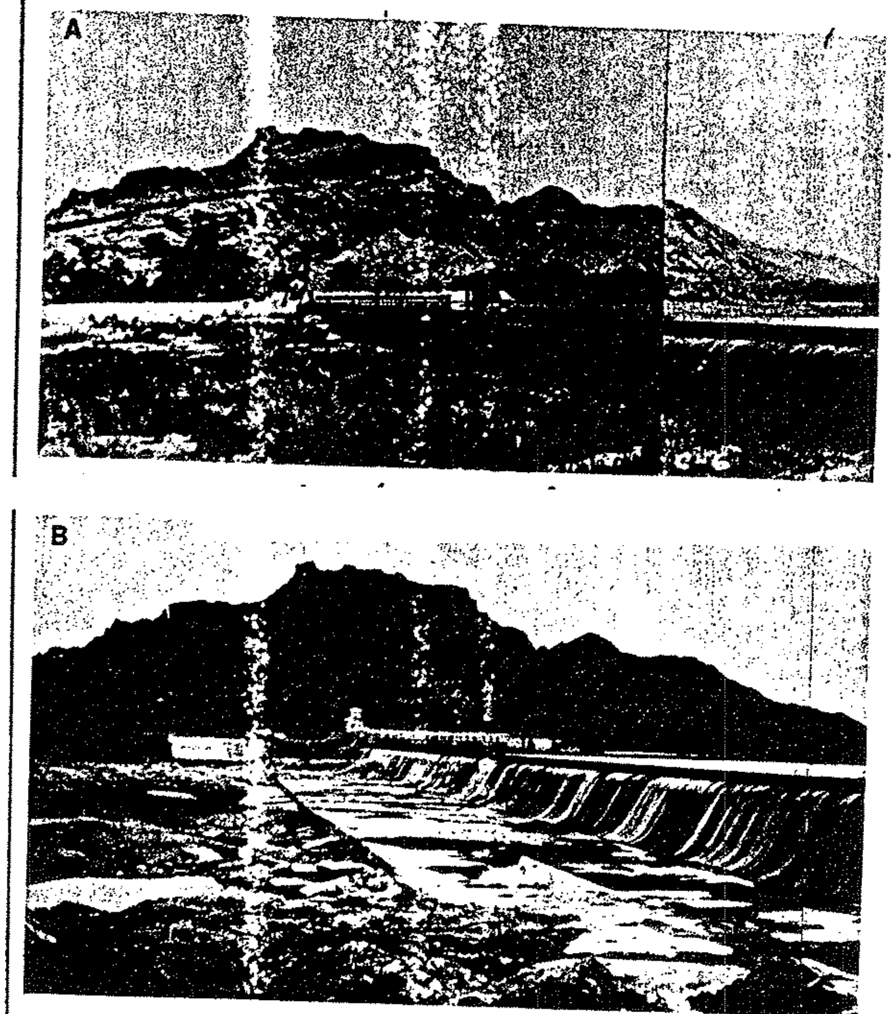

Figure 4.5 Comparison of the channel bed elevation at Granite reef Dam. Photo A shows the aggraded channel bed with vegetation in September 1949 (photo by U.S. Army Corps of Engineers). Photo B shows the present day degraded channel as it appeared in December 1981. (photo by W.L. Graf).

Granite Reef Dam thus represents a transition point on the Salt River. Upstream the river flows through narrow canyons; downstream onto a broad alluvium-filled valley. The dam is the starting point for channel entrenchment and for diversion of Salt River water for irrigation, both processes which have a profound effect on the population living downstream.

A

B

Figure 4.6 View of the Salt River channel downstream from Granite Reef Dam comparing the phreatophytic vegetation cover in September 1949 (photo A, by W.L. Graf) and in 1986 after 20 years of fairly regular flooding (photo B, by the author).

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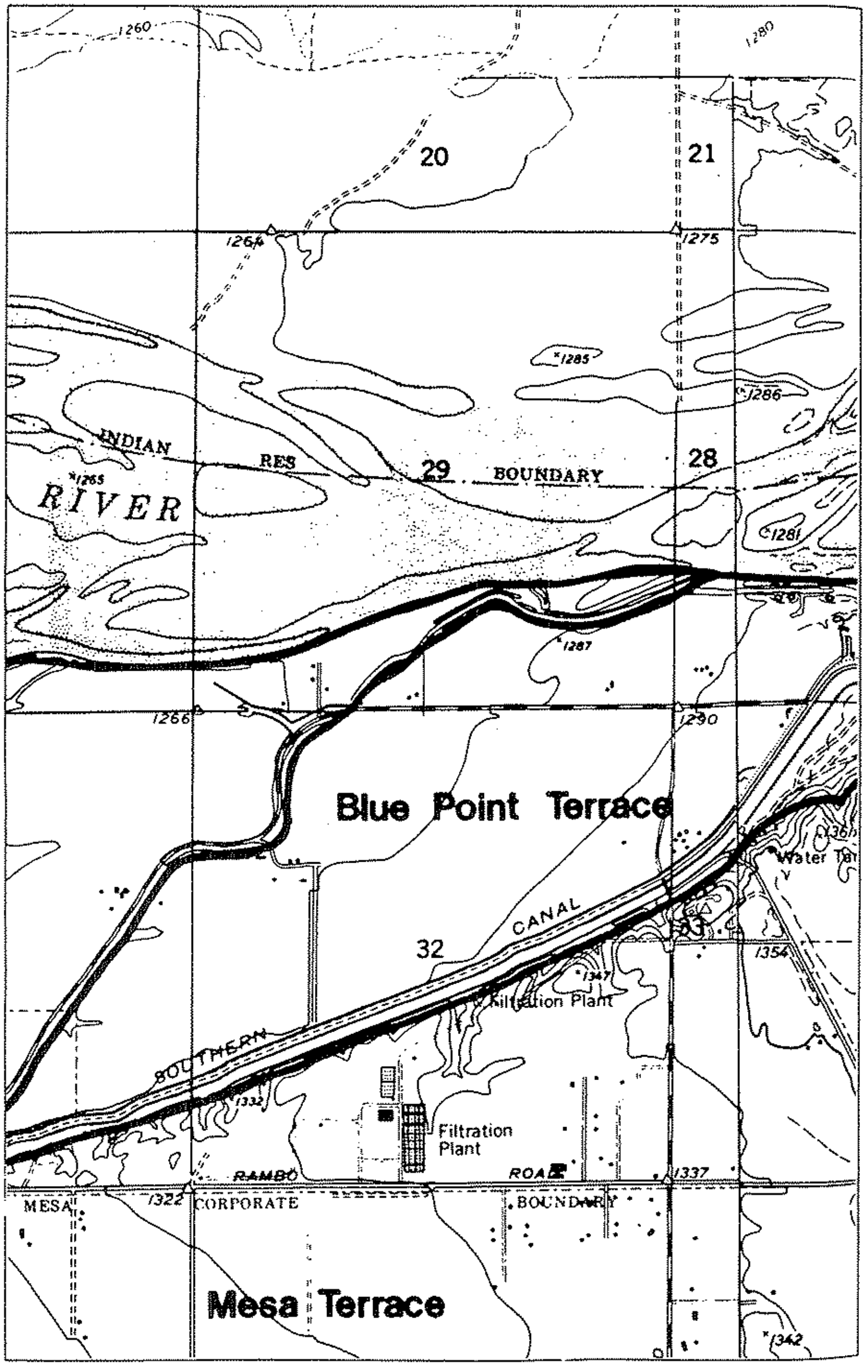

CHAPTER 5

THE McDOWELL CROSSING

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INTRODUCTION

The site of the McDowell Crossing is the first place where we are able to observe the Salt River flowing on the deep alluvial fill (3,000-6,000 m) of the Salt River basin. The channel of the Salt River is somewhat constricted immediately downstream of Granite Reef Dam by an alluvial fan on the north and bedrock (pediment surfaces) of the Usery Mountains on the south (Fig. 5.1). The high-flow channel is poorly defined but appears to widen from about 0.5 km (0.3 mi) at the McDowell Crossing to about 1 km (0.6 mi) wide a short distance (2 km) downstream. A well-defined low flow (main-flow) channel about 200 m (656 ft) wide bifurcates immediately downstream into two main channels 50-70 m (164-230 ft) wide separated by up to 2 km (1.2 mi). The presence of the natural constriction in the river channel at the McDowell Crossing is significant because it became a logical location for both a river crossing (Fort McDowell Trail) and a canal heading for historic and pre-historic human occupants. Discussion at this site will include the history of the McDowell Crossing in terms of early Mormon settlement, abandoned irrigation canals, Salt River terraces, channel-bed materials, channel-bed elevations, channel stability, and the threshold discharge of instability.

HISTORICAL BACKGROUND

Human settlement of the Salt River Valley has depended upon the water

Figure 5.1 The McDowell Crossing located on the Mesa, Sawik Mountain, Buckhorn quadrangles, U.S. Geological Survey.

supply provided by the Salt River. The Hohokam were a pre-historic sedentary group who occupied the broad river valleys and deserts in southern Arizona from about 300 B.C. to 1450 A.D. (Haury, 1967). The present-day Pima Indians are thought to be descendants of the pre-historic Hohokam (Doyel, 1981). The Hohokam are best known for their complex irrigation systems which were being constructed by 1200 A.D. and in many cases survived intact to be re-used by modern agriculturalists (Haury, 1967). The Hohokam had disappeared by 1450 A.D. due to unknown circumstances; perhaps some combination of disease, drought, floods, soil salinization, invasion by outsiders, or internal political strife (Haury, 1976; Ambler, 1977). The map in Figure 5.2 shows how extensive the Hohokam canal system was in the eastern portion of the Salt River Valley.

A 72 km (45 mi) trail that connected Fort McDowell on the Verde River to Maricopa Wells on the Gila River crossed the Salt River at what is now called the McDowell Crossing (alternatively named the Maryville, Whitlow, or Mesa Crossing) (Fig. 5.3). This site was the only favorable place to cross the Salt River for many miles. The narrow channel and a rocky riffle allowed wagons to cross without sinking into the finer bed materials common in most other locations on the Salt River. The town of Maryville (or Rowe's Station) was located just north of the crossing, but the operation of the ferry at Hayden's Ferry in 1871 (present-day Tempe) probably led to the abandonment of Maryville and the diminished importance of the McDowell Crossing.

The period of 1876-1879 marked a great colonization movement by the Mormon Church (Church of Jesus Christ of Latter-Day Saints). In their effort to extent the boundaries of their influence, two separate groups of settlers were sent from Utah to southern Arizona. Both groups eventually established footholds in the Salt River Valley that were typical of at least 100 other Mormon colonies established during this period (Merrill, 1970).

The Lehi party, consisting of 84 individuals led by Daniel Webster Jones, was the first group to leave Utah in October of 1876. They followed a western route around the Grand Canyon, crossing the Colorado River at Stones Ferry, and arrived at the McDowell Crossing in March of 1877. Historical descriptions (Merrill, 1970) noted a high bank on the south side of the river that had growing on it a straight row of large cottonwoods that appeared to be at least 30 years old and planted by hand. Previously (on March 1, 1872), an army officer recorded that the Salt River was about 180 m (300 ft) wide at the McDowell Crossing (he also described the Hohokam canal that the Mesa pioneers would later re-excavate). The Lehi party made camp at the site of a Hohokam canal that was recommended to them by Winchester Miller of Hayden's Ferry as "the best ditch site on the river" (Merrill, 1970). The first priority of the settlers was to construct an irrigation canal in time for the planting of summer crops. In order to conserve time and effort the Hohokam canal was re-excavated by shovel and made partly operational in just two months (named the Utah Canal, see Fig. 5.3). The

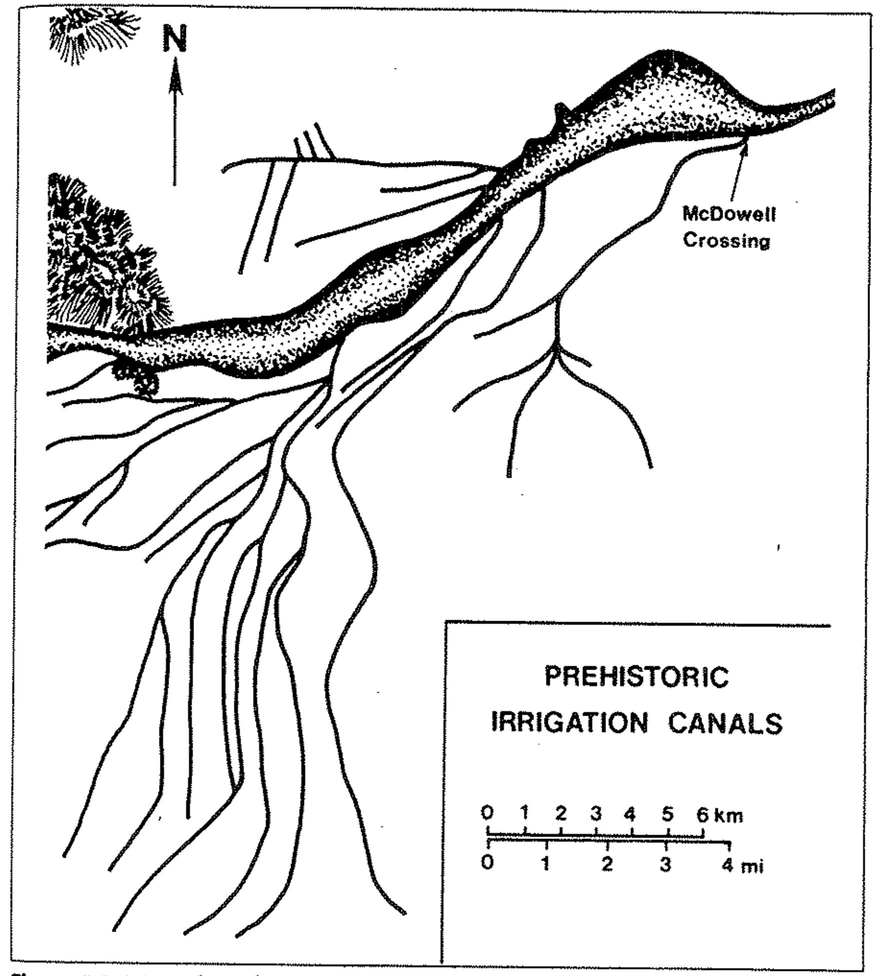
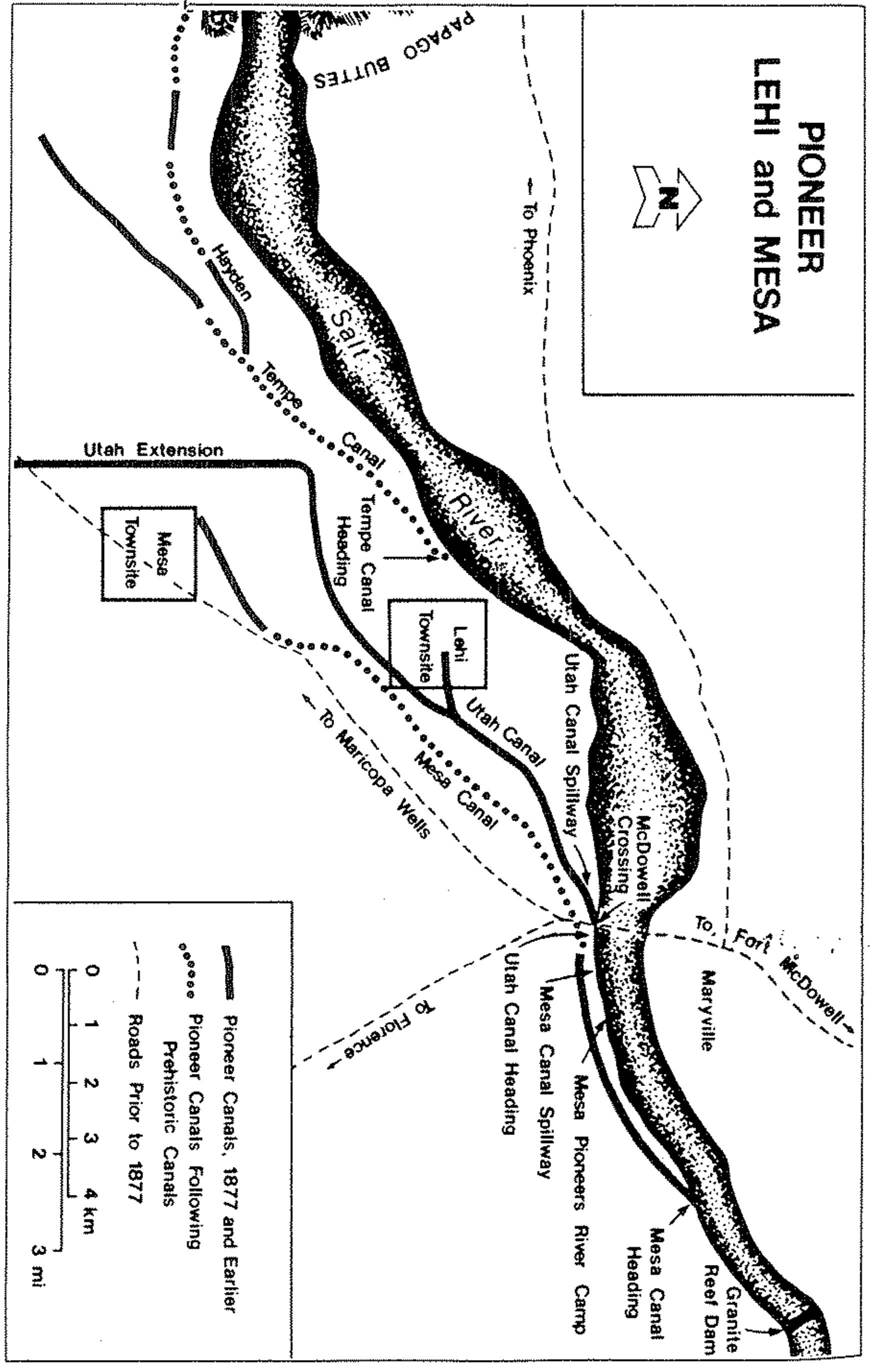


Figure 5.2 Map of pre-historic Hohokam Canals in the eastern Salt River Valley (modified from Dr. Omar A. Tunney, "Prehistoric Irrigaion Canals", published by Major George H. Kelley, State Historian, Capitol Building, Phoenix, Arizona).

Lehi party established a settlement that was first called Camp Utah, then Utahville, Jonesville, and finally Lehi.

Eight months after the departure of the Lehi party a second group of Mormon colonizers, the Mesa party, consisting of 78 individuals, left homes in Utah and Idaho on an eastern route around the Grand Canyon, crossing the Colorado River at the present location of Lee's Ferry. The Mesa party arrived in the Salt River Valley on February 14, 1878 and established a river camp on the left bank of the Salt River about 1.6 km (1 mi) upstream of the McDowell Crossing (Fig. 5.3). The Mesa party also constructed the Mesa



Canal in the remains of a pre-historical Hohokam canal that had its heading about 6 km (4 mi) upstream of the Utah Canal heading.

The only recorded clash between the Mormons and their neighbors to the west occurred during the 1879 drought (McClintock, 1921). The Salt River was dry for 8 km (5 mi) below the Mesa, Utah, and Tempe canal headings (Fig. 5.3). Mormon water appropriation was blamed for the shortage that was hurting irrigated agriculture in the western part of the valley. An armed group of at least 20 farmers from Phoenix rode eastward to the Mormon settlements near the McDowell Crossing prepared to fight for their water rights. An agreement was reached whereby the Mesa and Utah canals were closed for three days to determine the effect on water supply downstream. No increase in water flow was observed downstream due to transmission losses into the permeable bed materials. After this incident there were no further squabbles recorded over water rights with the Mormons.

The chronology and locations of Hohokam and Mormon canal systems are difficult to determine precisely because the canals were constantly expanded, abandoned, and re-routed into earlier ditches. According to Merrill (1970), there is no evidence today of either the Utah Canal, which had its heading at this site, or the Hohokam canal that would later become the Mesa Canal. However, at the place where the Mesa Third Ward Boy Scouts erected a monument in 1931 to the Lehi Pioneers, the remains of two other canals are visible (Fig. 5.4). The larger one is an abandoned section of Dr. A. J. Chandler's Consolidated Canal of 1893 which follows at this point a later re-routing of the 1878 Mesa Canal (Merrill, 1970)(Fig. 5.5). The smaller canal closer to the river bank was never used and is often mistaken for the earliest Mesa Canal (Fig. 5.6). Named Spite Ditch, it was hastily constructed in 1912 by Lehi farmers after a dispute with the U.S. Reclamation Service (forerunner of the U. S. Bureau of Reclamation) over terms for the delivery of river water diverted by Granite Reef Dam. Spite Ditch was built to collect Lehi's water at a point upstream of where the Reclamation Service had threatened to dump it back into the river.

GEOMORPHOLOGY

Three of the four terraces of the lower Salt River Valley (Péwé, 1978; Kokalis, 1971) are found in the immediate vicinity of the McDowell Crossing (Fig. 5.1). The origin of the terraces could be explained by either climatic changes or tectonic uplift in the mountains, both of which would cause

Figure 5.3 Map of pioneer canals, the settlements of Lehi and Mesa, and the surrounding areas adjacent to the Salt River from Granite Reef Dam to Papago Buttes and Tempe Buttes (modified from David Merrill in W.E. Merril, 1970).

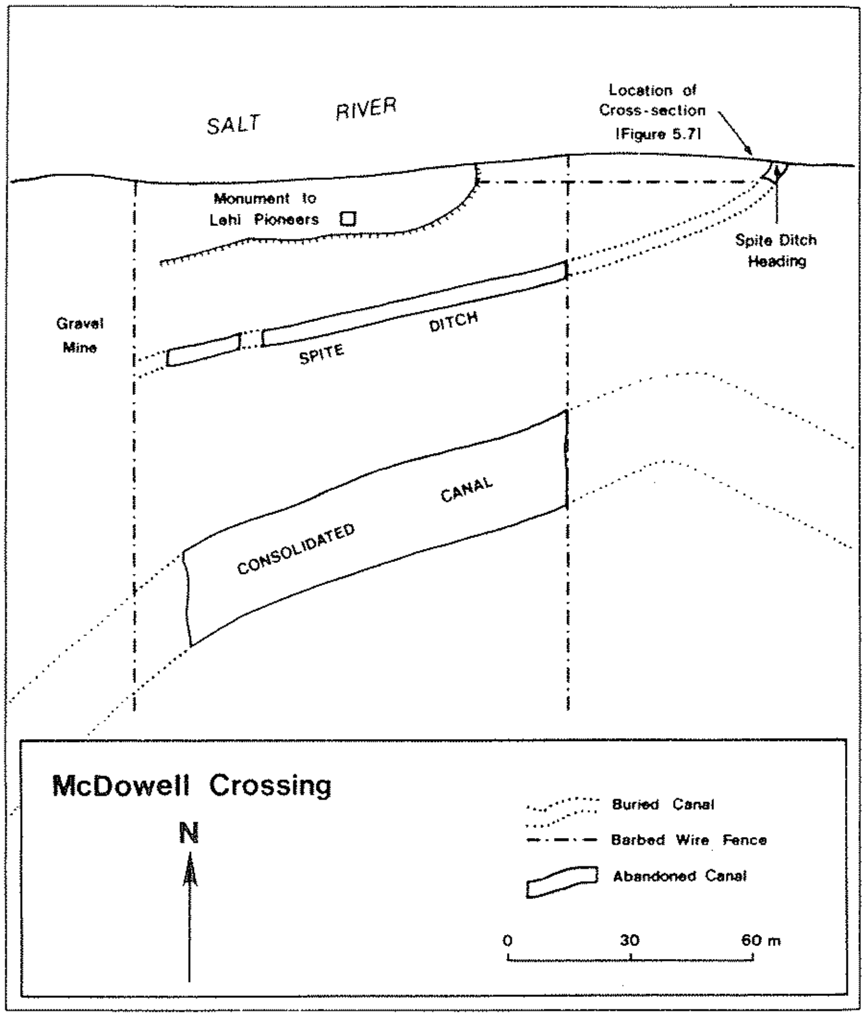


Figure 5.4 Site of McDowell Crossing stop.

periodic rejuvenation of the Salt River. However, longitudinal profiles of paired sets of terraces converge downstream until they terminate at Tempe Butte (Hayden's Ferry). Because climatic change probably would have produced terraces parallel to the modern stream profile, Péwé (1978) suggested that periodic regional uplift of the mountains to the east was responsible for terrace formation. Furthermore, particle sizes on the terraces are approximately the same size as those in the modern channel (Kokalis, 1971), suggesting that the Salt River has not significantly altered its competence (Péwé, 1978).

Figure 5.5 Remains of a section of the 1893 Consolidated Canal at the McDowell Crossing site, looking northeast (photograph by author).

Figure 5.6 Remains of the never-used Spite Ditch, built in 1912, looking northeast (photograph by author).

At the McDowell Crossing, the Lehi Terrace is about 7 m (23 ft) above the present stream bed with about 1.5-2.3 m (4.9-7.5 ft) of overbank deposits (silt and fine sand with a few small cobbles) resting on top of coarse, rounded river cobbles (Fig. 5.7). Aldridge (1970) indicated that before dam construction the Lehi Terrace would be inundated by extreme flood events. But today, unless substantial deposition and re-filling of the channel occurs, extreme floods are unlikely to reach the level of the Lehi Terrace. The next higher terrace is the Blue Point Terrace, which has cobbles slightly cemented by caliche, a near-surface accumulation of CaCO common to soils in arid and semiarid environments with a year-round moisture deficiency (Péwé, 1978).

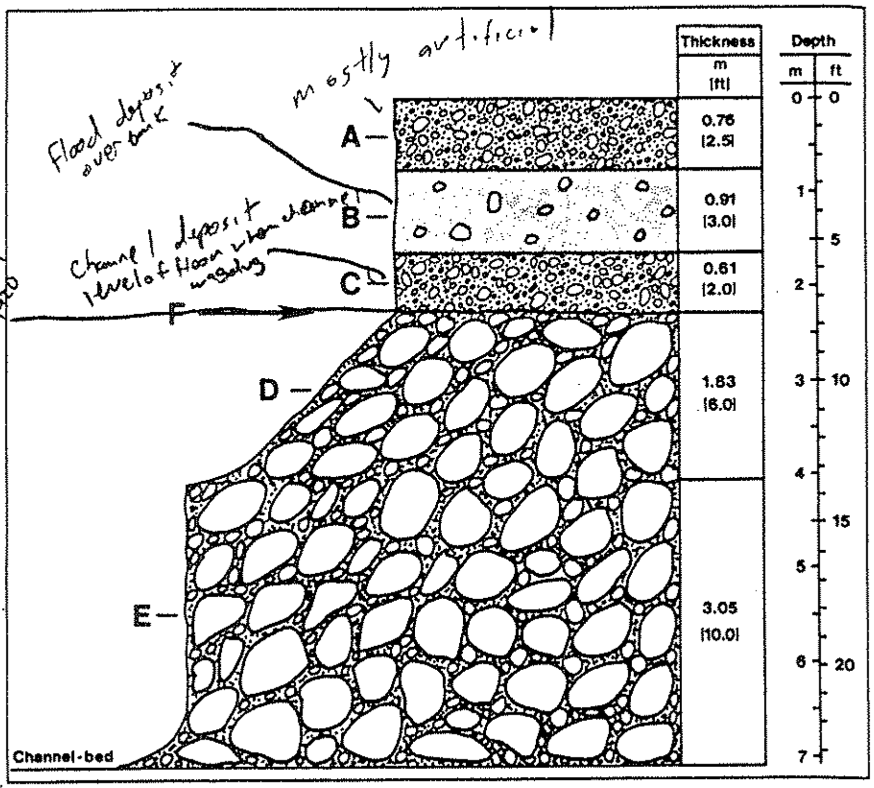


Figure 5.7 Cross Section of Salt River Bank deposits. The cross-section is located on the left bank looking upstream. A: Small Cobbles (5-25 cm diameter) in sandy matrix. B: Fine sand and silt with a few small cobbles (3-15 cm diamter). C: Similar to bed A. D: Ledge covered with boulders and grass. E: Large cobbles and boulders (up to 45 cm diameter) in matrix of coarse sand and pebbles. Large particles are imbricated; caliche present. F: Bottom of the pre-1965 channel; same as bottom of Spite Ditch.

Caliche rinds on individual cobbles on the Blue Point Terrace are no more than 0.65 cm (0.26 in) thick. The boundary between the Blue Point Terrace and the Lehi Terrace follows the remains of the Consolidated Canal at this site, although there is no obvious change in elevation. The highest terrace at this site is the Mesa Terrace which has well-calichified gravels, excellent development of laminar layers, and surface cobbles with caliche rinds up to 10 cm (4 in) thick. The Mesa Terrace can be seen rising 12-18 m (40-60 ft) above the Lehi Terrace at this site. The Sawik Terrace is the oldest of the Salt River terraces, but it is not found at this location. Although the terraces do not have absolute dates, Péwé (1978) estimated that they may be as old as 5 million years.

The lithologic characteristics of bed materials are highly variable due to complex geology in the large catchments of the Salt and Verde rivers. Analysis of 6,600 cobbles in the 5 and 6 phi size classes identified three primary lithologic groups and the percentage of bed materials that fell into each group (Kokalis, 1971): (1) Tertiary volcanic rocks (36.3%), (2) Precambrian arkosic and orthoquartzitic sandstones (48.4%), and (3) granitic rocks from the Precambrian basement complex (15.3%). Neither lithologic nor textural characteristics can be used to distinguish Salt River terraces from one another or from modern channel materials (Kokalis, 1971). Textural analysis of modern flood-plain sediments by Kokalis (1971) has shown that the sediment size distribution is bimodal, poorly sorted, and positively skewed. The coarse fraction consists of pebble to boulder size particles that are rounded and rod-shaped or disk-shaped. Organic debris are rare in these sediments.

Channel changes on the Salt River occur in response to high magnitude and low frequency flood events. Before construction of dams upstream, the low discharge of the Salt River was about 22.6 m^3/s (800 ft^3/s)(Powell, 1893). Since 1941 the channel has remained dry except during floods (Table 4.1).

The location of the Salt River channel at the McDowell Crossing has been relatively stable in the last 100 years. Historical maps show a constriction of the channel at the same location as it exists today (Fig. 5.2). Comparison of aerial photographs taken in 1961 (Fig. 5.8) and 1985 (Landis, 1986) showed no locational changes. The stability of the channel at this site has been due to inherent sinuosity in the channel, recent downcutting during large floods

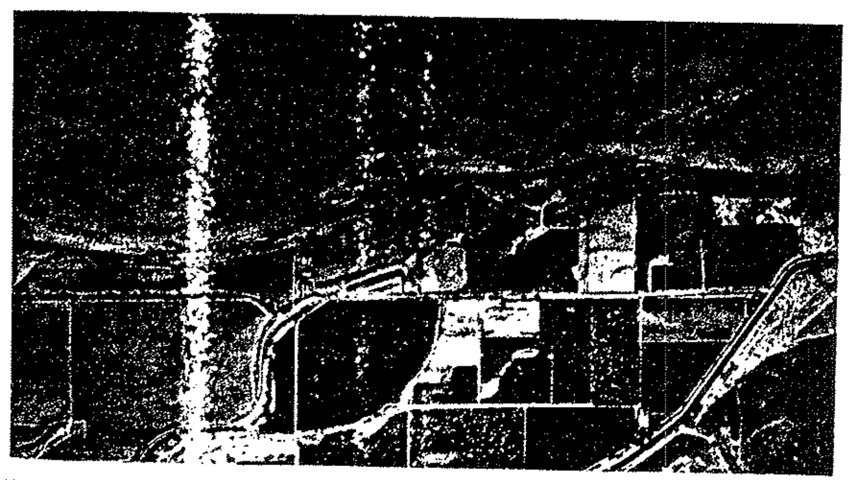


Figure 5.8 Arial photograph of Salt River and the area surrounding the McDowell Crossing showing the Arizona Canal at the top, the Southern Canal at the bottom, and the channel constriction at the McDowell Crossing (photo by U.S. Geological Survey).

that has increased horizontal stability, and the presence of gravel mines that concentrate flow and encourage further downcutting (Graf, 1983).

Comparison of main-flow channel width at the McDowell Crossing is similar to mean width calculated for a reach of the Salt River from Granite Reef Dam to its confluence with the Gila River. These channel width values averaged 125 m (411 ft) for the entire reach and 250 m (820 ft) for the upper part of the reach (Graf, 1983). The historical description by the army officer in 1872 (he estimated channel width to be about 180 m) indicates that channel width has remained relatively stable during the past 100 years. This site is representative of channel width stability found throughout the Salt River Valley (Graf, 1983).

Channel depth, however, is a different story. Photographs from other sites along the river show that from the late 1880s until 1965 the maximum vertical distance from bank top to bed was less than 1.5 m (4.9 ft) (Fig. 5.9a). Erosion since 1965 has lowered the bed of the main-flow channel about 6 m (19.6 ft) below the pre-1965 bed elevation, with most of this downcutting occurring during the floods of 1978 or later. Although historical photographs of the McDowell Crossing are not available, photographs taken nearby (Fig. 5.9) and elevations of Hohokam and Mormon canal headings built prior to 1912 suggest that the bed of the main-flow channel may have been about 4.7 m (15.4 ft) above its present location.

Two possible explanations for these 'hanging' Hohokam canals were proposed by Merrill (1970): (1) channel downcutting or (2) lateral migration and erosion of the left channel bank into canals that once ran parallel to the channel. The later explanation would give the false impression of a canal heading at the McDowell Crossing when in fact the heading was located far upstream. While it is possible that the later situation occurred for the Hohokam canals, recent channel downcutting appears to have been responsible for leaving the Mormon canals hanging

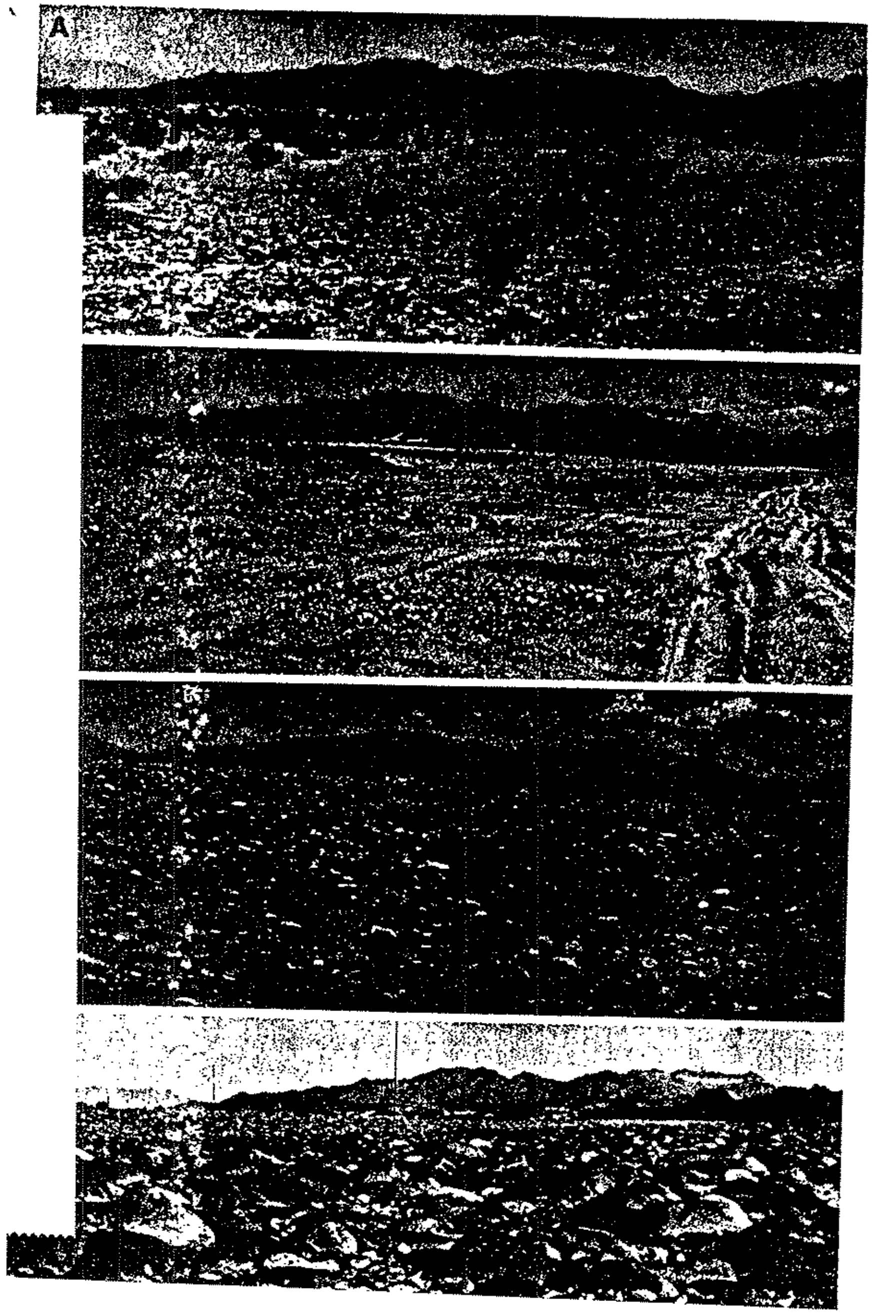


Figure 5.9 Series of views showing changes in channel-bed materials looking upstream from a point 1.2 km (0.75 mi) downstream of the McDowell Crossing. Photo A: September 1949; a predominantly sandy bed (U.S. Bureau of Reclamation photo held by the Phoenix Urban Corps of Engineers). Photo B: January 1980; downcutting has exposed a lower cobble bed, yet a significant amount of snad remains (photo by W.L. Graf). Photo C: December 1980: continued downcutting; more cobbles (photo by W.L. Graf) Photo D: November 1986; continuous cobble bed, surface sand from Photo C removed by low flows or wind deflation (photo by author).

above the present bed of the channel. Spite Ditch (2-2.5 m deep), whose heading is located at the McDowell Crossing (Fig. 5.4), clearly shows the elevation of the channel bed as early as 1912 in the bank cross section (Fig. 5.7). A photograph taken in 1949 (Fig. 5.9a) 1.2 km (0.75 mi) downstream from this site shows amounts of downcutting that are similar to those found throughout the upper reach (Graf, 1983).

The exposure of bed materials in the left channel bank (Fig. 5.7) is typical of fluvial sediments deposited by the Salt River. Alternating beds of fine and coarse materials are well defined. Presumably the coarse materials were deposited by single large magnitude flood events, while the fine sediments represent deposition by overbank flow or small flood discharges.

The upper 2.3 m (7.5 ft) of fine sediments represent the pre-1965 channel bank, some of which may have been deposited by overbank flow during the 1891 flood (8,496 m^3/s). The pre-1965 channel bed is marked by a ledge that is 1.5-3.0 m (4.9-9.8 ft) below the top of the bank and fairly continuous for some distance upstream and downstream from this site (Fig. 5.10). The bottom of Spite Ditch grades to the same level as the top of the ledge, which is composed of large materials (Fig. 5.7). The lower 3 m (9.8 ft) of vertical incision was probably accomplished by the 1978 and later floods which were competent to transport these coarse bed materials. The depth of downcutting may vary from 3 m (9.8 ft) at this site to 6-8 m (19.7-26.2 ft) just 0.5 km (0.3 mi) upstream.

Figure 5.10 Left bank of the Salt River at the McDowell Crossing. The Spite Ditch heading is at the far left of the photograph. The ledge that marks the pre-1965 channel bed is marked by the grass growing about half way up the bank. (photograph by author).

Bed material changes over time are most evident in historical photographs. Downcutting has proceeded through several different units. Historical photographs show the textural composition of channel-bed sediments during different time periods. In 1949 (Fig. 5.9a), channel sediments were dominated by sands and silts with a few small cobbles. Because there was no flow from 1941-1965, the bed probably did not change until after the 1965 flood when the channel incised into a coarser cobble unit shown in the bank exposure in Figure 5.7. The sequence of photographs in Figure 5.9

shows the channel bed downstream from this site dominated by increasingly coarse sediments.

In 1980, the gravel mine immediately downstream of this site provided a striking example of the amount of bed load transported during a large flood event (Graf, 1983). The mining operation had excavated a pit 12 m (39.3 ft) deep. The 1980 flood with a discharge of 5,098 m^3/s (180,000 ft^3/s) completely filled in the pit, which has since been re-excavated (Fig. 5.11).

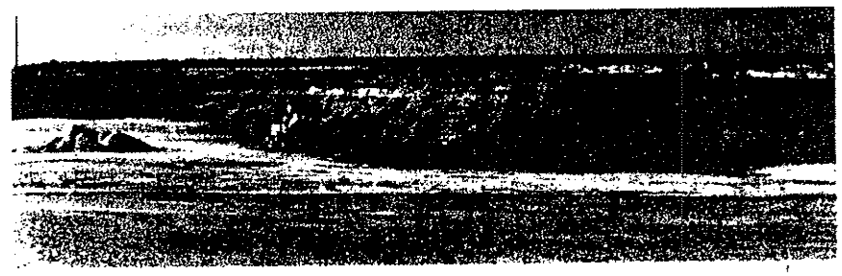


Figure 5.11 Gravel pit immediately downstream of the McDowell Crossing (photo by author).

The threshold discharge of instability is that discharge which is competent to move the coarse bed load (Graf, 1983). Floods greater than this value may produce channel instability, lateral bank erosion, or downcutting. Based on direct observations and deductive calculations, Graf (1981) estimated the threshold of instability in the Salt River to be about 560 m^3/s (20,000 ft^3/s).

Definition of this threshold raises an interesting question. If the threshold discharge of instability is about 560 m^3/s (20,000 ft^3/s), then why was there no channel incision during the 1891 flood (8,498 m^3/s)? The question can not be answered conclusively, but two speculative answers can be proposed. First, the 1891 flood probably carried significant amounts of sediment from upstream in the drainage basin (there were no dams yet), so although material was eroded and moved downstream, inputs of new sediment may have replaced what was removed. Second, because channel banks were only about 1.5 m (4.9 ft) above the bed, the channel was relatively unconfined, allowing large amounts of overbank flow. Flood waters covered the Lehi Terrace and were waist deep in the town of Lehi (Péwé, 1978).

This portion of the Salt River is relatively unaffected by human activities. In spite of several gravel mining operations nearby, this site is upstream from the major man-made controls imposed by bridges, encroachment by urban developments, and channelization efforts. Evidence of catastrophic channel downcutting at this site provides an interesting contrast with the next stop, where the catastrophic tendencies of an arid region stream have been largely removed.

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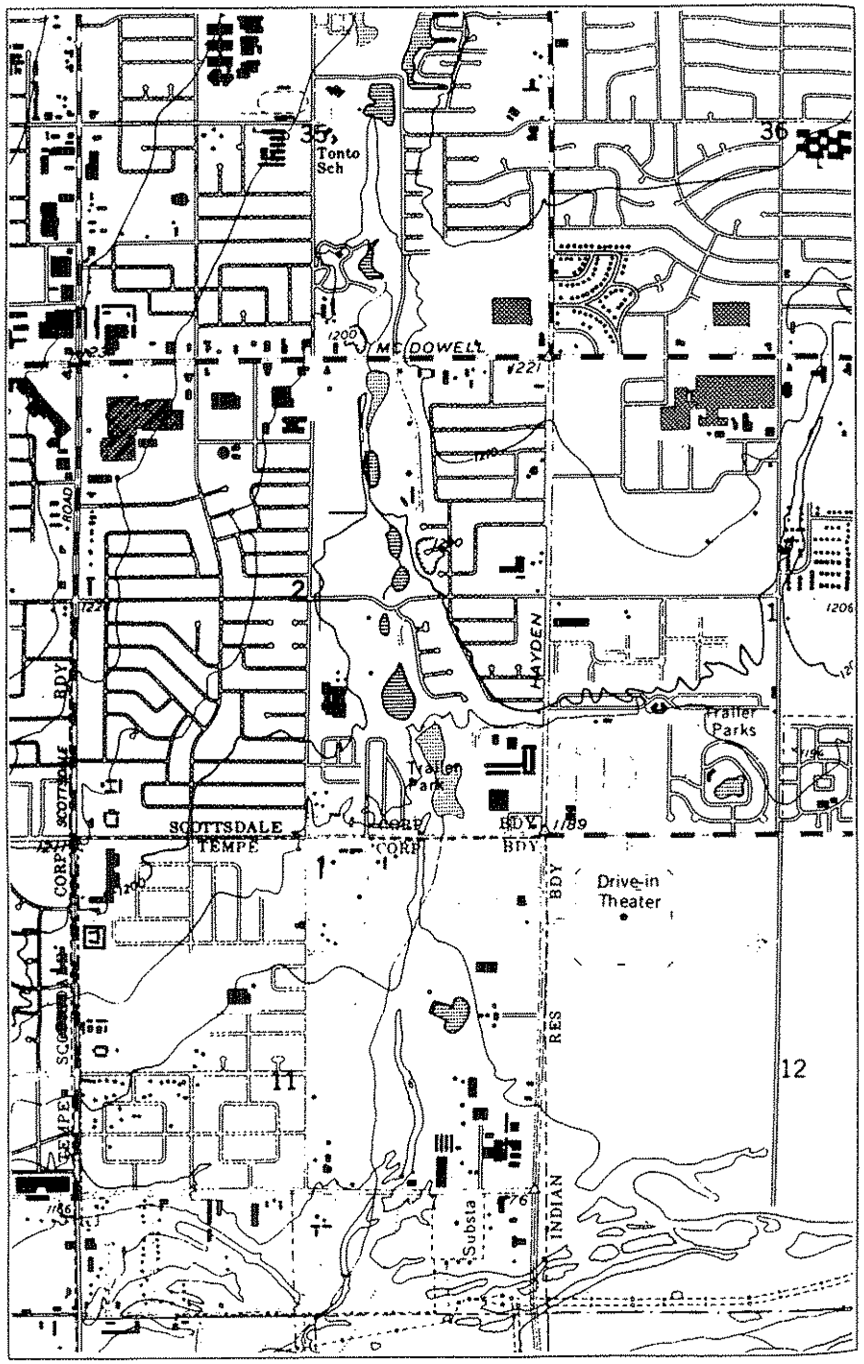

CHAPTER 6

INDIAN BEND WASH

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INTRODUCTION

The Indian Bend Wash project is a flood control project designed by the U.S. Army Corps of Engineers to protect the cities of Scottsdale and Tempe, Arizona, from floodwaters originating in the Phoenix and McDowell mountain ranges. The project was authorized by the Flood Control Act of 1965 and is designed to confine the floodwaters up to the 100-year flood which has a discharge of 850 m^3/s (30,000 ft^3/s). The project is located on the lower 12.1 km (7.5 mi) of the 49.9 km (31 mi) long wash and extends from Indian Bend Road in Scottsdale, south to the Salt River in Tempe (Fig. 6.1).

