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BEFORE THE ARIZONA NAVIGABLE STREAM ADJUDICATION COMMISSION

IN THE MATTER OF THE NAVIGABILITY OF THE GILA RIVER, FROM THE NEW MEXICO BORDER TO THE CONFLUENCE WITH THE COLORADO RIVER

No. 03-007-NAV (Gila)

GILA RIVER INDIAN COMMUNITY'S SUBMISSION

Pursuant to the direction of the Arizona Navigable Stream Adjudication Commission, the Gila River Indian Community states that it may use any of the materials identified in the attached Reference Materials at the hearing of this matter.

DATED this 14th day of January 2014.

GILA RIVER INDIAN COMMUNITY

By
Thomas L. Murphy

FILED on the 14th day of January, 2014 with:

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ANSAC No. 03-007-NAV

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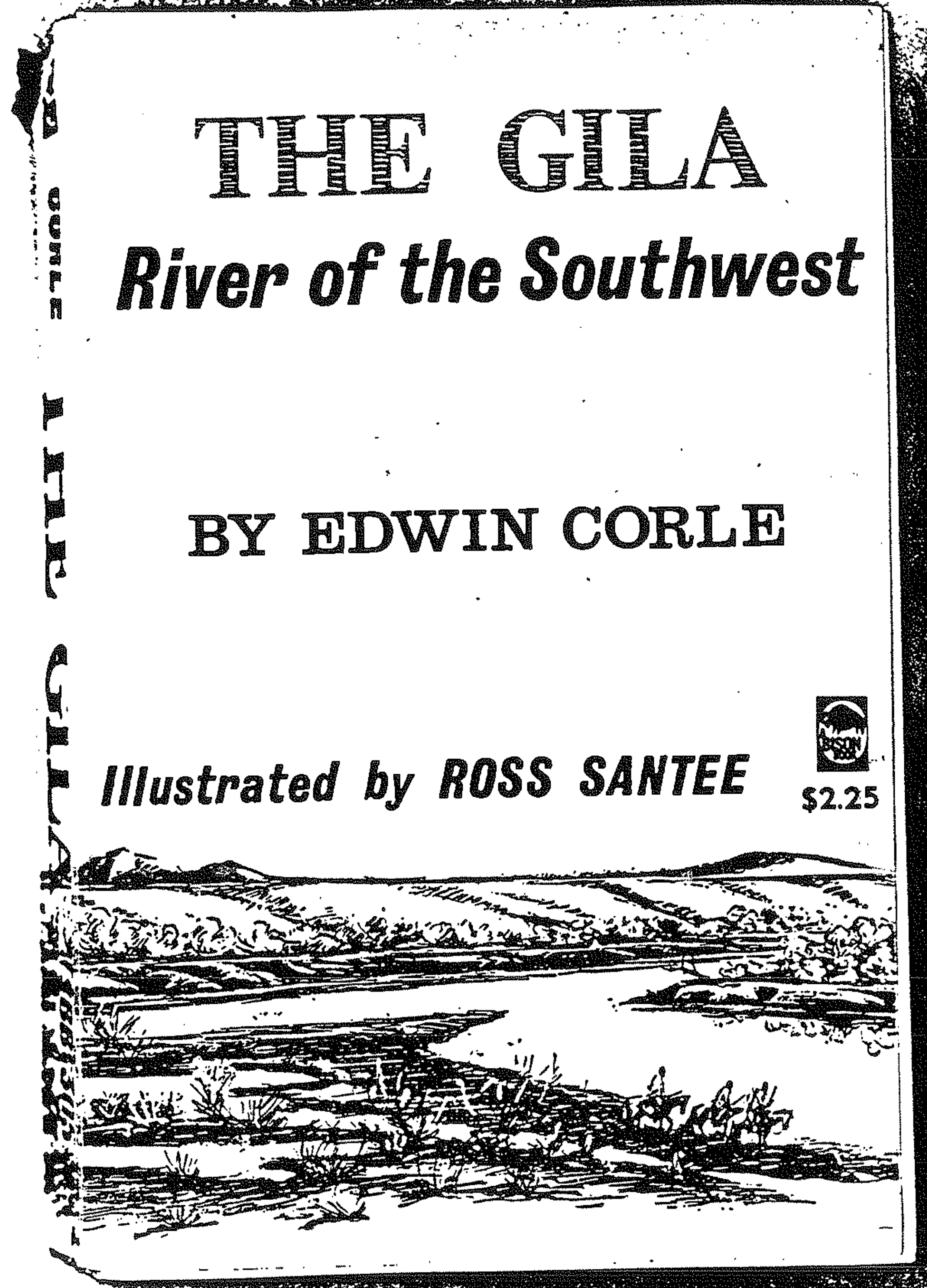

THE GILA

River of the Southwest

BY EDWIN CORLE

Illustrated by ROSS SANTEE

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Foreword

"The important thing about a river," wrote Captain Richard Bissell, an Ohio River pilot, "is that it is made of water, has fish in it, and steamboats, rowboats, or floating logs on its surface."

The Gila has been a changeable river throughout its lifetime of many millions of years, of which only the past twenty-five thousand years can be called history visible to man. It has never known a steamboat, very few rowboats, some floating logs, and only a fair assortment of fish. At one time it resembled the modern Everglades and at another time the Mississippi. In 1950 fully half its length, the lower river, was as dry as dust. Where it "flows" into the Colorado there hasn't been a drop of water come downstream in over four years. From its ice caves and raging mountain torrents, through its tortuous canyons and dam-impounded waters, across its broad desert valley to its parched, sandy and sunbaked confluence with the Colorado, this six-hundred-mile river of unpredictable liquid content has a history as long, as dramatic, and as significant as any in America.

The Colorado, entirely west of the Great Divide, might be called the river of the West; and the Rio Grande, entirely east of the divide, might be designated the international river. But the Gila is literally the river of the American Southwest. There is no other stream that even resembles it.

E. C.

General Kearny. They turned the animals over to Colonel Cooke, and again he recorded his admiration of the Gila Valley inhabitants:

> They live in cordial amity . . . and their religion consists in a simple belief in a great ever-ruling spirit. This seems to have proved a foundation for a most enviable practical morality. . . . Their dwellings are domed shape wicker work, thatched with straw or cornstalks, and from twenty to fifty feet in diameter; in front is usually a large arbor, on which is piled the cotton in the pod for drying; horses, mules, oxen, chickens, and dogs seem to be the only domestic animals; they have axes, hoes, shovels, and harrows. The soil is so easily pulverized as to make the plow unnecessary. . . .
>
> They have the simplicity of nature, and none of the affected reserve and dignity characteristic of other Indians, before whites. At the sound of a trumpet, playing of a violin, the killing of a beef, they rush to see and hear, with delight or astonishment strongly exhibited.

With all this happiness of environment, Colonel Cooke made his first mistake of the trip. He took a look at the Gila River, which was at this point, and would be today if there were any water in it, about four or five feet deep and 150 yards wide.

He decided to construct a boat, to be made of two wagon beds lashed together, and ballasted by two long cottonwood logs.

Lieutenant George Stoneman, whose self-shot thumb had now healed, was put in command of this first ship to attempt to run the Gila. The clumsy craft was overloaded. Colonel Cooke's thought was to lighten the burden of the wagon train, and to utilize water power by letting the Gila pull his boat downstream as if it were a raft. That plan might have worked on eastern rivers, but not on the unpredictable Gila.

Lieutenant Stoneman became the first skipper on the Gila River—and he regretted it. The improvised boat carried mostly meat and flour. At times the craft caught on sand bars and spun crazily. Once it was half submerged and Stoneman and his crew of three had to hustle the cargo ashore. Then the boat was freed of the sand bar and they had to moor it and reload. Irksome was the word for it. For in less than a mile it snagged on another sand bar and the same tedious process had to be repeated. As this kind of thing became the routine of the day, Stoneman decided he'd never get to the mouth of the Gila. So he lightened his ship by making a cache of half the cargo and eventually guided, pushed, and poled her to the lower end of the Gila, and beached her just in time to prevent her from being sucked into the more mighty Colorado. Here he met his commanding officer. Boating on the Gila, he reported to Colonel Cooke, was definitely not to be recommended to Washington. Cooke, being a man of adaptability, dropped the subject. And, without making an issue of it, he sent four men and four mules back upstream to salvage the cached meat and flour.

The battalion didn't find the Yuma Indians quite so co-operative as the Pimas and the Maricopas, but at least there was no hostility. It took three days to get the expedition across the Colorado to the California side. But by swimming the animals and fording the wagons it was finally accomplished at the site of the present city of Yuma, a point virtually the same as when Kearny had crossed. And the cumbersome first ship to navigate the Gila saw useful service at last as a ferryboat.

West of the Gila, across the dreaded Colorado Desert of California, the battalion met its greatest hardships. Mules and horses collapsed and some of the weaker members could not keep up with the advance guard. The party became strung out, and for a while it appeared that lack of water would take a heavy toll. But those in the lead, finding a spring in the mountains, sent back water to the stragglers, and at last the Mormon Battalion reached the security of Warner's Ranch and from there on their troubles were over.

And so was the war in California. Shortly before the battalion arrived in San Diego, Stockton and Frémont, plus what was left of Kearny's Army of the West, managed to crush the last vestige of native strength at Los Angeles. As a military force the battalion was no longer necessary, but it could indeed function as a colonizing force. In July of 1847, one year after its organization in Iowa, the battalion was marched to Los Angeles and its members honorably discharged.

The importance of the Mormon Battalion in southwestern history was institutional rather than active. It brought the Mormon culture through the Gila Valley to California, it proved that wheels could move west; and it instilled the idea in some men's minds that where wagon wheels could go so might, some future day, a railroad. It demonstrated that the Gila River was not practical for navigation, and it added considerably to the knowledge of remote Arizona. Because of the success of the expedition other wagons prepared to move west. Americans were on the march.

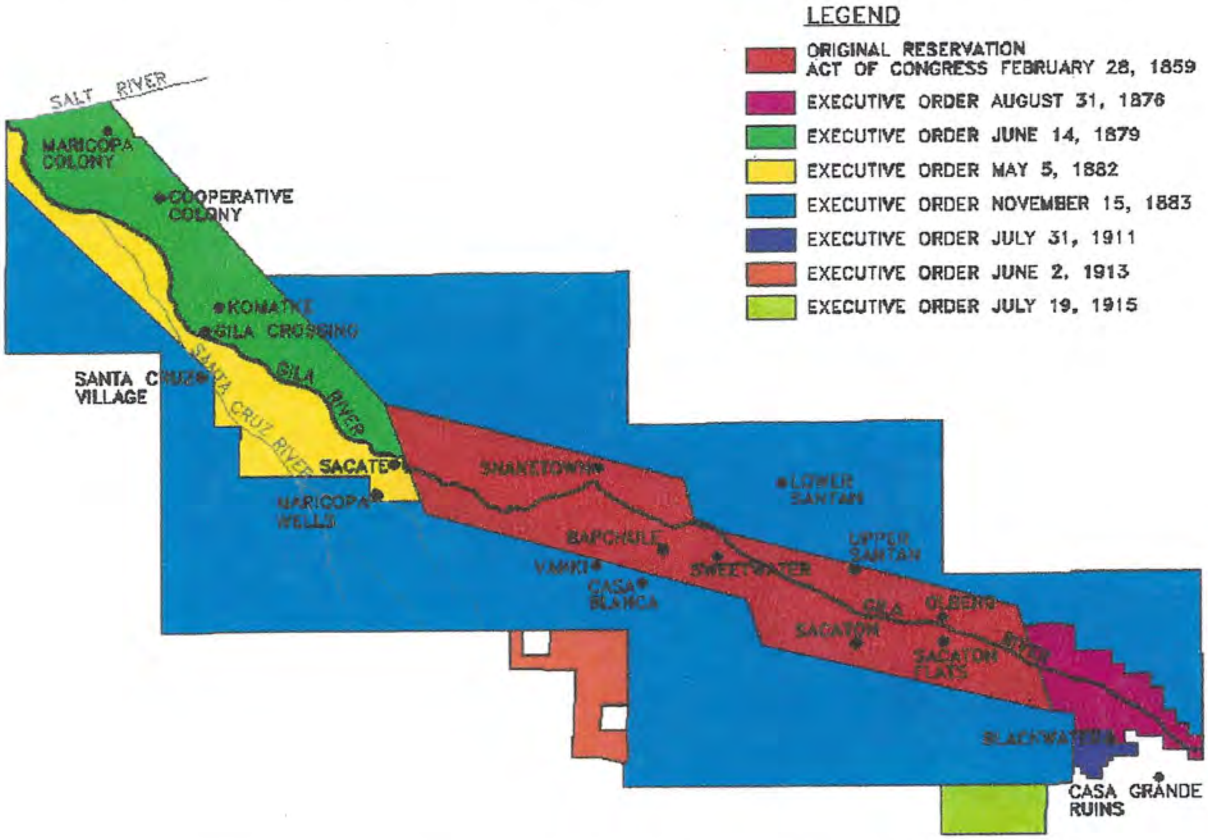
14

THE OATMAN CASE

IT WAS Hilaire Belloc who wrote, "R
odrama," and the story of the Oatman case
tragedy with a happy ending for only two
occurred on the banks of the Gila Rive
until 1857 that it received national pu
tional news value, and made its printed
its day. *The Captivity of the Oatman*
Royal B. Stratton sold thirty thousand co
remarkable sale for nonfiction in 1857. T
road west by the Mormon Battalion, ba
rance of Indians on the part of the fath
Oatman, and the murderous lust and i
Apaches—all were the causes of this stor

With the end of the Mexican Wa
covery of gold in California that same y
immigration of Americans moving west. T
Hidalgo, formally terminating the Mexica
States all of California, New Mexic
Arizona north of the Gila River. In oth
its mouth to the western boundary of
formed the international line. For the
was an unsatisfactory choice; but Wash
stand the topography of Arizona suffici
need of grabbing more of it. North of

Creation and Expansion
Of the Gila River Indian Reservation



Prepared for the
Gila River Indian Community
Office of Water Rights

By

Dr. Henry F. Dobyns

With Assistance From
Gookin Engineers, Ltd.

November 1, 2000

> was described as nearly as possible by natural objects the boundary lines of the proposed enlarged reservation, and at the same time urged the Commissioner's immediate attention to it, as I then, as now, considered it of much importance, both to the Indians and also to the government.[13]

Even though Levi Ruggles took a leading role in Euroamerican usurpation of Pima-Maricopa Gila River waters upstream from Gila River Indian Reservation, he honorably reported that Leihy had meant to reserve land and water "to meet the present, and probable future demands of these people."

The Pima-Maricopa Confederation received significant support from Arizona Territory's non-voting delegate to Congress during 1866 and early 1867. In the fall of 1865, Territorial Governor John N. Goodwin won election to the delegate's seat. Leaving Arizona Territory before the end of 1865, Goodwin served as delegate until 4 March 1867. Inasmuch as John N. Goodwin had previously served in the House in 1860-1862 representing Maine,[14] he probably wielded somewhat more influence than an ordinary territorial delegate. Goodwin informed Congress and the Executive branch with respect to the Pima and Maricopa 1859 reservation "that there is not within the limits of this reservation a sufficient area to supply the land for agriculture and pasture necessary for these tribes."[15]

In Washington, Indian Service bureaucrats discovered what they regarded as a reason for not acting to expand Gila River Indian Reservation. Their excuse was that Congress had created the original 1859 reservation. Consequently, the Indian Service officials reasoned, Congress would have to enlarge it.

> The superintendent has been instructed to enlarge the boundaries of their reservation so as to provide a sufficient area, which is at present not afforded, for agricultural and grazing purposes, as also to secure irrigation facilities. As the act of Congress authorizing the existing reservation restricts the area to its present extent, the enlargement will have to be confirmed by Congress in order to be made permanent; the matter will, in due time, be laid before that body.[16]

By that time, the question of prior water rights to Gila River flow was critical. Euroamerican colonization on Gila and Salt Rivers began in 1866 and increased annually. In the spring of 1868, Maj.-Gen. O. E. C. Ord, commander of the Military Department of Arizona, recommended reserving for Pimas and Maricopas lands upstream from Gila River Indian Reservation.[17] By 1869,

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[13] Ruggles, "No. 36," 163.

[14] Goff, *Arizona Territorial Officials, II, The Governors*, 37, 29.

[15] Clum, "14 December 1870, to Hon. C. Delano," 2.

[16] Parker, *ARCIA for 1869*, 19, 461.

[17] DeJong, "See the New Country," 371, 391, citing Ord to Devin, April 2, 1869.

> [f]our or five hundred settlers above them, on the Gila River, have built acequias and diverted the water from the Pima reservation, instead of returning it to the river as they should.
>
> The Pimas and Maricopas assert very justly that in a dry season their crops will be ruined in consequence of this action of the settlers, and so an unfriendly feeling has sprung up. The Pimas, having remonstrated in vain, are beginning to assert themselves by riding over the crops of the settlers, and in some cases by stealing their stock, &c. In due time this will lead to open war, if it is not checked.[18]

Two years after Delegate Goodwin left Congress, the Indian Service presented to the Secretary of the Interior its recommendation that "the superintendent, with the assistance of the agent, make such enlargement of the reservation, as may be deemed necessary, and report the same to this Department, to be submitted to Congress for appropriate legislation."[19] Consequently, on 4 August 1869, the Commissioner of Indian Affairs instructed Territorial Superintendent of Indian Affairs Colonel George L. Andrews

> to cause the extension of the reservation to be made and surveyed as above, and directed to avoid conflict, as far as possible, with other claims, but that when it was found unavoidable in protecting the interests of the Indians, to inclose lands claimed by settlers, and also to make a full report of all the facts, defining accurately the boundaries of the proposed extension; and in cases of conflicts, giving particulars in detail, so that the Department would be fully advised, and accompanying the same with a plat, with the boundaries of the reserve, the proposed extension, and the location of any conflicting claims accurately marked thereon.[20]

The United States army colonel acting as Arizona Territory's Superintendent of Indian Affairs agreed that Gila River Indian Reservation should be expanded.

> The subject of the extension of the reserve occupied by the Pimo and Maricopa Indians is one of no little importance, and the opinion expressed by Agent Ruggles, I fully concur in, and shall use my best efforts to place before the department at as early a day as possible, the survey, plats, &c., called for by the honorable Commissioner of Indian Affairs in his letter of August 4, 1869.[21]

By the fall of 1869, Levi Ruggles was on his way out of office as Gila River Indian Reservation agent. Clearly Ruggles and Superintendent Dent had never achieved a good working relationship.

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[18] Andrews, "No. 38," 1869, 535.

[19] Clum, "14 December 1870, to Hon. C. Delano," 2.

[20] Clum, "14 December 1870, to Hon. C. Delano," 2.

[21] Andrews, "No. 38," 646-647.

SONORAN DESERT TRADERS

The Pima-Maricopa Confederation

(*Akimel 'O'odham, Kohatk, Pee Posh*)

By

Henry F. Dobyns

15 September 2002

In the 1690s, Wa:k contained the largest population concentration that colonial explorers reported in Northern Piman country, 800 to 900 persons.[44] Wa:k's populousness suggests that it might have functioned as a trading center.[45] Certainly its size made Wa:k a significant market among Northern Piman settlements, along with San Agustin de Oiaur, with 800 inhabitants, a short day's journey down the Santa Cruz River at its confluence with the Rillito.[46]

Colonial explorers found Wa:k inhabitants raising macaws in 1701,[47] showing that at least part of its population participated in the international feather trade. The Pueblo Market absorbed numerous macaws, parrots, and their feathers which originated in the tropics or other macaw-raising ultra tropical settlements such as Casas Grandes, Chihuahua. The Akimel 'O'odham and other Northern Pimans were primarily middlemen in the macaw and parrot trade. They consumed some such feathers themselves. As late as 1723, Northern Piman warriors bound to battle donned red macaw plumes during their rituals.[48]

The Western Shell Trade

The 1697 post flood food crisis among the Akimel 'O'odham on the middle Gila River also revealed to colonial explorers Northern Piman-Northern Panya (*Hal Chedom*) commerce. After a single post flood growing season, the *Huhu'uhla* tribesmen residing at Au:p Oidak ("Enemy Fields") at the western terminus of the river's Great Bend imported white tepary beans from the Northern Panya trading center on the lower Colorado River.

More indicative of normal international commodity exchange between the Northern Panya trading center and the Kohatk trading center on the middle Gila River--Kohatk Oidak--was a buckskin wrapped around red hematite thoroughly worked into deer tallow. Northern Panya middlemen had routed that Northeastern Pai export southeast to Kohatk-on-Gila instead of bartering it to Cahuilla or Gabrielinos to their west. Always dreaming of striking it

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[44] Burrus, *Kino and Manje*, 348.

[45] In November, 1697, Juan M. Manje reported that "the natives of the great rancheria of the Va:k" carried off two children from hostile Apaches by lower San Pedro River warriors led by Chief Humari (Manje in Burrus, *Kino and Manje*," 338). Thus Manje implied Wa:k's participation in the colonial frontier slave trade.

[46] Manje reported counting 800 people in 186 houses (in Burrus, *Kino and Manje*, 347-48).

[47] Kino, *Kino's Historical Memoir of Pimeria Alta*, I:291-92 ["They gave us . . . red feathers of the many macaws which are raised here."]

[48] José Agustín de Campos, "Texto del Primero Documentos de Campos." Pp. 249-57 in *Etnologia y Misión en la Pimería Alta 1715-1740: Informes y Relaciones Misioneras*, Edición de Luis González R. México: Universidad Nacional Autónoma de México, 1977, 250.

rich, colonial explorers deluded themselves into thinking that the red stained melting tallow was mercury. A young man using the red hematite to paint his face reported that he traveled five days northwest to obtain it--at the Northern Panya trading center. The riverine Kohatk "generously shared their food with the soldiers" and lodged at least a missionary and army officer in a house made of poles covered with mats.[49]

Kohatk, other Piman, and Northern Panya traders traveled at least three paths between the middle Gila and lower Colorado Rivers. Prior to 1650, traders took a major trail due north from Shoo:tak shon and its Akimel 'O'odham companion rancheria *Skai'kaik* ("Many Rattlesnakes") on the north side of the stream to Salt River.[50] There, travelers turned downstream to Las Colinas, a redoubt-warehouse type settlement like Casa Grande. An area at the edge of Las Colinas where exclusively Lower Colorado River Buff Ware ceramic sherds have been discovered identifies where Northern Panya traders either camped during periodic visits, or perhaps resided year round at an Akimel 'O'odham port-of-trade.[51] The pathway paralleled Salt River downstream (westward) to its confluence with the Gila River. Then the trail curved around the Great Bend of the Gila River to where Centennial Wash flows--when it flows--from the west-northwest into the perennial stream. Traders often chose to leave the riverine oasis to follow Centennial Wash across the arid desert from mountain spring to mountain spring and the Colorado River.

Alternatively, traders could take a more circuitous route, following the Gila River all the way around the Great Bend and then westward along the lower reach to the trickle entering the north side from Aguas Caliente (Hot Springs). Another trans-desert trail conducted merchants to the Northern Panya trading center on the lower Colorado River. Piman guides led Jesuit explorer Jakob Sedelmayr over this route in 1744.[52] The newcomer could

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[49] Burrus, Kino and Manje, 210-11.

[50] David R. Wilcox, Thomas R. McGuire and Charles Sternberg, *Snaketown Revisited: A Partial Cultural Resource Survey, Analysis of Site Structure and an Ethnohistoric Study of the Proposed Hohokam-Pima National Monument.* Tucson: University of Arizona, Arizona State Museum, Cultural Resource Management Division, Archaeological Series No. 155, 1981, 98-101.

[51] Patricia L. Crown, "Analysis of the Las Colinas Ceramics." Pp. 87-169 in *The 1968 Excavations at Mound 8, Las Colinas Ruins Group, Phoenix, Arizona,* edited by Laurens C. Hammack and Alan P. Sullivan. Tucson: University of Arizona, Arizona State Museum, Cultural Resource Management Section, Archaeological Series No. 154, 1971.

[52] Jakob Sedelmayr, "Sedelmayr's Relacion of 1746," translated by Ronald L. Ives. Pp. 97-117 in *Anthropological Papers.* Bureau of American Ethnology, Bulletin 123. Washington, D. C.: Government Printing Office, 1939, 107.

confuse the trading path entering the lower Colorado River oasis. Sedelmayr did: "The sheep and deer, of which there are an infinite number on the banks of the river, where they go to drink, have made many wide trails in their wandering. The labyrinth of trails confused us, as we could not tell which was the trail of the people. On the valley floor these trails divide."[53] Walapai traders exchanged commodities at the Northern Panya trading center; they also carried commodities eastward to the Hopi Pueblos. In return, they transported Hopi textiles to the Colorado River trading center. Thus, Akimel 'O'odham obtained Hopi textiles, and perhaps ceramic vessels, via a long, circuitous trade route.

Pacific Coast Marine Shells. The Jesuit pioneer missionary among Northern Piman speaking natives, Eusebio F. Kino, S.J., was a cartographer. He explored the Colorado River delta and a portion of the Sonoran shore of the Gulf of California during his Piman mission which began in 1687. Earlier, Kino had sailed to the Peninsula of Lower California with Admiral Isidro de Atondo y Antillón early in 1685. Kino hypothesized that the Peninsula was not an island, as colonial maps then showed it, but truly a peninsula.

Kino saw blue abalone shells on the gulf coast of Lower California, but not on the Sonoran coast. Yet he saw abalone shells in a Piman speaking ranchería near the confluence of the Gila and Colorado Rivers on 21 February 1699. Kino reasoned that the abalone shells reached the Gila River overland, inasmuch as the natives living along the shores of the Gulf lacked craft sea worthy enough to carry them across it. Then the leader of the Gila River Cocomaricopas (*Kokomalik au:p,* the Piman term for the Southern Panya, or *Kavelt Chedom*) sent Kino a string of twenty abalone (blue) shells which he received at his Remedios mission on 20 March 1700.[54]

The Kavelt Chedom leader could have obtained California coastal abalone shells from two trading partners. One trade route is the Panya trading center to middle Gila River Akimel 'O'odham route with Centennial Wash and Agua Caliente alternatives already described.

The other route by-passed the Gila River, as a result of the amity-enmity network of lower Colorado River tribes. It started on the California coast in the modern Los Angeles

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[53] Sedelmayr, "Sedelmayr's Relación of 1746," 111.

[54] Earnest J. Burrus, S.J., ed., *Kino and Manje, Explorers of Sonora and Arizona; Their Vision of the Future: A Study of Their Explorations and Plans.* Rome: Jesuit Historical Institute, 1971, 114, 140, 155.

area, crossed the desert to the Colorado River Quechan. In Kino's time, two rancherías on the lower Gila River, immediately above its confluence with the Colorado, were inhabited by Piman-speakers and some Yuman-speaking Kavelt Chedom. The Pimans belonged to the northern band of the westernmost Hia' Ced tribe, then and later trading peacefully with the riverine Quechan and sharing their resources. The Hia' Ced were one of the Tohono 'O'odham tribes; they traded with the Akimel 'O'odham and the other Tohono 'O'odham tribes to their east. In 1706, Kino identified Quechan as the source of gift abalone shells sent to him at Sonoita.[55]

Probably the Northern Panya routed nearly all of the abalone shells reaching their lower Colorado River trading center eastward via their Walapai trading partners to the Hopi Pueblo of Oraibi. For the Pueblo peoples considered abalone shells sacred and utilized them in ceremonies. Consequently, the Northern Panya and Walapai traders could have anticipated more profitable exchanges at the Oraibi Pueblo gateway to the Puebloan Market than they could have anticipated from the Akimel 'O'dham. After all, the peoples along the southern trading route reportedly prosaically employed abalone shells as drinking cups.[56]

The Akimel 'O'odham apparently bartered primarily cotton textiles for their marine shell imports. They exported cotton blankets to the Northern Panya trading center on the lower Colorado River. The Northern Panya in turn exported some Gila River Pima cotton blankets westward to the Pacific coast tribes[57] which harvested abalone and sent abalone shells eastward.

The traders among the Northern Panya also dealt in Hopi woolen textiles that Hopi men wove from the wool of sheep they acquired from the Spaniards. Some Hopi blankets they routed southeastward toward the Akimel 'O'odham. In 1770, Francisco Garcés, O.F.M., visited the middle Gila River to baptize children afflicted by epidemic measles. West of the three rancherías comprising the Great Town of Shootak Shon,

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[55] Kino, *Kino's Historical Memoir,* II:185. Kino identified another tribal source of abalone shells as "Quiquimas," but this is merely a Northern Piman term for Piman-speakers of unknown affiliation, so constitutes no evidence of actual identity.

[56] "Complete Text of Salvatierra's Journal." Pp. 587-618 in Burrus, *Kino and Manje*, 591.

[57] Ezell, *The Hispanic Acculturation of the Gila River Pimas*, 29; George P. Hammond, "Pimeria Alta After Kino's Time," *New Mexico Historical Review* 4 1929) 220-38, 231.

Garcés passed two Kaveltchedom rancherías. He reached the second on 26 October. "There I arrived at noon, and saw a lot of new Hopi blankets."[58] In November of 1775, Garcés described the Shootak Shon Kohatk and Akimel 'O'odham of the other middle Gila River rancherías as wearing both cotton and woolen blankets. "Go dressed do these Indians in blankets of cotton (*fresadas de algodon*) which they fabricate, and others of wool, either of their own sheep or obtained from Moqui."[59]

Minerals. At least one precious stone apparently passed through the Northern Panya trading center en route to the Akimel 'O'odham. Turquoise excavated from the earlier (pre-redoubt-warehouse) portion of *Skai' Kaik* ranchería was quarried in Southern Paiute territory in modern Southern California, near modern Baker.[60] Ancestral Chemehuevis--the southwesternmost Southern Paiutes--conceivably exchanged that turquoise with Northern Panya traders for marine shells from the Gulf of California which ended up on sites in Death Valley.[61] The Northern Panya could then have exchanged the precious blue/green stones over the Aguas Calientes or Centennial Wash routes to the middle Gila River (or at that period over the Walnut Creek Trail to the Northern Piman traders on the middle Verde River). From Tuzigoot, traders carried turquoise along trails paralleling the Verde River downstream to its confluence with the Salt River. There they turned westward downstream to the Akimel 'O'odham market on that stream and on the middle Gila River.

Turquoise has been persistently valued by the Akimel 'O'odham. In the early 1870s, Indian Agent Capt. F. E. Grossman reported that Gila River Pimas picked up turquoise from the ground surface near ruined earlier villages. "Stones of this kind are highly prized by the Pimas, and worn as charms."[62] .

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[58] Francisco H. T. Garcés, Diario que se ha formado por el viaje hecho al Rio Gila," translated by Paul H. Ezell. Archivo General de la Nación, Ramo de Historia 396.

[59] Francisco H. T. Garcés, *On the Trail of a Spanish Pioneer: The Diary and Itinerary of Francisco Garcés (Missionary Priest) In His Travels Through Sonora, Arizona, and California 1775-1776*, translated by Elliott Coues. New York: Francis P. Harper, 1900, I:108.

[60] Anne Sigleo, "Turquoise Mine and Artifact Correlation for Snaketown Site, Arizona," *Science* 189:4201 (1975) 459-60; Haury, *The Hohokam: Desert Farmers & Craftsmen*, 277-78.

[61] Richard E. Hughes and James A. Bennyhoff, "Early Trade." Pp. 238-55 in *Great Basin. Volume 11*, edited by Warren L. D'Azevedo, in *Handbook of North American Indians*, Gen. Ed. W. C. Sturtevant. Washington, D. C.: Smithsonian Institution, 1986, 254.

[62] F. E. Grossman, "The Pima Indians of Arizona." Pp. 407-19 in *Twenty-Sixth Annual Report of the Board of Regents of the Smithsonian Institution . . . for the Year 1871.* Washington, D. C.: Government Printing Office, 1873, 410.

Chapter 3

Akimel 'O'odham Irrigation Horticulture

The extant historical and anthropological literature about Gila River Pimas and Maricopas describes their aboriginal crop irrigation technology in oversimplified terms. This analysis attempts an accurate, yet reasonably brief, description.

Akimel 'O'odham Canal and Ditch Technology

The Gila River Pimas employed not one kind of irrigation ditch, or *waikka*,[1] but a range of field laterals, ditches, and primary canals to convey irrigation water from the Gila River to fields with growing crops. This complex technology reflected many centuries of experience with the Gila-Salt River oasis and the streams sustaining it.

Default: subterranean irrigation

Each *shon* along the middle reach of the Gila River fed and maintained a pond (*shongam*)[2] or lake (*Gu shuhdagi*) surrounded by marsh rich in shellfish, fish, aquatic vegetation, endemic and migratory waterfowl, and oasis and desert game animals drinking the water. The pond and marsh water as well as the surfacing aquifer sub-irrigated some acres of crop land surrounding each marsh. The Gila River Pimas had only to sow seed in these sub-irrigated fields, pull or hoe weeds, and harvest the crops on these naturally irrigated fields. This was technologically the simplest style of oasis horticulture, so it is labeled the "default" mode.

Dual function primary canal

Hydrostatic pressure in the aquifer kept ground water surfacing at the several *shoshon* at a fairly steady rate. Despite the high rate of evaporation from the pond and marsh surface, sufficient water surfaced via the shon so that the pond or marsh overflowed, even when dammed by beavers. The Akimel 'O'odham excavated canals to conduct that pond-marsh overflow to cultivated fields down-gradient in the middle Gila River Valley--approximately west-northwest.

Being riverine springs, the *shoshon* were close to the Gila River channel or in its

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[1] Dean Saxton & Lucille Saxton, *Dictionary: Papago & Pima to English, English to Papago & Pima.* Tucson: University of Arizona Press, 1969, 65.

[2] Saxton and Saxton, *Dictionary*, 85, 78.

1694 and 1697, failed to mention the "island."[10] Kino's not mentioning the island is, of course, not conclusive. He could have seen it and not reported it; he could have not noticed it.

On the other hand, Kino's description of Casa Grande furnished good clues to the chronology of Blackwater village's primary irrigation canal abandonment and replacement. In 1697, the Casa Grande-Blackwater village's main canal remained very visible, with embankments three yards high and six or seven yards wide. "This very great aqueduct, as is still seen, not only conducted the water from the river to the Casa Grande, but at the same time, making a great turn, it watered and enclosed a champaign many leagues in length and breadth, and of very level and rich land."[11] The condition of the canal in 1697 indicates that it had then not long been abandoned, inasmuch as a canal of such dimensions disintegrates quickly without annual maintenance.

Kuupa

The instream structure diverting stream flow into a primary irrigation canal was crucial to Akimel 'O'odham pre-Columbian and historic life as River People. The Akimel 'O'odham called this diversion structure *kuupa*. The English language lacks a word of equivalent specificity. A dam touches both banks of a stream, and backs up stream flow even if it is not high enough to impound it. A dam may be constructed of metal, concrete, stone, squared wooden pieces, soil, and so on. *Kuupa* may be glossed in English as "river water flow diverting structure made entirely of local vegetative materials." The kuupa was central to Akimel 'O'odham life as irrigation gardeners and farmers.

Most Akimel 'O'odham and Pee Posh uses for the mesquite tree and its products can be equated with Euroamerican or European uses of trees in analogous habitats. One distinctive although not unique Gila River Pima and Maricopa use for mesquite tree trunks was historically crucial to Akimel 'O'odham crop irrigation, and even to the self image as

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[10] Kino, *Kino's Historical Memoir of Pimeria Alta*, I:127-29; 172-73. Lacking writing, cities, the wheel, animal power, etc., the Hohokam culture did not qualify as a civilization. The Hohokam did not, on the other hand, abruptly disappear in A. D. 1450, although most regional archeographers have inferred a magical (usually labeled "mysterious") disappearance at that time. The "disappearance" amounted to an Akimel 'O'odham abandonment of massive public structures and the Casa Grande-Blackwater primary canal, one village migrating a short distance to the riverside near Blackwater Slough, and a population crash which the author attributes to Old World contagious diseases transmitted by Native American traders and dates to A. D. 1520-1650.

[11] Kino, *Kino's Historical Memoir of Pimeria Alta*, I:172. *Champaign* (French) = *campiña* (Spanish).

THE STATE OF ARIZONA

OFFICE OF THE STATE CLIMATOLOGIST

MAJOR STORMS AND FLOODS IN ARIZONA 1862-1977

Compiled from the records of the National Weather Service

Robert W. Durrenberger
Office of the State Climatologist

Robert S. Ingram
National Weather Service

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October 1895

A railroad bridge near Maricopa was ripped out by floods on the Gila.

October 1896

On October 1, two cloudburst in the Whetstone Mountains sent flash floods through Benson. Two mothers and four children drowned.

September 1897

On the 11th and 12th, nearly all crop correspondents reported water plentiful, the ground moist on the ranges, water holes full, and the streams supplying the canals and ditches with water needed for irrigating purposes. The rainfall at a few places was excessive, and downpours caused short-lived floods that damaged the aggregate canal and other property to a considerable extent. An excessive fall (1.89 inches in fifty-five minutes) occurred at Phoenix on the 11th. The shower also covered the valley below Phoenix. From previous recent lighter rains in the valley above Phoenix and in the mountainous part of the Salt River watershed, the river was well up and the canals full when the storm occurred. The river was not able to hold the additional supply. The banks gave way in many places, and the country was flooded for a few hours.

Severe wind and rain hit Tempe also. The Salt River was nowhere fordable and people were obliged to cross the river on foot by way of the railroad bridge.

July 1898

The Florence stage due at Mesa on the night of the 15th did not reach there until noon on the 16th. The delay was caused by the rise of the Gila at Riverside where the stage from Globe had overturned in the river, throwing all the mail and two passengers into the raging current.

Reports from the Phoenix Daily Enterprise of July 19 stated: "Even the most incredulous now believe that there has been rain in the mountains. The town ditch is brim full and running over with muddy water. For several blocks through the city the overflow has been so great that one could have floated over the vacant lots in a skiff."

The Holbrook Argus reported on July 30 that two Indian girls were killed when they rode onto a bridge on the flooded Puerco. Bystanders shouted warnings, but the bridge gave way and the girls were carried downstream. Efforts to save them were of no avail.

December 1898

The month was remarkable for the general severity of the weather, and this severity was evidenced not only by reports received from voluntary observers in all sections of the Territory reciting personal experiences, but also by a comparison of the mean temperature of stations, which showed a deficiency of nearly five degrees.

With the exception of the southwestern part, a snowstorm pervaded the whole Territory, the snowfall recorded varying from a trace to thirty inches. In the vicinity of Phoenix, the snow melted almost as fast as it fell; but it was estimated that the measurement would have exceeded six inches had the snow lain upon the ground. Since the meteorological records of this station extend over a period of only three years and during that time there is no record of snow, we depend upon tradition when we state that it was the heaviest snowfall within the recollection of the oldest inhabitant. The snowfall apparently occurred on the 10th. As the weather observer at Peoria stated: "On the 10th it snowed about twelve hours commencing about 1:00 a.m. and continuing until 12:00 midnight, making about three inches on the level which remained on the ground forty-eight hours before melting. This was the greatest snowfall ever recorded at this station."

January 1905

The rainfall was decidedly in excess of the normal amount over the greater portion of the Territory during January. That which fell occurred principally between the 8th and 18th. In Yavapai, Mohave, Coconino, Navajo, Apache, Graham, and Gila counties, the depth of snowfall was greater than for several winters past. In consequence, the runoff produced by the melting snow and large rainfall flooded many streams beyond their banks. In the Salt and Gila River watersheds, some damage was wrought by the floodwaters which washed away railway and turnpike bridges, embankments, dams, and telephone and telegraph poles and delayed traffic for about ten days. At the end of the month, there were from three to five inches of snow upon the ground in the northern tier of counties and a much greater amount upon the mountains. In the mountain ranges within Maricopa county, a thin covering of snow was visible until the 27th.

February 1905

Frequent and unusually heavy rainfall was measured throughout the Territory. In some localities, particularly Maricopa, Gila, Yavapai, Pinal, and Coconino counties, the monthly amounts ranged between 3.00 and 10.00 inches. At Phoenix, the total for February was 4.64 inches. The amount recorded this year to date is 7.95 inches--2.38 inches greater than that which occurred during the entire year of 1904. There was slightly less snowfall in the mountains than during January. That which fell in the northern sections of the Territory during the first two decades began to melt slowly on the 21st, and by the end of the month the runoff, augmented by the rainfall, filled the river beds to overflowing and caused several washouts.

March 1905

There was frequent and heavy rainfall in the south and heavy snowfall in the north portion of the Territory from the 1st to the 18th. Farmwork was practically suspended during the second decade of the month. Rapidly melting snow produced flood stages in the Salt, Gila, and Little Colorado basins, which washed lands badly, injured crops, and caused much damage to railroad property, thereby delaying traffic for several days.

April 1905

Above normal precipitation continued over much of the Territory. In the northern counties farm work was greatly delayed by the moist condition of the soil and by the thick coverings of snow. There, grass grew very slowly. Lands were irrigated in the central and southern counties according to the small need of water for growing crops. The supply of water was adequate for all purposes.

November 1905

Precipitation was excessive over the entire Territory during November, the departures ranging from plus 1.25 inches to plus 5.00 inches. Twenty to 40.0 inches of snowfall was measured over the San Francisco range near Flagstaff and 11.0 to 20.0 inches over the Bradshaw range near Prescott. This is considered the greatest depth of snow on record for November. The heavy precipitation of the 26th swelled the streams to very large proportions, washed roadbeds, and damaged toll and railway bridges.

August 1906

The precipitation was greatly in excess of the normal with the exception of a few localities in the southern counties where the departures ranged from minus 0.75 of an inch to minus 1.60 inches. The departure over the northern counties was plus 1.29 inches; and, for the western section, the departure was plus 1.52 inches.

The runoff produced by the generous and heavy rains of the first two decades added large volumes of water to the bounteous supplies within the river beds. Many of the streams were unfordable from the 13th to the 21st. The depth of water within the river beds throughout the month was variously estimated at being between three and eight feet. The supply of water was so plentiful that the larger canals and cross-cut canals were running under full head and flow during the entire month without any intermissions. At the end of the month, the volume of summer irrigation water available was fully 30 percent greater than the supplies of any other summer during the past six years.

December 1906

During the month, there was excessive precipitation. The northern division received the largest amount of precipitation and the southwestern section the smallest. Under the influence of the warm rains of the 1st, 2nd, 3rd, and 4th over the watersheds, the accumulated snow of November melted rapidly. This runoff filled the river beds, causing freshets in many of the streams and severe floods in the San Francisco River, a tributary of the Gila, on the 3rd, 4th, and 5th, whereby many lives were lost from drowning, much property was destroyed, and railroad traffic was delayed for more than a week. Additional rain and snowfall on the 12th, 26th, and 27th kept the Colorado, Little Colorado, Gila, Salt, San Francisco, San Pedro, and Verde rivers at high and unfordable stages during the last half of the month.

October 1907

Exceptionally heavy rains occurred over the entire Territory and were general on the 4th, 5th, 15th through 18th, 23rd, and 31st.

At most of the stations in southern Maricopa, western Pima, and Yuma counties, the amounts that fell in October were in excess of the total amounts of precipitation recorded during the preceding six months. At Mohawk Summit, the heavy rains of the 23rd damaged county roads and railroad beds, delaying traffic for several days. The region of greatest precipitation embraced the San Francisco, the Black Mesa, the Mogollon, and the Mount Graham ranges and extended from northern Coconino County southeastward to northern Graham County. The amounts within this area ranged from 2.70 inches to 8.50 inches. As usual, the area of least precipitation included Pima, southern Pinal, southern Maricopa, and Yuma counties, the amounts varying from 0.86 of an inch at Vail to 1.32 inches at Yuma.

February 1908

The average precipitation was largely in excess of the normal, being exceeded only twice during the past twelve years, in 1901 and 1905. Precipitation was general over the Territory on the 3rd and 4th, the 10th through 12th, and the 22nd. The precipitation on the 3rd was exceptionally heavy, with amounts equalling or exceeding 2.00 inches reported at a number of stations (maximum 4.55 inches at Pinal Ranch).

On the 3rd and 4th and the 9th through 13th, the combined rain and snowfall produced a large runoff in the upper drainage areas of the Salt, the Gila, the San Pedro, the Hassayampa, the Auga Fria, and the Bill Williams Fork rivers, filling the river beds to moderate depths for their entire lengths.

December 1908

The average precipitation for the Territory was largely in excess of the normals. In the northern counties snow fell on the 3rd, and there was alternating rain, sleet, and snow from the 14th to 17th. Rain occurred in the southern counties on the 3rd, 14th to 16th, and on the 26th. The area of greatest precipitation covered the Bradshaw, the San Francisco, and the Mogollon ranges, the amounts ranging from four to seven inches. The heavy rainfall of the 15th and 16th caused some damage from washouts in Navajo and Coconino counties.

March 1912

The month was cold and stormy. The greatest monthly amounts of precipitation were reported from stations in the central and south central portions of the state. Reporting stations throughout the state, however, almost without exception recorded monthly amounts of from two to four times their respective monthly averages. A general storm on the 9th and 10th contributed largely to this excess although there were an unusual number of lesser storms during the month.

July 1914

The month was chiefly notable for the frequency of showers at elevations above two thousand feet and for the prevalence of an unusual amount of cloudiness at lower levels in the southwest.

A comparison of the July records for the state for the last eighteen years shows that there has been no preceding July on record with so many rainy days and so few clear days even though in most years the temperature has held higher than that of the current month and in two instances the rainfall has been greater.

December 1914

The excessive precipitation was the most notable feature of the month's weather, the monthly average for the state never having been equalled in December during the eighteen years of authentic record and having been exceeded only four times in other months during the same period.

Two general storms occurred during the first half of the month. The first important snowfall of the season in the mountain districts came with the storm of the 1st and 2nd. From the 17th to the 24th, inclusive, rain or snow fell every day over the greater part of the state, and this, together with another heavy rain on the 27th with intervening unsettled weather, constituted the most protracted and excessively stormy period that has occurred in Arizona for many years. Floods resulted in the various streams, dry beds, and washes of the southern half of the state, causing considerable damage to bridges and to the diversion dams of the smaller irrigation projects.

December 1915

Precipitation was about twice the normal amount. The excess was attributed to the heavy amounts that occurred in the storm at the end of the month. Periods of stormy weather lasting two or three days began on the 4th, 14th, and 29th. In the central part of the state, the storm of the 29th through 31st was one of the heaviest that has ever occurred. New records of heavy snowfall were established at many places in the Verde and Agua Fria watersheds. At Flagstaff, several poorly constructed buildings collapsed from the weight of the snow. During and following the storm, there was great difficulty in moving range stock to places with feed and shelter, but no serious losses were reported.

January 1916

January 1916 will go on record as the wettest month since the establishment of the Arizona climatological service in 1892. Moderate winter temperatures prevailed throughout the month except during the storm periods when some of the nights were unusually warm. Storm conditions prevailed continuously from the 15th to the 21st and from the 26th to the 30th.

Because the ground was saturated from the melting of the December snows, the series of heavy rains beginning on the 15th caused general flood conditions throughout the state from the 17th to the 24th. The storm beginning on the 26th caused more floods from the 28th to the 31st. According to reliable sources, the highwater marks of the Salt and the Gila rivers this January have not been exceeded since 1891. Four lives were lost. The property damage sustained is estimated at $305,000, the principal items of loss being bridges, irrigation works, and agricultural land. Traffic over the various railroads and stage lines was interfered with and in some cases was entirely suspended.

September 1916

The rains of the 8th and 9th were excessive on the uplands bordering the Salt River Valley, and the resulting floods broke the main canal and flooded a portion of the Project. The damage to the canal system amounted to about $10,000, while the direct loss to the farmers occasioned by the washing of newly planted crops and by the injury to hay and cotton from the heavy rains was undoubtedly much greater.

July 1919

The outstanding feature of the weather for July 1919 was its record-breaking rainfall. Thunderstorms accounted for practically all of the rainfall, which in a number of cases approached the dimensions of a cloudburst. Amounts in excess of 2.0 inches in twenty-four hours fell at sixteen stations. Benson (Cochise County) reported 2.43 inches in less than one hour. The heavy rains washed out roads badly and caused heavy loss to railroads from wrecks, bridges destroyed, and track washed out. Some damage to irrigating systems was reported on the San Pedro River. The Salt River and Tonto Creek, flowing into Roosevelt Reservoir, showed the remarkable runoff of 215,380 acre feet during the month, Tonto Creek being higher than at any time last winter or spring. The Gila River also reached the highest stage of the year.

November 1919

The outstanding feature was the heavy precipitation. While falling far short of the state average of 5.22 inches recorded in November 1905, it was exceeded only by that month during the last twenty-three years. The daily falls were remarkably heavy for November, several stations recording more than 4.0 inches for the twenty-four-hour period.

The heavy rains of the 26th and 27th resulted in an unusual rise for the season in the streams of the north central counties. The Hassayampa attained a stage of five feet at Wickenburg on the 27th, and the wagon bridge at that place was carried away by the force of the water backed up by the accumulation of debris. Eight feet was reached on the same day in the Agua Fria at Marinette, and bridges at Avondale were carried away. A stage of 12.5 feet was attained by the Salt River at Phoenix on the 28th. Warnings were issued to points on the Gila; and the rise, as was forecast, reached Yuma on the morning of the 30th.

February 1920

Except over the southeastern portion of the state, precipitation was decidedly above normal. Two general storm periods are to be noted: from the 7th to 10th and 19th to 23rd, the latter yielding much heavier rainfall. High water in many streams resulted from the storm of the 19th to 23rd and caused much damage to roads and bridges. The loss to the state highways alone was placed at $342,000. For the first time in four years, on February 17, the water reached the level of the waste weirs.

August 1921

Excessively heavy rains throughout the mountain regions of the state continued from the latter part of July with little abatement until the close of August when they ceased as abruptly as they had begun. Channel water continued in the Gila over most of its length, preventing crossing except at bridges. Many floods occurred, owing to excessively heavy local rains. The most noteworthy occurred on the 21st from the usually dry channel of Cave Creek. Ashdale Ranger Station reported 6.25 inches in two days. This flood washed out the irrigation ditches and overflowed about four thousand acres of cultivated land, causing an average damage of about $10 an acre. The basement of the Capitol was flooded and the first floor was covered by several inches of water. The total damage, including crops, irrigation ditches, equipment, loss of records, damage to homes, etc., is estimated at $240,000.

August 1922

A heavy rainfall on the 2nd in the Chocolate Mountains north of Yuma caused three serious breaks in the main canal of the Yuma irrigation project, which cut off the water supply in the irrigation ditches in the Yuma Valley for about ten days. The storm also occurred in Mohave and Yavapai counties where small bridges and culverts were washed out and highways were somewhat damaged.