The project utilizes the greenbelt concept which involves both flood control and recreational usage of the flood plain. The greenbelt floodway, which spans about 7.2 km (4.5 mi) of the project, confines the flow of floodwaters, preventing flooding of the surrounding developed areas. It also provides many recreational areas for the surrounding communities including golf courses, ball parks, swimming pools, hiking trails, and playgrounds. The greenbelt concept is ideal for the community because it provides the highly needed flood control for the area while at the same time allows for a variety of recreational usages of the flood plain which otherwise may not be utilized at all.

SITE DESCRIPTION

The section of Indian Bend Wash included in Stop 4 of the field trip extends from East Roosevelt Road north for 0.8 km (0.5 mi) to the McDowell

Figure 6.1 Indian Bend Wash located on the Tempe Quadrangle, U.S. Geological Survey.

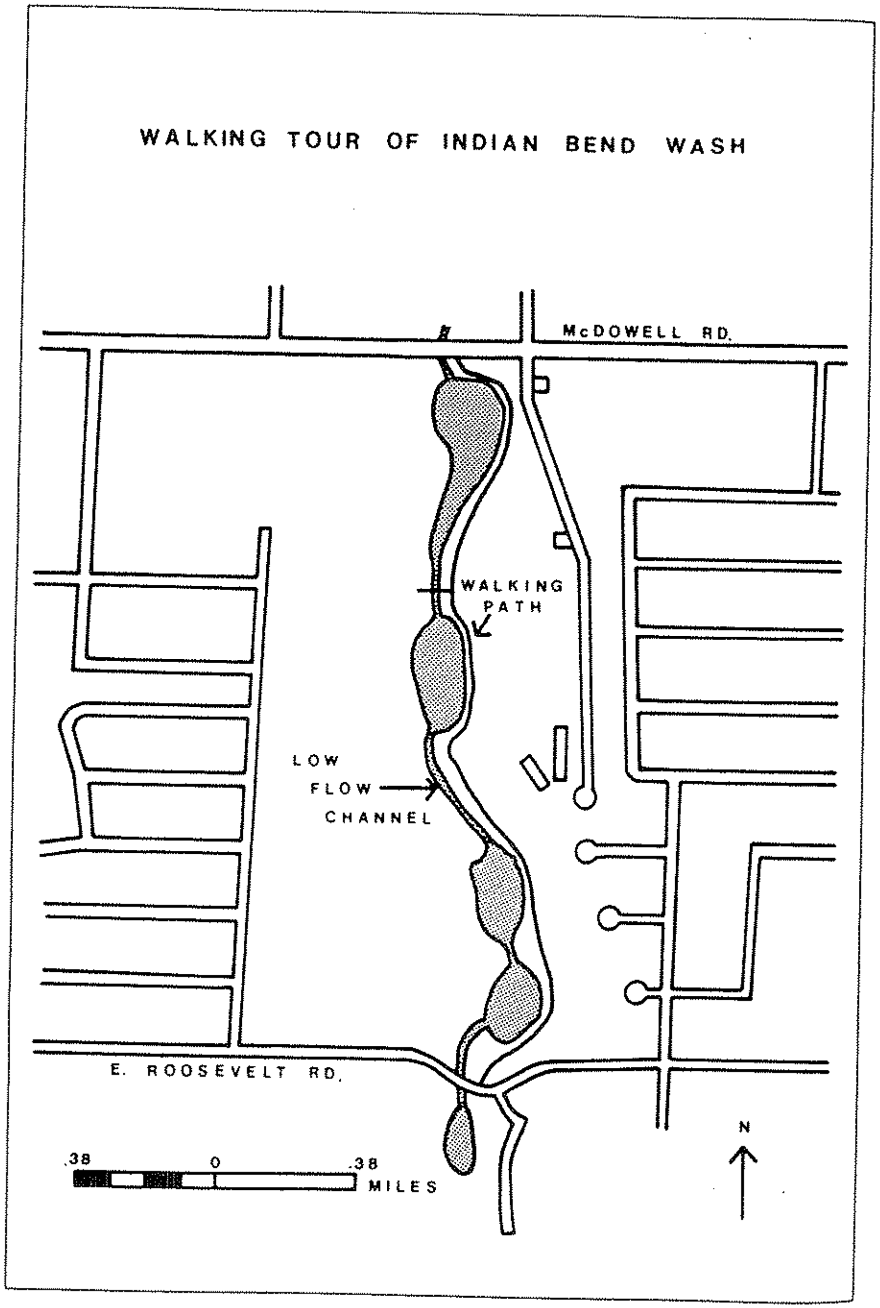


Figure 6.2 Site map of Indian Bend Wash stop.

Exhibit Plaza. A short walk is possible along the trail system which winds through the greenbelt floodway (Fig. 6.2). The average width of the floodway at this section is 137 m (450 ft) and the sides of the channel rise 1.5-3.0 m (5-10 ft) above the floor of the floodway. The developed areas along the side of the wash are protected from flood flows up to the 100-year flood. This section of the wash has a variety of recreational features: the trail system, playgrounds, basketball courts, picnic areas, and even a frisbee golf course. There is a water deflection device just north of the McDowell Road bridge. Water is channeled over to the right side of the channel and flows in a low flow channel. The McDowell Exhibit Plaza is host to cultural events, art festivals, and exhibits of varying sorts. The plaza is designed to withstand flood flows and the water is channeled through the plaza by a number of drainage channels.

HISTORY OF THE PROJECT

Indian Bend Wash lies within the Indian Bend Wash sub-drainage basin and is entirely in Maricopa County. The drainage basin ranges in elevation from 354-1,230 m (1,160-4,034 ft) and has a gradient of 0.0190 at the headwaters and 0.0038 at the end of the wash. Twenty-four percent of the area within the basin is mountainous while the remaining areas are mainly alluvial plains (U. S. Corps of Engineers, 1973).

The Paradise Valley Detention Dike (Fig. 6.3), built by the Bureau of Reclamation as a part of the Central Arizona Project, alleviated part of the threat of flooding by reducing the standard project flood from 1,756 m^3/s to 1,104 m^3/s (62,000 ft^3/s to 39,000 ft^3/s). However, without the protection of the Indian Bend Wash project, both Scottsdale and Tempe would still sustain flood damage from floodwaters originating below this dike.

Prior to the project, high intensity rainfall, originating in the Phoenix and McDowell mountain ranges (Fig. 6.3), would cause flash flooding in Indian Bend Wash. Because the existing channel could not contain these flows, overflow into the surrounding urban developments would cause severe flood damage. Flooding would also result from sheetflow across the alluvial plains which would be intercepted and build up on the uphill side of the Arizona Canal (Maricopa County Flood Control District, 1964). These flows would then back up and cause damage to the areas west and north of the canal. After sufficient flood flows were collected, these waters would then overtop the canal, sometimes causing breaks in the downstream side of the canal, and cause flooding in the surrounding areas (Water Resources Associates, 1967).

Because of the dramatic increases in population that Scottsdale experienced after World War II, development along and on Indian Bend Wash began to take place. Because of this development, the wash became a flood hazard and a growing concern for flood control developed. In 1959 the

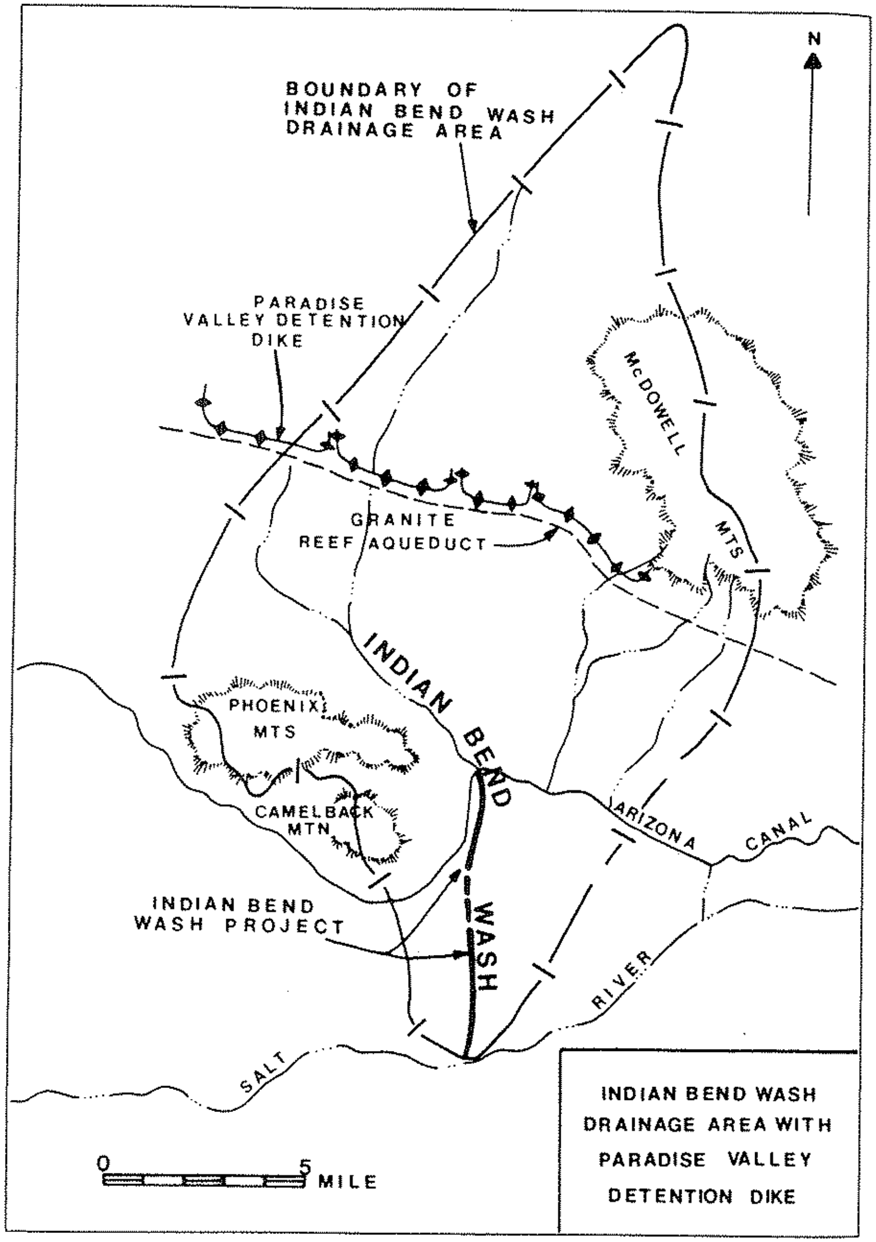


Figure 6.3 Indian Bend Wash drainage basin

Flood Control District of Maricopa County was established to develop a comprehensive county-wide flood control program and to act as legal local

sponsor on federal flood control projects. The Corps of Engineers also became interested in flood control for Maricopa County and initiated a study to develop a flood control project for Indian Bend Wash. In 1961 the Corps of Engineers presented an improvement plan for Indian Bend Wash which called for a concrete-lined channel, trapezoidal in shape, extending from the Arizona Canal downstream to the Salt River (MacLean, 1980). The dimensions of the channel would be 11.3 km (7 mi) long, 42.7 m (140 ft) wide across the top, 4.3 m (14 ft) wide across the bottom, and 7.6 m (25 ft) deep (U. S. Corps of Engineers, 1962, 1964).

The city council approved the plan and sent it to the U. S. Congress for official authorization by the Flood Control Act of 1965. During this time there was a growing concern that the concrete channel would physically and psychologically divide Scottsdale (U. S. Corps of Engineers, 1985). A central component of the project was the greenbelt concept, the idea of redesigning the channel to confine floodwaters and still utilize the floodway for recreational use.

The greenbelt concept developed out of the need for a flood control project which would be pleasing to the community and not create a feeling of division of the town like the concrete channel would. The Corps of Engineers published a reformulated plan for flood control known as Design Memorandum No. 1, General Design Memorandum-Phase 1, Plan Formulation for Indian Bend Wash. This plan replaced the concrete lined channel with a greenbelt floodway which would be designed to confine flood flows up to 850 m^3/s (30,000 ft^3/s) and also be developed for recreational usage. The project also included the construction of a collector and side-channel system which would eliminate the build up of floodwaters along the uphill side of the Arizona Canal. The reformulated plan was presented to the community and obtained full support. The project gained its "go ahead" when the City of Scottsdale voters authorized a $10 million bond issue to finance the city's portion of the project (U. S. Corps of Engineers, 1985).

PROJECT FEATURES

The new greenbelt project includes the following features: an interceptor channel, a siphon, a side channel system and collector channel, an inlet channel, the greenbelt floodway, a low flow channel, and an outlet channel (Figs. 6.4, 6.5).

The interceptor channel is approximately 2.1 km (1.3 mi) long, 91.4 m (300 ft) wide, and 2.1-3.0 m (7-10 ft) deep. It is an open unlined channel and can contain flows up to 156 m^3/s (5,500 ft^3/s). It was designed to prevent overtopping and breakage of the south levee of the Arizona Canal between Pima Road and Indian Bend Wash. The interceptor channel intercepts floodwaters originating from the McDowell Mountains and channels them into the wash. This prevents damage to the canal from overtopping of flood

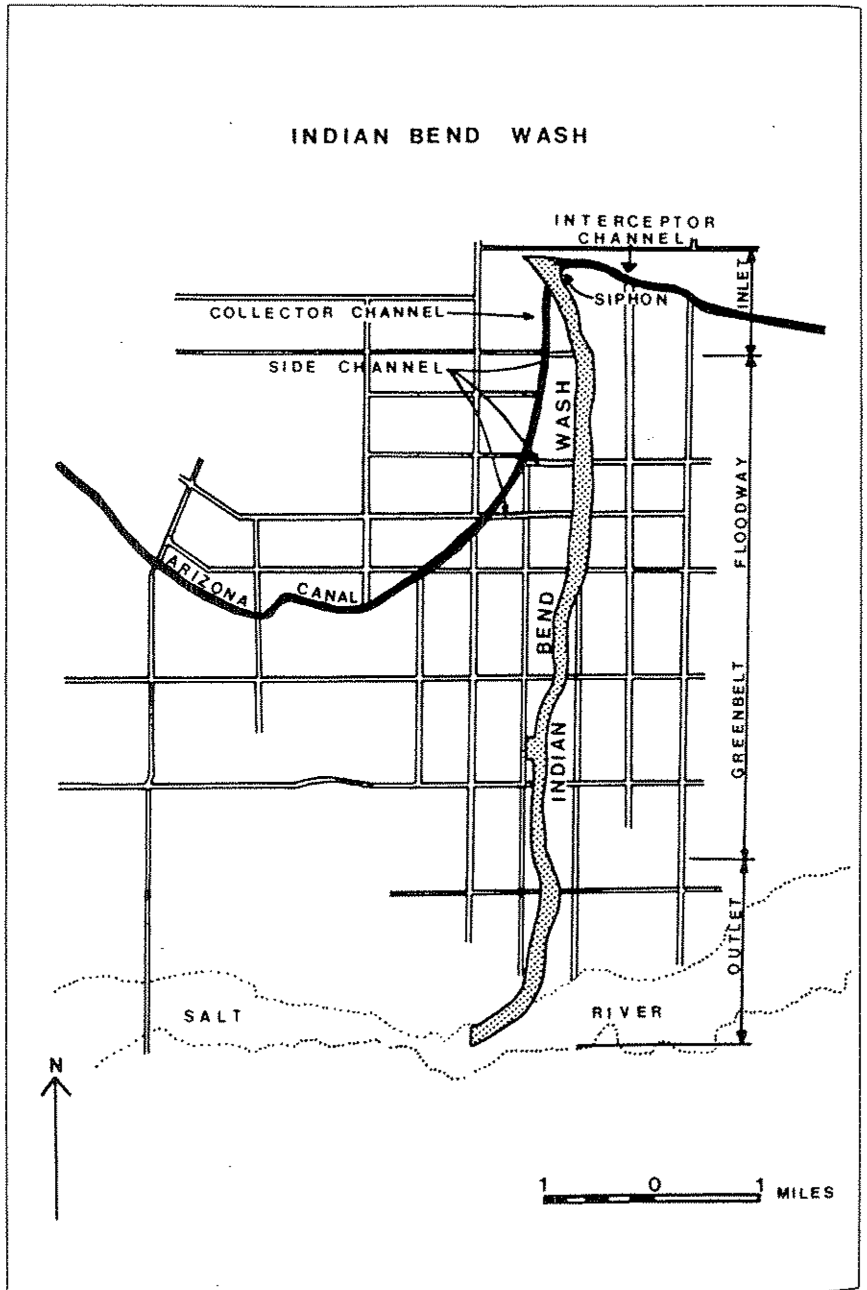


Figure 6.4 Project features of Indian Bend Wash

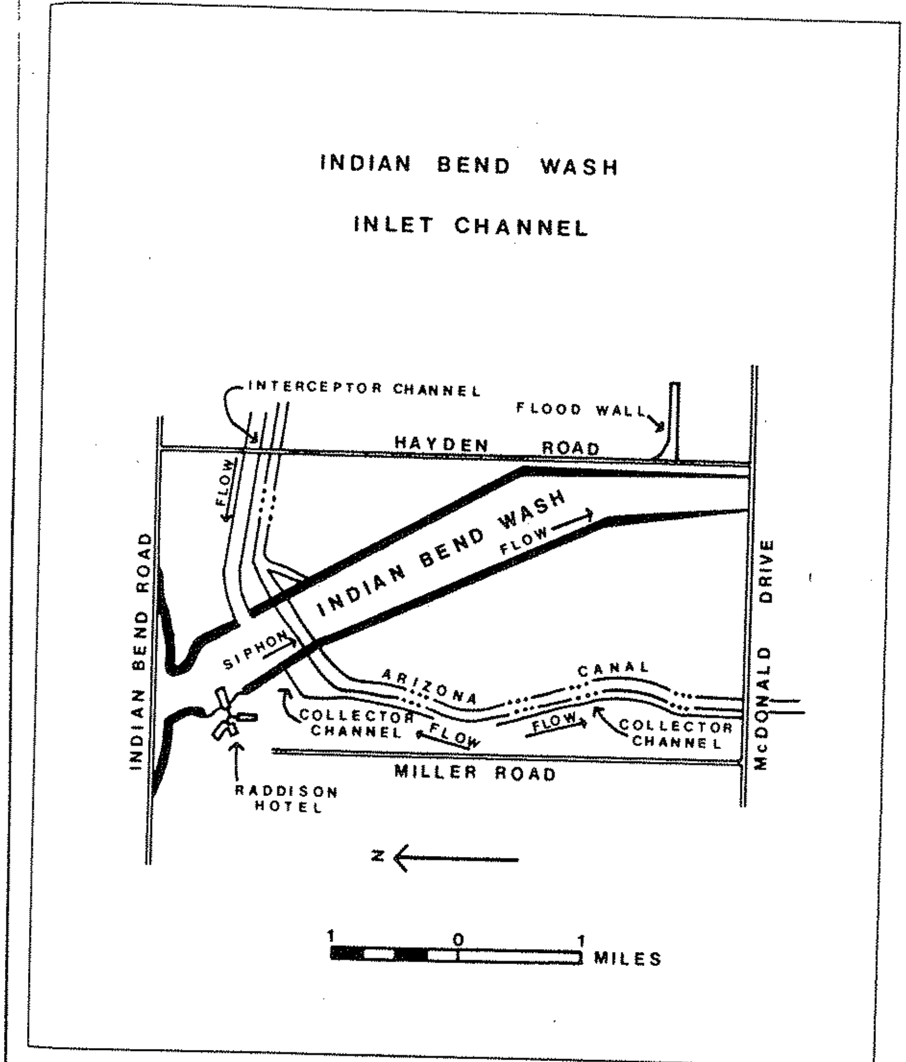


Figure 6.5 Indian Bend Wash inlet channel.

waters, breakage of the downhill levee, and the subsequent flooding which would occur.

The siphon (Fig. 6.5) carries water, flowing in the Arizona Canal, underneath Indian Bend Wash and allows the floodwaters from the north to pass in between the two sections of canal into the lower wash (U. S. Corps of Engineers, 1978). The siphon is made up of three compartments each measuring 3 x 3.4 x 274 m (10 x 11 x 900 ft). It is designed to control up to 56.6 m^3/s (2,000 ft^3/s) of irrigation flows. During major floods the siphon and wasteway can be used to control floodwaters. Excess flows in the canal can be discharged through the wasteway into Indian Bend Wash (Corps of Engineers, 1973). The wasteway is a 18.3 m (60 ft) wide, 2.4 m (8 ft) deep channel designed to release excess flows in the canal into the wash.

The collector channel and side channel system were built along the Arizona Canal west of the wash. The collector channel is 4.8 km (3 mi) long and 1.5-30.5 m (5-100 ft) wide. It is designed to collect floodwaters which pond along the west side of the canal and can carry flows up to 25.5 m^3/s (900 ft^3/s). These flows then pass under the canal through the side channel system which consists of covered conduits located along McDonald Drive, Chaparral Road, and Camelback Road. These flows are then discharged into Indian Bend Wash. This system is similar to the interceptor channel in that it collects and discharges floodwaters which build up along the canal; they would otherwise overtop the canal causing damage to the canal and flooding in the surrounding areas.

The inlet channel extends from Indian Bend Road to McDonald Drive. It is 1.6 km (1 mi) long, 152-305 m (500-1,000 ft) wide, and 2.1-3.0 m (7-10 ft) deep. The flows north of the canal, including flows collected by the interceptor channel, are passed through the inlet channel and then flow onto the greenbelt floodway.

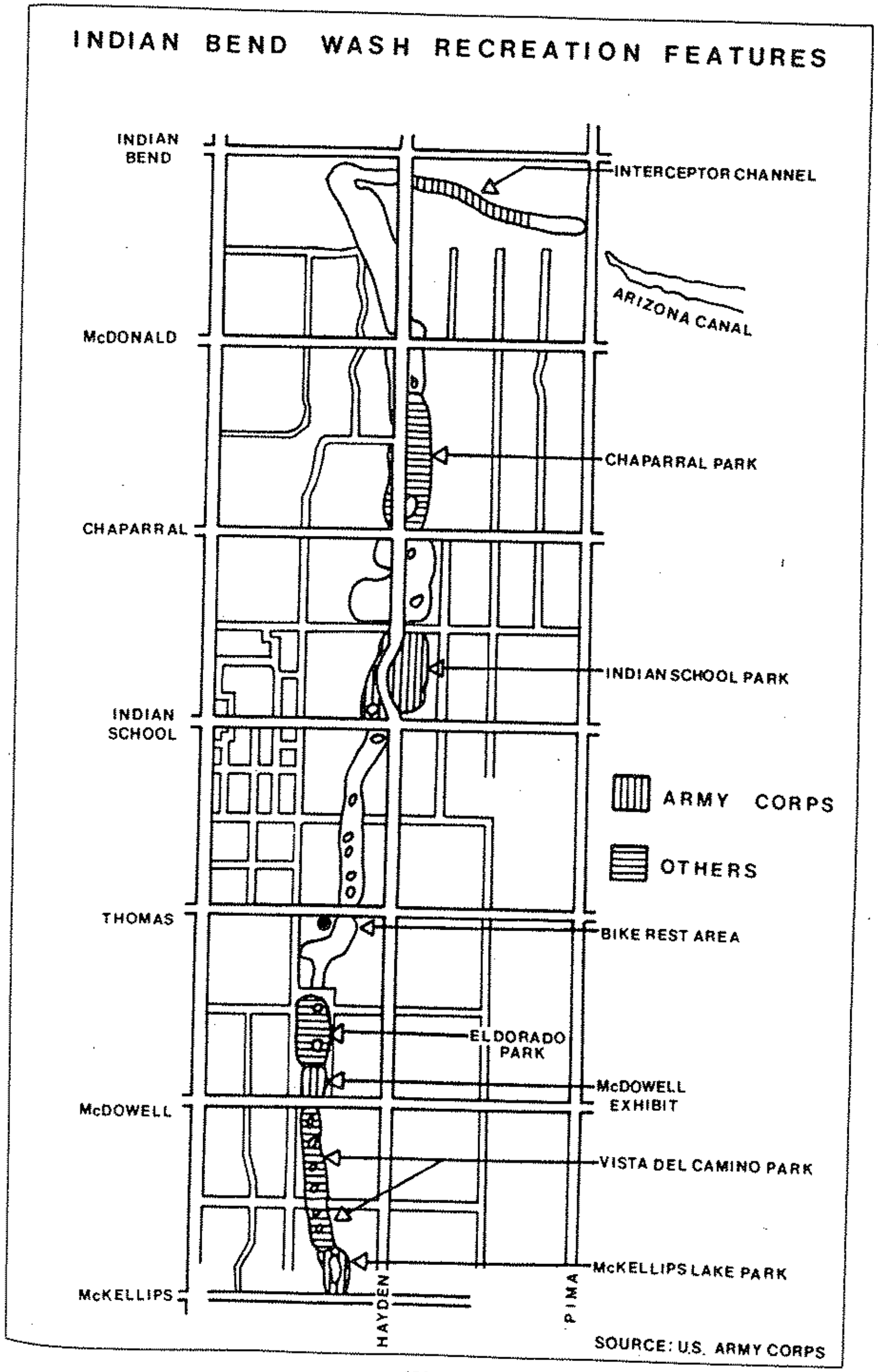
The greenbelt floodway extends approximately 7.2 km (4.5 mi) from McDonald Drive downstream to McKellips Road (Fig. 6.6). It ranges in width from 244-366 m (800-1,200 ft), is 1.5-2.4 m (5-8 ft) deep, and is designed to confine flows up to the 100-year flood of 850 m^3/s (30,000 ft^3/s). Within this floodway there is a low flow channel designed to carry discharges up to 113 m^3/s (4,000 ft^3/s). The low flow channel consists of a small channel running in between larger containment ponds and extends from McDonald Drive to Indian School Road. It is along the greenbelt floodway that all the recreation features are located.

The outlet channel is 3.2 km (2 mi) in length, 107-183 m (350-600 ft) wide, and extends from McKellips Road south to the Salt River. It contains several energy dissipating features to reduce the flow of the floodwaters before they enter the Salt River. This section also contains a low flow channel which can carry flows up to 113 m^3/s (4,000 ft^3/s). The channel is partially entrenched, trapezoidal in shape, and ranges in depth from 1.5-4.6 m (5-15 ft).

The 7.2 km (4.5 mi) of the greenbelt floodway is fully developed for its recreational capabilities. Many recreation facilities, designed by the Corps of Engineers, City of Scottsdale, and other private developers, exist along the length of the wash (Fig. 6.6). The Corps of Engineers projects include: McKellips Lake Park, McDowell Exhibit Plaza, Scottsdale Bike Stop, Indian School Park, the trail system, and the nature area.

The Corps of Engineers recreational features cost approximately $6,300,000.

Figure 6.6 Indian Bend Wash recreational features.



McKellips Lake Park is a 7.3 ha (18 ac) park including a 2.4 ha (6 ac) lake. The lake can be used for fishing and boating and is stocked by the Arizona Department of Fish and Game. It also contains picnic areas and restrooms. The McDowell Exhibit Plaza is a 3.2 ha (8 ac) site with a design theme of Indian culture. It is used for cultural displays, art festivals, and exhibits. The trail system contains 12 km (7.5 mi) of trails for jogging, walking, and bicycling. The trails are concrete and are lighted for night use. The trail has underpasses at major road crossings and extends from the Arizona Canal to the Salt River. The Scottsdale Bike Stop is a rest area for people using the trail system. It covers 0.8 ha (2 ac) of land and provides picnic areas, drinking fountains, and restrooms. Indian School Park is one of the larger recreational areas, is near the center of the greenbelt, and is designed as a focal point of greenbelt use (U. S. Corps of Engineers, 1985). It is designed for intensive recreation usage and contains athletic playing fields, a swimming pool, basketball courts, picnic areas, playgrounds, and a variety of other recreational uses. The Indian Bend Wash visitors information center, El Posadero de la Tira Verdosa (Host of the Greenbelt), is located at this site. This area also contains a control and maintenance center. The last Corps project is the nature area which is a 4.8 ha (12 ac) wildlife sanctuary located along the interceptor channel. This was designed to compensate for the loss of vegetation and wildlife habitat due to construction of the project.

Other areas, some of which already existed before construction of the project, were developed by the City of Scottsdale and private developers. There are three public parks along the wash: Chaparral Park (28.3 ha; 70 ac), Eldorado Park (21.8 ha; 54 ac) and Vista Del Camino Park (19.8 ha; 49 ac). These all contain picnic areas, playing fields, small ponds, and have the trail system running through them. Other parts of the wash were developed by private developers and contain golf courses and playgrounds for the surrounding neighborhoods.

TABLE 6.1 INDIAN BEND WASH PROJECT COSTS

FLOOD CONTROL		
Federal	$23,800,000	
Non-federal	$8,700,000	
Total Flood Control		$32,500,000
RECREATION		
Federal	$6,300,000	
Non-federal	$6,300,000	
Total Recreation		$12,600,000
TOTAL PROJECT COSTS		$45,100,000

Source: U.S. Army Corps of Engineers, 1982.

The greenbelt floodway is fully utilized to its recreational potential. The recreational areas were developed to withstand damage from floodwaters and where possible, to allow the floodwaters to flow underneath or around the structures. Because of the design of the recreational facilities, the greenbelt floodway can be used for recreational purposes and still confine floodwaters to prevent damage from flooding to the surrounding community.

Funding from local and federal sources accounted for the the total project cost of approximately $45,000,000 (summarized in Table 6.1). Scottsdale financed its portion of the costs through a $10 million bond issue. The cities of Scottsdale and Tempe are responsible for the operation and maintenance of the facilities.

CONCLUSION

The Indian Bend Wash project, which provides protection against flooding up to the 100-year flood, has converted a hazardous flood plain into an enjoyable recreational area. Damage from flooding of the wash has been reduced to zero and developments along the wash no longer experience the flooding problems that once existed in this area. The Indian Bend Wash project was selected as one of the top 10 outstanding engineering achievements of 1974 by the National Society of Professional Engineers. The U. S. Army Corps of Engineers and the city of Scottsdale jointly developed one of the most successful flood control projects in the nation.

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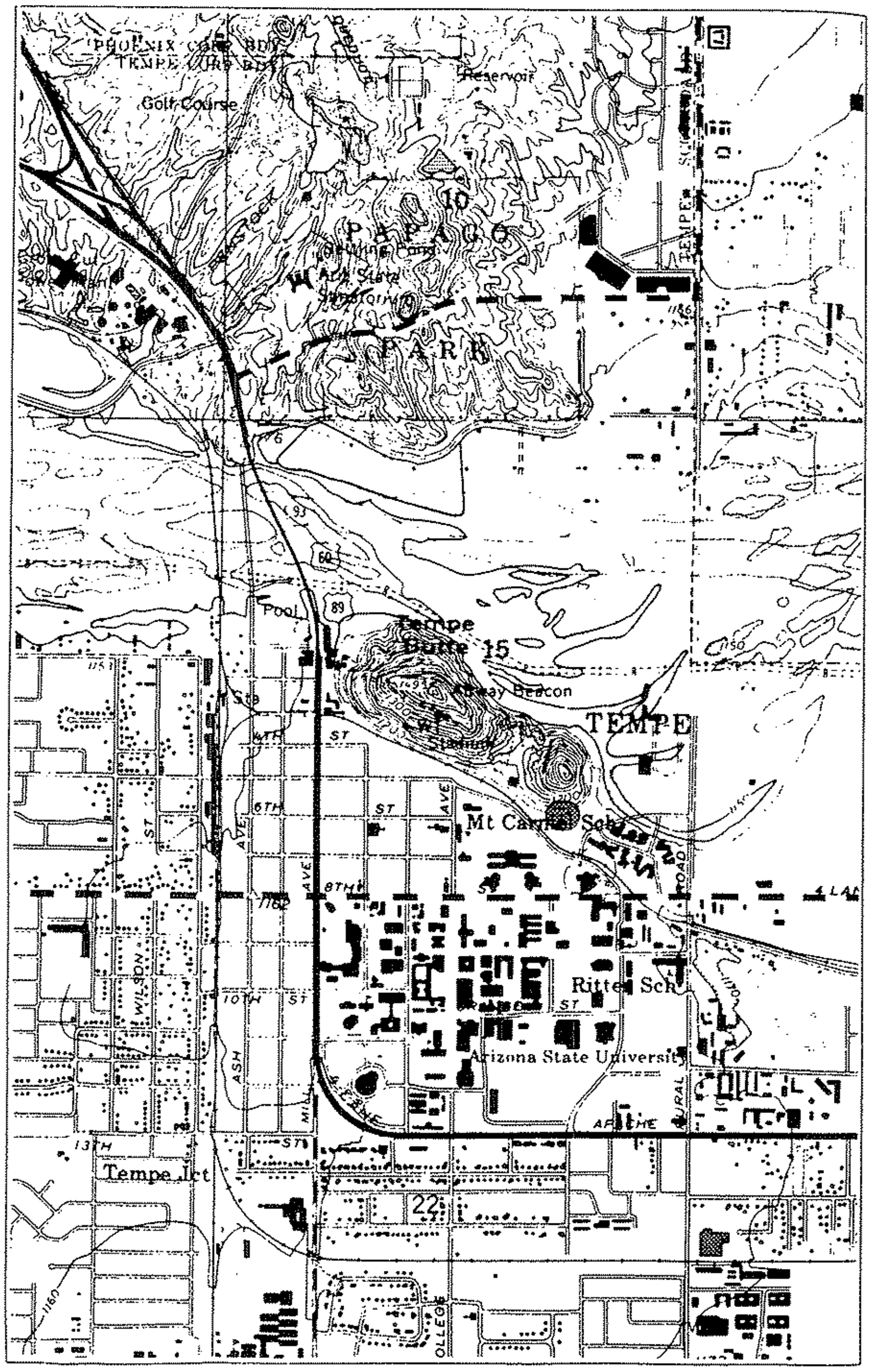

CHAPTER 7

HAYDEN'S FERRY CROSSING

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INTRODUCTION

Hayden's Ferry or Tempe Crossing is an historic site. The dilapidated Ash Avenue bridge and the currently used Mill Avenue bridge are listed in the National Register of Historic Places (ADT, 1986). The Salt River is constricted here by Tempe Butte on the south and the Papago Hills on the north (Fig. 7.1). A dike running from the butte to the Papago Hills makes this an excellent location for bridges. The dike provides bedrock on which to anchor the bridges, instead of the alternative construction on highly unstable alluvium at other sites. The Salt River is effectively narrowed at Tempe Crossing, which makes it an ideal location for a ford and bridge crossing (Fig. 7.2).

In addition to being an historic crossing site, this area has a long recreational tradition (Fig. 7.3). Tempe Beach Park and Papago Park are all that remain of this recreation area which at one time extended along both banks from the Mill Avenue Crossing to the present location of Scottsdale-Rural Road.

Several historic buildings are located near Tempe Crossing (Fig. 7.4). Hayden Mills has been in operation for over one hundred years, and Monti's Restaurant is the converted home of the Hayden family. The restaurant is on the National Registry of Historic Places.

Figure 7.1 Hayden's Ferry Crossing located on the Tempe Quadrangle, U.S. Geological Survey

Figure 7.2 Pre-1900 photograph of a horse and carriage fording the Salt River at Tempe Crossing (photo courtesy of the Tempe Historical Museum, photo # OS255).

Figure 7.3 Swimming in the Salt River lake near Tempe Beach Park, 1916, with the Ash Avenue Bridge in the background (photo courtesy of the Tempe Historical Museum, photo # OS245).

HAYDEN'S FERRY

Prior to 1870, the Salt River was forded on horseback at Tempe Crossing (Fig. 7.2). A ferry was constructed shortly after the opening of Hayden Mills in 1870. Charles Hayden, a pioneer and entrepreneur, built the mill, a house for his family, and the ferry (Hayden, 1972). Hayden's ferry was built large enough to accommodate two wagons and teams, and it operated using the power of the river on a pulley system (Fig. 7.5). Hayden milled wheat grown by local farmers and Indians. Eventually, a little town grew up around the mill and was named Hayden's Ferry, later changed to Tempe (Robinson and Bunham, no date; Weisiger, no date).

The ferry served the needs of the community fairly well, despite the fact that occasional floods washed the ferry downriver. The citizens of the town

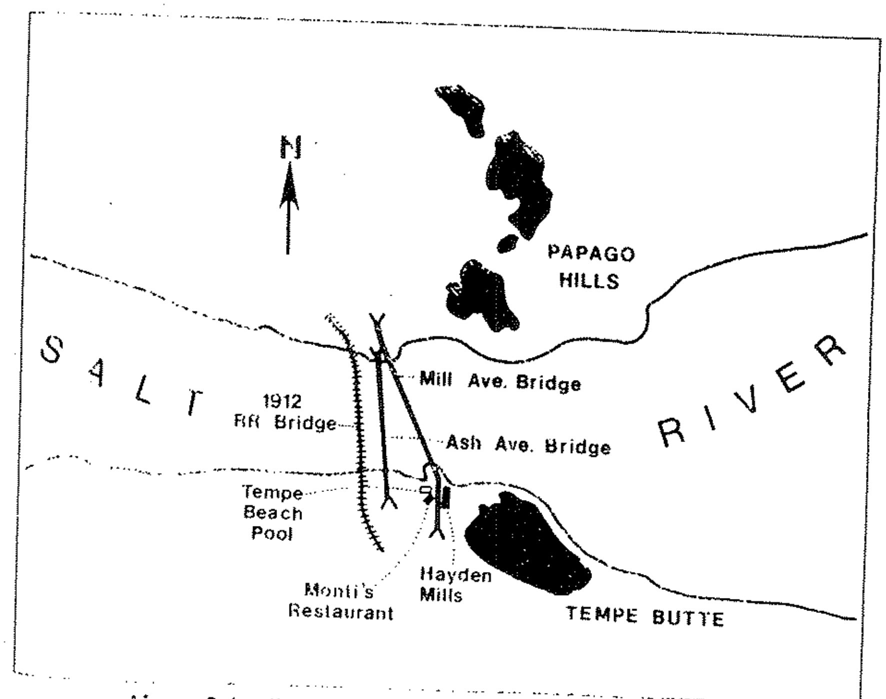

Figure 7.4 Site map of Hayden's Ferry Crossing stop.

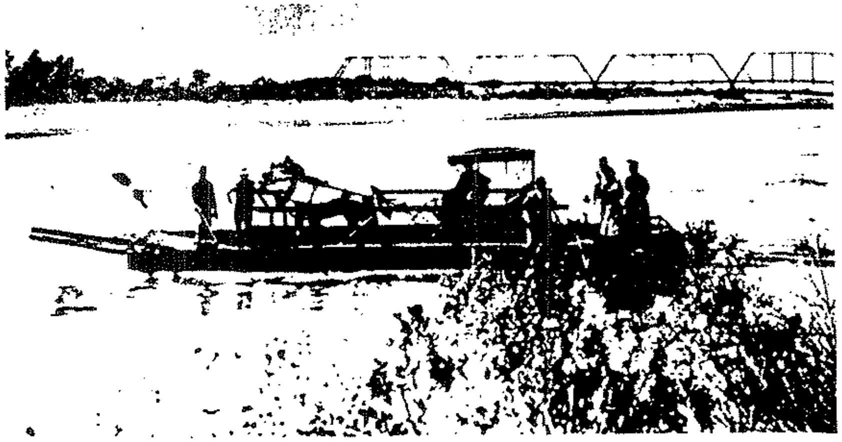

Figure 7.5 Hayden's Ferry in operation circa 1895
(photo courtesy of the Salt River Project Research Archives).

seemed to take the floods in stride. Floating debris was common in the Salt River during the early Anglo period, however. One newspaper reported almost nonchalantly "on Monday two horses, a buggy and a rocking chair went past Jonesville [later known as Lehi] down the river." The absence of dependable crossings during high-water periods lead to public investment in bridges.

THE BRIDGES

The Ash Avenue bridge was the first highway bridge built across the Salt River at Tempe (Fig. 7.6). Built in 1911, it is the oldest surviving multiple arch

Figure 7.6 Salt River in flood under the Ash Avenue Bridge
(photo courtesy of Tempe Historical Museum, photo # OS147).

concrete bridge in Arizona. The eleven-span reinforced concrete spandrel rib arch bridge was built entirely by prisoners from the penitentiary at Florence, Arizona. It is 460 m (1,507 ft) long and 5.5 m (18 ft) wide. Every third pier is anchored on bedrock, surrounded by concrete. The intermittent piers are each anchored on two concrete-filled steel cylinders 1.8 m (6 ft) in diameter resting on bedrock.

The Ash Avenue bridge is currently closed to any traffic, and it is in poor condition. The Tempe Historical Society is attempting to generate funds to restore the bridge and reopen it as a bicycle or footpath.

The bridge has remained fairly stable, sustaining only slight damage during the floods in 1916, 1919 and 1920 (Arizona Republic, 1920). Most of the damage was due to an unstable pier resulting in the sinking of a span. When the Ash Avenue bridge became inadequate to handle automobile traffic as cars became larger and heavier near the end of the 1920s, the need for a new structure became apparent.

The Mill Avenue bridge was designed by the Arizona Highway Department in 1929 and construction began in 1930 (Arizona Republic, 1978). Although the original plan was to build the bridge orthogonal to the trend of the river channel, it was constructed at an angle relative to the river in order to allow anchorage on the natural rock dike that connects Tempe Butte and the Papago Hills. The original plan was abandoned when preliminary excavation for the bridge piers found only caliche material on which to build. Angling the bridge enabled every footing to be anchored on granite, making the Mill Avenue bridge extremely stable. The concrete footings for the Mill Avenue bridge are set 0.9 m (3 ft) deep into bedrock, except for pier number nine which was set on a huge boulder.

The Mill Avenue bridge is 481 m (1,577 ft) long and 11 m (36 ft) wide between curbs with 1.5 m (5 ft) of sidewalk on either side. It was one of only two bridges that remained passable during the floods of the late 1970s and early 1980s, which had discharges of up to 5,098 m^3/s (180,000 ft^3/s). These floods involved heavy use of the bridge. It was not uncommon to wait four hours to cross by car, with the line of automobiles several kilometers long on either side of the river. Bridge crews worked late night to early morning daily, filling potholes and repairing damage from heavy daytime use. This continued for a week in 1978 and again in 1980.

During the floods, traffic crept so slowly across the bridge the commonly repeated joke was that commuters had time to leave their cars and eat a leisurely breakfast before any car had moved. Youths ran up and down the lines of cars selling sodas, fruit, donuts, and candy to the waiting drivers. Despite the wait, newspaper clippings from the flood years reveal an affection for the bridge, and it was dubbed "old faithful."

The first railroad bridge here was built in 1887. It was a 393 m (1,291 ft) long nine-span Pratt-type truss bridge. Completely destroyed in 1891 by a flood (Tempe News, 1905), its piers were abandoned and a new bridge built adjacent to it. The new bridge was subsequently destroyed by floods in 1905, but rebuilt on the same piers (Fig. 7.7). Although damaged again in 1912, rebuilding took place quickly, again on the same piers. Since 1912, only relatively minor repairs have been needed. Three bridges built previously upstream from the present location of the Mill Avenue bridge were also washed away in the late 1800s and early 1900s.

Figure 7.7 Railroad bridge destroyed by the Salt River in the 1905 flood (photo courtesy of Tempe Historical Museum, photo # OS147).

TEMPE BEACH PARK

Tempe Beach Park, on the south bank of the Salt River between the Ash Avenue and Mill Avenue bridges, is almost all that remains of an extensive recreation area enjoyed by early Tempe residents. The river banks around the crossing were popular as far back as the early 1900s for baseball games, picnicking, camping, and other social events. Tempe Beach Park was opened in 1923 and included an olympic-sized swimming pool. It is Tempe's oldest park and one of its largest covering 6 ha (15 ac). The park was originally opened in an effort by a Tempe civic group to keep the town youth out of the canals and the Salt River. The olympic pool was closed in the mid-1950s and replaced by a smaller pool which was finally closed in 1985. Tempe Beach remains popular for picnickers.

In addition to the formal pools in the park, swimming holes, ponds, and lakes have been built in the Salt river bed. On at least three separate occasions, 1916, 1923, and around 1940, there was a lake for swimming, boating, and fishing. Often, the lakes amounted to the remains of flood-waters, and while swimming in them was popular, the civic groups of Tempe encouraged swimming in the park pool.