September 1923

While there were not many rainy days and the mean precipitation for the month was not unusually large owing to the deficiencies in the southeastern and extreme northwestern portions, the fact that most of the rain occurred almost continuously from the 16th to the 18th and was particularly heavy in the north central and northeastern portions caused many washouts in the highways and railroads in that section. The rains were particularly bad in the vicinity of Cosnino and Holbrook. One man drowned near the latter place, and much property was damaged. Trains were delayed and had to be rerouted. A serious train wreck in which four men were killed was indirectly due to the heavy rain.

November 1923

November was a mild month, neither very warm nor very cold. The outstanding feature was the large amount of precipitation that fell, especially on the 9th and 10th and again on the 16th and 17th. Phoenix had a twenty-four-hour rainfall of 2.40 inches on the 9th and 10th. This was the greatest twenty-four-hour rainfall on record at this station with one exception, July 1 and 2, 1911, when 4.98 inches fell in the twenty-four-hour period.

September 1925

On the 15th, general rainstorms accompanied by thunder and high winds overswept the state and lasted until the 19th. Many highway washouts occurred in southwestern Arizona; highways were rendered impassable near Florence where minor crop damage occurred. The Winkelman branch of the Southern Pacific was washed out as was the United Verde extension railroad. The Eastern Canal near Gilbert, Queen Creek near Chandler, and the San Carlos canal near Florence overflowed. The bridge four miles from San Carlos was washed out, delaying the Southern Pacific train for four hours. The Gila River crossing at Gillespie Dam was closed to traffic for three days because approximately 4.5 feet of water poured over the apron of the dam.

September 1926

On the 26th and 27th, one of the most damaging rainstorms in Arizona history swept over central and southeastern Arizona and extended as far south as central Mexico and as far east as El Paso, Texas. Excessive rainfall lasting in many instances for forty-eight hours occurred. The Southern Pacific Railroad suffered from damaged roadbeds, washed-out bridges, and suspended traffic west of Douglas from the morning of the 27th to the afternoon of October 1 and between Phoenix and Maricopa on the 27th and 28th. The Agua Prieta River ran half a mile wide, submerging bridges and highways. The Gila River was above flood stage at Kelvin.

On the 30th, the crossing at Gillespie Dam was closed, with water four feet deep on the crest of the dam. It remained closed for three days. Thatcher, Nogales, Douglas, and Safford were flooded and many adobe houses crumbled. The Southern Pacific Railroad placed its damage at $375,000. Camp Little at Nogales was damaged to the extent of $12,000 by the rains. Bisbee reported the heaviest monthly rainfall ever known there--10.19 inches. The State Bureau of Highways placed the damage to improved roads and small bridges at $60,000.

September 1927

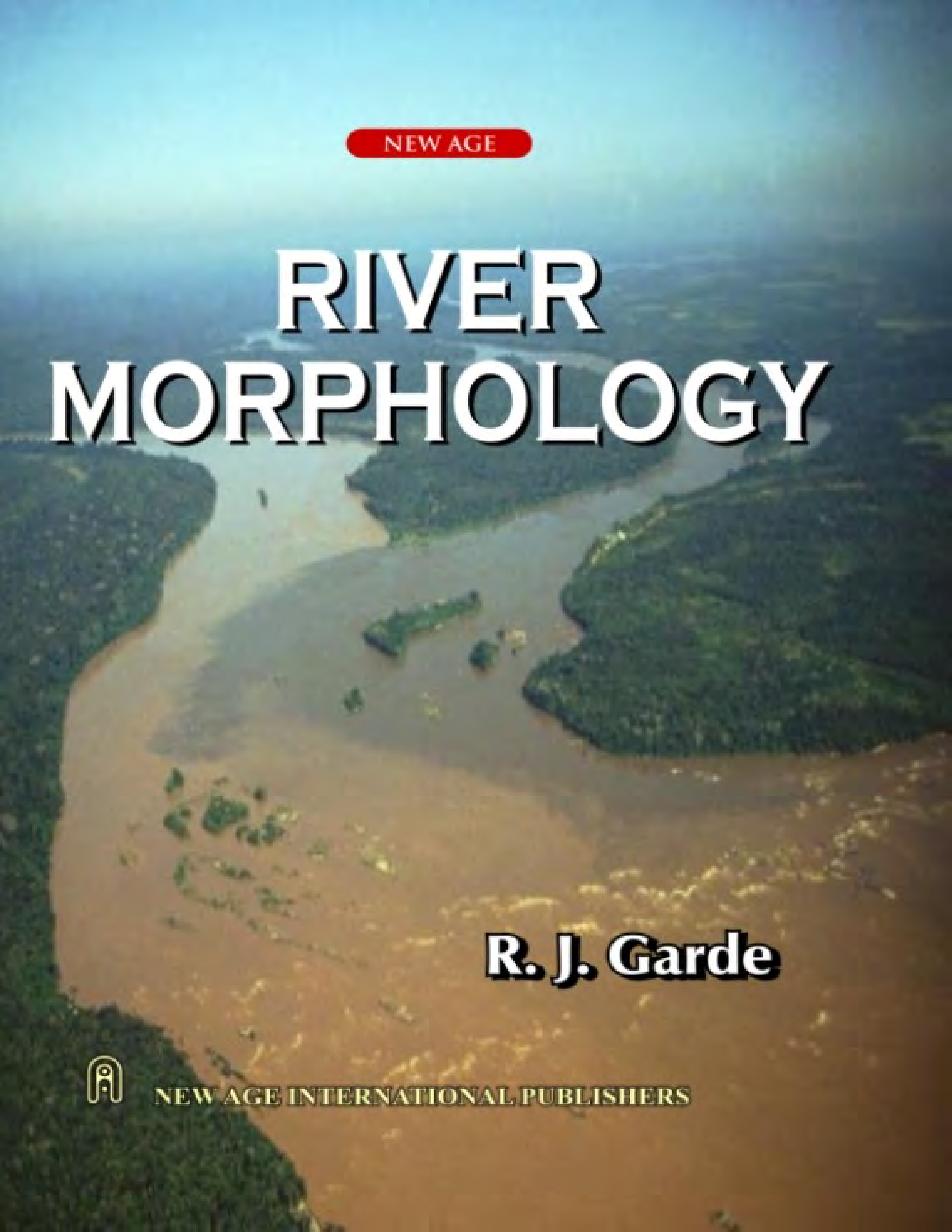
Heavy rains were general from the 11th to the 13th, culminating in the first severe autumn flood of the season. One death at Coolidge Dam, serious damage to the Verde supply and intake system of the Phoenix waterworks, railroad tracks washed out between Pima and Central and also between Kelton and Pearce, the overflow of many rivers, streams, and washes, and a rise of six feet in the Gila River at Ray Junction resulted from the storm.

July 1928

A flood occurred at Miami on the 27th, doing about $300,000 damage to property. A wall of water swept down Miami Wash from the Pinal Mountains and spread out over the town, demolishing houses and uprooting trees. The business section of Miami was under four feet of water at the crest of the storm.

September 1929

From the 19th to the 24th, damaging wind and rain storms and flood waters occurred in south central and southeastern Arizona. The prison at Florence was damaged by wind and rain. A flood in the Little Colorado isolated the Leupp Indian agency, and a cloudburst occurred between Safford and Pima. Highway 80 east and west of Douglas was washed away in places. Benson was marooned by washouts on railroads and highways, and traffic was



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List of Symbols

a_1,a_2,a_3	coefficients/exponents
A	area of cross-section, area of basin
A_b	area at bankful stage, area corresponding to bed
A_f	area of fan
A_u	area of basin of order u
$\overline{A}_u$	mean area of basin of order u
A_w	area of corresponding to wall
b	exponent
B	width of rectangular channel
BI	Brice braiding index
C	Chezy’s coefficient, suspended sediment concentration at a point, climate index
C_a	reference suspended sediment concentration
C_D	drag coefficient
C_L	lift coefficient
$\overline{C}_B, \overline{C}$	bed material concentration in ppm by wt., total load concentration
d_*	dimensionless sediment size
d, d_{50}	median size of bed material, rain drop size
d_{16}, d_{50}, d_{84}, d_{90}	sediment size such that 16,50,84,90 percent material is finer than this size respectively
d_a	arithmetic mean size
d_i	any size fraction
$d_{\max}$	maximum size of sediment
D	depth of flow ($WD=A$)
D_C	depth at the centre
D_d	drainage density
$D_{\max}$	maximum depth
E	kinetic energy of storm
E_R	entrenchment ratio
f	Darcy-Weisbach resistance coefficient

f'	friction factor corresponding to grain roughness
f''	friction factor corresponding to form roughness
f_1	Lacey's silt factor
F	stream frequency
F_b	Blench's bed factor
F_{bo}	value of F_b when bed load is negligible
F_D	drag force
F_e	erosion factor
F_L	lift force
Fr	Froude number (= $U/\sqrt{gD}$)
F_s	Blench's side factor
g	gravitational acceleration
G	transport rate of any section
G_e	equilibrium transport rate
G_∞	sediment transport rate at infinity
ΔG	change in G
h_b	head loss in bend
h_s	saltation height
H	average height at ripple or dunes, bars; relief
i	index
I	intensity of rain fall
I_{30}	maximum 30 minute intensity during storm
j	index
k_s	roughness parameter
K	erodibility index, diffusion coefficient, wave number (= $2\pi D/L$)
K_o	theoretical diffusion coefficient
l	length, distance, length of aggradation
L	average length of ripples or dunes, length of stream up to drainage divide
l_s	saltation length
L_u	total length of streams of order u
$\bar{L}_u$	mean length of streams of order u
m	exponent
M	percent of silt-clay in perimeter, Kramer's uniformity coefficient, dimensionless velocity bed or water wave
M_b	meander belt
M_L	meander length
M_W	meander width (M_B-W)

n	index, exponent, Manning's n
n_b	Manning's n with respect to bed
n_s	Strickler's n
N_u	number of streams of order u
n_w	Manning's n with respect to wall
p_i	per cent
P	perimeter, annual rainfall
$P_{\max}$	average monthly maximum precipitation
q	discharge per unit width
q_b	bed load transport rate in weight/width
q_{Bv}	volumetric bed load transport rate per unit width
q_c	critical water discharge per unit width
q_s	suspended load transport rate per unit width
q_T	total sediment transport rate in volume per unit width
q_{Tv}	total volumetric sediment transport rate per unit width
q_*	dimensionless discharge ($= q/\sqrt{gd^3}$)
q'	lateral inflow per unit length on both sides
Q, Q_w	water discharge
Q_1	$= Q_b/d^2\sqrt{gd}$
Q_2	$= Q_bS/d^2\sqrt{gd}$
Q_3	$= Q_b/d^2\sqrt{gdS}$
$Q_{2.33}$	flood discharge of return period 2.33 years
Q_b	bankful discharge
Q_B	bed-load discharge
Q_{ma}	mean annual discharge
Q_{maf}	mean annual flood discharge
Q_r	runoff rate per unit area
Q_S	suspended load discharge
Q_T	total sediment transport rate in weight or volume
r	radius
r_c	centre line radius of bend
r_i, r_o	inner and outer radius of bend
R	hydraulic radius, annul run off, run off parameter
R_A	area ratio
R_b	hydraulic radius corresponding to bed, bifurcation ratio

R_b', R_b''	R_b with respect to grain and form roughness respectively
R_e	Reynolds number
R_L	length ratio of Horton
R_m	mean radius of meander bends
R_{o*}^2	$= \Delta\gamma_s d^3/\rho_f \nu^2$
R_s	bifurcation ratio for slope
R_W	hydraulic radius corresponding to walls
R_*	particle Reynolds number $u_* d/v$
S, S_o	slope, bed slope, slope at $x = o$
S'	slope corresponding to grain roughness
S''	slope corresponding to form roughness
S_a	annual erosion rate in cm (absolute)
S_f	energy slope, fan slope
S_i	sinuosity
S_W	water surface slope
$\bar{S}$	average catchment slope
$\bar{S}_u$	average slope of segments of order u
SDR	sediment delivery ratio
SE	super-elevation
t_p	time to peak
T	number of years, also dimensionless excess shear $\{= (\tau' - \tau_{0c})/\tau_{0c}\}$
TE	trap efficiency of reservoirs
u	local velocity in x direction, order of stream
$\sqrt{\overline{u'^2}}$	r.m.s. value of velocity function in x direction
u_d	velocity at the top of particle
u_{dcr}	critical velocity at particle level
u_*	shear velocity (= $\sqrt{\tau_0/\rho_f}$)
u_*'	shear velocity corresponding to grain roughness
u_*''	shear velocity corresponding to form roughness
U	average velocity
U_{cr}	average critical velocity
U_g	average velocity of particle moving as bed load
U_W	average velocity of bed form or wave
v	local velocity in y direction

$\sqrt{\overline{v'^2}}$	r.m.s. value of velocity fluctuations in *y* direction
v_θ	velocity in θ direction
$v_{\max}$	maximum velocity at any vertical
$\mathrm{v_r}$	velocity in *r* direction
V_{cp}	average velocity in the vertical
w	local velocity in *z* direction, mean width of rib
$\sqrt{\overline{w'^2}}$	r.m.s. value of velocity fluctuations in *z* direction
W	average width ($WD = A$); weight of the particle
W_{av}	average unit weight over *T* years
W_b	bankful width
W_o	unit weight value of sediment
W_s	water surface width
x	distance in *x* direction, a dimensionless coefficient
y	distance from the wall
Y_1	hydraulic mean depth ($=A/W_s$)
z	lateral distance from the origin,
Z	actual slope of suspended sediment distribution curve, elevation of bed at given *x* and *t*; side slope of channel (*Z* hor.: 1 vert.)
Z_o	theoretical value of suspended distribution curve; bed elevation at $x = 0$
α	energy correction coefficient
$\alpha_1, \alpha_2, \alpha_3$	exponents
β	$\varepsilon_s/\varepsilon_m$ ratio of sediment transfer coefficient to the momentum transfer coefficient
γ_s, γ_f	specific weights of sediment and fluid
δ	lag distance
δ'	thickness of laminar sub-layer
$\Delta\gamma_s$	difference in specific weights of sediment and fluid
$\in_m$	momentum transfer coefficient
$\in_s$	sediment transfer coefficient
η	dimensionless distance in the vertical
θ	angle
κ	Karman constant (actual)
κ_0	Karman constant (clear water)
λ	porosity, wave length
μ	dynamic viscosity of fluid
ν	kinematic viscosity of fluid
ξ	sheltering coefficient

ρ_f	mass density of fluid
ρ_s	mass density of sediment
σ	arithmetic standard deviation
σ_g	geometric standard deviation
τ	shear stress
τ_o	average shear stress on the bed
τ_{0c}	critical shear stress for sediment
τ_r, τ_θ	components of shear stress on the bed along r and θ direction
τ_*	dimensionless shear stress
τ_{*c}	dimensionless critical shear stress
φ	angle of repose
φ_B, φ_S, φ_T	dimensionless bed-load, suspended load and total load transport rate respectively
ψ	$= \Delta\gamma_s d_{35}/\tau_0$
ψ'	$= \Delta\gamma_s d_{35}/\tau_0'$
ω	fall velocity
ω_0	fall velocity under ideal conditions

Subscripts and superscripts

Subscripts

$*$	dimensionless quantity
c	pertaining to critical condition
$_{1,\,2}$	pertaining to section 1, 2.

Superscripts

$'$	corresponding to grain roughness
$''$	corresponding to form roughness

Contents

Enough information is not available about the relationship between Q_b and Q_d or bed generative discharge. Gandolfo (1955) found that the bed generative discharge is greater than Q_d corresponding to average sediment transport rate and that the latter is greater than Q_{ma}. The relationship between Q_b and Q_{ma} is already given in Fig. 6.4.

6.4 EMPIRICAL RELATIONSHIPS FOR HYDRAULIC GEOMETRY

Leopold and Maddock (1953) explored the applicability of equations of the type

$$\left.\begin{aligned} W &= a\,Q^b \\ D &= c\,Q^f \\ U &= k\,Q^m \\ Q_s &= p\,Q^j \end{aligned}\right\} \qquad \text{...(6.21)}$$

at a station for variable discharge, and along the stream length for mean annual discharge Q_{ma}, by using data from American rivers in Great Plains and South-West. Since $Q = WDU$ it follows that for both these types of relationships ack = 1 and $b + f + m = 1$. For twenty cross-sections representing a variety of rivers Leopold and Maddock found that "at a station" the average values of b, f and m were $b = 0.26$, $f = 0.40$ and $m = 0.34$. Since the depth increases faster than the width, the (width/depth) ratio decreases with increase in discharge. The relationship between suspended load discharge Q_s and Q at a station showed greater scatter, with j values ranging between two and three. Since j is greater than unity, it is obvious that at a station Q_s/Q i.e., suspended sediment concentration increases as Q increases. While relating width, depth and velocity to discharge along the stream, they preferred to use mean annual discharge Q_{ma} which had an average frequency of 25 percent, i.e., it is equaled or exceeded one day in every four days over a long period. With this discharge Q_{ma} in Eq. (6.21), average values of b, f and m were $b = 0.50$, $f = 0.40$ and $m = 0.30$. It may be noted that values of b and f and m agree fairly well with those obtained by Lacey. In as much as the percentage of land not contributing sediment increases in the downstream direction and percentage of land contributing water discharge increases in downstream direction, one would expect Q_s/Q to decrease in the downstream direction, as concluded by Rubey (1933). However, individual rivers may differ in this respect.

Experience has shown that "at a station" relationships are significantly affected by the climatic changes, namely depending on whether the stream is perennial, ephemeral or in arid or semi-arid region.

Nixon (1959) while studying the hydraulic geometry of rivers in England and Wales found that the bankful discharge Q_b is equaled or exceeded 0.6 percent of the time i.e., on the average about two days in a year. He further found that in the equation $P = W = aQ^b$ the coefficient "a" depends on the frequency of discharge used, see Table 6.2.

Table 6.2 *Dependence of constant of proportionality in $W = aQ^b$ on the* frequency of discharge (Nixon 1959)

Percentage frequency	30	20	10	5	3.7	0.6
"a" in $W = aQ^b$ in SI units	8.87	7.61	6.16	5.23	4.84	3.00

Nixon also mentioned that if the mean annual discharge were used, the constant in the above equation would be 7.66 which is not much different from that for 20 percent frequency. For rivers in England and Wales, Nixon found that

$$\left.\begin{aligned} W &= 1.65\, Q_b^{1/2} \\ D &= 0.545\, Q_b^{1/3} \\ U &= 1.112\, Q_b^{1/6} \\ Q_s &= 0.9\, Q_b^{3/4} \end{aligned}\right\} \qquad \text{...(6.22)}$$

in SI units for Q_b ranging from 10 m^3/s to 500 m^3/s. After Leopold and Maddock as well as Nixon's works were published, a number of investigators in U.S.A., U.K., Norway, Malaysia, Brazil and Puerto Rico applied the same technique using either bankful discharge or discharge of certain frequency and obtained the exponents b, f, m. Similar studies were also conducted in U.S.A., U.K. and other countries on gravel-bed rivers (see Chapter VII).

Langbein (1964) considered streams in humid regions in which the discharge increases in the downstream direction. He stipulated that along with the three equations of Leopold and Maddock for W, D and U two additional equations can be considered as

$$\left.\begin{aligned} & S \;\alpha\; Q^z \\ \text{and Manning's } n \qquad & n \;\alpha\; Q^y \end{aligned}\right\} \qquad \text{...(6.23)}$$

$$\left.\begin{aligned} \text{so that} \qquad & b + f + m = 1 \\ \text{and} \qquad & m = \frac{2}{3} f + \frac{z}{2} - y \end{aligned}\right\} \qquad \text{...(6.24)}$$

since in the downstream direction stream would satisfy continuity and Manning equation. In addition, he stipulated that (i) streams have a tendency for uniform distribution of work per unit width along the channel, and (ii) the rate of work in the whole system is also as small as possible. On these premises he showed that

$$\left.\begin{aligned} & S = \sqrt{\frac{W}{Q^2}} \\ \text{or} \qquad & z = \frac{b}{2} - 1 \end{aligned}\right\}$$

Further, to fulfill the conditions mentioned above he argued that $|b^2 + f^2 + m^2 + z^2 + (1 + z^2)|$ should be minimum. This condition is satisfied by the following values.

$$b = 0.53, \;\; f = 0.37, \;\; m = 0.10, \;\; z = -0.73$$

These values of b. f and m agree fairly well with those obtained by Leopold and Maddock.

Some support to this approach of studying the hydraulic geometry of rivers was provided by Smith (1974) who represented a straight stream channel as a surface

$$y = y\,(x, z, t) \qquad \text{...(6.25)}$$

subjected to the following three conditions: (i) sediment mass is conserved during the transport; (ii) channel has the form just sufficient to carry the total discharge of water given the law of water movement; and (iii) the channel has the form just sufficient to carry its total sediment discharge given the sediment transport law. Smith also assumed that the channel is carried in non-cohesive material and that one has the freedom to choose a time scale for which the channel has a steady state form. He further assumed that Q and Q_s increase linearly with x, and lateral sediment transport rate is equal to longitudinal transport rate multiplied by $\frac{\partial D}{\partial z}$. He used Manning's equation for flow velocity and sediment transport equation of the form

$$q_s = \text{const}\; q^2\, S^2 \qquad \text{...(6.26)}$$

Rather than solving the system of equations, Smith tried to find out the values of the exponents which will satisfy all the imposed conditions. He thus obtained

$$W \sim Q_b^{7/11},\; D \sim Q_b^{3/11},\; U \sim Q_b^{1/11} \text{ and } S \sim Q_b^{-2/11} \qquad \text{...(6.27)}$$

in the downstream direction. These values are comparable to those obtained by Leopold and Maddock, and by Langbein.

In order to study the variation of the exponents b, f and m. Park (1977) analysed data from 139 "at a station" sites and data from 72 "in the downstream" direction. The ranges of variation in b, f and m obtained by Park are listed below in Table 6.3. In the analysis of data in downstream direction Q used is the observed or estimated Q_b or Q with a return period of 2.33 years.

Table 6.3 indicates that values of b, f and m vary over a wide range and hence for a given stream these values can be very different from those given by the theory. To study further the simultaneous variations of these exponents, Park plotted b, f and m on tri-axial diagram with one side for each exponent. Typical tri-axial diagrams for at a station and downstream exponents in different climatic conditions are shown in Figs. 6.6 and 6.7. The climatic factors did not seem to affect "at a station" exponents. Hence, Park suggested that local factors such as the composition of bank material, differences between braiding and meandering reaches, between pools and riffle sections, flow magnitude, suspended load and channel migration might be responsible for such variations.

Table 6.3 *Summary of distribution characteristics of hydraulic geometry* exponents data (Park 1977)

	At a station; N = 139			*In downstream direction; N = 72*		
Exponent	*B*	*f*	*m*	*b*	*f*	*m*
Range	0.20 – 0.59	0.06 – 0.73	0.07 – 0.71	0.03 – 0.89	0.09 – 0.70	0.51 – 0.75
Modal class	0.01 – 0.10	0.30 – 0.40	0.40 – 0.45	0.40 – 0.50	0.30 – 0.40	0.10 – 0.2
Theory (1)*	0.23	0.42	0.35	0.55	0.36	0.09
Theory (2)**				0.68	0.30	0.90

(1)* Leopold and Langbein (2)** Smith

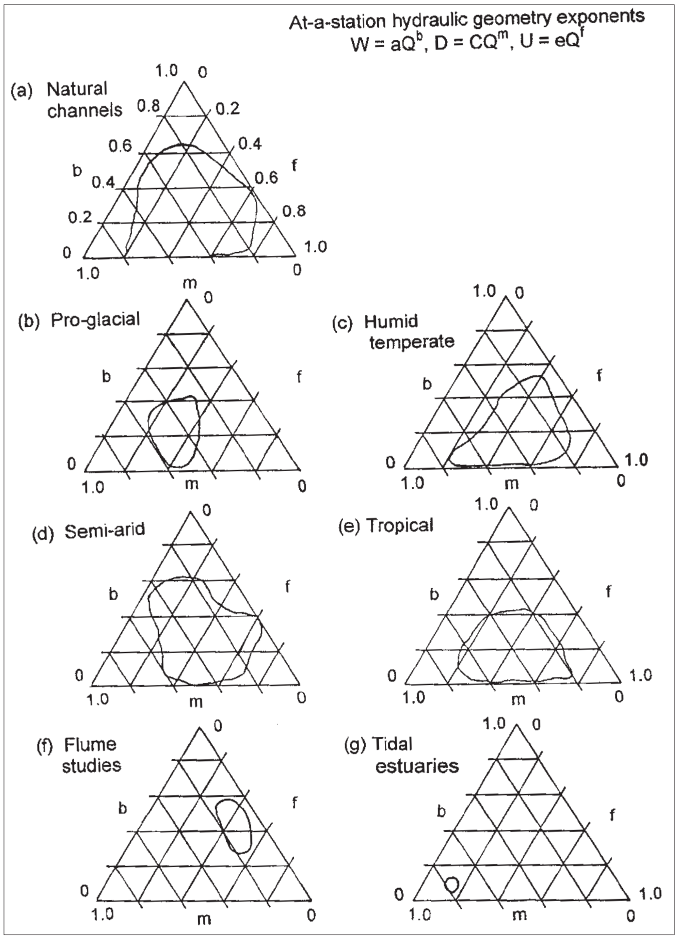

Fig. 6.6 Tri-axial graph of at-a-station hydraulic geometry exponents (Park 1977)

As regards the "downstream" data, Park found that for perennial streams in semi-arid regions the exponents are similar to those found in humid temperate climate, whereas ephemeral streams in semi-arid region tend to have lower *b* and high *f* exponents. In addition local factors such as lithology, variation in bank erodibility, channel instability, coarser bed material, and the downstream variation in slope are also responsible for the variation in *b*, *f* and *m*. On the basis of this study of tri-axial diagrams under various environments, Park casts doubt on the use of mean values of the samples of exponents to characterise the hydraulic geometry of streams in particular areas, and suggests that quoting mean values gives a misleading impression. While Park concentrated on the effect of environmental factors on *b* – *f* – *m* variation, Rhodes (1977, 1987) concentrated on the effect of hydraulic factors.

Some recent studies do not endorse Leopold and Maddock's conclusion that this is a rational or even a good way of describing cross-sectional channel adjustment. Some have also questioned whether log-linear model of hydraulic geometry is either appropriate or meaningful. However, the greatest

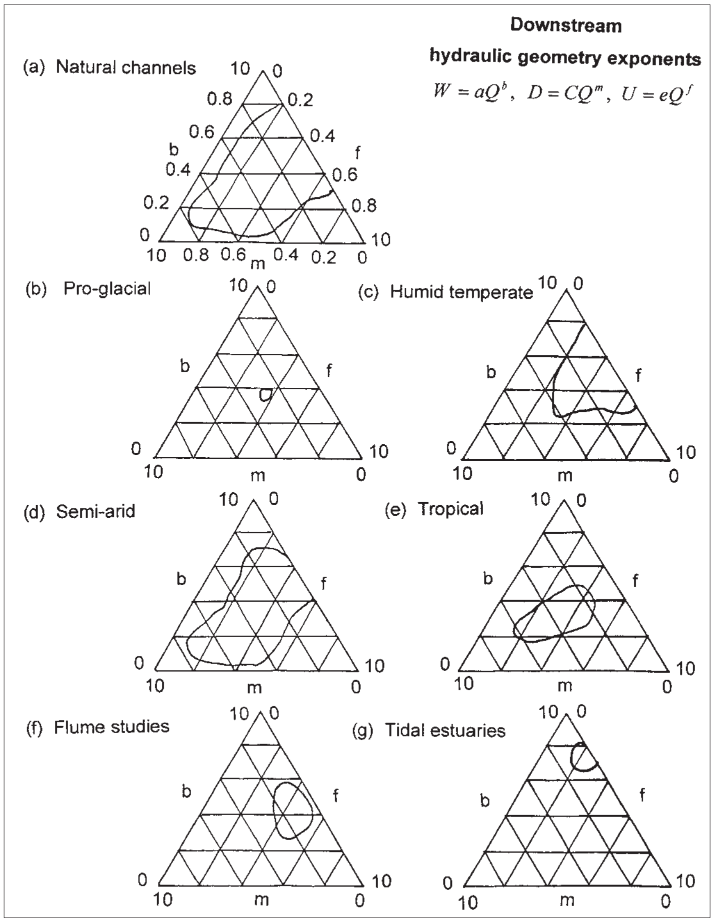

Fig. 6.7 Tri-axial graph of down stream hydraulic geometry exponents

drawback seems to be the non-inclusion of sediment size, difference in specific weights of sediment and water, and channel slope from the downstream relationships. However, in spite of these limitations investigators continue to use this analysis as a basis, since in regional and climatically homogenous regions they may give good approximation of hydraulic geometry.

Studies of Leopold and Maddock, and Langbein indicate that for downstream geometry $m = 0.05$ to 0.10 indicating that velocity at bankful stage or for mean annual discharge varies very slowly in the downstream direction. Leopold, Wolman and Miller (1964) show constancy of U for 50 year and 5 year floods in Yellow Stone basin, see Fig. 6.8. Some studies indicate that constant velocity along the length of the stream is attained at a stage between mean annual discharge and modest over-bank stage of 5 year flood (Chorley 1969). This needs further study in view of the commonly accepted view that stream velocity decreases as it flows from mountains to the plains.

Some other efforts to include additional variables to describe the hydraulic geometry, include the investigations of Schumm (1977) who analyzed the data on channel dimensions, mean annual discharge

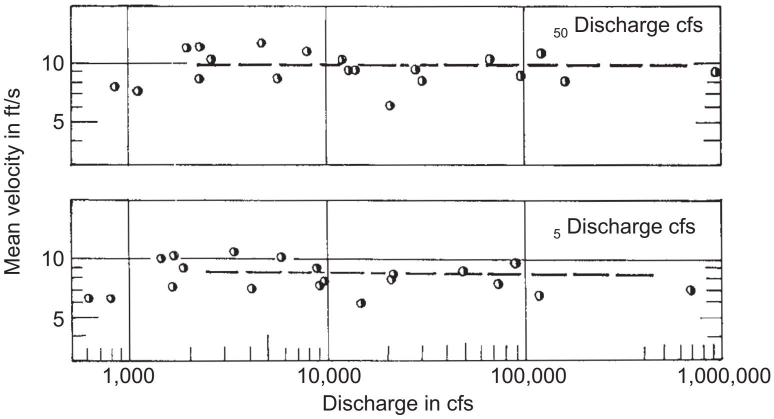

Fig. 6.8 Variation of average velocity at Q_5 and Q_{50} in Yellow stone river basin and down stream (Leopold et al. 1984)

Q_{ma} and bed and bank sediments at 36 cross-sections from semi-arid to humid regions in the Great Plains of U.S.A. and Plains in New South Wales in Australia in sand-bed streams. Schumm indicated that (width/depth) ratio in these channels was related to the percentage of silt-clay M in the perimeter of channel (see Fig. 6.9), and obtained the equations

$$\left.\begin{aligned} \text{W/D} &= 255\,M^{-1.08} \\ W &= 0.38\,Q_{ma}^{0.38}/M^{0.39} \\ D &= 0.6\,Q_{ma}^{0.29}\,M^{0.342} \end{aligned}\right\} \quad \text{...(6.28)}$$

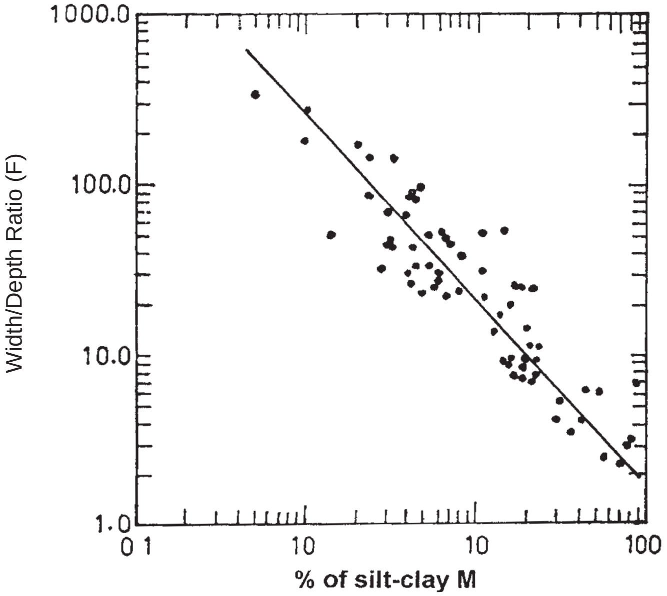

Fig. 6.9 Variation of width to depth ratio with M (Schumm 1977)

where Q is expressed in ft^3/s and D and W in ft. Gregory and his associates (see Fergusson 1981) studied bankful dimensions vis-à-vis the catchment area in humid areas and found that for catchment area A between 0.1 and 4.0 km^2, $W \sim A^{0.32}$, $D \sim A^{0.16}$ and channel capacity $\sim A^{0.48}$. Hey (1982), and Hey and Thorne (1986) while analyzing gravel-bed river data from U.K. related width and depth to bankful discharge, d_{50} and the sediment transport rate Q_s. These types of relationships developed in different countries are listed by Wharton (1995).

Since in the relationships discussed above some have used bankful discharge and some mean annual discharge, it is difficult to compare their results. Further, in studying the transient flows discharge needs to be replaced by some hypothetical constant discharge related to sediment transport or riverbed variation. Lastly, the relationships developed above do not contain other variables such as slope, sediment size, $\Delta\gamma_s$ and are not dimensionally homogenous. These aspects are discussed in the next two sections.

6.5 NON-DIMENSIONAL RELATIONS FOR HYDRAULIC GEOMETRY

Some attempts have been made to obtain non-dimensional form of equations for W, D and U or A. Thus Rybkin in 1947 (see Goncharov 1962) used the data from the upper Volga and the Oka basins and proposed the following equations

$$\left.\begin{aligned} W &= a_1 \left(\frac{\omega_o^2}{gS}\right)\left[\frac{Q_b}{\omega_o}\left(\frac{gS}{\omega_o^2}\right)^2\right]^{\alpha_1} \\ D &= a_2 \left(\frac{\omega_o^2}{gS}\right)\left[\frac{Q_b}{\omega_o}\left(\frac{gS}{\omega_o^2}\right)^2\right]^{\alpha_2} \\ U &= a_3 \left(\frac{\omega_o^2}{gS}\right)\left[\frac{Q_b}{\omega_o}\left(\frac{gS}{\omega_o^2}\right)^2\right]^{\alpha_3} \end{aligned}\right\} \quad \text{...(6.29)}$$

where ω_o is the fall velocity of bed material and a_1 , a_2 and a_3 as well as α_1, α_2 and α_3 are constants. In 1950 Velikanov proposed the following form of the equations

$$\left.\begin{aligned} \frac{W}{d} &= a_1 \left(\frac{Q_b}{d^2\sqrt{gdS}}\right)^{\alpha_1} \\ \frac{D}{d} &= a_2 \left(\frac{Q_b}{d^2\sqrt{gdS}}\right)^{\alpha_2} \end{aligned}\right\} \quad \text{...(6.30)}$$

According to his analysis α_1 = 0.50 to 0.53 and α_2 = 0.25 to 0.27. Ananian (1961) obtained $a_1 = 2.70$ and $\alpha_1 = 0.42$. Mukhamedov and Ismaghilov (1969) analysed the data from the middle and lower reaches of the Amu Darya and obtained the following equations for W and D

If the flood plain is 1.5 to 6.5 km wide, cut-offs together with levee construction are the accepted method of flood protection. For every wide flood plain, flood protection is seldom attempted using cut-offs. However, cut-offs can still be executed if the stream is used for navigation.

Lastly, it needs to be emphasized that when cut-off is executed the banks in that reach need protection, otherwise stream will have a tendency to develop a meander loop again.

10.6 CHANNEL PATTERN CHANGES

Sinuosity is earlier defined as length of stream divided the length of the valley. The sinuosity values range from 1 to slightly greater than 3.5. Analysis of American rivers by Leopold and Wolman (1960) indicated that the sinuosity varied from 1.0 to 3.0. The average sinuosity of the Mississippi is 2.3 while its maximum value at the Greenville Bends at Greenville was 3.3.

In single channel stream it is interesting to study variation in the sinuosity of the stream. Studies by Schumm (1977) have indicated that the sinuosity is significantly affected by the differences in the flow variation. To support this argument he has given example of two streams the Tanoro and the Guanipa. The characteristics of these two streams are given below.

River	d mm	Mean annual discharge Q_{ma} m^3/s	Q_{max} m^3/s	Q_{max}/Q_{ma}	S_i
Tonoro	0.35	11.34	535.6	47.23	1.1
Guanipa	0.35	17.00	104.9	6.17	2.3

From this it seems that Q_{max}/Q_{ma} ratio is morphologically important in determining the sinuosity; higher sinuosity is associated with lower value of Q_{max}/Q_a.

Experiments in a laboratory flume by Khan (1971) have indicated that the sinuosity was function of slope. For small slopes the channel was straight; when the slope exceeded a certain limit the channel meandered and sinuosity increased with increase in slope and reached a maximum value. Further increase in slope decreased the channel sinuosity and then the channel became straight and braided. Similar variation between valley slope and sinuosity has been reported for the Mississippi between Cairo (Illinois) and Head of Passes (Louisiana) by Schumm (1977). Schumm argues that the valley slope reflects the past discharges and sediment loads while the channel slope corresponds to the present discharge and sediment load variations. By plotting valley slope versus channel slope for some streams and palaeo channels, he found that channels with low percentage of silt and clay in channels, had sinuosity of unity and the two slopes were almost the same, while for channels with higher values of percentage of silt and clay, channel gradient was smaller than valley gradient and streams were sinuous with different sinuosity.

In a river system, it is many times found that for essentially constant discharge and sediment load, change in river pattern or plan form occurs along the length. The fact that in many cases the channel slope varies slightly but the slope of the valley changes explains this significantly. Within the valley; there are reaches of valley floor that are steeper or gentler than the average stream gradient. This happens wither due to tectonic movements or by the large difference between sediment load of the tributary and the mainstream. Hence to maintain relatively constant gradient, the stream lengthens its course on steeper reaches.

Hydrologic History
Of the Gila River Indian Reservation

Prepared for the
Gila River Indian Community
Office of Water Rights

By
Gookin Engineers, Ltd.

With Assistance From
Dr. Henry F. Dobyns

November 1, 2000

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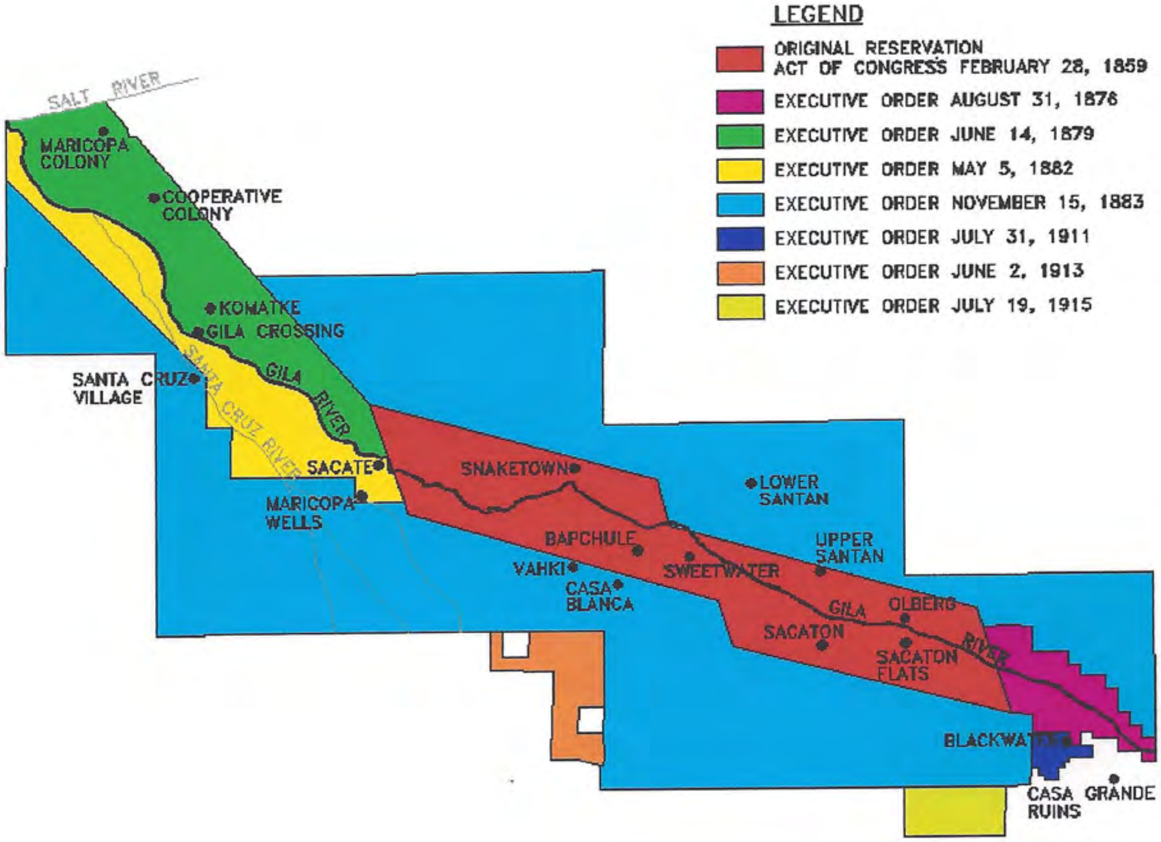
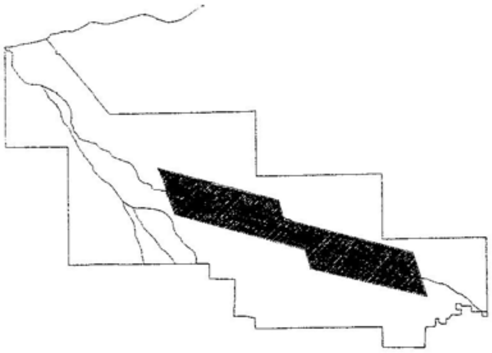

LEGEND
🟥 ORIGINAL RESERVATION ACT OF CONGRESS FEBRUARY 28, 1859
🟪 EXECUTIVE ORDER AUGUST 31, 1876
🟩 EXECUTIVE ORDER JUNE 14, 1879
🟨 EXECUTIVE ORDER MAY 5, 1882
🟦 EXECUTIVE ORDER NOVEMBER 15, 1883
🟦 EXECUTIVE ORDER JULY 31, 1911
🟧 EXECUTIVE ORDER JUNE 2, 1913
🟨 EXECUTIVE ORDER JULY 19, 1915
SALT RIVER
MARICOPA COLONY
COOPERATIVE COLONY
KOMATKE
GILA CROSSING
SANTA CRUZ VILLAGE
GILA RIVER
SANTA CRUZ RIVER
SACATE
MARICOPA WELLS
SNAKETOWN
LOWER SANTAN
BAPCHULE
UPPER SANTAN
VAHKI
CASA BLANCA
SWEETWATER
GILA RIVER
OLBERG
SACATON
SACATON FLATS
BLACKWATER
CASA GRANDE RUINS

CHAPTER 3

THE 1859 RESERVATION

The Gila River Indian Reservation was created in 1859 by an Act of Congress. The acting Commissioner of Indian Affairs Charles Mix, had recommended making a reservation of 240,000 acres for the Pima and Maricopa Indians[1]. Congress, however, chose to make a reservation of only 64,000 acres. In ordering the survey that would create the Reservation, Lieutenant Sylvester Mowry stated that the boundaries should be set so as to "secure their lands all privilege of irrigation, without fear of interruption in all time to come."[2] In addition, Congress authorized the sum of $10,000 to purchase gifts for the Indians. In enacting that provision, the federal government spent the money on farm implements and other tools for the Indians. The 1859 Reservation is shown to the right in black relative to the size of the current Reservation.



The Reservation was also created to prevent encroachment, primarily by the Butterfield Overland Mail Company. The Butterfield Overland Mail Company was running wagons and stagecoaches out of a station east of the newly created Reservation. They had invested money in building wells at Blue Water between Picacho and the Gila River. They also had relay stations at Sacaton and Maricopa Wells. The Pimas and Maricopas were farming efficiently along the Gila River in the Central Arizona Basin at this time. Building additional wagon stops for the Butterfield Overland Mail Company would have deprived a number of Indians of their

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[1] USOIA 1858.

traditional homes and farms, as towns would grow around the wagon stop, and result in more and more Indians being dislocated.

As laid out, the Reservation encompassed 25 miles along the Gila River in a swath 4 miles wide. This Reservation encompassed many of the irrigation features of the Pimas, but none of the irrigation features of the Maricopas existing at the time. The Reservation did not encompass a critical hydrologic area, the Blackwater area, which led to difficulties in the future. The Reservation did include the *Shodak Shon*, a spring which provided some water for irrigation. The villages primarily served by this *shon* were *Shodak Shon, Va-aki* and *Ska'kaik.*[3]

The Gila River, at that time, was clearly the primary source of supply for the Pimas and Maricopas. As a source of water, the Gila River was little changed from its condition back in 1604 when it was called the "Río del Nombre de Jesus". In 1694, Father Kino gave the Gila River the name "Río Grande de Gila".[4]

The Gila River upstream from Kelvin has major tributaries of the San Pedro, the San Simón, the San Carlos, and the San Francisco Rivers. Prehistoric irrigation apparently occurred in the Safford Valley. Remnants of later prehistoric cultures show crops such as maize, beans, and pumpkins were grown.[5] Some of the present canals are located along the same general routes as the prehistoric canals.[6]

Early accounts on the mainstream of the Gila River are sketchy, since most travelers generally bypassed the region. Except for the San Pedro River, the upper Gila River basin was

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[2] Mowry April 26, 1859, 23.

[3] Dobyns, 1998a, 53-57.

[4] Jaeger 1957, 66.

[5] USBOR 1963b, 95.

[6] USEO 1945a, 6.

one of the last areas explored by the Spanish.[7] In 1697, Father Kino found more than 2,000 Indians in the San Pedro River valley irrigating farmland.[8] Generally, development in the region was limited due to the Apache threat. The Apaches also practiced limited irrigation along the Gila River system.

The general characteristic of the Gila River before Anglo-American development was considerably different than it is today. The river was perennial with the exception of a very few short stretches where the Pimas and Maricopas had diverted the entirety of the river. The major tributaries were also in a mostly perennial state. The Gila River near Geronimo was described as a "deep and reedy stream".[9] The San Pedro River generally was described, by numerous people, as being lush with numerous ciénegas. The flow was described as being steady and marshy.[10]

Records do exist that beaver trappers worked through the Gila River area. The beaver trappers had trapped out the region so that the moderating impact of the beaver dams was no longer in place. There was limited mining in the area at the Santa Rita del Cobre mine, east of the present Silver City.[11]

The beaver, *Castor canadensis*,[12] North America's largest rodent, lived in streams across the continent when the white men came. Trappers and mountain men came across the country, far in advance

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[7] USBOR 1963a, 4.

[8] USGS 1973, 5.

[9] USBLM 1987, 21.

[10] USBLM 1987, 21-22.

[11] USBOR 1963a, 5.

[12] Peterson, 1955, 666.

of the settlers, to meet the demand for beaver pelts, especially for export to Europe's hatmakers. "Beaver pelts soon became a widely recognized standard of exchange. In the 1780's, 12 skins bought a four-foot gun."[13]

A small trapping party headed by Sylvester Pattie first trapped beaver from the west fork of the Gila River in December 1825.[14] The party had hired two local guides at the Santa Rita del Cobre mines who led them to this part of the Gila River Watershed. According to journal accounts "we caught thirty beavers, the first night we encamped on this river."[15] Winn cites from Pattie's journal:

> The next morning accompanied by another man I began to ascend the bank of the stream to explore ...the first day we were fatigued by the difficulty of getting through the high grass which covered the heavily timbered bottom.[16]

In January of 1826, Sylvester Pattie and his son, James, began to trap beaver along the San Francisco River, which is a tributary of the Gila River. They caught 37 beaver their first day on that stream. The party spent two weeks trapping along the San Francisco River and got 250 beaver pelts.[17]

The Patties' stories about their trapping successes prompted a rush of trappers into the Gila River basin. No less than four different trapping parties, with permits issued by the New Mexico governor, Antonio Narbona, entered the Gila River Watershed in the fall of 1826.[18]

The trapping of beavers is significant because the beaver ponds along the creeks and rivers slowed floodwaters and precipitated sand and gravel carried by the run-off waters. With a

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[13] Peterson 1955, 677.

[14] Winn 1926, 16-17.

[15] Thwaites, editor 1905, 87; Dobyns 1981, 107.

[16] Winn 1926, 17.

[17] United States Congress. Senate 1965, 61.

healthy beaver population, the dams were kept in constant repair and the ponds could function to provide a more regular flow.

The Central Arizona Basin is an arid region in which irrigation must be performed in order to practice agriculture. In order to irrigate successfully in an arid region, a steady stream of water must be obtained. As discussed earlier, the Pimas and Maricopas double-cropped. The cropping pattern of the Indians was dictated by the precipitation patterns. The winter precipitation and the resulting snowmelt provided a sustained, late winter, early spring flow. The summer rains are very spotty, short and intense. The size of the watershed tends to help even out this flow, since the water from a storm that occurs on one creek may pass by before the water from a storm on another creek enters the river. The presence of beaver dams would also help smooth out the water flow. Beaver dams can also provide for a substantial amount of water storage.

> ...The value of the dams built by those intelligent animals is well illustrated by the following article entitled "When Beavers Aid Irrigation," by Ivan E. Houk:
>
> The natural trait of beavers to build dams for the protection of their homes has long been known, but it is only recently that its economic value has been recognized for irrigation work. The United States Forest Service, in a recent survey of the Cochetopa National Forest, near the San Luis Valley, Colo., made by Fred Agee, United States forest supervisor of Salida, found that the water stored above the dams in that forest alone amounted to 1,241 acre-feet; that is, enough water to cover 1,241 acres 1 foot deep—the equivalent of 24,000 Colorado statute inches running for 24 hours, or enough to irrigation 30,000 acres of land for one day.
>
> Mr. Agee's survey, which was carefully and thoroughly conducted, showed that in the Silver Creek Valley alone 46 dams were located in a total length of about 5 ¾ miles. These dams averaged about 660 feet apart, although they generally occurred in groups with a somewhat closer spacing. In some case the water was backed up above the dams to depths as great as 5 ½ feet...

---

[18] Thwaites, editor 1905, 99.

> Consequently, it is evident that the value of the beaver as an aid to irrigation is of no minor importance.[19]

This large amount of storage behind a beaver dam would affect the runoff in two ways. First, the dams built by the beavers leaked. The water in storage can help provide a slow, steady, component downstream from the dam. The second impact is that, even if the beaver reservoir is full, a wedge of storage forms as the water enters and exits the reservoir. This wedge is called the superelevation and will operate to create a dampened streamflow. This dampened streamflow improves the reliability of the river flow and hence, its divertability. Other than this impact, the 1859 Reservation received water in virtually its virgin state.

The 1859 Reservation contained much, but not all, of the irrigated lands of the Pimas. The 1859 Reservation did not include the lands of the Maricopa Indians and their irrigation, located on the Gila and Salt Rivers in the general vicinity of the confluence. The 1859 Reservation also did not include the important *sTjuk shon* called Blackwater. This *shon* was a major diversion point for the Pimas. Water from this diversion entered into a canal called the Little Gila Canal. Remnants of the Little Gila Canal can still be seen today as the Casa Blanca Canal. At the time explorers were traveling through, the Little Gila Canal was at times thought to be a natural river.

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[19] United States Congress. Senate 1965, 61.

CHAPTER 4

THE 1876 EXPANSION

The cessation of the Civil War caused settlers to begin moving to Arizona with a plan to set up housekeeping and farm. In addition, in 1865, Camp McDowell was established providing a fairly sizable demand for agricultural products.

By 1869, these newcomers had formed enough settlements upstream of the Reservation to impact the water supply available to the Reservation. The impact on the water supply was not due, as much, to the amount of water that the upstream farmers were beneficially using, but rather, due to the extreme waste that the non-Indian farmers engaged in. As Vincent Colyer stated in 1869:

> Four or five hundred settlers above them, on the Gila River, have built acequias and diverted the water from the Pima reservation, instead of returning it to the river as they should.
>
> The Pimas and Maricopas assert very justly that in a dry season their crops will be ruined in consequence of this action of the settlers . . .[1]

The misuse of the river flow significantly reduced the water supply of the Reservation. Without the river flow being allowed to grease the river (keep the riverbed moist), the water that was sometimes able to pass by the upstream diverters would be more likely to disappear into the subflow of the river.

> In early September 1869, Arizona Indian Affairs Superintendent Col. George L. Andrews requested the Commissioner to include in the next appropriation supplies for the Indians to relieve their deteriorated condition. Special Indian Agent Capt. J. C. Grossman advised Col. Andrews that in dry seasons the sinking of the river beneath the surface deprived the lower villages of water.[2]

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[1] USOIA 1869, 93.

[2] Gila River Indian Community May 23-24, 1977 , 11.

At this time, Agent Stout, the Gila River Indian Reservation agent, noted that nearly 1,000 Indians had relocated upstream of the 1859 Reservation, to an area known as Blackwater. By this relocation, the Pimas were able to get water. The underground waters of the Gila River re-emerged in the Blackwater area as a lake, or slough, sufficient in quantity to irrigate nearby fields. This lake, or slough, was known as *sTjuk shon*. An ancient Pima village, known as Blackwater, is situated near the *shon* to use its water.

The acreage developed on the Gila River, upstream of the Reservation in 1876, was fairly small. The total acres, developed upstream from the Reservation by non-Indians were 8,953 acres. In addition, there were probably 3,000 acres of developed Apache land for a total value of 12,953 acres.[3] The diversions of water by the upper valley farmers had a downstream impact disproportionate to the amount of land that they were irrigating. The reason for this impact on the river flow is that the upstream diverters took their entire demand from the base flow of the river and wasted any they didn't use by dumping any excess water into the desert rather than returning it to the river for others to use.

Rivers have three characteristic types of flow: base flow, snowmelt, and rainfall runoff. Each of these flow types has distinct characteristics and distinct values.

BASE FLOW

Many rivers run year-round. Most large rivers will run for weeks, or even months, during periods when there is no rainfall and the snows are totally gone. The reason that rivers flow in a perennial state is that they are flowing over groundwater basins where the water table is higher than the river. Water flows downhill (unless it is in a contained device, such as a pipe). If a groundwater basin has been filled to the point where the water table is higher than the stream, the water will run downhill to the stream and enter the stream where it will flow farther down. This result is similar to water in a pitcher, which has been tilted so that the water level in the pitcher is higher than the pitcher's spout. The water will initially flow out of the pitcher very fast. The water level will continue to lower in the pitcher until the water level is at the level of the spout. Groundwater flows in response to the same laws and principles as surface water but does so much slower. Therefore, the groundwater draining into the river can continue for substantial periods of time. The slow drainage of the groundwater into the river gives the surrounding watershed a chance to receive additional rainfall or snow which, in turn, contributes additional recharge to the basin and restores the basin back to the original water levels that were higher than the river. The groundwater acts as a huge flywheel that averages out the more spontaneous inputs of water from rainfall and snowmelt and causes a continuous flow to occur in the river. This continuous flow of water in the river is termed base flow and is the reason that rivers are perennial. Base flow is vital to irrigation from an unregulated stream because the base flow can be counted on to maintain the water supply.

Base flow also allows a farmer to better utilize other irregular water flows. All crops can withstand shortages of water, some more readily than others. The farmer could, and would, be able to plant in such a manner that the base flow of the river would sustain a minimal yield from the crops. Any additional water that comes down the river would be a gift and could be diverted by the farmer to increase his productivity. Due to the ability of the farmer to count on a base flow supply, the farmer can plant a larger acreage with an expectation of getting at least some yield. A

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[3] Appendix A. Summary table.

farmer who has a large amount of land irrigated can divert a larger portion of the irregular water supplies of the river since he has more places to use the water.

Contemporary authorities had recognized the effect of base flow. For example, in 1902, Superintendent Alexander indicated that 1,000 miner's inches (40 miner's inches equals 1 cubic foot per second "cfs") of base flow emerging from the *komatke shon* would support 3,000 acres of farming.[4] This equates to a water supply for the farms of 1/120th cfs per acre.[5] The commonly accepted water supply required to farm in the 1800s was, however, 1/80th cfs per acre.[6] Superintendent Alexander's statement would seem to be a recipe for disaster for the farmers. Cropping one acre of barley with only 1/120th cfs per acre would lead to a significant water shortage. There were several things the farmer could do to stretch the water supply. First, the farmer could "bank" water in the soil by irrigating before the crop is planted (pre-irrigation) so that when the crop is planted, the soil is already wet. Second, in a typical year, the available water supply exceeds the demand from early December through early February. During this period, the farmers will divert the river and apply it to their fields, further building up the water supply in the soil. Third, the farmer can use the spring snowmelt, or rainfall, to supplement the base flow of the river.

Beginning in late February, the demand of the crop begins to exceed the supply of water. The water that was banked in the soil, combined with the base flow, will sustain the crop's requirements until the end of March. At that point, the soil moisture has expired and the supply of water is no longer capable of meeting the crops demand. At any point in time during that

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[4] Jones, 1902.

[5] 1,000 miner's inches / 40 = 25 cfs. 25 cfs / 3000 acres = 1/120th cfs per acre.

[6] See Gila Decree, Kent Decree, Haggard Decree, and Ackerly 1991.

period if additional water became available, the farmer could divert and bank that additional water and get the crop through the end of the growing season. Due to the need for only a little flow sometime during the season, the base flow permits the farmer to utilize a greater portion of the river.

SNOW MELT

During the winter season, snow occurs in the higher elevations of the Gila watershed. As spring comes and temperatures begin to rise, the snow begins to melt. This leads to an enhanced water supply during the spring months. This enhanced water supply can normally be depended upon to provide water for crops that would be grown in the winter/spring. The principal crops that would make use of this water are the grain crops. The winter melt provides a critical source of dependable water above the base flow. Snowmelt and base flow combined to provide the primary water supply for the winter/spring crops for the Pimas and Maricopas, as well as the upstream non-Indian farmers.

RAINFALL

The final type of river flow is runoff due to rainfall. Rain can provide a useful supply for growing winter grains. Crops do not require much water in the winter so that small amounts of rain are sufficient. Also, rain generally falls slowly for long periods during the winter. The runoff generated by this type of rainfall is steady and easy to divert.

In the summer, the rainfall comes quickly and in a very intense manner. This leads to sudden, short freshets of water. Although large amounts of water can flow past an area, these freshets are difficult to utilize. Additionally, in the 1800s, the freshets would tend to wash away the wooden diversion dams built by the farmers. A portion of these freshets could be captured and utilized, but, on the whole, most of the water would pass by unused. The monsoonal storms of July, August, and September provided the primary supply of water to the Pimas and Maricopas during the summer months. When combined with the base flow to provide minimal irrigation requirements, the rainfall permitted the Pimas and Maricopas to develop a crop in the late summer and early fall.

IMPACT OF DEVELOPMENT

Upstream development, through 1876, had made the water supply less reliable and of a more flashy, sudden type flow for the Gila Indians. Grazing had dramatically changed the types of vegetation so that, when rainfall did occur, the water would run off quickly, similar to a short, intense, flash flood. Prior to upstream development, the rate of runoff was slower, yielding a more usable water supply to the Pimas and Maricopas. The beavers had added their own brand of regulatory storage to the rivers. Overall, the water supplies available, as of 1876, were less dependable than in the virgin state.

The primary impact to the water supply of the Pimas and Maricopas occurred due to the diversions upstream of the Reservation. The water that made it past the canals upstream is water that the upstream farmers did not wish to use or could not use for one reason or another. The water that remained available to the Reservation was from the flash floods or from water supplies during the very coldest months of winter, when little to no irrigation is needed due to the water available from the base flow and snowmelt.

Some of the canals in the Florence region diverted water from the Gila River and wasted it into the desert. Gookin Engineers has examined the maps prepared in 1914 by the U. S. Indian Service, to determine which canals did not return any water back into the Gila River. The end of each canal was compared to the location of the Gila River. Gookin Engineers determined that, when a canal ended in the desert, the canal did not return water to the Gila River. The following canals were found to be in this group: the White Ditch, Adamsville Canal, Chino Ditch, Alamo Amarillo Ditch, Holland Ditch, Brash Ditch, and Montezuma Canal. The canals that returned flow to the Gila River were: Sylvester Andrate Ditch, Styles Mason Ditch, Walker Ditch, McClelland Ditch, Pearson Nicholas Ditch, Sharp Ditch, and Moore Ditch.

The capacity for the Brash Ditch was computed based on the dimensions provided in the Southworth report[7] with an estimated velocity of 2 feet per second. The velocity of 2 feet per second represents a safe velocity that can be used in an earthen ditch without creating long-term problems with scour. The remaining capacities were estimated using the Ackerly formula[8] relating the areas irrigated to the discharge. The resulting capacities are shown in Table 4-1.

TABLE 4-1
CANALS THAT DID NOT RETURN FLOWS TO THE GILA RIVER

DATE OF CONSTRUCTION	NAME OF CANAL	IRRIGATED ACREAGE	CAPACITY (CFS)
1864	White Ditch	560	6.50
1866	Adamsville Canal (south side)	1000	20.00
1867	Chino Ditch (south side)	200	2.33
1868	Alamo Amarillo (south side) Ditch	440	5.11
1868	Holland Ditch	950	11.01
1876	Brash Ditch	310.4	20.80
1876	Montezuma Canal	1000	15.00
	TOTAL	4460.4	80.75

Over 80 cfs was continually being diverted from the Gila River through these ditches and used or wasted by upstream diverters in 1876. In addition, there were farms that diverted from

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[7] Southworth June 30, 1919, 145.

[8] Ackerly 1991, 52.

the river, consumed all or a portion of the water, and returned the remaining flows to the Gila River.

As a result of the upstream diverters eliminating much of the base flow coming out of the Gila River, the amount of water that the Pima and Maricopa farmers could rely upon was drastically reduced. At the earlier documented rate of 1/120th cfs per acre required for base flow, the impact of the continuous diversion of 80.75 cfs was to eliminate the potential irrigation for 9,690 acres on the Gila River Indian Reservation. The San Carlos Irrigation and Drainage District (SCIDD) predecessors had developed 4,460 acres upstream. Due to the development, the Reservation lost the ability to farm 9,690 acres.

- 4,460 acres were lost because the SCIDD's predecessors took the water for their own use and
- 5,230 acres were lost because SCIDD's predecessors wasted additional quantities of water into the desert rather than letting the water return to the Gila River.

As a result of this upstream development, the first changes in the Pima and Maricopa cropping occurred. The Superintendent of Indian Affairs for Arizona Territory reported in 1871:

> ...This waste (which is waste indeed) can never be beneficial to any extent under their management, and this season proves the correctness of these suppositions, inasmuch as the usual second [summer] crop of corn will not be planted, while the settlers above, at or near Phoenix, have planted. Such has been the result of the water question this year that the Maricopas, who occupy the lower end and worst part of the reserve, have actually left and gone off some thirty miles, near the Salt River, for the purpose of raising a crop; while the Pimas have been steadily moving toward the upper end.[9]

Resident Agent F. E. Grossman reported in August 1871:

> The crops of the Indians (wheat and barley) the winter crop, were abundant during the past season, but the corn and melon and pumpkin crops will be a failure, owing to the scarcity of water in the Gila River.[10]

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[9] U. S. Court of Claims January 7, 1981, 52.

[10] U. S. Court of Claims January 7, 1981, 53.

Agent Grossman further stated:

> ...it is clear that, owing to the increasing settlements made by whites and Mexicans above the reservation on the Gila River, the time is not far distant when the Pimas and Maricopas (an agricultural people, without doubt) will be without the necessary water to enable them to raise any crops.[11]

General Howard reaffirmed this in June 1872:

> General Howard reported four possible solutions to the Pima water problem: (1) extending the reservation to Adamsville, buying the claims of settlers; (2) extending the reservation above Florence, including both Adamsville and Florence and all improvements; (3) divert the Gila River high upstream into two large canals under government control and see to a fair diversion of the water supply to all cultivators of the land irrigated; (4) relocate the Pimas to another location either inside or outside where there...[12]

General Howard forwarded a petition by the Pima Chief and the Maricopa Chief that explained the impact of losing the base flow:

> We always raised two crops a year, one of wheat and one of corn. Now since the Americans and Mexicans have moved on our land above us, and taken the water from our river (the Gila) to water their grain, we never raise but one crop (wheat), some of us who live on the lower part of the land * * * do not get even enough to water our wheat, and much of it is even now lying down upon the ground dead. We cannot raise any beans, or pumpkins or melons or corn down there any more, because there is no water.[13]

The *sTjuk shon* (Blackwater) was an important source of re-emergence of river flow for the Pimas and Maricopas. Due to the geology of the region, the water was forced to the surface and due to its dependability, the canals were located at this point. When non-Indian settlers began to look at taking the water, the Pimas moved to protect this critical site. The expansion of

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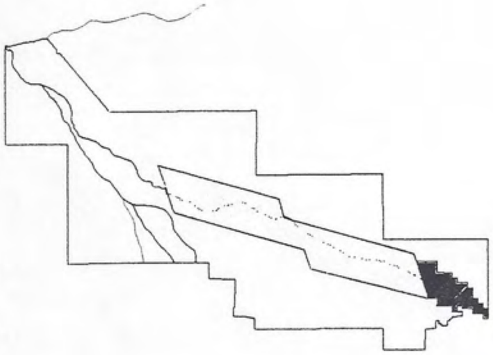
[11] U. S. Court of Claims January 7, 1981, 54.

[12] U. S. Court of Claims January 7, 1981, 54.

[13] U. S. Court of Claims January 7, 1981, 54.

the 1876 Reservation permitted the Pimas to secure this critical re-emergence site and the base flow that was associated with it.

After a number of conflicts with white settlers, in 1876, the United States government chose to expand the Gila River Indian Reservation to include the Blackwater lands and the heading to the Little Gila Canal. The map to the right shows the 1876 Expansion to the Reservation in black, with the previous Reservation shown in gray.



(4)

EXHIBIT NO. DX 38 131-BB
U. S. COURT OF CLAIMS
INDIAN CLAIMS COMMISSION DOCKET NO. 236D 4

ESTIMATED TOTAL FLOW OF GILA RIVER AT BUCKEYE HEADING
1896 - 1916

by
Paul V. Hodges,
January 29, 1942.

The "Notes on the Discharge of Gila River at Buckeye Heading", dated December 16, 1941, explains some of the details of computing the base flow at Buckeye Heading for period 1896 to 1904, which was a critical low-water period.

A more complete analysis over a longer period was desired and, therefore, the base flow, run-off, and total flow at Buckeye Heading has been computed in this report. The methods used in making the computations for the different sources of flow are explained in some detail.

Base Flow

During the year 1905 there was a relatively high flow from the Salt, Verde, and Gila Rivers. The summer precipitation, however, was quite low over the lower Salt and Gila Valleys.

The 1905 base flow was computed to be considerably higher than that for 1904, due to the very high run-off during 1905.

Based on a comparison with the run-off of the Salt, Verde, and Gila Rivers the base flow for 1906 to 1909 shows a gradual increase.

The flow of the Salt River was controlled by the Roosevelt Reservoir starting in 1910, and irrigation in the Phoenix Valley increased rapidly after that year.

The base flow during 1910 to 1916 was computed under conditions as it would have been without storage and without any increase in irrigation.

Without storage more run-off would reach Buckeye Heading from the Salt River during the winter months and during temporary summer peaks caused by intense summer rains.

Without an increase in irrigation, the groundwater table would not have built up as high or as rapidly as under actual conditions prevailing during the period of 1910 to 1916. (See Salt River Project Diagram Showing Groundwater Level, Page 35 of Hodges November Report.)

Starting in 1910 more water was diverted for irrigation, which built up the water table very rapidly, reaching its maximum height in 1919 and 1920. Under natural conditions, without storage or

Gila River at Buckeye Heading
Discharge Comparison During 1896, 1903 and 1929

	1896		1903		1929	
Month	Av. Precip. Ins.	Computed Base Flow S.F.	Av. Precip. Ins.	Computed Base Flow S.F.	Av. Precip. Ins.	Actual Discharge S.F.
May	T	155	.07	130	T	152
June	.01	111	.17	91	.04	112
July	3.18	102 h	.60	79	.91	105
Aug.	1.24	96 x	.55	74	1.48	216 *
Sept.	.83	116 x	2.48	96 h	1.17	218 *
Oct.	1.38	155 x	.04	113	.03	162 *

* Some flood run-off.
x Indicates the probability of a moderate amount of run-off.
h Indicates the probability of a relatively high amount of run-off.

1900, 1939 and 1940 Comparison

The year 1900 had the lowest run-off of any of the years during the period 1896 to 1904. This is clearly indicated by the records of precipitation and run-off.

Measurements of the Buckeye Canal in 1899, 1902 and 1903 give a basis for estimating the Buckeye flow during 1900.

The relation between the flow at Buckeye Heading during 1900, 1939 and 1940 is indicated as follows:

Flow at Buckeye Heading
in Second-Feet

Month	Recorded 1939	Computed 1900	Recorded 1940
May	95.0	125	87.1
June	66.4	87	61.5
July	58.8	76	58.5
Aug.	141	71	99
Sept.	126	92	90.8
Oct.	117	109	95.8
Average	100.7	93.3	82.1

The droughts of 1896-1904 and 1928-1940 affected both the Salt and Gila Rivers in a similar manner, and would so affect the flow at Buckeye Heading.

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Statistical Summaries of Streamflow Data and Characteristics of Drainage Basins for Selected Streamflow-Gaging Stations in Arizona Through Water Year 1996

By G.L. POPE, P.D. RIGAS, *and* C.F. SMITH

Water-Resources Investigations Report 98–4225

Prepared in cooperation with
Arizona Department of Water Resources,
Bureau of Reclamation,
Pima County Board of Supervisors,
Flood Control District of Maricopa County, and
Salt River Project

Tucson, Arizona
1998

09444500 SAN FRANCISCO RIVER AT CLIFTON, AZ--Continued

Annual peak discharges

Water year	Date	Annual peak discharge (ft^3/s)	Discharge codes	Water year	Date	Annual peak discharge (ft^3/s)	Discharge codes
1891	02-21-91	65,000	HP	1952	01-19-52	15,800	
1905	01-10-05	60,000	HP	1953	08-18-53	6,090	
1906	11-27-05	65,000	HP	1954	08-07-54	7,280	
1907	12-03-06	[1]70,000	HP	1955	07-23-55	8,450	
1911	03-07-11	15,000		1956	10-04-55	5,820	
1912	03-10-12	20,000		1957	07-26-57	5,230	
1913	07-00-13	10,000		1958	09-12-58	7,000	
1914	07-04-14	5,000		1959	08-2859	11,600	
1915	12-20-14	23,000		1960	01-12-60	11,800	
1916	01-19-16	59,000		1961	09-10-61	7,100	
1917	10-14-16	60,000		1962	09-26-62	14,300	
1918	00-00-18	3,000	ES	1963	10-18-62	12,200	
1919	00-00-19	15,000	ES	1964	07-31-64	8,670	
1920	00-00-20	5,500	ES	1965	08-02-65	5,640	
1921	00-00-21	16,000	ES	1966	12-23-65	30,500	
1922	00-00-22	3,500	ES	1967	08-12-67	34,700	
1923	00-00-23	10,000	ES	1968	12-20-67	9,480	
1924	00-00-24	10,000	ES	1969	09-01-69	1,270	
1925	00-00-25	16,000	ES	1970	10-21-69	902	
1926	00-00-26	5,000	ES	1971	10-04-70	5,420	
1927	09-12-27	4,060		1972	10-25-71	9,200	
1928	07-15-28	3,380		1973	10-20-72	[2]64,000	
1929	09-23-29	5,200		1974	07-21-74	964	
1930	08-11-30	3,420		1975	09-09-75	30,000	
1931	09-29-31	3,330		1976	02-10-76	3,100	
1932	02-10-32	10,000		1977	09-05-77	2,520	
1933	07-23-33	3,800		1978	03-03-78	9,500	
1934	08-26-34	11,700		1979	12-19-78	56,000	
1935	09-01-35	2,450		1980	02-16-80	9,900	
1936	02-17-36	3,700		1981	07-09-81	1,570	
1937	02-08-37	12,400		1982	03-13-82	2,020	
1938	03-04-38	4,540		1983	03-25-83	6,060	
1939	04-06-39	1,230		1984	10-02-83	90,900	
1940	09-06-40	8,700		1985	12-28-84	27,400	
1941	12-31-40	8,700		1986	10-17-85	3,590	
1942	12-11-41	7,930		1987	11-03-86	1,940	
1943	03-05-43	1,580		1988	08-31-88	3,630	
1944	09-26-44	3,800		1989	10-15-88	882	
1945	08-22-45	2,820		1990	08-14-90	952	
1946	09-05-46	1,380		1991	03-02-91	13,800	
1947	08-23-47	5,860		1992	02-14-92	6,420	
1948	06-01-48	5,850		1993	01-18-93	42,900	
1949	01-13-49	24,100		1994	09-04-94	972	
1950	07-27-50	825		1995	01-05-95	22,200	
1951	08-29-51	735		1996	08-30-96	1,750	

[1] Highest since 1870.

[2] Highest since 1907.

09508500 VERDE RIVER BELOW TANGLE CREEK, ABOVE HORSESHOE DAM, AZ

Annual peak discharges

Water year	Date	Annual peak discharge (ft³/s)	Discharge codes
1000	00-00-00	[1]180,000	ES,PF
1760	00-00-00	[1]130,000	ES,PF
1891	02-24 91	[2]150,000	ES,HP
1906	11-27-05	[3]96,000	ES,HP
1916	01-20-16	68,900	ES,HP
1920	02-22-20	[4]95,000	ES,HP
1925	09-17-25	20,000	ES
1926	04-06-26	32,000	ES
1927	02-17-27	70,000	ES
1928	02-05-28	14,000	ES
1929	04-05-29	26,000	ES
1930	08-09-30	8,100	ES
1931	02-14-31	34,000	ES
1932	02-09-32	53,000	ES
1933	03-13-33	1,660	ES
1934	08-25-34	3,300	ES
1935	02-07-35	14,300	ES
1936	02-24-36	12,000	ES
1937	02-07-37	63,000	ES
1938	03-04-38	100,000	ES
1939	09-14-39	17,700	ES
1940	02-27-40	5,020	ES
1941	03-14-41	43,800	ES
1942	10-14-41	3,510	ES
1943	08-14-43	16,600	ES
1944	03-14-44	7,530	ES
1945	03-16-45	9,710	ES
1946	04-08-46	8,660	
1947	09-19-47	11,500	
1948	03-25-48	2,560	
1949	01-13-49	11,000	
1950	10-19-49	9,330	
1951	08-30-51	16,400	
1952	12-31-51	81,600	
1953	08-29-53	6,390	
1954	03-23-54	19,700	
1955	08-23-55	11,600	
1956	07-31-56	12,800	
1957	01-10-57	14,500	
1958	03-23-58	21,100	
1959	08-17-59	6,060	
1960	12-26-59	23,400	
1961	08-23-61	2,800	
1962	02-13-62	13,300	
1963	08-22-63	18,900	
1964	08-27-64	6,910	
1965	01-07-65	25,700	
1966	12-22-65	39,300	
1967	12-07-66	53,000	
1968	12-19-67	32,600	
1969	01-26-69	45,800	
1970	09-06-70	61,900	
1971	08-03-71	3,030	
1972	12-27-71	21,100	
1973	10-20-72	63,400	
1974	08-02-74	1500	
1975	04-15-75	5,420	
1976	02-10-76	39,900	
1977	08-24-77	1,620	
1978	03-01-78	91,400	
1979	12-19-78	94,000	
1980	02-15-80	94,800	
1981	04-06-81	2,030	
1982	03-12-82	42,100	
1983	12-23-82	22,400	
1984	10-01-83	27,200	
1985	12-28-84	19,300	
1986	11-30-85	10,300	
1987	03-10-87	5,000	
1988	02-03-88	19,800	
1989	02-05-89	2,670	
1990	09-03-90	2,790	
1991	03-02-91	34,300	
1992	08-23-92	27,200	
1993	01-08-93	145,000	
1994	02-08-94	4,770	
1995	02-15-95	[5]108,000	
1996	08-03-96	2,450	

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[1] Ely and Baker (1985).

[2] Highest since 1888.

[3] Highest since 1891.

[4] Highest since 1906.

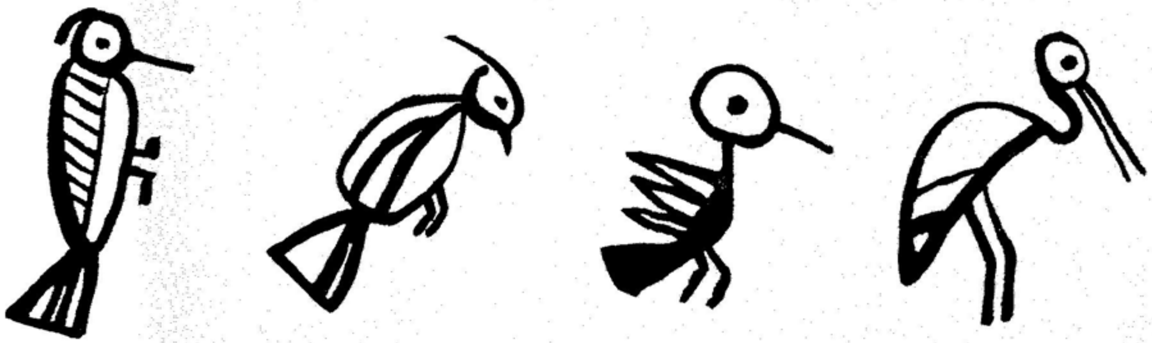
[5] Highest since 1920.

ONCE A RIVER

Bird Life and Habitat Changes on the Middle Gila

AMADEO M. REA

Bird Sketches by Takashi Ijichi



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About the Author...

AMADEO M. REA's field of expertise is the taxonomy and distribution of birds of western North America. His interest in natural history began during a childhood spent on a ranch in El Dorado County, California. Five years of teaching on the Gila River Reservation at St. John's Indian School, Komatke, gave him the opportunity not only to pursue ornithological studies but also to tap the wealth of biological data in the oral history of the Pima Indians. He earned his Ph.D. at the University of Arizona, Tucson, and in 1977 became curator of birds and mammals at San Diego's Natural History Museum.

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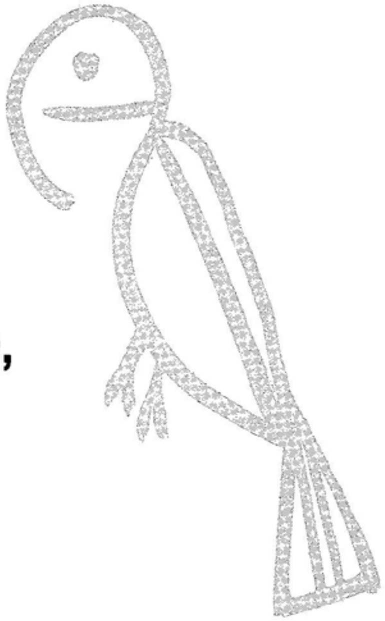

CHAPTER 1

The Pima People, Past and Present

The Gila River was once a well-defined stream meandering across a Lower Sonoran Desert floodplain with here and there marshes, lagoons, and oxbows. Its gallery forest of native cottonwoods and willows formed a green ribbon that travelers could trace for hundreds of miles through the desert. Other living streams—the San Pedro, Santa Cruz, Salt, Agua Fria—added their own waters to the middle Gila. Villages of agricultural Indians, early historic as well as prehistoric, dotted the fertile floodplains. These streams with their woods, lagoons, and grasslands, all abounding in birds and other forms of wildlife, are a thing of the past. The rivers are dead. Their biotic communities are gone. Their fragile watersheds have collapsed during decades of abuse. By the time the middle Gila had its first resident ornithologist (1907), the water regime had been altered, the channel was broad and unstable, the marshes and most of the timber had been scoured away by years of floods, and the grasslands had entirely disappeared. The native villages Father Kino found in the 1690s all along the Gila from the mouth of the San Pedro River to Yuma had been reduced to about half a dozen settlements.

This study of bird life and habitat change takes a close look at what was once the most mesic part of the Gila—its middle in south central Arizona, or what is now the Gila River Indian Reservation (Fig. 1.1). For several reasons, the reservation is ideal for such a study. When the first Spanish explorers pushed their way northward into the area they called Pimería Alta, they found Piman Indians dwelling along 150 miles (250 km) of the prime Gila River bottoms. These indigenous people have preserved an oral history extending back at least a century and a half and a lexicon of avian ethnotaxonomy reaching well over three centuries into the past. Later, when Europeans began traveling overland to California, the Pima Villages were a major outpost until

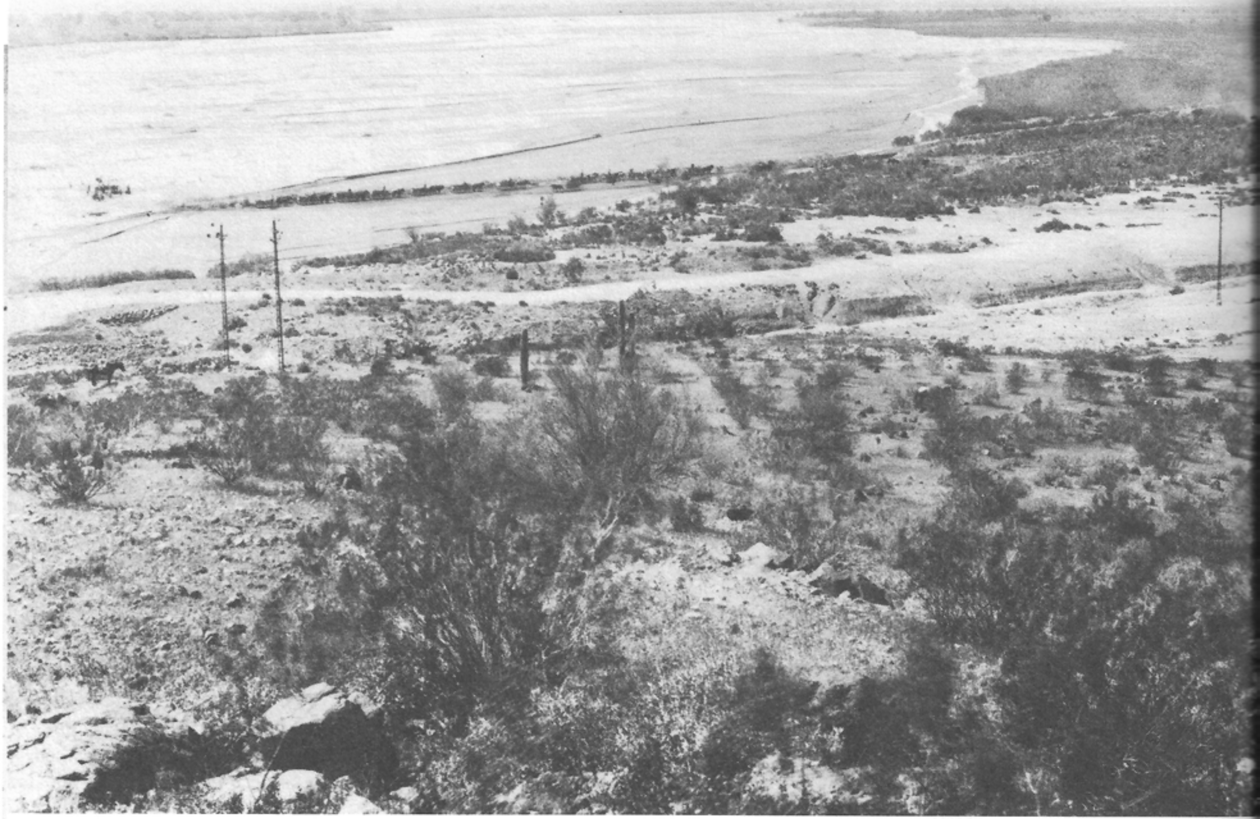

Fig. 2.2a. The Gila River channel at Sacaton in 1905.

A thin fringe of cottonwoods can be seen along the opposite bank of the river, but by this date years of drought and devastating floods had scoured away most of the riparian community. The formerly well-defined channel had become a bare sandy bed. M. French Gilman began studies here two years later. (Photo by H. L. Shantz, courtesy of University of Arizona Herbarium.)

> be charged the obliteration of bird life in the so-called desert portions of the Territory. The stock business at one time promised enormous profits and because of this the country was literally grazed to death. During the years 1892 and 1893 Arizona suffered an almost continuous drouth, and cattle died by the tens of thousands. From 50 to 90 per cent of every herd lay dead on the ranges. The hot sun, dry winds and famishing brutes were fatal as fire to nearly all forms of vegetable life. Even the cactus, although girdled by its millions of spines, was broken down and eaten by cattle in their mad frenzy for food. This destruction of desert herbage drove out or killed off many forms of animal life hitherto common to the great plains and mesa lands of the Territory. Cattle climbed to the tops of the highest mountains and denuded them of every living thing within reach. The ranges were foolishly overstocked, and thus many owners of big herds were financially ruined by their covetousness, but under the most favorable circumstances it will be years before the life, once so common to the desert country, recovers from the shock.

But Herbert Brown was wrong—the country was never to recover. A point of no return had been reached in the arid ecosystem. Drought, coupled with overgrazing, reduced the surface flow of the Gila River (see Fig. 2.2). Writing in 1924, Hayden (1965:59) said:

THE PIMA INDIANS

FRANK RUSSELL

Re-edition
with Introduction,
Citation Sources, and Bibliography
by BERNARD L. FONTANA

The University of Arizona Press
Tucson, Arizona

About the Author . . .

FRANK RUSSELL was an early and dedicated member of the anthropological profession whose detailed work on the material culture of the Piman people was accomplished in Arizona virtually on the eve of his death from tuberculosis. A member of the Harvard Faculty of Arts and Sciences, in 1900 Russell was given leave of absence for field work on the Gila River Reservation for the Bureau of American Ethnology. By contrast, his previous investigations had been among the tribes around Great Slave Lake and Herschel Island in the Arctic Sea. Russell's distinction as researcher and author is relatively little known to modern students of anthropology because his career was cut short at age 35. By that time he had completed this standard reference work on the Gila River Pimas, originally published as part of the *Twenty-sixth Annual Report of the Bureau of American Ethnology, 1904–1905.*

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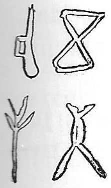
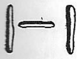


The Pimas went on a campaign against the Salt River Apaches soon after a heavy rain. When they reached the Salt river it was too high to be safely forded, so they built a raft and tried to take their saddles and blankets across upon it. The raft sank and they lost all their effects. Some of the party who had not engaged in the raft enterprise found a safe ford and continued on their raid, in which they killed several of the enemy, and near Four Peaks captured an Apache lad.[a]

1874–75



Gila Crossing. A man trying to catch his pony approached from the rear so that he could reach its tail, which he probably thought it advisable to lay hold on until he could fasten the rope around the animal's neck. One end of the lariat was attached to his waist, the other he tied to the horse's tail. The animal broke away and dragged him to death.[b]

Blackwater. The Apache White Hat killed a Pima.

1875–76

Gila Crossing. In this year sickness prevailed in the village of Rsânûk, apparently the same as in 1866, when the principal symptom of the disease was shooting pains through the body. Two medicine-men were suspected of having caused the trouble by magic means, and they were killed to stop the plague.

Blackwater. For a short time the Pimas were free from Apache attacks, and they ventured into the mountains to gather mescal. While there, a race took place between a man and a woman, in which the woman won.

Later in the season there was a general gathering of the villages to witness a race with the kicking-ball.

1876–77

Gila Crossing. There was an Apache village called Hâvany Kâs at the junction of the Gila and Salt rivers while a truce existed between the Pimas and Apaches. During this year an epidemic of smallpox prevailed in that village, as well as in all those of the Pimas and Maricopas.

---

[a] He afterwards became known as Doctor Montezuma, now a prosperous physician practising in the city of Chicago.

[b] This, the only event of the year in the Gila Crossing record, is unimportant in itself, and yet it illustrates a phase of Pima character that is worthy of notice. In handling horses they exhibit a patient subtlety resembling that of the snake creeping upon its prey, until they have gotten a rope or halter on the animal, when their gentleness disappears. Yet in all their harnessing or saddling they manifest an innate tendency toward carelessness. They always work up on the right instead of the left side of a horse, and they also mount from that side.

1900–1901

Gila Crossing. It was during this year that the President came to Phoenix.[a]

Gila Crossing, Salt River. During the spring the man employed to carry the mail between Phoenix and Scottsdale became insane and shot a white man and a Pima youth whom he met on the road near the latter place.

1901–2

Gila Crossing. In September, 1901, the day school was started at Masâ'kimûlt, the Gila Maricopa village.

TECHNOLOGY

The Food Supply

The Pimas subsist upon a mixed diet in which vegetable food predominates. In the past it would seem probable that the proportion of meat was greater than at present, though they have long been tillers of the soil. Certain articles of their diet appear to be markedly flesh producing, and this tendency is at least not diminished by the habits of life resulting from the semitropical climate of the Gila valley. They are noticeably heavier than individuals belonging to the tribes on the Colorado plateau to the north and northeast, and many old persons exhibit a degree of obesity that is in striking contrast with the "tall and sinewy" Indian conventionalized in popular thought. (Fig. 2.)

About every fifth year in primitive times the Gila river failed in midwinter, the flow diminishing day by day until at length the last drop of water that could not gain shelter beneath the sands was licked up by the ever-thirsty sun. The fish gathered in the few pools that were maintained by the underflow, the ducks and other water birds took flight, but the deer and antelope could the more readily be stalked because of their resorting to known watering places. Without water in the river and canals there could be no crops, and necessity drove the people to seek far afield for the native plants that in some degree produce fruits or seeds even in dry seasons. The fruit of the saguaro and the seed or bean of the mesquite were the most abundant and accessible resources. When even these failed the Pimas were driven to make long journeys into the Apache country—

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[a] The visit of President McKinley to Phoenix, in May, 1901, made a profound impression upon the Pimas. Kâemâ-â lives but 20 miles south of the Arizona capital, and was present at the time of the President's visit. He made no mark upon the calendar stick to commemorate the event, but related the circumstances as a part of the history.

It is not surprising that the Pimas, who had heard for many years of the Great Chiefs in Washington, should be desirous of seeing one in the flesh when the opportunity presented itself. The official interpreter at the agency frequently, during the winter of 1901–2, expressed her desire to obtain a good biography of the late President. After commenting upon the hideous crime of the assassin at Buffalo she made the truthful and suggestive remark that ' no Pima would do such a thing; he would never kill his chief."

placed it in a horizontal position on the top of the heap of mesquite wood; as it was, her load weighed nearly 100 pounds, yet she knelt down, engaged her head under the carrying strap, and struggled to her feet without assistance (*c*). The method of unloading is shown in *d*, where, by bending forward, the entire burden is thrown off clear of the head. Figure 65 illustrates the manner in which a kiâhâ net is mended.

As the kiâhâ is distinctively a woman's utensil, so is it closely associated with her life history. The young girls of 8 or 10 begin to use small kiâhâs made especially for them or that have been cut down from old ones. They learn the methods of loading so that the burden may be stable and of proper bulk, they acquire the necessary nerve and muscle coordinations that enable them in later years to lift loads weighing more than do they themselves, they become inured to the fatigue of long journeys, and they learn to preserve their kiâhâs with care from rain. The maiden must have long and gaily-spotted frame sticks at the front of her kiâhâ, which are wound with long hair cords. She uses a helping stick that is ornamented with a long deerskin fringe pendent from the binding at the crotched end (fig. 64). As she walks along with the sharpened end of the stick thrust into the load the fringe hangs above and forward of her head, swinging at every step or fluttering with every breeze. It is indeed a conspicuous object, and it is not surprising that it should have caught the attention of every passing traveler, whose illustrations of it are uniformly bad.[a]

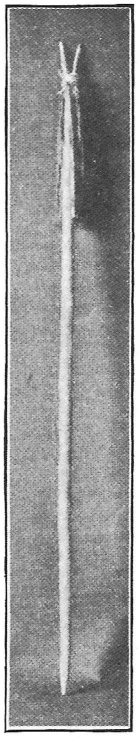
FIG. 64. Helping stick.

As the age of the owner advances she becomes careless of the appearance of her kiâhâ, the spots on the frame are less frequently renewed, the cordage grows short and worn, and the foresticks of the frame are cut down in length. However, her burdens do not diminish, and the woman here photographed, though her age exceeds the scriptural allotment, is yet able to carry more than 100 pounds at a load.

The kiâhâ is of entirely different materials from the ordinary Pima baskets. Wood is used for the four frame sticks, two at the front and two at the rear. Saguaro ribs are invariably used for the purpose, as they are very light, symmetrical, straight, and sufficiently strong. The hoop is a double band of willow.

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[a] "They are highly prized by their owners, as they are very useful to them, and are made with much labor. For the only specimen I could obtain I was obliged to give goods to the value of $10." Bartlett, Personal Narrative, II, 236.

Oats are seldom raised in that region. They are called "white tassels" by the Pimas. Barley is the universal grain feed of Arizona, and there is a ready market for the small quantity the Pimas raise.

VEGETABLES

Watermelons, muskmelons, pumpkins, and squashes are extensively cultivated. The watermelons are preserved until after the 1st of January by burying them in the sands of the river bed. The pumpkins, squashes, and muskmelons are cut in strips and dried, the best-keeping varieties being left in the storehouses until midwinter (pl. xxxv, *f*). According to tradition the first pumpkins, called rsas′katûk, were obtained from the Yumas and Maricopas.[a]

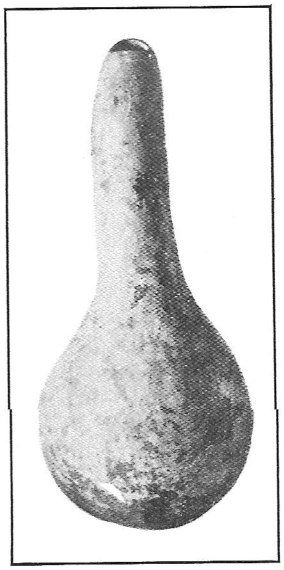

FIG. 7. Gourd canteen.

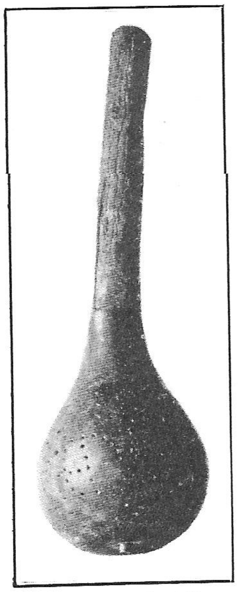

FIG. 8. Gourd rattle.

There are three species of wild gourds that are quite common along the Gila, namely: Cucurbita fœtidissima H. B. K., C. digitata Gray, and Apodanthera undulata Gray. Cultivated gourds have been known to the Pimas for a long period—how long it is impossible to say. The Papagos have a tradition that this plant was introduced by Navitco, a deity who is honored by ceremonies at intervals of eight years—or, if crops are bountiful, at the end of every four years—at Santa Rosa. The gourd is used as a canteen (fig. 7), and if it becomes cracked a rabbit skin is stretched over it which shrinks in drying and renders the vessel water-tight again. Dippers and canteens are occasionally made of gourds, but the chief use of gourds seems to be in the form of rattles (fig. 8) which contain a little

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[a] When Garcés was among the Yumas in 1775 they were raising "countless" calabashes and melons—"*calabazas y melones*, perhaps better translated squashes and cantaloupes, or pumpkins and muskmelons. The Piman and Yuman tribes cultivated a full assortment of cucurbitaceous plants, not always easy to identify by their old Spanish names. The *sandia* was the watermelon invariably; the *melon*, usually a muskmelon, or cantaloupe; the *calabaza*, a càlabash, gourd, pumpkin, or squash of some sort, including one large rough kind like our crook-neck squash. * * * Major Heintzelman says of the Yumans, p. 36 of his Report already cited [H. R. Ex. Doc. 76, 34th Cong., 3d sess., 1857]: 'They cultivate watermelons, muskmelons, pumpkins, corn, and beans. The watermelons are small and indifferent, muskmelons large, and the pumpkins good. These latter they cut and dry for winter use [they were brought to Pimería before the Maricopas came to Gila Bend].'" Note in Coues' On the Trail of a Spanish Pioneer, New York, 1900, I, 170.

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Indians of the United States: Appendixes: A. Report on the San Carlos ...

United States. Congress. House. Committee on ...

APPENDIXES A, B, AND C

INDIANS OF THE UNITED STATES

HEARINGS

BEFORE THE

COMMITTEE ON INDIAN AFFAIRS

HOUSE OF REPRESENTATIVES

SIXTY-SIXTH CONGRESS
FIRST SESSION

ON

THE CONDITION OF VARIOUS TRIBES OF INDIANS

ACT OF JUNE 30, 1919

HOMER P. SNYDER, New York, *Chairman.*

PHILIP P. CAMPBELL, Kansas.
ROYAL C. JOHNSON, South Dakota.
JOHN A. ELSTON, California.
FREDERICK W. DALLINGER, Massachusetts.
BENIGNO C. HERNANDEZ, New Mexico.
MARION E. RHODES, Missouri.
JAMES H. SINCLAIR, North Dakota.
CLIFFORD E. RANDALL, Wisconsin.
ALBERT W. JEFFERIS, Nebraska.
R. CLINT COLE, Ohio.
JOHN REBER, Pennsylvania.
M. CLYDE KELLY, Pennsylvania.
CHARLES D. CARTER, Oklahoma.
CARL HAYDEN, Arizona.
WILLIAM J. SEARS, Florida.
JOHN N. TILLMAN, Arkansas.
HARRY L. GANDY, South Dakota.
WILLIAM W. HASTINGS, Oklahoma.
ZEBULON B. WEAVER, North Carolina.
RICHARD F. McKINIRY, New York.

(IN TWO VOLUMES)

VOL. 2—APPENDIXES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

APPENDIX A

REPORT ON THE

SAN CARLOS IRRIGATION PROJECT AND THE HISTORY OF IRRIGATION ALONG THE GILA RIVER

THE HISTORY OF IRRIGATION ALONG THE GILA RIVER

BY

C. H. SOUTHWORTH
United States Indian Irrigation Service

CONTENTS.

Previously used canals:

History of irrigation on the Gila River Indian Reservation—Continued.
  Irrigation on the tributaries of the Gila—Continued.
    San Pedro—Continued.

los project and the recommendations contained therein form the basis of the work of the Gila surveys.

HISTORY OF THE GILA RESERVATION CANALS.

The detailed history of the early canals on the reservation must necessarily come from the Indians themselves. With this in mind, many of the older Indians residing in the various districts of the reservation were interviewed.[1]

Whenever possible two or more persons were questioned, independently, in the same subject so as to obtain corroborative evidence.

Indian calendar sticks were also interpreted in order that the different events to which the older Indians referred could be related to our own time or calendar.[2]

FORMERLY USED CANALS OF PREVIOUS CULTIVATION.

The term "previous cultivation" as used in this report, will refer to those tracts of land not being irrigated at the present time, but which show unmistakable evidence of having been irrigated at some past time. This term will likewise include inactive ditches, which were evidently used for irrigation in the past.

Obviously it is impossible to obtain definite or precise information concerning the history of irrigation on the Gila River Reservation during that period of time, which antedates the memory of the oldest inhabitants. Efforts have been made, therefore, to determine the manner and extent of irrigation at a time just prior to the coming of the whites, as well as during the period from that time until the present.

The canals here described are, as a rule, plainly visible on the ground, and are shown on the survey plats of the reservation. The outlines of the previously irrigated areas were traced by the aid of the old borders and ditches. As already stated, these ditches are comparatively modern, most of them having been out of use since the early fifties—that is, subsequent to the advent of the whites, as will be shown later in this report.

The Gila River is particularly a flood or "flash" stream, and as a rule the diversion dams at the heading of the various Indian ditches are washed out during each large flood, consequently the diversion sites or heading are changed often to meet the various new conditions brought about by floods. Frequently old and inactive

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[1] In the supplemental exhibits accompanying this report will be found statements made by the Indians during the course of these interviews. Three interperters were employed at various times, and although not a few of the men interviewed were able to talk English, a far greater number belonged to an older generation and required the services of an interpreter.

The translations have been made as near verbatim and in keeping with the Indian expressions and idioms as was consistent with at least understandable English.

Louis Nelson, John Enis, and Rudolph Johnson (Pima Indians) were employed as translators, and to these men acknowledgments are due. Especial praise and credit are due Rudolph Johnson for his untiring efforts and keen interest in this work.