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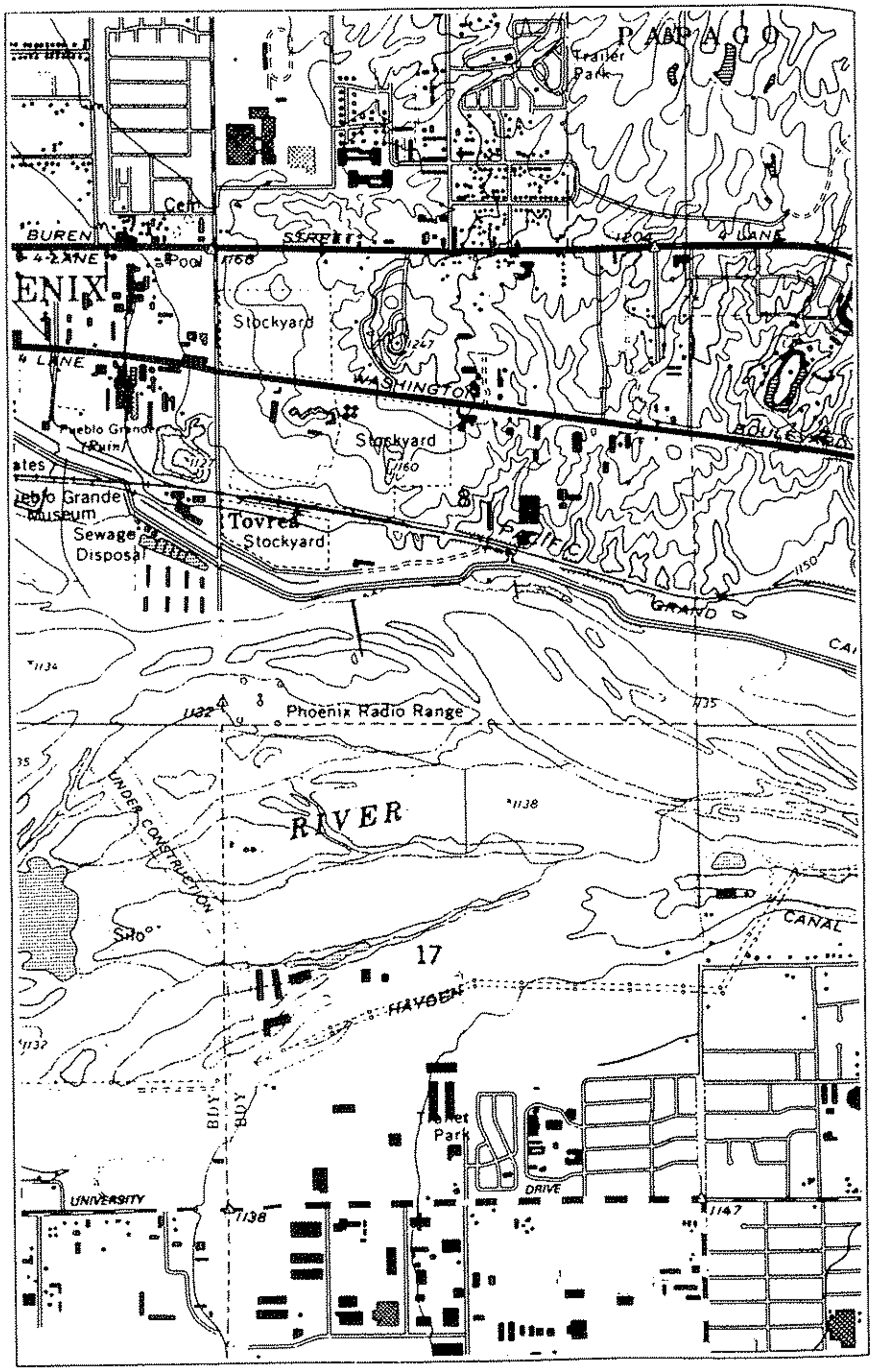

CHAPTER 8

JOINTHEAD DAM

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INTRODUCTION

Stop 6 derives its name from a single head or single withdrawal point to supply two canals. The precise history of Jointhead Dam remains sketchy, but authorities on the early canals agree that the dam was completed around 1886. The project was to serve as the jointhead for the Swilling Ditch and the North Extension. These were also known as the Salt River Canal and the Maricopa Canal, respectively. Although the dam was in full service for only several decades, it was one of the first permanent water resource structures in the Salt River Valley (Gacioch, 1986; Zarbin, 1986).

At this location the Salt River is a braided channel and is noteworthy because of the shallow depth to bedrock and because of the radical increase in width from points immediately upstream (Fig. 8.1).

HISTORY

Jack Swilling, an ex-Confederate calvary soldier, was one of the first to notice the ruins of the ancient canal system built by the Hohokam Indians. The Hohokams inhabited the Salt River Valley between about 300 AD and 1450 AD. Archeologists identified more than 240 km (150 mi) of ancient canals by 1920. Most of the canal ruins have since been lost to development, though in Swilling's time many were still visible. Swilling worked delivering hay by wagon to Wickenburg. Noticing the canal ruins, he realized the

Figure 8.1 Jointhead Dam site located on the Tempe Quadrangle, U.S. Geological Survey potential for irrigating land in the Valley via similar canal routes. In 1867, he formed the Swilling Irrigation and Canal Company and began building the Swilling Canal or Ditch. He was the first during this era to develop organized, large scale withdrawals from the Salt River and to transport the water through canals to irrigate crops. In March 1868, he sold his first crops to miners in Wickenburg and to the U. S. troops stationed at Fort McDowell. Around this time, Phoenix began to appear. It was a period in which the entire area went "canal crazy" (SRP, 1983).

Another canal built by the Swilling Irrigation and Canal Company around this time period was the North Extension. This canal was an extension that split to the north from the Swilling Ditch. Both canals originally shared the same head from the Jointhead Dam location. The diversion head, made of brush and rocks, was frequently damaged by annual high flows on the Salt River. A large flood in 1874 severely damaged the head. The decision of whether or not to replace it caused a dispute between the shareholders that led to the split and forming of the Maricopa Canal Company and the Salt River Valley Canal Company. The Maricopa Canal Company controlled the North Extension and the Salt River Canal Company controlled the Swilling Ditch. At this time the canals were also known as the Maricopa Canal and the Salt River Canal, respectively. Separate headings were used to supply each canal but only for a short time. About 1884 both companies pooled their resources and began construction of the more permanent Jointhead Dam. It is uncertain exactly what portion of the existing structure was constructed by the completion date in 1886 (Zarbin, 1986). Not only was the Jointhead Dam one of the first joint-venture water resource projects in the Valley, but it was also one of the first concrete and stone structures designed to withstand the damaging high flows in the river channel. Some modifications were made over the next twenty years. Exactly when these modifications were made is uncertain, but it is known that the sill was added around 1911 to supplement the flow diverted to the gates (Figs. 8.2, 8.3).

By 1890, the Arizona Canal Company controlled the north canals from the upstream diversion point near the junction of the Salt and Verde rivers. This was a better withdrawal point that led to the gradual phasing out of withdrawals from the Jointhead Dam. By 1920, the Dam was used only on a supplementary basis. The early diversion dam for the Arizona Canal was also constructed of brush and rocks or wooden boxes filled with rocks. They were not always able to divert as much water from this location as was desired due to water flowing through and over this crude dam. Surface water traveling downstream would then be available for withdrawal at the Jointhead Dam. Even during extreme low flow, subchannel flow would often resurface at this location because of the shallow depth to bedrock. Thus, the Jointhead Dam served to supplement water to the canal system prior to the more regulated flows following the upstream dam closures. Numerous changes in the canal systems occurred in the early 1900s and

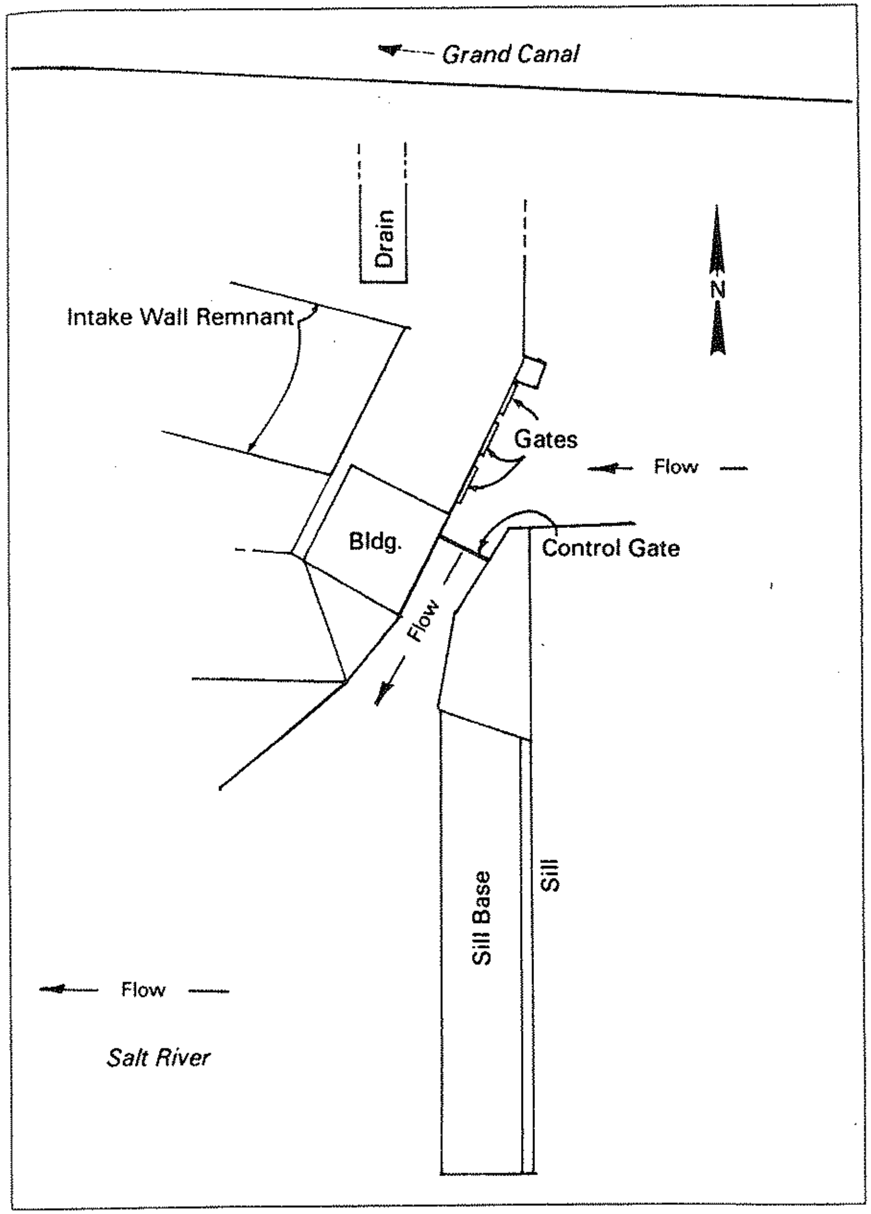

Figure 8.2 Site map of Jointhead Dam stop.

eventually the services of the Swilling Ditch and the Maricopa Canal were completely replaced by the Grand Canal (Gacioch, 1986). The Grand Canal originally took its heading near the present-day Scottsdale Road but later

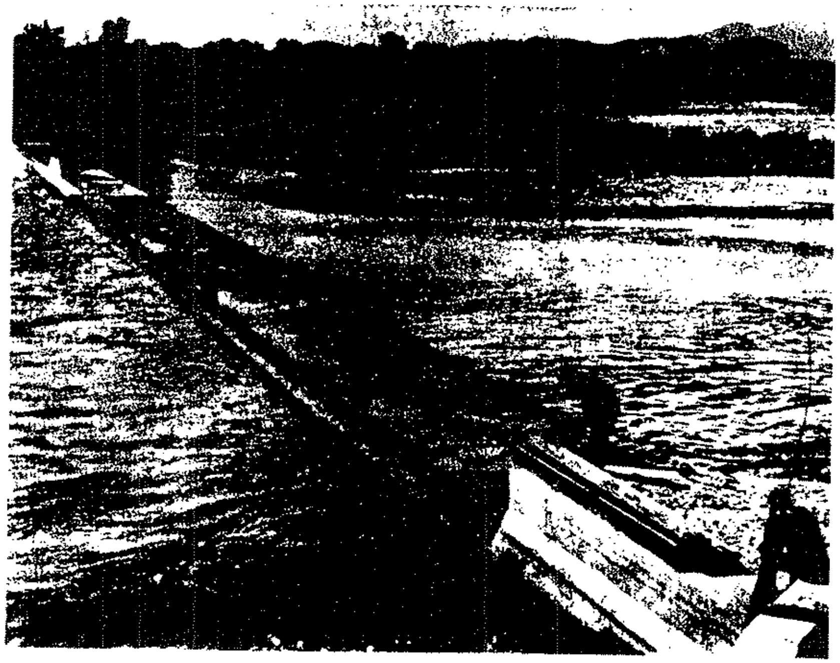

Figure 8.3 Construction of sill, Jointhead Dam, 1911 (photograph courtesy of the Arizona Collection, Arizona State University, Carl Hayden Photo Collection, photo # 507).

was supplied solely by water diverted from the Arizona Canal (to the north) via the "new" Crosscut Canal. More recently, the Jointhead Dam served as a drain for the Grand Canal but was replaced by a new drain built by Salt River Project (SRP) about 91 m (300 ft) upstream. Notice the difference in elevation of the Dam's head gates and the Grand Canal (SRP, 1983).

The Salt River Project operated a gage at this site to monitor the flow of the Salt River. The length of record was substantial, but the SRP officials considered the data inaccurate due to the frequent shifting of the main channels through this braided reach. Thus, the record was not formally documented. The U. S. Geological Survey later operated this station. The period of record began in October 1978, but unfortunately vandalism and channel instability precluded its use by 1980 (Reigle, 1986).

SOILS AND GEOLOGY

The U.S. Soil Conservation Service (1974), or SCS, classified the soil at this location as "alluvial land." The soil that is present is characteristic of geolog-

ically recent stratified deposits.

The surface here is primarily fluvial deposits, although bedrock outcrops and disintegrated granite are exposed on the north bank and in very isolated portions in the channel. Bedrock exposed at the surface and at such underlying shallow depths is unusual along the Salt River through the Valley. Péwé and others (1986) mapped the geology through this region and identified the bedrock outcrops here as Tovrea Granite, a gray coarse-grained granite having large rounded crystals coupled with ferromagnesium minerals which enabled deep weathering and the characteristic red rind visible at the surface.

VEGETATION

The vegetation has gone through drastic changes over the past fifty years. Prior to dam closures, when the Salt River was perennial through the metropolitan area, vast dense stands of tamarisk, creosote bush, mesquite, and annual grasses and weeds flourished on the banks and on exposed islands.

Following the dam closures, the Salt River flow regime was completely altered, flowing only during extreme events. This drastically reduced the amount of water available to the riparian vegetation. Much of the vegetation could not survive the reduced water availability. Although similar types of vegetation are still evident, it is very sparse.

CHANNEL FORM

The channel pattern here is braided (Fig. 8.4). As opposed to most other reaches of the Salt River, vertical channel degradation has been restricted here by the relative shallow depth to bedrock.

The exposed bedrock on the north bank has also restricted the channel from migrating laterally toward the north. The bedrock outcrops are not evident along the southern bank. Thus, the channel has migrated considerably toward the south. The 1.6 km (1 mi) wide channel through this reach is considerably wider than the channel 1.6 km (1 mi) upstream in the vicinity of Tempe Buttes. This can be attributed solely to the underlying bedrock.

The frequent shifting of the main channels may be attributed to the relative steepness of the bedrock-controlled slope and the regulated flow regime. The shifting channels are possibly changing more rapidly due to the demise of the vegetation that once added stability to the banks and islands. By referring to the photographs in Figure 8.3 and 8.5, and viewing the present channel, a visual comparison can be made of the channel changes. It is evident that vegetation had recently begun to establish on the bars and islands in the 1911 photo. This vegetation had matured by the time the 1941

Figure 8.4 Aerial photo of the Jointhead Dam vicinity (Landis Aerial Survey, 1986, photo # N-17).

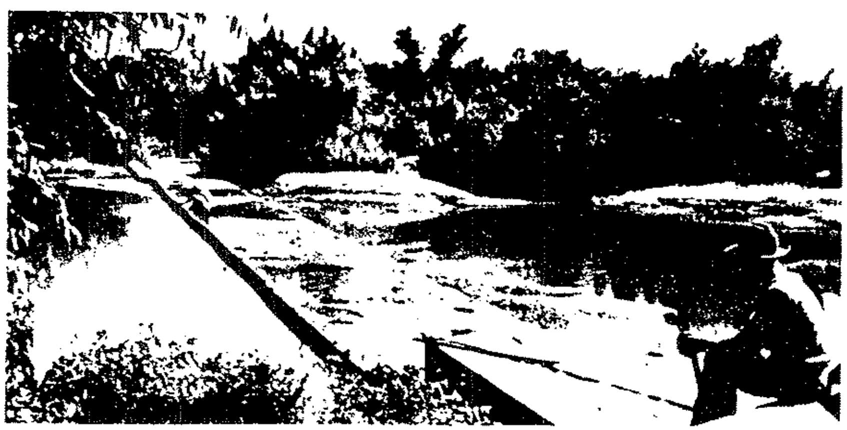

Figure 8.5 Jointhead Dam, 1941 (photo courtesy of the Arizona Collection, Arizona State University, Carl Hayden Photo Collection, photo # 508).

photo was taken. The demise of the vegetation is very obvious today. Less obvious is the sedimentation that has occurred behind the sill and toward the center of the channel. This can be appreciated by venturing to the base of the gate structure near the iron intake gates and visually sighting a level line toward the center of the channel. Sediment sizes through this reach range from fine sand-sized to cobble-sized particles in the main channels.

Jointhead Dam has long outlived its usefulness to the irrigators of the Valley. One of its original design objectives, construction to withstand the high flows in the Salt River, has been accomplished. It represents one of the early projects that initiated an era of large scale, permanent water supply projects in the Salt River drainage.

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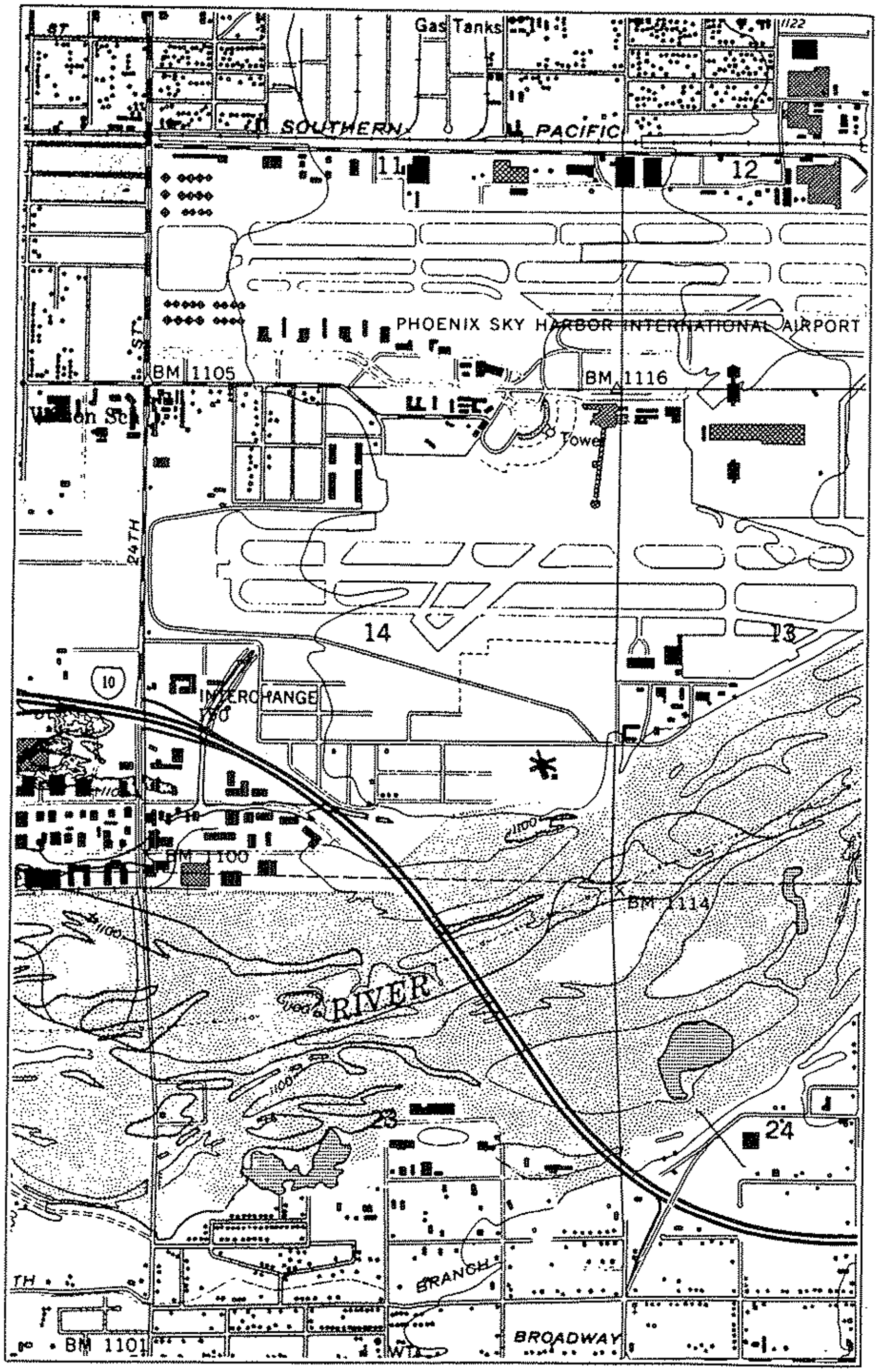

CHAPTER 9

INTERSTATE-10 BRIDGE CROSSING

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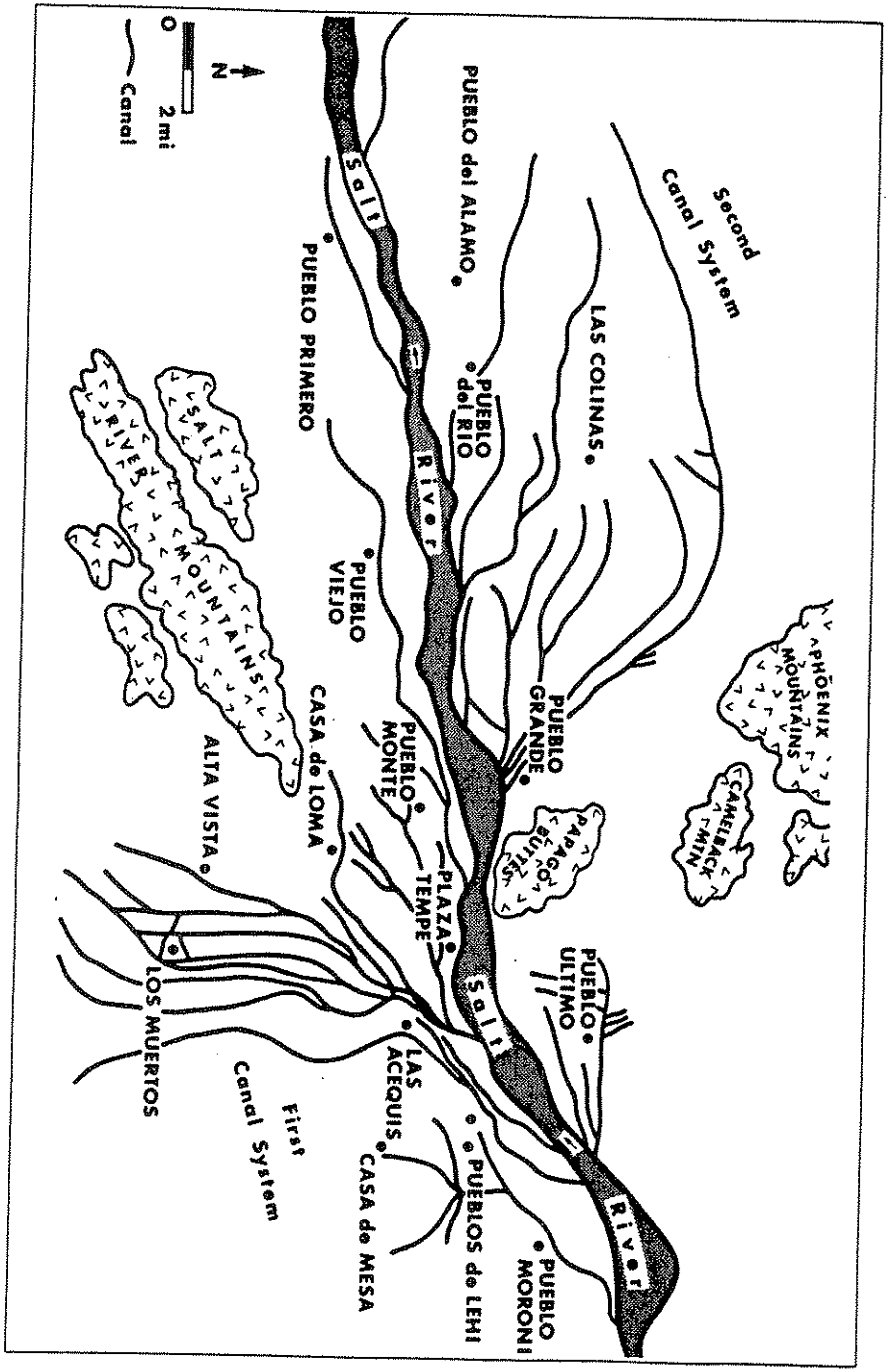
INTRODUCTION

The Interstate-10 bridge over the Salt River is located between 24th and 32nd streets in Phoenix and forms the primary transportation link between the metropolitan Phoenix area on the northwest side of the river and the suburban communities on the southeast side of the river (Fig. 9.1). Designed by the Arizona Department of Transportation in 1960, the bridge was constructed in 1962 and opened to traffic in 1965.

HISTORICAL SETTING

The bridge site appears to have been rather insignificant in the local history until the bridge was constructed. However, the general area was occupied from about 300 A.D. to 1400 A.D. by the Hohokam civilization (Waugh, 1984). This relatively complex society built canals and water diversion facilities to transport water to agricultural plots that were kilometers away from the river. Although no canals were apparently built at the I-10 bridge site (Fig. 9.2), one canal appears to have been located somewhat north of the bridge site where Sky Harbor International Airport is presently located, and a major Hohokam community developed about 4 km (2 mi) northeast of the site; the ruins of this community have been preserved and given the name "Pueblo Grande." By 1450 A.D. the Hohokam seem to have disappeared for unknown reasons (Waugh, 1984).

Figure 9.1 Interstate-10 Bridge Crossing located on the Phoenix Quadrangle, U.S. Geological Survey.



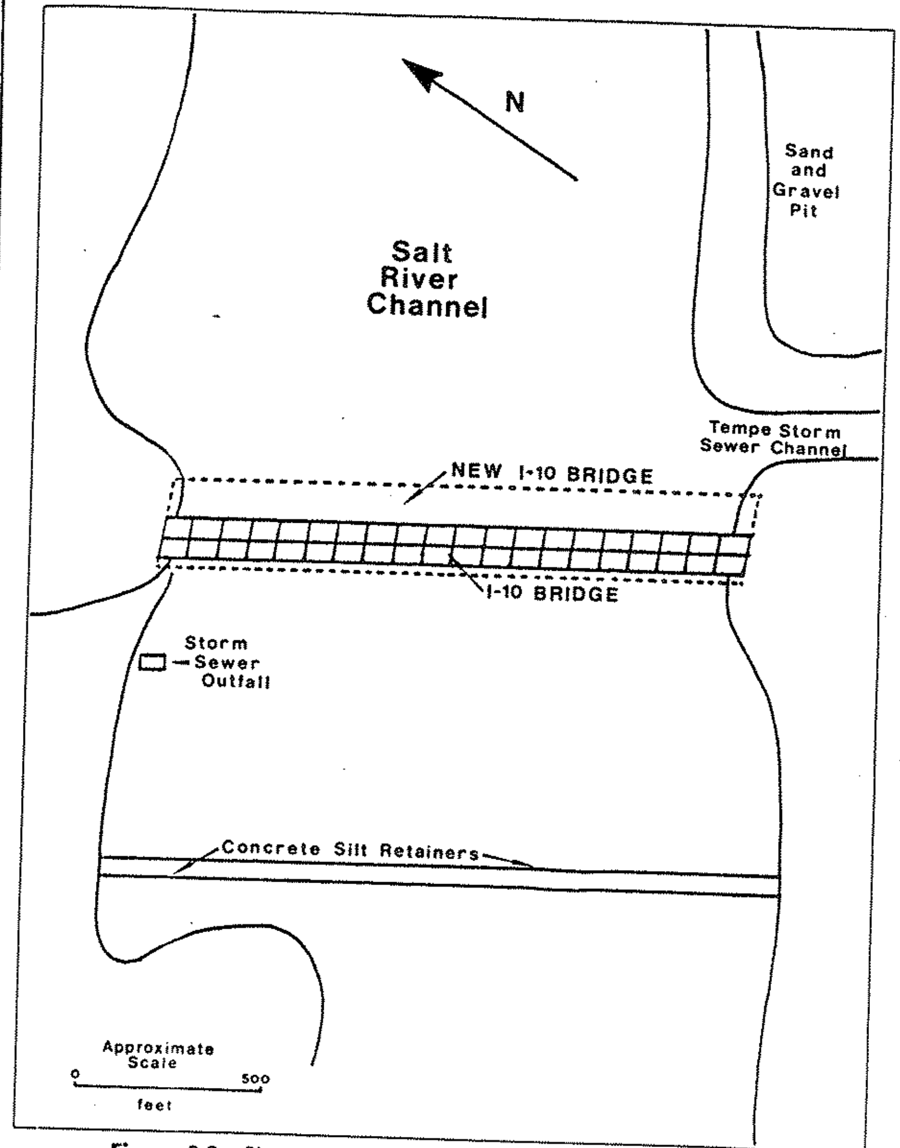


Figure 9.3 Site map of Interstate-10 Bridge Crossing stop.

Early European settlers came to the Salt River Valley in the late 1860s and refurbished some of the Hohokam waterworks in order to grow their own crops. In 1865, John Y. T. Smith began growing hay in a field that is now

Figure 9.2 Prehistoric Irrigation Canals - Phoenix Arizona (Turney, 1949).

occupied by Sky Harbor International Airport, approximately 1 km (0.6 mi) north of the bridge site. The original Phoenix townsite was intended to be located about 3.5 km (2 mi) north-northeast of the bridge site but was moved westward near the present location of downtown Phoenix before much development began (Brown, 1970).

Prior to construction of upstream dams early this century a riparian habitat existed along the banks of the Salt River in Phoenix. Home to many forms of wildlife, the habitat consisted of mesquite, cottonwood, and willow trees (Waugh, 1984).

BRIDGES

The I-10 bridge comprises two parallel prestressed concrete structures, both of which are 479 m (1,570 ft) in length and supported by 19 reinforced concrete piers on spread footings set on alluvium of unknown depth (Fig. 9.3). The bridge was designed with a protection of rock, 1.2 m (4 ft) in thickness, on the sides and bottom of the low flow channel between piers 5 and 10 (from the right bank) with flow centerline between piers 7 and 8. The piers were designed to be angled about 80 degrees to the centerline of the bridge so that they would approximately parallel the flow in the low flow channel (Dames and Moore, 1979).

The end spans of both structures are supported by concrete piers built into abutments that are covered by cobbles and wire mesh for erosion protection. Originally, dikes 46 m (150 ft) in length were extended upstream and away from the channel at both ends of the structures, although the dikes eventually sustained damage as a result of flooding (Dames and Moore, 1979).

In the vicinity of the bridge the flood plain extends to more than 1.6 km (1 mi) on both sides of the stream centerline, and because the approaches to the bridge are located in the flood plain, the bridge represents a constriction in the channel. However, it was designed to pass a 100-year flood, which at the time was determined to have a flow rate of 4,980 m^3/s (176,000 ft^3/s). Since construction of the bridge major flooding, including one flood with flow rate in excess of the 100-year estimate, has created significant changes in the channel configuration. The flood of March, 1979 alone resulted in a shift of the low flow channel 85 m (280 ft) to the south (Fig. 9.4) with consequent damage to eastbound pier 11. As a result, the pier settled and moved laterally, thereby causing the bridge deck to settle. Repairs consisted of grout injection at the base of the footing and construction of a new footing with concrete reinforcement. The bridge was then reset to proper grade and shimmed (Dames and Moore, 1979). Otherwise, the bridge has passed all flows to which it has been subjected without damage, including the 5,098 m^3/s (180,000 ft^3/s) flow in 1980.

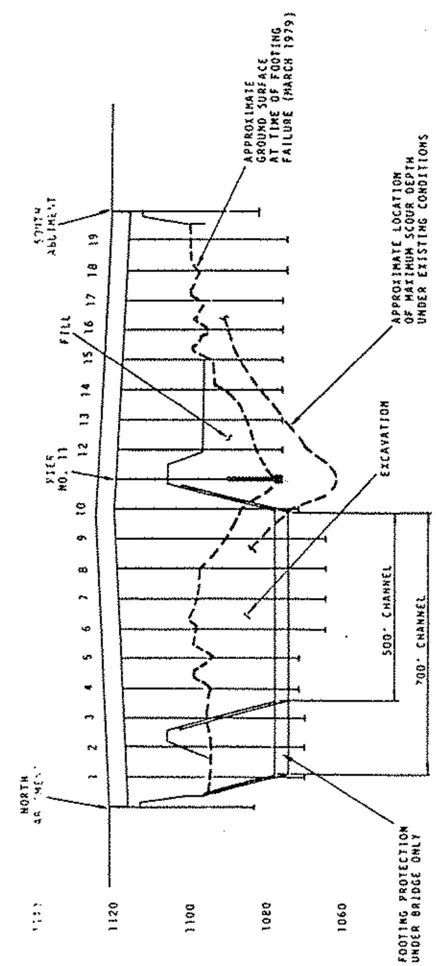


Figure 9.4 Interstate-10 Bridge profile (Dames and Moore, 1979).

CHANNEL CHARACTERISTICS

The bed of the Salt River in Phoenix comprises silt, sandy gravel, and cobbles up to 0.6 m (2 ft) in diameter, although the average size by weight is 10-13 cm (4-5 in) in diameter. The main channel surface is primarily made up of cobbles and gravel with the average size by weight being about 25 cm (10 in) in diameter. The average channel gradient is about 0.002. For the low flow channel, the Manning roughness coefficient is estimated to be about 0.03 (Dames and Moore, 1979).

The sediment supply for the I-10 bridge reach comes from upstream river beds and bank erosion. Immediately upstream the source is being depleted by sand and gravel mining. Nevertheless, the passage of the 100-year flood is estimated to have a sediment yield of 2,550 m3 (90,000 ft³), or approximately 15,500 metric tons, in the vicinity of the bridge. The sediment at the I-10 bridge today is particularly fine-grained due to low flows since the 1980 flood (Dames and Moore, 1979).

Activities in the vicinity of the bridge have resulted in changes in channel configuration. These include sand and gravel mining, construction of power line tower foundations in the river channel, and construction of storm drain outfalls near the bridge. One of the outfalls is located on the right bank immediately downstream of the bridge. The maze-like design of the spillway below the outfall opening aids in dissipating the energy of the falling water.

The series of photographs in Figures 9.5 through 9.8 show the changes in the Salt River channel at the I-10 bridge since its construction in 1962. The condition of the channel in 1962 (Fig. 9.5) was typical of many rivers in arid regions. The wide, shallow channel indicates vertical stability and horizontal instability. The appearance of sizeable vegetation in most parts of the channel imply that discharges had been slight for some time prior to 1962 (The most recent significant flood had occurred in 1941). Low flows seem to have deposited sediment in the channel rather than scouring it; thus, no distinct low flow channel is obvious.

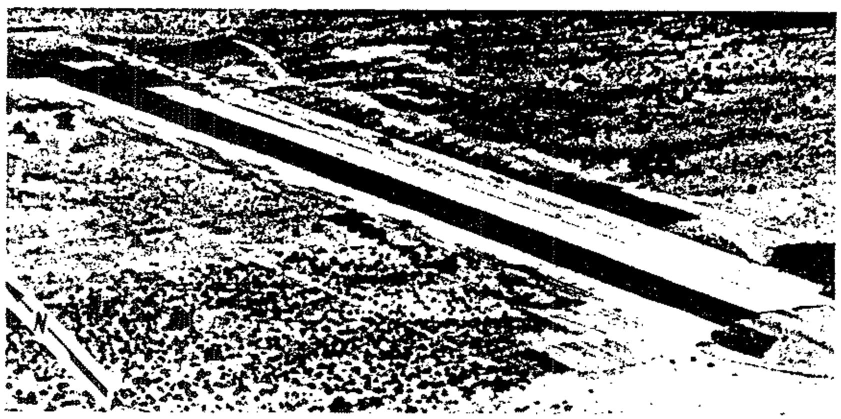


Figure 9.5 Interstate-10 Bridge, August, 1962 (Dames and Moore archives, Phoenix).

Flooding in December, 1965, left the channel in a braided state (Fig. 9.6). The flow centerline remained in the vicinity of piers seven to nine, but a number of other secondary channels are obvious.

The 1973 flood was contained within the low flow channel (Fig. 9.7), and the river once again has the appearance of a meandering stream rather than

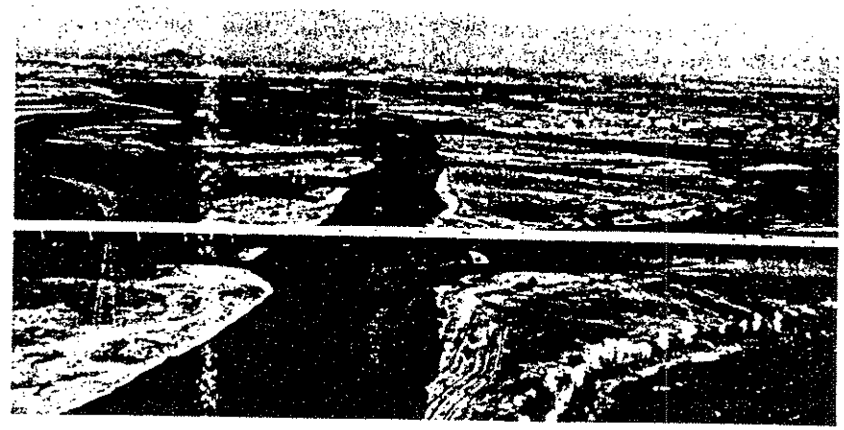


Figure 9.6 Interstate-10 Bridge, December, 1965 (Dames and Moore archives, Phoenix).

a braided one. Some vegetation still remains in the flood plain, although the trees in the lower portion of the 1965 photograph are gone in the 1973 photograph, probably the result of earth-moving and construction activities. Major flooding in 1978, 1979, and 1980 resulted in widespread scouring of the channel (Fig. 9.8). Most vegetation was removed from the flood plain and the low flow channel was deeply scoured. Figure 9.4 shows the change in channel configuration caused by the 1979 flood.

Since 1980 the main channel has been stabilized by the construction of dikes reinforced with cobbles. Two concrete walls were built several hundred

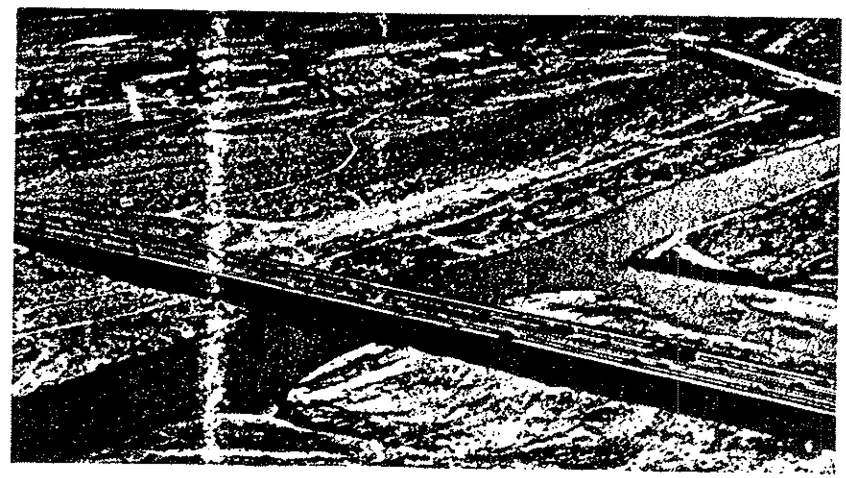


Figure 9.7 Interstate-10 Bridge, April, 1973 (Dames and Moore archives, Phoenix).

meters downstream of the bridge to prevent upstream cutting. Complete aggradation behind the walls has occurred in the last several years, but they are still effective in preventing upstream erosion toward the bridge (Briscoe, 1986).

Figure 9.8 Interstate-10 Bridge, August, 1980 (Dames and Moore archives, Phoenix).

Presently, the bridge is being completely replaced. Designed to pass a flow of 5,660 m^3/s (200,000 ft^3/s), the new 11-lane bridge is being built on caisson foundations that are set in the alluvium bed at a depth of 30.5 m (100 ft) (Hawthorne, 1983; Briscoe, 1986). New features of construction include a new sand and gravel pit with dike, as well as the new 32nd Street Tempe storm sewer outflow channel, all of which are located on the left bank on the upstream side of the bridge (Fig. 9.3).

The I-10 bridge is located in a corridor along the Salt River that some metropolitan residents hope to see developed as part of the Rio Salado Development District. The concept includes development of parcels along the river for recreational, commercial, industrial, and other uses. However, the scope of such a project, including planning, funding, and environmental considerations, is so great that it is not likely that any plans will be realized in the near future, if at all.

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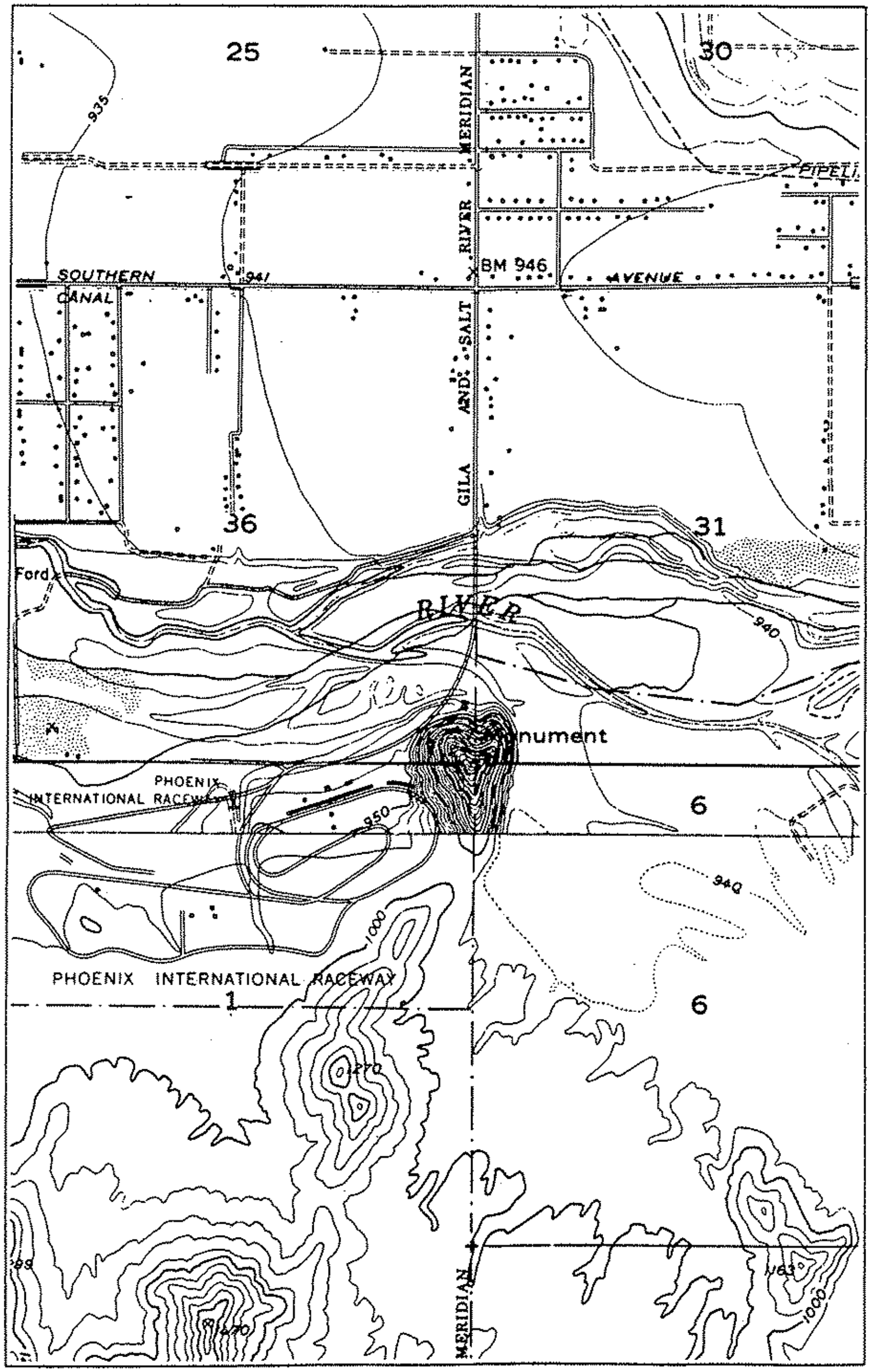

CHAPTER 10

CONFLUENCE OF THE SALT AND GILA RIVERS

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INTRODUCTION

The confluence of the Salt and Gila rivers emphasizes two points in the examination of dryland rivers. First, the junction is a region of sedimentation resulting from the different flow regimes, channel gradients, and sediment sizes of the two rivers. The Salt River has experienced significant degradation upstream during contemporary flooding, which was depicted at the McDowell Crossing stop. At the junction the eroded cobble-sized sediment from the Salt River is intermixed with sand-sized sediment of the Gila River.

The growth of tamarisk *(Tamarix chinensis)*, which affects channel hydraulics and stability, is the second focus of this stop. The growth and spread of tamarisk in the riparian community in the Gila River basin is one causal factor for increased sedimentation, notable in the confluence area. The area occupied by tamarisk in and along channel boundaries expands flow width during floods, increasing sedimentation and flood hazards. The density of tamarisk influences channel stability because associated sedimentation induces greater sinuosity in conjunction with flood events. In the Gila River between the Salt River confluence and Gillespie Dam the sinuosity of the low flow channel increased during a period of greater tamarisk density.

GENERAL DESCRIPTION

The westward flowing Salt River joins the northwest flowing Gila near Monument Hill which is the origin point for the Township and Range Survey

Figure 10.1 The Salt and Gila Confluence located on the Avondale and Tolleson Quadrangles, U.S. Geological Survey.

system for Arizona (Figs. 10.1 10.2, and 10.3). At the top of the hill is a marker indicating the intersection of the Gila and Salt River Meridian and the Gila and Salt River Base Line. The Gila River Indian Reservation lies to the southeast with the Gila and Salt Meridian delineating the western boundary of the Reservation. The Phoenix International Raceway is tucked behind Monument Hill to the southwest.