[2] These calendar sticks are chronological records kept by a few older men of the tribe. They resemble the ordinary walking cane with numerous markings or characters cut into the wood. Each marking or set of markings represents a yearly period. These indentations served to stimulate the memory of the owner. The Pima year differs from our calendar year, beginning, as it does, at the time of the saguaro harvest. For full description of the calendar sticks see Russell Twenty-sixth Annual Report, Bureau of American Ethnology, p. 36. Interpretations of these calendar sticks are submitted in the supplemental exhibits accompanying this report. vol. 1. p. 91

ditches are found that represent merely the former headings of ditches farther down the valley. Accordingly, in writing a history of the old ditches no account will be taken of these various former headings.

The previously irrigated areas and the canals by which they are supplied will be taken up in the order in which they are found, beginning at the east end of the reservation and proceeding down the river to the west boundary line.

Old Woman's Mouth ditch.—The first ditch[1] at the upper end of the reservation which is now unemployed, but which was formerly in use, is the Old Woman's Mouth, named after its builder.[2]

This ditch was constructed in 1881.[3]

A total of 173 acres was shown to have been irrigated at one time under this ditch. Failure of the water supply was given as the cause of its idleness. Partial disuse of this ditch commenced about 15 years ago, but it has been in use as late as 1904. The flood of 1905 washed out the heading and filled the ditch with silt, resulting in its complete suspension.

Old Woman's Mouth and his coworkers lived in the Blackwater settlement and did their planting and other work from this village. After the failure of their ditch these families still remained in Blackwater district. At least one family still cultivates a few acres under this ditch, but the water is derived from the rains and collected from an adjoining gulch. This ditch, from measurements taken at the time of the survey, had a bottom width of 5 feet, a top width of 8 feet, and a water depth of about 1 foot, the maximum capacity being approximately 20 second-feet. The new Blackwater project already referred to covers practically all of the land previously irrigated by the Old Woman's Mouth ditch.

Cayau ditch.—The Cayau (Woods) ditch was located on the north side of the river opposite the Old Woman's Mouth and had its heading near the section line between secs. 24 and 25, T. 4 S., R. 7 E., G. & S. R. B. & M.

This canal was constructed in 1869[4] by an Indian whose name was Cayau, or Woods. From 1869 until 1880 300 acres were irrigated under this ditch. The scarcity of water in the river and the establishment of the present Santan district, the district where the irrigators formerly under the Cayau ditch now live, are given as the reasons for its inactivity. According to the survey, 235 acres were previously irrigated under the Cayau ditch. This ditch originally had a bottom width of 4 feet, was about 7 feet wide on top, and had a capacity of 15 second-feet.

Within the last five or six years the present North Side Blackwater ditch was extended to the Cayau ditch, and the surplus water of the

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[1] Another inactive Indian ditch which had a heading somewhat higher up on the river than this Old Woman's Mouth, is designated on the map as the Old Indian (Upper Blackwater) ditch. This ditch was constructed in 1884, but inasmuch as it was never used for irrigation, it has not been treated separately. It appears that this ditch was constructed through land that was afterwards thrown open to the public. The consequent white occupation, in addition to the fact that the ditch was constructed on a very poor grade, probably accounts for its nonuse. The lower end of this ditch was used in connection with the recent Blackwater project, which is discussed elsewhere in this report.

[2] The peculiar name given to this ditch is a nickname applied by the Indians to its original builder or promotor.

[3] See statement, supplemental exhibit, Vol. 1, p. 9.

[4] See statement, vol. 1, p. 9, supplement exhibits accompanying this report.

former was used to irrigate some of the land under the latter. However, very little of the old land has been cultivated as a result of this arrangement, since it appears that the Blackwater ditch is inadequate to supply more than a very small quantity of surplus water. The land under the Cayau ditch, therefore, is now practically idle.

Yaqui Canal.—Next in order from the eastern boundary of the reservation, and diverting from the Little Gila River is the ditch generally known as the Yaqui Canal. While this canal has not yet ceased operations the area irrigated under it at the present time is so limited that it will here be considered under the head of previous irrigation. This canal was constructed in 1891, deriving its name from the Yaqui Indians who worked on the ditch at the time of its construction, and into whose possession it eventually came. This ditch during the dry season derives its water supply from the so-called Blackwater Lake.[1]

This lake is a sort of lagoon or small swamp, and from all accounts the springs by which it is fed yielded much more water in former times than they do at present.

Even the Pimas had their local water trouble, for it appears that the appropriation of the waters of this lake by the Yaqui Canal deprived the previous diverters lower down on the Little Gila of a portion of this flow. The lake, which is situated some three or four hundred feet south of the Little Gila, was connected with that stream by a ditch constructed prior to the Yaqui Canal. The water trouble which ensued as a result of the appropriation of water through the Yaqui Canal was brought to the attention of the agent on the reservation. A decision was rendered in favor of the lower diverters and a new, better, and somewhat larger ditch was built in order that the waters of the lake could more quickly reach the Little Gila. This construction took place in 1902, which date naturally marks the decline of the lands under the Yaqui Canal.

According to the survey, 289 acres over and above the acreage at present under cultivation had previously been cultivated by the use of the Yaqui Canal. It may be stated that this maximum cultivation took place during the period dating from 1890 to 1900. The ditch at present has a top width of 6 feet, bottom width of 3 feet, water depth of 2.5 feet, and a grade of 1 in 1,000. Its capacity is 22 second-feet. When it became necessary to vacate their lands under the Yaqui ditch these Indians took up and cultivated lands under the present Santan Canal. Brief reference will again be made to the Yaqui ditch under the head of "Present irrigation," since it still serves for the irrigation of a limited acreage.

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[1] Blackwater Lake appears to be simply a natural depression containing several small springs. Several reports are current to the effect that this lake represents an artificial reservoir constructed during some more or less remote period to furnish water to the Little Gila River for irrigation purposes. In this connection it may be stated that while the Little Gila itself is thought to have been built by the Indians or by prehistoric irrigators, yet inquiry among the Indians fails to supply any information supporting the artificial-construction theory regarding the lake. Several of the Indians have pointed out, however, that if this lake had been constructed by any of the early tribes related to them, there would no doubt have remained some tradition in reference to this work.

There is a tradition among the Pimas regarding Blackwater Lake, but it is to the effect that it is of fathomless depth, that strange and awesome animals have appeared in it, and that it communicates with the ocean, but no reference is made to its artificial construction. The name Blackwater is derived from this mysterious pool of dark water. For further information, see The Myths and Legends of the Pimas, by J. William Lloyd, p. 241.

Old Santan ditch.—Six miles below the old headworks of the Yaqui Canal, and on the same (south) side of the river, is the diversion site of the Old Santan ditch.[1]

This ditch formerly served to irrigate a strip of land between the Little Gila and the Gila proper, part of which now constitutes the agency farm. A new canal, recently constructed by the Indian irrigation service, and which is described under the head of "Present cultivation," is intended to irrigate practically the same lands as formerly irrigated by this old Santan Canal. George Pablo,[2] who is 63 years old, says that this ditch was built in his childhood, while Miguel [3] says that he helped in its construction, and that it was excavated some years before the battle between the Blackwater Pimas and Santan Pimas.[4]

Mr. Cook, the first missionary among the Pimas, in 1871 established a school near the old Santan village,[5] where the irrigators under this canal used to live; and it is therefore safe to assume that this canal was completed prior to 1870, probably about 1865.

Failure of this canal project took place gradually, beginning in the late seventies or the early eighties, or at the time of the construction of the present Santan Canal on the north side of the river. The date of the latter undertaking was 1879.

The area of land which was observed to have been previously cultivated under this old canal amounts to 1,272 acres, including most of the land under the present agency farm, which embraces an area of 168 acres.[6]

While the line of this old ditch is still plainly visible, it is now so badly filled with silt that, like many others of the older ditches, its original dimensions are difficult to determine. From measurements taken, it would appear that this ditch had a bottom width of 5 feet, top width of 8 feet, water depth of 2 feet, and a grade of 1 in 500. The capacity, therefore, is in excess of 30 second-feet.

Failure of the water supply, as well as the tribal fight already mentioned, are stated to be the reasons for the nonuse of this ditch.

New Mount Top ditch.—The New Mount Top ditch, called "new" because the Indians who built it originally came from the Old Mount Top settlement near the present village of Sweetwater. This former diversion had its heading at a point in the south side of the Little Gila, just below the Sacaton Agency, in sec. 16, T. 4 S., R. 6 E., G. and S. R. B. and M. This ditch was built in 1868. According to Miguel,[7] of Sacaton, who assisted in its construction, only one crop of grain was harvested before the ditch was abandoned. The builders moved to other locations.

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[1] This ditch should not be confused with the modern Santan Canal and district. In former years the present Santan Indians or their predecessors lived on the south side of the river, and their former villages, ditches, etc., were called Santan.

[2] Supplemental exhibits, vol. 1, p. 34.

[3] Supplemental exhibits, vol. 1, p. 50.

[4] This trial fight took place in 1878–79, according to the calendar of Maj. Johnson; also confirmed by Russell, p. 57, 26th American Ethnological Report.

[5] The remains of this old schoolhouse, which was of adobe, are still to be seen about 2 miles west of the present Sacaton Agency, on the road between Sacaton and Casa Blanca. Although the old Santan ditch. and the fields which it served to irrigate, are situated on the opposite side of the Little Gila from the site of their old village, yet it appears that these Indians preferred to cross the Little Gila each day on their way to and from work rather than to pitch their camp on the comparatively low lands near the fields.

[6] The land included in the agency farm was originally irrigated by Antonio Azul, who in later years irrigated the eastern portion of this same area from Cottonwood ditch and the remainder from the old Santan ditch. This land was acquired from Azul for agency purposes in 1892.

[7] See statement, p. 50, vol. 1, supplemental exhibits.

The evidence available on the ground would show that about 182 acres were planted under cultivation. This ditch varied in width from 5 feet near the heading to 3 feet at its lower extremity. Its capacity was at least 10 second-feet. After the failure of this venture the Mount Top villagers appear to have amalgamated with the Sacaton Indians, as they no longer have a separate village.

Old Maricopa ditch.—A few miles further down the Little Gila, in section 7, T. 4 S., R. 6 E., G. & S. R. B. and M., another of these many idle canals had its heading. This, the Old Maricopa ditch, is not to be confused with the Ancient Maricopa ditch, which is also an inactive canal, located near the present Sacaton siding of the Maricopa-Phoenix Railroad. The Old Maricopa ditch was constructed in 1848–49, according to Antonito Azul,[1] who states that this ditch was completed and water turned in at the time that a band of Maricopa Indians went to the Picacho Mountains after mescal, and were ambushed by the Apaches. This incident, according to Maj. Jackson's calendar,[2] took place during the years 1848–49.

The builders of the Old Maricopa ditch were Maricopa Indians, who had withdrawn from the main body of their tribesmen, then cultivating land under the Ancient Maricopa ditch. Upon the failure of the former ditch, these Maricopas reunited with their tribesmen and they or their descendants are now cultivating land near the confluence of the Gila and Salt rivers at the western extremity of the reservation. The date of the inactivity of the Old Maricopa ditch is not definitely known. Apachoes[3] says he thinks the fields were vacated about 50 years ago, but his memory was rather vague on that point. This district, as well as the Ancient Sweetwater district, was undoubtedly under cultivation in 1852, at the time of Bartlett's visit,[4] but was evidently vacated before Rev. Mr. Cook's school was established (1871), since the latter fails to mention this district in his description.[5]

It is believed, therefore, that this ditch became inactive in about the year 1870, which date is in conformity with the information obtained from Apachoes.

This ditch had originally a bottom width of 5 feet, top width of 8 to 10 feet, and capacity of 15 second-feet. The area formerly under cultivation under this ditch, as nearly as could be ascertained from the remaining borders, etc., amounts to 238.5 acres. The Old Maricopa Canal discharges into the Ancient Sweetwater, and it is evident that the lower part of this latter ditch was used as an extension to the former.

A branch ditch taking out of the Old Maricopa Canal a short distance below its heading was added soon after the construction of this canal by a number of Old Mount Top Indians, who desired to cultivate a portion of the alkali lands situated south of the main ditch. Some land was placed under cultivation (6.2 acres), but the soil was so poor that the attempt was soon given up.

Ancient Stotonic.—This ditch, called "Ancient" to distinguish it from the present Stotonic ditch, which heads lower down the Gila River, had its point of diversion about 2 miles below the Old Mari-

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[1] See statement, p. 17, vol. 1, supplemental exhibit.
[2] See calendar, supplemental exhibit, vol. 1, p. 108.
[3] See statement, vol. 1, p. 1, supplemental exhibits.
[4] See p. 25 of this appendix covering the early history of the Gila River Reservation.
[5] See letter of Dr. Cook, in supplemental exhibits, vol. 1, p. 86.

copa Canal and near the north boundary of sec. 2, T. 4 S., R. 6 E. This inactive canal is one of the very oldest ditches on the reservation, and its heading may be considered practically a former heading of the present Stotonic ditch. Inasmuch as certain lands were covered and irrigated by this old ditch that can not be covered by the present Stotonic, the former will be treated separately.

According to the statements of the oldest living inhabitants, the Ancient Stotonic ditch was in operation as early as they can remember, and so far as the knowledge of the Pimas goes, this ditch, or others in the same vicinity, has been supplying the same body of land continuously since the earliest times. Unquestionably the irrigated lands or rancherias first described by the early Spaniards were located in this vicinity.

An area of 590 acres was found to have been under cultivation under this old canal, exclusive of the land now under cultivation under the present Stotonic. This area was vacated because of the removal of the heading to a point lower down the river and the construction of the present Stotonic Canal.

According to Joseph Head, the change of heading affecting this land took place about 35 years ago, consequently, it may be stated that this land has been unoccupied since about 1880. Several headings have been constructed at various times for this canal, as well as for the present Stotonic, but it is thought that the one covering the greatest area of cultivation is as above stated. This ditch at a point above the uppermost of its old laterals had a bottom width of 6 feet, top width of 10 feet, water depth of 2 feet. With its present grade of about 1 in 1,000, these diversions would give this ditch a carrying capacity of 28 second-feet.

Old Mount Top.—The so-called Mount Top ditch is not a separate ditch, but a branch of the Stotonic. It had no independent heading, but inasmuch as it was built and operated by the Mount Top Indians and also later became useless to them, it will be considered in this report as an independent ditch. This canal took out of the present Stotonic ditch in the SW. ¼ sec. 28, T. 3 S., R. 5 E.

According to the statements of Vanico[1] and Pablo[2] this ditch was built prior to their earliest recollection, and undoubtedly before their births. Irrigation in this district was probably carried on contemporaneously with the former irrigation in the adjacent districts of Stotonic and Casa Blanca. According to Pablo[2] this district was at least partially vacated 45 years ago, or approximately at the time of the construction of the New Mount Top, which is said to have been constructed in 1866.

The area previously cultivated under this ditch, all of which has since been in nonuse, according to the survey, amounted to 718.5 acres.

This ditch has a bottom width of 5 feet, depth of 1½ feet, and is not much wider at the top than at the bottom. Its grade is only 1 in 1,800, giving the ditch a theoretical capacity of about 9 second-feet.

The Mount Top Indians when cultivating these lands were prosperous and occupied a village of no mean size near the conspicuous little butte just south of their fields. This little hill is known to

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[1] Supplemental exhibits, vol. 1, p. 47.

[2] Supplemental exhibits, vol. 1, p. 30.

the Indians as Rattlesnake Home, because a small cave in its banks was the legendary abode of a monstrous rattlesnake and her numerous young. As we already know, these Mount Top Indians, after having vacated their fields, went to the old Santan district, near the old Cooks School, later joining the present Santan villagers.

Sranuka ditch (*Alkali Camp Canal*).—The Sranuka ditch was in reality only partially serviceable, since a portion of this old ditch is now known as the Alkali Camp Canal, which will be taken up under the head of "Present irrigation."

This is one of the older ditches, having been in use at the time of the coming of the Whites.[1] Much of this old ditch has been washed out, especially near its original heading which was located nearly opposite the village of Casa Blanca and approximately 2 miles above the present heading of the Alkali Canal. This ditch was one of the longest of the older ditches, extending from the heading just mentioned to a point 1 mile or more beyond the railroad at Sacaton siding, a distance of 8 miles. A large portion of the land previously irrigated under this ditch, as well as a part of the ditch itself, has been washed away by the floods.

Many of the Pimas now living at Gila crossing originally irrigated or farmed in the Sranuka district, but the lands which they irrigated under the Sranuka Canal were gradually vacated, beginning at the time of the first diversion in Gila crossing, i. e., in the late seventies or early eighties. Several new headings have been made for the Sranuka Canal, but the area under irrigation has decreased constantly. In recent years this ditch has been known as Alkali Camp Canal, so named because of the unusually large quantities of alkali to be found in the vicinity of the canal. The extreme western portion of the area irrigated under this old ditch was known by the Indians as the Skunk's district.[2]

Pablo in his sketch showing the distribution of the previously irrigated area is under the impression that the Skunk fields were irrigated by a separate ditch other than the Sranuka. It is believed, however, that Pablo confused the Skunk Ditch with the Santa Cruz, since no evidence of another ditch could be found on the ground.

When the survey was made in the early part of 1914, 736 acres were shown to have been previously irrigated under this ditch. At the extreme lower end of the Sranuka Canal there is a comparatively recent ditch, constructed about 10 years ago to utilize the waste water or the drainage from the Sranuka or present Alkali Camp Canal. Although this new ditch was excavated for a distance of about 2 miles, it was never used, owing to the failure of the water supply. The ditch was built by a few Indians living at Gila Crossing.

Sratuka (*Wet Camp*) *Canal and Snaketown district.*—All of the inactive canals thus far described, with the exception of the Cayau, had their headings either in the Little Gila or in the south bank of the Gila River proper. The Sratuka, however, is one other canal which lies on the north side of the main river, its heading being

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[1] Supplemental exhibits, vol. 1, p. 75. Also statement of Pablo, p. 30.

[2] This rather peculiar name, Skunk, or Oopia in Pima, comes from a family and their descendants of that name who formerly lived in this section. Whether this was a family name or merely an applied name, my informant did not state. (C. H. S.)

built near the isolated hill known as Double Buttes, or sometimes as Rattlesnake Hill. The former heading of this canal was near the section line between sec. 20–21, T. 3 S., R. 7 E., G. and S. R. B. & M.—that is, about a quarter of a mile above the present Snaketown canal diversion.

The old Sratuka district is identical with the district now known as the Snaketown or Skukaika.

The original Sratuka Indians located their village and also cultivated a small area of land on the south side of the river opposite their canal, which, as already, stated, was situated on the north side. This arrangement, while affording better protection for the Indians, required them to cross the river in order to reach their fields. Although the site of the original village of Sratuka has long since been washed away, there still exists a village of this name on the south side of the river in this same locality, and its farms are now irrigated by the Bapchil Ditch.

The proximity of the former village to the river lowlands accounts for the name Sratuka, which means wet camp. It is stated that many of the fields required only one or two irrigations to mature crops, so close was the water to the surface of the ground.

About the year 1872 many of the Indians living in this district vacated their farms and moved over to the Salt River Valley, where they began the cultivation of lands in the present Salt River Reservation. Their reasons for moving seem to have been several, viz. loss of their lands by floods, scarcity of water, and an invotation by the Mormon settlers to come over and settle near them, and thus afford protection from the Apaches. Some five or six years after this migration some of the Indians remaining at the village of Sratuka crossed the Gila and founded the present village of Snaketown.

Several different headings have from time to time been constructed for this ditch. The original canal, located as it was along the mesa edge, was capable of irrigating an area greater than that covered by the modern Snaketown Canal. The present heading of the Snaketown Canal was constructed subsequent to the disastrous flood of 1905.

The original Sratuka was in existence at the time of the earliest recollection of the present-day Pimas, but, as already indicated, the present-day village of Snaketown, on the north side of the river, is of comparatively recent origin.

The area of land which shows evidence of previous cultivation, and which is not included in the area at present under cultivation, amounted at the time of the survey to 1,273 acres. It is estimated that 500 acres has been washed away by floods since the survey by Meskimons[1] in 1904 shows an area in excess of the above figures by this amount.

The old canal, while badly filled up at present with silt, appears to have had a bottom width of 6 feet, top width of 12 feet, water depth of 2 feet. It has a grade of 1 in 1,200, giving a capacity of at least 30 second-feet.

Bridlestood Canal.—Continuing on down the river, the next no longer used ditch is the Bridlestood,[2] which is located on the same

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[1] Information concerning this survey is given on p. 97, of this appendix.

[2] The origin of this peculiar name is connected with a certain bush or scrub tree, the branches of which are said to have grown in the shape of a bridle. It seems that this particular tree grew in a prominent place near the principal road or trail leading through this district, and in this way the district became known as "where the bridle stood," or the Bridlestood district.

(north) side of the river. The Bridlestood, like the Snaketown Canal, is a very old district, this canal having been built prior to the remembrance of any of the older Indians. It became idle about the time of the Sranuka, the Skunk, and the old Maricopa—that is, about 25 years ago, or in the late eighties. This old Bridlestood ditch has since been used, in part, by several Indians under the leadership of an Indian known as Paloma, who constructed a ditch to divert the waters of the Gila into this old canal. Some of these old Bridlestood fields were rehabilitated, but were again vacated within a year because of a change in the river channel.

Another attempt to irrigate this territory was later made by a number of these same Indians by means of an extension to the Snaketown Canal. While considerable work seems to have been done of this extension within recent years, no success seems to have resulted from these efforts. A great deal of land, especially at the lower end of the Bridlestood district, has been washed away by the numerous floods of the Gila. The land shown to have been previously irrigated by the Bridlestood ditch amounted to 1,143 acres. This ditch was approximately 4 feet wide at the bottom, 10 feet wide on top, had a maximum water depth of 2 feet and a grade of 1 in 1,000. Its carrying capacity was probably at least 20 second-feet.

Old Santa Cruz Canal.—The remains of the upper portion of the old Santa Cruz Canal are found just below the railroad station at Sacaton siding. Much of this old ditch, as well as the land formerly irrigated by it, has been washed away. This ditch, like many others, was named after the Indians, or rather the village of Indians, by whom it was built. It appears that the Indians who were responsible for its construction afterwards moved to the Santa Cruz River near the lower end of the reservation not far from the Estrella Mountains, and for this reason the ditch, as well as the old idle fields under it, are called by other Indians the Santa Cruz.

The old Santa Cruz Canal, while antedating the coming of the whites, was built within the remembrance of at least some of the older Indians. Pablo[1] mentions it as one of the older ditches, having been in existence longer than he can remember. Ben Thompson,[2] however, states that he thinks it was built when he was a small boy, and that it became inert when he was old enough to fight the Apaches. This would indicate this ditch to be at least 60 years old, the year of its last activity probably being about 1875. Thompson corroborates this by stating that the old Santa Cruz Canal and the old Sranuka ditch became useless about the same time. So much of the area formerly irrigated under this ditch had evidently been washed away by floods that it was found impossible to determine the exact area of previous cultivation. The area remaining undisturbed by the floods and which showed evidence of previous irrigation, amounted to 400 acres. By assuming the probable location of the river bank at former times, it has been estimated that an additional area of 100 acres was at one time irrigated under this ditch.

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[1] See statement, supplemental exhibits, vol. 1, p. 30.
[2] See statement, supplemental exhibits, vol. 1, p. 27.

The old Santa Cruz ditch was probably 3 feet wide at the bottom, 10 feet wide on top. It had a grade of 1 foot in 1,000, and a probable capacity of 10 second-feet.

Ancient Maricopa Canal.—As in the case of the old Santa Cruz Canal, the heading and a considerable portion of this old ditch have been washed away by the floods. The original intake of the ancient Maricopa Canal was located near the heading of the old Santa Cruz, but on the opposite (north) side of the river. This ditch[1] according to Ben Thompson, was constructed by Maricopa Indians soon after this tribe joined forces with the Pimas. Nearly all of the existing calendars of the older Indians include prominent references to the Maricopas, but their coming to this reservation antedates the earliest of these records. According to Col. Emory[2] these Indians were found by Dr. Anderson at Gila Bend as late as 1828. They were then moving gradually from their old location on the Gulf of California to their present position near the Pimas. It is probable, therefore, that the ancient Maricopa Canal was started about 1830 or 1840. Each Indian who was interviewed upon the subject claimed that the canal was built prior to his knowledge.

As in the Santa Cruz district just across the river, much of the land formerly irrigated by means of the Ancient Maricopa Canal has been washed away. The remaining portion, according to the survey, measured 386 acres, and assuming again the probable former width of the river, it is estimated that at least 750 acres were at one time cultivated under this old ditch. The ditch, as it exists to-day, is 3 feet wide on the bottom, 5 or 6 feet on top, and appears to have had a water depth of 1½ feet. Its grade is 1 in 1,000. With these dimensions it would have a carrying capacity of 10 second-feet.

ACTIVE CANALS OF PRESENT IRRIGATION ON THE GILA RIVER RESERVATION.

North Blackwater (Cholla Mountain) ditch.—This canal, which lies on the north side of the river, has its heading about 3 miles up the river from the east line of the Gila River Reservation, in sec. 12, T. 5 S., R. 8 E. Two other ditches supplying reservation lands have their point of diversion opposite the heading of this ditch, but on the south side of the Gila.

Juan Thomas[3] states that this ditch was in operation when he came to the Blackwater district 38 years ago; that is, prior to 1876. Havilena[4] says this ditch was constructed 49 years ago; that is, in 1865, when he was serving as scout for the United States Government. Samuel Scoffer[5] states that it was constructed at some time prior to his arrival in this district, which was in 1867. It will be reasonable to assume, therefore, that the year 1866 represents very closely the date of its construction.

Juan Thomas also states that at the time of his arrival in the Blackwater district about two-thirds of the land irrigated at the present time was under cultivation. Thomas having arrived there in

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[1] See statement, supplemental exhibits, vol. 1, p. 27.
[2] See footnote, p. — of this appendix.
[3] See statement, p. 1, vol. 1, supplemental exhibits.
[4] See statement, p. 3, vol. 1, supplemental exhibits.
[5] See statement, p. 9, vol. 1, supplemental exhibits.

1876, it may be safely assumed that with this rate of development the entire district was irrigated by the year 1881.

The North Blackwater ditch has a top width of 11 feet, a bottom width of 5 feet, a water depth of 1½ feet, and a velocity of 15 feet per second; the ditch thus possessing a capacity of 16 second-feet. This canal, at present, is in good condition. At the time of the survey it served to irrigate 941 acres of land, an additional area of 309 acres showing evidences of previous culture. A survey made by Mr. Meskimons in 1904 showed an area of 1,456 acres under cultivation at that time.

Blackwater or Island ditch.—The first ditch constructed for the irrigation of the Blackwater Island district, which lies between the Little Gila and the main channel of the river, was commenced in 1862. Juan Thomas has recorded this date in his calendar,[1] while William Wallace,[2] who claims to have been the chief promoter of the ditch, also gives the year of its construction at 1862. Frank Hayes,[3] states that it was built about 54 years ago and that within four or five years all the land which it could serve to irrigate had been placed under cultivation. In order that this might be possible, the ditch was enlarged from 3 feet to 4 or 5 feet on the bottom.

The present heading of this canal lies in sec. 2, T. 5 S., R. 8 E., about 1 mile upstream from the reservation line. Various other headings, however, have been in use during the past.

Formerly the Island ditch was flumed across the Little Gila to Blackwater Island. Several years prior to 1913 the Little Gila was permitted to choke up, and instead of using the flume, this ditch was then permitted to discharge into the Little Gila, the water being rediverted by means of a dam some distance farther down.

In 1913 the Indian Irrigation Service opened up the Little Gila heading and constructed a new flume to carry this ditch across the Little Gila, as formerly had been done. This work was known as the Little Gila project.

The Island Canal at the present time has a capacity of 35 second-feet. It has a top width of 10 feet, a bottom width of 7 feet, water depth of 2 feet, and has a velocity slightly greater than 3 feet per second. This canal serves to irrigate 1,029 acres, according to the survey of 1914. According to the Meskimons survey in 1904, 1,506 acres were then being irrigated.

Under this canal there are, in addition, 30 acres which have been cultivated at some former date, while 330 acres more are susceptible of irrigation.

Little Gila Canal.—It is generally conceded that the so-called Little Gila River is of artificial construction. Its general location in respect to the topography of the surrounding country, the evident remains of side drainage channels which formerly continued across the present bed of the stream, as well as the directness of the alignment of the channel itself are evidences supporting this belief.

Unquestionably the Little Gila, as originally constructed, was not as large as it is now; its present size and shape is probably due to the action of flood waters which, entering the head of the original canal, not only deepened and widened the channel but also cut a

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[1] See statement, p. 1, supplemental exhibits, vol. 1.
[2] See statement, p. 5, supplemental exhibits, vol. 1.
[3] See statement, p. 7, supplemental exhibits, vol. 1.

pathway from the end of the original ditch back to the bed of the main river.

Whether or not the Little Gila Canal was constructed contemporaneously with the other near-by prehistoric canals is, of course, problematical. Needless to state, no knowledge of its artificial construction is possessed by the present day Pimas, and the credit of this enterprise must be given to an unknown race of agricultural people, perhaps ancestors of the Pimas, who had attained a remarkably advanced stage of culture and civilization.

No particular reference to the Little Gila has been found in the narratives of the early Spanish explorers. It is evident that some of the earlier adventuerers into this region were of the opinion that the Little Gila was the main river channel. Russel Bartlett, who was connected with the United States and Mexican boundary survey during the years 1850–1853, and who has been previously quoted,[1] evidently made this mistake, for he states: " We found the river banks about 15 feet high and so abrupt that it was with some difficulty we reached the water." The banks of the Little Gila in many places are 15 feet or more in height, while the banks of the main river are seldom more than 6 or 7 feet high.

During former times no trouble was encountered in keeping the river water diverted into the Little Gila, and the principal ditches serving the land that was irrigated prior to the coming of the whites had their heading in this channel or, in other words, were laterals or subditches of the Little Gila.

With the recent recurring floods, the main river channel has been washed much wider than formerly, and as a result the diversion of the Little Gila has been maintained with some difficulty.

During the disastrous flood of 1905 the old heading was completely washed away and a mile or more of the upper portion of the Little Gila channel was filled with silt, and, as previously stated, this portion of the channel was occupied by the Island ditch.

In February, 1913, it was decided to reopen the Little Gila, and the work in this connection, which was done under the direction of this service, has been known as the Little Gila project.

Little Gila project.—The Little Gila project, which was completed in 1914, had for its primary object the opening up of the Little Gila and the installation of a suitable heading at its point of diversion from the Gila River. This work necessitated the relocation of a portion of Blackwater Island ditch and the excavation and the cleaning out of the channel for a distance of 3,950 feet. The Blackwater Island ditch was reconstructed through a distance of 3,725 feet. A flume was built to carry this ditch across the Little Gila below its heading and a drop was installed to discharge the water into the original Island ditch. Bank protection, both above and below the Little Gila headgate structure, was installed as a part of this project. Two wing dams were built, one above the heading to divert the water against the headgate and one below to protect the downstream bank.

The great flood of December, 1914. did considerable damage to the bank protection and headwork of the Little Gila. The flood

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[1] See p. 13 of this appendix.

was of such magnitude that the high water overflowed the river banks in all directions and washed out much of the bank protection, as well as portions of the fill or revetment around the Little Gila structures. Subsequent to the flood a new channel has been cut from the main Gila to the Little Gila and the channel of the Little Gila was again cleaned for a distance of 2,400 feet.

The Indian Island ditch, which closely follows the river bank at the Little Gila heading, was also washed out and 8,200 feet of new ditch was constructed to replace the washed-out portion. The flume carrying the Indian ditch across the Little Gila was also damaged by the flood, and this flume, as well as some other minor structures, were repaired.

The trouble experienced with the Little Gila heading is common with all the ditch headings on the reservation and emphasizes the need of a permanent diversion dam.

The cost of this project during the fiscal year of 1913–14 amounted to $12,984.81, and during the fiscal year 1915 $3,531.27, or, in all $16,516.08.

Blackwater project ditch (B line).—The ditch shown on the map as the Blackwater project ditch (also known as the B line) has its heading 1 mile east of the reservation and was constructed by this service in 1914. This canal was not quite complete at the time of this survey and, of course, no land was yet in cultivation under it. The ditch will serve to irrigate 2,500 acres in the Blackwater district, which includes all of the land in the Old Woman's Mouth district, as well as all land that was intended to be irrigated by the Upper Blackwater ditch, which is described elsewhere in this report as never having been used.

This canal, according to the survey, has a bottom width of 6 feet, top width of 15 feet, water depth of 2 feet, and a grade of 1 in 1,500. Its calculated capacity is 18 second-feet. The total costs for the construction of this ditch up to end of fiscal year 1915 amounted to $7,769.75.

Yaqui Canal.—The history of the so-called Yaqui Canal has already been related under the heading of "Previous cultivation." The area cultivated under this ditch at the present time amounts to only 44 acres. Owing to a continued diminution in the quantity of water available, the lands formerly cultivated under this ditch are gradually reverting to the desert state, and unless a better water supply is soon obtained all remaining cultivation must likewise be suspended.

The land previously cultivated amounts to 290 acres.

Sacaton Flat Canal.—The Sacaton Flat Canal, sometimes called the Upper Stotonic Canal because the ditch was originally built by Indians coming from the Sacaton district, has its heading on the north side of the Little Gila about 1 mile below the Yaqui. According to John Hayes[1] this ditch was built in 1872. Has Makil[2] claims that the canal in question was in operation prior to his residence in that section, stating that he arrived in 1879. Hayes claims also that within five years after work was first begun on the canal all of the land irrigated at the present time had been placed under cultivation. At the time of this survey the area cultivated under this canal was

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[1] See statement, p. 7, supplemental exhibits, vol. 1.
[2] See statement, p. 16, supplement exhibits, vol. 1.

899 acres, 384 acres in addition showing evidences of previous cultivation. The survey of Meskimons in 1904 gave 1,105.2 acres as the area then under cultivation.

The Sacaton Flats Canal is 5 feet wide on the bottom and about the same width on top; it has a depth of 2½ feet, a grade of 1 in 800, giving a carrying capacity of 40 second-feet.

Cottonwood ditch.—This ditch, so-called from the numerous large cottonwood trees that line its banks, was constructed in 1872, according to a statement of its builder, Antonito Azul.[1]

Hokee refers us to the ditch captain and promoter, Azul, for the exact date of the construction of this ditch, but states that to the best of his recollection it was constructed 45 years ago. The area cultivated under this ditch at the time of the survey was 819 acres, while 152.9 acres additional were found to have been previously cultivated. The survey of Meskimons in 1904 gives 439 acres as the area then under cultivation. Azul and other farmers cultivating lands under this ditch came from the Sweetwater district, although Hokee Wilson,[2] who also helped to build the ditch, came from the Old Mount Top district.

The Cottonwood ditch is 8 feet wide on the top, 6 feet on the bottom; it had a depth of 1½ feet and a grade of 1 in 1,000, giving a carrying capacity of 20 second-feet.

The Santan Indian Canal.—The Rev. Dr. Cook,[3] in his letter relative to the early irrigation on the reservation, states that "at one large village north of the river and for a distance of near 10 miles there were fine ancient fields without a ditch and near the head of it there was fine strata of rock and river bed, "and while Dr. Cook mentioned further on that he assisted the Indians to overcome the difficulty of getting a ditch started, he fails to mention any dates.

John Manuel,[4] however, says that Dr. Cook made a survey of the above ditch in 1887 and that he "rod for him."

He states that construction began immediately after this survey, but that this ditch was not completed until 1883.

Cos Chin,[5] an Indian 90 years of age, claims that he moved from the Island or "old" Santan district to the "modern" Santan district in 1880 or 1881. It appears from the calendar of Maj. Jackson[6] that attempts to build a canal in this district were made as early as 1869, but it is quite probable that not much work was done until after the survey of Dr. Cook in 1877.

At the time of the survey of 1914 there were cultivated under this ditch 3,319.3 acres, an additional 201 acres showing evidences of

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[1] See statement, p. 17, supplemental exhibits, vol. 1.
[2] See statement, p. 41, supplemental exhibits, vol. 1.
[3] See p. 86, supplemental exhibits, vol. 1.
[4] See statement, p. 20, supplemental exhibits, vol. 1.
[5] See statement, p. 61, supplemental exhibits, vol. 1.
[6] See p. 108, supplemental exhibits, vol. 1.

previous cultivation. According to Tor White,[1] the original ditch had a bottom width of 5 feet near its lower extremity and 9 feet near its heading. At present the Old Santan ditch is 10 feet wide on the bottom, 16 feet on top; it has a water depth of about 3 feet and a grade of 1 in 1,500, its capacity, therefore, being at least 75 second-feet.

Lower Santan Canal.—John Manuel[1] claims that there was constructed in 1879 a canal known as the Lower Santan Canal, which a few years later was combined with the Santan Indian Canal.

According to Manuel, this lower canal later was almost entirely washed away. Very few sections of the original ditch remain, but those which were found showed the ditch to have had a cross section about 6 feet wide at the bottom, 11 feet on top, with a water depth of 2 feet. Its capacity was about 15 second-feet.

As already stated, this ditch not long after its construction was used simply as an extension to the Santan Indian Canal. The land lying under the Lower Santan Canal is considered a part of the main Santan district since those two canals were constructed at about the same time and would carry with them priorities which are approximately equal.

The Santan Flood Canal (Sacaton Project).—In December, 1904, the board of engineers of the Reclamation Service submitted a report to the Secretary of the Interior on the question of furnishing water to the Gila River Indian Reservation. In January, 1906, the Secretary of the Interior issued special instructions that surveys be made and plans prepared for the construction of an irrigation system. The investigation was accordingly made under the direction of the chief engineer of the Indian irrigation service, with the result that an irrigation system consisting of a flood water canal supplemented by pumping plants was decided upon. The Reclamation Service, under the direction of the Indian Office, was detailed to carry out these plans. Reimbursable appropriations for the construction of this project were made as follows:

Mar. 3, 1905	$50,000
June 21, 1906	250,000
Apr. 4, 1910	75,000
Mar. 3, 1911	125,000
Total	500,000

Of this amount there remained on hand March 31, 1912, a balance of $32,648.21.[3]

In addition to the above amount, there has been expended by this service for the construction of the distribution system and other necessary work, some $39,837.70.

This project has for its object the irrigation of about 10,000 acres of land on the north side of the river embracing all the territory within the Santan District, including the land covered by the Santan Indian Canal. The plans for the distribution of water in this district, as they were finally evolved and carried out, may be described as follows: The Santan Indian Canal was already located on a low ridge whose general direction parallels the river. Situated on either side of this ditch are the lands of the Indians,

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[1] See statement, p. 63, supplemental exhibits, vol. 1.
[2] See statement, p. 20, supplemental exhibits, vol. 1.
[3] H. Rept. No. 1506, p. 569, 52d Cong., 3d sess.

where these people live and are using water for irrigation.. The wells were drilled along a line located from one-half to 1 mile north of the Santan Indian Canal, while a short distance farther north was constructed the large Santan Flood Canal.

Connecting the different wells is a ditch which is joined at its upper end'to the flood canal.

A large lateral which takes out of the flood canal and enters the Santan Indian Canal above the uppermost of its laterals, serves to conduct the flood water into the Indian Canal. At frequent intervals along the course of the flood canal, feeder and drain ditches have also been constructed.

The Santan Flood Canal has dimensions as follows: Bottom width, 26 feet; side slopes, 1 to 1; water depth, 4 feet. It has a grade of 0.0003 and its capacity is 300 second-feet.

The lateral already referred to, connecting the flood canal with the Santan Indian Canal, has a bottom width of 10 feet; side slopes, 1 to 1; depth, 3½ feet; and a grade of 0.005. Its capacity is 110 second-feet.

The well ditch (also referred to above) has a bottom width of 6 feet; side slopes, 1½ to 1; grade, between 0.003 and 0.0025. Its capacity is approximately 30 second-feet.

Work was begun on this project on April 20, 1908, with the drilling of the first well. The drilling of the ninth and last well was completed on January 15, 1909. Survey work and the preliminary location of the flood canal was started in May, 1909, and actual construction was commenced in October of the same year.

Opposition to this project[1] soon arose among the Indians, with the result that the United States Reclamation Service suspended operations after the main flood canal had been completed but before work had proceeded very far on the distribution system. Work on this project was resumed by the Indian irrigation service in 1913 shortly after the suspension of work by the Reclamation Service. Since that time, the Indian lands under the canal were surveyed and allotted, the distribution and drainage systems have been completed, and another well had been drilled.

Owing both to the continued opposition of the Indians and to the lack of a diversion dam at the head of the Santan Flood Canal, this canal has been used only in connection with the Santan Indian Canal, although it was always intended that the flood canal should some day entirely supplant the Indian Canal.

The lack of a suitable diversion works at its head has greatly limited the usefulness of the flood canal, since the Indians find it much easier to divert the flow of the Gila directly into the Santan Indian Canal.

At the time of this survey there was under cultivation under this canal a total area of 3,319.3 acres, which is identical with the area cultivated under the Santan Indian ditch. The area cultivated under the Santan Flood Canal was no greater at the time of the survey than that formerly cultivated under the Indian ditch, but much land was being cleared and other efforts were being made at that time to increase this area. It is proposed by the Indian Service to irrigate at least 10,000 acres under this project.

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[1] Hearing before the Committee on Indian Affairs, House resolutions 330, No. 1, December 21, 1911; No. 2, January 5, 1912.

Agency project at Sacaton.—This project has for its purpose the irrigation of lands on the so-called island, that strip of land lying between the Little Gila and the Gila River just north of the Sacaton Agency. The necessary surveys were commenced in November, 1913, actual construction work started in March, 1914, and the project was completed in June of that year.

This irrigation system consists of one main canal and a number of laterals. Its water supply is obtained by diversion from the Little Gila at the north and south midsection line of section 23, T. 4 S., R. 6 E. The main canal has a bottom width of 6 feet, side slopes, 1½ to 1, water depth 2 feet, maximum grade of 1 in 1,000, and a carrying capacity of 30 second-feet.

The territory to which this ditch now furnishes water embraces the district formerly known as the Old Santan district, as well as a considerable area formerly belonging to the Cottonwood Canal district. This project, including these two areas, mentioned above, was built with the intention to irrigate 2,000 acres. At the time of the survey, some land was already being cleared in anticipation of the completion of the ditch. During the summer of 1914, and after survey had been made, about 30 acres were put under irrigation in addition to the land which was being irrigated by the Cottonwood ditch. Disbursements made for the construction of this project to the end of the fiscal year 1915, have amounted to $26,754.28.

Hendricks ditch.—This canal, which takes out of the Little Gila about 2 miles above Sacaton[1] was constructed by its present owner, Mr. Hendricks, in 1904. The Hendricks ditch served to irrigate 76 acres of land at the time of this survey.

An old ditch known as the Louis Morago, which has its heading about 300 feet east of the present heading of Hendricks ditch, formerly irrigated about 40 acres of the land now irrigated by means of the latter. This ditch was constructed by the Sacaton agency in 1882, but after about two years of use it was found unserviceable.

In connection with this old Morago ditch, another ditch heading in the Big Gila extended across the Cottonwood lands, and, discharging into the Little Gila, supplied water to the Morago ditch. This connecting ditch has been largely effaced by the continued plowing of fields and the excavation of new ditches since the time of its inactivity. Traces of this old ditch, however, are still visible, the approximate location being shown on the survey map of the reservation. Owing to the limited acreage served by this ditch, as well as its short life, it has not been treated under a separate heading.

Casa Blanca Canal project.—This project is situated on the south side of the Little Gila, west of the Sacaton Agency. By means of this canal it is proposed to irrigate some 35,000 acres of land, including the areas of Casa Blanca and Sweetwater, which are irrigated at the present time, and the previously irrigated district of the

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[1] Sacaton was merely a stage station in the early sixties, and did not become an Indian village until less than 30 years ago. Previous to this time these Indians were living in the Cottonwood district just adjacent. Sacaton takes its name from a long-bladed grass, a sort of hay, called sacaton grass, which formerly grew in abundance in this vicinity. This word is evidently of Spanish origin, the Pima name for this village being Ku'-u Key (high house), referring to the relatively large houses built by the whites for the agency.

Old Maricopa, Ancient Sweetwater, Mount Top, and the Sranuka. Work was begun on this project in May, 1914, and by the end of that fiscal year the canal had been excavated throughout a length of 18,100 feet. During the fiscal year 1915, 22,100 feet of laterals were constructed for the distribution system and several concrete structures were built. The total expenditures on this project to the end of the fiscal year 1915 were $25,300.34.

This canal has a bottom width of 14 feet; side slopes 1½ to 1, depth, 6 feet; grade, 0.0006; velocity, 3.25 feet per second. Its capacity is consequently 350 second-feet.

Alkali Canal.—Alkali Canal is a name recently applied to a portion of the old Sranuka ditch, which still remains in use. The latter has already been referred to under the head of "Previous Irrigation" as a partially inactive ditch. The so-called Alkali village of to-day is situated approximately 2 miles west of the site of the former Sranuka village, which, for the purpose of protection, had been established close to the town of Casa Blanca.

After peace had been made with the Apaches, Sranuka village was vacated. Many of the Indians found new habitations elsewhere, but a few remained to build the present Alkali village. At the present time this canal is irrigating only 198 acres of land in what was formerly the upper portion of the old Sranuka district. Great quantities of alkali are found in this portion of the old district, giving rise to the more recent name of the canal and of the camp as well. The presence of these injurious salts has greatly limited the extent of cultivation in this district.

Stotonic (or Sweetwater ditch).—The Stotonic ditch (often erroneously called the Casa Blanca)[1] has its present heading near the center of sec. 35, T. 3 S., R. 5 E., at the point where the Little Gila discharges into the main channel of the Gila River. As already pointed out under the title of Ancient Sweetwater (see Previous Irrigation), the present Stotonic ditch is identical with the Ancient Stotonic except that its heading has been moved from a point on the Little Gila to a new location below the junction of this stream with the Big Gila. The motive for this change was undoubtedly a desire on the part of the Indians to take advantage of the flow in both of these streams. This ditch should have a priority identical with the Ancient Stotonic, since all the lands now cultivated under this ditch were cultivated under the ancient ditch.

At the time of this survey 1,559.3 acres were being cultivated under this ditch, and an additional 810 acres had been previously irrigated. This area of previous cultivation does not include that already noted under head of Mount Top ditch or Ancient Sweetwater. A considerable portion of the land formerly irrigated under this ditch has been washed away. It is recorded that the flood of 1869–70 destroyed a flour mill which was built in this section by Ammie White who was the first white person to live among the Pimas, and who later was appointed resident agent. Mr. White resided at the

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[1] The name Stotonic, meaning many ants, has been variously applied by the whites to several different villages and canals in this general district. The village called Sweetwater by the whites is the Stotonic village of the Indians, while Casa Blanca village is known to the Indians as Wakey. The Sweetwater Canal, also called the Casa Blanca Canal, is known to the Indians as the Stotonic. The Bapchil Canal in this same district is sometimes also erroneously called the Casa Blanca.

old Casa Blanca or Wakey village, but his flour mill was down near the river bottom.

At the time of this survey the Stotonic ditch had a bottom width of 4 feet, top width of 10 feet, water depth of 2½ feet and a grade of 0.0006, with a capacity of 29 second-feet.

Bapchil (*Ooist*) *Canal.*—The Bapchil Canal[1] the heading of which lies a little more than a mile below the Stotonic, possesses a history similar to that of the latter canal, both of these being ancient Pima ditches. This Bapchil ditch, called also Ooist by Pablo[2] and other Indians, serves to irrigate the land below the Stotonic in the same general district. The village and district known as Wet Camp, or in the Indian, Sra-tuka, "full of moisture," is situated under this Bapchil ditch.

At the time of the survey this ditch served to irrigate 1,937 acres of land, an additional 936 acres having been previously irrigated. The canal above its uppermost laterals was being cleaned out at the time of this survey, consequently it was found to be much larger than appears necessary from the area of land which it covers. In that portion of the ditch which had been cleaned a cross-section 14 feet on the bottom, 22 feet on top with a water depth of 2½ feet was measured. With these excessive dimensions, the canal would have a very large capacity. At a point lower down, however, after several lateral diversions had been made, this ditch was found to have a cross-section of 7 feet on top, 3 feet on the bottom, 1½ feet depth, with a grade of 1 in 1,000. This would give a capacity of 10 second-feet.

It is estimated that at least 700 acres of land which were formerly irrigated by this ditch have been washed away by the floods. The previous survey by Meskimons in 1904 shows the irrigated lands to have extended a half mile or more beyond the present river bank.

Snaketown Canal.—On the south side of the river opposite the Bapchil is the present point of diversion of the Snaketown Canal, called in Pima, Skakaik ("many snakes"). Like the Stotonic fields across the river, this district is one of the ancient rancherias of the Pimas, and the history of the early irrigation in this region has already been given under the title of "Previous cultivation." At the time of this survey the area cultivated under this ditch was 354 acres. The area of previous cultivation has already been discussed under that heading. The Meskimons survey of 1904 showed an area of 3,499.1 acres, representing past and present cultivation in this district.

MASS-ACUMULT.

After passing the Alkali Canal no further diversions from the Gila are found until just below the region known as Mass-Acumult. This name, Mass-Acumult, translated means "clear river." This district is a portion of the broad river bottom in which the clear underflow[3] appears in springs, forming numerous little lakes or sloughs dividing the low bottom lands into small tracts or islands. In former years, and even now at favorable times, these lowlands

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[1] Bapchil, meaning hook nose in Pima, is a sort of nickname given to the Indians of this locality because they were supposed to possess this facial peculiarity.

[2] See statement of Pablo, vol. 1, p. 30, supplemental exhibits.

[3] For a description of the underground waters of this district, see The Underground Waters of the Gila River Valley, Arizona, Water Supply Paper No. 104, p. 24.

were sometimes cultivated, but there was no artificial irrigation, nor was the land even plowed. The Indians merely planted the seed, relying upon the natural moisture of the ground to mature their crops. Such crops as corn and watermelons, and even a little cotton, were grown. This method of cultivation never became very extensive in this district, not only owing to the limited area suitable for cultivation, but also because of the constant damage of floods. This particular area is situated in a very hazardous position with respect to the river, since every large flood completely changes the topography of this so-called Mass-Acumult district. During the recent flood of 1914 the topography of the bottom lands was completely altered. The river bed was shifted a considerable distance, lakes and ponds were filled up, while the near-by ditches were greatly damaged.

At the time of this survey no land was being cultivated in this district. The survey of Mr. Meskimons, however, gave an area of 168.7 acres as being under cultivation in 1904.

Just below the Mass-Acumult district, and supplied largely by the waters collected in these ponds or clear lakes, is the first diversion of the Gila Crossing district. [1]

At many points between the Mass-Acumult locality and the west line of the Gila River Reservation, and in the districts beyond, more or less water rises to the surface of the river bed. As this water rises it is collected and diverted by several canals, furnishing the principal water supply for the irrigation of the Gila Crossing district, and other districts beyond the reservation.

IRRIGATION AT GILA CROSSING.

The Gila Crossing district is comparatively recent, the first ditch having been constructed in 1873. This district apparently owes its origin to the shortage of water on the Gila farther up on the reservation, the Indians who now far mhere or their antecedents formerly having lived and cultivated fields in the old Sranuka, Bridlestood, Skunk, and other districts.

That the return flow from the Mass-Acumult or from other sources along the river was not used by the Indians in former times is due to the disfavor with which this water was always regarded by the Indians for irrigating purposes. They early realized that the water contained elements deleterious [2] to their plants and they plainly preferred the surface flow. They never used this alkaline water until compelled to do so by the failure of the flood water supply.[3]

Although the Indians still make use of the flood waters at times for irrigation, it is used more especially for neutralizing and fertilizing purposes, irrigation during the time of maximum drought depending entirely upon these seepage or return flows. The floods which are so frequent on the Gila invariably destroy the low dams built by the Indians, necessitating considerable work of maintenance in connection with these canals. This difficulty is increased by the fact that after a heavy flood the return flow usually reappears in entirely new locations.

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[1] The Gila Crossing district is known to the Pimas as Kawertk-Weercho ("under the hills").

[2] See Analysis, p. 25, Water Supply and Irrigation Paper No. 104.

[3] See statement, supplemental exhibits, vol. 1, pp. 75, 76–78.

According to Mr. Lee, of the Geological Survey, the return or seepage flow in the Gila Crossing district on June 1, 1903, amounted to 2,050 inches.[1]

The development of the underground water in this district, as well as at other points on the reservation, has been undertaken at different times by the Indian Department with a view of increasing the water supply. Owing, however, to the frequent floods to which the river is subject, and its constantly changing condition, these attempts have met only with doubtful success.

Hollen (Simon Webb) ditch.—This ditch has the most easterly heading—that is, it is highest on the Gila River—of the several ditches used for irrigation at Gila Crossing. Its heading is shown on the map as being very near the township line adjacent to sec. 25, T. 2 S., R. 2 E., G. and S. R. B and M. This ditch was constructed in 1877, according to several persons[2] who were connected with its construction. According to their statements, one year was consumed in its construction, and within four years all of the land now being irrigated under this ditch was in cultivation. The area cultivated, as shown by this survey, amounts to 660 acres, while the survey of Meskimons shows an area of 900.4 acres as having been cultivated in 1904. The ditch which was originally only 3 or 4 feet wide is now 6 feet on the bottom, 8 feet on top, has a grade of 1 in 1,500, and, with a water depth of 1 foot, has a capacity of 8 second-feet. Water Supply Paper No. 104 gives its flow on June 1, 1903, as 200 miner's inches, or about one-half the above capacity.

About 2 miles south of the Hollen Canal, but diverting water from the Santa Cruz River, is a small ditch known as the Breckenridge. This ditch serves to irrigate a small acreage nearly adjacent to the upper end of the area irrigated by the Hollen. This ditch was constructed about 13 years ago—that is, in 1902. It has a bottom width of 2½ feet, top width of 3 feet, water depth of 1 foot, and has a grade of 1 in 2,000. At the time of this survey only 5 acres were in cultivation, while 30.8 acres had been cultivated at some previous period.

Hoover ditch.—The first ditch constructed in Gila Crossing district was the Hoover ditch. According to several sources[3] this ditch was constructed in 1873, a year being consumed in its construction. The area under cultivation in 1914 amounted to 954 acres, according to this survey, while the former survey of Meskimons gave 827.1 acres as having been cultivated in 1904. This canal has across section 8 feet wide on the bottom, 10 feet on top, depth of 1 foot, grade of 1 in 1,400, giving a capacity of 12 second-feet. According to the statement of Head, when originally constructed this ditch was 4 feet wide on the bottom and when filled with water was knee-deep. In June, 1903,[4] this ditch was flowing 300 miner's inches.

John Thomas Canal.—This ditch, like the Hollen, lies on the south side of the river, its heading being located very near to the northern boundary of sec. 22, T. 2 S., R. 2 E., G. and S. R. M. This canal, according to information from several sources, was constructed three or four years subsequent to the Hoover ditch, which fixes the date of construction as 1876 or 1877. According to Joseph Head, this ditch

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[1] Water Supply Paper No. 104, p. 24.
[2] See statements pp. 78–83, supplemental exhibits, vol. 1.
[3] See statement of Joseph Head, p. 80, supplemental exhibits, vol. 1.
[4] See Water Supply Paper No. 104.

was in course of construction for two years, and after three years all of the bottom land had been placed under cultivation.

A branch ditch, known as the Lancisco was also constructed. In 1905 nearly all the bottom land under the John Thomas Canal was washed away by the exceptionally heavy flood of that year. The major portion of the land remaining after the flood was situated under this branch ditch, and for this reason the canal is sometimes known as the Lancisco.

The amount of land being cultivated under this canal at the time of the survey was 587 acres, while 108 acres showed signs of previous irrigation. The survey of Meskimons in 1904 gave an area of 827 acres as being cultivated at that time. This canal has a bottom width of 6 feet, top width of 8 feet, water depth of 1.4 feet, and a grade of 1 in 100, with a carrying capacity of 15 second feet. Water Supply Paper No. 104, already referred to, gives the actual measurement of its flow for June 1, 1903, as 600 miner's inches, or 12 second-feet.

Joseph Head Canal.—The so-called Joseph Head ditch, which properly should come under the head of previous cultivation, is no longer a separate ditch, it having been consolidated with the John Thomas some 10 years ago. This ditch, according to the statement of its builder, Joseph Head,[1] was constructed in 1886.

Other old residents of Gila Crossing also give this date as the time of its construction. Joseph Head states, furthermore, that the ditch was in use 18 years until the disastrous flood of 1905, which took out the heading and a portion of the ditch, as well as considerable land formerly irrigated under it. It was then arranged to conduct the water into this ditch from the John Thomas Canal and a connecting ditch was constructed for this purpose. This method of obtaining water still remains in force.

The land formerly irrigated by this ditch and which is now cultivated under the John Thomas Canal adjoins the lower end of the John Thomas district. According to this survey, 139 acres were being cultivated under the old Joseph Head ditch, an additional 30.3 acres showing evidences of previous cultivation. The survey of Meskimons, which shows these two ditches to have been separate, gave an area of 786.4 acres as being cultivated under the Joseph Head ditch in 1904, including, however, some land later coming under the John Thomas ditch. So much of the upper end of this ditch had been washed out that no cross section was taken. Water Supply Paper No. 104 shows a discharge of 150 miner's inches on June 1, 1903.

Cooperation Canal.—Proceeding down the river, the next diversion following the Hoover is the Cooperation ditch. This ditch is comparatively recent, having been constructed in 1900 by a number of Indians of the younger generation—men who had been given some educational training either at the reservation school or elsewhere. These Indians have endeavored to farm after the manner of the whites and have met with very encouraging results. They have increased the extent of their fields, have built comfortable farm houses, and in general have become more progressive, as they are proud to describe themselves, than the older Indians. They also have inaugu-

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[1] See statement, p. 80, sup. exh., vol. 1.

rated a system of cooperation which has given rise to the name of their ditch.

At the time of the survey, this canal was irrigating 594 acres of land, an additional 390 acres showing evidences of previous cultivation. At the time of the Meskimons survey in 1904, 314.7 acres were being cultivated. This ditch has a section 6 feet wide on the bottom, 8 feet wide on top, 1 foot deep. Its grade is 1 in 100, giving a carrying capacity of 10 second-feet. Water Supply Paper No. 104, already referred to, gives a flow on June 1, 1903, of 150 miner's inches for this ditch.

Oscar Walker Canal.—This ditch constitutes the lowest diversion from the Gila River on the reservation. It is of small proportions and irrigates a very limited area. This ditch is of comparatively recent date, having been constructed in 1903, and has been in continual operation since that year. At the time of the survey this ditch served to irrigate 13.1 acres, while 45.4 acres additional had been irrigated at some previous time. In 1904, at the time of the Meskimons survey, 28.5 acres are shown to have been irrigated. The ditch is 3 feet wide on the bottom, 5 feet wide on top, has a depth of 1 foot, grade of 1 in 1,000, and a capacity of 4 second-feet. Water Supply Paper No. 104, already referred to, shows a flow of 50 miner's inches.

IRRIGATION IN MARICOPA DISTRICT.

Maricopa Canal.—A short distance northwest of the Gila Crossing district and situated between the Salt and Gila Rivers just above their confluence is found the present Maricopa district. The lands irrigated in this district are served by a ditch diverting water from the Salt River, and although the diversions from the Salt River are not within the scope of this investigation, the survey was extended so as to include this district.

Irrigation in the Maricopa district is relevant to a study of irrigation along the Gila because of the fact that the Indians of the former district formerly cultivated tracts along the Gila, but were later forced to vacate these because of the scarcity of water. It may be assumed, therefore, that this irrigation by means of water from the Salt River represents in a manner the irrigation formerly practiced by these Indians along the Gila.

This Maricopa district is served by one main canal heading several miles northeast of the reservation boundary. At the time of the survey (June, 1914), 1,271 acres were being irrigated in this district, an additional 219 acres showing evidences of previous cultivation.

The water supply is derived largely from the return flow of the Salt River. This flow subsequent to the recent increased use of water for irrigation in the Salt River Valley has doubled in amount, and has now become sufficient to supply not only this canal but to furnish water to several other irrigation canals farther down.

At the point where the Maricopa Canal enters the reservation it has a top width of 8 feet, bottom width of 7 feet; it is 2½ feet deep and has a grade of 1 in 2,000.

In 1903 the Government instituted suit in the United States district court to determine the relative water rights of several canals using water near the lower end of the Salt River. In the evidence submitted during the action it was shown that prior to 1894 the Indians had been irrigating 580 acres; that in 1901, 1,180 acres were under cultivation, and the court decreed that the Indians' lands were entitled to water from the Salt River in accordance with these findings.

A decree in the case above referred to was handed down by Judge Kent in Phoenix, Ariz., on June 11, 1903. A copy of this decree, as well as a supplemental decree of later date, is to be found in volume 4 of the supplemental exhibits accompanying this report.

HISTORICAL ANALYSIS OF IRRIGATION ON THE GILA RIVER RESERVATION.

The analysis chart shown in the body of this report has been compiled from all the evidence and data gathered during the progress of this investigation and survey. The areas as determined by a survey of the reservation, made in 1904 by Mr. J. R. Meskimons, then superintendent of irrigation of the Indian Service, have been included with other data and are shown on the chart.

The survey of Meskimons was not made in sufficient detail to permit the segregation of the areas in actual cultivation from those previously cultivated. The outlines of the tracts shown on the Meskimons map included, in some instances, both cultivated and previously cultivated areas. However, in the report accompanying his map Mr. Meskimons gave an estimate of the irrigated area based on the results of his survey. A copy of this report is to be found on page 149, volume 1, of supplemental exhibits.

The areas as compiled in the chart shown in the body of the report represents proportional acreage areas covering a period of several years and do not take into consideration single years of exceptional droughts, for which no reliable information could be obtained. The compilations were made after a careful consideration of the life of the several ditches and from evidence obtained from the Indians and from other sources. These estimates, of course, were governed largely by the results of the survey made in connection with this investigation and the Meskimons survey.

It will be seen from the chart that the Indians during former years had a larger area under cultivation than they have at present, and that the irrigated tracts are scattered over a much more extended area of the reservation than they were at the time of the coming of the whites.

The principal factors which led the Indians to locate in the many districts in which they are now farming are the depletion of their low-water surface supply, necessitating the use of the meager seepage flow, peace with the Apaches, and to take advantage of the short period during which flood water was available in order to produce one crop.

The total agricultural yield realized by the Indians has become greatly reduced in recent years, and this one-time proud and powerful race has been forced since the advent of the whites to depend at least partly upon the bounties of the Government.

FLORENCE-CASA GRANDE DISTRICT NO. 3.

The next oldest irrigated district along the Gila is in the Florence-Casa Grande Valley.

and the average evaporation from the soil adjacent to the canals is therefore taken as 2 feet per year over a width of 16 feet. The average width of water surface is taken as 7 feet for main canals and 3 feet for laterals. The average annual rainfall, which amounts to 13 inches, reduces the evaporation from the soil by about 25 per cent and adds to the flow of the canal a volume of water equivalent to a depth of 1.1 feet falling on an area one foot wider than the water surface. Assuming main canals to be in operation eight-tenths of the year and the laterals four-tenths, we obtain 5.5 acre-feet and 1.82 acre-feet, respectively, as the net annual evaporation from main canal and laterals per mile.

It is assumed that any additional seepage water will penetrate to a greater depth than 8 feet, and will be unaffected by evaporation, and, joining the underground stream, will return to the river. Taking these values as a basis, the net loss in the Solomonville-Safford Valley would be 57,553 acre-feet per year, derived as follows:

	Acre-feet.
Evaporation from 170 miles main canal, at 5.5 acre-feet per mile	933
Evaporation from 342 miles laterals, at 1.8 acre-feet per mile	620
Transpiration from 26,633 acres cultivated, at 2.1 acre-feet per acre	56,000
Total	57,553

The discharge measurements made during 1914–15 show that the total annual diversions by all canals in the Solomonville-Safford Valley amounted to 189,285 acre-feet. Considering that this total diversion is diminished by 57,533 acre-feet through transpiration by plants and evaporation in the canals, the return flow should amount to 131,752 acre-feet, which flowing within the period of 0.8 of a year is equivalent to 230 second-feet. Owing to the excessive diversions and the wasteful methods of irrigation which greatly increase the loss by evaporation, the actual amount of the return water flow would probably be much less than the value derived above.

Between the dam site and Kelvin, a distance of 35 miles, an evaporation loss of about 6 second-feet takes place in June, assuming 100 feet to be the average width of the water surface and 10 inches to be the evaporation during that month. During other months the evaporation loss would be correspondingly less. The San Pedro River adds to the flow of the Gila in this section. No direct measurements have been made of the flow of the San Pedro near the confluence of the two streams, but, as previously stated, recent investigations indicate that the low water of the San Pedro at this point may be about one-fifth that of the Gila at the dam site. The first investigation made by Lippincott in 1899[1] indicates that the total run-off of the San Pedro was one-tenth of the Gila. This probably very closely represents the relative flow at high water.

SUMMARY OF FLOW LOSSES AND GAINS ALONG THE GILA.

The following summary gives an estimate of the losses and gains taking place between Solomonville and Sacaton.

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[1] U. S. Geological Survey, Water Supply Paper No. 33.

LOSSES.

1. Diversion at Solomonville, taking the entire flow of the stream, up to about 225 second-feet.
2. Evaporation from river bed between Solomonville and Kelvin, amounting to about 73 second-feet in June. This would increase somewhat for higher stages of the river.
3. Diversions in the canals of the Florence district, the quantity depending on the amount of water in the river, but averaging about 50 second-feet.
4. Seepage in the sand between Kelvin and Sacaton, amounting to 110 second-feet; more following a protracted drought.

GAINS.

1. Underground flow from adjacent watershed and return flow from canals in Solomonville valley, amounting to from 180 to 300 second-feet. Decreasing the irrigation decreases the return flow in the approximate ratio of 0.7 acre-feet of return flow for each acre-foot of diversion.
2. Flow of San Carlos River negligible during low water.
3. Flow of San Pedro River varying from one-fifth the flow of the Gila at the dam site during low water to one-tenth of the flow during high water.

In tabular form this is as follows:

	Gain.	Loss.
	Second-feet.	*Second-feet.*
River discharge at Solomonville	243	
Evaporation, Solomonville to Kelvin		73
Solomonville Canals		225
Florence Canals		50
Solomonville underground and return	180	
San Pedro River	35	
Seepage between Kelvin and Sacaton		110
Available for Indian uses at Sacaton		
Total	458	458

The above table shows the conditions as they exist to-day according to the most reasonable theory. Adopting the same basis for calculations as to effects under the assumption that no water be diverted at Solomonville and at Florence, we get the following results:

	Gains.	Loss.
	Second-feet.	*Second-feet.*
River discharge at Solomonville	243	
Evaporation, Solomonville to Kelvin		73
Inflow, Solomonville Valley	110	
San Pedro River	35	
Seepage in sand above Sacaton		110
Transmission loss between Kelvin and Sacaton		10
Available at Sacaton		95
Total	288	288

A comparison of these two tables shows that the effect of diverting 225 second-feet in the Solomonville Valley and 50 second-feet at Florence is sufficient to diminish the flow at Sacaton by 95 second-feet. The 50 second-feet diverted at Florence would be equivalent to 45 second-feet at Sacaton after deducting the transmission loss of 10 per cent; therefore the diversion of 225 second-feet at Solomonville represents 50 second-feet at Sacaton, or, in other words, the transmission loss is 78 per cent. This loss is much greater in proportion to the distance than the 10 per cent loss from Kelvin to Sacaton. The transmission loss can not be stated as a constant proportion of the run-off for all stages of the river, since a large portion of it is a constant independent of the flow. At low stages it is greater than 80 per cent, and at high stages it is less. For the average stage, however, 60 per cent may be taken as the most probable value until a better value can be obtained by a series of careful measurements extending over several years.

It is a notable fact that at certain times the quantity of water flowing past the dam site at San Carlos exceeds the flow at Solomonville, although at the same time diversions may be taking place in the Solomonville-Safford Valley, and this has been taken by some as proof that irrigation in the Solomonville Valley produces no diminution in the natural flow of the river below the valley. If the theory set forth above is correct, then at any time when the quantity of water actually used for irrigation added to the amount of evaporation between Solomonville and the dam site is less than the inflow on this district there will be an actual increase in the flow of the river between these two gauging stations. References to the diagram of the inflow shows that this condition generally occurs each year about the end of the irrigation season, in October and November, when the amount of water used for irrigation is rapidly falling off and much water in the canals is wasted back into the river, and yet when the return water from irrigation earlier in the season is still flowing into the river from lands situated some distance from the stream.

Table showing losses between Kelvin and Sacaton.

Date.	Kelvin.	Florence canal.	Kelvin, less Florence canal.	Sacaton.	Loss.
1914.					
Oct. 21	525	40	485	340	145
Oct. 26	510	30	480	350	130
Nov. 1	560	10	550	415	135
Nov. 5	580	5	575	560	115
Nov. 26	615	20	595	390	205
Dec. 1	470	....	470	300	170
Dec. 11	585	60	525	290	235
Dec. 15	450	50	400	260	140
1915.					
June 1	515	60	455	310	145
June 6	425	85	340	125	215
June 11	335	115	220	90	130
June 16	260	75	185	65	120
June 21	215	75	140	15	125
June 26	165	70	95	5	90

Table showing diversion and inflow in Solomonville-Safford Valley.

Canal.	Mile.	Diversion.	Inflow.
Brown	0.8	4.0	
San Jose	2.4	26.0	
Michelena	4.0	1.2	
Montezuma	7.0	22.0	
Union	8.4	34.8	
Do	12.0		11.5
Graham	12.8	15.0	
Do	14.2		6.0
Oregon	14.4	17.0	6.5
Smithville	15.8	12.0	12.0
Bryce	18.3	10.0	10.0
Dodge	20.3	3.0	3.0
Nevada	22.6	2.0	2.0
Curtis	24.8	11.0	11.0
Consolidated	28.4	2.0	2.0
Dam site	46.0		28.0
		160.0	92.0

Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona

Prepared by the
U.S. GEOLOGICAL SURVEY
Water Resources Division

Prepared for
Flood Control District
of Maricopa County

Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter
square foot (ft^2)	0.0929	square meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
acre-foot (acre-ft)	0.001233	cubic hectometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called *Sea Level Datum of 1929*.

ESTIMATED MANNING'S ROUGHNESS COEFFICIENTS FOR STREAM CHANNELS AND FLOOD PLAINS IN MARICOPA COUNTY, ARIZONA

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ABSTRACT

A procedure for the estimation of Manning's roughness coefficient (*n*) was applied to channels and flood plains of streams in Maricopa County with different roughness factors. Manning's roughness coefficients that ranged from 0.025 to 0.200 were estimated at 16 sites. Roughness coefficients were estimated by comparison of site characteristics with published photographs and descriptions of channels and flood plains where *n* values were verified for other studies. The base value of *n* and the values for surface irregularities, obstructions, and vegetation that affect the total *n* value are described and presented in tables, cross sections of channels, and photographs. All sites are readily accessible to facilitate field inspection of roughness factors by hydrologists and engineers for definition of Manning's *n*. Subdivision of channel cross sections was based mostly on changes of channel geometry and to a lesser degree on the basis of large changes of vegetation density.

INTRODUCTION

Computations of flow in open channels require evaluation of roughness characteristics of the channel. Roughness coefficients represent the resistance to flow and cannot be quantitatively determined by direct measurement or calculation. Values of roughness coefficients have been computed for many artificial surfaces and typical natural channels and have been verified for selected channel sites. Characteristics of natural channels and the factors that affect channel roughness vary greatly, however, and the combinations of these factors are numerous. Selection of roughness coefficients for natural channels, therefore, requires judgment and skill that is acquired mainly through experience.

The purpose of this report is to illustrate recommended techniques for estimating roughness coefficients for 16 sites on streams in Maricopa County, Arizona (fig. 1). The sites are readily accessible for field inspection of roughness factors by hydrologists and engineers working on flood-engineering studies, bridge design, or other hydraulic computations. A wide range of channel-roughness characteristics from 0.025 to 0.200 can be observed at the sites. The techniques are based on the work of Chow (1959), Barnes (1964), Aldridge and Garrett (1973), and Arcement and Schneider (1984) and are adapted for the desert channels of the study area. The adaptations were based on the experience of the authors in river hydraulics in the deserts of the southwestern United States. The resulting

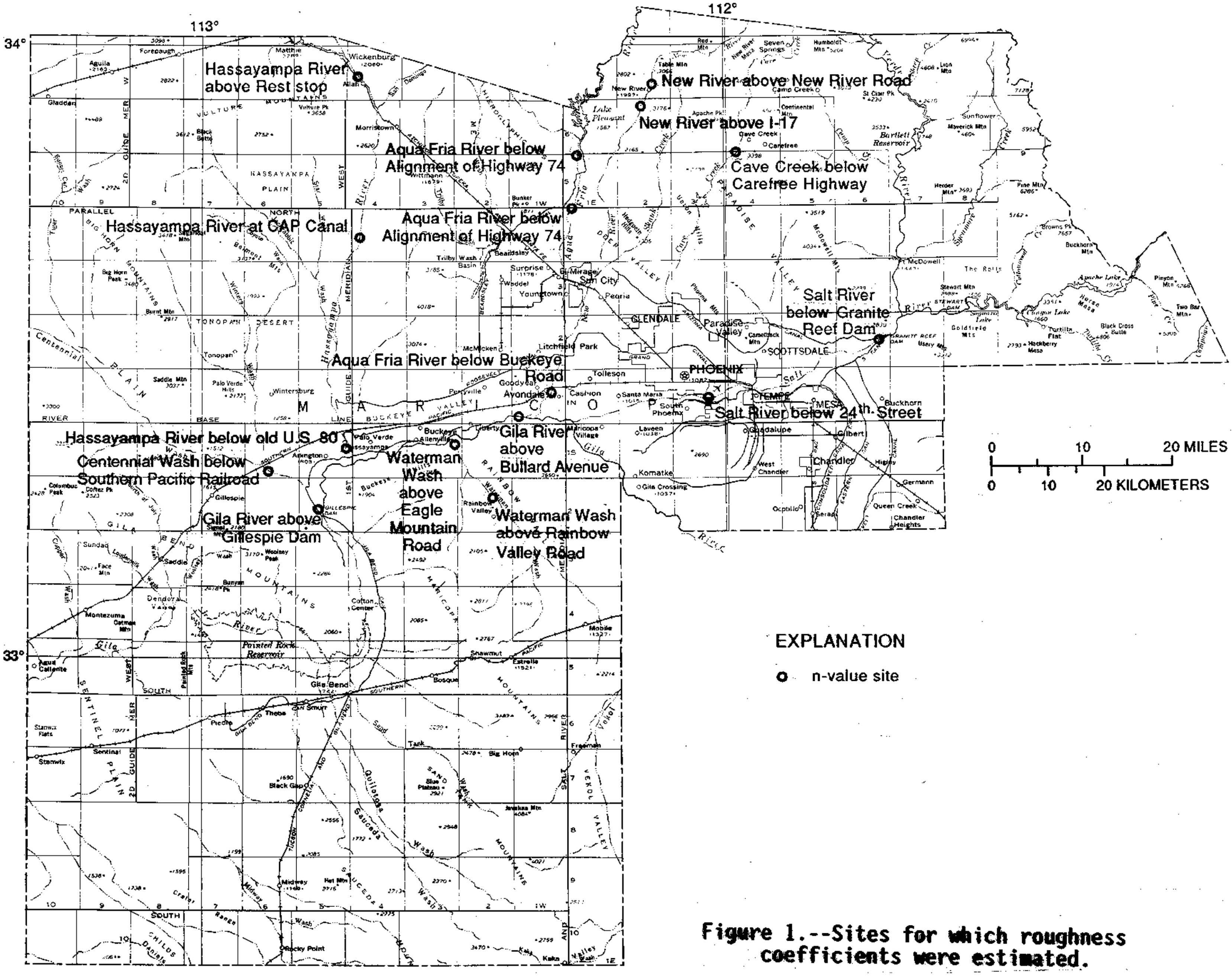


Figure 1.--Sites for which roughness coefficients were estimated.

estimates should not be used as verified values of roughness coefficients. The Flood Control District of Maricopa County furnished maps and channel data and was the cooperator in the study.

The total *n* value is determined by using a base *n* for the channel or flood plain and applying adjustments for various roughness components such as vegetation and obstructions to flow. Where there are distinct segments of different channel roughness in a channel section or subsection, the *n* values for the segments are weighted by area or wetted perimeter to determine the total *n* value. Where there is an unequal distribution of velocity across a channel, the channel cross section was subdivided into sections of more uniform velocity distribution on the basis of changes in channel geometry and roughness.

MANNING EQUATION

The Manning equation in the following form is commonly used to compute discharge in natural channels:

$$Q = \frac{1.486}{n} A R^{2/3} S_e^{1/2}, \qquad (1)$$

where

Q = discharge, in cubic feet per second,

A = cross-section area of channel, in square feet,

R = hydraulic radius, A/P (P, wetted perimeter, in feet), in feet,

S_e = energy gradient, and

n = roughness coefficient.

The equation was developed for conditions of uniform flow in which the water-surface profile and energy gradient are parallel to the streambed and the area, depth, and velocity are constant throughout the reach. The equation was assumed to be valid for nonuniform reaches if the energy gradient is modified to reflect only the losses resulting from boundary friction (Barnes, 1967). The modified energy gradient is called the friction slope. Use of the Manning equation in discharge computations generally involves the concept of channel conveyance. Conveyance, *K*, is defined as

$$K = \frac{1.486}{n} A R^{2/3} \qquad (2)$$

and is a measure of the carrying capacity of the channel. Where the conveyance concept is used, Manning's equation is reduced to

$$Q = KS^{1/2}, \tag{3}$$

where S is the friction slope. The friction slope for a reach of nonuniform channel can be expressed as

$$S = \frac{h_f}{L}, \tag{4}$$

where

h_f = energy loss resulting from boundary friction in the reach and

L = length of the reach.

The main components of h_f are the difference in water-surface elevation and the difference in velocity head at the ends of the reach.

Velocity-Head Coefficient

The velocity-head coefficient is not directly used for the estimate of channel roughness in this report. Several of the cross sections, however, are subdivided on the basis of velocity-head considerations, and a Manning's roughness coefficient is estimated for each of the subsections. A basic understanding of the velocity-head coefficient, therefore, is necessary for the estimation of channel roughness coefficients for channels with irregularly shaped cross sections and varying distribution of vegetation across the channels.

Roughness factors and nonuniformities in channel geometry cause the velocity in a given cross section of channel to vary from point to point. As a result of nonuniform distribution of velocities, the true velocity head (h_v) generally is greater than the value computed from the expression

$$h_v = \frac{V^2}{2g}, \tag{5}$$

where

V = mean velocity in the cross section and

g = acceleration of gravity.

The ratios of the true velocity head to the velocity head computed on the basis of the mean velocity is the velocity-head coefficient, alpha. For a reasonably straight channel with uniformly shaped cross section, the effect of nonuniform velocity distribution on the computed velocity head is small and, for convenience in the absence of a more suitable method, the coefficient is assumed to be unity (Chow, 1959). A detailed study of the velocity-head coefficient, alpha, in natural channels showed a significant correlation between alpha and channel roughness for channels without overbank flow. Variation in the horizontal distribution of velocity had a greater effect on the value of alpha than variation in the vertical. Computed values of alpha at 894 sites in a variety of settings ranged from 1.03 to 4.70, and the median value for trapezoidal channels was 1.40 (Hulsing and others, 1966). In the computation of water-surface profiles in open channels, the value of alpha is assumed to be 1.0 if the section is not subdivided (Davidian, 1984). In subdivided channel cross sections, the value of alpha is computed as

$$\alpha = \frac{\Sigma(k_i^3/a_i^2)}{K_T^3/A_T^2}, \tag{6}$$

where

k_i = conveyance of individual subsections,

a_i = area of individual subsections,

K_T = conveyance of entire cross section, and

A_T = area of entire cross section.

Channel n Values

The Manning roughness coefficient, *n*, is a measure of the flow resistance or relative roughness of a channel or overflow area. The flow resistance is affected by many factors including bed material, cross-section irregularities, depth of flow, vegetation, channel alignment, channel shape, obstructions, suspended material, and bedload. In general, all factors that cause turbulence and retard flow tend to increase the roughness coefficient (Jarrett, 1984). Channel roughness also is directly related to channel slope (Riggs, 1976; Jarrett, 1984). The relation of roughness to slope results partly from the interrelation between channel slope and bed-material particle size. For similar bed material, however, channels with low gradients have lower roughness coefficients than channels with high gradients (Jarrett, 1984). The direct relation between channel roughness and channel slope is not evident in low-gradient channels where high roughness coefficients result from vegetation. Roughness coefficients as great as 0.20 have been verified for channels with low gradients and dense vegetation (Arcement and Schneider, 1984). For vegetation that will bend under the force of flowing water, the relation between roughness and gradient can be inversely related. Steep slopes cause greater velocities that bend and flatten vegetation if depths of flow are sufficient, resulting in lower *n* values. Because of the relation between channel slope and size of bed material, the effect of slope on *n* values is considered in the selection of base *n* values.

A common method of selecting the roughness coefficient, *n*, is to first select a base value of *n* for the bed material (table 1). The base values of *n* are for a straight uniform channel of a given bed material. Cross-section irregularities, channel alignment, obstructions, vegetation, and other factors that increase roughness are accounted for by adding increments of roughness to the base value of *n*. Ranges of adjustments for the factors that may add to channel roughness are shown in table 2.

Many alluvial channels in Maricopa County have bed material that moves during floodflow. In addition to the changing channel geometry of these channels, the roughness coefficient may change during floodflow because of the changing form of the channel bed in parts of the channel cross section (Davidian, 1984). Bedforms, such as dunes, antidunes, and plane bed have been observed during large floods. Within a few minutes, dunes can appear, disappear, and reappear at different locations across a large stream channel. The Manning roughness coefficient can double or triple when the bedform changes from plane to dunes. A method of defining reliable values of Manning's *n* for unstable alluvial channels is not available. A plane bedform is common during large floods, and for this report, plane-bed conditions are assumed where the roughness coefficient is related to the size of the channel material and not the form of the channel bed. Plane-bed conditions were assumed for nearly all indirect measurements of peak discharge where the slope-area method was used.

Table 1.--*Base values of Manning's n for stable channels*

[Modified from Aldridge and Garrett, 1973, table 1]

Channel material	Size of bed material		Base *n* values	
	Millimeters	Inches	Benson and Dalrymple (1967)[1]	Chow (1959)[2]
Concrete	-------	--------	0.012-0.018	0.011
Rock cut	-------	--------	-----------	.025
Firm soil	-------	--------	.025- .032	.020
Coarse sand	1-2	--------	.026- .035	-----
Fine gravel	-------	--------	-----------	.024
Gravel	2-64	0.08-2.5	.028- .035	-----
Coarse gravel	-------	--------	-----------	.028
Cobble	64-256	2.5-10.0	.030- .050	-----
Boulder	>256	>10.0	.040- .070	-----

[1] Straight uniform channel.
[2] Smoothest channel attainable in indicated material.

Table 2.--*Adjustment factors for the determination of overall Manning's n values*

[Modified from Chow, 1959]

Channel conditions	Manning's n adjustment[1]	Example
Degree of irregularity:		
Smooth	0.000	Smoothest channel attainable in given bed material.
Minor	.001- .005	*Channels with slightly eroded or scoured side slopes.*
Moderate	.006- .010	Channels with moderately sloughed or eroded side slopes.
Severe	.011- .020	Channels with badly sloughed banks; unshaped, jagged, and irregular surfaces of channels in rock.
Effects of obstruction[2]:		
Negligible	.000- .004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	.005- .015	Obstructions occupy 5 to 15 percent of the cross-sectional area and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
Appreciable	.020- .030	Obstructions occupy from 15 to 50 percent of the cross-sectional area or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
Severe	.040- .060	Obstructions occupy more than 50 percent of the cross-sectional area or the space between obstructions is small enough to cause turbulence across most of the cross section.
Vegetation:		
Small	.002- .010	Dense growths of flexible turf grass, such as Bermuda, or weeds where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow weed, or saltcedar where the *average depth of flow is at least three times the height of* the vegetation.
Medium	.010- .025	Grass or weeds where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings where the average depth of flow is from two to three times the height of the vegetation; moderately dense brush, similar to 1- to 2-year-old saltcedar in the dormant season, along the banks and no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 feet.
Large	.025- .050	Turf grass or weeds where the average depth to flow is about equal to the height of vegetation; small trees intergrown with some weeds and brush where the hydraulic radius exceeds 2 feet.

See footnotes at end of table.

Table 2.--*Adjustment factors for the determination of overall Manning's n values*--Continued

Channel conditions	Manning's n adjustment[1]	Example
Vegetation—Continued:		
Very large	.050- .100	Turf grass or weeds where the average depth of flow is less than half the height of vegetation; small bushy trees intergrown with weeds along side slopes of dense cattails growing along channel bottom; trees intergrown with weeds and brush.
Variations in channel cross section:		
Gradual	.000	Size and shape of cross sections change gradually.
Alternating	.001- .005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
Alternating	.010- .015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
Degree of meadering[3]:		
Minor	1.00	Ratio of the meander length to the straight length of the channel reach is 1.0 to 1.2.
Appreciable	1.15	Ratio of the meader length to the straight length of channel is 1.2 to 1.5.
Severe	1.30	Ratio of the meander length to the straight length of channel is greater than 1.5.

[1] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base n value (table 1) before multiplying by the adjustment for meander.

[2] Conditions considered in other steps must not be reevaluated or duplicated in this section.

[3] Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders. The adjustment is a multiplier.

For floodflows in sand channels with moveable beds, roughness mainly is a function of the size of the bed material as shown in the following table (Benson and Dalrymple, 1967, p. 22).

Median grain size, in millimeters	Manning's *n*	Median grain size, in millimeters	Manning's *n*
0.2	0.012	0.6	.023
.3	.017	.8	.025
.4	.020	1.0	.026
.5	.022		

The above n values are for upper-regime flow that is common during floods. Where these n values are used, the assumed flow regime should be confirmed (Benson and Dalrymple, 1967, p. 24). Stream channels in Maricopa County commonly are sandy in the low-flow part of the channel where flows are common. Higher parts of the channel beds and the channel banks commonly are stabilized by gravel, cobbles, and boulders, and (or) to some extent by vegetation.

Depth of flow must be considered in selection of n values. The effects of roughness elements on and near the channel bottom tend to diminish as the depth of flow increases. The effect of vegetation on n values depends greatly on the depth of flow and to some extent on the flexibility of the vegetation. If the flow is of sufficient depth to submerge and (or) flatten the vegetation, n values will be lowered. Density of vegetation below the high-water level and the alignment of vegetation in relation to direction of flow also affect n values. If the vegetation is aligned in rows along the direction of flow, less vegetation is in contact with higher velocity flow. The roughness of aligned vegetation tends to be less than the roughness of nonaligned vegetation.

Generally an n value is selected for a cross section that is representative of a reach of channel. If two or more cross sections are being considered, the reach that applies to a given section extends halfway to the next section. In this study, channel data including maps showing cross-section locations were furnished by Maricopa County Flood Control District. A cross section for each of the 16 sites was selected on the basis of the following criteria: (1) cross section should be located so that visual inspection is reasonably convenient; (2) cross section should be within a reach that is minimally affected by roads, bridges, and other structures that may obstruct floodflow; and (3) cross section should contain roughness elements typical of the reach. Widths of the cross sections range from a few hundred feet to a few thousand feet. Some sections have a distinct main channel and overflow areas; others are one large trapezoidal section.

Components of Manning's n

The general procedure for determining n values was to first select a base value of n for the bed material (table 1) followed by selection of n-value adjustments for channel irregularities and alignment, obstructions, vegetation, and other factors (table 2). In this procedure, the value of n was computed by

$$n = n_b + n_1 + n_2 + n_3, \tag{7}$$

where

n_b = base value of n for a straight uniform channel,

n_1 = value for surface irregularities,

n_2 = value for obstruction, and

n_3 = value for vegetation.

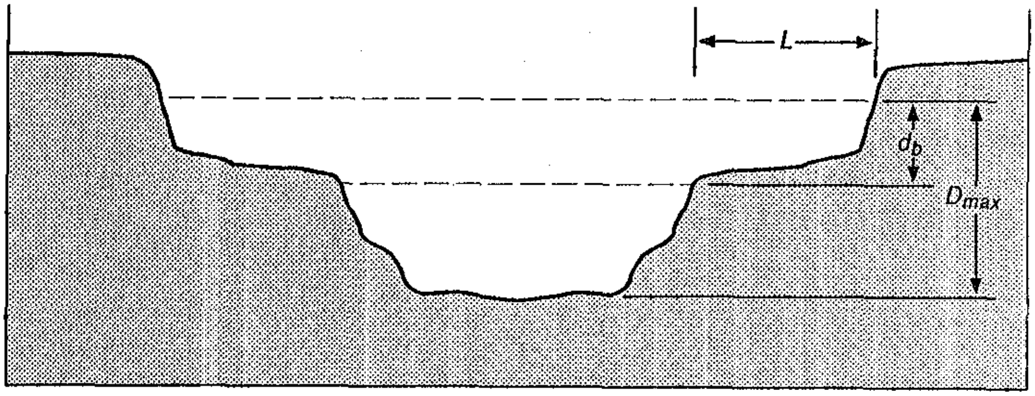
The major adjustments to the base value of *n* used in this report are for cross-section characteristics. Other adjustments for the reach characteristics between cross sections that include changes in shape and size of cross sections and channel meandering are not given. Procedures for evaluating the adjustment factors for the reach characteristics are given in several publications including Chow (1959), Aldridge and Garrett (1973), Jarrett (1985a, b), and Arcement and Schneider (1989).

SUBDIVISION OF CROSS SECTIONS

Sections with distinct changes in shape were divided into subsections, and *n* values were determined separately for each subsection. Subdivision location primarily was based on major breaks in cross-sectional geometry. Cross sections were subdivided if main channel depth was more than twice the depth at the stream edge of the overflow area (fig. 2). Subdivision also commonly was made where the depth of the overflow at the stream edge is nearly half the depth of the main channel and the width of the overflow area is at least five times the depth of the overflow area (fig. 2). Values of *n* for overflow areas commonly were estimated from table 2.

For sections or subsections with a nonuniform distribution of vegetation, a composite *n* was computed by using weighted values for segments having different roughness. Where sections were divided into segments of equal roughness, dividing lines were selected to parallel the general flow line and to represent the average contact between segments of different roughness. Composite *n* values were computed by using weighted values of either area (*A*) or wetted perimeter (*P*). Weighting was done by estimating area or wetted perimeter for each portion of channel and assigning weighting factors that were proportional to the total area or wetted perimeter. The general rule for deciding which weighting method to use is as follows: Use area weighting where vegetation is dense and occupies a distinct part of the cross section. Use wetted-perimeter weighting where the roughness factor for each segment is the result of low-lying boundary material.

Where overflow areas are cultivated fields, *n* values are for fields without crops. Values of *n* for fields with crops can be based on the work of Chow (1959). Fields of mature cotton plants are comparable to dense brush in summer; defoliated cotton to medium to dense brush in winter (fig. 3). Fields of alfalfa are comparable to field crops with *n* value depending on height of the crop and depth of water (table 3). The value of *n* generally varies with the stage of submergence of the vegetation. In all instances, *n* values associated with cultivated fields will change with time.



Subdivide if D_{max} is greater than or equal to $2d_b$

Subdivide if D_{max} is approximately equal to $2d_b$
and if L/d_b is equal to or greater than 5

L = width of flood plain
d_b = depth of flow on flood plain, in feet
D_{max} = maximum depth of flow in cross section, in feet

Modified from Davidian (1984)

Figure 2.--Subdivision criteria commonly used for streams in Maricopa County, Arizona.

Table 3.--*Values of Manning's n for flood plains*

[Modified from Chow, 1959]

Description	Minimum	Normal	Maximum
Pasture, no brush:			
Short grass	0.025	0.030	0.035
High grass	.030	.035	.050
Cultivated areas:			
No crop	.020	.030	.040
Mature row crops	.025	.035	.045
Mature field crops	.030	.040	.050
Brush:			
Scattered brush, heavy weeds	.035	.050	.070
Light brush and trees, in winter	.035	.050	.060
Light brush and trees, in summer	.040	.060	.080
Medium to dense brush, in winter	.045	.070	.110
Medium to dense brush, in summer	.070	.100	.160
Trees:			
Dense willows, summer, straight	.110	.150	.200
Cleared land with tree stumps, no sprouts	.030	.040	.050
Same as above, but heavy growth off sprouts	.050	.060	.080
Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	.080	.100	.120
Same as above, but with flood stage reaching branches	.100	.120	.160

Figure 3.--Cotton fields at different seasons.

SITE INFORMATION

The following sets of site information consist of a description of the site, a table showing values of *n* for sections and subsections of the channel for the 10-year and 100-year floods, channel cross sections, and photographs (tables 4-19; figs. 4-35). Photographs of the 16 sites taken during the spring and summer of 1989 include an overview showing the location of the cross section; additional photographs show major items that affect the *n* value. The frame of the square grid shown in several photographs is 1.5 ft outside dimension on a side with an internal square of 1 ft on a side and grid spacing of 1 in. Cross-section diagrams show approximate elevations of the 10-year and 100-year flood levels, appropriate subdivisions, selected *n* values, and the approximate location and height of the vegetation. The approximate flood elevations were computed from conveyance-slope computations using cross-section geometry furnished by Flood Control District of Maricopa County.

The photographs were taken from different locations on the ground and from an aircraft. For most sites, a photograph of typical bed material is included. The photographs of the channel and flood plain can be used for comparison of field conditions with photographs of channels and flood plains where *n* values have been verified (Arcement and Schneider, 1989; Chow, 1959; Barnes,1964; Aldridge and Garrett, 1973). Several of the photographs and descriptions refer to the horizontal stationing of the cross section.

The description of each site includes the location of the channel cross section, the description of the channel, the basis for subdivision of the cross section, and the evaluation of the estimated *n* value. Changes in channel geometry and type and distribution and density of vegetation are described. The area or wetted-perimeter basis for weighting of *n* for portions of sections and subsections is defined. The channel cross section and the photographs should be used in conjunction with the site description to assess how *n* was defined.

The table shows the components of the roughness coefficient for the 10-year and 100-year floods that were estimated for the sections and subsections. The total *n* values are the sum of the base value of *n* for a straight uniform channel (n_b); surface irregularities (n_1); obstruction (n_2); and vegetation (n_3). Dashes indicate that a roughness coefficient of zero was used. Where portions of sections and subsections were used, the part of the section or subsection used for the estimate of the composite *n* is listed under "Portion of area or wetted perimeter of subsection from left end." Where portions of sections or subsections were not used, values for portions and weighted and composite values were not listed. The sum of the parts for each portion of the section and (or) subsection is equal to 1. The composite value of *n* for the sections and subsections is the sum of the weighted *n* values for each portion.

GILA RIVER ABOVE BULLARD AVENUE NEAR AVONDALE

Location of cross section: 1,000 ft upstream from bridge.

Description of channel: Bed material is mostly sand and gravel with some cobbles and small boulders except for the low-flow channel, which is mainly clay, silt, and sand. Low-flow channel has dense brush and trees on right bank and light brush and trees on left bank. Many of the trees are taller than the maximum flood level. About half the section is clear of vegetation but the bed is uneven and has smooth irregularities. Scattered areas of dense brush and trees are along the left side of the channel. Some of this vegetation would be overtopped and bent over by major floods. The trees and brush on the right bank are dense and probably will not be overtopped or bent over by major floods.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided at edge of terrace on left side at a major break in cross-sectional geometry and a large change in vegetation density. Subdivision on the basis of large changes in vegetation density at cross-section station 20,450 ft was considered but because the geometry did not change, no cross section subdivision was made. Also, subdivision on the basis of vegetation-density changes would result in nonalignment of subareas with adjacent cross sections. Composite *n* values were computed for the main channel because of distinct changes in vegetation across the channel. Weighting of *n* for portions of subsections was done on the basis of area.

Table 4.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .027		
		n = .055		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_2 = ----		
		n_3 = .025		
.10	x	n = .055	=	.006
		n_b = .025		
		n_1 = .002		
		n_2 = ----		
		n_3 = .003		
.55	x	n = .030	=	.017
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .055		
.05	x	n = .080	=	.004
		n_b = .020		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.15	x	n = .020	=	.003
		n_b = ----		
		n_1 = ----		
		n_2 = ----		
		*n_3 = .200		
.15	x	n = .200	=	.030
1.00				.060

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .017		
		n = .045		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .003		
		n_2 = ----		
		n_3 = .017		
.10	x	n = .045	=	.004
		n_b = .025		
		n_1 = .001		
		n_2 = ----		
		n_3 = .002		
.55	x	n = .028	=	.015
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .040		
.05	x	n = .065	=	.003
		n_b = .020		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.15	x	n = .020	=	.003
		n_b = ----		
		n_1 = ----		
		n_2 = ----		
		*n_3 = .150		
.15	x	n = .150	=	.022
1.00				.047

*Only value of n_3 of consequence.

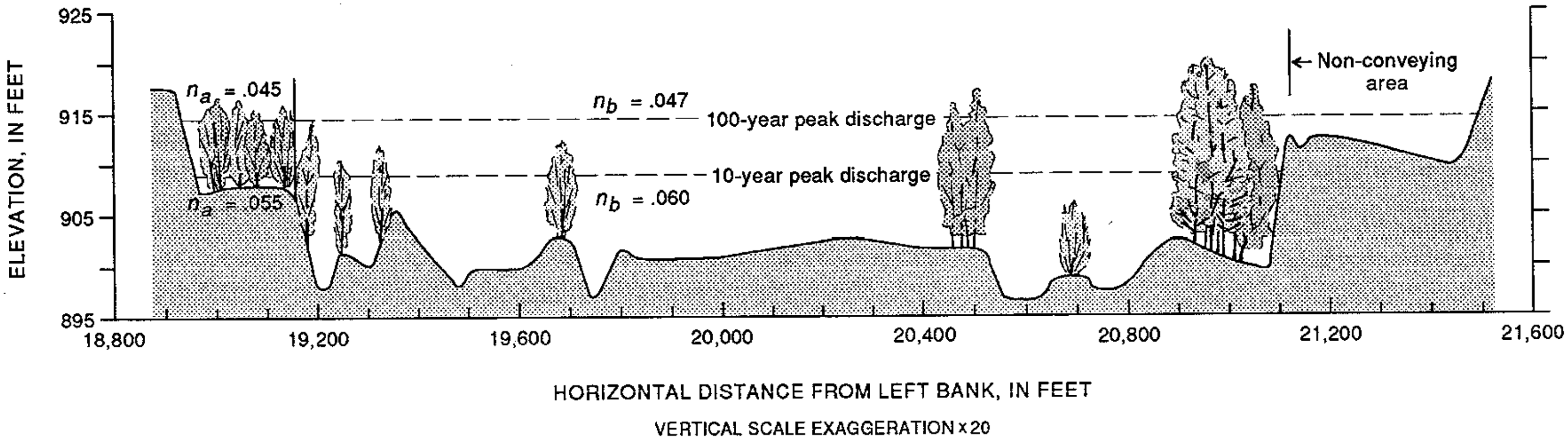


Figure 4.--Cross section of Gila River above Bullard Avenue near Avondale.

A. Looking upstream and across at cross section from above right side.

B. Looking upstream and across at center and left end of cross section from below Bullard Avenue.

Figure 5.--Gila River above Bullard Avenue near Avondale.

C. Looking upstream at left bank. Man is at left end of cross section.

D. Looking upstream from Bullard Avenue at left floodplain area.

Figure 5.--Gila River above Bullard Avenue near Avondale--Continued.

E. Looking upstream near center of channel.

F. Typical bed material near center of channel.

Figure 5.--Gila River above Bullard Avenue near Avondale--Continued.

G. Looking upstream at small open area on right side (cross-section station 20,800 feet) where vegetation is dense and about 15 feet high.

H. Looking upstream at right bank. The man is about 100 feet downstream from the cross section. The vegetation is about 15 feet high; *n* value equals 0.200.

Figure 5.--Gila River above Bullard Avenue near Avondale--Continued.

GILA RIVER ABOVE GILLESPIE DAM

<u>Location of cross section</u>: 500 ft upstream from dam.

<u>Description of channel</u>: Sediment has filled the storage behind the dam except for several low-flow channels. The sediment supports an abundant growth of saltcedar and mesquite except for a wide section (about 65 percent) of channel that has been cleared. Cattails and other reeds grow where water is shallow. The vegetation is supple, and some of it would be overtopped by floodflows. The cleared part of the section has a scattered growth of weeds that will have little effect at flood stages.

<u>Subdivision of cross section and evaluation of *n*</u>: n_b = 0.025 for cleared channel. Subdivision for 10-year flood was made on the basis of changes in cross-sectional geometry. Subdivision for 100-year flood was made at cross-section station 10,130 ft on the basis of the major change of vegetation density along the reach and to a lesser degree on the basis of a small change of cross-sectional geometry.

GILA RIVER ABOVE GILLESPIE DAM--Continued

Table 5.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_3 = .004	
	n = .029	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n = .025	

Subsection D

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .002	
	n_3 = .003	
	n = .030	

Subsection E

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	*n_3 = .200	
	n = .200	

*Only value of n_3 is of consequence.