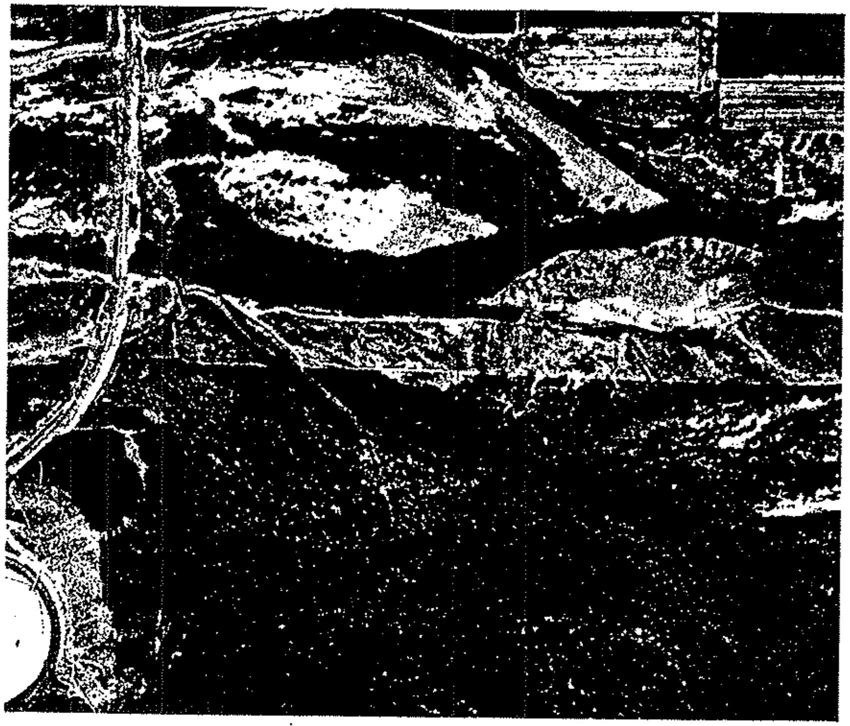

Figure 10.2 Aerial photograph of Salt and Gila confluence (Landis Aerial Survey, 2985, photo # 0-13).

The relatively low, irregular mountains surrounding the alluvial-filled basin vary in geologic composition from Precambrian deformed crystalline rocks to middle Tertiary volcanics and sedimentary rocks (Euge and others, 1978). The Sierra Estrella and Monument Hill are composed of Precambrian granite gneiss and Precambrian schist, locally described as diorite, rhyolite, and greenstone. Laramide granite and related crystalline rocks are found on the southern side of the Sierra Estrella (Wilson and others, 1957). Potassium-argon dating indicates that basalt interbeds, alluvium, and volcanic rocks in the basin vary in age from Miocene to Holocene (Euge and others, 1978). Alluvium consists of silt, sand, and gravel with conglomerate along mountain fronts.

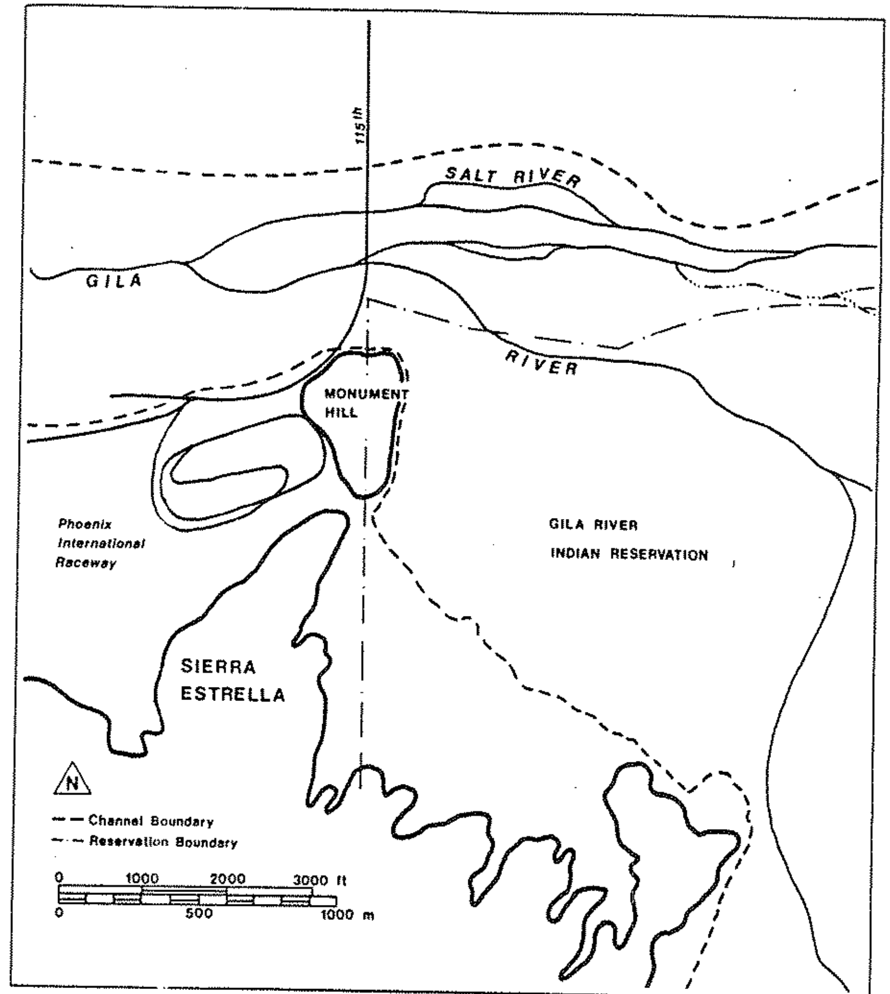

Figure 10.3 Site map of Confluence of the Salt and Gila Rivers stop.

Loam and clay loam soils of the Gilman-Estrella-Avondale association cover the nearby valley plain. Stream channel soils consist of gravelly sandy loams and sandy loams of the Carrizo-Brios association. The soils of this association as well as the loams of the Gilman-Estrella-Avondale association blanket low stream terraces. At the base of nearby mountains Ebon-Pinanit-Tremant gravelly loams, very cobbly loams, and gravelly clay loams of old alluvial fans prevail (U.S. Department of Agriculture, 1977). The character of these soils is of primary importance in determining the species and distribution of vegetation communities, particularly perennial species (Shreve and Wiggins, 1964). This area is dominated by lower Sonoran grasses, shrubs, and saguaro cacti. Riparian vegetation includes arrowweed, mesquite, cottonwood, seepwillow, and tamarisk.

SEDIMENTATION

At the confluence the Gila River basin extends over approximately 75,628 km^2 (29,200 mi^2). Its headwaters, located in northwestern New Mexico, originate in the Mogollon and Black Range Mountains. The Salt River drains a basin area of approximately 38,850 km^2 (14,200 mi^2) when it intersects the Gila River (Aldridge, 1970).

The hydrologic regimes of the two rivers have been dramatically altered by dam structures (Table 10.1). The majority of the dams were built for irrigation diversion purposes and not for flood control. At the gaging station below Gillespie Dam, the largest flood in the pre-dam period, 7,079 m^3/s (249,200 ft^3/s), occurred in 1891 (Table 10.2). After the period of dam closure a 5,040 m^3/s (177,962 ft^3/s) flood flowed in the Gila River in 1980. Six additional flood events can be speculated for the pre-dam period between 1891 and 1921 based on the Salt River records in Phoenix (Graf, 1981) although specific magnitudes are unavailable. Considering these additional floods, the

TABLE 10.1 DAM CLOSURE IN THE GILA RIVER BASIN

RIVER	STRUCTURE	DATE
Gila River Basin		
Gila	Gila Bend (Peoria)	1891(?)*
	Buckeye Heading	1914
	Gillespie	1921
	Ashwist-Hayden	1923
	Sacaton	1925
	Coolidge	1928
Agua Fria	Waddell	1927
Salt River Basin		
Salt	Jointhead	1886(?)
	Roosevelt	1911
	Granite Reef	1908
	Mormon Flat	1926
	Horse Mesa	1927
	Stewart Mountain	1930
Verde	Bartlett	1939
	Horseshoe	1945
Cave Creek	Cave Creek	1923

*Dam at present site of Gillespie Dam, existent in 1892, exact date of origin unknown.

Source: Halpenny and Green, 1975.

TABLE 10.2 FLOODS IN THE GILA RIVER*

DATE	DISCHARGE BELOW GILLESPIE DAM[1] m^3/s (ft^3/s)	DISCHARGE NEAR LAVEEN[2] m^3/s (ft^3/s)
Feb 1891	7,079 (249,960)	
Aug 1921	759 (26,800)	
Jan 1922	926 (32,700)	
Dec 1923	2,407 (84,990)	
Sep 1926	1,084 (38,280)	
Feb 1927	1,906 (67,300)	
Apr 1929	582 (20,550)	
Feb 1931	487 (17,200)	
Feb 1932	1,260 (44,490)	
Feb 1937	1,297 (45,800)	
Mar 1938	1,699 (59,990)	
Aug 1940		248 (8,760)
Jan 1941		337 (11,900)
Mar 1941	1,297 (45,800)	
Aug 1945		79 (2,790)
Aug 1954		128 (4,520)
Aug 1955		92 (3,250)
Dec 1965		309 (10,660)
Jan 1966	1,818 (64,190)	
Dec 1967		167 (5,900)
Jan 1977		337 (11,900)
Oct 1977		180 (6,360)
Oct 1977		2,556 (90,250)
Mar 1978	2,631 (92,900)	
Dec 1978	3,540 (125,000)	
Jan 1979	2,452 (86,600)	
Jan 1979		192 (6,780)
Jan 1979		81 (2,860)
Mar 1979	1,696 (59,890)	
Feb 1980	5,040 (177,960)	
Oct 1983	2,179 (76,940)	792 (27,970)

* Minimum flood return interval: 3.5 years.
1 Majority of flow contributed by Salt River.
2 Gaging station approximately 25 km (15.5 mi) upstream of the confluence.

Source: U.S. Geological Survey Water-Supply Papers.

flood frequency decreased from 17 floods during the pre-dam period to 7 floods during the post-dam period. Except for large flood events, the discharge contributed by the Salt River at the confluence is effluent released from the 91st Avenue Sewage Treatment Plant. The mean annual discharge of the Gila River is 2.8 m^3/s (98.9 ft^3/s), which consists primarily of irrigation return flows.

The different channel gradients at the confluence are conducive to sedimentation. The Gila River has an average gradient of 0.0012, whereas the Salt River gradient is 0.0020. An estimated 4.5×10^6 m^3 (1.59×10^8 ft^3) of Salt River sediment has been eroded upstream of the confluence and transported during contemporary floods (Graf, 1983). The geologically diverse sediment ranges in size from coarse sand to very large cobbles with a few boulders measuring greater than 600 mm (23.6 in) in median diameter. The steeper gradient of the Salt River transported this material but the gentler slope of the Gila River could not continue sediment transportation. The confluence is the initial depositional zone of the eroded material. With increased distance downstream from the confluence the brownish sand-sized particles of the Gila River dominates over the cobbles of the Salt River. The channel gradient of the Gila River further decreases to 0.0005 at Gillespie Dam approximately 56 km (37.8 mi) downstream. The shallow gradient is the result of siltation behind the diversion dam.

TAMARISK

Riparian vegetation communities play an important role in dryland river behavior. Tamarisk, an artificially introduced phreatophyte, has become a dominant component of the riparian community (Fig. 10.4). Tamarisk, with heights up to 12 m (39.4 ft) and trunks as great as 0.5 m (1.6 ft) in diameter, has the ability to densely populate an area creating jungle-like thickets (Robinson, 1958). Tamarisk competes successfully with native vegetation for several reasons. A mature tree produces as many as 0.5 million seeds per year. The optimal seedling locations for tamarisk are surfaces of moist sand and silt. When natural riparian vegetation is destroyed by floods or reservoir water levels fluctuate, new moist bed areas are exposed. Tamarisk seedlings grow rapidly and can quickly colonize the disturbed area. The penetrating taproot system of tamarisk, which extends 3 to 4 times the root depth of native phreatophytes, provides a needed water supply and an anchoring mechanism for flood event stability. Tamarisk can resprout from roots and branches buried by sediment during flooding events.

Tamarisk seeds were introduced in the United States in the mid-1800s as part of a seed exchange program with Mediterranean countries. Tamarisk was used as an ornamental shrub in California and later for erosion control in New Mexico. By the late 1800s tamarisk had escaped from cultivation and spread throughout the Southwest (Robinson, 1965; Graf, 1978), thriving

Figure 10.4 Tamarisk along the Gila River west of Phoenix, 1987 (photo by Anne Chin).

along riparian zones of many streams by the 1900s. In the Gila River basin tamarisk was introduced between 1892 and the 1920s. By the 1930s the potential problem of tamarisk was clearly demonstrated by its rapid spread in irrigation canals, requiring clearing efforts, and overall increase in density. The impact on hydrologic processes was recognized in the 1940s and 1950s. Evapotranspiration in dense thickets causes local ground-water level reductions (Horton and Campbell, 1974) as well as streamflow depletion (Robinson, 1965). Much effort was expended to eradicate or at least reduce the abundance of tamarisk using methods ranging from rootplows (Horton, 1960) to chemicals and antitranspirants (Horton and Campbell, 1974). These programs, however, were not very successful because of resprouting capabilities and seed abundance.

Tamarisk affects fluvial processes by increasing channel perimeter roughness (Hadley, 1961). Increased roughness decreases flow velocity and effectively increases the probability of sediment deposition (Burkham, 1976). A thicket of tamarisk growing within channel boundaries can trap large quantities of sediment up to 2 m in depth. This sedimentation phenomenon is easily observed in the confluence area and occurs significantly in the Gila River basin (Robinson, 1965).

Flowing water in channels confines tamarisk growth to outer dry channel boundaries. Tamarisk invades channel beds following occasional moist periods after flooding or upstream reservoir release. River channels, once invaded by tamarisk, have reduced water carrying capacities because the newly established plants and the sediment they trap occupy channel space previously available for flood flows (Burkham, 1976; Graf, 1982). Channel

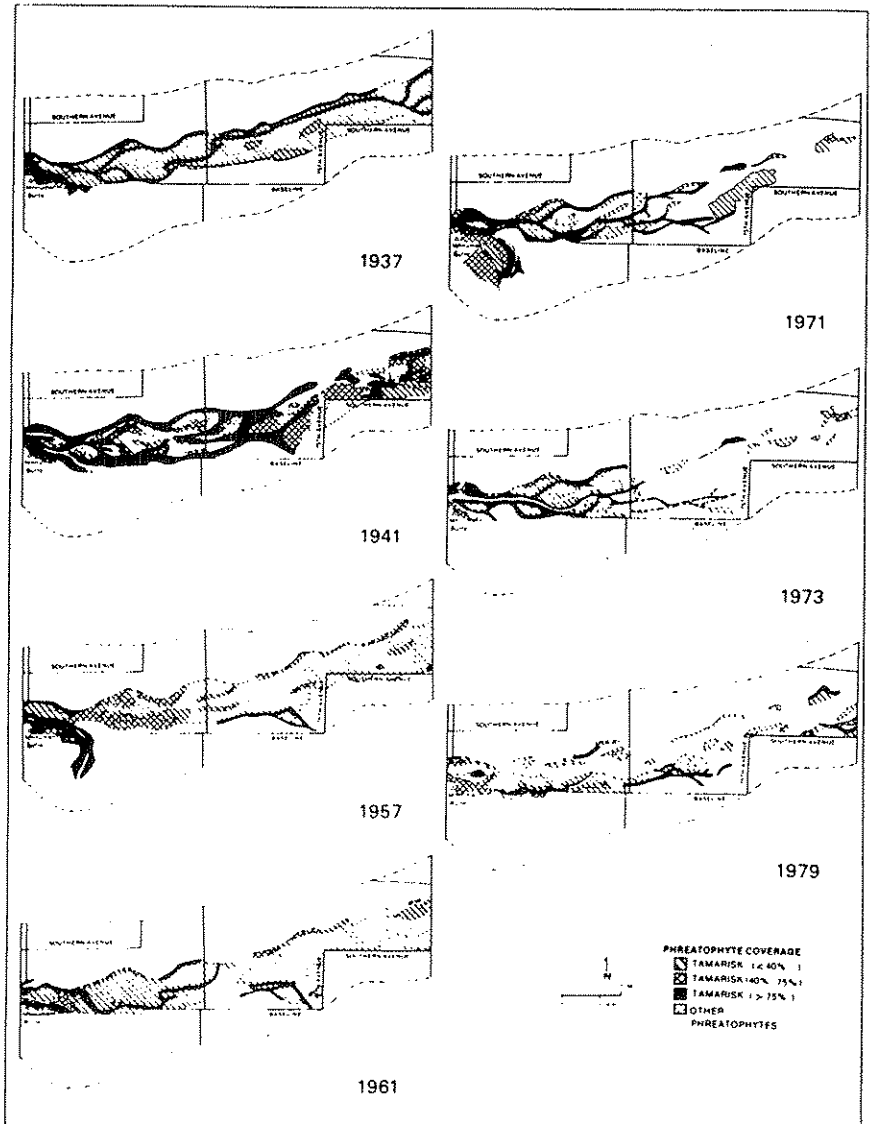

Figure 10.5 The distribution and density of phreatophytes between 59th Street and Monument Hill (Graf, 1980b).

overflows onto surrounding areas become more common. Wider flow inundation not only increases flood hazards but also reduces flow depth which triggers further sedimentation due to lower shear stresses of streamflow. Wider flood inundation also creates additional seedling beds perpetuating tamarisk growth in the channel.

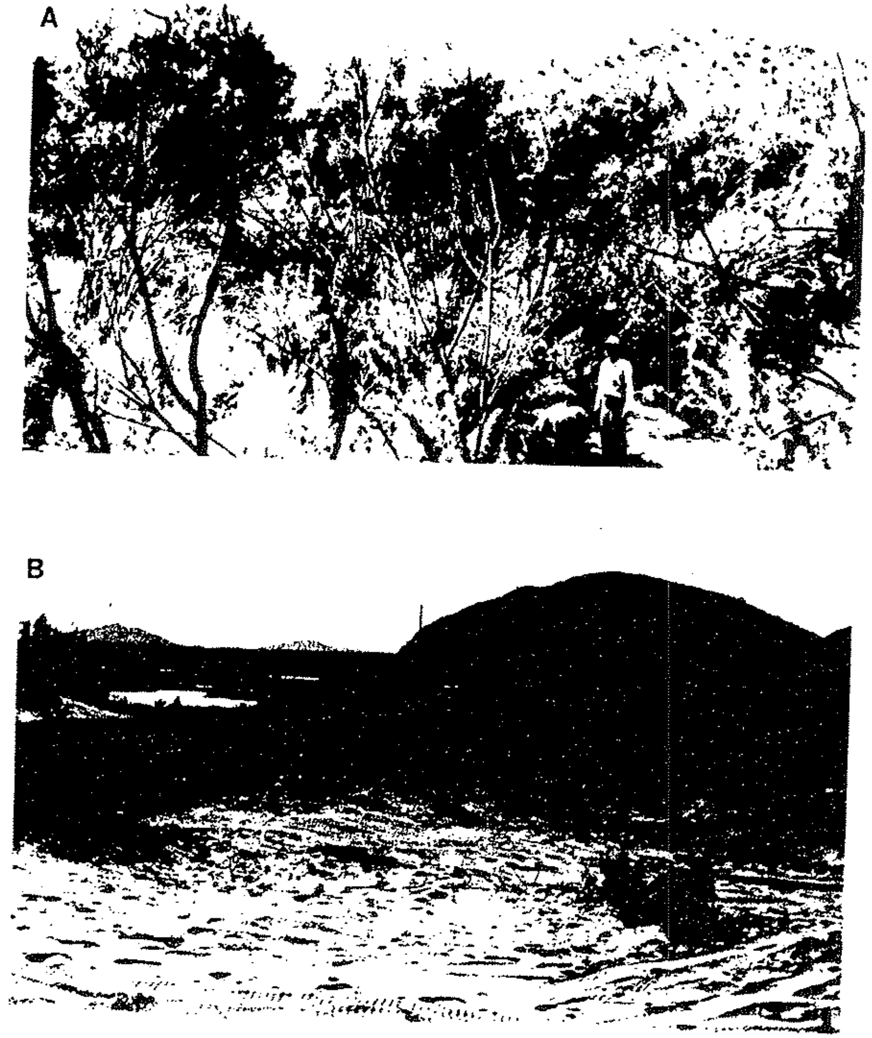

Figure 10.6 Change of tamarisk density near Monument Hill. Photo A, dense tamarisk growth, August 1949 (photo by U.S. Army Corps of Engineers). Photo B, dramatic reduction of tamarisk, January 1981 (photo by W.L. Graf).

The density of tamarisk varies in the Salt River, increasing toward the confluence with the Gila River. The confluence is part of a transition zone separating the upstream Salt River reach, which is sparsely covered with tamarisk, from the Gila River south of Buckeye to Gillespie Dam, which is densely covered (Graf, 1980b). Wide, shallow channels with gentle gradients are more conducive to tamarisk growth because flood stages have greater width with subsequent exposure of moist sand and silt after flood passage. The shallower gradient of the Gila River is a partial explanation for the more densely covered reach between Buckeye and Gillespie Dam.

The distribution and density within this transition zone has changed dramatically over time since tamarisk was first introduced in the Gila River basin (Fig. 10.5). The density increased to its peak areal extent between the 1930s and early 1940s when sufficient water was available from surface flows and a shallow ground-water table. As ground-water levels declined below a

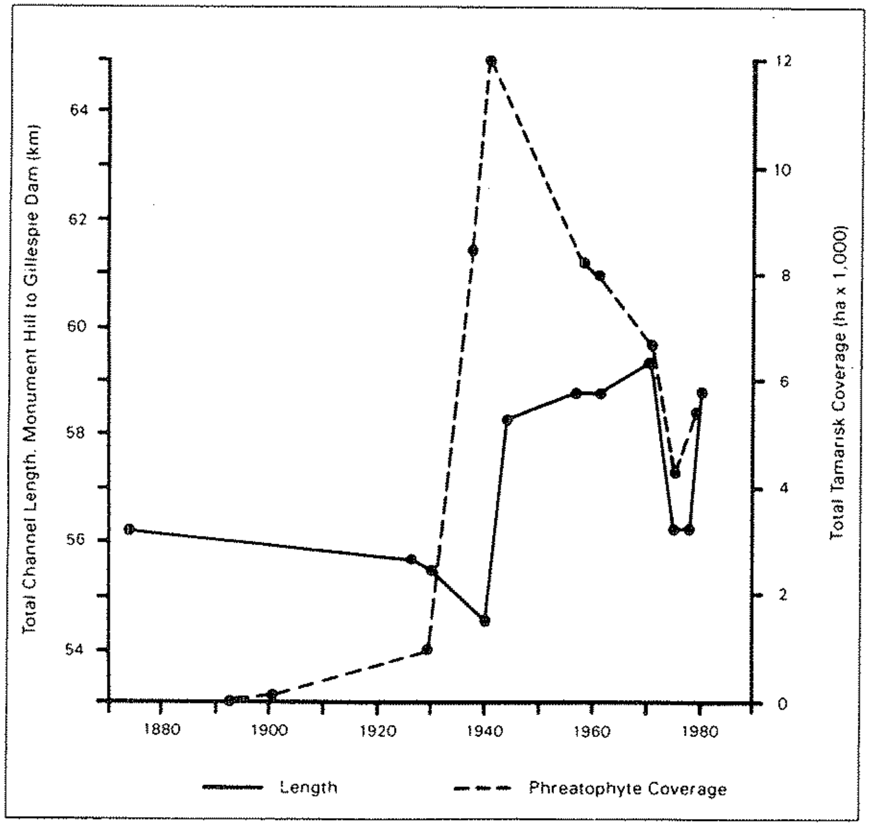

Figure 10.7 Density of phreatophytes from the Salt and Gila junction to Gillespie Dam compared to channel length, indicating sinuosity, over time (Graf, 1980a).

calculated 6-9 m (20-30 ft) threshold depth in the transition zone between the 1940s and 1970s (Graf, 1980b), tamarisk experienced a reduction in density. The frequency of surface flows influences the density of tamarisk because greater frequency maintains or recharges the ground-water level to the minimum threshold for tamarisk survival. A recent recovery of tamarisk was initiated by flooding in the Salt and Gila River basins in the late 1970s and early 1980s (Fig. 10.6).

The sedimentation induced by tamarisk affects channel stability. The sinuosity of the Gila River from the Salt River confluence to Gillespie Dam has changed over time (Graf, 1980a). Before 1930 when tamarisk was not very dense due to its introduction stage, the low flow channel averaged 55.7 km (34.6 mi) in length with little variation between individual length estimates (Fig. 10.7). After the 1930s when tamarisk had greater channel density, the length averaged 57.9 km (36.0 mi), indicating greater sinuosity in this period. The variation of channel lengths after 1940 can be interpreted as a greater tendency for channel migration (Graf, 1981). The actual change in sinuosity was induced during flood events but before dense growth, the channel was less sinuous. Thus, the channel had greater stability because it was less likely to migrate.

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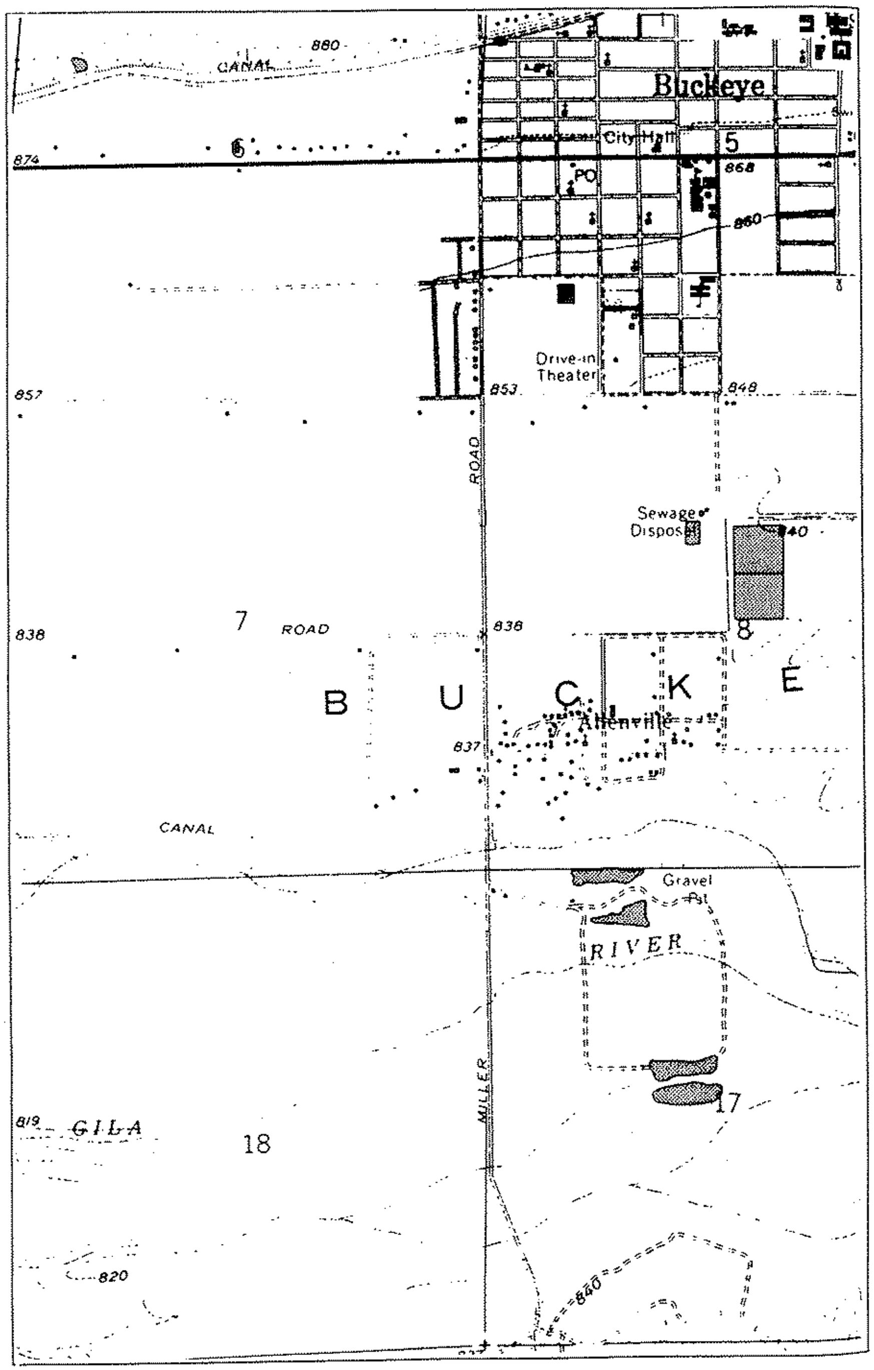

CHAPTER 11

THE BUCKEYE CROSSING

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INTRODUCTION

The Buckeye Crossing illustrates the dramatic story of sedimentation and channel instability in the Salt and Gila River system. This is an area of continuing deposition, where the large volume of eroded coarse materials cannot be transported as the Salt River debouches into the more gentle Gila 28 km (17 mi) upstream. Extensive sedimentation in this area has resulted from contemporary floods, causing overbank flooding and channel migration of about one kilometer. The Buckeye Crossing thus provides an excellent opportunity to illustrate the fluvial response of a dryland river to high magnitude events.

SITE DESCRIPTION

This site is located approximately 2.4 km (1.4 mi) south of the town of Buckeye where Miller Road (1st Street) crosses the Gila River (Fig. 11.1). The river presently occupies the southern portion of Buckeye Valley, a deep alluvial valley in the Basin and Range geomorphic province. The rugged Buckeye Hills, an east-west trending complex composed primarily of Pre-cambrian granites and metamorphics (Euge and others, 1978), prominently flank the Gila to the south (Fig. 1.9). Buckeye Irrigation District takes water from the Gila River here and distributes it through the Buckeye Canal to the north side primarily to irrigate agricultural lands. Baseflow through this

Figure 10.1 The Buckeye Crossing located on the Buckeye Quadrangle, U.S. Geological Survey.

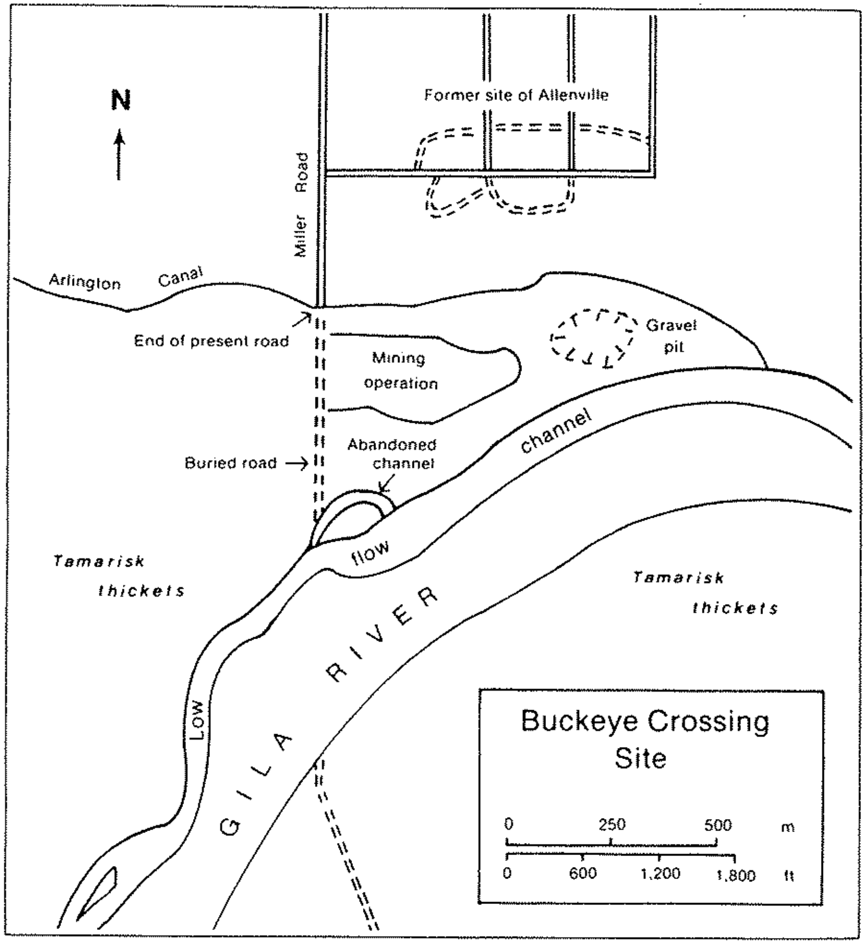

Figure 11.2 Site map of Buckeye Crossing stop.

reach is maintained by irrigation return waters and effluent from the 91st Avenue Waste Water Treatment Plant operated by the City of Phoenix.

The channel at this location is wide and shallow with a slight gradient, typical of braided, sand-bed rivers in alluvial valleys. Materials in the channel consist mainly of sand, silt, and clay from the Gila, but localized deposits of gravel from the Salt are also found. The banks of an abandoned channel at the end of the old Miller Road (Fig. 11.2) illustrate these materials in typical vertical deposits. Horizontal beds of fine sand indicate deposition from the Gila River but lag deposits of Salt River cobbles stand out and indicate zones of concentrated energy or higher flows (Fig. 11.3).

Movement of channel materials occurs primarily during large floods. The

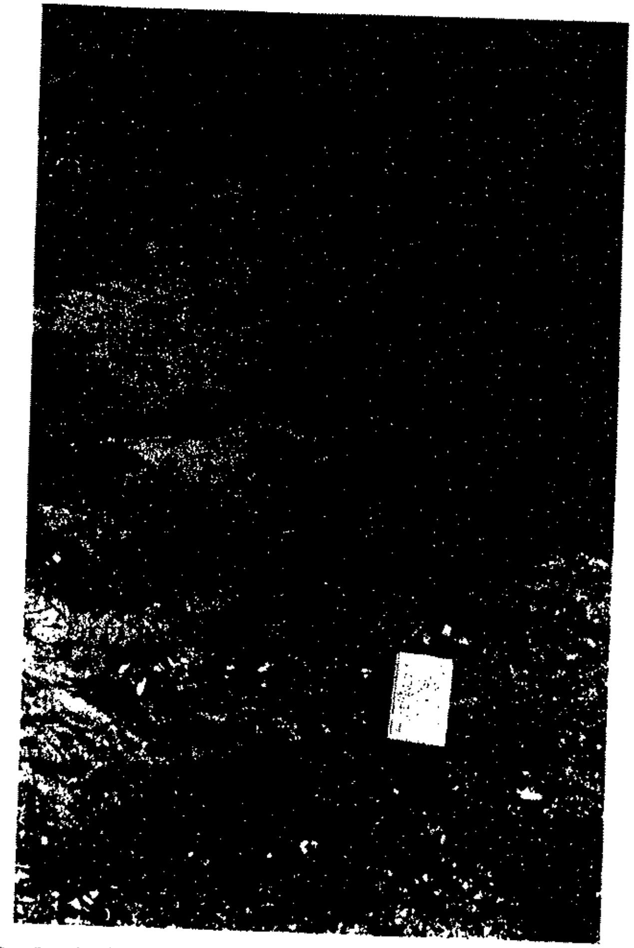

Figure 11.3 Bank deposits in an abandoned channel showing the coarse layer of cobbles from the Salt River and the fine sediments from the Gila (photo by author).

most serious of the early floods occurred in February of 1891, with a peak flow of 7,079 m^3/s (249,960 ft^3/s) (Table 10.2). Since 1891, major flooding in this area has occurred in 1905, 1916, 1920, 1938, 1941, 1966, 1973, 1978, 1980 (U.S. Army Corps of Engineers, 1980), and most recently, in 1983 and 1984. The first significant flood to cause major damage in this area occurred in January of 1966, at a peak discharge of 1,818 m^3/s (64,190 ft^3/s). Severe floods in 1978 and the early 1980s particularly caused major changes in the channel as well as the total destruction of the nearby town of Allenville.

Allenville was a small (65 ha; 160 ac) unincorporated community formerly located along the north boundary of the Gila River flood plain (Fig. 11.2). The community was founded in the early 1940s by John Allen who organized migratory Black farm workers. Unable to reside in Buckeye because of housing discrimination, these workers constructed a cluster of shacks south of town which became known as Allenville. Although generally less affluent than most others in the area, the 51-family community was content and closely-knit.

Allenville had been continually plagued by flooding problems from the Gila since 1966 (U.S. Army Corps of Engineers, 1980). The flood of March 2, 1978 (2,631 m^3/s; 92,900 ft^3/s) devastated the town and forced residents from their homes. As they began clean-up operations to move back into their homes, an even larger flood struck in December, 1978 (3,540 m^3/s; 125,000 ft^3/s), again inundating the town and causing extensive damages. The U.S.

Figure 11.4 Buckeye Crossing, May 18, 1961 (photo by U.S. Geological Survey).

Army Corps of Engineers (1980) determined that permanent evacuation of the community to a location away from the flood plain was the only economically, environmentally, and socially acceptable solution. The entire community is now relocated to a site 13 km (8 mi) northwest of Buckeye. Debris from Allenville can still be seen today on the flood plain near the location where Miller Road now ends.

MAGNITUDE OF SEDIMENTATION

Although the Buckeye Crossing is generally a depositional area in the Salt and Gila River system, much of the sedimentation seen at this site today resulted since 1941 and particularly from the floods of 1978 and the early

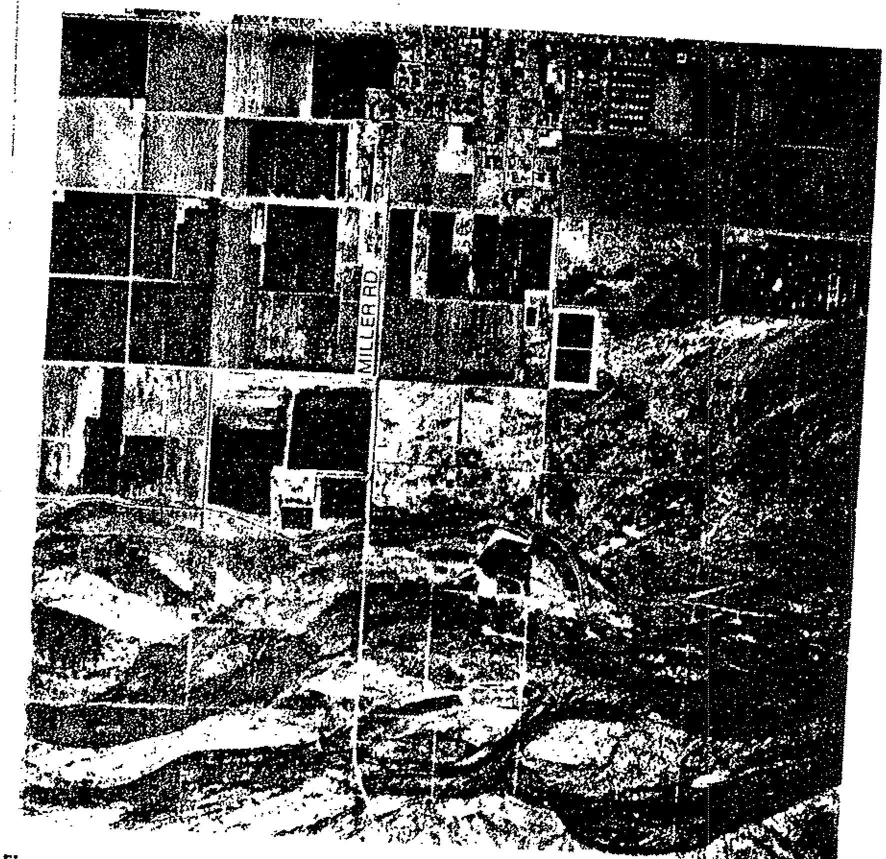

Figure 11.5 Buckeye Crossing, May 2, 1971 showing Miller Road crossing the channel (photo by U.S. Geological Survey).

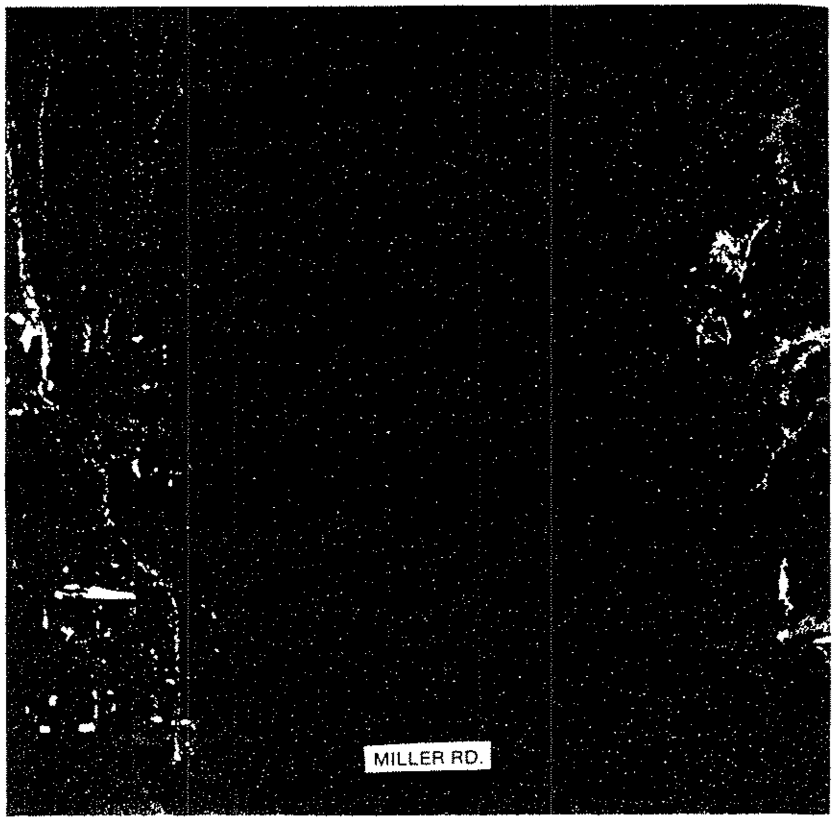

Figure 11.6 Buckeye Crossing one day after the March 2, 1978 flood (Landis Aerial Survey, Flt. 3-48).

1980s. Before 1978, Miller Road crossed the Gila River and continued to the south side (Figs. 11.4, 11.5). This road, however, became completely buried by sediments deposited during the March 2, 1978 flood (Fig. 11.6). Subsequent floods in December 1978 and the early 1980s caused extensive sedimentation to a depth of about 2 m (7 ft) in the flood plain area. The end of Miller Road today (Fig. 11.2) provides a visual impression of the magnitude of this sedimentation as the present flood plain is 2 m (7 ft) higher than the road surface.

The buried Miller Road on this new flood plain is still visible today as it is lined by dense thickets of tamarisk. Tamarisk had developed into very dense thickets in this area by the early 1940s owing to the presence of a high water table and fine sediments (Graf, 1980a; 1982) (See Chapter 10 for a more complete discussion of tamarisks). This phreatophyte has played a significant role in increasing sedimentation rates since its invasion. Tamarisk accelerates

sedimentation by increasing hydraulic roughness and reducing flow velocity (Hadley, 1961). Excavations of the flood-plain sediments beside tamarisk trees immediately west of Miller Road identified the trees rooted at the level of the buried road (Smith, 1981). The average depth of sediments accumulated above the root collars in 1980 was 76 cm (30 in) at this site. This depth of accumulation is significantly higher in nearby areas of higher tamarisk density.

In addition to the general depositional layer, tamarisk influences sedimentation rates by trapping sediments and producing streamlined forms in the area behind the tree (Fig. 11.7). These wedge-shaped mounds are deposits caused by increased turbulence as flow encounters obstructions. The widest and highest portions of the sediment tails occur at the base of the tamarisk trees. These elongated mounds contribute a significant volume of sediments to the flood plain at this site, each averaging 23.6 m^3 (833 ft^3) (Smith, 1981). The present sediment mounds on the flood plain trend from northeast to southwest, indicating the direction of the most recent high flow.

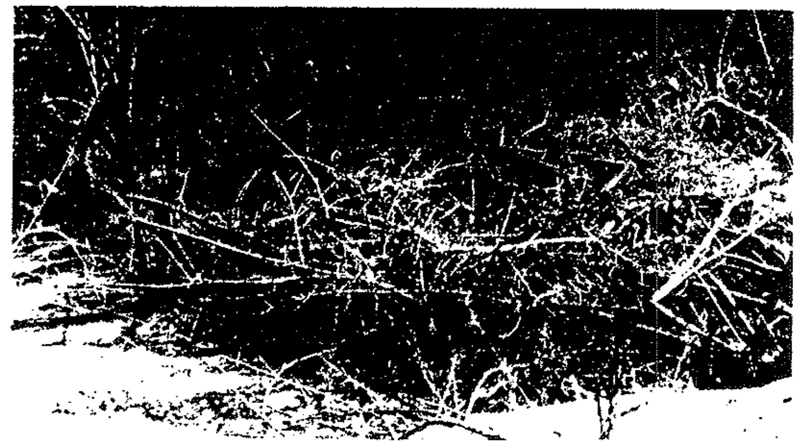

Figure 11.7 A typical streamlined sediment mound on the flood plain (photo by author).