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .001	
	n_3 = .002	
	n = .028	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	*n_3 = .150	
	n = .150	

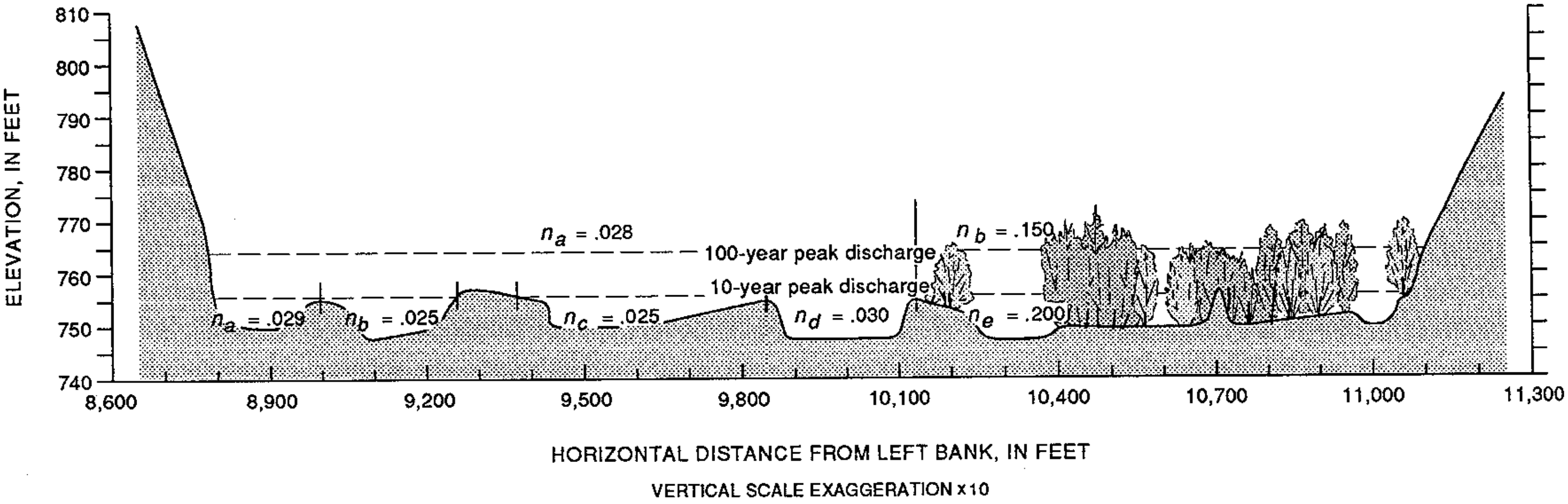


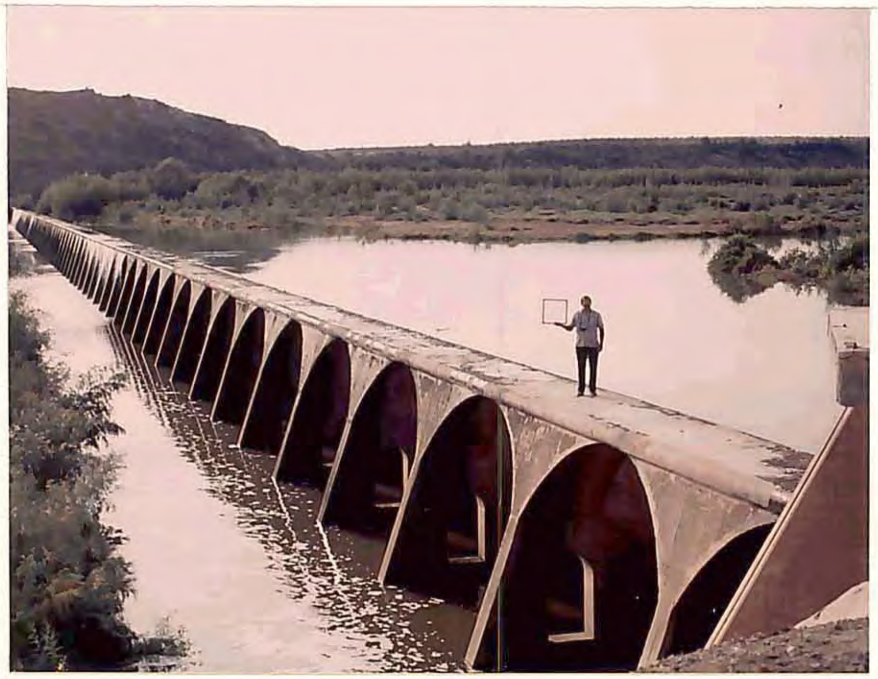
Figure 6.--Cross section of Gila River above Gillespie Dam.

A. Looking downstream at cross section.

B. Looking at cross section and Gillespie Dam from left end.

Figure 7.--Gila River above Gillespie Dam.

C. Looking upstream from crest of dam at left side of channel.



D. Looking across and upstream from left side at dam. Center of cross section is in the background.

Figure 7.--Gila River above Gillespie Dam--Continued.

E. Looking upstream at right side of channel. Diameter of gage well in left center is 2 feet; the vegetation is dense and about 10 to 15 feet high.

F. Looking upstream and across at left center of cross section from right bank.

Figure 7.--Gila River above Gillespie Dam--Continued.

G. Looking upstream and across from right side at right end of cross section where vegetation is dense and 10 to 15 feet high.

Figure 7.--Gila River above Gillespie Dam--Continued.

SALT RIVER BELOW GRANITE REEF DAM

Location of cross section: About 2,000 ft downstream from dam and 500 to 600 ft downstream from road crossing.

Description of channel: A low-flow channel next to the right bank is flanked on the left by two terraces. The first terrace is about 10 ft above the low-flow bed; the second terrace is about 5 ft above the first terrace. The low-flow channel has a few relatively large rock outcrops scattered throughout. Rock outcrops are slightly rounded but irregular. Banks have scattered trees. Channel is nonuniform in shape. Bed material on the first terrace is gravel, cobbles, and a few boulders; bed material on the second terrace is sand and gravel. The bed is uneven and contains scattered small bushes.

Subdivision of cross section and evaluation of *n*: Left bank terrace had a panhandle shape, and subdivision was made at the edge of the terrace on the basis of cross-sectional geometry. Composite *n* values were used for the main channel because of distinct changes in the components of roughness. Weighting of *n* for portions of subsections were done on the basis of wetted perimeter.

SALT RIVER BELOW GRANITE REEF DAM--Continued

Table 6.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_2 = ----		
		n_3 = .008		
		n = .038		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .007		
.60	x	n = .035	=	.021
		n_b = .028		
		n_1 = .004		
		n_2 = .008		
		n_3 = .015		
.40	x	n = .055	=	.022
1.00				.043

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .002		
		n_2 = ----		
		n_3 = .006		
		n = .033		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .004		
.60	x	n = .032	=	.019
		n_b = .028		
		n_1 = .002		
		n_2 = .007		
		n_3 = .008		
.40	x	n = .045	=	.018
1.00				.037

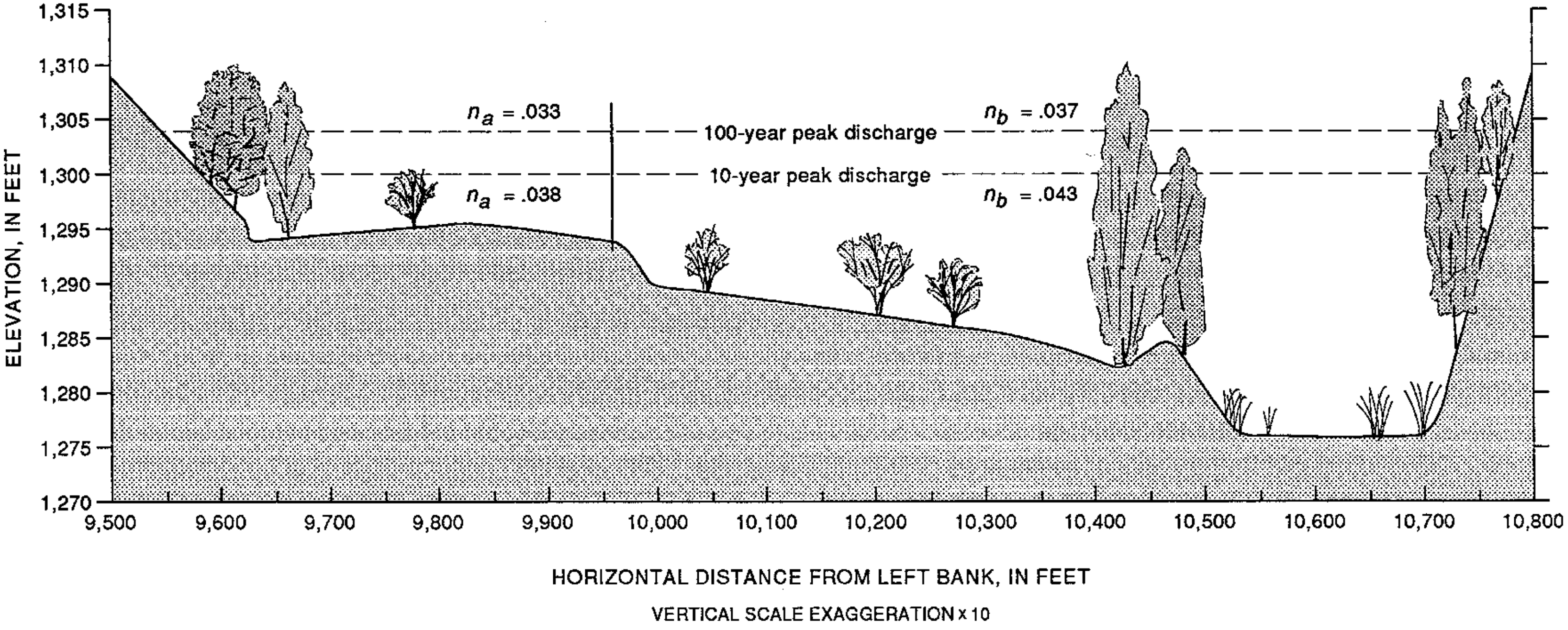


Figure 8.--Cross section of Salt River below Granite Reef Dam.

A. Looking downstream at cross section.

B. Looking across channel at cross section from left side. Man is at cross-section station 9,650 feet.

Figure 9.--Salt River below Granite Reef Dam.

C. Looking downstream at left flood plain (cross-section station 9,700 feet).

D. Looking downstream near left edge of first terrace near cross-section station 10,000 feet.

Figure 9.--Salt River below Granite Reef Dam--Continued.

E. Looking at finest channel-bed material in cross section.

F. Looking upstream at left edge of main channel near cross-section station 10,500 feet.

Figure 9.--Salt River below Granite Reef Dam--Continued.

G. Looking across channel at section from right bank. Row of trees on opposite side of water is at cross-section station 10,480 feet.

Figure 9.--Salt River below Granite Reef Dam--Continued.

SALT RIVER BELOW 24TH STREET AT PHOENIX

Location of cross section: 600 ft downstream from bridge.

Description of channel: Bed material is gravel, cobbles, and boulders; channel bottom is somewhat irregular. Shape of cross section apparently has changed since mapping was done. A small channel cuts diagonally across the center of the cross section from the right to left end.

Subdivision of cross section and evaluation of *n*: Subdivision was not needed for 100-year peak discharge, and roughness was fairly uniform across the cross section. Subdivision for 10-year peak discharge was based on geometry of cross section.

SALT RIVER BELOW 24TH STREET AT PHOENIX--Continued

Table 7.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .032	
	n_1 = .003	
	n_2 = ----	
	n_3 = ----	
	n = .035	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .032	
	n_1 = .003	
	n_2 = .001	
	n_3 = ----	
	n = .036	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = .005	
	n_2 = .001	
	n_3 = ----	
	n = .033	

100-Year Flood

Section

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .028	
	n_1 = .004	
	n_2 = ----	
	n_3 = ----	
	n = .032	

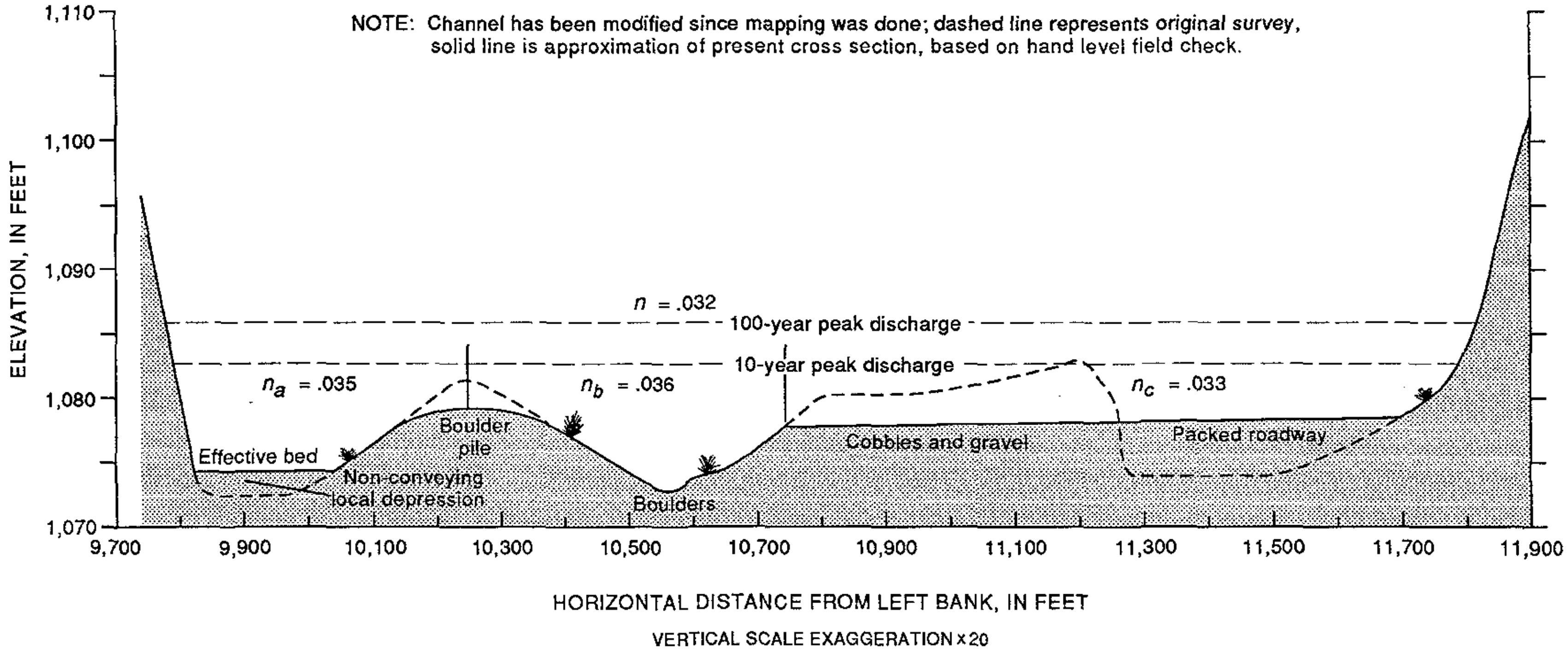


Figure 10.--Cross section of Salt River below 24th Street at Phoenix.

A. Looking downstream and across at cross section from above left side.

B. Looking downstream near center of channel.

Figure 11.--Salt River below 24th Street at Phoenix.

C. Looking downstream along left bank.

D. Looking across channel from right bank.

Figure 11.--Salt River below 24th Street at Phoenix--Continued.

E. Looking at coarsest bed material in cross section.

F. Looking downstream along right bank.

Figure 11.--Salt River below 24th Street at Phoenix--Continued.

G. Looking downstream at right bank.

Figure 11.--Salt River below 24th Street at Phoenix--Continued.

HASSAYAMPA RIVER ABOVE HIGHWAY REST STOP NEAR WICKENBURG

Location of cross section: 100 ft upstream from rest stop.

Description of channel: Bed material in the low-flow part of the channel is silt and sand. Low-flow channel is slightly irregular and has scattered weeds along edges. The rest of the bed in the low-flow channel and the overflow area is covered with grass except for the railroad track area on the narrow ledge along the right bank.

Channel has a dense growth of brush and trees between the low-flow channel and the right bank. Arrow weeds to the left of the low-flow channel are 10 ft high and will bend under the force of flowing water. Overflow area has large trees at right edge, dense brush and trees along left edge, and an irregular open area between the two stands of vegetation.

Subdivision of cross section and evaluation of *n*: Subdivision was not needed. Composite *n* values were computed because of changes in vegetation roughness across the channel. Weighting of *n* for portions of subsections was done on basis of area.

HASSAYAMPA RIVER ABOVE HIGHWAY REST STOP NEAR WICKENBURG--Continued

Table 8.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .100		
.40	x	n = .125	=	.050
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .030		
.35	x	n = .055	=	.019
		n_b = .022		
		n_1 = ----		
		n_2 = ----		
		n_3 = .003		
.10	x	n = .025	=	.002
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .100		
.15	x	n = .125	=	.019
1.00				.090

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .100		
.45	x	n = .125	=	.056
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .010		
.30	x	n = .035	=	.010
		n_b = .022		
		n_1 = ----		
		n_2 = ----		
		n_3 = .003		
.10	x	n = .025	=	.002
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .100		
.08	x	n = .125	=	.010
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.07	x	n = .030	=	.002
1.00				.080

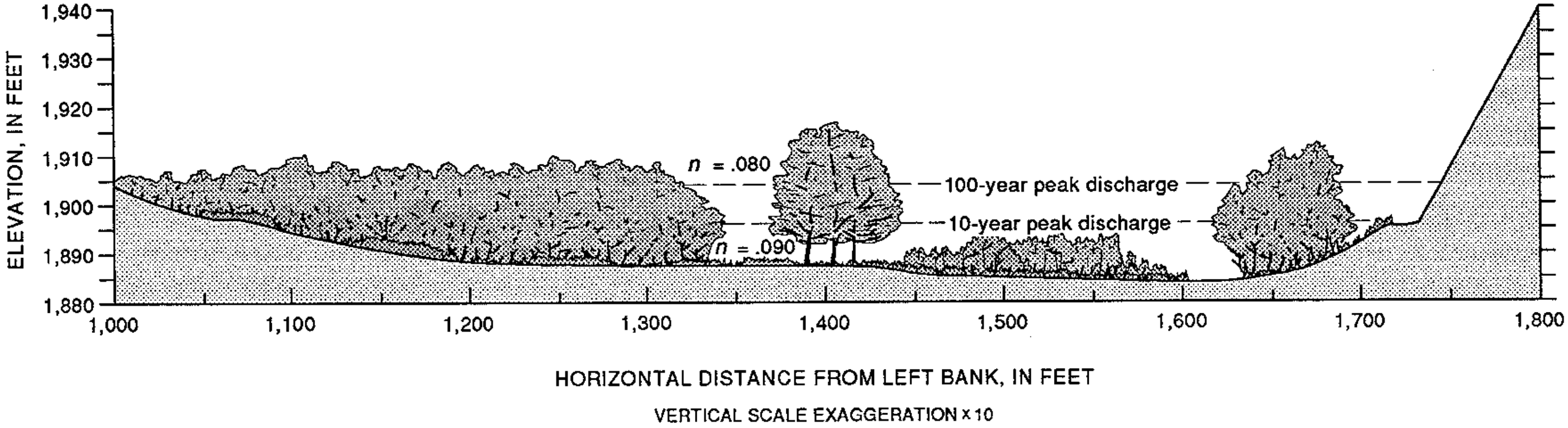


Figure 12.--Cross section of Hassayampa River above Highway Rest Stop near Wickenburg.

A. Looking downstream at and across from above left bank.

B. Looking upstream and across from above left bank.

Figure 13.--Hassayampa River above Highway Rest Stop near Wickenburg.

C. Looking toward left bank from open area near middle of cross section.

D. Looking upstream along low-flow channel.

Figure 13.--Hassayampa River above Highway Rest Stop near Wickenburg--Continued

E. Looking downstream along low-flow channel.

F. Looking upstream along right bank.

Figure 13.--Hassayampa River above Highway Rest Stop near Wickenburg--Continued.

HASSAYAMPA RIVER AT CENTRAL ARIZONA PROJECT CANAL

Location of cross section: Section intersects the alignment of the Central Arizona Project canal siphon near the right bank of the river. Right bank end of the section is 400 ft upstream from the canal; left bank end is 1,000 ft downstream.

Description of channel: Bed material is silt and sand, and channel bottom is uneven. Low-growing brush and weeds and small trees are scattered throughout the channel and slightly concentrated along the low-flow channel.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided on the basis of changes in shape although the changes are somewhat subtle in this wide and generally shallow section. Subdivision was made at cross-section station 3,550 ft for the 10-year flood and at cross-section stations 2,300 and 4,400 ft for the 100-year flood.

HASSAYAMPA RIVER AT CENTRAL ARIZONA PROJECT CANAL--Continued

Table 9.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = .003	
	n_2 = ----	
	n_3 = .007	
	n = .032	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = ----	
	n_2 = ----	
	n_3 = .005	
	n = .027	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = .003	
	n_2 = ----	
	n_3 = .007	
	n = .032	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = ----	
	n_2 = ----	
	*n_3 = .003	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = .003	
	n_2 = ----	
	n_3 = .007	
	n = .032	

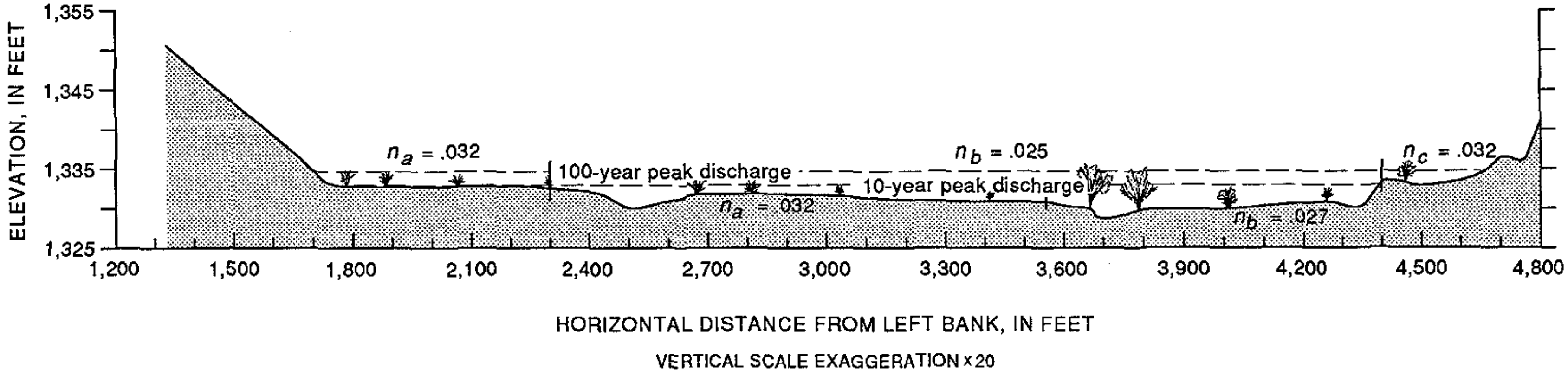


Figure 14.--Cross section of Hassayampa River at Central Arizona Project Canal.

A. Looking across channel from left bank.

B. Looking toward left bank from right bank; vehicle on road is near low-flow channel at cross-section station 3,500 feet.

Figure 15.--Hassayampa River at Central Arizona Project Canal.

C. Typical bed material and vegetation on flood plain at cross-section station 2,300 feet.

D. Looking downstream along right bank.

Figure 15.--Hassayampa River at Central Arizona Project Canal--Continued.

E. Typical bed material and vegetation in low-flow channel at cross-section station 3,900 feet.

F. Closeup of bed material in low-flow channel.

Figure 15.--Hassayampa River at Central Arizona Project Canal--Continued.

HASSAYAMPA RIVER BELOW OLD U.S. HIGHWAY 80

Location of cross-section: 800 ft downstream from bridge.

Description of channel: Bed material is mainly sand and gravel with a few scattered cobbles and boulders. Main channel is constrained by dikes that are several feet higher than flood plains on either side. A small low-flow channel is within the main channel. Grass and weeds along the low-flow channel and an occasional bush or small tree will affect roughness at the 10-year flood level but will wash away at the 100-year flood level. Wide flood plains on either side of the main channel are cultivated fields.

Subdivision of cross section and evaluation of *n*: The 10-year flood is confined in the main channel. The 100-year flood also can be conveyed in the main channel at this cross section. However, floodwater may spill from channel upstream or erode dikes and occupy parts of flood plains. Elevation of 100-year flood was computed on the assumption of a common water level in the main channel and the flood plain; therefore, that section consists of two subareas.

HASSAYAMPA RIVER BELOW OLD U.S. HIGHWAY 80--Continued

Table 10.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = .003	
	n = .028	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

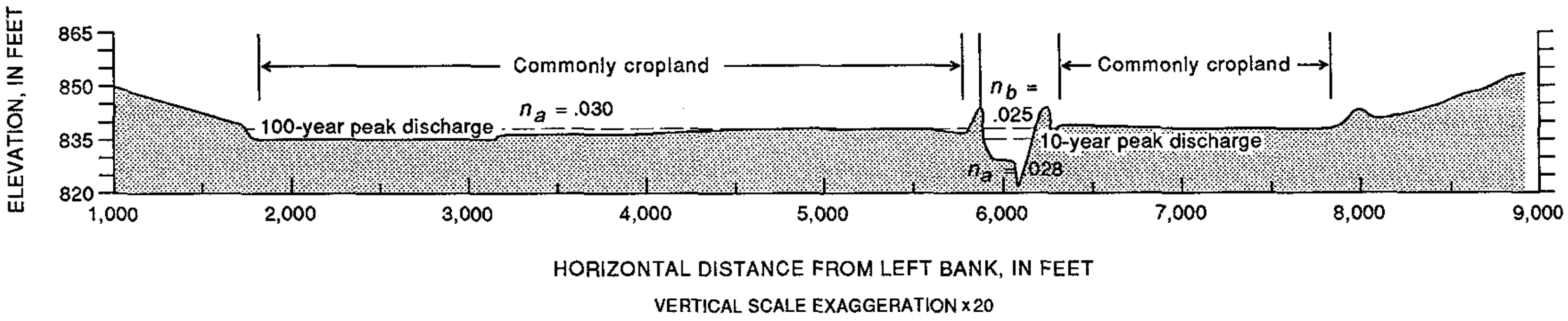


Figure 16.--Cross section of Hassayampa River below old U.S. Highway 80.

A. Looking downstream showing approximate location of cross section.

B. Typical bed material.

Figure 17.--Hassayampa River below old U.S. Highway 80.

C. Looking downstream along left bank.

D. Looking downstream along right bank.

Figure 17.--Hassayampa River below old U.S. Highway 80--Continued.

E. Looking downstream along low-flow channel.

F. Looking across left flood plain.

Figure 17.--Hassayampa River below old U.S. Highway 80--Continued.

NEW RIVER ABOVE NEW RIVER ROAD

Location of cross section: 500 ft upstream from bridge.

Description of channel: Bed material is cobbles and boulders. The main channel has been cleared and shaped, and dikes on either side are several feet above the natural flood plain. A narrow strip of flood plain beyond the dike on the left bank will not convey floodwater because it is isolated from the main channel. The main channel upstream from the cleared portion and the right flood plain has a light to medium cover of brush and trees.

Subdivision of cross section and evaluation of *n*: Main channel is large enough to contain the 10-year and 100-year floods at this section. However, floodwater may spill from the channel upstream or erode dikes and occupy parts of the flood plain. Flood elevations were computed on the assumption of a common water level in the main channel and flood plain; thus cross sections consist of main channel and flood-plain subareas.

NEW RIVER ABOVE NEW RIVER ROAD--Continued

Table 11.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .040	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .040	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .040	
	n_1 = ----	
	n_2 = ----	
	n_3 = .010	
	n = .050	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .035	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .035	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .040	
	n_1 = ----	
	n_2 = ----	
	*n_3 = .002	
	n = .042	

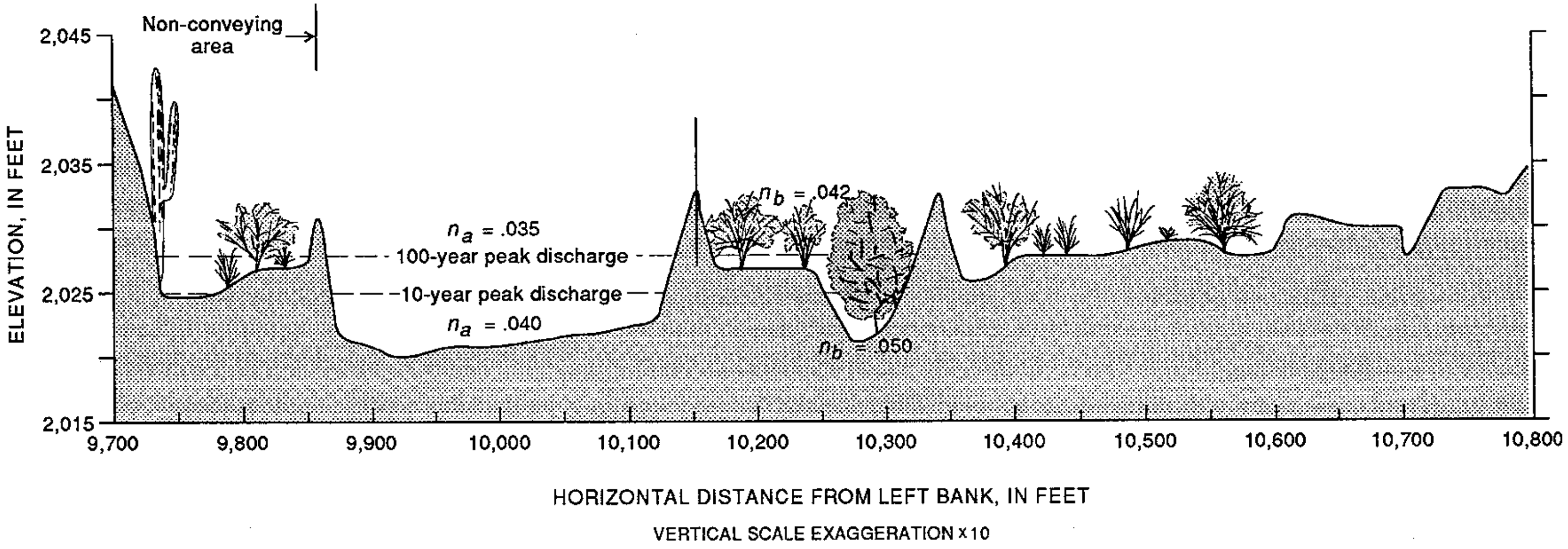


Figure 18.--Cross section of New River above New River Road.

A. Looking downstream and across channel from above left bank.

B. Looking across channel from above left bank.

Figure 19.--New River above New River Road.

C. Typical bed material.

D. Looking upstream from bridge along left bank. Man is at cross-section station 10,000 feet.

Figure 19.--New River above New River Road--Continued.

E. Looking upstream from bridge at center of channel. Man is at cross-section station 10,100 feet.

F. Looking upstream from bridge along right bank. Man is at cross-section station 10,280 feet.

Figure 19.--New River above New River Road--Continued.

NEW RIVER ABOVE INTERSTATE HIGHWAY 17

Location of cross section: 700 ft upstream from bridge.

Description of channel: Bed material is firm soil with boulders protruding in the low-flow channel. Edges of low-flow channel are lined with trees, and the rest of the main channel has scattered brush. The overflow plain has a medium to dense cover of brush and trees except for a small ditch and a narrow roadway that are parallel to the main channel.

Subdivision of cross section and evaluation of *n*: Cross section is subdivided at left edge of main channel on basis of channel shape. Composite *n* value computed for main channel because of distinct differences in vegetation across section. Weighting of *n* for portions of subsections was done on the basis of wetted perimeter.

NEW RIVER ABOVE INTERSTATE HIGHWAY 17--Continued

Table 12.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .030		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.35	x	n = .030	=	.010
		n_b = .030		
		n_1 = .010		
		n_2 = ----		
		n_3 = .050		
.20	x	n = .090	=	.018
		n_b = .030		
		n_1 = .010		
		n_2 = ----		
		n_3 = .010		
.45	x	n = .050	=	.022
1.00				.050

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .030		
		n_1 = ----		
		n_2 = ----		
		n_3 = .065		
		n = .095		

Subsection B

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .030		
		n_1 = ----		
		n_2 = ----		
.35	x	n = .030	=	.010
		n_b = .030		
		n_1 = .010		
		n_2 = ----		
		n_3 = .050		
.20	x	n = .090	=	.018
		n_b = .030		
		n_1 = .005		
		n_2 = ----		
		n_3 = .007		
.45	x	n = .042	=	.019
1.00				.047

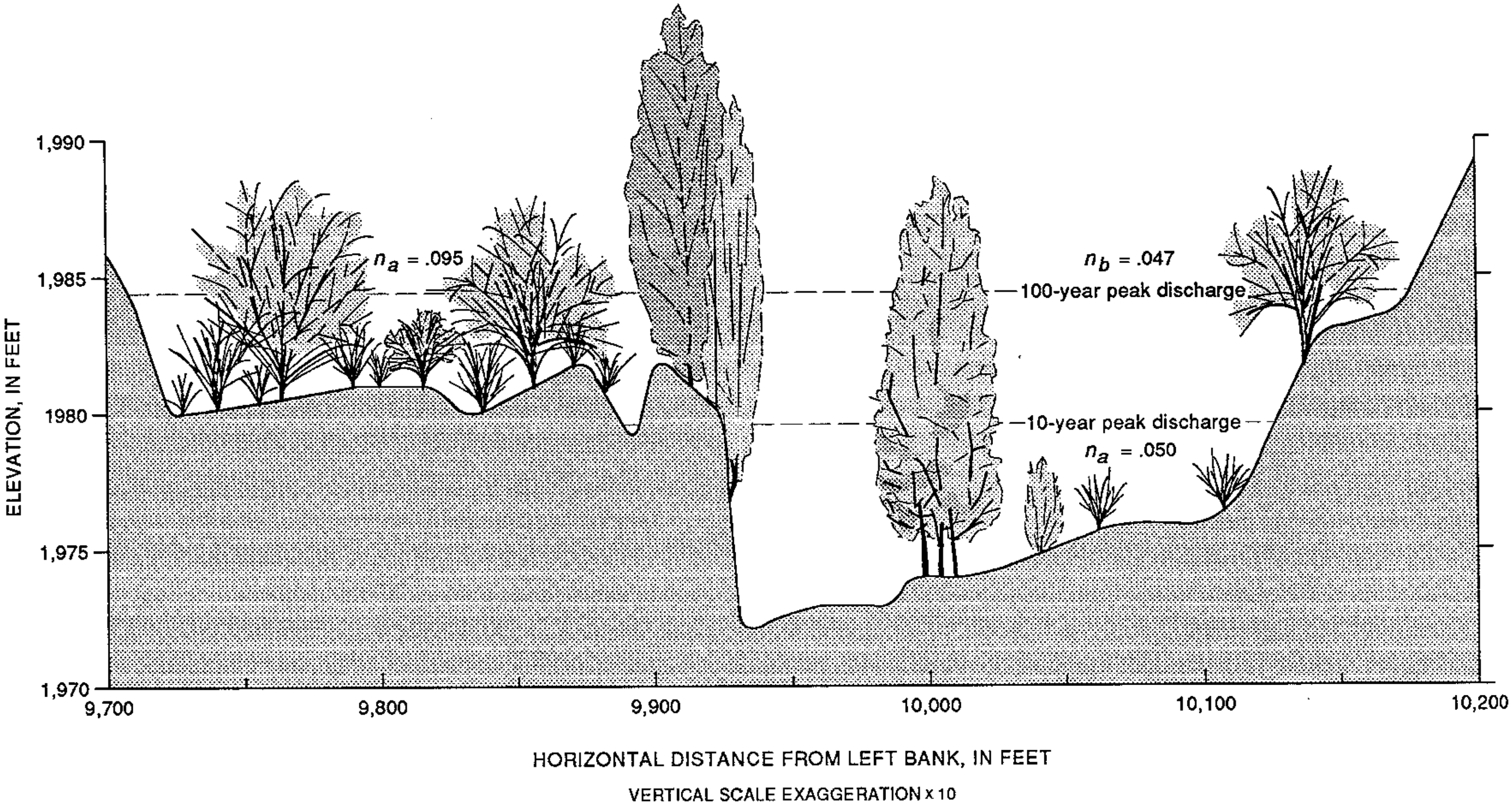
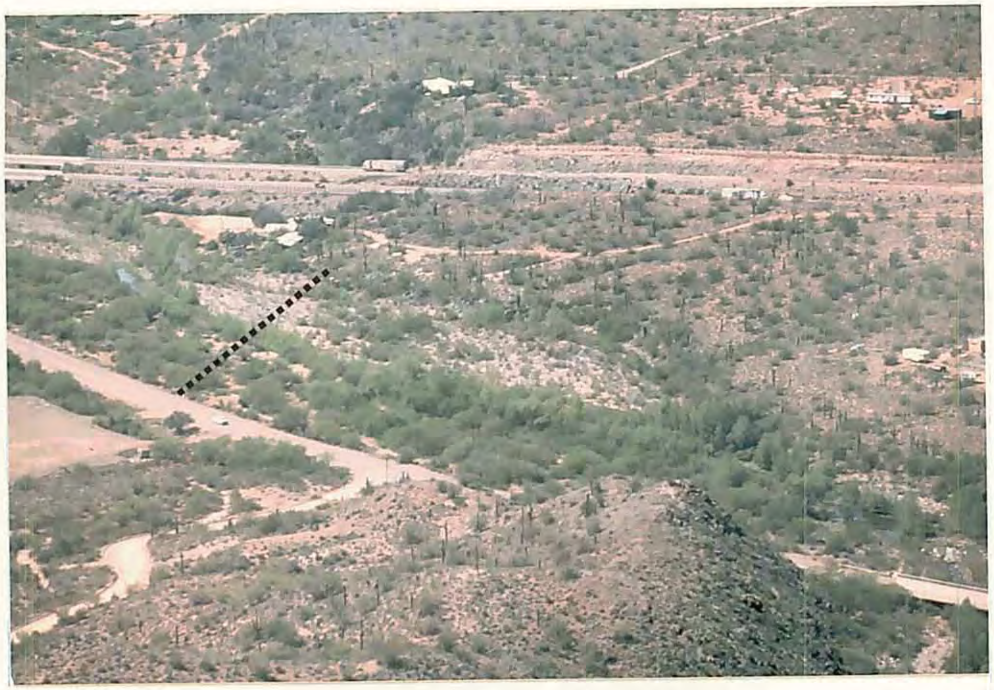


Figure 20.--Cross section of New River above Interstate Highway 17.

A. Looking upstream at cross section from above Interstate Highway 17.



B. Looking downstream and across channel from above left bank.

Figure 21.--New River above Interstate Highway 17.

C. Looking across channel from right bank. Man standing on left bank edge of main channel at cross-section station 9,900.

D. Looking downstream along right bank. Man is at cross-section station 10,030 feet.

Figure 21.--New River above Interstate Highway 17--Continued.

E. Looking upstream at low-flow part of main channel. Man is at cross-section station 9,960 feet.

Figure 21.--New River above Interstate Highway 17--Continued.

CAVE CREEK BELOW CAREFREE HIGHWAY

Location of cross section: 400 ft downstream from bridge.

Description of channel: Bed material is cobbles and boulders; bed surface is fairly even. Main channel has scattered low-growing brush and weeds on the bed and banks. Right overflow has brush and trees. Left overflow has low-growing brush of light to medium density.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided at major breaks in channel shape to separate overflow areas from main channel.

CAVE CREEK BELOW CAREFREE HIGHWAY--Continued

Table 13.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = .010	
	n = .040	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .025	
	n = .060	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .045	
	n = .080	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = .002	
	n = .032	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .015	
	n = .050	

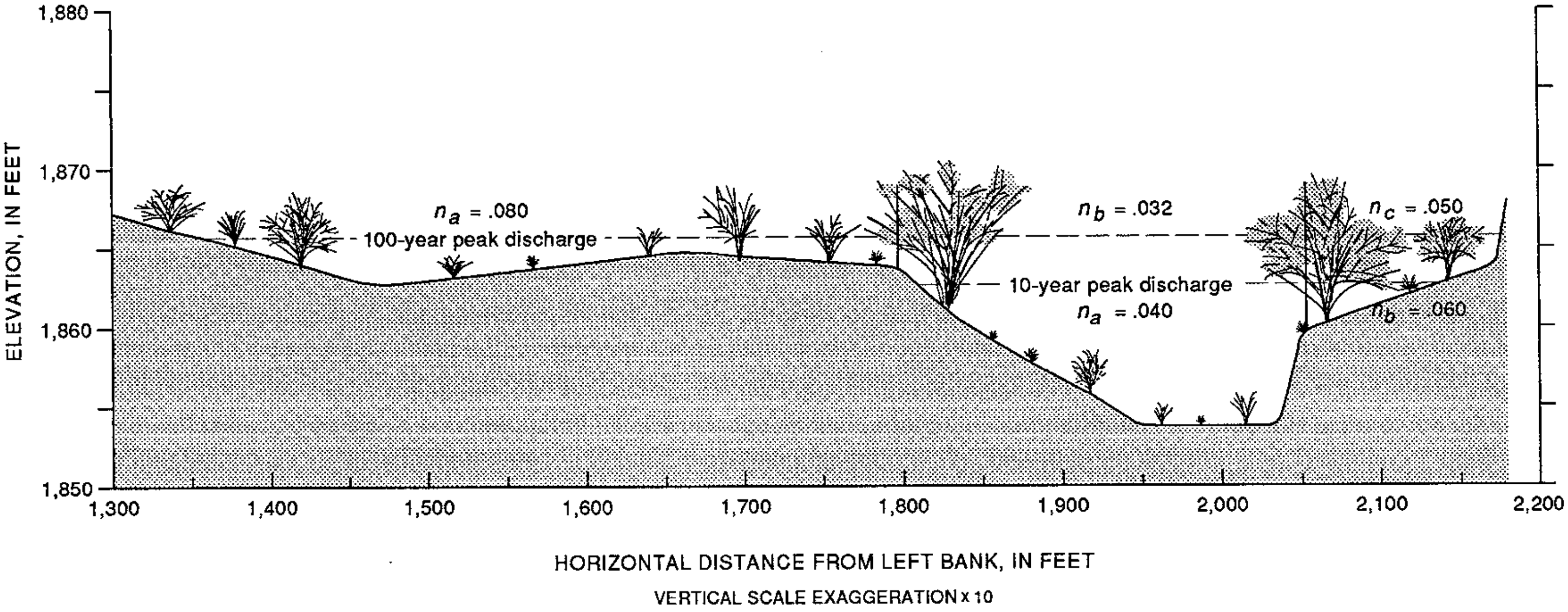


Figure 22.--Cross section of Cave Creek below Carefree Highway.

A. Looking upstream and across channel at cross section from above left bank.

B. Looking downstream from bridge at man in center of cross section. Man is at cross-section station 1,960 feet.

Figure 23.--Cave Creek below Carefree Highway.

C. Looking downstream along right bank. Man is at cross-section station 2,030 feet.

D. Looking upstream at low-flow channel.

Figure 23.--Cave Creek below Carefree Highway--Continued.

E. Typical bed material.

Figure 23.--Cave Creek below Carefree Highway--Continued.

CENTENNIAL WASH BELOW SOUTHERN PACIFIC RAILROAD

Location of cross section: 600 ft downstream from railroad bridge.

Description of channel: Bed material is sand and gravel, banks are generally smooth and uniform. Right overflow area has medium to dense growth of brush and trees. Left overflow area has light growth of brush and trees adjacent to the main channel and a wide cultivated field, which is separated from the area of brush and trees by a small dike.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided for shape at the edges of the main channel. The dike along the left side of the main channel probably would not be overtopped by the 100-year flood. However, openings under the railroad on the left of the main channel probably will carry floodwater onto the left overflow area. Elevation of floodwater was computed on the assumption of a common water level in the main channel and the left overflow area.

CENTENNIAL WASH BELOW SOUTHERN PACIFIC RAILROAD--Continued

Table 14.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .030	
	n = .060	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .030	
	n = .060	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection D

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .010	
	n_2 = ----	
	n_3 = .065	
	n = .100	

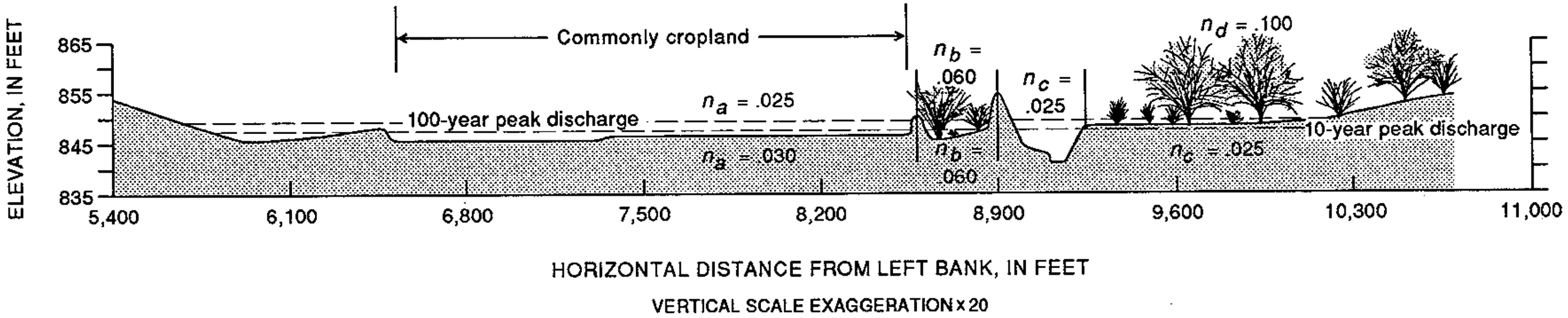
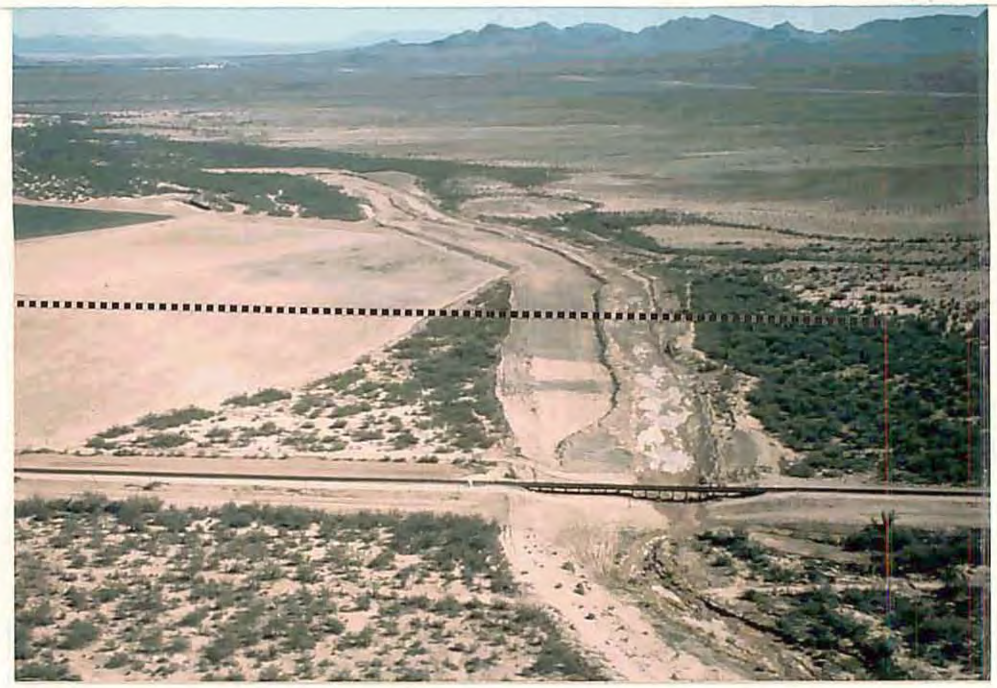
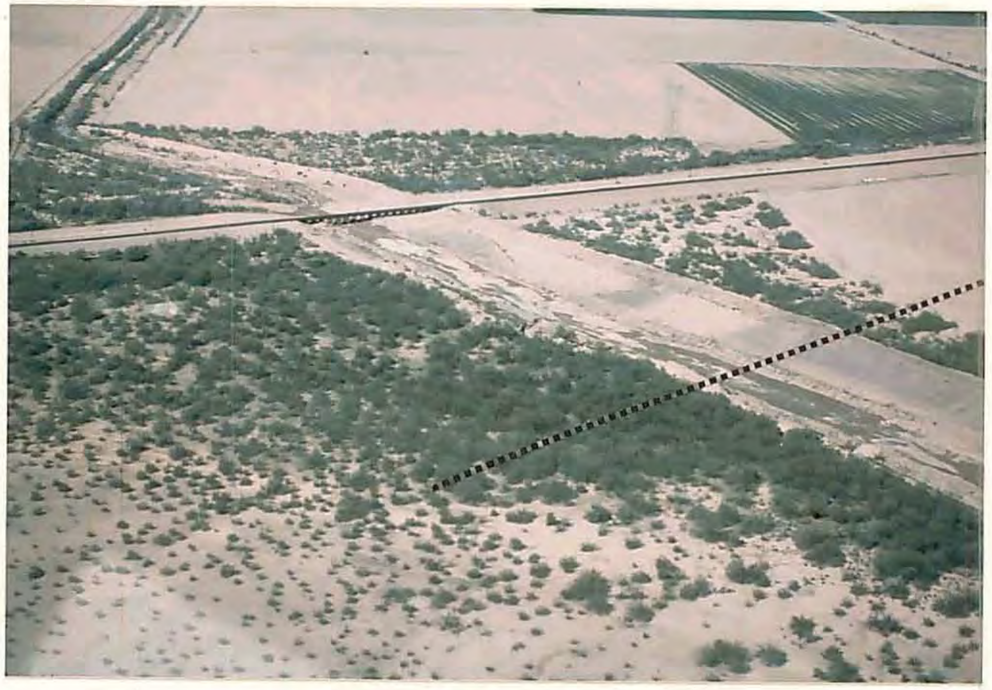


Figure 24.--Cross section of Centennial Wash below Southern Pacific Railroad.



A. Looking downstream at railroad bridge and cross section from above channel.



B. Looking upstream and across channel at cross section and railroad bridge from above right bank.

Figure 25.--Centennial Wash below Southern Pacific Railroad.