An excavation of a gravel mine on the east side of Miller Road (Fig. 11.2) provides a different view of the magnitude of sedimentation. The level of the 1941 flood plain is well defined at various locations about 1 m (3 ft) above the base of the gravel pit, with much finer materials comprising this layer (Fig. 11.8). Two to three meters (7 to 10 ft) of sediments above this level again show the depth of sedimentation since 1966 and particularly since 1978. The gravel pit also reveals depositional sequences and structures. Layers of fine sand indicate vertical accumulations from the Gila River system but coarser gravels as well as flood debris such as bottles and cardboard are inset into

Figure 11.8 Excavation of gravel pit illustrating depth of sedimentation. The 1984 flood plain is shown as finer (lighter) sediments of about 1 m depth at the base of the pit. Note field book on left side of photo for scale (photo by author).

this fine material. One extensive lens of gravels is found on the west wall of the excavation (Fig. 11.9). Materials deposited around obstacles such as trees result in arched structures seen on the east side. Tree trunks and roots protrude from several locations near these structures.

A sediment budget calculated between Miller Road and Powers Butte provides a volumetric assessment of the magnitude of sedimentation that has occurred in this reach. Smith (1981) estimated that 2,740,000 m^3 (2,246 ac-ft) of sediment has accumulated in this 14.5 km (9 mi) long reach of the Gila River since the invasion of tamarisk in the early [illegible]. This enormous volume reflects the overall character of deposition predominant at the Buckeye Crossing, and contributes to the horizontal channel instability experienced near this site.

Figure 11.9 Gravel lens on west wall of mining pit. About 4 m depth of sediments is shown in this view (photo by author).

CHANNEL MIGRATION

Similar to many sand-bed rivers in alluvial basins, the Gila River is characterized by inherent instability and frequent channel migration. The horizontal position of the Gila River has migrated consistently throughout the past century (Graf, 1980b). Changes in channel location occur when sediment is deposited in parts of the channel, preventing flow from continuing its original course and causing it to seek a new one. This filling process, or channel avulsion, is primarily responsible for channel migration in the Gila River system. It is particularly effective during floods when large quantities of sediments are deposited. Channel avulsion is further accelerated by the presence of tamarisk which increases hydraulic roughness, restricts the channel, and therefore inhibits natural adjustment (Hadley, 1961; Graf, 1978). Channel migration varies spatially along the Gila River, with horizontally unstable areas usually associated with areas of sedimentation. These areas of frequent channel migration also vary temporally with variability in the density of tamarisk growth (Graf, 1980b). Because both sedimentation and tamarisk growth strongly characterize the Buckeye Crossing, it is not surprising that the channel at this location has been highly unstable in the past century.

Extensive horizontal movement of about one kilometer has occurred primarily in response to floods, with the most numerous and largest changes resulting from the floods of 1941 and early 1980 (Graf, 1980b). Analysis of channel location over a 112-year period shows the low flow channel located well to the north, near the former site of Allenville, during the early years of

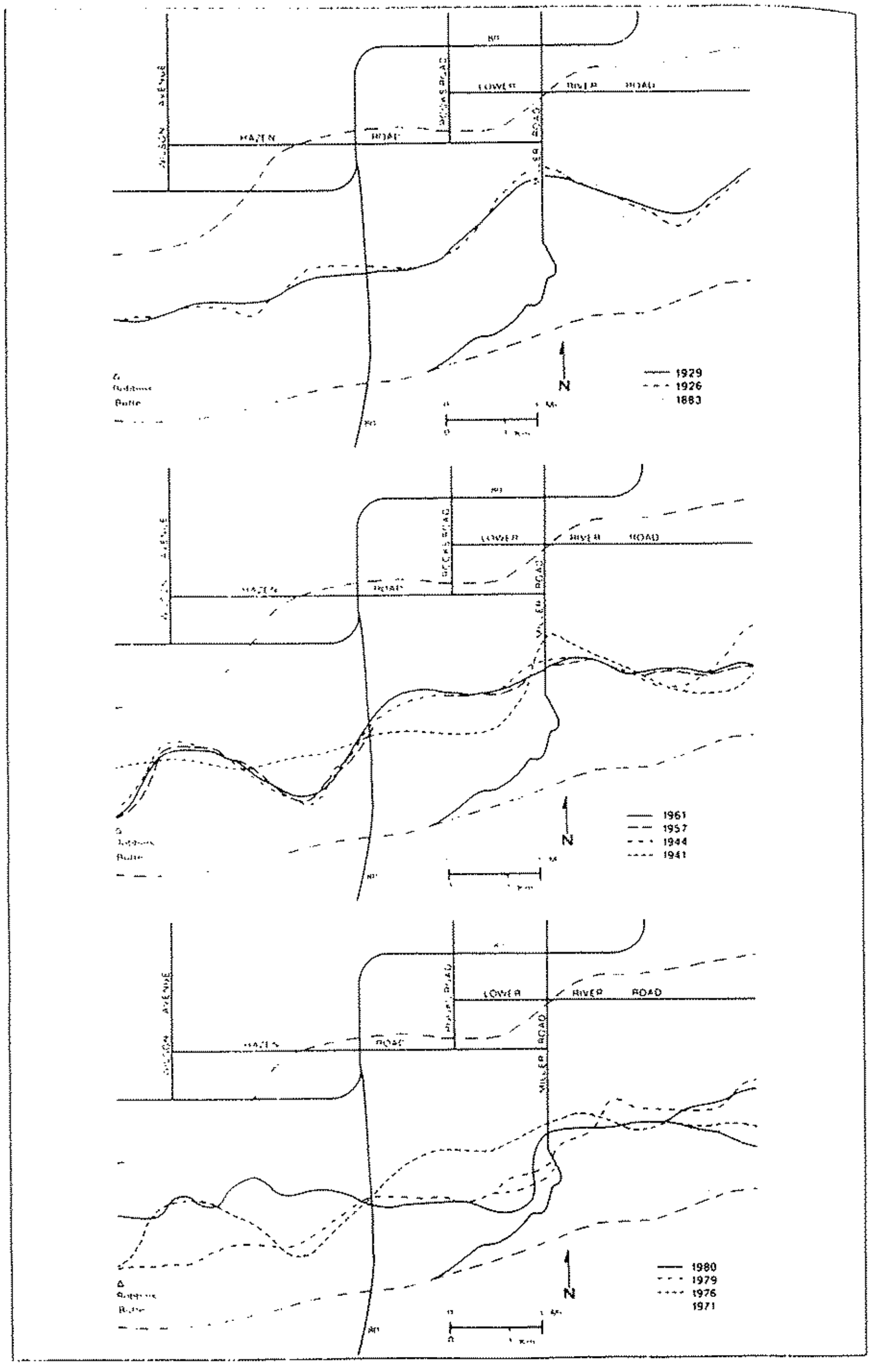

Figure 11.11 Buckeye Crossing, January 4, 1984
(Landis Aerial Survey, 1984, Photo # P-8).

Figure 11.10 Channel location changes at the Buckeye Crossing, 1883-1980
(Graf, 1980b).

Figure 11.12 Buckeye Crossing, December 29, 1986, showing Miller Road buried by sediment with dense tamarisk thickets. The abandoned channel is at the end of the buried Miller Road, separated from the main channel by a sand bar. (Landis Aerial Survey, 1986, Photo # P-8).

record (Fig. 11.10a). The channel responded to the 1941 flood by migrating southward about 0.8 km (0.5 mi) (Fig. 11.10b). Figure 11.4 shows the position of the channel after this horizontal movement. While the 1966 flood did not

cause major changes (Figs. 11.4, 11.5), southward migration of the channel at this location continued an additional 0.8 km (0.5 mi) during the large floods of the late 1970s (Fig. 11.10c). During the February 1980 flood, locational adjustment again occurred, when the channel moved northward at the Miller Road crossing while just downstream, it meandered radically to the south. Although this configuration was generally reflected in the early 1984 channel (Fig. 11.11), floods later that year caused the Gila River to abandon the outer portion of the bend just upstream of the buried Miller Road where it intersects the channel (Landis, 1985). This abandoned channel is now separated from the main channel by a bar, depicted as a lighter patch of sand in the most recent aerial photograph (Figs. 11.2, 11.12). The 1984 floods also caused the river to abandon its southern braid at this location, resulting in the single low flow channel observed at present.

The channel migration experienced at the Buckeye Crossing contributes to a larger spatial pattern of instability in the Gila River system. Graf (1980b, 1981) has shown that, taken as a whole, the Gila River exhibits localized segments of stability and instability that alternate with each other at 3.2 km (2 mi) intervals, reflecting the geometry of meanders when they exist. Stable areas are usually associated with control factors such as bedrock buttes or bridge locations. Unstable areas relate to intense sedimentation, dense phreatophyte growth, and the lack of confining topography near the channel. Near the unstable Buckeye Crossing, areas of extreme stability are found about 1.6 km (1 mi) both upstream and downstream. The high probability of channel migration at the Buckeye Crossing is reflected in a low threshold of instability between 28 and 616 m^3/s (1,000 and 22,000 ft^3/s) (Graf, 1980b). Since channel adjustment will occur even at these relatively low discharges, the remarkable channel instability experienced at this site in the past is likely to continue in the future.

CONCLUSION

In summary, the geomorphology observed at the Buckeye Crossing today is the end-product of centuries of channel changes and adjustments, and of extensive sedimentation during contemporary floods. Tamarisk has played an important role in both these processes since the 1940s, accelerating sedimentation which, in turn, promotes channel migration. The interactions between these complex processes, however, are not unidirectional, and cause and effect relationships are likely to be obscured by positive feedbacks.

The dramatic channel changing episodes experienced at this site reflect the fluvial response of the dryland system as a whole to high magnitude events. Previous stops have witnessed evidence of drastic downcutting and the removal of enormous amounts of materials. The Buckeye Crossing stop documents, in an equally impressive manner, one stopping place for those eroded materials and thereby partially completes the Salt and Gila River story.

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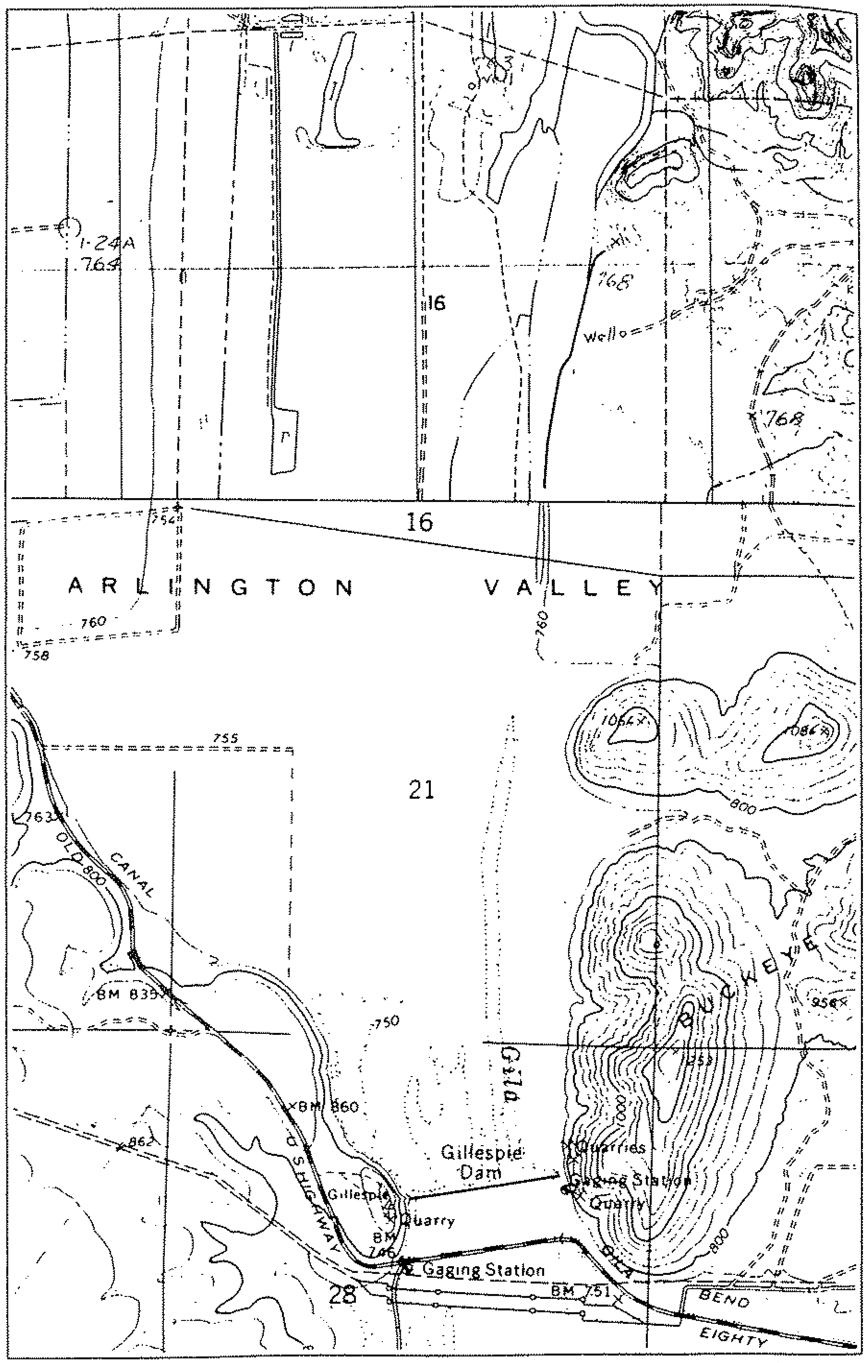

CHAPTER 12

ARLINGTON VALLEY OVERLOOK

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INTRODUCTION

The Arlington Valley Overlook is most noted for the sheer basalt cliffs occurring at the edge of the Arlington Valley. These cliffs offer an excellent view of the Gila River, and in addition an opportunity is afforded to observe some relationships between the soils and geology of the region.

GILA RIVER CHANNEL CONFIGURATIONS

At the Arlington Valley Overlook the Gila River is approximately 1 km (0.6 mi) upstream from Gillespie Dam which acts as a base-level control on the river (Figs. 12.1 and 12.2). Fine-grained delta sediments from Gillespie Dam extend upriver into this reach. The presence of Gillespie Dam has also served to maintain a constant water table close to the surface, which subsequently allowed for the establishment of a thick cover of tamarisk. This cover is evident in a 1949 photograph (Fig. 12.3), covering at that time essentially the entire valley floor. Flow was confined to a single channel on the eastern side of the valley at this time. Since 1949, tamarisk has been cleared from the western portion of the valley to permit agricultural use (Fig. 12.4).

During the floods of the Spring of 1980, the flow left its channel and swung around in a wide meander to the west, joining with the irrigation canal at the base of the bluff. As the flow increased, the channel expanded

Figure 12.1 Arlington Overlook located on the Spring Mountain and Arlington Quadrangles, U.S. Geological Survey.

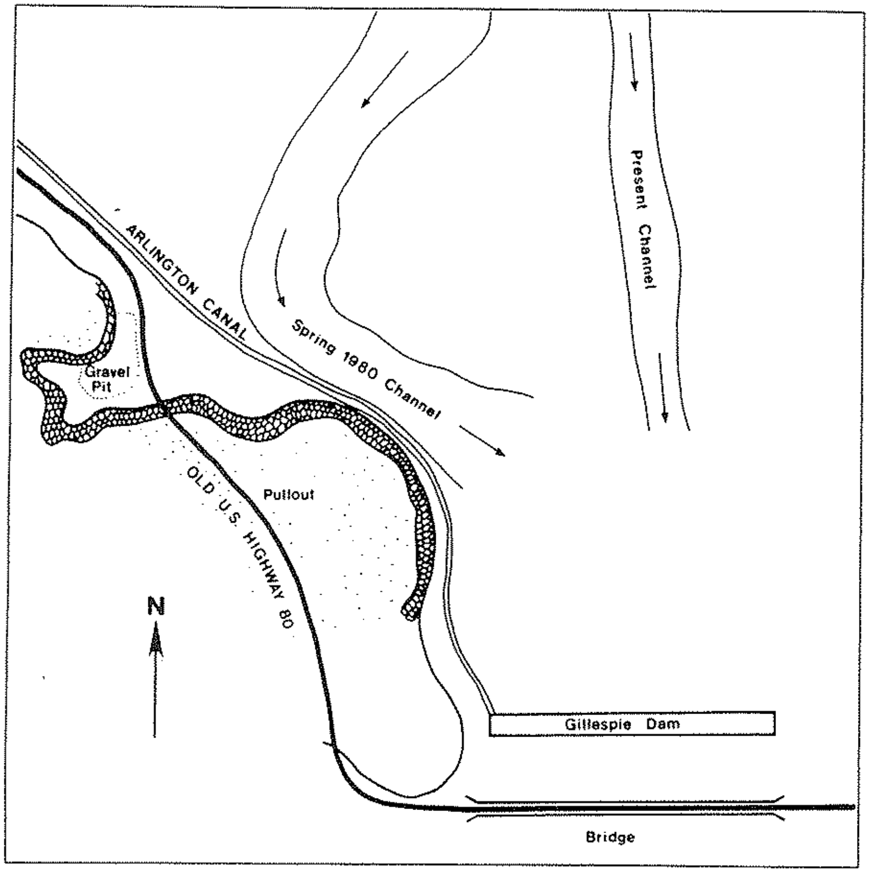

Figure 12.2 Site map of Arlington Valley Overlook stop.

until it occupied the entire valley floor between the bluffs (Fig. 12.5). This peak flow was responsible for removing most of the vegetation in the channel. As the flood water receded, it continued to occupy the new channel to the west against the overlook bluffs (Fig. 12.6). Subsequent to the 1980 flood the channel has been artificially straightened, occupying a position toward the east side in approximately the same location as the 1949 channel (Fig. 12.2).

RELATIONSHIP BETWEEN BASALT FLOWS AND TERRACE DEPOSITS

The first episode of volcanic activity in the Arlington area occurred during the Miocene period. Volcanism was extensive during this period, this unit exhibiting a thickness of 1,830-2,135 m (6,000-7,000 ft), consisting of

interbedded basalt, andesite, and tuff. Potassium-argon dates for these volcanics range from 17.7 to 20.3 million years (Euge and others, 1978). Integration of drainages in this region did not occur until after this late Tertiary flow. Basin fill continued to accumulate, forming a broad coalescent bajada comprised of dominantly fine-grained deposits.

Subsequent to the integration of the drainage system a series of three terraces were formed, corresponding with changes in base level of the Gila River. These terraces consistently occur at the 6, 12, and 24 m levels above the current channel, and as such are referred to as the "6-m," "12-m," and "24-m" terraces.

A second period of volcanic activity occurred during the early Quaternary. Two separate flows have been identified, and are referred to as the Arlington and Gillespie flows. Potassium-argon dates have been determined at 3.3 million years for the Gillespie flow and 2.2 million years for the Arlington flow. The "12-m" and "24-m" terraces underlie both the Arlington and Gillespie flows, indicating an age for these terraces of greater than 3.3 million years. In addition, the presence of well-developed paleosols on these terraces where overlain by basalt indicates that these terraces were stable for an extensive period prior to volcanic activity (APS, 1975).

At this stop, we are standing on the older Gillespie flow. A gravel pit located immediately adjacent to this site (Figs. 12.2 and 12.7) illustrates the relationship between the Gillespie flow and terrace sediments. Terrace sediments exposed in this cut belong to the "24-m" terrace. Evidence of strong calcification can be seen in the upper layers of these sediments.

SOIL MORPHOLOGY AND GENESIS

The soil on this site is mapped as Pinal gravelly loam (Hartman, 1977). The Pinal series is classified as a coarse-loamy, mixed, hyperthermic Typic Durorthid. The major diagnostic horizon is a duripan at a depth of less than 51 cm (20 in).

A duripan is a subsurface horizon that is cemented by silica with or without the presence of carbonates (Soil Survey Staff, 1975). Duripans occur most frequently in soils of subhumid Mediterranean climate; they grade into petrocalcic horizons in semiarid and arid climates. A petrocalcic horizon is a continuous, cemented or indurated horizon that is cemented by calcium carbonate. Silica may be present but must not form a continuous cementing matrix (Soil Survey Staff, 1975). A laminar cap commonly is present but is not required.

Duripans in Arizona commonly exhibit cementation by calcium carbonate as well as silica. Typically the dominant matrix is calcium carbonate, with the silica-cemented layer confined to the laminar cap. This suggests a polygenetic process of soil formation, as amorphous silica is most soluble at higher pH than is calcium carbonate (Flach and others, 1969).

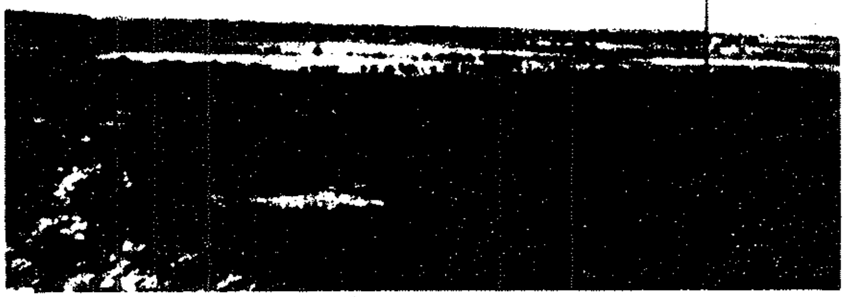

Figure 12.3 July 1949, looking north from Arlington Overlook. Note the dense cover of tamarisk (U.S. Bureau of Reclamation photograph, U.S. Army Corps of Engineers, Phoenix Urban Study Office).

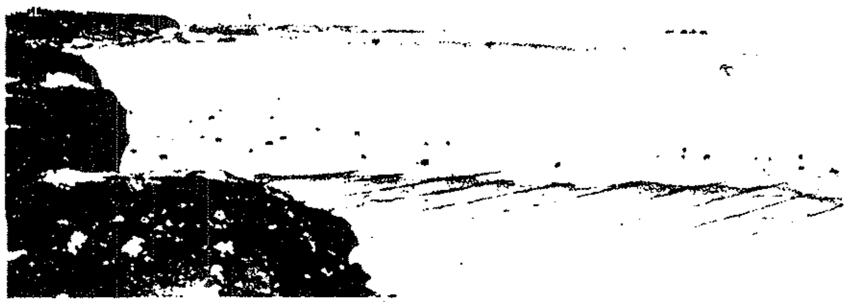

Figure 12.4 January 1980, same view as Figure 12.3. Leveled fields have replaced tamarisk thickets (photo by W.L. Graf).

Formation of duripans is closely correlated with a source of glass in the soil profile, restricting them largely to areas of vulcanism (Soil Survey Staff, 1975). Local sources for volcanic material, including observed beds of volcanic tuff, favor the formation of duripans in this area. Initially a layer of carbonate accumulation formed; a feedback between increased concentration of carbonates and decreased permeability resulted in an indurated layer.

Cementation can occur in either gravelly or nongravelly sediments (Fig. 12.8). As cementation progresses, these sediments are engulfed and become part of the cemented horizon (Gile and others, 1966). At this location it is significant that very few gravels can be observed in the pan fragments, indicating that this layer formed in alluvium low in gravel. In addition,

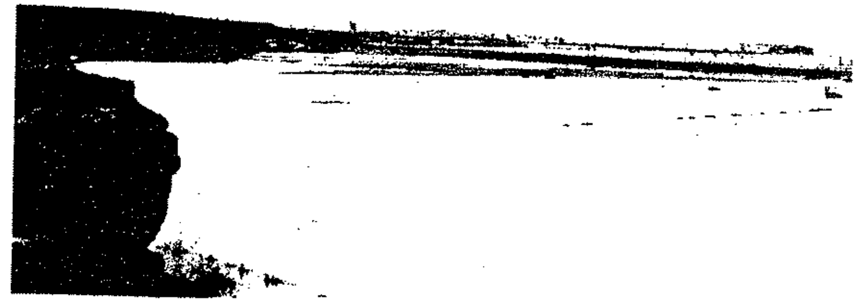

Figure 12.5 February 1980, same view as Figures 12.3 and 12.4. Flood waters have inundated the entire valley floor (photo by W.L. Graf).

Figure 12.6 May 1980, same view as Figure 12.3, 12.4, and 12.5. Main channel has moved to the west side of the valley following the February 1980 flood, destroying the agricultural land shown in Figure 12.4 (photo by W.L. Graf).

Figure 12.7 Vertical exposure of the Gillespie basalt overlying the "24-m" terrace gravels in the gravel pit located on the west side of Old U.S. Highway 80 (photo by Scott A. Lecce).

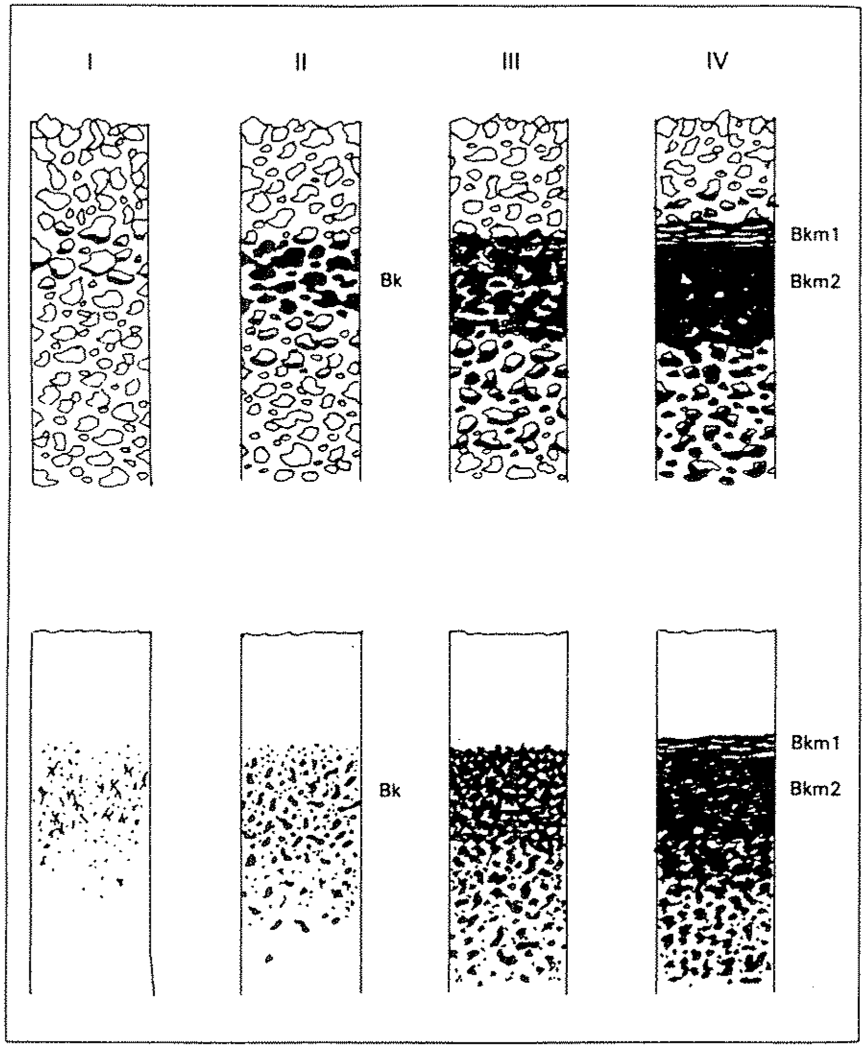

Figure 12.8 Stages of carbonate horizon formation in gravelly and non-gravelly materials (Gile and others, 1966).

pendants of the cemented material can be observed on the lower surface of these pan fragments. This indicates that as carbonate accumulation proceeded lobes extended into the underlying material, thus ruling out the possibility that this horizon formed directly over bedrock. Duripans and petrocalcic horizons, once formed, tend to be persistant on the landscape (Lattman, 1973). Thus it often occurs that changes in the depositional environment will result in the surface being scoured down to

the pan, and subsequently mantled with a new veneer of alluvium. The presence of a high volume of subrounded pan fragments on the surface and in the profile would indicate that this surface at one time was scoured and this material deposited downslope. This scouring and downslope deposition would also account for the high amounts of free carbonates in the soil profile above the pan.

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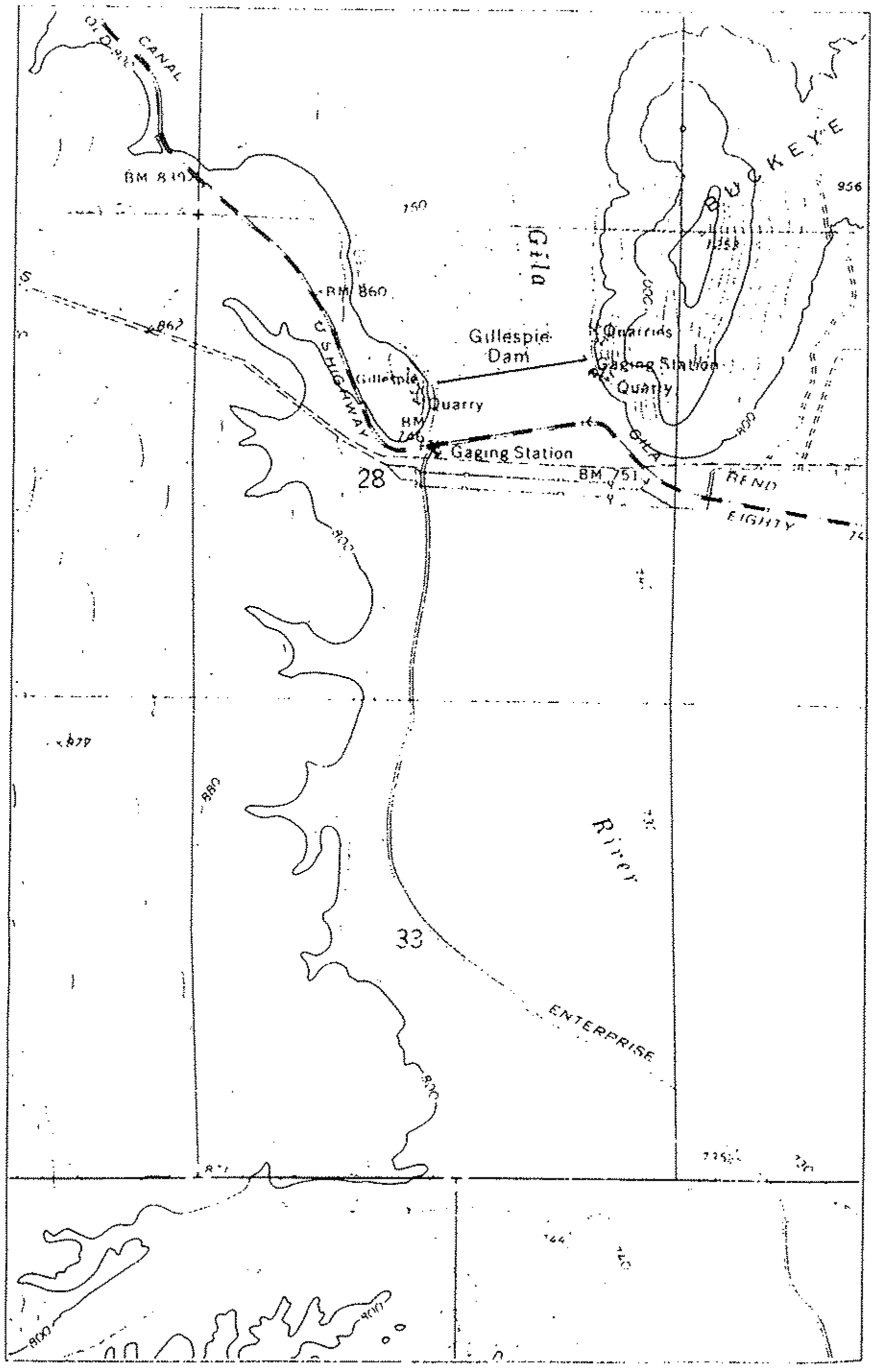

CHAPTER 13

GILLESPIE DAM

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INTRODUCTION

The Gillespie Dam is the main takeout point for water used in the Gila River Valley between the dam and the town of Gila Bend. As a diversion structure, its primary purpose is to direct water into two canals, the Enterprise Canal on the west and the Gila Bend Canal on the east. This site marks the narrowest point in the river channel downstream from Granite Reef Dam, providing irrigators and engineers in the late-1800s and early-1900s with an ideal location for the construction of temporary and permanent dams. In addition to supplying water for irrigated agriculture downstream, the dam has had a significant impact on stream channel stability upstream. This chapter will examine the history of dam construction at this site, as well as the sedimentation, vegetation, and channel instability of the area above the dam.

SITE DESCRIPTION

The Gillespie Dam is located at the southern end of Arlington Valley about 65 km (40 mi) southwest of Phoenix and 22 km (14 mi) southwest of the town of Buckeye where Old U.S. Highway 80 crosses the Gila River (Fig. 13.1). Arlington State Wildlife Area occupies part of the valley north of the dam. The Arlington Canal serves as an agricultural drain at this location, emptying return flow from irrigated fields upstream to a point directly

Figure 12.1 Gillispie Dam site located on the Spring Mountain and Cotton Center NW Quadrangles, U.S. Geological Survey.

behind the dam (Fig. 13.2). The Gila River flows under the Gillespie Dam Bridge and the El Paso Natural Gas lines to the south towards the city of Gila Bend, 32 km (20 mi) away.

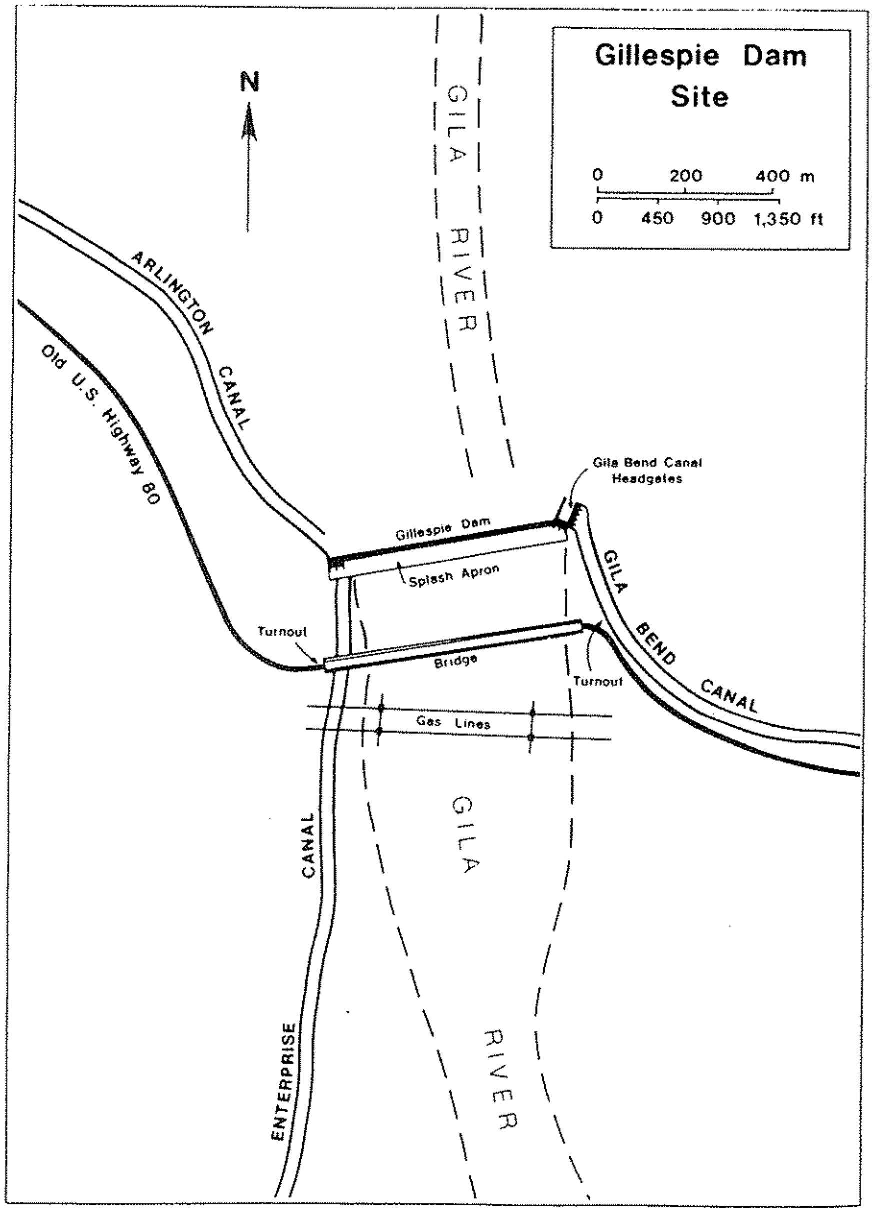


Figure 13.2 Site map of Gillespie Dam stop.

Quaternary basalt flows (described in Chapter 12) from the Gila Bend Mountains constrict the west side of the river while the Buckeye Hills impinge upon the east side. The Buckeye Hills, a small east-west trending complex of Precambrian granites and metamorphics intruded by late Mesozoic granites (Euge and others, 1978), are situated to the west of the Sierra Estrella. The Maricopa Mountains can be seen to the southeast across the western end of Little Rainbow Valley. They are composed of Precambrian granites with localized pegmatitic intrusions (Euge and others, 1978).

The areal extent of the drainage basin upstream is 128,594 km^2 (49,650 mi^2) (Aldridge, 1970). Average discharge at the gaging station located downstream from the dam is small, only 1.3 m^3/s (44.4 ft^3/s) during the period 1941-1970 (records do not include flow in the Gila Bend and Enterprise canals). Even after the diversion of water into the two canals, flow is often available to maintain a very small low-flow channel. Channel banks are poorly defined and channel-bed materials are predominantly fine sand and silt. Infrequent large magnitude floods (Table 10.2) are responsible for stream channel change.

HISTORY OF DIVERSION STRUCTURES

As early as 1885, at a location about 16 km (10 mi) below this site, a temporary dam of brush and stone directed water into the lower Gila Bend Canal which irrigated a narrow strip of land about 24 km (15 mi) long on the east side of the river (Davis, 1897). The west side of the river was irrigated by the Enterprise Canal, constructed in 1886, which received water diverted at this site by a modest wood and rock known as Wolfey Dam (Phoenix Gazette, 1981). The February 1891 flood of 8,496 m^3/s (300,000 ft^3/s) apparently washed away the structure, so later that year the Gila Bend Reservoir and Irrigation Company started construction of a more substantial diversion work, the Gila Bend Dam. There is some confusion regarding this early dam which centers around whether there were two different dams at this location in the early 1890s, or merely two different names for the same dam. Granger (1960) referred to the predecessor of Gillespie Dam as Peoria Dam (built in 1892 and destroyed in 1900), while Davis (1897) called it the Gila Bend Dam (built in 1891 and destroyed in 1895). However, because the Peoria Canal Company was the successor of the Gila Bend Reservoir and Irrigation Company (Arizona Republican, 1898) it appears likely that the Gila Bend Dam was simply renamed Peoria Dam by its new owners.

Gila Bend (Peoria) Dam was planned at first to be a 732 m (2,400 ft) long overflow weir made of wooden cribs loaded with rock and secured to piles driven into the bed of the river (Davis, 1897). However, the high cost of completing the first 183 m (600 ft) of the east end caused the company to reconsider its original plans and to build the remaining section with loose rock about 1.8 m (6 ft) higher than the eastern portion (Fig. 13.3). The completed eastern part was then used as a waste weir (Fig. 13.4). There was

Figure 13.3 The Gila Bend (or Peoria) Dam in 1891-1895 showing the masonry wall on the eastern abutment (photo courtesy of the Arizona Historical Foundation).

some concern that the first flood that overtopped the loose rock portion would wash out the dam. This scenario was easily attained because the capacity of the waste weir was only about 850 m^3/s (30,000 ft^3/s) (Davis, 1897). In January 1893, a slight rise in the river caused the rock portion of the dam to settle several meters, bringing into question the dam's ability to survive a large flood. The rock portion was raised to its original height, but a larger flood in March 1893 washed out 152 m (500 ft) of the center of the dam. Following repair, a high flow in October of the same year washed out 122 m (400 ft) of the west end.

The owners then decided to modify the dam so that the waste weir reached across the entire width of the river. The original wooden waste weir was overhauled and raised 0.8 m (2.5 ft) and the loose rock portion was reinforced with several additional rows of piles set 4.0-5.5 m (13-18 ft) into the bed of the river. But before reconstruction was complete the flood of January 1895, discharging an estimated 5,098 m^3/s (180,000 ft^3/s), flowed 2.4 m (8 ft) deep over the entire length of the dam and washed out the uncompleted portion about 122 m (400 ft) from the west end (Davis, 1897, 48; Aldridge, 1970; Phoenix Gazette, 1977). The above account describing the destruction of the dam in 1895 contradicts Granger (1960) who suggested that Peoria (Gila Bend) Dam was washed out in 1900, even though the years 1898-1904 were reportedly drought years (See Chapter 4). Since a large magnitude

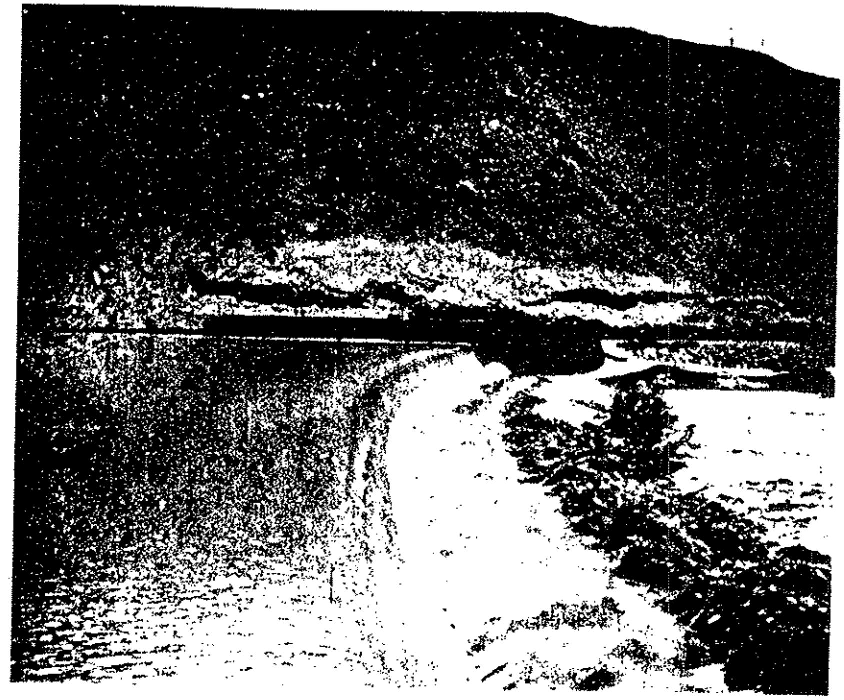
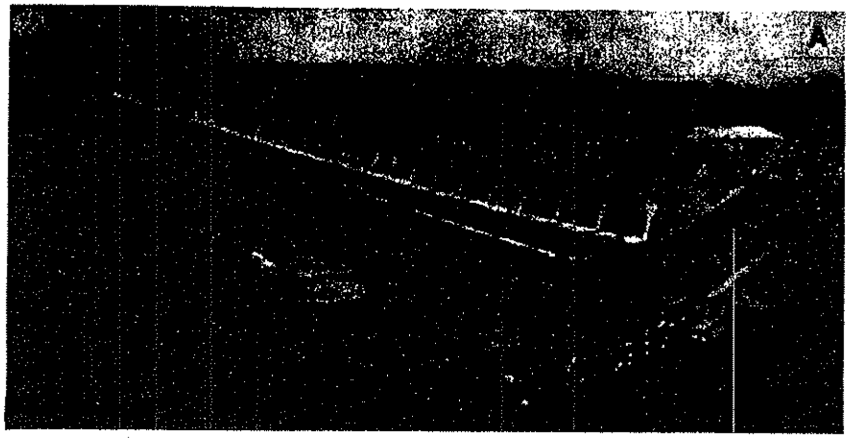


Figure 13.4 Closer view of the Gila Bend (Peoria) Dam overflow weir (foreground) and the Gila Bend Canal Headworks. Note the masonry wall in background (photo courtesy of the Arizona Historical Foundation).

flood capable of destroying the dam was not reported in 1900 (Table 4.1 and 10.2), and because a flow of 3,257 m^3/s (115,000 ft^3/s) was reported for April 1895 at Granite Reef Dam (Table 4.1) as well as the January 1895 flood (Davis, 1897; Aldridge, 1970), it seems reasonable to assume Davis' account accurate. The Gila Bend (Peoria) Dam was not repaired after it was washed out in 1895, thus rendering Gila Bend Canal unusable until 1921 when Gillespie Dam was completed (Phoenix Gazette, 1977). Following the destruction of Gila Bend (Peoria) Dam, the owners of the Enterprise Ranch built an earth and brush diversion dam in 1906 to supply water to the Enterprise Canal which irrigated land on the west side of the river.

Construction of the Gila Bend Canal began in May 1892 and was finished the next year. The canal was originally 61 km (38 mi) long with another 121 km (75 mi) of laterals. Water for the canal was diverted from the east side of Gila Bend (Peoria) Dam through large iron headgates attached to massive masonry abutments (Fig. 13.4).

Frank A. Gillespie had the present multiple-arch concrete diversion dam built in 1921. Gillespie Dam was the central feature of the Gillespie Land and Irrigation Company's project designed to irrigate and develop the 35,209 ha (87,000 ac) of land they owned along the Gila Bend Canal on the east side of the river from this site towards the city of Gila Bend. The Gillespie family



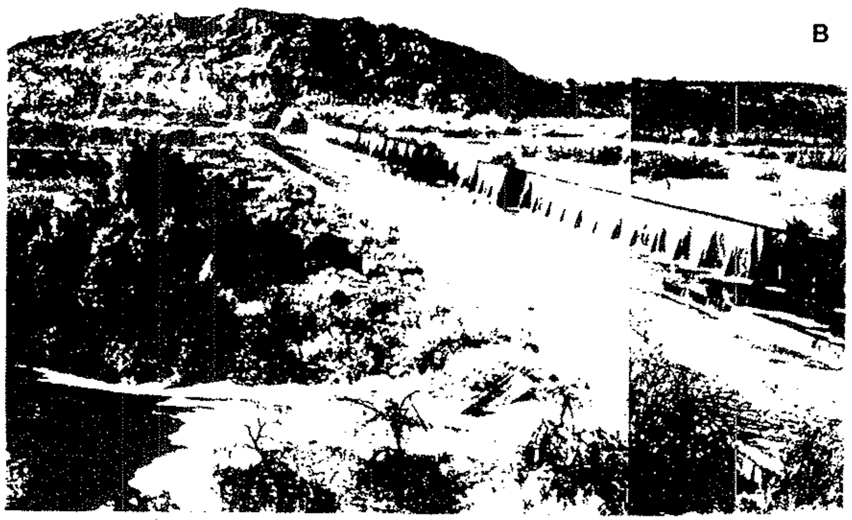
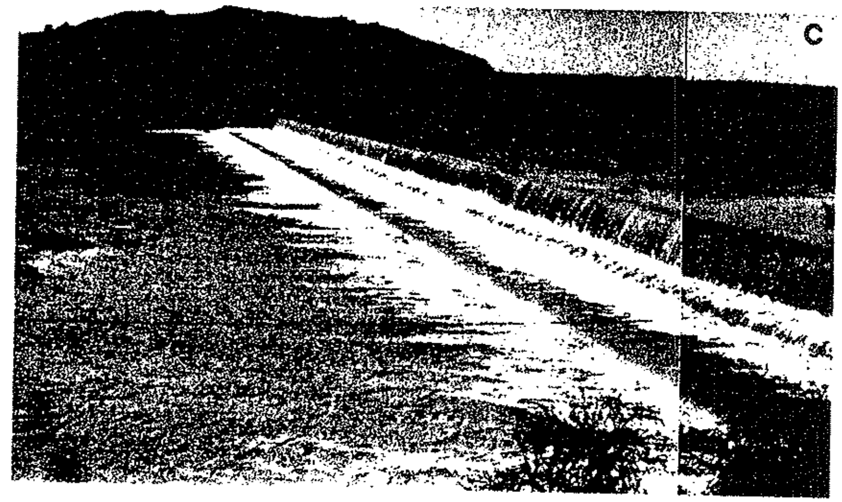


Figure 13.5 Series of photographs showing historical changes in vegetation and sedimentation behind Gillespie Dam (views from 15 m above east side). Photo A: March 1923, only two years after completion, the dam shows signs of rapid sedimentation with sand bars and vegetated islands in center of the reservoir (photo courtesy of the Arizona Historical Foundation, Barry Goldwater Collection, Photo # G-842, 109B, N-1296). Photo B: January 1980, vegetation now covers most of the reservoir (photo by W.L. Graf)

holdings later passed on to the Painted Rock Development Company and as of 1977 they belonged to the Northwestern Mutual Life Insurance Company



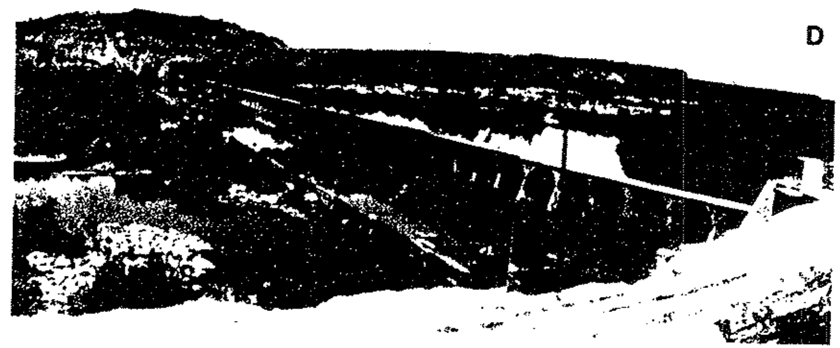


Photo C: February 1980, flood waters overtop dam, removing a significant amount of vegetation (photo by W.L. Graf) Photo D: June 1987, in the four years since the last major flood (October 1983), vegetation has bee re-established in areas above and below the dam (photo by author)

(Phoenix Gazette, 1977). In late 1987 the holdings, including the dam, were again for sale with a purchase price of $80-100 million (Arizona Republic, 1987).

The arch structure is 539 m (1,768 ft) long, 17 m (56 ft) high, anchored to bedrock, and built at a cost of $3 million. The remnant masonry headgate abutments from the Gila Bend (Peoria) Dam (Figs. 13.3 and 13.4) are still visible on the east side of the dam (Fig. 13.5). The bell-shaped structures shown in Figures 13.6 and 13.7 are buried by sediment, increasing the stability of the dam. The concrete splash apron on the south side of the dam was used as a river crossing for vehicles until the Gillespie Dam Bridge was constructed in 1927 (Fig. 13.2).

RESERVOIR SEDIMENTATION AND CHANNEL INSTABILITY

Following the completion of the dam in 1921, the Gillespie Reservoir was quickly filled with fine-grained sands and silts (Fig. 13.5a). Unlike Granite Reef Dam, dredging operations have not been attempted at Gillespie Dam, although some maintenance is required to remove sediment from the canals. Sedimentation in the reservoir area has reduced the gradient of the Gila River in this reach from 0.001231 to 0.000597 (Graf, 1981). The sediment wedge now extends approximately 11 km (7 mi) upstream from the dam.

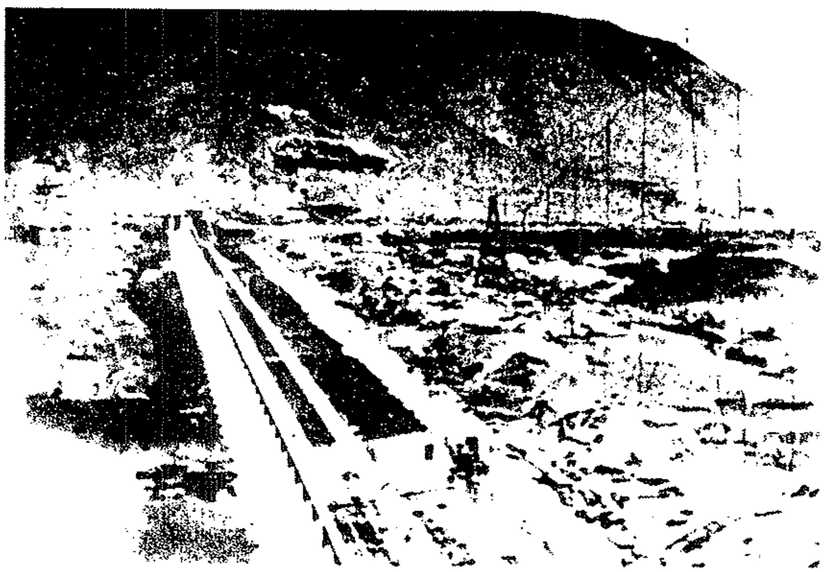


Figure 13.6 Ground level view of the north side of Gillespie Dam under construction in 1921. Part of the dam was buried with reservoir sediments within two years (photo courtesy of the Arizona Historical Foundation, photo # QD0104, 5199).

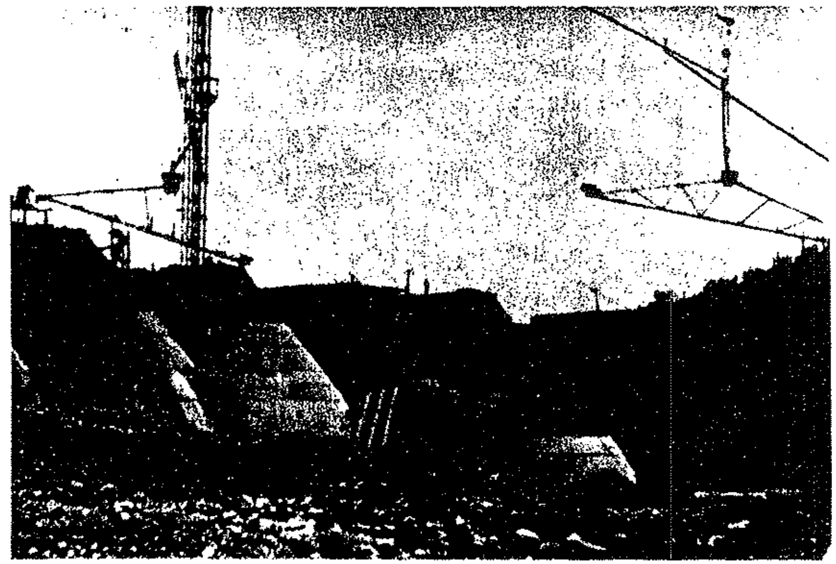


Figure 13.7 Oblique view of Gillespie Dam under construction in 1921, looking east. Note the persons in the lower left corner of the photograph for scale (photo courtesy of the Arizona Historical Foundation, McClintock-Halseth Collection, photo # Mc-H-323, view 1, N-1412).

The area immediately upstream from Gillespie Dam was one of the earliest sites (late 1920s) in the Salt River Valley to develop dense tamarisk thickets (Robinson, 1965). The high water table, fine sediments, and wide shallow channels provided optimal conditions for tamarisk colonization (see Chapter 10 for a more detailed discussion of tamarisk). Because Gillespie Dam was constructed on bedrock, it helps retain ground water as well as surface water. As a result, the water table behind the dam has been within a couple feet of the surface since the early 1920s (Graf, 1980b) so that it is not necessary for tamarisk to send down deep taproots. The shallow-rooted tamarisk in this area are therefore easily uprooted during flood flows (Figs. 13.5c).

Horizontal channel stability varies considerably in this area. The bedrock constriction between the Buckeye Hills and the Gila Bend Mountains is a naturally stable location which has been further stabilized by dam and bridge construction. However, analysis of channel locational probability and sinuosity has indicated that the reach above the dam on the sediment wedge is one of the most unstable areas on the Gila and Salt rivers (Graf, 1980a, 1981). This is partly explained by sedimentation behind the dam which has reduced channel gradients and increased channel plugging, avulsion, and therefore sinuosity (Graf, 1981, 1092). Another partial explanation is provided by the growth of tamarisk which increases hydraulic roughness, thereby enhancing the channel plugging and avulsion process leading to sedimentation (Graf, 1978). The densest thickets of tamarisk are closely related to channel reaches with the greatest sinuosity (Graf, 1981). A positive feedback appears to operate between tamarisk growth and sedimentation (Graf, 1982) whereby shallow gradients increase channel migration and lead to wide, shallow channels which encourage tamarisk growth. Greater tamarisk density, in turn, promotes sedimentation by increasing hydraulic roughness. This tamarisk-induced sedimentation decreases channel gradients which further increases sedimentation.

In recognition of the increased overbank flooding caused by dense phreatophyte growth in stream channels, clearing operations have been carried out intermittently since 1957 in an 11 km (7 mi) long channel reach between Powers Butte and Gillespie Dam (Fig. 13.8). This operation was expanded in the early 1980s to extend 58 km (36 mi) from 91st Avenue to Gillespie Dam (U.S. Fish and Wildlife Service, 1981). The objective was to clear a straight channel through the vegetation that would be followed by flood waters, thereby reducing overbank flooding. A 305 m (1,000 ft) wide corridor is periodically cleared of all vegetation and a pilot channel then constructed along the centerline of the clearing. The material excavated for the pilot channel is spread over the cleared area and at the upstream end of some meanders. One of the environmental consequences of this action involves the impact on wildlife habitat, in particular, dove productivity. The riparian vegetation in this area supports one of the most important white-winged dove and mourning dove nesting habitats in the state, but because neither of these birds is a threatened or endangered species the loss of

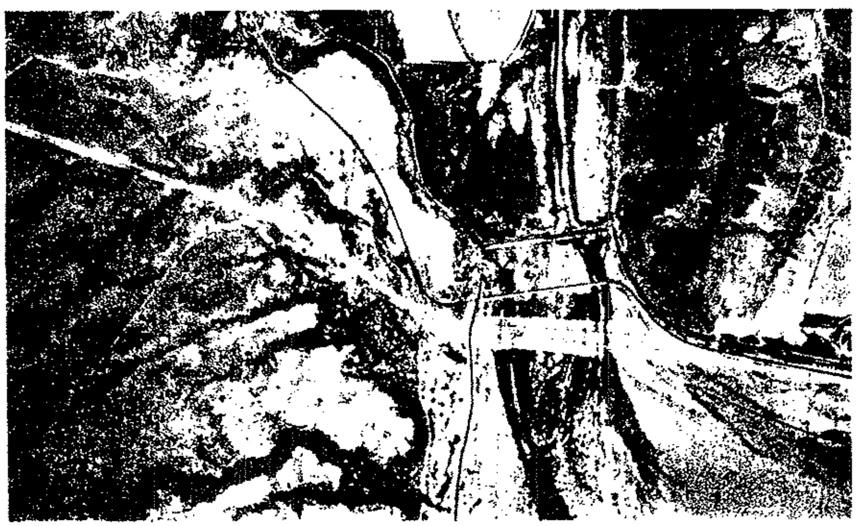


Figure 13.8 Gillespie Dam on the Gila River. The Gila River is channelized north of the dam and agricultural activities have cleared tamarisk thickets growing on the reservoir sediments (photo by U.S Geological Survey, May 22, 1961).

habitat was deemed acceptable in light of the anticipated flood protection. Although these clearing and channelization efforts have continued to the present, they have failed to alter the natural sinuosity of the channel as later floods invariably re-establish a more sinuous course (Fig. 13.9).

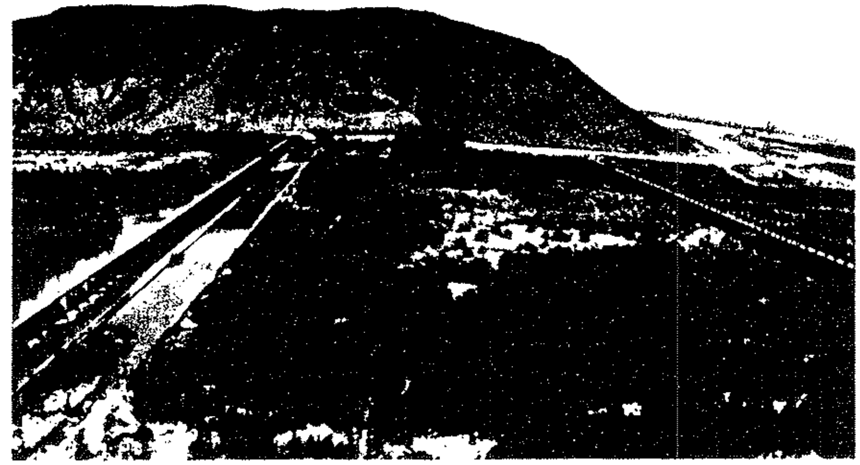


Figure 13.9 Oblique view of the Gillespie Dam site and the Buckeye Hills from the hilltop above the west abutment in June, 1987 (photo by author).

The Gillespie Dam represents a temporary stopping point for the channel-bed materials eroded from upstream portions of the Salt River since 1965 (described in Chapters 4 and 5). While large magnitude floods periodically transport these sediments over the dam, deposition behind the dam continues as the growing sediment wedge extends farther upstream. The site also illustrates the contrast between the stability of the dam itself and the instability of the Gila River behind the dam. This instability has not been caused solely by dam construction, but it has been enhanced by the dam's influence on reservoir sedimentation (decreased stream gradient) and the increased growth of phreatophytes.

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Historic Channel Changes in the Salt River, Arizona 1890-1931

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Introduction
Channel stability and the nature of channel change are important considerations for development along rivers as well as river restoration. Our ability to predict and understand channel change is imperfect, particularly for dryland rivers. An historic, geographical approach to channel change can provide important insights into the dynamic nature of river environments. The Salt River through Phoenix provides a unique setting to combine historic photographs and hydrological data in an effort to better understand channel change.

My research addresses the questions:
How stable was the Salt River prior to dam construction?
How are channel stability and instability reflected in vegetation patterns?

Study site and timeframe
Hayden Butte: This reach of the river has undergone substantial changes in the past century, and these changes are conveniently documented through photographs taken from the butte.

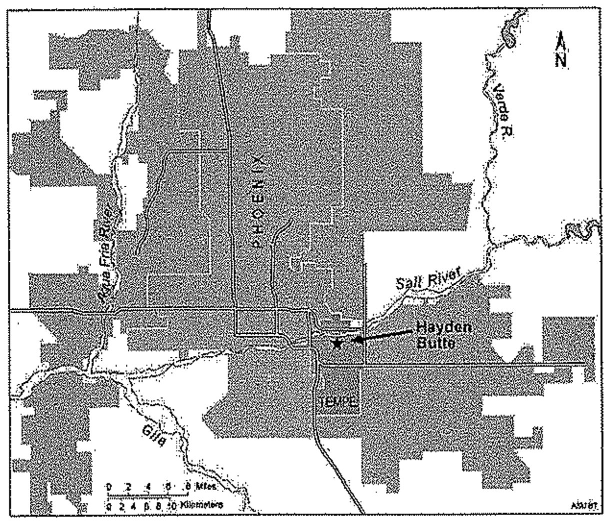
1890-1931: This time period represents the river prior to extensive regulation, and the ground photographs predate earliest available aerial photographs.

Methods
I collected historic photographs from the Tempe Historical Museum, and chose the subset that best reflected channel change due to the 1891 flood, the largest flood on record.

I visually analyzed the photographs in conjunction with hydrological data and a collection of historic accounts (Graf et al. 1994) to assess channel stability and vegetation patterns.

Results
Three historic photographs, 1890, 1900, and 1931, captured a view of the Salt River northwest of Hayden Butte from approximately the same orientation and elevation.

Hydrologic data recorded at Granite Reef Diversion



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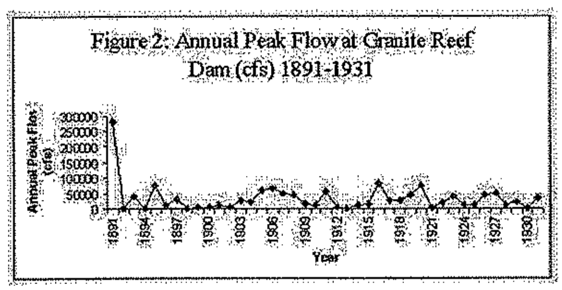

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1890

Note groves of trees (cottonwoods, willow and alder according to historic accounts) lining the banks of the high flow channel. Floodplain terraces north of the river support mesquite, greasewood, and palo verde thickets with sagebrush and native grasses in more open areas. Agricultural fields dominate the southern bank in the foreground, with the darkest area possibly native vegetation. The low flow channel is slightly wider than the middle section of the

Dam (25 km upstream) reflects a large flood event in 1891, followed by a series of much smaller events through 1931.

1890: Pre-flood conditions.
Vegetation: Mature cottonwoods, willows and alder grow along banks; floodplain terraces support mesquite greasewood, and palo verde thickets.

Channel: Lowflow channel angles across the highflow channel, confined by sand bars. Deep meander bends present downstream from the railroad bridge.

1900: Post-flood conditions.
Vegetation: Bank vegetation has grown, stringer of vegetation present in 1890 persists.

Channel: Meander bends of 1890 are abandoned.

1931: Conditions after several years with moderate flood events.
Vegetation: Cottonwoods along riverbanks, agricultural fields present north of the river.

Channel: Low flow channel of 1900 still visible, marked by parallel bands of vegetation just downstream of the railroad bridge.

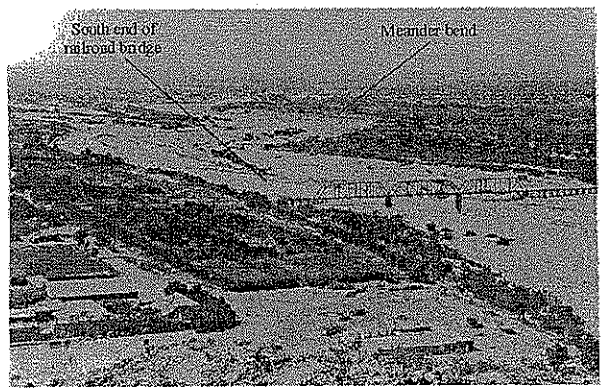
Conclusions:

These photographs and hydrological data document the geomorphic and vegetation changes associated with a large flood event. Because this event predates aerial photography and the construction of dams, historical ground photo analysis represents the only visual evidence for channel change.

How stable was the Salt River prior to dam construction?
The Salt River's largest recorded flood event changed the river channel and patterns of vegetation. Subsequent smaller events did not appreciably change the low flow channel, evidence that the Salt River's geomorphology is event-driven. This combination of historic photographs and hydrological data provides unique insight into the nature and degree of channel change in response to a specific flooding event.

How are channel stability and instability reflected in vegetation patterns?
Vegetation, particularly trees, serves as a useful visual clue to the location of the low flow channel. Woody vegetation may play an important role in maintaining channel stability during moderate flood events by restricting and directing flood flow. The flood of 1891 was large enough to destabilize bank vegetation and resulted in channel change.

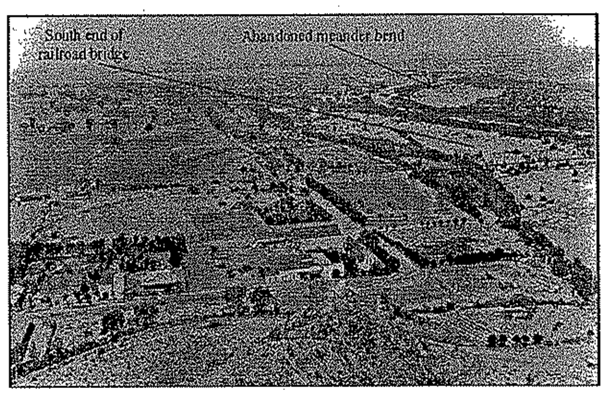
bridge, and sand bars and point bars occur along its length. Stringers of vegetation mid-channel indicate stabilized sand bars and help direct flow.



Click on the photo for a larger view.

1900

The bank vegetation is taller and more extensive (compare trees near railroad bridge with those in the 1890 photograph), as are the planted rows of trees surrounding the fields. Following a flood in 1891, the low flow channel shifted north, and is delineated by bands of dark vegetation. The most dominant stringer of vegetation in 1890 is still visible, now south of the low flow channel. The trees marking the north bank of the low flow channel in 1890 delineate the south bank of the low flow channel in 1900. The trees closest to the bottom of the photograph mark the Hayden Canal, an irrigation canal out of view (but present) in the 1890 photograph.



Click on the photo for a larger view.

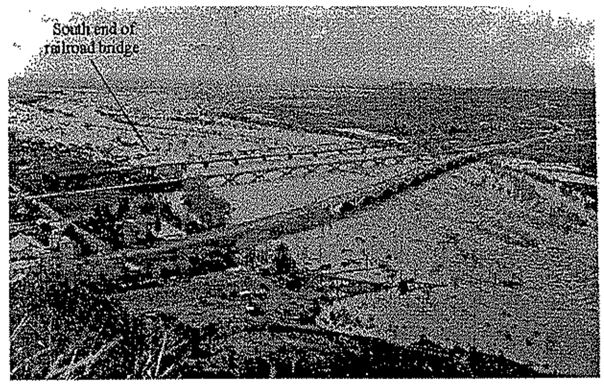
1931

Reference:

Graf, William L., Patricia J. Beyer, and Thad A. Wasklewicz. 1994. Geomorphic Assessment of the Lower Salt River, Central Arizona. U.S. Army Corps of Engineers Contract DACW09-94-M-0494.

All photographs were taken from Hayden Butte facing northwest, with the river flowing towards the west. Tempe Historical Museum provided the 1890, 1900, and 1931 photographs, and the 2000 photograph is by Wendy Bigler. Salt River Project provided the hydrological data. Funding provided by a National Science Foundation Integrative Graduate Education Research and Training fellowship.

This photograph shows the Salt River in flood, obscuring some vegetation and channel details. The tops of mature cottonwoods are visible between the two automobile bridges, and the low flow channel in the 1900 photograph is still visible in 1931 as parallel bands of vegetation. Agricultural fields replaced native vegetation north of the river. In the center foreground, conveyor belts mark a sand and gravel quarry, and the Tempe Beach Park swimming pool is located south of the river between the two automobile bridges.



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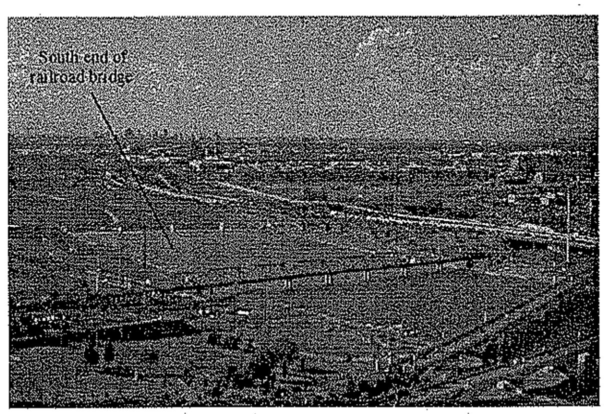
2000

This modern view reflects the impacts of urbanization on the Salt River during a period of rapid growth. In 1998, the city of Tempe constructed Tempe Town Lake to stimulate economic growth. The river is entirely channelized and native vegetation is minimal.



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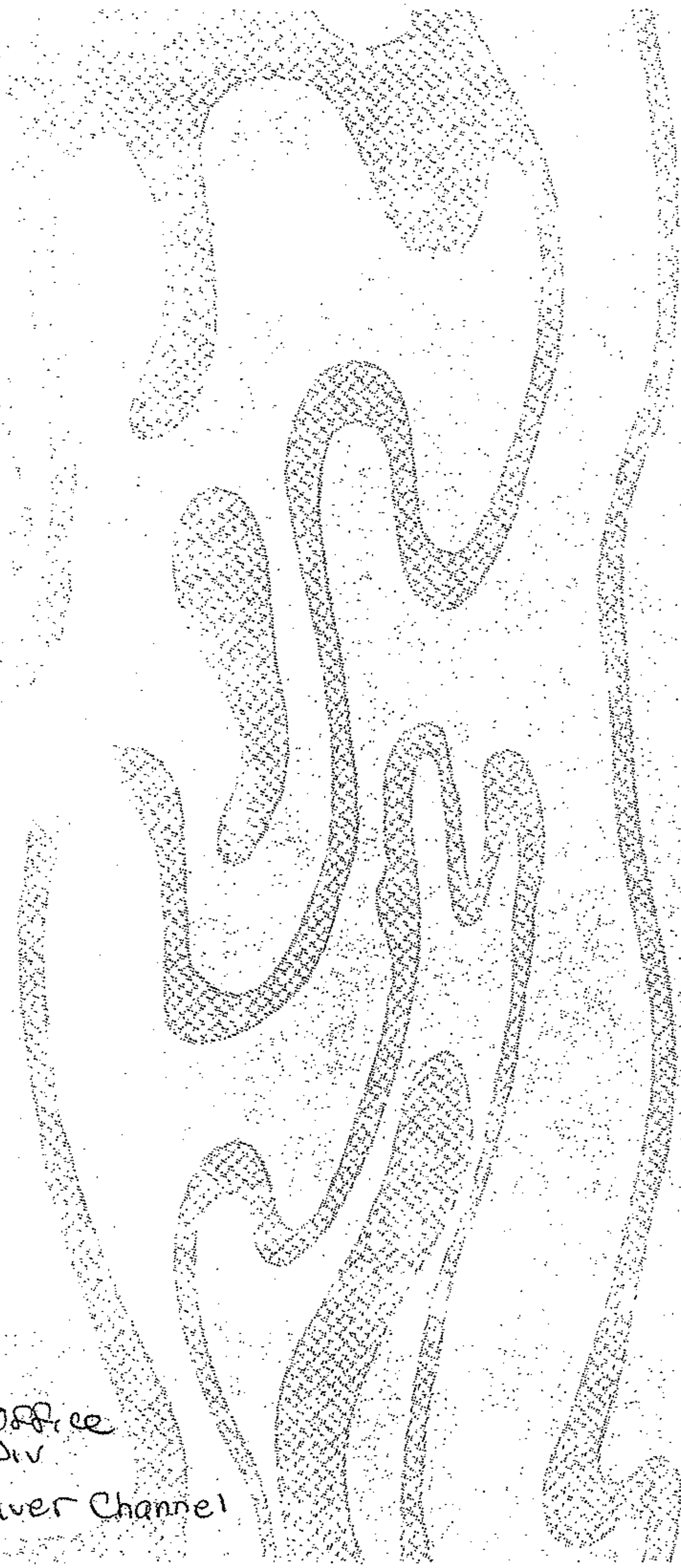

A HISTORY OF THE SALT RIVER CHANNEL IN THE VICINITY OF TEMPE, ARIZONA

1868-1969

by

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Associate Professor of Engineering
Arizona State University

1971

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History of Salt River Channel

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

CONTENTS

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.

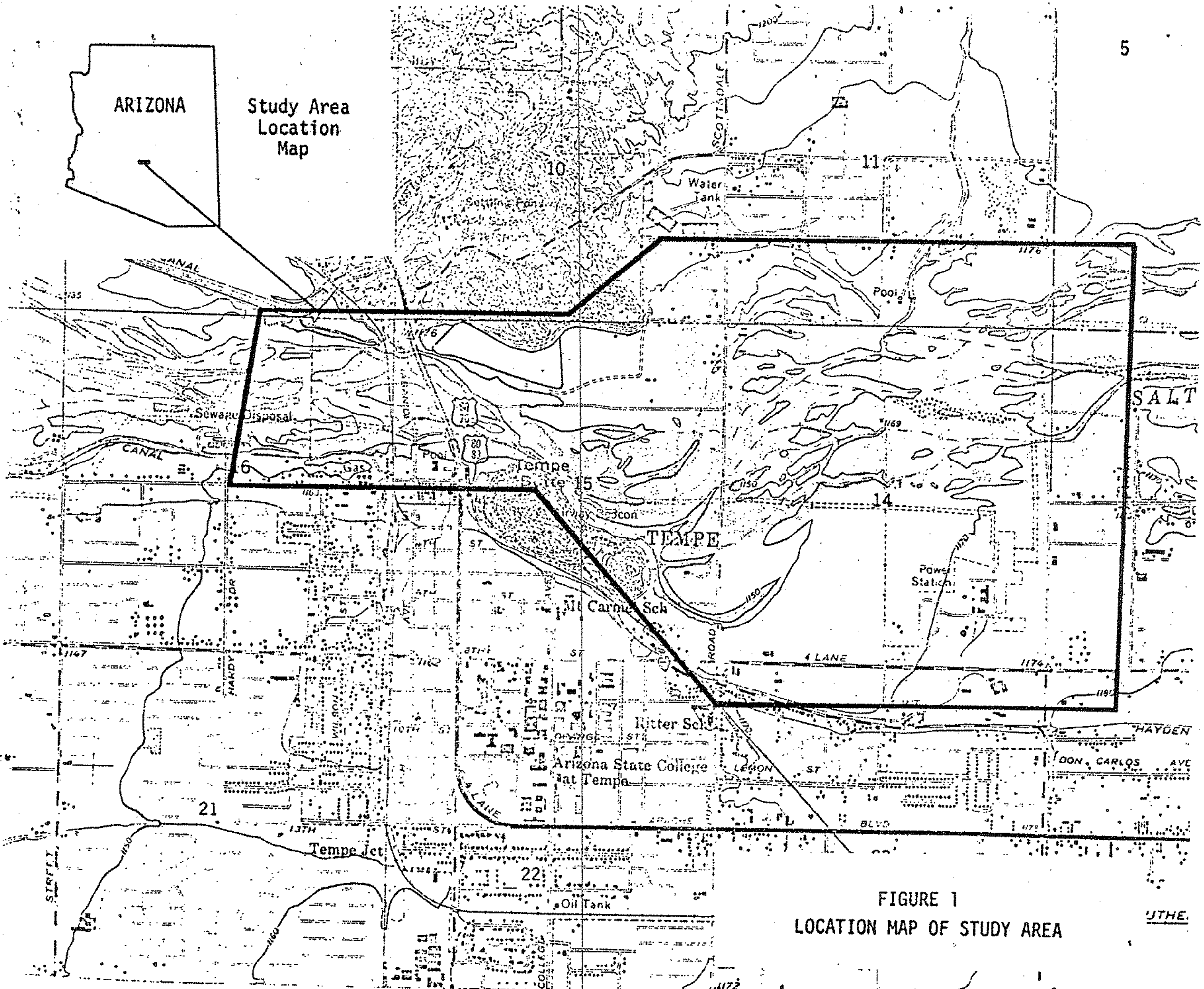


FIGURE 1
LOCATION MAP OF STUDY AREA

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

<u>1868</u>

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.

<u>1891</u>

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.

<u>1903-04</u>

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 2

July 26, 1941

Page 17 →

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.

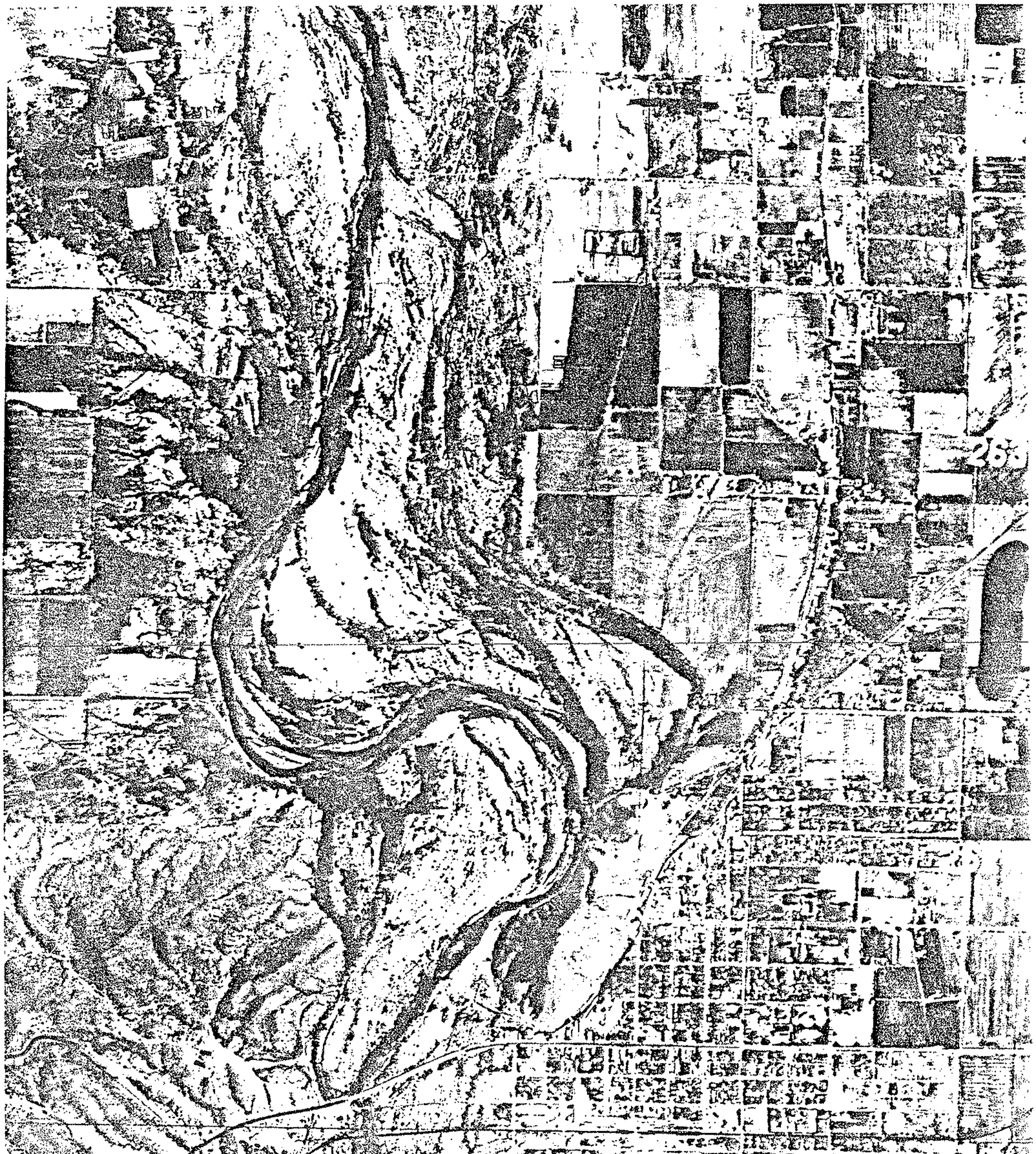


PLATE 3

February 17, 1949

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

Page 19 →

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.

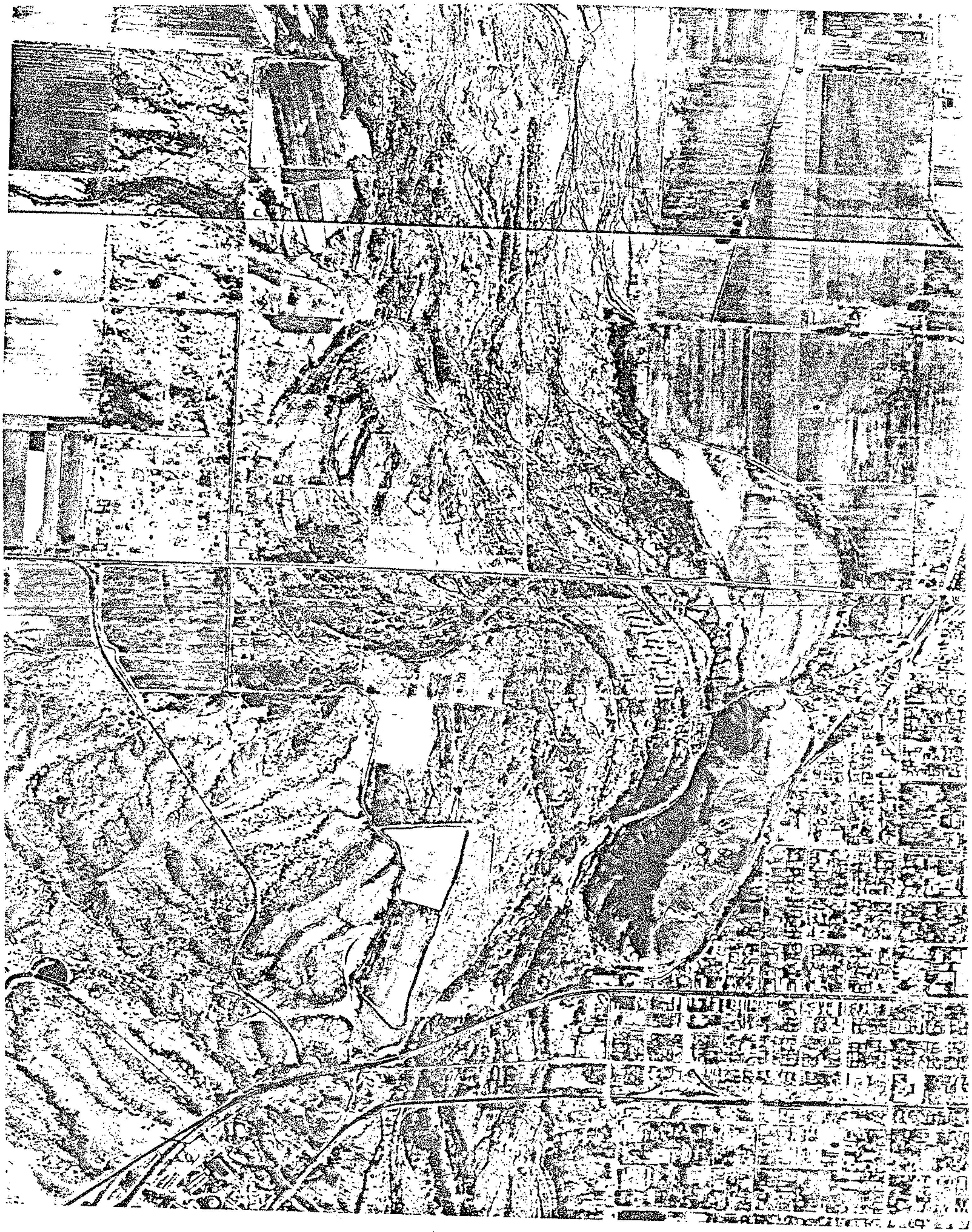


PLATE 6

January 2, 1964

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.

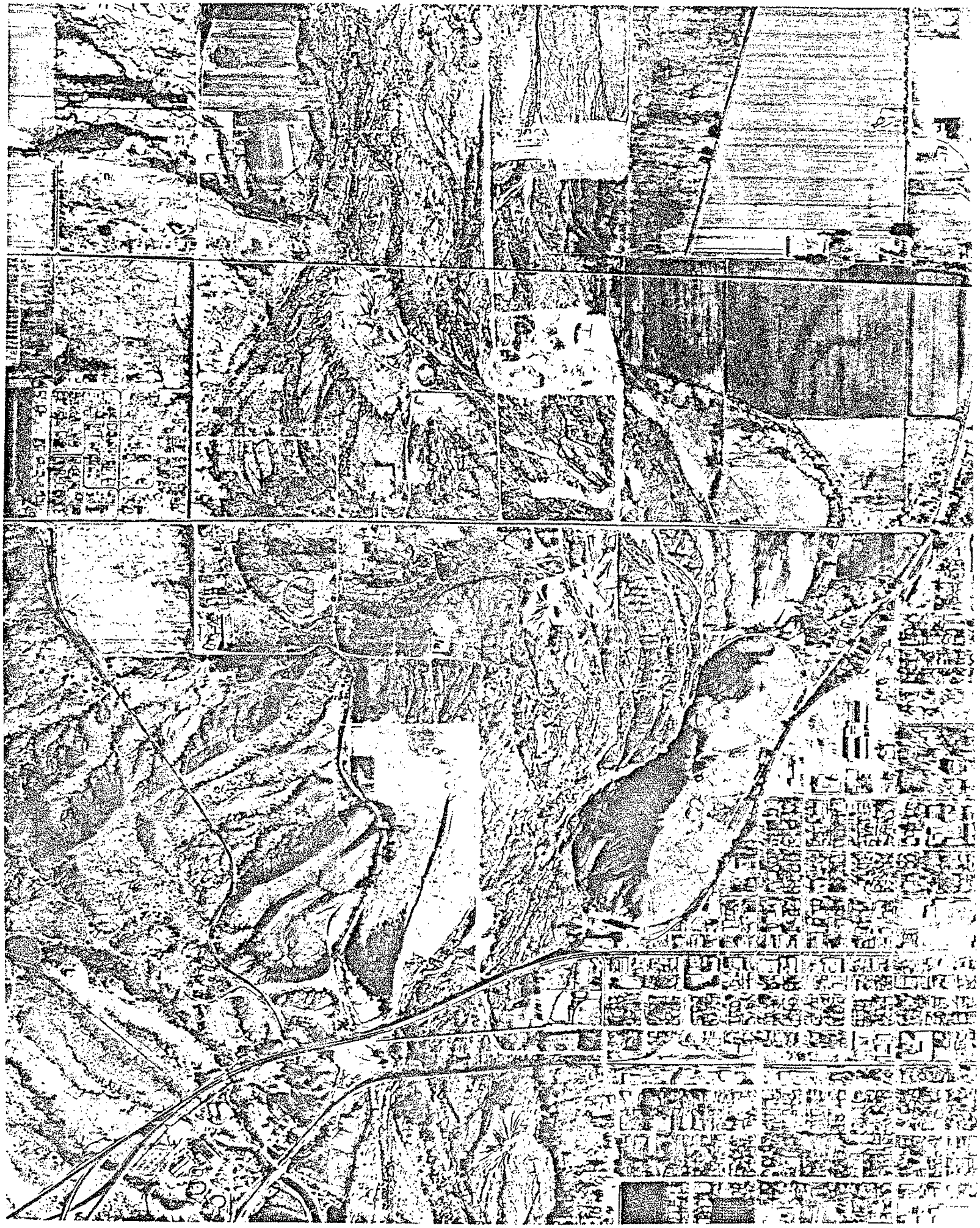


PLATE 7

January 12, 1965

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.

1-2-64
B-21

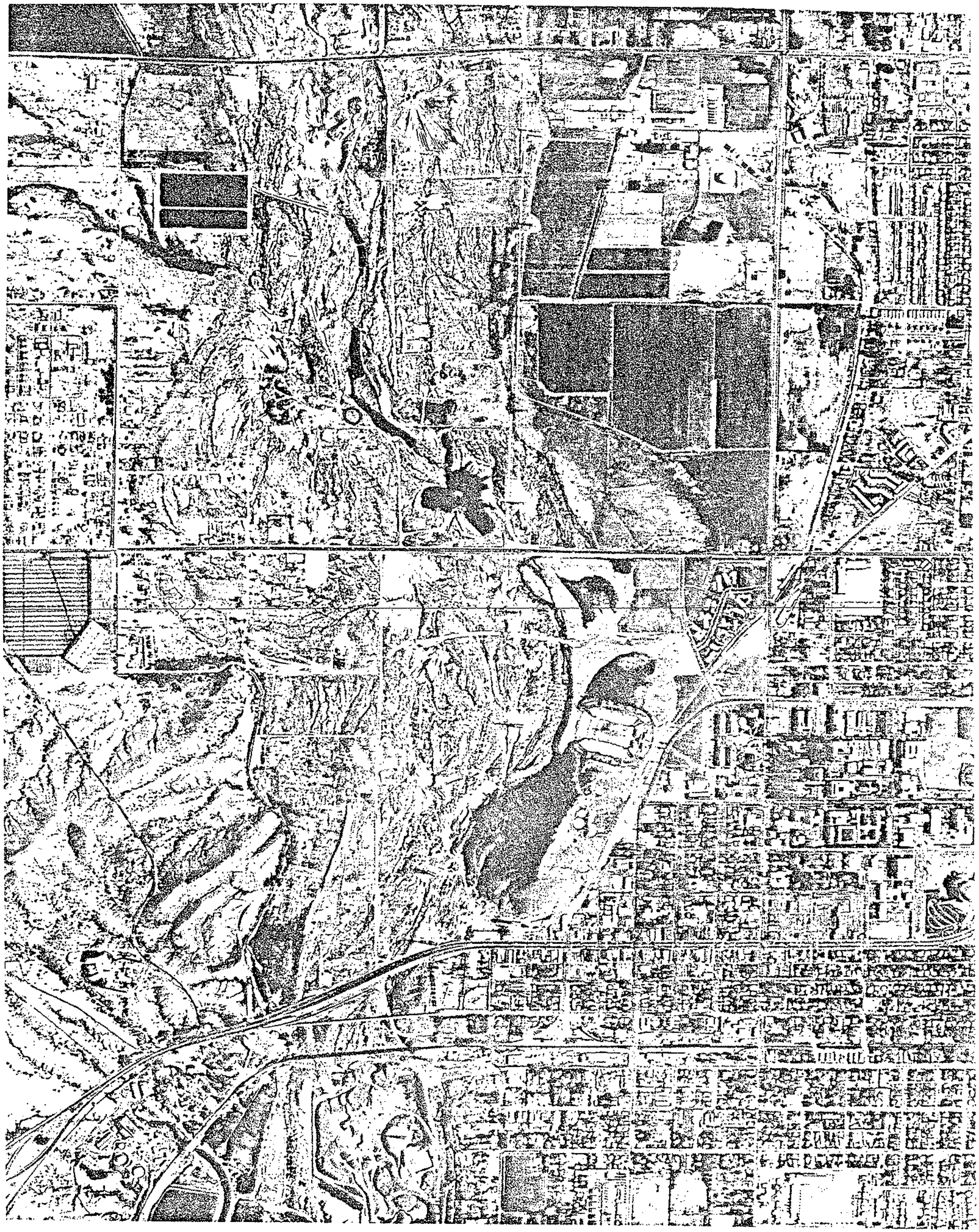


PLATE 8

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.