C. Looking upstream at typical bed material in main channel.

D. Looking downstream through main channel.

Figure 25.--Centennial Wash below Southern Pacific Railroad--Continued.

E. Looking downstream along channel side of right bank overflow.

F. Vegetation on right overflow area.

Figure 25.--Centennial Wash below Southern Pacific Railroad--Continued.

G. Vegetation on left overflow area at cross-section station 8,700 ft.

H. Looking downstream at small dike that separates cultivated field from native vegetation on left overflow at cross-section station, 8,570 ft.

Figure 25.--Centennial Wash below Southern Pacific Railroad--Continued.

AGUA FRIA RIVER BELOW ALIGNMENT OF U.S. HIGHWAY 74

Location of cross section: 500 ft downstream from road crossing.

Description of channel: Bed material is sand and gravel; banks are generally clean and uniform. Right edge of main channel is uneven, and small overflow channel adjacent to right edge of main channel contains brush and trees and a local rough area. Overflow area is undulant and has scattered brush and trees. Small channel along right bank is a tributary that enters the river a short distance upstream.

Subdivision of cross section and evaluation of n: Cross section was subdivided on the basis of shape at the right edge of main channel. Composite n value was computed for main channel because of the distinct difference in roughness between the clear part of the section and the vegetated part along the right edge. The small channel along the right bank was considered part of the overflow area (not subdivided) because it is a local condition. Weighting of n for portions of subsections were done on the basis of area.

AGUA FRIA RIVER BELOW ALIGNMENT OF U.S. HIGHWAY 74--Continued

Table 15.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .003		
		n_2 = ----		
		n_3 = ----		
.80	x	n = .028	=	.022
		n_b = .025		
		n_1 = .005		
		n_2 = ----		
		n_3 = .040		
.20	x	n = .070	=	.014
1.00				.036

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .025	
	n = .055	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.80	x	n = .025	=	.020
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .035		
.20	x	n = .060	=	.012
1.00				.032

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .015	
	n = .045	

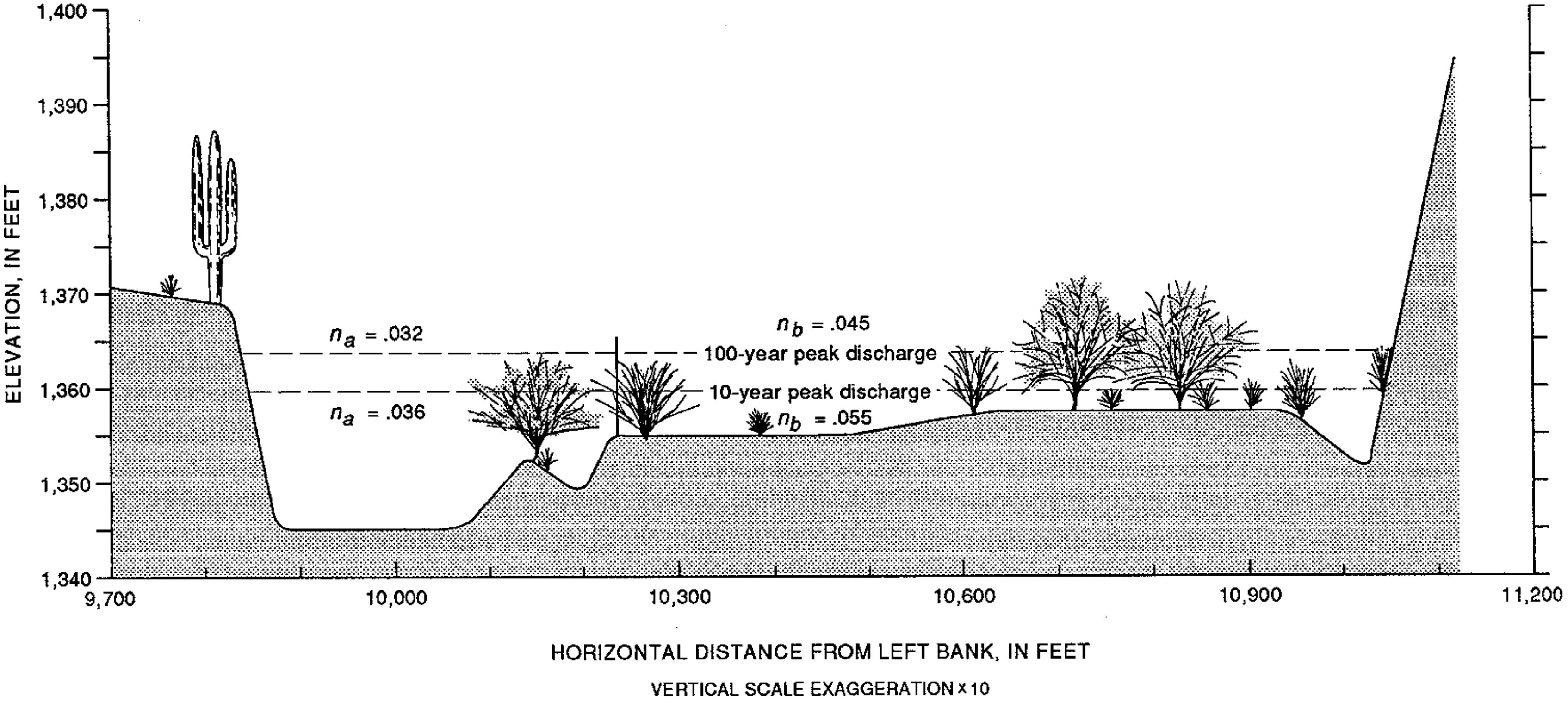
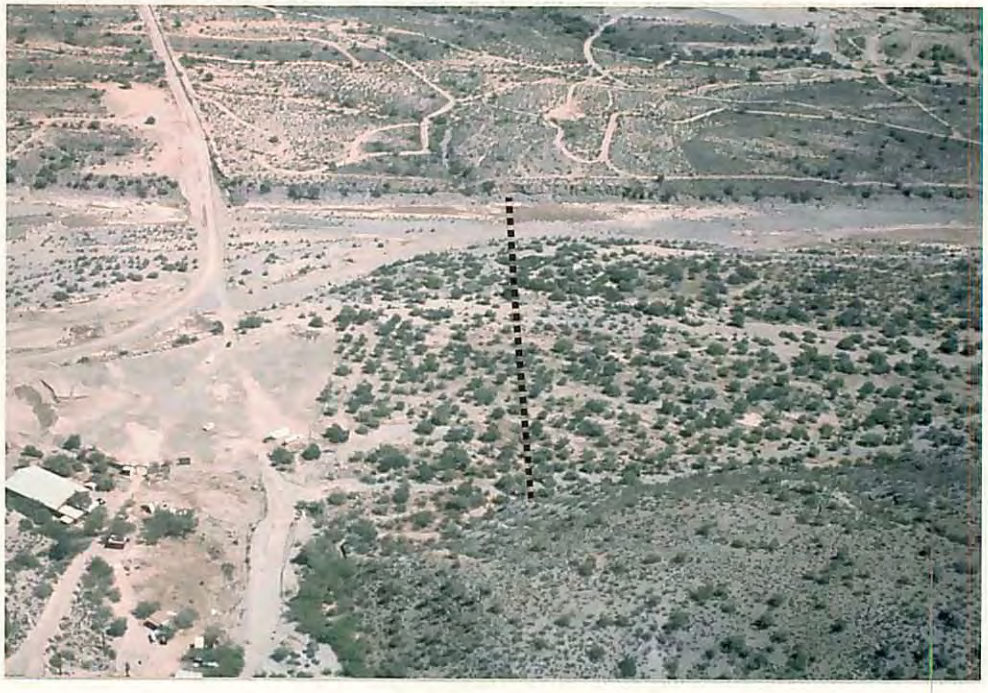
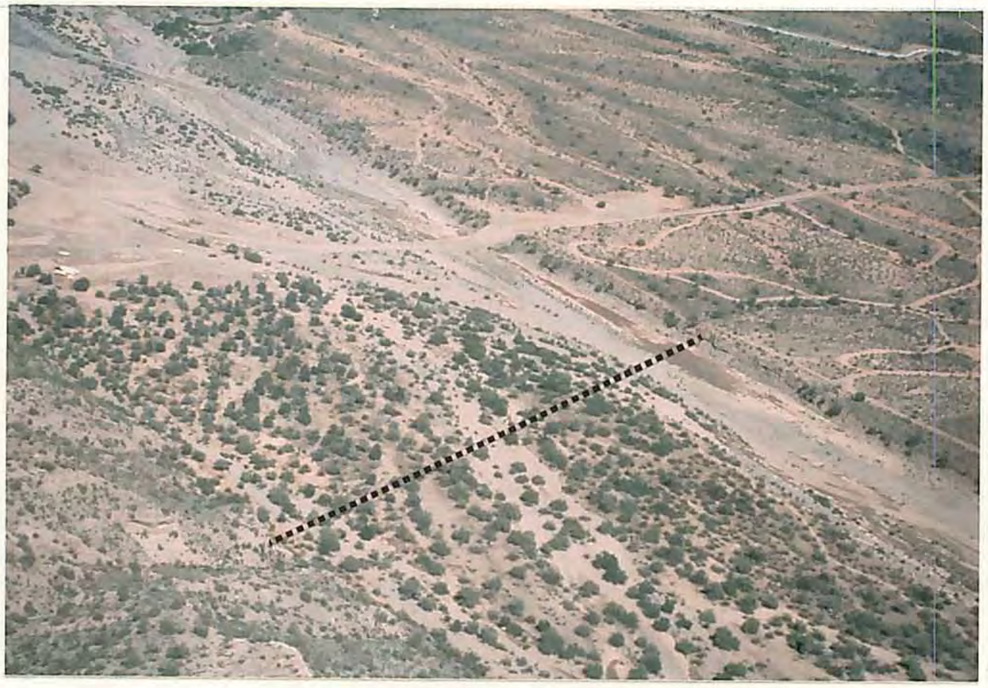


Figure 26.--Cross section of Agua Fria River below alignment of U.S. Highway 74.



A. Looking across channel at left bank from above right bank.



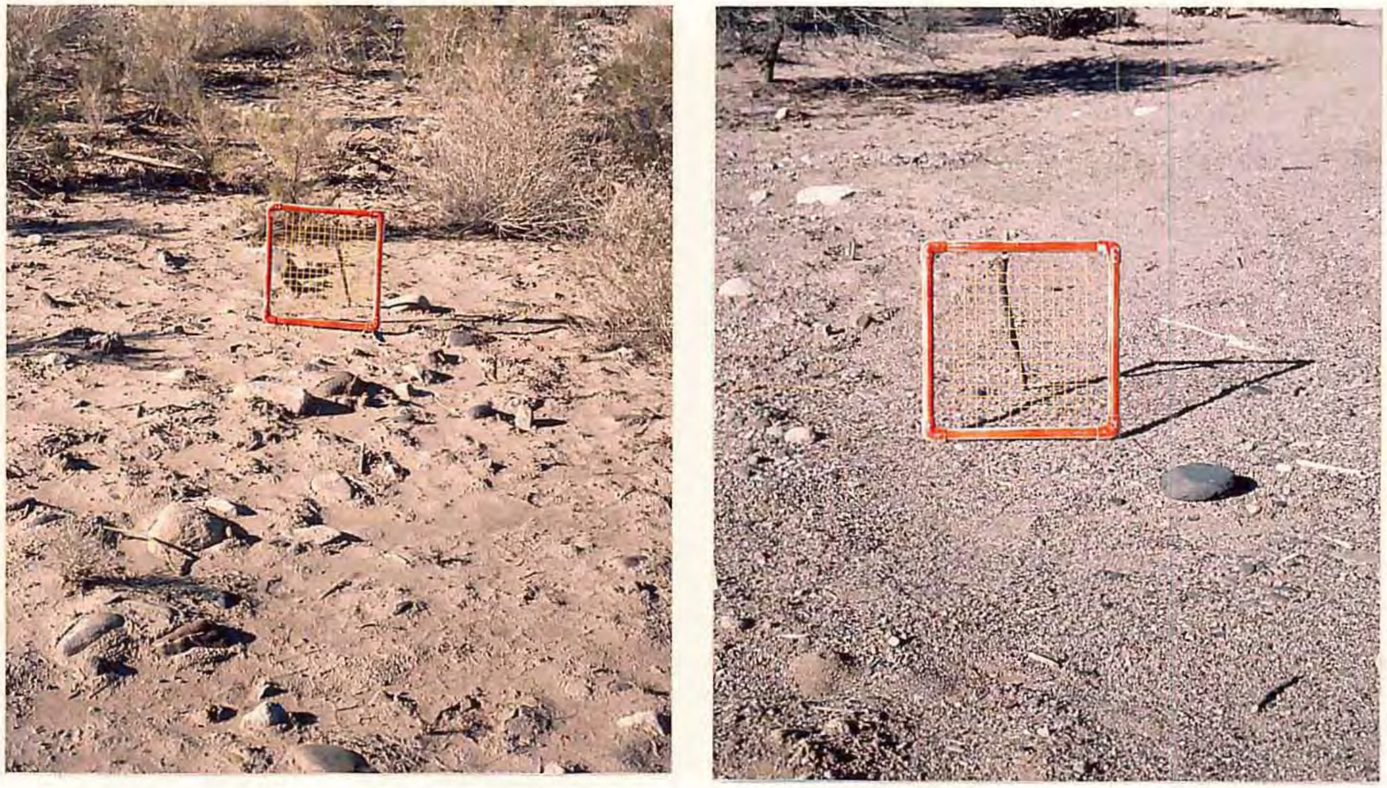
B. Looking upstream and across channel at cross section from above right bank.

Figure 27.--Agua Fria River below alignment of U.S. Highway 74.

C. Looking downstream along left bank. Man is at cross-section station 9,910 feet.

D. Looking downstream along right edge of main channel. Man is at cross-section station 10,080 feet.

Figure 27.--Agua Fria River below alignment of U.S. Highway 74--Continued.



E. Typical bed material near left edge of overflow plain.

F. Typical bed material near right edge of overflow plain.

G. Looking upstream along right bank.

Figure 27.--Agua Fria River below alignment of U.S. Highway 74--Continued.

AGUA FRIA RIVER BELOW JOMAX ROAD

Location of cross section: 800 ft downstream from road crossing.

Description of channel: Bed material is coarse sand and gravel, banks are smooth and uniform and has scattered growth of weeds. Overflow areas have uneven surface and scattered low-growing brush and weeds.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided on the basis of shape at either edge of main channel. Small deep channels represent a local condition that may not be present at adjacent sections.

AGUA FRIA RIVER AT JOMAX ROAD--Continued

Table 16.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = .003	
	n_3 = ----	
	n = .028	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .015	
	n = .043	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .005	
	n = .033	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .005	
	n = .033	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .005	
	n = .033	

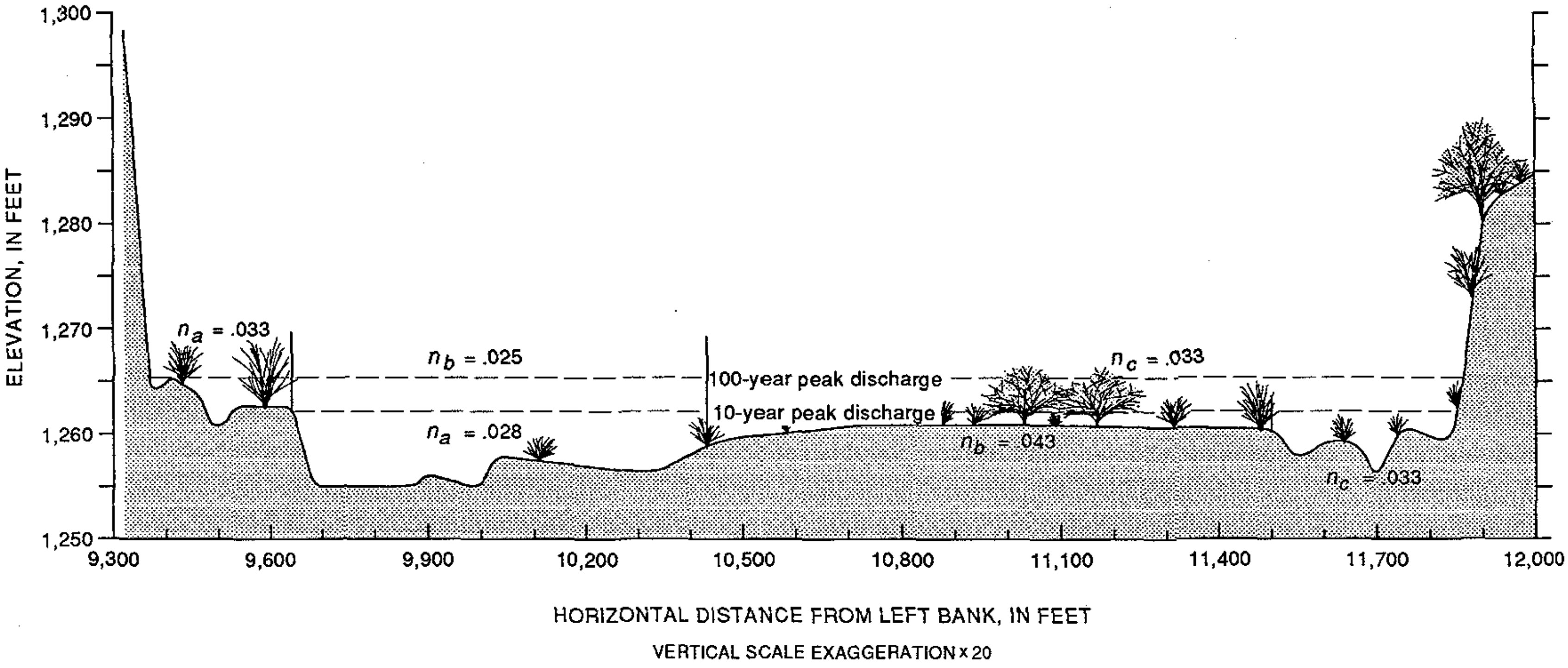


Figure 28.--Cross section of Agua Fria River below Jomax Road.

A. Looking upstream at cross section.

B. Looking upstream and across channel from above right bank.

Figure 29.--Agua Fria River below Jomax Road.

C. Looking downstream along left bank.

D. Looking downstream along right bank.

Figure 29.--Agua Fria River below Jomax Road--Continued.

E. Looking across channel from right bank.

F. Typical vegetation and bed material on right overflow area.

Figure 29.--Agua Fria River below Jomax Road--Continued.

G. Bed material in main channel.

Figure 29.--Agua Fria River below Jomax Road--Continued.

AGUA FRIA RIVER BELOW BUCKEYE ROAD

Location of cross section: 800 ft downstream from bridge.

Description of channel: Bed material is mixture of sand and gravel with some cobbles and boulders in low-flow channel that meanders within floodway. Floodway is straight with smooth, uniform banks. Right bank is a nearly vertical soil-cement embankment.

Subdivision of cross section and evaluation of *n*: Base roughness is uniform across the section. Channel subdivided at major breaks in geometry. Subdivision for 100-year peak discharge based on ratio of depth of flow in flood plain and maximum depth (fig. 2) where the width of the flood plain is more than five times the maximum depth of flow in the flood plain.

AGUA FRIA RIVER BELOW BUCKEYE ROAD--Continued

Table 17.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .027	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = .003	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .027	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .027	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = .001	
	n_2 = ----	
	n_3 = ----	
	n = .028	

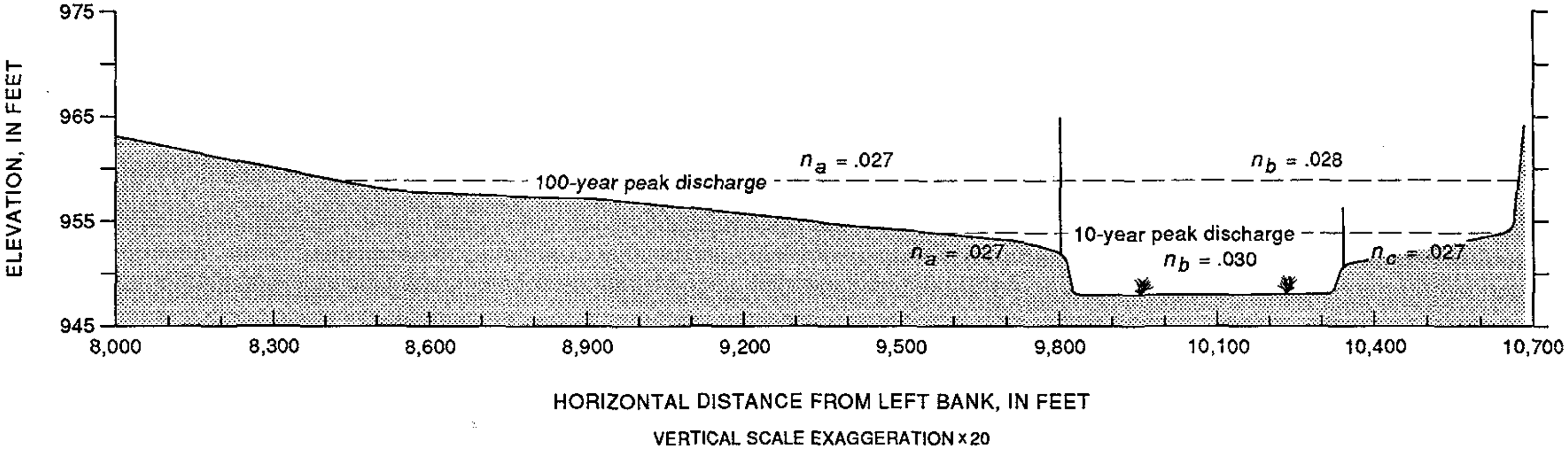


Figure 30.--Cross section of Agua Fria River below Buckeye Road.

A. Looking downstream from bridge on Buckeye Road.

B. Looking upstream from middle of channel. Man is at cross-section station 10,100 feet.

Figure 31.--Agua Fria River below Buckeye Road.

C. Looking upstream along left bank. Man is at cross-section station 10,250 feet.

D. Looking upstream along right bank.

Figure 31.--Agua Fria River below Buckeye Road--Continued.

E. Soil cement on right bank.

F. Typical bed material.

Figure 31.--Agua Fria River below Buckeye Road--Continued.

WATERMAN WASH ABOVE RAINBOW VALLEY ROAD

Location of cross section: 800 ft upstream from bridge.

Description of channel: Main channel has dikes on either side that are a few feet higher than the flood plains, which are wide cultivated fields. Bed material in main channel is sand. Bed and banks have scattered growth of weeds and saltcedar that are as much as 6 ft tall. All vegetation will be overtopped and flattened by 100-year flow.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided for shape at the edges of the main channel. Main channel might carry the 10-year flood at this section if water does not spill out upstream. Elevations of floodwater were computed on the assumption of a common water level in the main channel and overflow areas.

WATERMAN WASH ABOVE RAINBOW VALLEY ROAD--Continued

Table 18.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = .005	
	n = .030	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

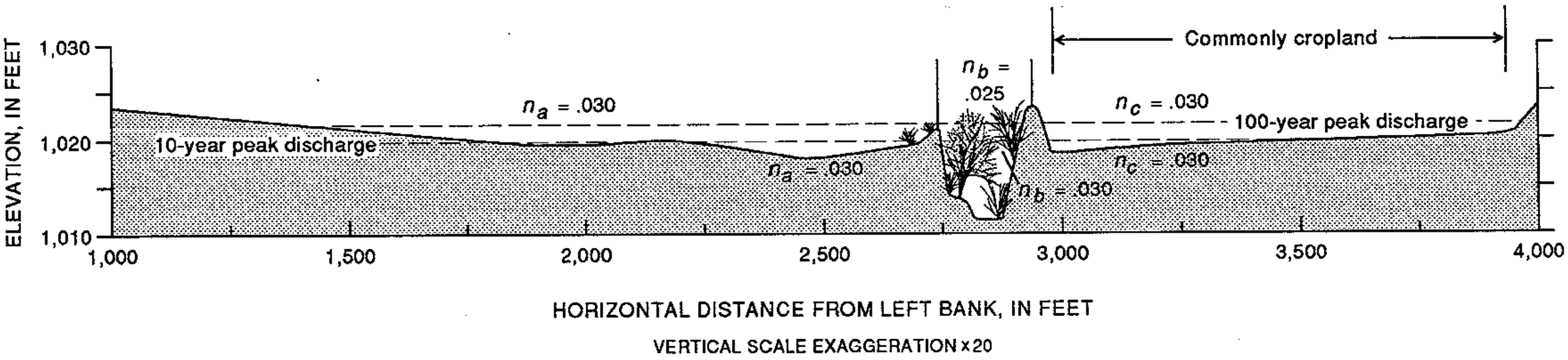


Figure 32.--Cross section of Waterman Wash above Rainbow Valley Road.

A. Looking downstream at cross section from left bank.

B. Looking downstream at middle of main channel.

Figure 33.--Waterman Wash above Rainbow Valley Road.

C. Looking downstream along left bank.

D. Closeup view of vegetation and bed material in main channel.

Figure 33.--Waterman Wash above Rainbow Valley Road--Continued.

E. Looking at left overflow area from left bank of main channel.

F. Looking at right bank overflow area from right bank of main channel.

Figure 33.--Waterman Wash above Rainbow Valley Road--Continued.

G. Closeup of bed material.

Figure 33.--Waterman Wash above Rainbow Valley Road--Continued.

WATERMAN WASH ABOVE EAGLE MOUNTAIN ROAD

Location of cross section: 700 ft upstream from roadway.

Description of channel: Bed material in main channel is mainly sand. Bed is uneven and has an occasional small bush. Banks contain brush and trees. The flood plain on the right is roadway and cultivated field. Flood plain on left has trees near the main channel and scattered brush in the rest of the area.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided on the basis of shape to separate the main channel from overflow areas. Composite *n* values were computed for overflow areas to account for distinct differences in roughness characteristics. Cultivated field was evaluated without crop. Field with mature cotton *shown in figure 35H* would allow storage of floodwater but would convey little unless plants were overtopped. Weighting of *n* for portions of subsections done on basis of wetted perimeter.

WATERMAN WASH ABOVE EAGLE MOUNTAIN ROAD--Continued

Table 19.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .002		
		n_3 = .006		
		n = .033		

Subsection B

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_3 = .030		
.15	x	n = .060	=	.009
		n_b = .025		
		n_1 = .003		
		n_3 = .015		
.85	x	n = .030	=	.026
1.00				.035

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_3 = .020		
.65	x	n = .050	=	.032
		n_b = .025		
		n_1 = .010		
		n_2 = ----		
		n_3 = .045		
.35	x	n = .080	=	.028
1.00				.060

Subsection B

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .002		
		n_3 = .006		
		n = .033		

Subsection C

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_3 = .030		
.15	x	n = .060	=	.009
		n_b = .025		
.85	x	n = .025	=	.021
1.00				.030

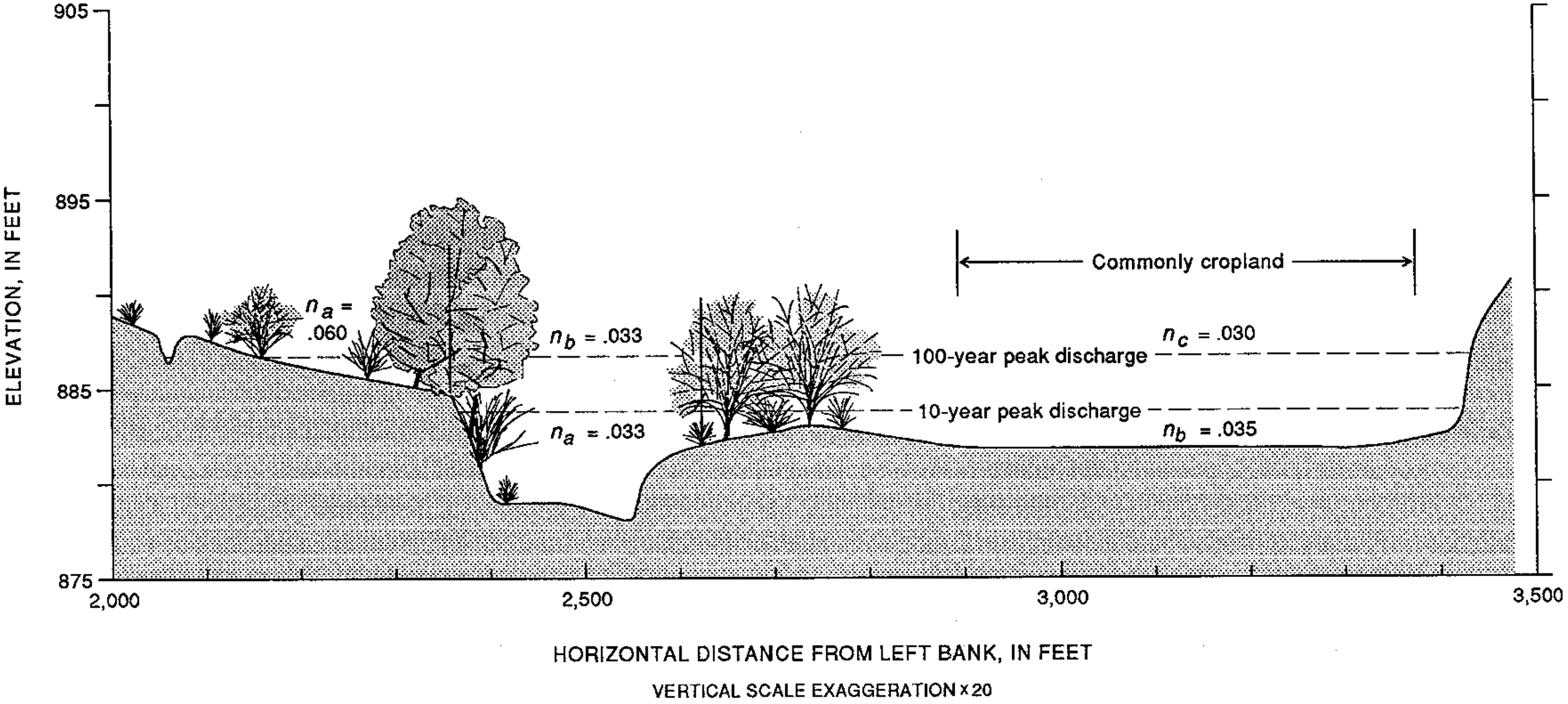


Figure 34.--Cross section of Waterman Wash above Eagle Mountain Road.

A. Looking downstream at cross section from right bank of main channel.

B. Typical bed material in main channel.

Figure 35.--Waterman Wash above Eagle Mountain Road.

C. Looking downstream along left bank of main channel.

D. Looking downstream along right bank of main channel.

Figure 35.--Waterman Wash above Eagle Mountain Road--Continued.

E. Looking upstream along left overflow area. Trees at left are near main channel.

F. Looking downstream along outer edge of left overflow area.

Figure 35.--Waterman Wash above Eagle Mountain Road--Continued.

G. Looking downstream at roadway that is between main channel and field on right overflow area.

H. Looking across at cotton field on right overflow area.

Figure 35.--Waterman Wash above Eagle Mountain Road--Continued.

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UNITED STATES
DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary

BUREAU OF RECLAMATION
Michael W. Straus, Commissioner

REGION 3
E. G. Nielsen, Regional Director

REPORT
ON
WATER SUPPLY
OF THE
LOWER COLORADO RIVER BASIN

PROJECT PLANNING REPORT

NOVEMBER 1952

Table 22 (Continued)

Sheet 5 of 11

LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Historic Runoff

For the 1914-1945 Period

Unit: 1,000 Acre-feet

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM GAGE NEAR VIRDEN, NEW MEXICO, TO NEW MEXICO-ARIZONA STATE LINE									
Gila River below Blue Creek, near Virden	77	0	0	0	155.0	0	0	0	155.0
Estimated inflow, Virden to State line	78	0	0	0	4.9	0	0	0	4.9
Consumptive use, Virden to State line	79	0	0	0	4.7	0	0	0	4.7
Volumes conveyed, Virden to State line	80	0	0	0	155.2	0	0	0	155.2
Channel losses, Virden to State line	81	0	0	0	$ 2.9	0	0	0	2.9
Gila River at New Mex.-Ariz. State line	82	0	0	0	152.3	0	0	0	152.3
GILA RIVER FROM NEW MEXICO-ARIZONA STATE LINE TO GAGE NEAR CLIFTON, ARIZONA									
Estimated inflow, State line to Clifton	83	17.7	0	0	4.9	0	0	0	22.6
Consumptive use, State line to Clifton	84	9.0	0	0	0	0	0	0	9.0
Volumes conveyed, State line to Clifton	85	8.7	0	0	157.2	0	0	0	165.9
Channel losses, State line to Clifton	86	$ .3	0	0	¢ 5.0	0	0	0	5.3
Gila River near Clifton, Arizona	87	8.4	0	0	152.2	0	0	0	160.6
SAN FRANCISCO RIVER FROM GAGE NEAR GLENWOOD, NEW MEXICO, TO NEW MEXICO-ARIZONA STATE LINE									
San Francisco River near Glenwood	88	3.7	0	0	61.0	0	0	0	64.7
Estimated inflow, Glenwood to State line	89	0	0	0	10.2	0	0	0	10.2
Volumes conveyed, Glenwood to State line	90	3.7	0	0	71.2	0	0	0	74.9
Channel losses, Glenwood to State line	91	0	0	0	$ .6	0	0	0	.6
San Francisco River at State line	92	3.7	0	0	70.6	0	0	0	74.3
SAN FRANCISCO RIVER FROM NEW MEXICO-ARIZONA STATE LINE TO GAGE AT CLIFTON, ARIZONA									
Estimated inflow, State line to Clifton	93	87.8	0	0	5.8	0	0	0	93.6
Consumptive uses, State line to Clifton	94	5.3	0	0	0	0	0	0	5.3
Volumes conveyed, State line to Clifton	95	86.2	0	0	76.4	0	0	0	162.6 161.4

Table 22 (Continued) Sheet 6 of 11

LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Historic Runoff

For the 1914-1945 Period

Unit: 1,000 acre-feet

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM GAGE NEAR CLIFTON, ARIZONA, TO HEAD OF SAFFORD VALLEY, ARIZONA									
Imported water from Black River	98	.2	0	0	0	0	0	0	.2
Estimated inflow, Clifton to Safford Valley	99	62.9	0	0	0	0	0	0	62.9
Consumptive use, Clifton to Safford Valley	100	5.9	0	0	0	0	0	0	5.9
Volumes conveyed, Clifton to Safford Valley	101	151.2	0	0	228.0	0	0	0	379.2
Channel losses, Clifton to Safford Valley	102	$ .4	0	0	¢ .6	0	0	0	1.0
Gila River at head of Safford Valley, Ariz.	103	150.8	0	0	227.4	0	0	0	378.2
SAN SIMON CREEK FROM NEW MEXICO-ARIZONA STATE LINE TO GAGE NEAR SOLOMON, ARIZONA									
San Simon Creek at New Mex.-Ariz. State line	104	2.1	0	0	1.3	0	0	0	3.4
Estimated inflow, State line to Solomon	105	11.5	0	0	0	0	0	0	11.5
Consumptive use, State line to Solomon	106	1.9	0	0	0	0	0	0	1.9
Volumes conveyed, State line to Solomon	107	11.7	0	0	1.3	0	0	0	13.0
Channel losses, State line to Solomon	108	$ .5	0	0	¢ .1	0	0	0	.6
San Simon Creek near Solomon, Arizona	109	11.2	0	0	1.2	0	0	0	12.4
GILA RIVER FROM HEAD OF SAFFORD VALLEY TO GAGE AT CALVA, ARIZONA									
Estimated inflow, head of valley to Calva	110	20.3	0	0	0	0	0	0	20.3
Reservoir evaporation depletion	111	.2	0	0	0	0	0	0	.2
Consumptive use, head of valley to Calva	112	61.8	0	0	0	0	0	0	61.8
Volumes conveyed, head of valley to Calva	113	120.3	0	0	228.6	0	0	0	348.9
Channel losses, head of valley to Calva	114	$15.8	0	0	¢30.1	0	0	0	45.9
Gila River at Calva, Arizona	115	104.5	0	0	198.5	0	0	0	303.0

Table 22 (Continued) Sheet 7 of 11

LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Historic Runoff

For the 1914-1945 Period

Unit: 1,000 acre-feet

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM CALVA TO GAGE BELOW COOLIDGE DAM, ARIZONA									
San Carlos River near Peridot, Arizona	116	50.5	0	0	0	0	0	0	50.5
Estimated inflow, Calva to Coolidge Dam	117	13.7	0	0	0	0	0	0	13.7
Consumptive use, Calva to Coolidge Dam	118	.4	0	0	0	0	0	0	.4
San Carlos Reservoir evaporation depletion	119	12.2	0	0	0	0	0	0	12.2
Accretion of surface storage in San Carlos Reservoir	120	1.7	0	0	0	0	0	0	1.7
Volumes conveyed, Calva to Coolidge Dam	121	154.4	0	0	198.5	0	0	0	352.9
Channel losses, Calva to Coolidge Dam	122	$ 9.4	0	0	¢12.1	0	0	0	21.5
Gila River below Coolidge Dam, Arizona	123	145.0	0	0	186.4	0	0	0	331.4
SAN PEDRO RIVER FROM GAGE AT PALOMINAS, ARIZONA, TO GAGE AT CHARLESTON, ARIZONA									
San Pedro River at Palominas, Arizona	124	3.9	0	0	0	0	26.1	0	30.0
Estimated inflow, Palominas to Charleston	125	32.6	0	0	0	0	3.6	0	36.2
Consumptive use, Palominas to Charleston	126	.8	0	0	0	0	0	0	.8
Volumes conveyed, Palominas to Charleston	127	35.7	0	0	0	0	29.7	0	65.4
Channel losses, Palominas to Charleston	128	$5.9	0	0	0	0	¢4.9	0	10.8
San Pedro River at Charleston, Arizona	129	29.8	0	0	0	0	24.8	0	54.6
SAN PEDRO RIVER FROM CHARLESTON TO GAGE NEAR MAMMOTH, ARIZONA									
Estimated inflow, Charleston to Mammoth	130	62.3	0	0	0	0	0	0	62.3
Consumptive use, Charleston to Mammoth	131	10.3	0	0	0	0	0	0	10.3
Volumes conveyed, Charleston to Mammoth	132	81.8	0	0	0	0	24.8	0	106.6
Channel losses, Charleston to Mammoth	133	$35.0	0	0	0	0	¢10.6	0	45.6
San Pedro River near Mammoth, Arizona	134	46.8	0	0	0	0	14.2	0	61.0

Table 22 (Continued)
LOWER COLORADO RIVER BASIN
Analysis of Contributions by States Based on Mean Historic Runoff
For the 1914-1945 Period

Sheet 8 of 11

Unit: 1,000 acre-feet

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM COOLIDGE DAM TO GAGE AT KELVIN, ARIZONA									
Estimated inflow, Coolidge Dam to Kelvin	135	75.2	0	0	0	0	0	0	75.2
Consumptive use, Coolidge Dam to Kelvin	136	10.5	0	0	0	0	0	0	10.5
Volumes conveyed, Coolidge Dam to Kelvin	137	256.5	0	0	186.4	0	14.2	0	457.1
Channel losses, Coolidge Dam to Kelvin	138	$15.2	0	0	¢ 5.2	0	¢ 1.8	0	22.2
Gila River at Kelvin, Arizona	139	241.3	0	0	181.2	0	12.4	0	434.9
SANTA CRUZ RIVER FROM GAGE NEAR NOGALES, ARIZONA, TO GAGE AT RILLITO, ARIZONA									
Santa Cruz River near Nogales, Arizona	140	6.6	0	0	0	0	8.6	0	15.2
Water obtained from average depletion of ground-water basin in Santa Cruz and Pima Counties	141	20.8	0	0	0	0	0	0	20.8
Estimated inflow, Nogales to Rillito	142	83.2	0	0	0	0	1.8	0	85.0
Consumptive use, Nogales to Rillito	143	66.6	0	0	0	0	0	0	66.6
Volumes conveyed, Nogales to Rillito	144	44.0	0	0	0	0	10.4	0	54.4
Channel losses, Nogales to Rillito	145	$20.0	0	0	0	0	¢ 4.7	0	24.7
Santa Cruz River at Rillito, Arizona	146	24.0	0	0	0	0	5.7	0	29.7
SALT RIVER FROM ABOVE ROOSEVELT RESERVOIR TO GRANITE REEF DAM, ARIZONA									
Salt River near Roosevelt, Arizona	147	706.5	0	0	0	0	0	0	706.5
Tonto Creek near Roosevelt, Arizona	148	107.9	0	0	0	0	0	0	107.9
Verde River below Bartlett Dam, Arizona	149	522.4	0	0	0	0	0	0	522.4
Estimated inflow to Granite Reef Dam	150	100.2	0	0	0	0	0	0	100.2
Consumptive use, Roosevelt to Granite Reef	151	.3	0	0	0	0	0	0	.3
Export diversions for City of Phoenix	152	10.2	0	0	0	0	0	0	10.2
Reservoir evaporation depletions from	153	27.0	0	0	0	0	0	0	27.0

Table 22 (Continued) Sheet 9 of 11

LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Historic Runoff

For the 1914-1945 Period

Unit: 1,000 acre-feet

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
SALT RIVER FROM ABOVE ROOSEVELT RESERVOIR TO GRANITE REEF DAM, ARIZONA (Continued)									
Accretions of surface storage in Salt River Reservoir system	154	24.6	0	0	0	0	0	0	24.6
Bank storage in Salt River Reservoir system	155	3.6	0	0	0	0	0	0	3.6
Volumes conveyed to Granite Reef Dam	156	1,371.3	0	0	0	0	0	0	1,371.3
Channel losses to Granite Reef Dam	157	$ 39.5	0	0	0	0	0	0	39.5
Salt River at Granite Reef Dam, Arizona	158	1,331.8	0	0	0	0	0	0	1,331.8
GILA RIVER FROM GAGE AT KELVIN TO GILLESPIE DAM, ARIZONA									
Agua Fria River at Lake Pleasant Dam	159	128.3	0	0	0	0	0	0	128.3
Import diversions for City of Phoenix	152	10.2	0	0	0	0	0	0	10.2
Water obtained from average depletion of ground-water basin in this stream section	160	133.6	0	0	0	0	0	0	133.6
Estimated inflow to Gillespie Dam	161	94.7	0	0	0	0	0	0	94.7
Lake Pleasant evaporation depletion	162	2.9	0	0	0	0	0	0	2.9
Accretion of surface storage in Lake Pleasant	163	.4	0	0	0	0	0	0	.4
Picacho Reservoir evaporation depletion	164	8.3	0	0	0	0	0	0	8.3
Consumptive use in this stream section	165	1,071.2	0	0	0	0	0	0	1,071.2
Volumes conveyed to Gillespie Dam	166	881.1	0	0	181.2	0	18.1	0	1,080.4
Channel losses to Gillespie Dam	167	$300.1	0	0	¢ 61.7	0	¢ 6.2	0	368.0
Gila River at Gillespie Dam, Arizona	168	581.0	0	0	119.5	0	11.9	0	712.4
Diversions by Gillespie Canal	169	63.2	0	0	0	0	0	0	63.2
Diversions by Enterprise Canal	170	7.7	0	0	0	0	0	0	7.7
Gila River below Gillespie Dam, Arizona	171	510.1	0	0	119.5	0	11.9	0	641.5

Sheet 10 of 11

Table 22 (Continued)
LOWER COLORADO RIVER BASIN
Analysis of Contributions by States Based on Mean Historic Runoff
For the 1914-1945 Period

Unit: 1,000 acre-feet

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM GILLESPIE DAM TO GAGE NEAR DOME, ARIZONA									
Water obtained from average depletion of ground-water basin in this stream section	172	21.9	0	0	0	0	0	0	21.9
Estimated inflow, Gillespie Dam to Dome	173	29.7	0	0	0	0	.2	0	29.9
Consumptive use, Gillespie Dam to Dome	174	49.4	0	0	0	0	0	0	49.4
Volumes conveyed, Gillespie Dam to Dome	175	583.2	0	0	119.5	0	12.1	0	714.8
Channel losses, Gillespie Dam to Dome	176	$210.4	0	0	¢43.1	0	¢4.4	0	257.9
Gila River near Dome, Arizona	177	372.8	0	0	76.4	0	7.7	0	456.9
COLORADO RIVER FROM GAGE NEAR TOPOCK TO LIMITROPHE SECTION AT INTERNATIONAL BOUNDARY									
Bill Williams River at Planet, Arizona	178	135.2	0	0	0	0	0	0	135.2
Estimated inflow, Topock to Limitrophe Section	179	19.4	12.1	0	0	0	0	0	31.5
Consumptive use, Topock to Limitrophe Section	180	196.0	139.2	0	0	0	0	0	335.2
Transbasin export diversions	181	0	2,432.0	0	0	0	0	0	2,432.0
Reservoir evaporation depletions	182	0	0	0	0	0	0	36.2	36.2
Accretion of surface storage in Havasu Lake	183	0	0	0	0	0	0	21.0	21.0
Bank storage in Havasu Lake	184	0	0	0	0	0	0	2.6	2.6
Volumes conveyed, Topock to Limitrophe Section	185	1,139.8	0	116.2	107.6	183.1	7.7	9,574.5	11,128.9
Channel losses, Topock to Limitrophe Section	186	$ 80.3	0	¢ 8.2	¢ 7.6	¢12.9	¢.6	¢ 674.8	784.4
Historic flow, Colorado River within Limitrophe Section at International Boundary	187	1,059.5	0	108.0	100.0	170.2	7.1	8,899.7	10,344.5

Item No.

69. Item 60 plus Items 61, 62, and 63 minus Items 64, 65, 66, 67, and 68.

70. Estimated channel losses of 121,100 acre-feet a year were prorated among the various contributors on the basis of the respective volumes conveyed as shown in Item 69 (see Table 14, Grand Canyon to Hoover Dam on Colorado River, 79,800 acre-feet; and Littlefield to mouth on Virgin River, 41,300 acre-feet).

71. Item 69 minus Item 70 (see Appendix A, Sheet 19A of Table 6 for total).

72. The total estimated inflow was computed as the differential needed to balance the measured flow of the Colorado River near Topock adjusted for depletions and channel losses in the section. The estimated inflow was prorated among Arizona, California, and Nevada on the basis of the respective drainage areas in each state.

73. Consumptive use of irrigation water by crops and noncropped areas as determined for each state in this river section (see Table 12. A-5-C for Arizona; City of Needles for California; and N-2-C for Nevada).

74. Item 71 plus Item 72 minus Item 73.

75. Estimated channel losses of 383,600 acre-feet a year were prorated among the various contributors on the basis of the respective volumes conveyed as shown in Item 74 (see Table 14 for total).

76. Item 74 minus Item 75 (see Appendix A, Sheet 20A of Table 6 for total).

77. Average annual historical flow of the Gila River at the gage below Blue Creek, near Virden (see Appendix A, Sheet 24 of Table 6); all in New Mexico.

78. The differential needed to balance the measured flow of the Gila River near Clifton, Arizona, when adjusted for stream depletions and channel losses between the two gages, was estimated as 27,500 acre-feet a year. Prorating this quantity on the basis of drainage areas, the contribution of the area in New Mexico between the gage near Virden and the State line was computed to be 4,900 acre-feet a year.

79. Consumptive use of irrigation water by crops and noncropped areas in this stream section (NM-2-G in Table 12); all in New Mexico.

80. Item 77 plus Item 78 minus Item 79.

Item No.

81. Channel losses in this river section (see Table 14); all in New Mexico.

82. Item 80 minus Item 81.

83. As in Item 78, the average annual inflow between the gages near Virden and near Clifton was prorated on the basis of the respective drainage areas. The total estimated inflow between the State line and the Clifton gage was thus computed to be 22,600 acre-feet a year with contributions of 17,700 and 4,900 acre-feet a year from Arizona and New Mexico, respectively.

84. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-1-G in Table 12); all in Arizona.

85. Item 82 plus Item 83 minus Item 84.

86. Estimated channel losses of 5,300 acre feet a year in this river section were prorated between New Mexico and Arizona on the basis of the respective volumes conveyed (see Table 14 for total).

87. Item 85 minus Item 86 (see Appendix A, Sheet 25A of Table 6 for total).

88. Average annual historical flow of the San Francisco River at the gage near Glenwood, New Mexico (see Appendix A, Sheet 26 of Table 6 for total). The flow was prorated between Arizona and New Mexico on the basis of their respective drainage areas with consideration for upstream depletions of 2,400 acre-feet a year in New Mexico.

89. The estimated inflow between the Glenwood gage and the State line was computed by applying the unit runoff rate at the Glenwood gage (adjusted for upstream depletions) to the drainage area in this river section; all in New Mexico.

90. Item 88 plus Item 89.

91. Estimated channel losses of 600 acre-feet a year between the Glenwood gage and the State line were prorated between New Mexico and Arizona on the basis of the respective volumes conveyed (see Table 14 for total). Arizona's proportion was negligible.

92. Item 90 minus Item 91.

Item No.

93. The total estimated inflow for this section was computed as the differential needed to balance the measured flow of the San Francisco River at the gage at Clifton adjusted for depletions and channel losses in the section. This quantity was prorated on the basis of the drainage areas in New Mexico and Arizona contributory to this stream section.

94. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-3-G in Table 12); all in Arizona.

95. Item 92 plus Item 93 minus Item 94.

96. Estimated channel losses of 1,200 acre-feet a year between the State line and the Clifton gage were prorated between New Mexico and Arizona on the basis of the respective volumes conveyed (see Table 14 for total).

97. Item 95 minus Item 96 (see Appendix A, Sheet 27A of Table 6 for total).

98. Importation of water from the Black River, a tributary of the Salt River, began in April 1945 for use in the vicinity of Morenci, Arizona. The average was determined on a 32-year basis (see Appendix A, Sheet 28 of Table 6). The contribution was all from Arizona.

99. The estimated inflow to this river section was computed as the differential needed to balance the measured flow of the Gila River at head of Safford Valley adjusted for depletions and channel losses in the section; all in Arizona.

100. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-4-G in Table 12); all in Arizona.

101. Item 87 plus Items 97, 98, and 99 minus Item 100.

102. Estimated channel losses of 1,000 acre-feet a year in this river section were prorated between New Mexico and Arizona on the basis of the respective volumes conveyed (see Table 14 for total).

103. Item 101 minus Item 102 (see Appendix A, Sheet 29A of Table 6 for total).

Item No.