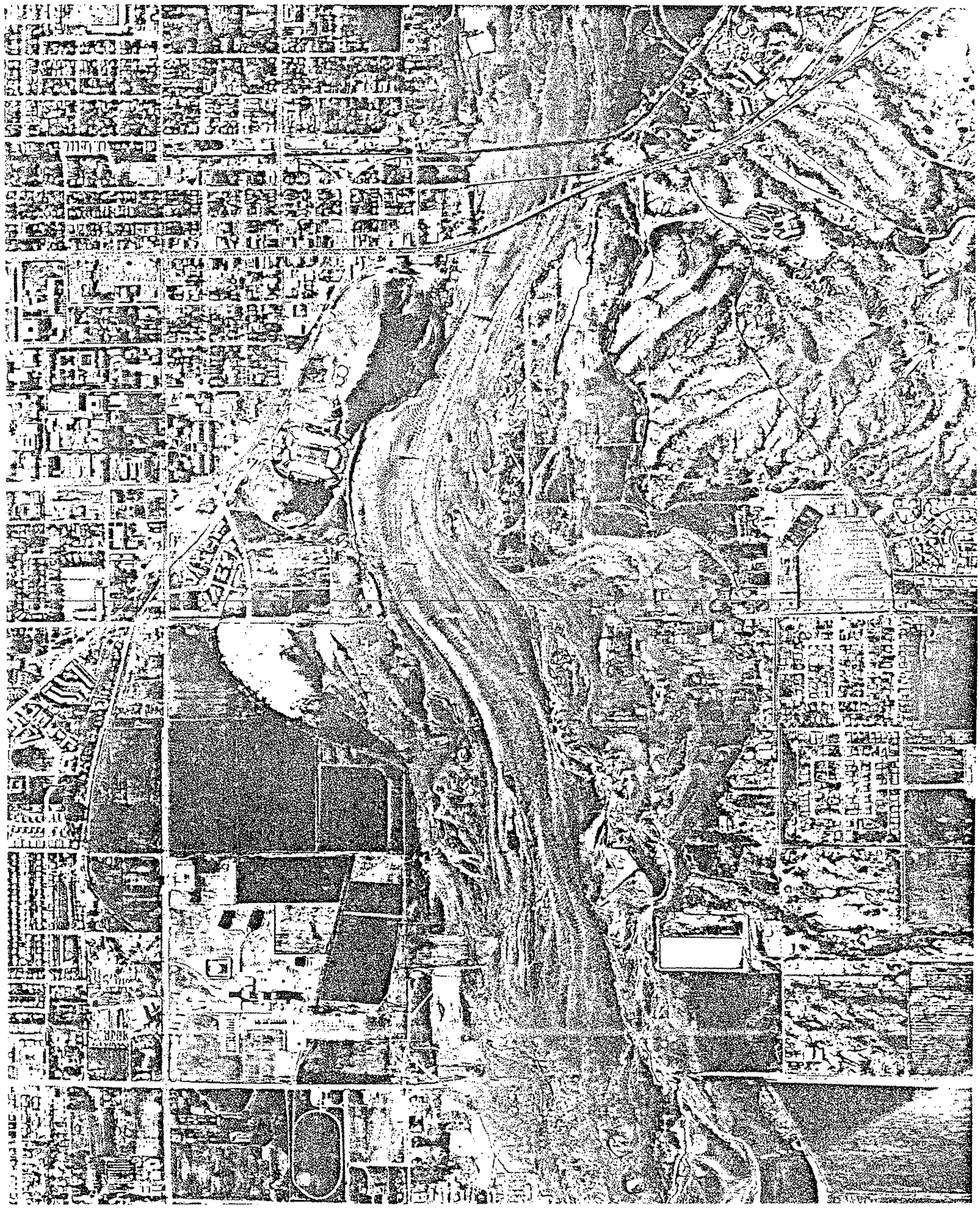


PLATE 10

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.

DEC 31 1965

PLATE 11

December 31, 1965 Page 26 →

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

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.

PLATE 13

January 13, 1966

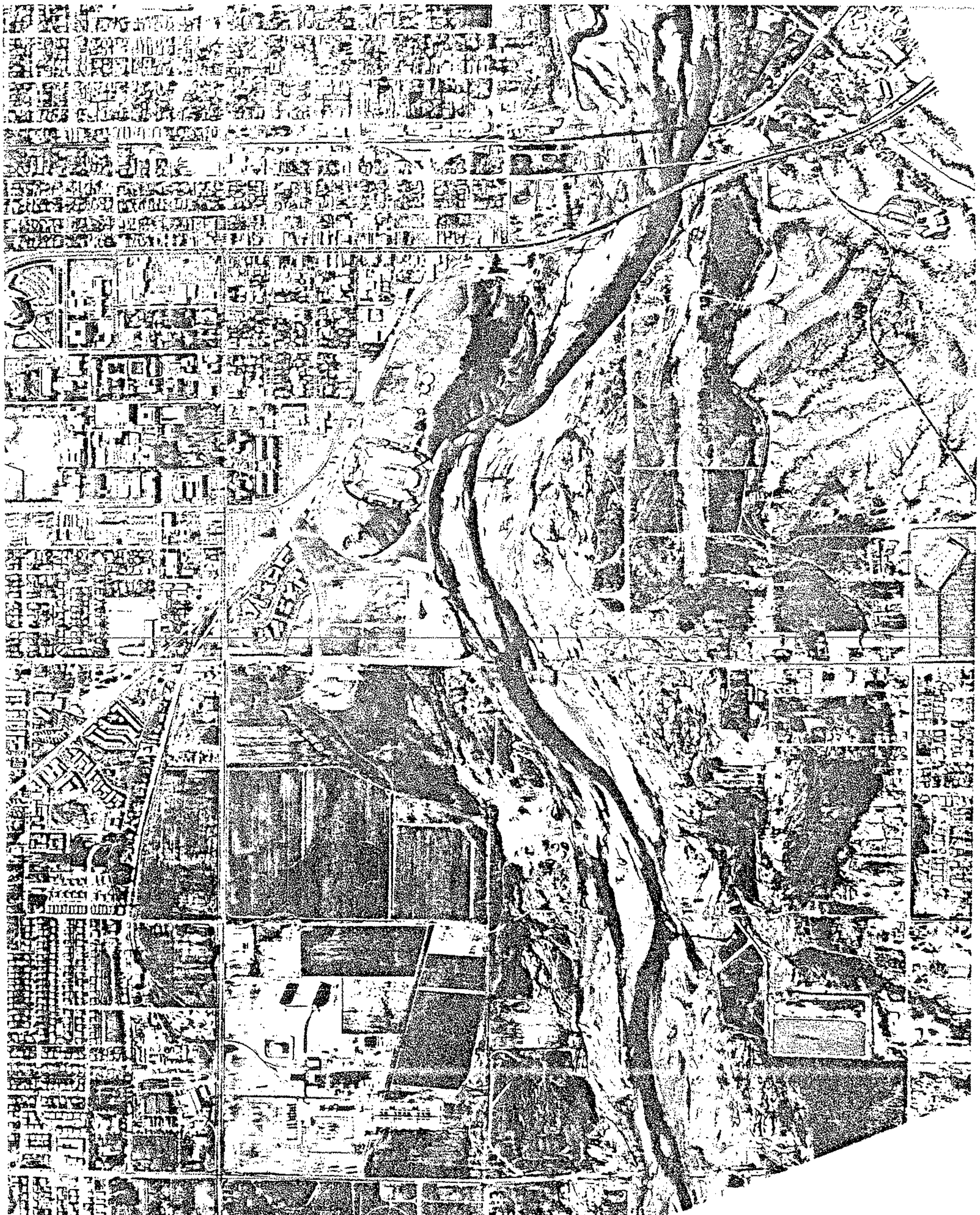
Page 28 →

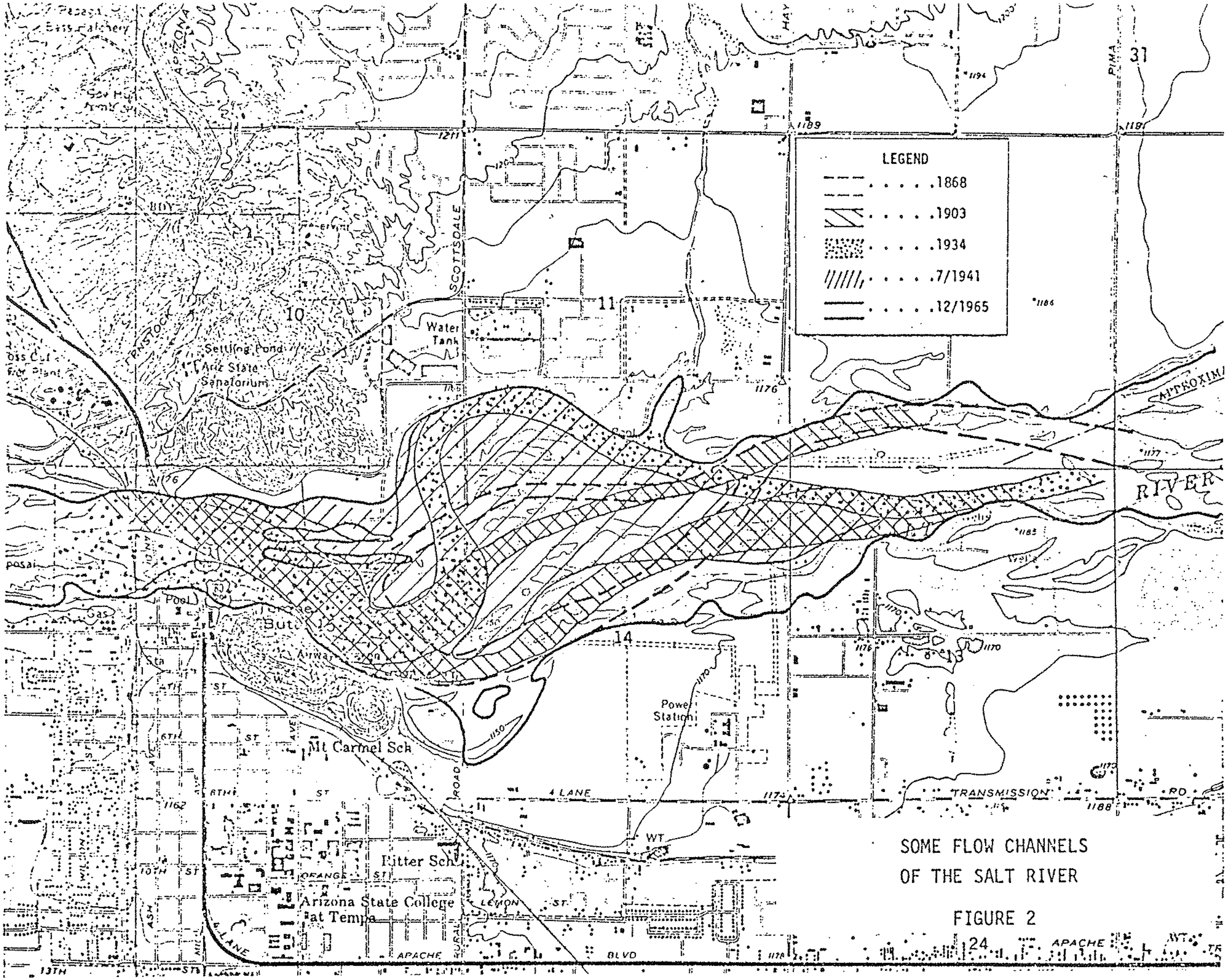
Extensive erosion results when major flows occur that have low sediment content. Sand bars have developed immediately north of the Arizona State University stadium, north of the electrical transmission towers, and northwest of the Tempe Butte. The sand bars were formed during the falling (stage) discharge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

PLATE 14

January 2, 1969

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.





SOME FLOW CHANNELS
OF THE SALT RIVER

FIGURE 2

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.

REFERENCES

1. Chow, V. T., Open Channel Hydraulics, 1959.

2. Leopold, L. B., M. G. Wolman, and J. P. Miller, Fluvial Processes in Geomorphology, 1964.

3. Personal communication with Professor H. A. Einstein, University of California, Berkeley, California.

4. United States Army, Corps of Engineers, Los Angeles District, "Interim Report on Survey for Flood Control, Gila and Salt Rivers," December 4, 1957.

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.

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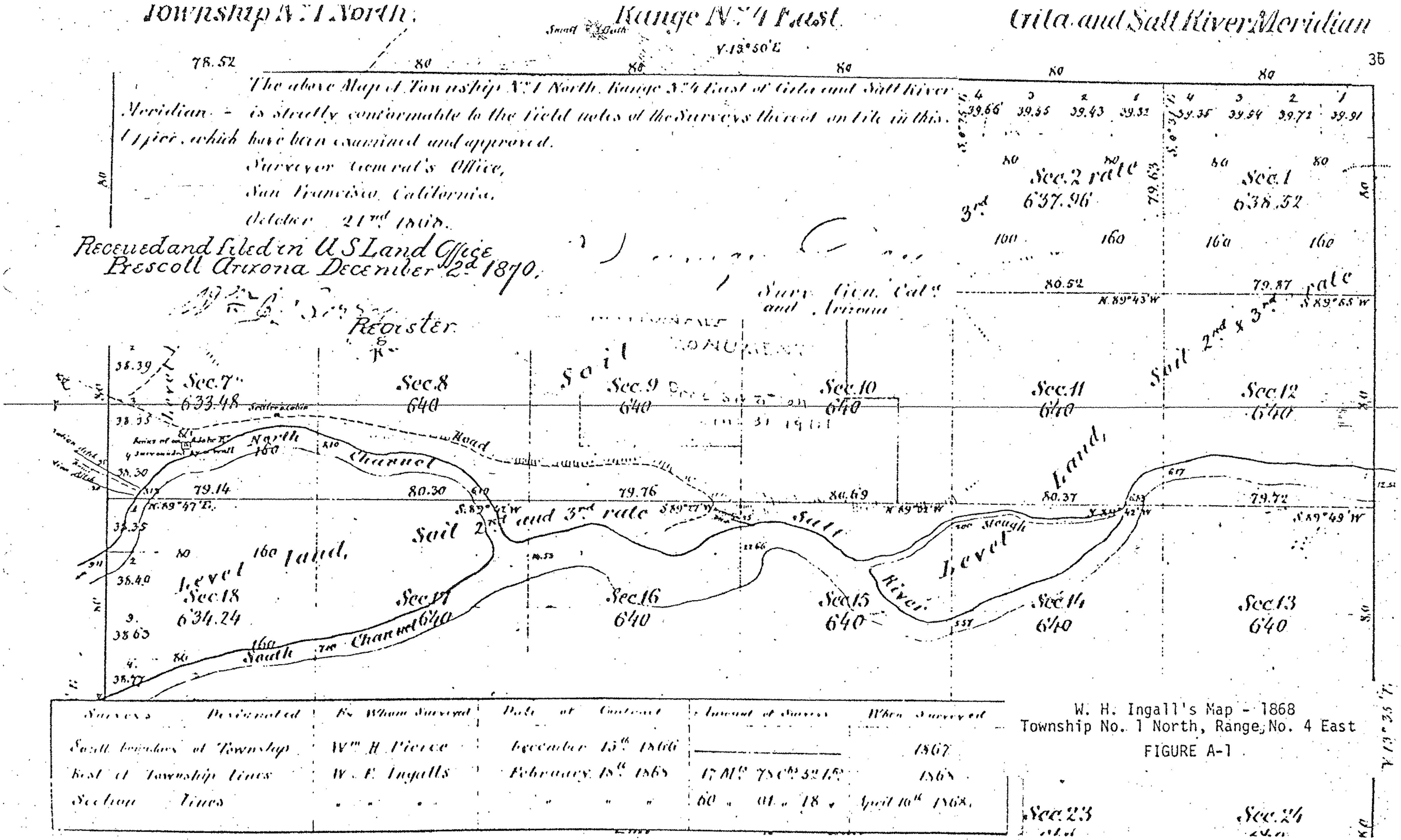
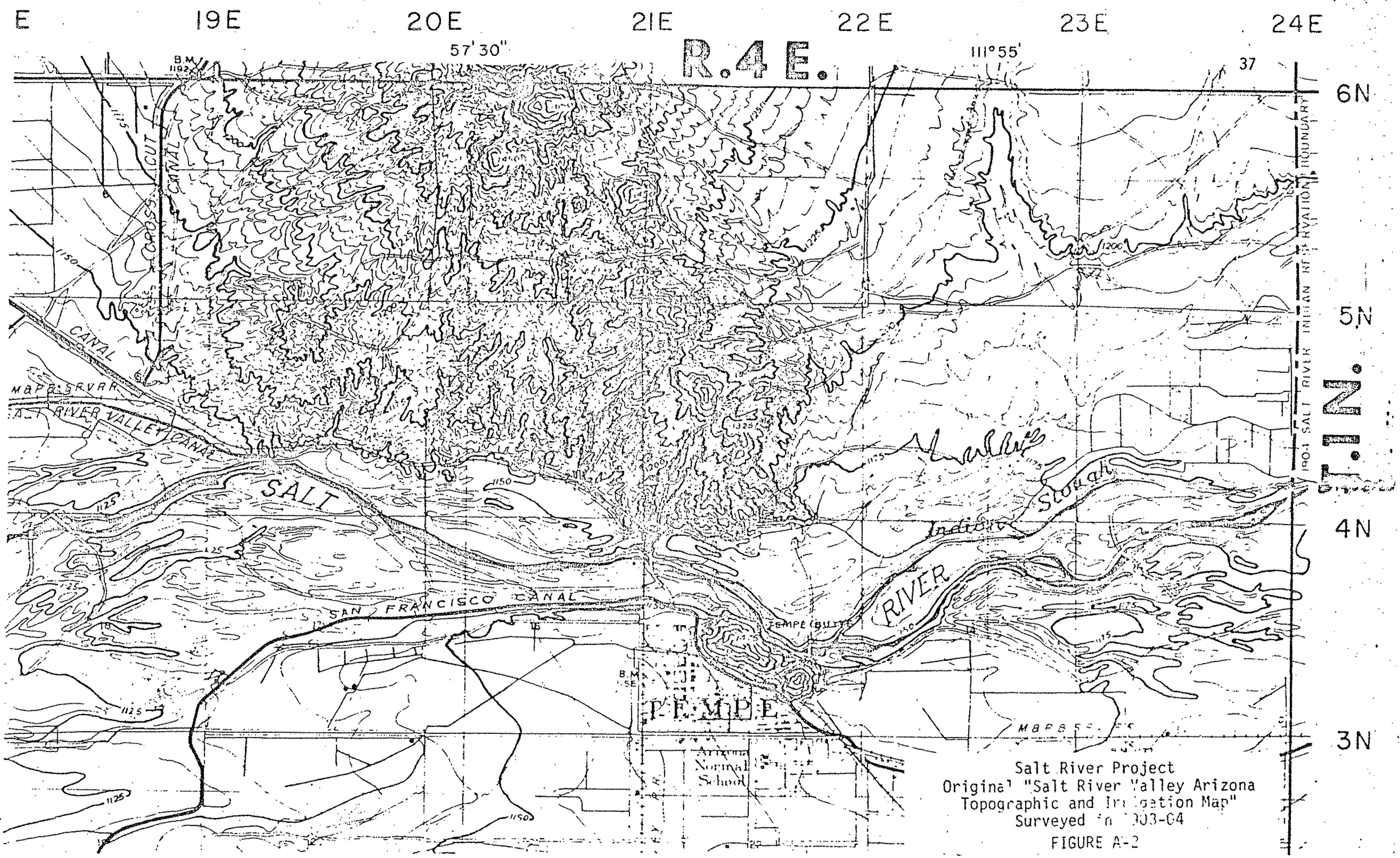
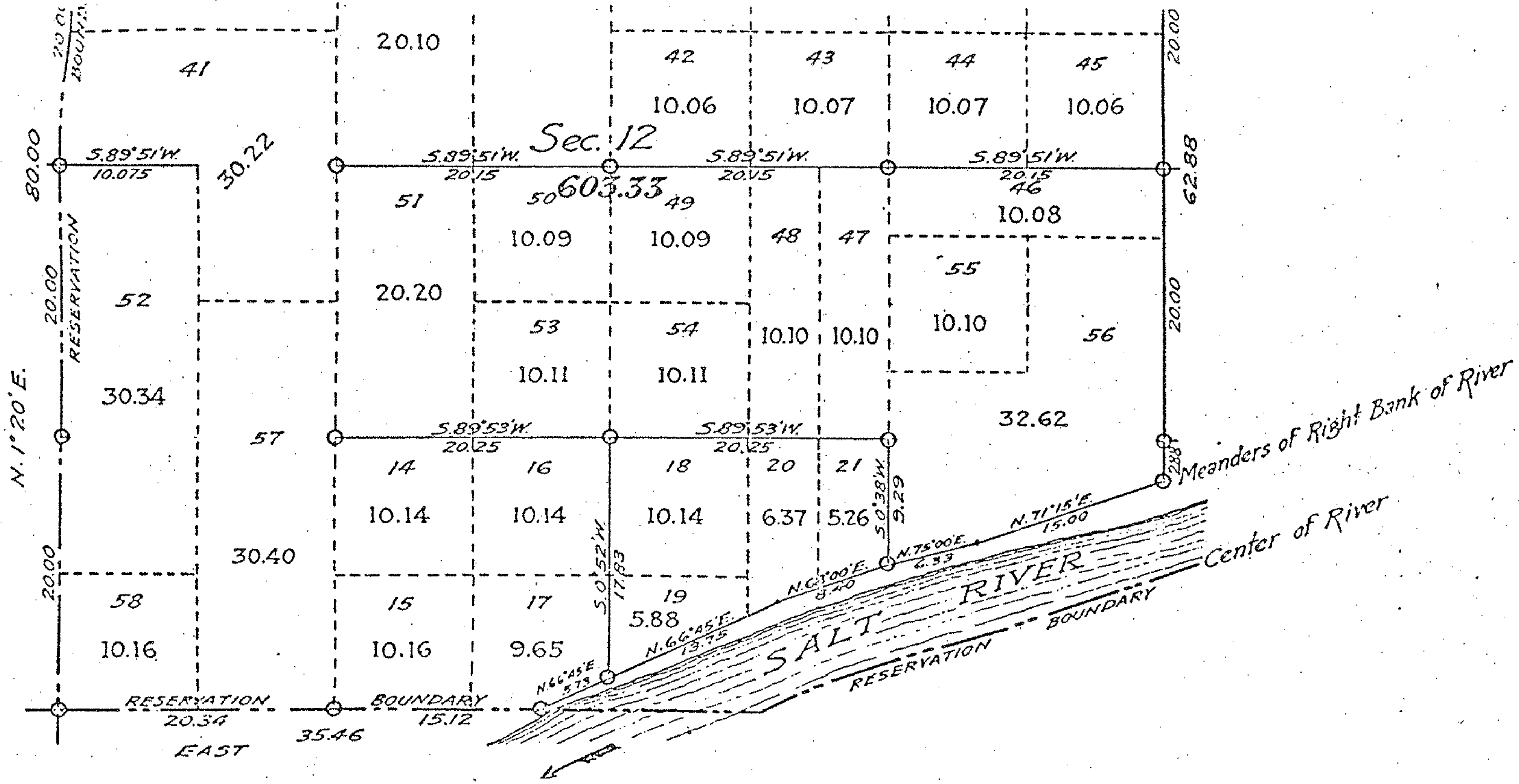


W. H. Ingall's Map - 1868
Township No. 1 North, Range No. 4 East
FIGURE A-1



Salt River Project
Original "Salt River Valley Arizona
Topographic and Irrigation Map"
Surveyed in 1903-04
FIGURE A-2

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.

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.

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

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

Charles M. Donaldson
U.S. Surveyor General.

FIGURE A-3

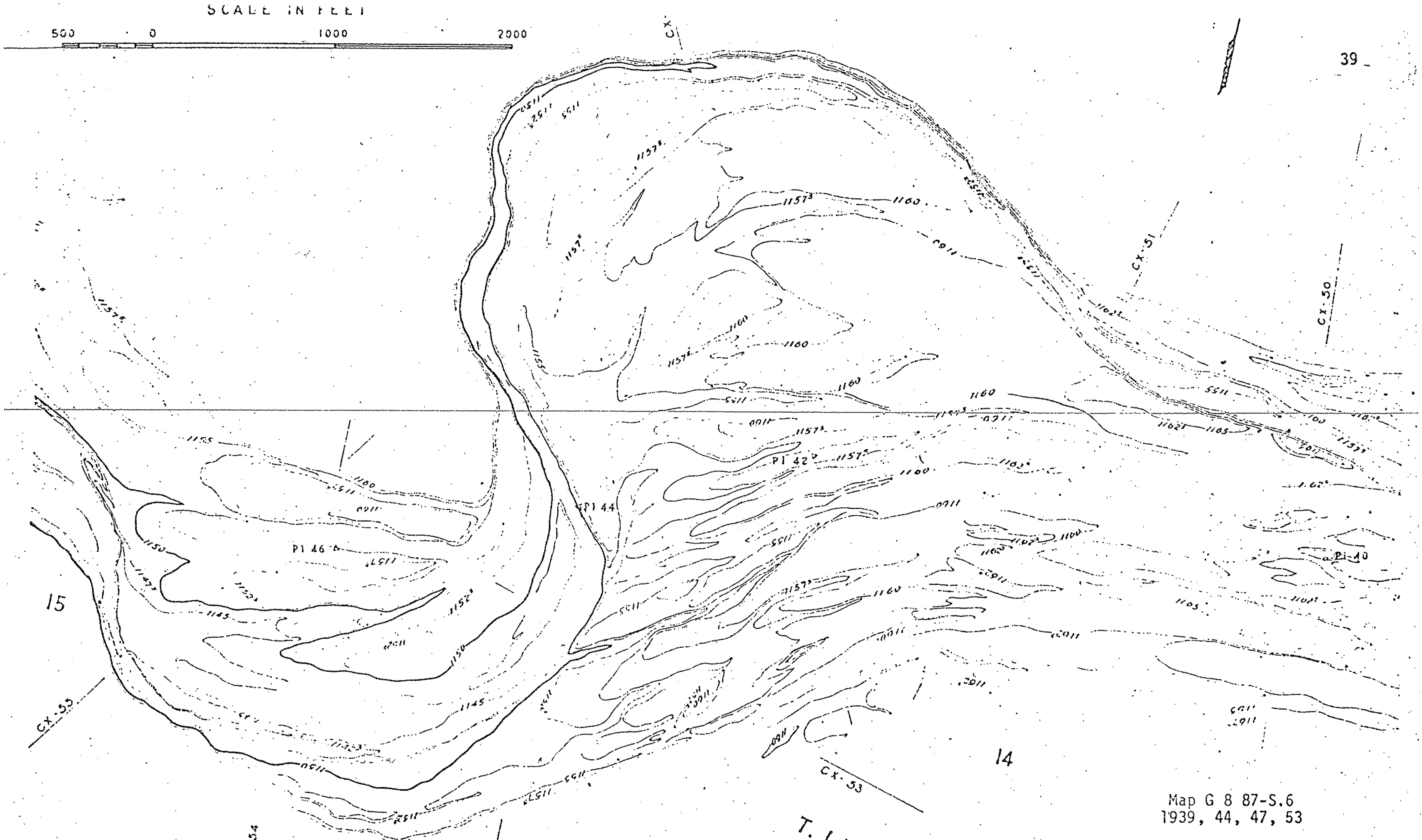
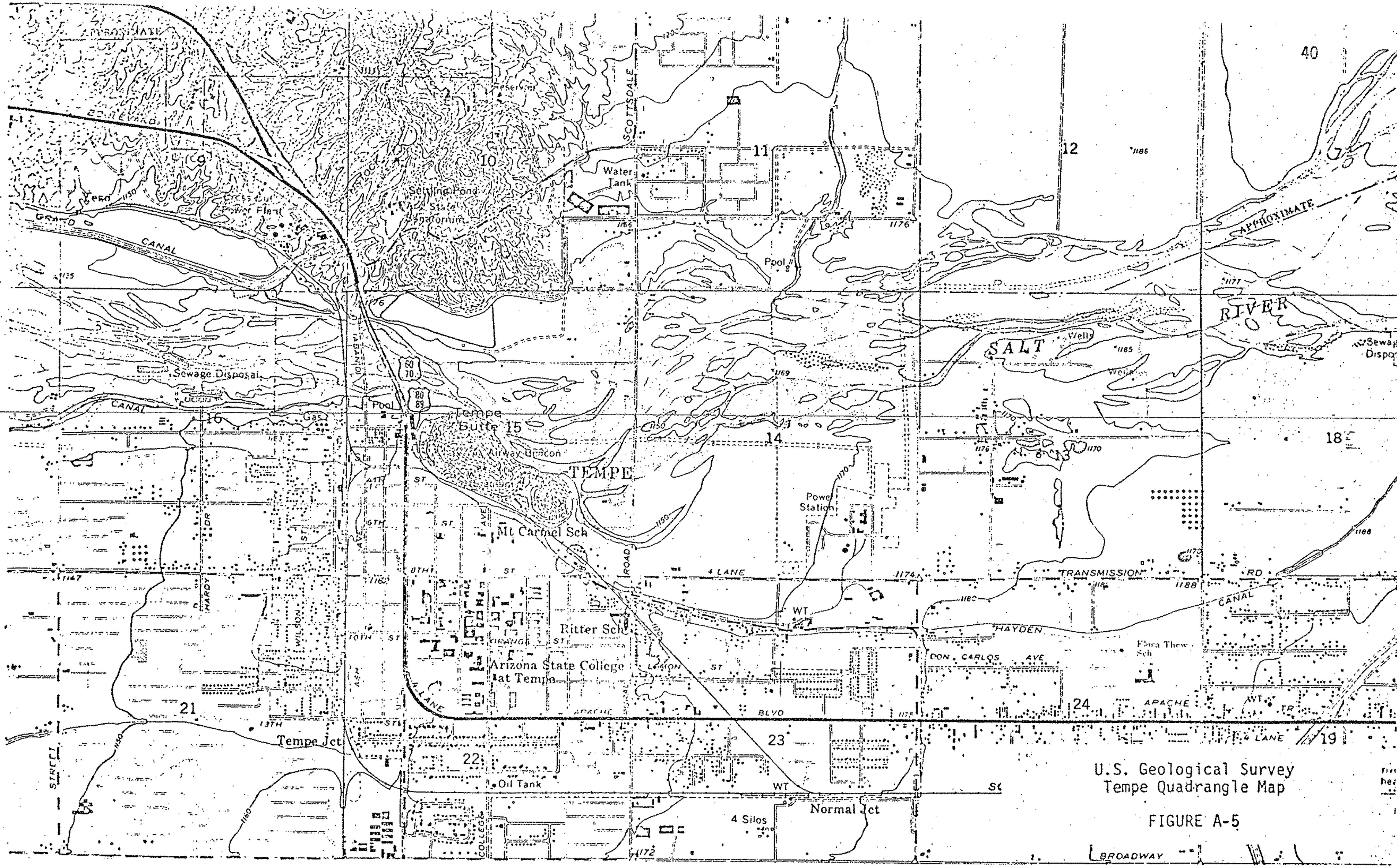
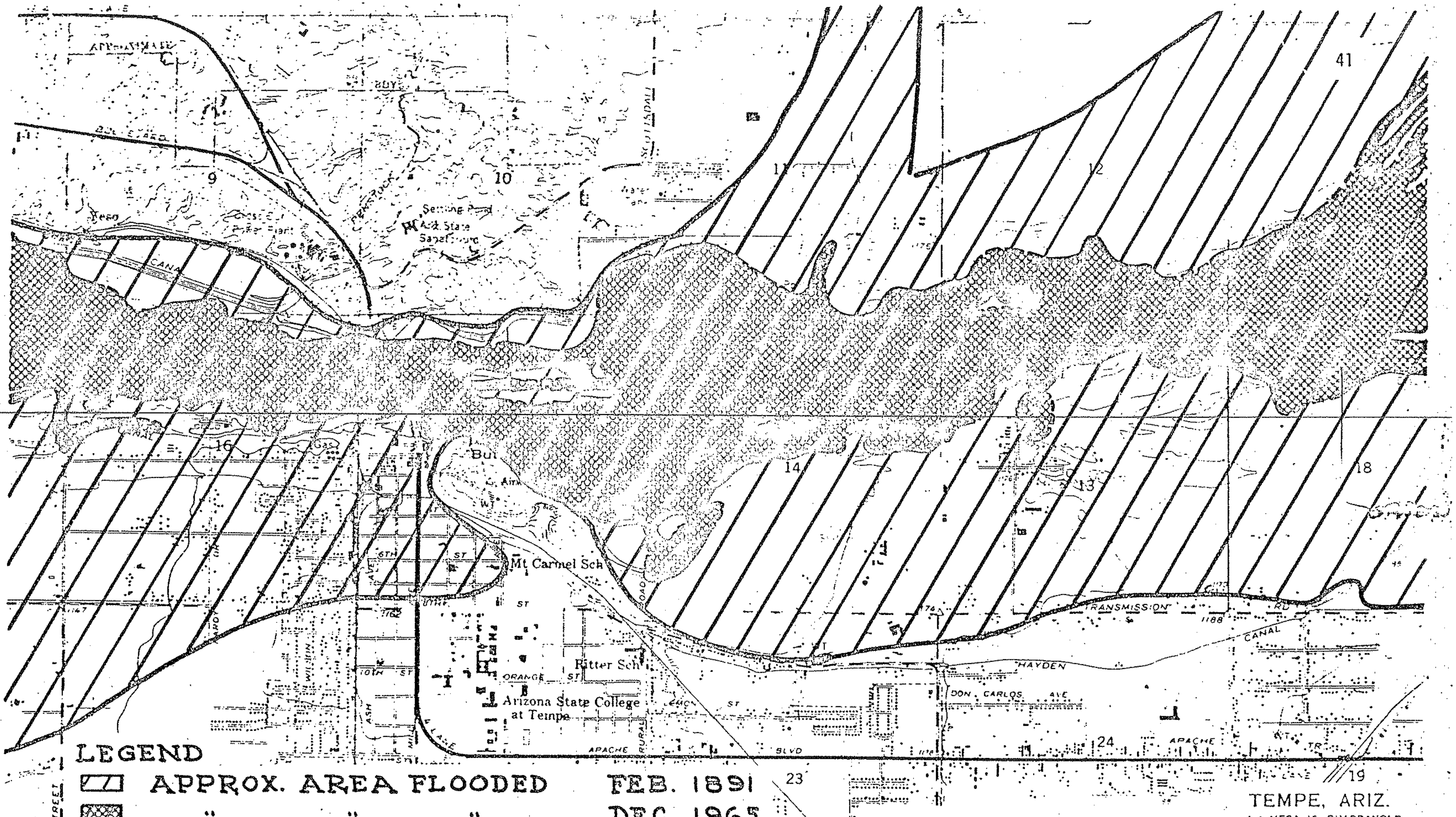

SCALE IN FEET
500
0
1000
2000
CX-51
CX-50
CX-53
CX-55
15
14
T.1N
P1 46
P1 42
P1 44
Pi-40
1160
1150
1145
1155
Map G 8 87-S.6
1939, 44, 47, 53

FIGURE A-4



U.S. Geological Survey
Tempe Quadrangle Map

FIGURE A-5



Areas of Inundation
February 1891 and December 1965

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FIGURES, PLATES, AND TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

APPENDIX C

FLOWS OF THE SALT RIVER AT GRANITE REEF DAM

FORM 12-26

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	56,743
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

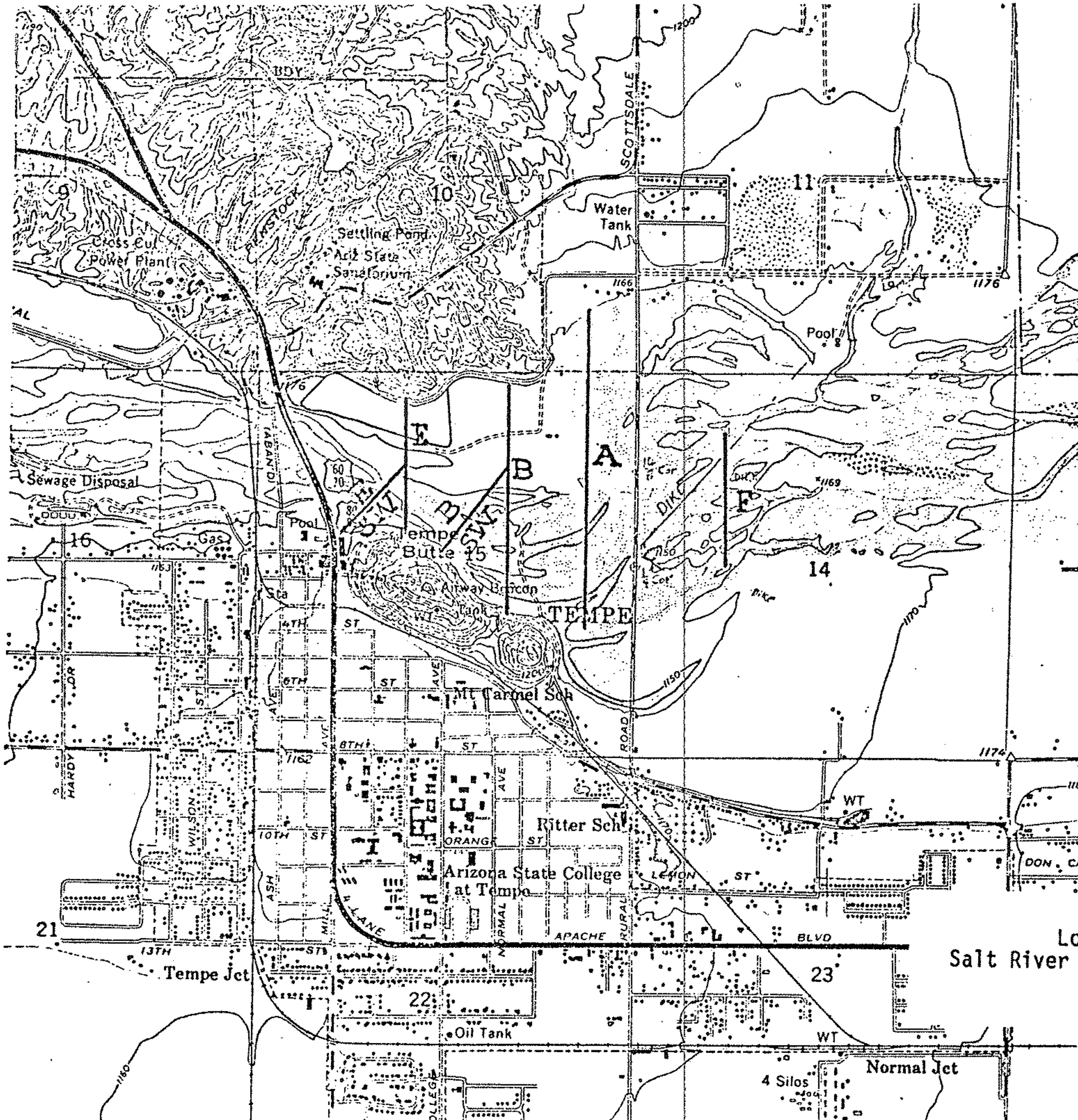
TABLE C-1

LCG/rf

L. C. Goldsmith

APPENDIX B

CROSS SECTIONS OF THE SALT RIVER
TEMPE, ARIZONA



Location Map of
Salt River Channel Cross Sections

FIGURE B-1

AVOID VERBAL ORDERS Date

. 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

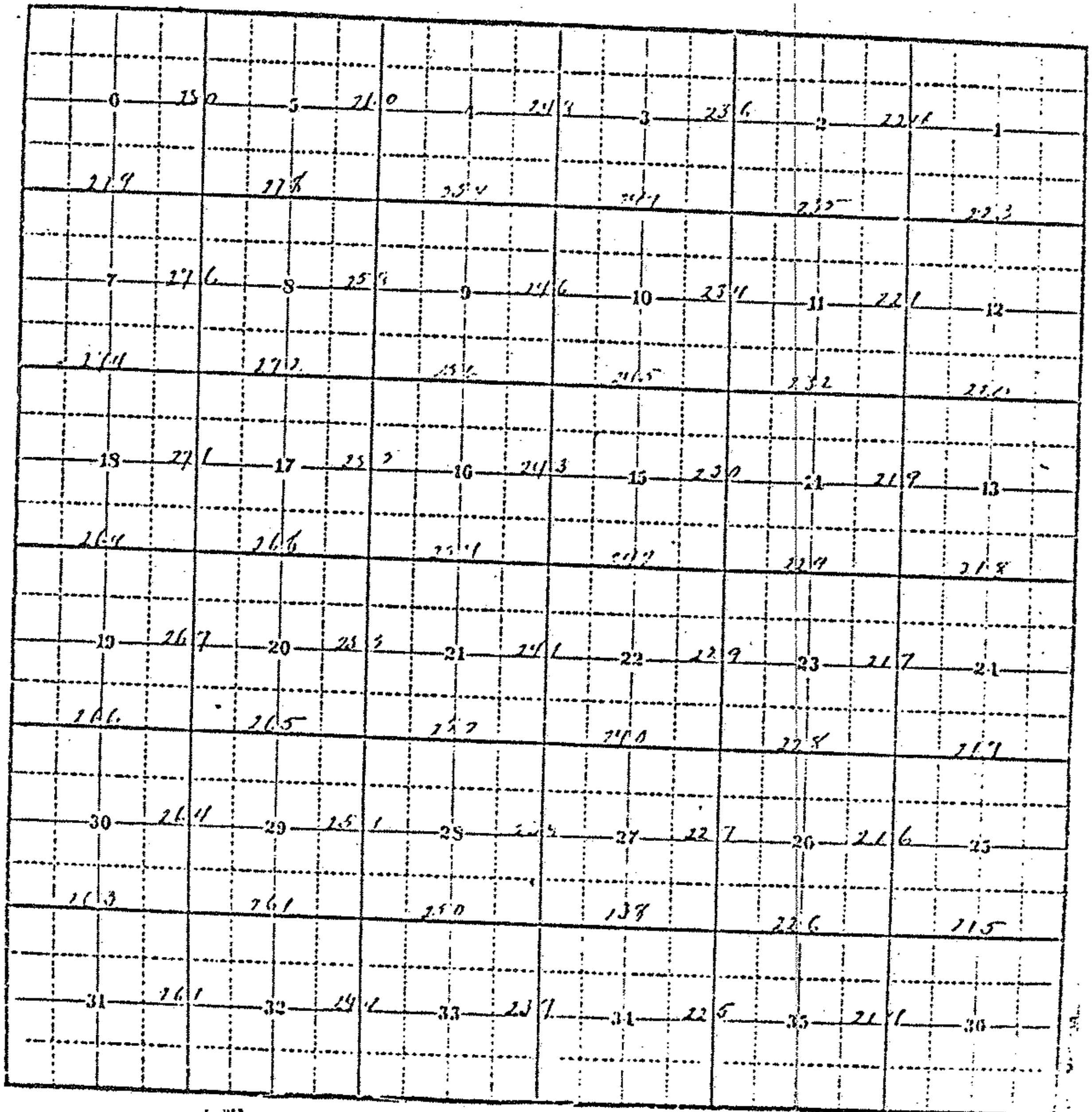
1966 (continued)			
	Feb.	20	1080
		21	1590
		22	2280
		23	2310
		24	1840
		25	1390
		26	1380
		27	1450
		28	1470
	Mar.	1	1330
		2	1230
		3	1240
		4	320
	Sept.	13	2450
1967	Dec.	15	500
		19	2510
		20	3170
1968	Feb.	14	1630
		15	3700
		16	3470
		17	3440
		18	3410
		19	1360
		25	1570
		26	2960
		27	2603
		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

Range No. [illegible] Mer.



Chs [illegible]

to sec[illegible]

any of [illegible]

North [illegible]

East Bn [illegible]

4020 [illegible]

8020 [illegible]

25.26.35 [illegible]

T 5 1 N Range 4 E

Gila & Salt River Meridian

31.50	To left bank of Salt River 10 ft high — runs S 84° W I now caused a flag to be set on the right bank and on the line bet secs 14 & 15 and from a 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 87¼° 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 north of place 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 main 2.00 chs wide runs SW

BOOK 2

ge 4 E

er Meridian

of Salt River to Ct
e S 80 W
ed a flag to be set
bank and on the
os 14 & 15 and from
line on left bank
ue East 4.24 chs
from which the
ht bank bears
which gives for
e across the river
ne bet secs 14 & 15
to which add 31.50 chs
th of river makes
ght bank of river

for ¼ sec cor with
d pits as per
ns
from main 2.00 chs
s S W

BOOK 2

Tp 1 N Range 4 E

Gila & Salt River Meridian

80.00	Set a post for cor to secs 10.11.14 & 14 with mound and pits as per instructions Land level - South of river 1st rate North of river level - rather sandy 3rd rate Mesquite and sage brush south of river Cottonwood on river banks
	East on a random line bet secs 11 & 14 Va 13°30' E
40.00	Set a post for temp. ¼ sec cor
65.70	To right bank of Salt River runs S 75° I now caused a flag to be set on the left bank and on the line bet secs 11 & 14 and from the corner on left right bank

22 [illegible] BOOK 2

Tp 1?2 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
	[illegible] of river makes
72.53	To flag on left bank of river
80.37	[illegible] line [illegible]
	corner 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	[illegible]

BOOK 2

uge 4 E

River Meridian

ne bet said sec
th 5.0 chs to a point
st on an offset line
a point from which
left bank of river
which gives for
across river on line
1 & 2 – 6.83 chs to
65.71 " dist
to makes
left bank of river

f line W 2 chs North
11, 12, 13 & 14
chs cor & sum

na true line
11 & 14
13°35' E

Set 1/4 sec cor

BOOK 2

Tp 1 N Range 4 E

Gila and Salt River Meridian

chs	with mound and pits as
	per instructions
80.37	The cor to secs 10, 11, 14 & 15
	Land level - East of river 1st rate
	" West of river 2nd " inclined to
	swampy
	Timber cottonwood along river
	banks
	Mesquite and arrow brush

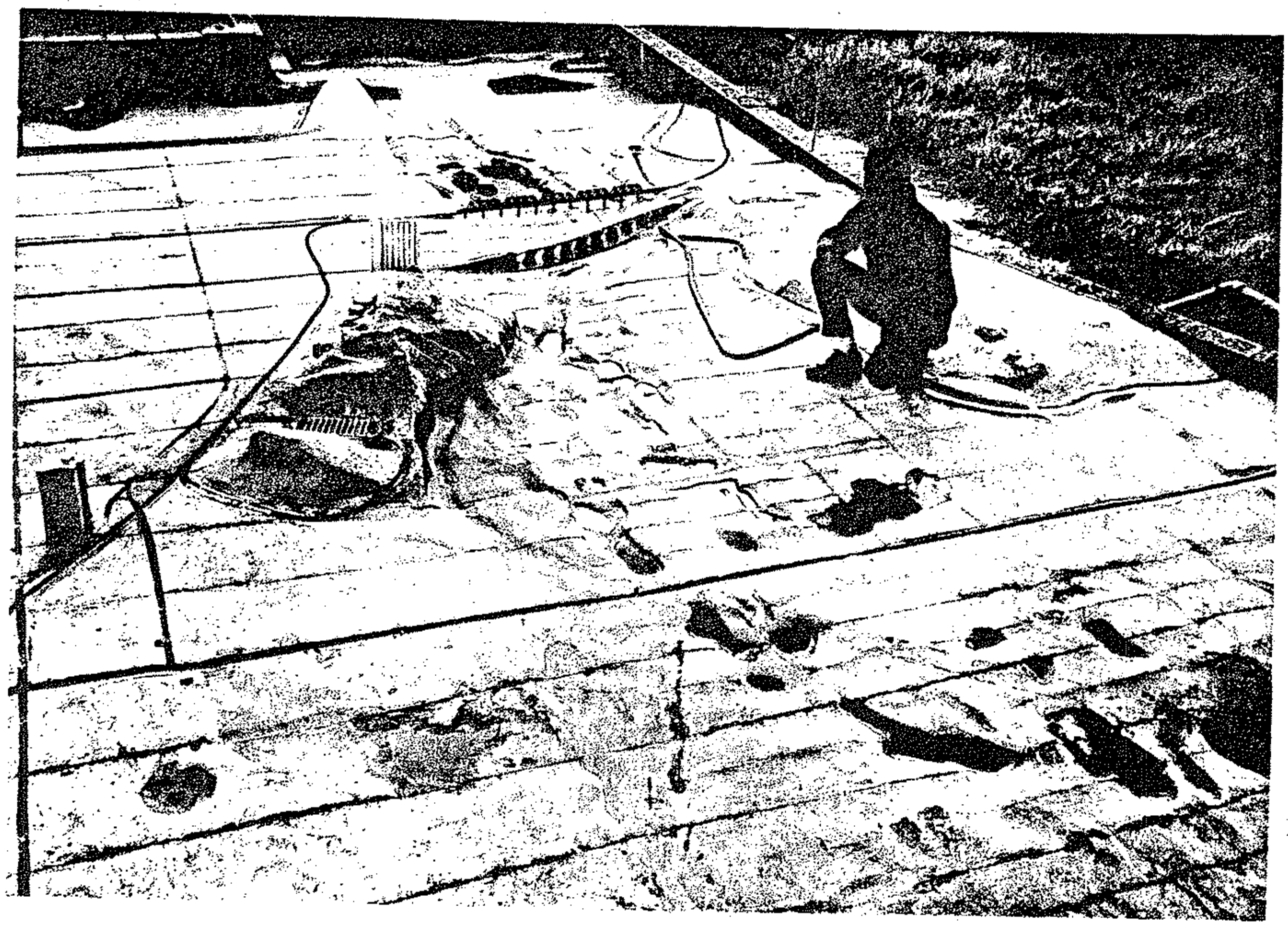
North bet secs 10 & 11
Va 13°35' E

40.00	Set a post for 1/4 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



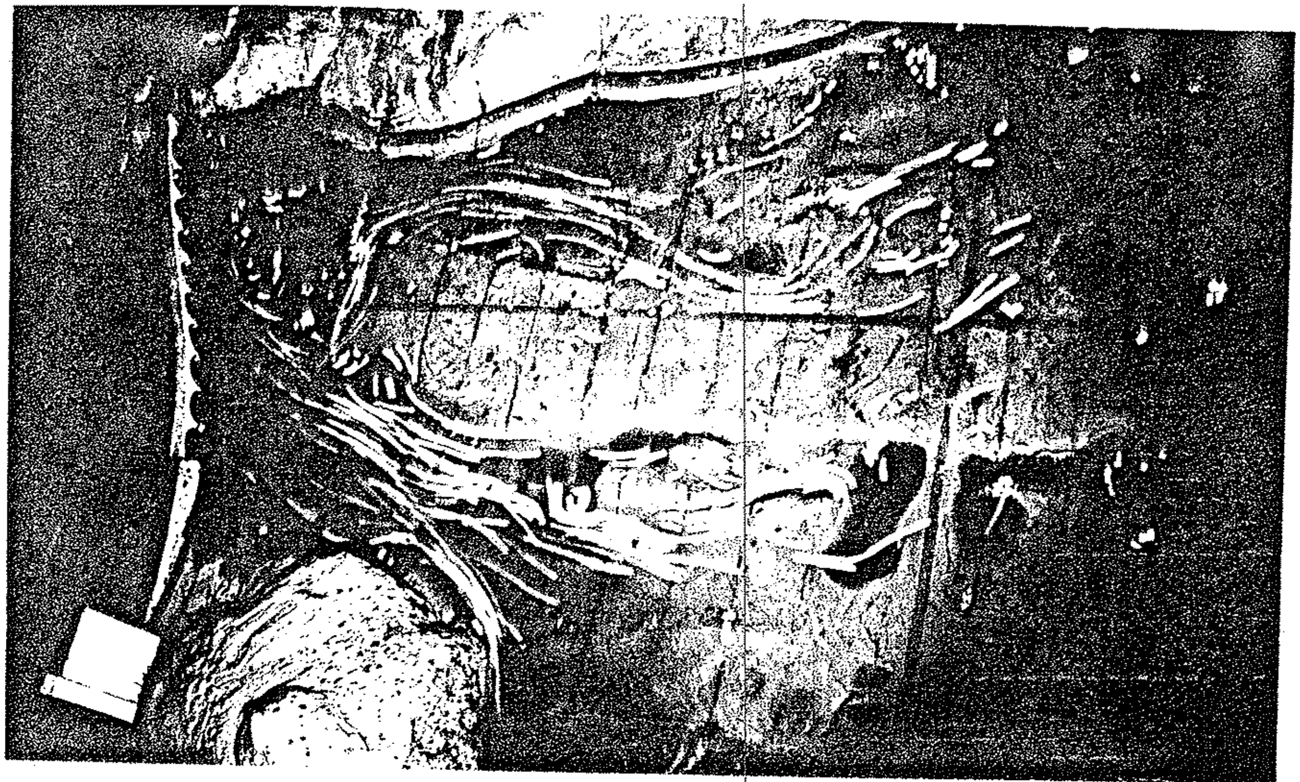
North

Scottsdale Road

PLATE E-1

General View
Hydraulic Model of the Salt River
Tempe, Arizona

Direction of
Flow



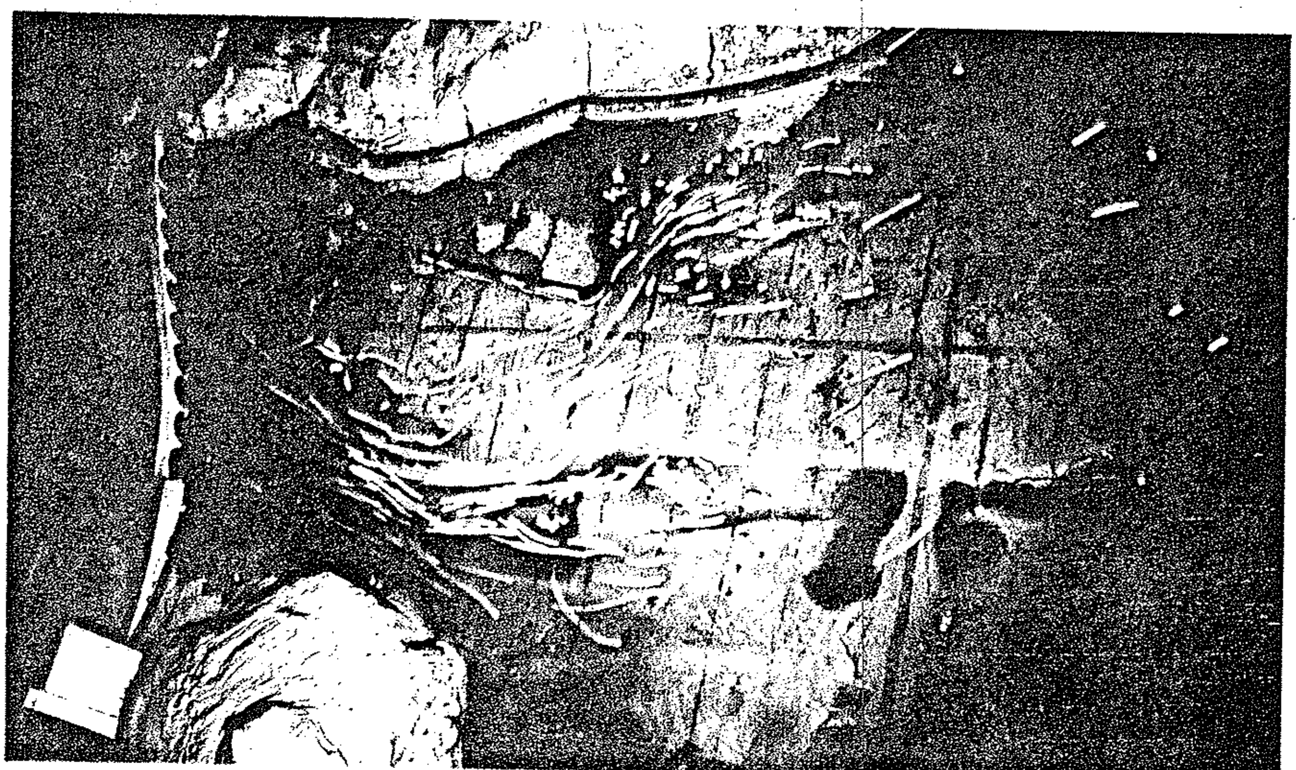


PLATE E-2

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

Direction of Flow

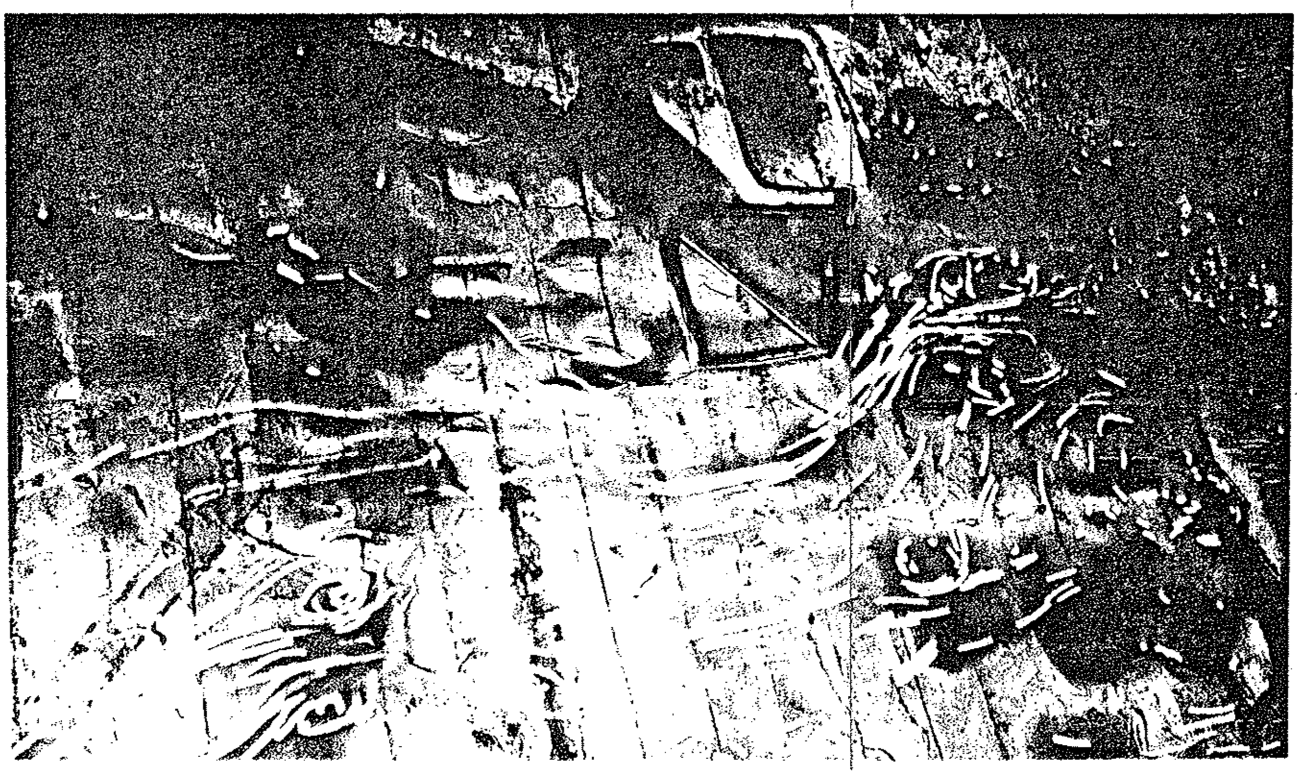


PLATE E-3

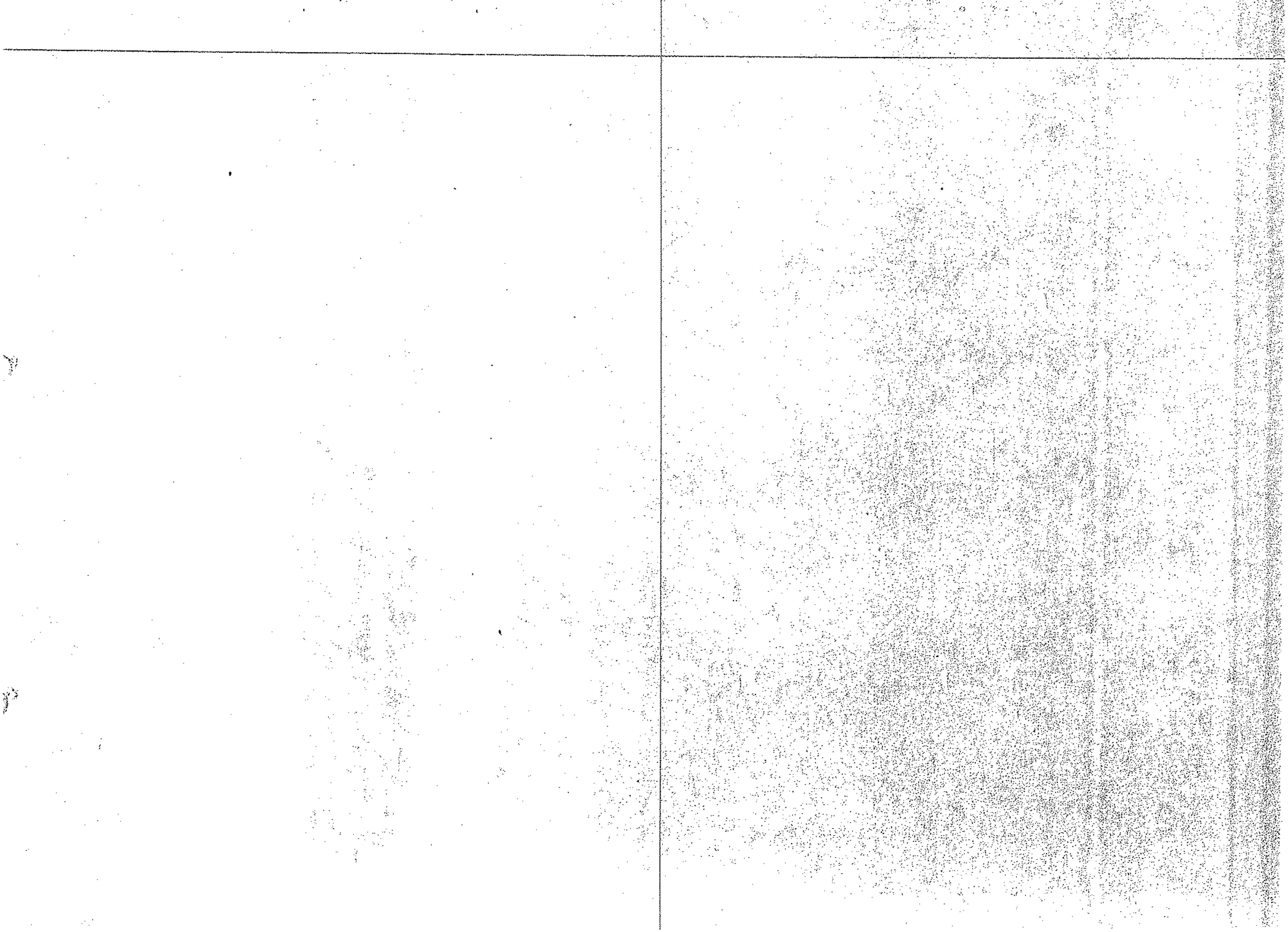
Model Study of the
Sewage Treatment Plant Facility
East of Scottsdale Road

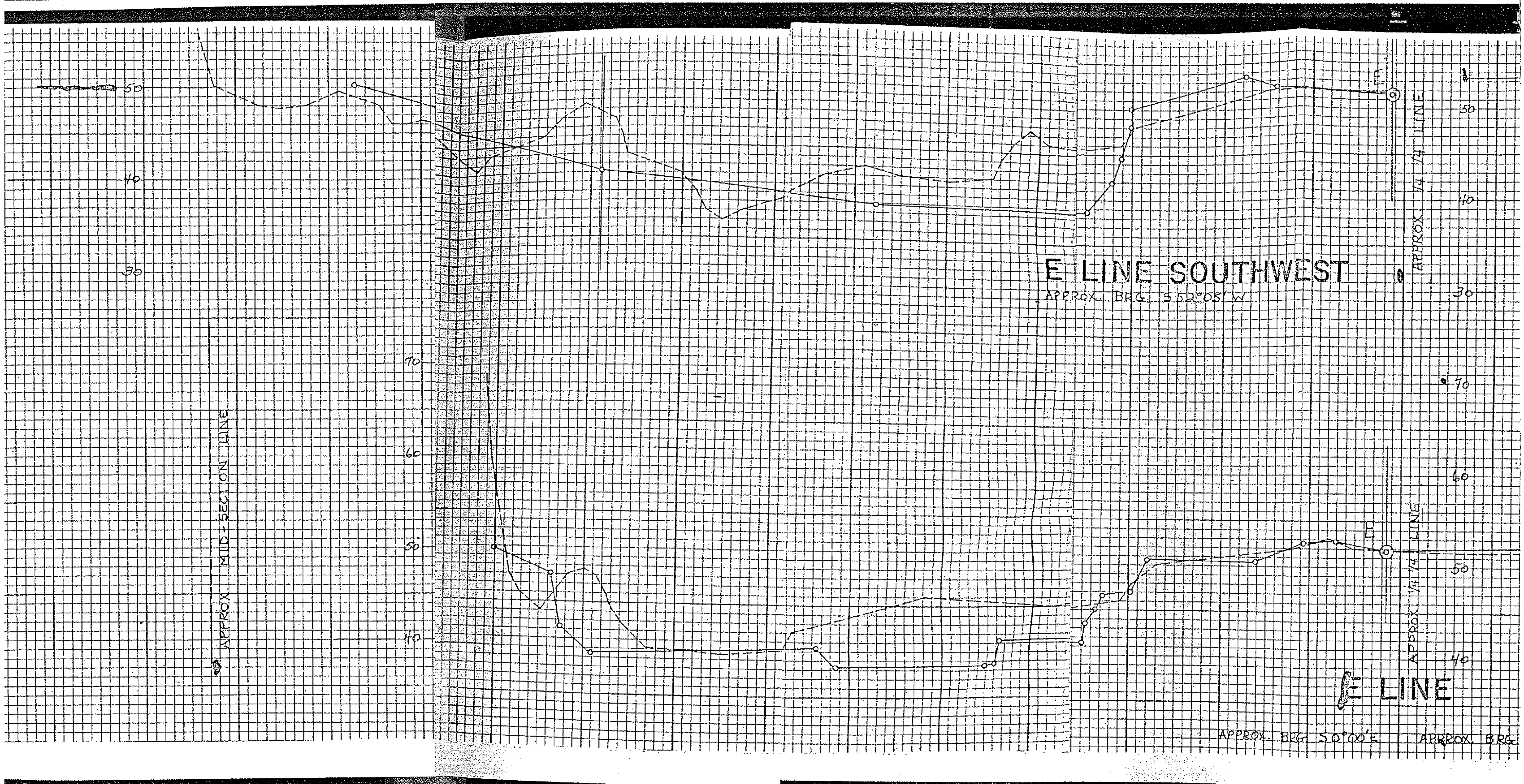
Direction of Flow

PLATE E-4

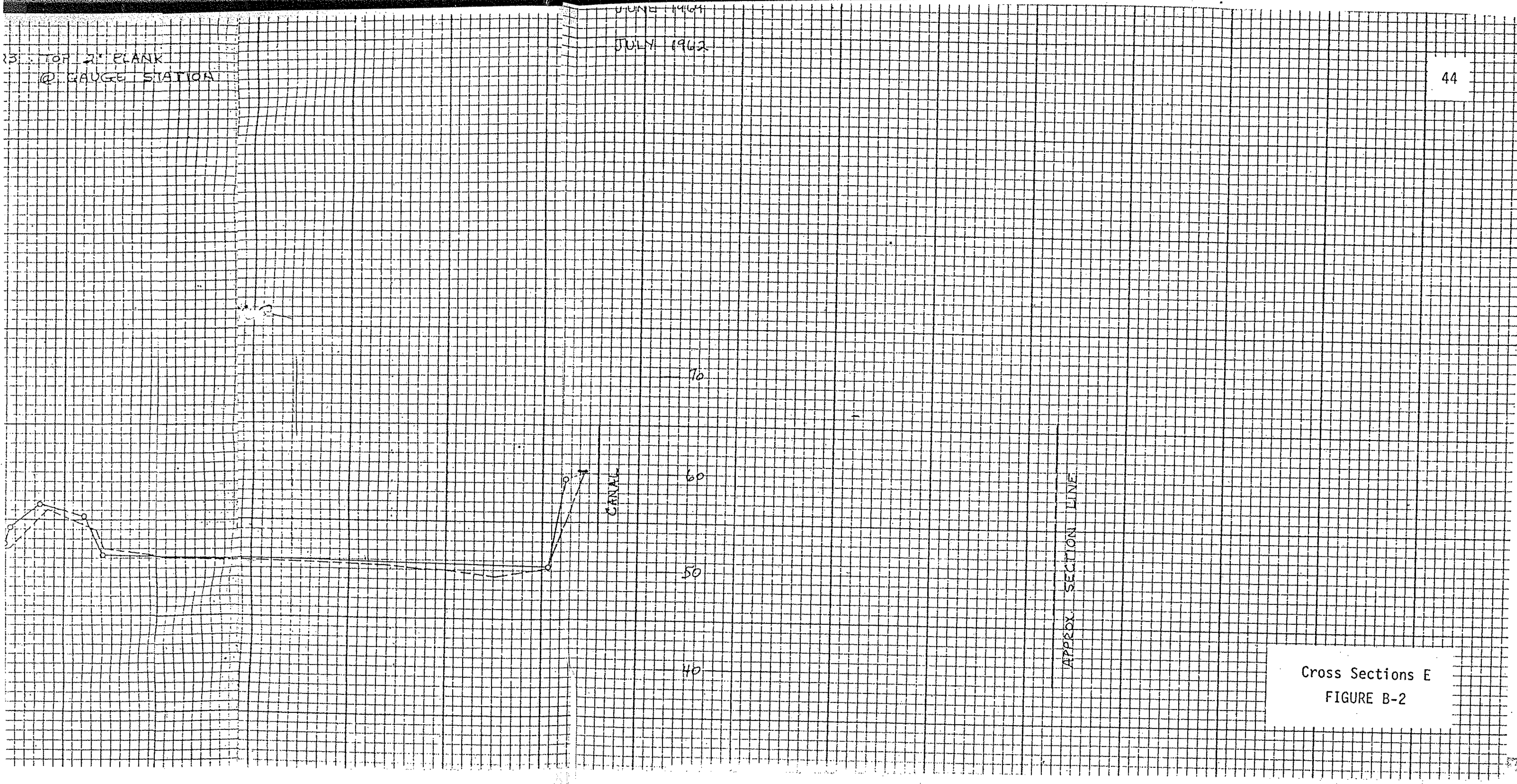
Model Study of the
Salt River Dike System
Immediately East of Scottsdale Road

story of Salt R. Channel, Tempe
U, P.F. Ruff 1971



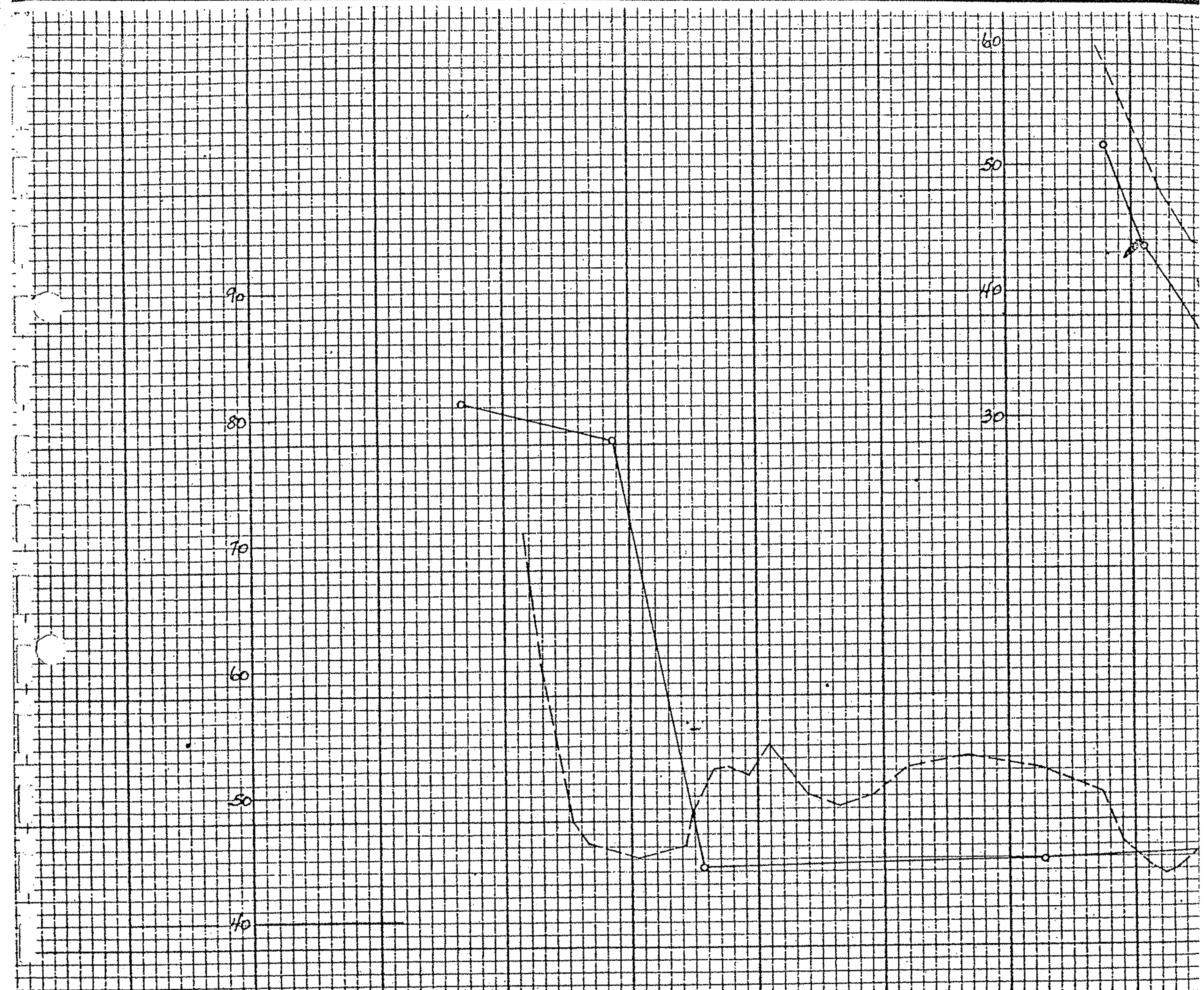


E LINE SOUTHWEST
APPROX. BRG. S 52°05' W
APPROX. 1/4 1/4 LINE
APPROX. MID-SECTION LINE
E LINE
APPROX. BRG. S 0°00' E
APPROX. BRG.

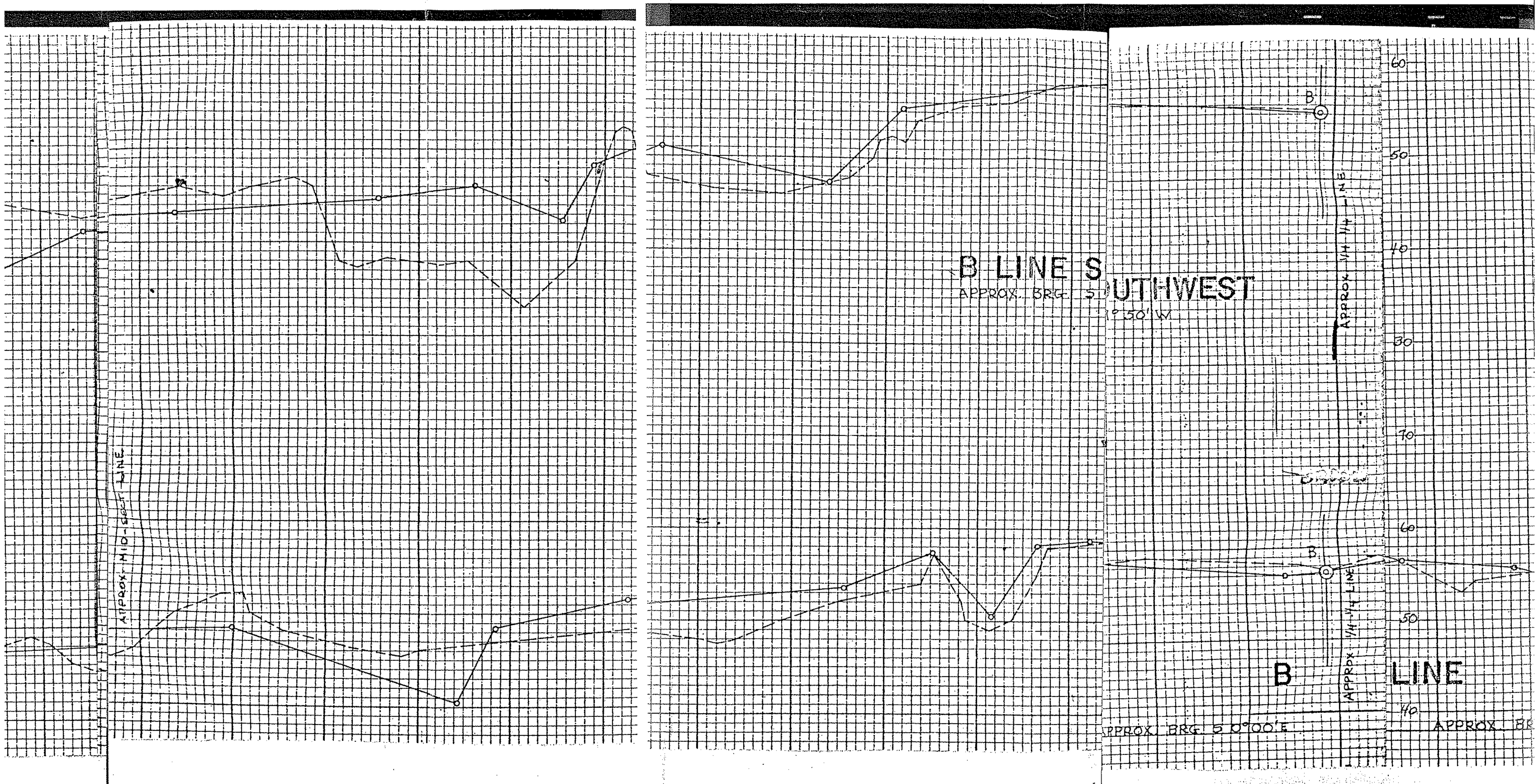


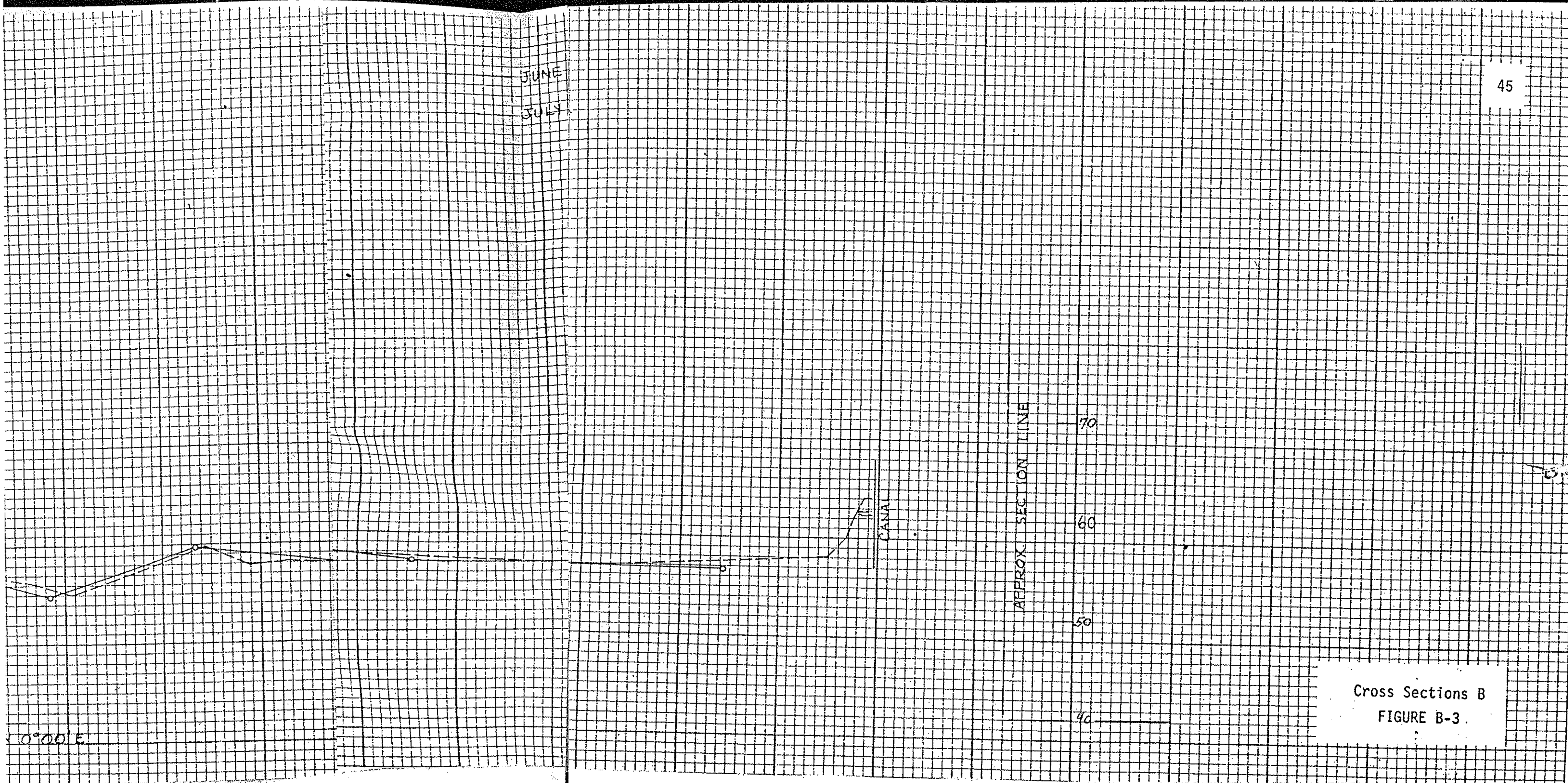
Cross Sections E

FIGURE B-2



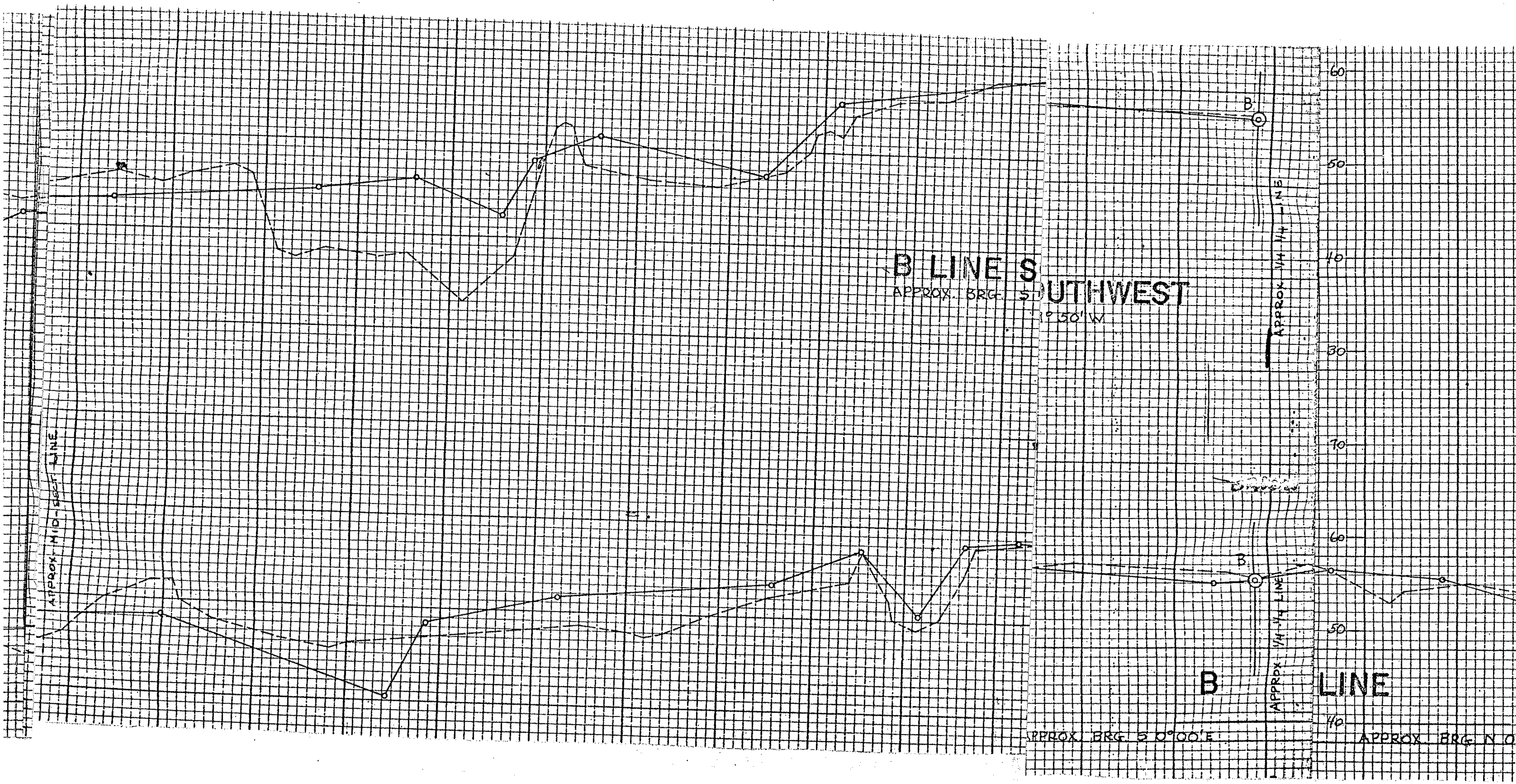
90
80
70
60
50
40
60
50
40
30


APPROX. MID-SECT. LINE
B LINE SOUTHWEST
APPROX. BRG.
B
APPROX. 1/4 1/4 LINE
60
50
40
30
70
60
50
40
B
B LINE
APPROX. BRG. S 0°00' E
APPROX. BR

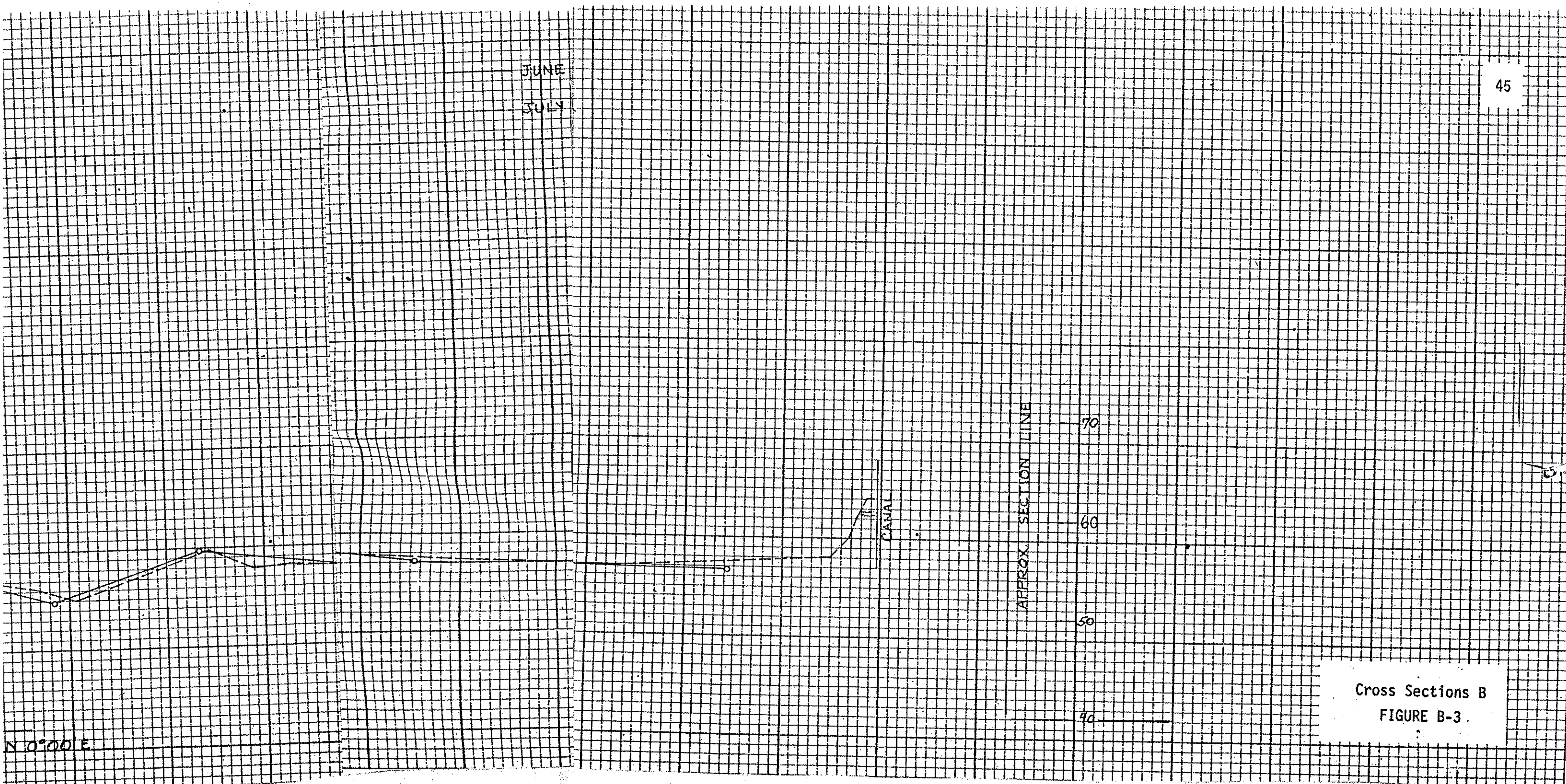


Cross Sections B
FIGURE B-3


90
80
70
60
50
40
60
50
40
30



B LINE SOUTHWEST
APPROX. BRG. S
°50' W
APPROX. MID-SECT LINE
APPROX. 1/4 LINE
B
60
50
40
30
70
60
50
40
B
APPROX. 1/4 1/4 LINE
B LINE
APPROX. BRG. S 0°00' E
APPROX. BRG. N 0



Cross Sections B
FIGURE B-3