104. The average historical flow of San Simon Creek at the New Mexico-Arizona State line was estimated by applying the weighted average runoff in acre-feet a square mile of San Simon Creek at Rodeo, New Mexico, and San Simon, Arizona. This average runoff as converted to represent the average for the study period and adjusted for upstream depletions was prorated between New Mexico and Arizona on the basis of the respective drainage areas and the Arizona portion corrected for the stream depletions.

105. Estimated inflow was computed as the differential needed to balance the measured flow of San Simon Creek near Solomon adjusted for depletions and channel losses in the section; all in Arizona.

106. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-6-G in Table 12); all in Arizona.

107. Item 104 plus Item 105 minus Item 106.

108. Estimated channel losses of 600 acre-feet a year in this stream section were prorated between New Mexico and Arizona on the basis of the respective volumes conveyed (see Table 14 for total).

109. Item 107 minus Item 108 (see Appendix A, Sheet 30 of Table 6 for total).

110. The estimated inflow to this stream section was computed as the differential needed to balance the measured flow of the Gila River at Calva adjusted for depletions and channel losses in the section; all in Arizona.

111. Stream depletion by small reservoirs in this section (see Table 8); all in Arizona.

112. Consumptive use of irrigation water by crops and noncropped areas in this river section (see Table 12. A-7-G, Safford Valley, 61,300 acre-feet; plus 500 acre-feet of A-8-G, San Carlos Indian Reservation distributed as upstream from the gage on Gila River at Calva); all in Arizona.

113. Item 103 plus Items 109 and 110 minus Items 111 and 112.

114. The estimated channel losses in this river section were prorated between New Mexico and Arizona on the basis of the respective volumes conveyed (see Table 14 for total).

115. Item 113 minus Item 114 (see Appendix A, Sheet 31A of Table 6 for total).

Item No.

116. Average annual historical flow of the San Carlos River at the gage near Peridot (see Appendix A, Sheet 32 of Table 6); all in Arizona.

117. The estimated inflow to this stream section was computed as the differential needed to balance the measured flow of the Gila River at the gage below Coolidge Dam adjusted for consumptive use by crops and noncropped areas, channel losses, and evaporation depletion and change in storage in San Carlos Reservoir; entire contribution from Arizona.

118. Consumptive use of irrigation water by crops and noncropped areas in this stream section (see A-8-G in Table 12. The total of 1,800 acre-feet for this area was distributed as 500 acre-feet on Gila River upstream from gage at Calva (Item 112), 900 acre-feet on San Carlos River upstream from the gage near Peridot, and 400 acre-feet on San Carlos River downstream from gage near Peridot for this river section item); all in Arizona.

119. Stream depletion by evaporation from San Carlos Reservoir (see Table 8); all in Arizona.

120. Stream depletion by average annual accretion of surface storage in San Carlos Reservoir (see Table 11); all in Arizona.

121. Item 115 plus Items 116 and 117 minus Items 118, 119, and 120.

122. The estimated channel losses of 21,500 acre-feet a year in this section were prorated between New Mexico and Arizona on the basis of the respective volumes conveyed (see Table 14 for total).

123. Item 121 minus Item 122 (see Appendix A, Sheet 33A of Table 6 for total).

124. Average annual historical flow of the San Pedro River at the gage at Palominas, Arizona (see Appendix A, Sheet 34 of Table 6 for total). The flow was prorated between Arizona and Mexico on the basis of their respective drainage areas with consideration for upstream depletions of 1,100 acre-feet a year in Mexico.

125. The total estimated inflow to this stream section was computed as the differential needed to balance the measured flow of the San Pedro River at Charleston adjusted for depletions and channel losses in the section. The total unmeasured inflow was prorated between Arizona and Mexico on the basis of their respective drainage areas

Item No.

126. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-9-G in Table 12); all in Arizona.

127. Item 124 plus Item 125 minus Item 126.

128. Estimated channel losses of 10,800 acre-feet a year were prorated between Arizona and Mexico on the basis of the respective volumes conveyed (see Table 14 for total).

129. Item 127 minus Item 128 (see Appendix A, Sheet 35 of Table 6 for total).

130. The estimated inflow to this stream section was computed as the differential needed to balance the measured flow of the San Pedro River near Mammoth adjusted for depletions and channel losses in the section; all in Arizona.

131. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-10-G in Table 12); all in Arizona.

132. Item 129 plus Item 130 minus Item 131.

133. Estimated channel losses of 45,600 acre-feet a year in this stream section were prorated between Arizona and Mexico on the basis of the respective volumes conveyed (see Table 14 for total).

134. Item 132 minus Item 133 (see Appendix A, Sheet 36 of Table 6 for total).

135. The estimated inflow to this stream section was computed as the differential needed to balance the measured flow of the Gila River at Kelvin adjusted for depletions and channel losses in the section; all in Arizona.

136. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-11-G plus A-12-G in Table 12); all in Arizona.

137. Item 123 plus Items 134 and 135 minus Item 136.

Item No.

138. Estimated channel losses of 22,200 acre-feet a year were prorated among Arizona, New Mexico, and Mexico on the basis of the respective volumes conveyed from Mammoth to the mouth of the San Pedro River and from Coolidge Dam to Kelvin on the Gila River. (See Table 14 for total. San Pedro River from Mammoth to mouth, 9,700 acre-feet plus Gila River from Coolidge Dam to Kelvin, 12,500 acre-feet).

139. Item 137 minus Item 138 (see Appendix A, Sheet 38A of Table 6 for total).

140. Average annual historical flow of the Santa Cruz River at the gage near Nogales, Arizona (see Appendix A, Sheet 39 of Table 6 for total). The flow was prorated between Arizona and Mexico on the basis of their respective drainage areas with consideration for upstream depletions of 600 acre-feet a year in Arizona and 5,400 acre-feet a year in Mexico.

141. It was estimated that the ground water stored in this river section prior to 1914 was depleted an average 20,800 acre-feet a year during the 1914-1945 period (see Upper Santa Cruz River in Table 4).

142. The total estimated inflow to this river section was computed as the differential needed to balance the measured flow of the Santa Cruz River at Rillito adjusted for consumptive use, channel losses, and change in ground-water storage in the section. The contribution from Mexico was estimated by applying the runoff rate of the undepleted flow near Nogales to the drainage area in Mexico in this section. The balance of the total estimated inflow was apportioned to Arizona.

143. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-14-G plus A-15-G in Table 12); all in Arizona.

144. Item 140 plus Items 141 and 142 minus Item 143.

145. The estimated channel losses of 24,700 acre-feet a year in this stream section were prorated between Arizona and Mexico on the basis of the respective volumes conveyed (see Table 14 for total).

146. Item 144 minus Item 145 (see Appendix A, Sheet 42 of Table 6 for total).

147. Average annual historical flow of the Salt River at the gage near Roosevelt (see Appendix A, Sheet 43A of Table 6); all in Arizona.

Item No.

148. Average annual historical flow of Tonto Creek at the gage near Roosevelt (see Appendix A, Sheet 44 of Table 6); all in Arizona.

149. Average annual historical flow of the Verde River below Bartlett Dam (see Appendix A, Sheet 45A of Table 6); all in Arizona.

150. The derivation of the estimated inflow to this section has been described in this report in connection with bank storage in the Salt River Reservoirs in the analyses section discussing stream depletions by reservoirs. All in Arizona.

151. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-24-G in Table 12); all in Arizona.

152. Average annual diversions from the Verde River for use in the City of Phoenix (see Appendix A, Sheet 46 of Table 6).

153. Evaporation depletion by the four reservoirs in the Salt River Reservoir system (see Table 8, Roosevelt Lake, 21,400 acre-feet; Apache Lake, 3,500 acre-feet; Canyon Lake, 1,300 acre-feet; and Sahuaro Lake, 800 acre-feet); all in Arizona.

154. Stream depletion by the average annual accretion of surface storage in the Salt River Reservoir system (see Table 11); all in Arizona.

155. Stream depletion by the average annual accretion of bank storage in the Salt River Reservoir system (see Table 11); all in Arizona.

156. Items 147 plus Items 148, 149, and 150 minus Items 151, 152, 153, 154, and 155.

157. Channel losses in this stream section were all in Arizona. (See Table 14. Verde River from Bartlett Dam to mouth, 7,900 acre-feet plus Salt River from above Roosevelt Lake to Granite Reef Dam, 31,600 acre-feet).

158. Item 156 minus Item 157 (see Appendix A, Sheet 47A of Table 6).

159. Average annual historical flow of the Agua Fria River into Lake Pleasant (see Appendix A, Sheet 50 of Table 6); all in Arizona.

Item No.

160. It was estimated that the ground water stored in this river section prior to 1914 was depleted an average 133,600 acre-feet a year during the 1914-1945 period (see Table 4, Pinal County and Maricopa County upstream from Gillespie Dam).

161. The estimated inflow to this river section was computed as the differential needed to balance the measured flow of the Gila River at Gillespie Dam adjusted for consumptive use, channel losses, reservoir depletions, ground-water depletions, and the water imported for use in Phoenix. All in Arizona.

162. Evaporation depletion by Lake Pleasant (see Table 8); all in Arizona.

163. Stream depletion by the average annual accretion of surface storage in Lake Pleasant (see Table 11); all in Arizona.

164. Stream depletion by Picacho Reservoir in Pinal County (see Table 8); all in Arizona.

165. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-16-G plus A-26-G in Table 12); all in Arizona.

166. Item 139 plus Items 146, 158, 159, 152, 160 and 161 minus Items 162, 163, 164, and 165.

167. The estimated channel losses of 368,000 acre-feet a year in this stream system were prorated among Arizona, New Mexico, and Mexico on the basis of the respective volumes conveyed (see Table 14 for total).

168. Item 166 minus Item 167.

169. Average annual diversions by Gillespie Canal during the 1914-1945 period for use downstream (see Appendix A, Sheet 51 of Table 6).

170. Average annual diversions by Enterprise Canal during the 1914-1945 period for use downstream (see Appendix A, Sheet 52 of Table 6).

171. Item 168 minus Items 169 and 170. This is the average annual historical flow of the Gila River at the gage below Gillespie Dam (see Appendix A, Sheet 53A of Table 6 for total).

172. It was estimated that the ground water stored in this river section prior to 1914 was depleted an average 21,900 acre-feet a year during the 1914-1945 period (see Table 4, Gillespie Dam to Dome).

Item No.

173. The estimated inflow to this river section was computed as the differential needed to balance the measured flow of the Gila River near Dome adjusted for consumptive use, channel losses, and change in ground-water storage in this section. The unmeasured inflow was prorated between Arizona and Mexico on the basis of their respective drainage areas.

174. Consumptive use of irrigation water by crops and noncropped areas in this stream section (A-27-G in Table 12); all in Arizona.

175. Item 168 plus Items 172 and 173 minus Item 174.

176. Estimated channel losses of 257,900 acre-feet a year in this river section were prorated among Arizona, New Mexico, and Mexico on the basis of the respective volumes conveyed (see Table 14 for total).

177. Item 175 minus Item 176 (see Appendix A, Sheet 54A of Table 6 for total).

178. Average annual historical flow of the Bill Williams River at the gage at Planet (see Appendix A, Sheet 21 of Table 6); all in Arizona.

179. The total estimated inflow to this river section was computed as the differential needed to balance the historical flow of the Colorado River within the Limitrophe Section at the International Boundary adjusted for consumptive use, channel losses, reservoir depletions, and transbasin exports in the section. The derivation of the historic flow of the Colorado River within the Limitrophe Section is described under Items 188 through 192. The unmeasured inflow was prorated between Arizona and California on the basis of their respective drainage areas.

180. Consumptive use of irrigation water by crops and noncropped areas as determined for each state in this stream section. (See Tables 12 and 13. For Arizona: the sum of A-6-C, A-7-C, A-8-C, and A-9-C in Table 12 plus 100 acre-feet for Arizona's share of All-American Canal depletions as discussed in footnote 2/to Table 13. For California: the sum of C-1-C and C-2-C in Table 12 plus 300 acre-feet for California's share of All-American Canal depletions as discussed in footnote 2/ to Table 13).

181. The sum of 1914-1945 average diversions by the Colorado River Aqueduct, All-American Canal, and Alamo Canal system for use in California outside of the natural drainage area of the Colorado River (see Appendix A, Table 6, Sheet 22 for Colorado River Aqueduct, Sheet 59 for All-American below Pilot Knob Wasteway, and Sheet 65A for diversions for use in California by Alamo Canal system).

182. Average annual stream depletions by evaporation at Havasu Lake and the diversion reservoirs at Headgate

Item No.

183. Stream depletion by the average annual accretion of surface storage in Havasu Lake (see Table 11, Havasu Lake); apportioned to undistributed stream flow.

184. Stream depletion by the average annual accretion of bank storage in Havasu Lake (see Table 11, Havasu Lake); apportioned to undistributed stream flow.

185. Item 76 plus Items 177, 178, and 179 minus Items 180, 181, 182, 183, and 184. Computations for California give historic inflow to this section of 14,200 acre-feet annually with depletions by California of 2,571,200 acre-feet a year. The 2,557,000 acre-feet needed to balance the California water account was taken from undistributed stream flow.

186. Channel losses from water surface evaporation and river bottom growth from Topock to the California-Baja California boundary and phreatophytic growth along the Arizona boundary of the Limitrophe Section (see Table 14 for total. Topock to Yuma, 741,900 acre-feet plus Yuma to International Boundary, 42,500 acre-feet). The losses were prorated among the various contributors on the basis of the respective volumes conveyed as shown in Item 185.

187. Item 185 minus Item 186.

188. The record for this constructed station is tabulated on Sheets 72 and 72A of Table 6 in Appendix A. It was prepared by combining the record of the flow of the Colorado River at the Yuma gaging station with records and estimates of downstream return flows by drains and wasteways in the United States and deducting diversions from the Colorado River downstream from Yuma gaging Station for use in the United States.

189. The contribution from the intermediate drainage area in this stream section was estimated by applying the unit rate of runoff determined for the entire river section from Topock to the Limitrophe Section in Item 179. This unit runoff rate has been determined by algebraic solution of the hydrologic equation of the entire section downstream from Topock with consideration for channel losses between Yuma and the International Boundary.

The contribution from the drainage area in Arizona downstream from the California-Baja California boundary was considered to have been included in the measured return flows within the Limitrophe Section.

190. Item 188 plus Item 189.

191. Channel losses from water surface evaporation and river bottom growth from Yuma to the California-Baja California boundary and phreatophytic growth along the Arizona boundary of the Limitrophe Section (see Table 14, Yuma to International Boundary).

Table 23 (Continued)

LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Virgin Runoff for the 1914-1945 Period, Unit: 1,000 Acre-feet

Item numbers not in parentheses are taken from Table 22, based on historic runoff

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
COLORADO RIVER FROM GAGE NEAR GRAND CANYON TO GAGE BELOW HOOVER DAM (Continued)									
Replacement of native vegetation	(77)	1.2	0	15.5	0	0	0	0	16.7
Increased losses from native growth change	(78)	.5	0	.9	0	0	0	0	1.4
Undepleted Colorado River below Hoover Dam	(79)	876.9	0	125.9	38.6	230.2	0	15,504.9	16,776.5
COLORADO RIVER FROM GAGE BELOW HOOVER DAM TO GAGE NEAR TOPOCK, ARIZONA									
Estimated inflow, Hoover Dam to Topock	72	13.4	4.1	8.1	0	0	0	0	25.6
Undepleted volumes conveyed to Topock	(80)	890.3	4.1	134.0	38.6	230.2	0	15,504.9	16,802.1
Historic channel losses	75	23.3	0	3.3	.9	5.3	0	350.8	383.6
Virgin channel losses	(81)	$11.6	0	$ 2.2	¢1.0	¢5.6	0	¢359.3	379.7
Salvage of channel evaporation	(82)	1.1	0	.2	.1	.3	0	19.8	21.5
Replacement of native vegetation	(83)	0	0	.2	0	0	0	0	.2
Increased losses from native growth change	(84)	12.8	11.3	1.5	0	0	0	0	25.6
Undepleted Colorado River near Topock	(85)	878.7	4.1	131.8	37.6	224.6	0	15,145.6	16,422.4
GILA RIVER FROM HEADWATERS IN NEW MEXICO TO NEW MEXICO-ARIZONA STATE LINE									
Consumptive use upstream from Virden	(86)	0	0	0	11.2	0	0	0	11.2
Less replacement of native vegetation	(87)	0	0	0	8.9	0	0	0	8.9
Net depletions upstream from Virden	(88)	0	0	0	2.3	0	0	0	2.3
Gila River below Blue Creek, near Virden	77	0	0	0	155.0	0	0	0	155.0
Undepleted Gila River near Virden	(89)	0	0	0	157.3	0	0	0	157.3
Estimated inflow, Virden to State line	78	0	0	0	4.9	0	0	0	4.9
Undepleted volumes conveyed to State line	(90)	0	0	0	162.2	0	0	0	162.2
Historic channel losses	81	0	0	0	2.9	0	0	0	2.9
Virgin channel losses	(91)	0	0	0	$ 5.8	0	0	0	5.8
Replacement of native vegetation	(92)	0	0	0	2.9	0	0	0	2.9
Undepleted Gila River at New Mex.-Ariz. State line	(93)	0	0	0	156.4	0	0	0	156.4

Sheet 7 of 14

Table 23 (Continued)
LOWER COLORADO RIVER BASIN
Analysis of Contributions by States Based on Mean Virgin Runoff for the 1914-1945 Period, Unit: 1,000 Acre-feet

Item numbers not in parentheses are taken from Table 22, based on historic runoff

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM NEW MEXICO-ARIZONA STATE LINE TO GAGE NEAR CLIFTON, ARIZONA									
Estimated inflow, State line to Clifton	83	17.7	0	0	4.9	0	0	0	22.6
Undepleted volumes conveyed to Clifton	(94)	17.7	0	0	161.3	0	0	0	179.0
Historic channel losses	86	.3	0	0	5.0	0	0	0	5.3
Virgin channel losses	(95)	$ 5.0	0	0	¢ 5.0	0	0	0	10.0
Replacement of native vegetation	(96)	4.3	0	0	0	0	0	0	4.3
Decreased losses from native growth change	(97)	.4	0	0	0	0	0	0	.4
Undepleted Gila River near Clifton	(98)	12.7	0	0	156.3	0	0	0	169.0
SAN FRANCISCO RIVER FROM HEADWATERS TO NEW MEXICO-ARIZONA STATE LINE									
Consumptive use above Glenwood, New Mexico	(99)	0	0	0	4.5	0	0	0	4.5
Reservoir evaporation depletion above Glenwood	(100)	0	0	0	.1	0	0	0	.1
Less replacement of native vegetation	(101)	0	0	0	2.2	0	0	0	2.2
Net depletions upstream from Glenwood	(102)	0	0	0	2.4	0	0	0	2.4
San Francisco River near Glenwood, New Mex.	88	3.7	0	0	61.0	0	0	0	64.7
Undepleted San Francisco River near Glenwood	(103)	3.7	0	0	63.4	0	0	0	67.1
Estimated inflow, Glenwood to State line	89	0	0	0	10.2	0	0	0	10.2
Undepleted volumes conveyed to State line	(104)	3.7	0	0	73.6	0	0	0	77.3
Virgin channel losses	(105)	0	0	0	$ .6	0	0	0	.6
Undepleted San Francisco River at New Mexico-Arizona State line	(106)	3.7	0	0	73.0	0	0	0	76.7

Table 23 (Continued)
LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Virgin Runoff for the 1914-1945 Period, Unit: 1,000 Acre-feet
Item numbers not in parentheses are taken from Table 22, based on historic runoff

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
SAN FRANCISCO RIVER FROM NEW MEXICO-ARIZONA STATE LINE TO GAGE AT CLIFTON, ARIZONA									
Estimated inflow, State line to Clifton	93	87.8	0	0	5.8	0	0	0	93.6
Undepleted volumes conveyed to Clifton	(107)	91.5	0	0	78.8	0	0	0	170.3
Historic channel losses	96	.6	0	0	.6	0	0	0	1.2
Virgin channel losses	(108)	$ .9	0	0	¢ .6	0	0	0	1.5
Replacement of native vegetation	(109)	.3	0	0	0	0	0	0	.3
Undepleted San Francisco River at Clifton	(110)	90.6	0	0	78.2	0	0	0	168.8
GILA RIVER FROM GAGE NEAR CLIFTON, ARIZONA, TO HEAD OF SAFFORD VALLEY, ARIZONA									
Estimated inflow, Clifton to Safford Valley	99	62.9	0	0	0	0	0	0	62.9
Undepleted volumes conveyed, Clifton to head of Safford Valley	(111)	166.2	0	0	234.5	0	0	0	400.7
Historic channel losses	102	0.4	0	0	0.6	0	0	0	1.0
Virgin channel losses	(112)	$ .9	0	0	¢ .6	0	0	0	1.5
Replacement of native vegetation	(113)	.5	0	0	0	0	0	0	.5
Undepleted Gila River at head of Safford Valley, Arizona	(114)	165.3	0	0	233.9	0	0	0	399.2
SAN SIMON CREEK FROM HEADWATERS IN ARIZONA THROUGH NEW MEXICO TO GAGE NEAR SOLOMON, ARIZONA									
Consumptive use upstream from State line	(115)	.1	0	0	0	0	0	0	.1
San Simon Creek at N.Mex.-Ariz.State line	104	2.1	0	0	1.3	0	0	0	3.4
Undepleted San Simon Creek at State line	(116)	2.2	0	0	1.3	0	0	0	3.5
Estimated inflow, State line to Solomon	105	11.5	0	0	0	0	0	0	11.5
Undepleted volumes conveyed to Solomon	(117)	13.7	0	0	1.3	0	0	0	15.0
Virgin channel losses	(118)	$ .5	0	0	¢ .1	0	0	0	.6

Table 23 (Continued)
LOWER COLORADO RIVER BASIN

Sheet 9 of 14

Analysis of Contributions by States Based on Mean Virgin Runoff for the 1914-1945 Period, Unit: 1,000 Acre-feet
Item numbers not in parentheses are taken from Table 22, based on historic runoff

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM HEAD OF SAFFORD VALLEY TO GAGE AT CALVA, ARIZONA									
Estimated inflow, head of valley to Calva	110	20.3	0	0	0	0	0	0	20.3
Undepleted volumes conveyed to Calva	(120)	198.8	0	0	235.1	0	0	0	433.9
Historic channel losses	114	15.8	0	0	30.1	0	0	0	45.9
Virgin channel losses	(121)	$21.3	0	0	¢ 30.1	0	0	0	51.4
Replacement of native vegetation	(122)	3.3	0	0	0	0	0	0	3.3
Decreased losses from native growth change	(123)	2.2	0	0	0	0	0	0	2.2
Undepleted Gila River at Calva, Arizona	(124)	177.5	0	0	205.0	0	0	0	382.5
GILA RIVER FROM CALVA TO GAGE BELOW COOLIDGE DAM, ARIZONA									
Consumptive use on San Carlos River upstream from Peridot	(125)	0.9	0	0	0	0	0	0	0.9
San Carlos River near Peridot, Arizona	116	50.5	0	0	0	0	0	0	50.5
Undepleted San Carlos River near Peridot	(126)	51.4	0	0	0	0	0	0	51.4
Estimated inflow, Calva to Coolidge Dam	117	13.7	0	0	0	0	0	0	13.7
Undepleted volumes conveyed to dam	(127)	242.6	0	0	205.0	0	0	0	447.6
Historic channel losses	122	9.4	0	0	12.1	0	0	0	21.5
Virgin channel losses	(128)	$ 9.7	0	0	¢ 12.1	0	0	0	21.8
Replacement of native vegetation	(129)	.3	0	0	0	0	0	0	.3
Undepleted Gila River below Coolidge Dam	(130)	232.9	0	0	192.9	0	0	0	425.8

Table 23 (Continued)
LOWER COLORADO RIVER BASIN
Analysis of Contributions by States Based on Mean Virgin Runoff for the 1914-1945 Period, Unit: 1,000 Acre-feet

Item numbers not in parentheses are taken from Table 22, based on historic runoff

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM COOLIDGE DAM TO GAGE AT KELVIN, ARIZONA									
Estimated inflow, Coolidge Dam to Kelvin	135	75.2	0	0	0	0	0	0	75.2
Undepleted volumes conveyed to Kelvin	(145)	366.4	0	0	192.9	0	15.3	0	574.6
Historic channel losses	138	15.2	0	0	5.2	0	1.8	0	22.2
Virgin channel losses	(146)	$20.8	0	0	¢ 5.2	0	¢ 1.8	0	27.8
Salvage of channel evaporation	(147)	.1	0	0	0	0	0	0	.1
Replacement of native vegetation	(148)	4.2	0	0	0	0	0	0	4.2
Decreased losses from native growth change	(149)	1.3	0	0	0	0	0	0	1.3
Undepleted Gila River at Kelvin, Arizona	(150)	345.6	0	0	187.7	0	13.5	0	546.8
SANTA CRUZ RIVER FROM HEADWATERS IN ARIZONA THROUGH MEXICO TO GAGE NEAR NOGALES, ARIZONA									
Consumptive use upstream from Nogales	(151)	.8	0	0	0	0	8.2	0	9.0
Less replacement of native vegetation	(152)	.2	0	0	0	0	2.8	0	3.0
Net depletions upstream from Nogales	(153)	.6	0	0	0	0	5.4	0	6.0
Santa Cruz River near Nogales, Arizona	140	6.6	0	0	0	0	8.6	0	15.2
Undepleted Santa Cruz River near Nogales	(154)	7.2	0	0	0	0	14.0	0	21.2
SANTA CRUZ RIVER FROM GAGE NEAR NOGALES TO GAGE AT RILLITO, ARIZONA									
Estimated inflow, Nogales to Rillito	142	83.2	0	0	0	0	1.8	0	85.0
Undepleted volumes conveyed to Rillito	(155)	90.4	0	0	0	0	15.8	0	106.2
Historic channel losses	145	20.0	0	0	0	0	4.7	0	24.7
Virgin channel losses	(156)	$56.4	0	0	0	0	¢ 5.6	0	62.0
Salvage of channel evaporation	(157)	4.5	0	0	0	0	.9	0	5.4
Replacement of native vegetation	(158)	23.6	0	0	0	0	0	0	23.6
Decreased losses from native growth change	(159)	8.3	0	0	0	0	0	0	8.3
Undepleted Santa Cruz River at Rillito	(160)	34.0	0	0	0	0	10.2	0	44.2

Table 23 (Continued)

Sheet 13 of 14

LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Virgin Runoff for the 1914-1945 Period, Unit: 1,000 acre-feet
Item numbers not in parentheses are taken from Table 22, based on historic runoff

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
SALT RIVER FROM HEADWATERS TO GRANITE REEF DAM, ARIZONA (Continued)									
Virgin channel losses	(178)	$ 39.4	0	0	0	0	0	0	39.4
Replacement of native vegetation	(179)	.3	0	0	0	0	0	0	.3
Increased channel evaporation losses	(180)	.2	0	0	0	0	0	0	.2
Increased losses from native growth change	(181)	.2	0	0	0	0	0	0	.2
Undepleted Salt River at Granite Reef Dam	(182)	1,423.8	0	0	0	0	0	0	1,423.8
AGUA FRIA RIVER FROM HEADWATERS TO LAKE PLEASANT, ARIZONA									
Consumptive use above Lake Pleasant	(183)	1.2	0	0	0	0	0	0	1.2
Agua Fria River at Lake Pleasant Dam	159	128.3	0	0	0	0	0	0	128.3
Undepleted Agua Fria River at Lake Pleasant Dam (inflow to lake)	(184)	129.5	0	0	0	0	0	0	129.5
GILA RIVER FROM GAGE AT KELVIN TO GILLESPIE DAM, ARIZONA									
Estimated inflow to Gillespie Dam	161	94.7	0	0	0	0	0	0	94.7
Undepleted volumes conveyed to Gillespie Dam	(185)	2,027.6	0	0	187.7	0	23.7	0	2,239.0
Historic channel losses	167	300.1	0	0	61.7	0	6.2	0	368.0
Virgin channel losses	(186)	$ 376.9	0	0	¢ 63.0	0	¢ 6.3	0	446.2
Salvage of channel evaporation	(187)	10.2	0	0	1.3	0	.1	0	11.6
Replacement of native vegetation	(188)	99.8	0	0	0	0	0	0	99.8
Increased losses from native growth change	(189)	33.2	0	0	0	0	0	0	33.2
Undepleted Gila River at Gillespie Dam	(190)	1,650.7	0	0	124.7	0	17.4	0	1,792.8
GILA RIVER FROM GILLESPIE DAM TO GAGE NEAR DOME, ARIZONA									
Estimated inflow, Gillespie Dam to Dome	173	29.7	0	0	0	0	.2	0	29.9
Undepleted volumes conveyed to Dome	(191)	1,680.4	0	0	124.7	0	17.6	0	1,822.7

Table 23 (Continued)

LOWER COLORADO RIVER BASIN

Analysis of Contributions by States Based on Mean Virgin Runoff for the 1914-1945 Period, Unit: 1,000 Acre-feet
Item numbers not in parentheses are taken from Table 22, based on historic runoff

River section	Item	Arizona	California	Nevada	New Mexico	Utah	Mexico	Undistributed	Total
GILA RIVER FROM GILLESPIE DAM TO GAGE NEAR DOME, ARIZONA (Continued)									
Virgin channel losses	(192)	370.2	0	0	¢ 44.3	0	¢ 4.6	0	419.1
Salvage of channel evaporation	(193)	16.2	0	0	1.2	0	.2	0	17.6
Replacement of native vegetation	(194)	12.9	0	0	0	0	0	0	12.9
Decreased losses from native growth change	(195)	130.7	0	0	0	0	0	0	130.7
Undepleted Gila River near Dome	(196)	1,310.2	0	0	80.4	0	13.0	0	1,403.6
COLORADO RIVER FROM GAGE NEAR TOPOCK TO LIMITROPHE SECTION AT INTERNATIONAL BOUNDARY									
Consumptive use, Bill Williams River	(197)	9.7	0	0	0	0	0	0	9.7
Less replacement of native vegetation	(198)	5.9	0	0	0	0	0	0	5.9
Net depletions, Bill Williams River	(199)	3.8	0	0	0	0	0	0	3.8
Bill Williams River at Planet, Arizona	178	135.2	0	0	0	0	0	0	135.2
Undepleted Bill Williams River at Planet	(200)	139.0	0	0	0	0	0	0	139.0
Estimated inflow, Topock to Limitrophe Section	179	19.4	12.1	0	0	0	0	0	31.5
Undepleted volumes conveyed to Limitrophe Section	(201)	2,347.3	16.2	131.8	118.0	224.6	13.0	15,145.6	17,996.5
Historic channel losses	186	80.3	0	8.2	7.6	12.9	.6	674.8	784.4
Virgin channel losses	(202)	$ 171.3	$ .1	¢ 8.9	¢ 8.1	¢14.2	¢ .6	¢ 820.7	1,023.9
Salvage of channel evaporation	(203)	9.5	.1	.7	.5	1.3	0	85.5	97.6
Replacement of native vegetation	(204)	87.1	65.9	0	0	0	0	0	153.0
Increased losses from native growth change	(205)	5.6	5.5	0	0	0	0	0	11.1
Undepleted Colorado River within Limitrophe Section at International Boundary	(206	2,176.0	16.1	122.9	109.9	210.4	12.4	14,324.9	16,972.6

$. Losses within state.
¢. Losses out of state.

Item No.

(82). The estimated water surface evaporation from the channel in this stream section was 21,500 acre-feet a year less for historical conditions as compared with virgin conditions and this salvage was prorated among the contributors on the basis of the respective volumes conveyed under virgin conditions (see Table 14, Hoover Dam to Topock, for total).

(83). Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14); all in Nevada.

(84). It was estimated that growth changes attributable to the influence of man increased the uses by river bottom growth by 25,600 acre-feet a year as compared with virgin conditions in this stream section (see Table 14). These increased losses were apportioned equally between Arizona on the one side and California and Nevada in their respective boundary sections.

(85). Item (80) minus Item (81).

(86). Consumptive use of irrigation water by crops and noncropped areas in this stream section (NM-1-G in Table 12); all in New Mexico.

(87). Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14, Gila River upstream from Virden); all in New Mexico.

(88). Item (86) minus Item (87).

(89). Item (88) plus Item 77.

(90). Item (89) plus Item 78.

(91). Channel losses were estimated to be 5,800 acre-feet a year in this stream section under virgin conditions (see Table 14, Virden to New Mexico-Arizona State line); all in New Mexico.

(92). Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14, Virden to New Mexico-Arizona State line); all in New Mexico.

(93). Item (90) minus Item (91).

(94) Item (93) plus Item 83

Item No.

(95). Channel losses in this river section were estimated to be 10,000 acre-feet a year under virgin conditions with evaporation from the water surface the same as for historical conditions (see Table 14 for total). Losses apportioned to New Mexico were thus considered the same as for historical conditions and the remainder of the virgin losses were apportioned to Arizona.

(96). Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14); all in Arizona.

(97). It was estimated that growth changes attributable to the influence of man decreased the uses by native vegetation as compared with virgin conditions in this stream section (see Table 14). As these changes occurred in Arizona, the decreased losses of 400 acre-feet a year were credited to Arizona.

(98). Item (94) minus Item (95).

(99). Consumptive use of irrigation water by crops and noncropped areas in this river section (NM-3-G in Table 12); all in New Mexico.

(100). Stream depletion by small reservoirs in this river section (see Table 8); all apportioned to New Mexico.

(101). Uses by native vegetation in cropped and noncropped areas under virgin conditions in this stream section upstream from Glenwood (see Table 14); all in New Mexico.

(102). Item (99) plus Item (100) minus Item (101).

(103). Item (102) plus Item 88.

(104). Item (103) plus Item 89.

(105). It was estimated that channel losses under virgin conditions were the same as under historical conditions for this river section as shown in Item 91 (see Table 14, Glenwood to State line); all in New Mexico.

(106). Item (104) minus Item (105).

Item No.

(107). Item (106) plus Item 93.

(108). Channel losses in this river section were estimated to be 1,500 acre-feet a year under virgin conditions with evaporation from the water surface the same as for historical conditions (see Table 14 for total). Losses apportioned to New Mexico were thus considered to be the same as for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.

(109). Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14); all in Arizona.

(110). Item (107) minus Item (108).

(111). Item (98) plus Items (110) and 99.

(112). Channel losses in this river section were estimated to be 1,500 acre-feet a year under virgin conditions with evaporation from the water surface the same as for historical conditions (see Table 14 for total). Losses apportioned to New Mexico were thus considered to be the same as for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.

(113). Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14); all in Arizona.

(114). Item (111) minus Item (112).

(115). Consumptive use of irrigation water by crops and noncropped areas in this stream section. These depletions are on the headwaters of the San Simon Creek system in Arizona (A-5-G in Table 12). The stream heads in Arizona, curves through a portion of southwestern New Mexico, and then reenters Arizona.

(116). Item (115) plus Item 104.

(117). Item (116) plus Item 105.

Item No.

(118). It was estimated that channel losses under virgin conditions were the same as for historical conditions in this stream section as shown in Item 108 with the same distribution (see Table 14 for total, New Mexico-Arizona State line to Solomon).

(119). Item (117) minus Item (118).

(120). Item (114) plus Items (119) and 110.

(121). Channel losses in this river section under virgin conditions were estimated to be 51,400 acre-feet a year with evaporation from the water surface the same as for historical conditions (see Table 14 for total). Losses apportioned to New Mexico were thus considered to be the same as for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.

(122). Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14); all in Arizona.

(123). It was estimated that growth changes attributable to the influence of man decreased the uses by native vegetation as compared with virgin conditions in this river section (see Table 14). As these changes occurred in Arizona, the decreased losses of 2,200 acre-feet a year were credited to Arizona.

(124). Item (120) minus Item (121).

(125). Consumptive use of irrigation water by crops and noncropped areas in this stream section; all in Arizona. (See A-8-G in Table 12. As discussed in the notes for Item 118 of Table 22, the total of 1,800 acre-feet for this area was distributed as 500 acre-feet on Gila River upstream from gage at Calva (Item 112), 400 acre-feet on San Carlos River downstream from gage near Peridot (Item 118), and 900 acre feet for this river section on San Carlos River upstream from gage near Peridot.)

(126). Item (125) plus Item 116.

(127). Item (124) plus Items (126) and 117.

(128). Channel losses in this river section were estimated to be 21,800 acre-feet a year under virgin conditions with evaporation from the water surface the same as for historical conditions (see Table 14 for total). Losses apportioned to New Mexico were considered the same as for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.

Item No.	
(129).	Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14); all in Arizona.
(130).	Item (127) minus Item (128).
(131).	Consumptive use of irrigation water by crops and noncropped areas in this stream section (M-1-G in Table 12); all in Mexico.
(132).	Uses by native vegetation in cropped and noncropped areas in this stream section under virgin conditions (see Table 14, San Pedro River in Mexico); all in Mexico.
(133).	Item (131) minus Item (132).
(134).	Item (133) plus Item 124.
(135).	Item (134) plus Item 125.
(136).	Channel losses in this river section were estimated to be 11,700 acre-feet a year under virgin conditions with evaporation from the water surface the same as for historical conditions (see Table 14, Palominas to Charleston for total). Losses apportioned to Mexico were thus considered the same as for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.
(137).	Uses by native vegetation in cropped and noncropped areas between Palominas and Charleston under virgin conditions (see Table 14); all in Arizona.
(138).	It was estimated that growth changes attributable to the influence of man decreased the uses by native vegetation between Palominas and Charleston as compared with virgin conditions (see Table 14). As these changes occurred in Arizona, the decreased losses of 300 acre-feet a year were credited to Arizona.
(139).	Item (135) minus Item (136).
(140).	Item (139) plus Item 130.

Item No.

(141). Channel losses in this river section were estimated to be 44,300 acre-feet a year under virgin conditions with evaporation from the water surface the same as for historical conditions (see Table 14 for total). Losses apportioned to Mexico were thus considered the same as for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.

(142). Uses by native vegetation in cropped and noncropped areas under virgin conditions in this river section (see Table 14); all in Arizona.

(143). It was estimated that growth changes attributable to the influence of man increased the uses by native vegetation in this river section as compared with virgin conditions (see Table 14). As these changes occurred in Arizona, the increased losses of 5,900 acre-feet a year were charged to Arizona.

(144). Item (140) minus Item (141).

(145). Item (130) plus Items (144) and 135.

(146). Channel losses in this river section were estimated to be 27,800 acre-feet a year under virgin conditions. (See Table 14: San Pedro River from Mammoth to mouth, 13,500 acre-feet plus Gila River from Coolidge Dam to Kelvin, 14,300 acre-feet.) The estimated water surface evaporation from the channel was 100 acre-feet a year less for historical conditions as compared with virgin conditions and the salvage was credited to Arizona on the basis of proportional volumes conveyed. Virgin losses in this stream section apportioned to Mexico and New Mexico were thus considered the same as for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.

(147). This salvage was discussed under Item (146) (see Table 14, Gila River from Coolidge Dam to Kelvin).

(148). Uses by native vegetation in cropped and noncropped areas in this river section under virgin conditions (see Table 14: San Pedro River from Mammoth to mouth, 2,100 acre-feet plus Gila River from Coolidge Dam to Kelvin, 2,100 acre-feet); all in Arizona.

(149). It was estimated that growth changes attributable to the influence of man decreased the uses by native vegetation in this stream section as compared with virgin conditions. (See Table 14: San Pedro River from Mammoth to mouth, decreased losses of 1,700 acre-feet; Gila River from Coolidge Dam to Kelvin, increased losses of 400 acre-feet; net decreased losses for this river section are thus 1,300 acre-feet.) As these changes occurred in Arizona, the decreased channel losses of 1,300 acre-feet a year were credited to Arizona.

Item No.

(150). Item (145) minus Item (146).

(151). Consumptive use of irrigation water by crops and noncropped areas in Arizona and Mexico in this stream section (see Table 12, San Rafael Ranch in Arizona, A-13-G, and Santa Cruz River in Mexico, M-2-G). The Santa Cruz River heads in Arizona, curves through northern Sonora, Mexico, and re-enters Arizona near Nogales.

(152). Uses by native vegetation in cropped and noncropped areas in Arizona and Mexico in this river section under virgin conditions (see Table 14, Santa Cruz River upstream from Nogales gage).

(153). Item (151) minus Item (152).

(154). Item (153) plus Item 140.

(155). Item (154) plus Item 142.

(156). Channel losses in this river section were estimated to be 62,000 acre-feet a year under virgin conditions (see Table 14 for total). The estimated water surface evaporation from the channel was 5,400 acre-feet a year less for historical conditions as compared with virgin conditions and the salvage was credited as 4,500 acre-feet to Arizona and 900 acre-feet to Mexico on the basis of the respective undepleted volumes conveyed. Virgin channel losses apportioned to Mexico were considered as 900 acre-feet a year greater than for historical conditions or 5,600 acre-feet a year and the remainder of the virgin channel losses were apportioned to Arizona.

(157). This salvage was discussed under Item (156) (see Table 14 for total).

(158). Uses by native vegetation in cropped and noncropped areas in this river section under virgin conditions (see Table 14); all in Arizona.

(159). It was estimated that growth changes attributable to the influence of man decreased the uses by native vegetation in this stream section as compared with virgin conditions (see Table 14). As these changes occurred in Arizona, the decreased channel losses of 8,300 acre-feet a year were credited to Arizona.

Item No.

(160). Item (155) minus Item (156).

(161). Consumptive use of irrigation water by crops and noncropped areas upstream from the gage on the Salt River near Roosevelt (see Table 12, the sum of A-17-G, A-18-G, A-19-G, and A-20-G); all in Arizona.

(162). Stream depletion by small reservoirs upstream from the gage on the Salt River near Roosevelt (see Table 8, Upper Salt River small reservoirs); all in Arizona.

(163). Uses by native vegetation in the cropped and noncropped areas upstream from the gage on the Salt River near Roosevelt under virgin conditions (see Table 14, Salt River above Roosevelt gage); all in Arizona.

(164). Item (161) plus Items (162) and 98 minus Item (163).

(165). Item (164) plus Item 147.

(166). Consumptive use of irrigation water by crops and noncropped areas upstream from the gage on Tonto Creek near Roosevelt (A-21-G in Table 12); all in Arizona.

(167). Uses by native vegetation in the cropped and noncropped areas upstream from the gage on Tonto Creek near Roosevelt under virgin conditions (see Table 14, Tonto Creek above Roosevelt gage); all in Arizona.

(168). Item (166) minus Item (167).

(169). Item (168) plus Item 148.

(170). Consumptive use of irrigation water by crops and noncropped areas upstream from the gage on the Verde River below Bartlett Dam (A-22-G plus A-23-G in Table 12); all in Arizona.

(171). Stream depletion by small reservoirs upstream from the gage on the Verde River below Bartlett Dam (see Table 8, Upper Verde River small reservoirs); all in Arizona.

Item No.

(172). Average annual evaporation depletion by Bartlett Reservoir (See Table 8); all in Arizona.

(173). Stream depletion by the average annual accretion of surface storage in Bartlett Reservoir (see Table 11); all in Arizona.

(174). Uses by native vegetation in the cropped and noncropped areas upstream from the gage on the Verde River below Bartlett Dam under virgin conditions (see Table 14, Verde River above Bartlett Dam); all in Arizona.

(175). Item (170) plus Items (171), (172), and (173) minus Item (174).

(176). Item (175) plus Item 149.

(177). Item (165) plus Items (169), (176), and 150.

(178). Channel losses in this river section were estimated to be 39,400 acre-feet a year under virgin conditions (see Table 14, Verde River from Bartlett Dam to mouth, 8,600 acre-feet plus Salt River from above Roosevelt Lake to Granite Reef Dam, 30,800 acre-feet); all in Arizona.

(179). Uses by native vegetation in the cropped and noncropped areas between the upstream gages and Granite Reef Dam under virgin conditions (see Table 14, Verde River from Bartlett Dam to mouth); all in Arizona.

(180). It was estimated that water surface evaporation from the channel in this river section was 200 acre-feet a year more for historical conditions as compared with virgin conditions. (See Table 14: Verde River from Bartlett Dam to mouth, decreased losses of 400 acre-feet; Salt River from above Roosevelt Lake to Granite Reef Dam, increased losses of 600 acre-feet; net increased losses for this river section are thus 200 acre-feet.) The increase was caused by the pool above Granite Reef Diversion Dam. The increased losses were charged to Arizona.

(181). It was estimated that growth changes attributable to the influence of man increased the uses by native vegetation in this river section as compared with virgin conditions (see Table 14, Salt River from above Roosevelt Lake to Granite Reef Dam). As these changes occurred in Arizona, the increased channel losses of 200 acre-feet a year were charged to Arizona.

Item No.

(182). Item (177) minus (178).

(183). Consumptive use of irrigation water by crops and noncropped areas in the Agua Fria River Basin upstream from Lake Pleasant (A-25-G in Table 12).

(184). Item (183) plus Item 159. Rillito Granite Reef Lake Pleasant
Kelvin

(185). Item (150) plus Items (160), (182), (184), and 161.

(186). Channel losses in this river section were estimated to be 446,200 acre-feet a year under virgin conditions (see Table 14 for total). The estimated water surface evaporation from the channel was 11,600 acre-feet a year less for historical conditions as compared with virgin conditions and the salvage was credited as 10,200 acre-feet to Arizona, 1,300 acre-feet to New Mexico, and 100 acre-feet to Mexico on the basis of the respective undepleted volumes conveyed. Virgin channel losses apportioned to Mexico were considered as 100 acre-feet a year greater than for historical conditions or 6,300 acre-feet a year, those for New Mexico were considered as 1,300 acre-feet a year greater than for historical conditions or 63,000 acre-feet a year, and the remainder of the virgin channel losses were apportioned to Arizona.

(187). This salvage has been discussed under Item (186) (see Table 14 for total).

(188). Uses by native vegetation in cropped and noncropped areas in this river section under virgin conditions (see Table 14); all in Arizona.

(189). It was estimated that growth changes attributable to the influence of man increased the uses by native vegetation in this river section as compared with virgin conditions (see Table 14). As these changes occurred in Arizona, the increased channel losses of 33,200 acre-feet a year were charged to Arizona.

(190). Item (185) minus Item (186).

(191). Item (190) plus Item 173.

Item No.

(192). Channel losses in this river section were estimated to be 419,100 acre-feet a year under virgin conditions (see Table 14 for total). The estimated water surface evaporation from the channel was 17,600 acre-feet a year less for historical conditions as compared with virgin conditions and the salvage was credited as 16,200 acre-feet to Arizona, 1,200 acre-feet to New Mexico, and 200 acre-feet to Mexico on the basis of the respective undepleted volumes conveyed. Virgin channel losses apportioned to Mexico were considered as 200 acre-feet a year greater than for historical conditions, those for New Mexico were 1,200 acre-feet a year greater than for historical conditions and the remainder of the virgin channel losses were apportioned to Arizona.

(193). This salvage was discussed under Item (192) (see Table 14 for total).

(194). Uses by native vegetation in the cropped and noncropped areas in this river section under virgin conditions (see Table 14); all in Arizona.

(195). It was estimated that growth changes attributable to the influence of man decreased the uses by native vegetation in this river section as compared with virgin conditions (see Table 14). As these changes occurred in Arizona, the decreased channel losses of 130,700 acre-feet a year were credited to Arizona.

(196). Item (191) minus Item (192).

(197). Consumptive use of irrigation water by crops and noncropped areas upstream from the gage on the Bill Williams River at Planet (A-1-BW plus A-2-BW in Table 12); all in Arizona.

(198). Uses by native vegetation in the cropped and noncropped areas upstream from the gage on the Bill Williams River at Planet under virgin conditions (see Table 14, Big Sandy River, 3,700 acre-feet plus Santa Maria River, 2,200 acre-feet); all in Arizona.

(199). Item (197) minus Item (198).

(200). Item (199) plus Item 178.

(201). Item (85) plus Items (196), (200), and 179.

Table 7 - Summary of estimates of normal consumptive use of water rates for irrigated crops for areas in the Lower Colorado River Basin (Continued).

Unit: No.	Unit: Area and crops	Growing period	Consumptive use: Factor (F)	Consumptive use: Coefficient (K)	Consumptive use: Use rate (U)	Effective precipitation 1/ (R)	(U-R)
		Dates			Inches	Inches	Inches
	ARIZONA (Continued)						
	Pima County (Continued)						
	Deciduous fruits	3/19-11/17	53.12	0.65	34.53	6.27	28.26
	Lettuce--fall	9/1-11/30	16.17	.65	10.51	2.31	8.20
	Lettuce--spring	11/1-3/31	19.74	.65	12.83	4.52	8.31
	Melons	4/1-7/31	28.89	.65	18.78	1.84	16.94
	Misc. hay & pasture	3/19-11/17	53.12	.80	42.50	6.27	36.23
	Misc. hay & pasture	11/18-3/18	15.41	.60	9.25	3.70	5.55
	Miscellaneous truck	8/15-3/31	36.11	.70	25.28	7.14	18.14
	Potatoes--white	4/1-6/30	20.44	.70	14.31	0	14.31
	Small grains	3/1-6/10	20.03	.70	14.02	.73	13.29
	Small grains	10/15-5/31	35.33	.70	24.73	4.52	20.21
	Sorghums	6/15-9/30	27.08	.70	18.96	5.45	13.51
A-16-G	Pinal County--Gila and Santa Cruz Rivers 7/						
	Alfalfa 8/	3/10-11/19	45.25	.85	38.46	2.74	35.72
	Alfalfa	11/20-3/9	13.83	.60	8.30	3.45	4.85
	Beans	4/1-6/30	21.22	.60	12.73	0	12.73
	Carrots--fall	8/1-12/31	28.38	.70	19.87	4.46	15.41
	Carrots--spring	11/1-6/30	41.16	.70	28.81	4.48	24.33
	Corn	6/15-10/15	31.06	.75	23.30	3.75	19.55
	Cotton	4/1-10/31	50.82	.62	31.51	3.75	27.76
	Dates	1/1-12/31	70.76	.65	45.99	8.23	37.76
	Deciduous fruits	3/10-11/19	56.93	.65	37.00	4.78	32.22
	Flax	10/1-6/30	46.73	.80	37.38	4.48	32.90
	Grapes	3/10-11/19	56.93	.60	34.16	4.78	29.38

Table 7 - Summary of estimates of normal consumptive use of water rates for irrigated crops for areas in the Lower Colorado River Basin (Continued).

Unit No.	Unit Area and crops	Growing period	Consumptive use Factor (F)	Consumptive use Coefficient (K)	Consumptive use Use rate (U)	Effective precipitation 1/ (R)	(U-R)
		Dates			Inches	Inches	Inches
	ARIZONA (Continued)						
	Pinal County (Continued) 7/						
	Lettuce--fall	9/1-11/31	16.58	0.65	10.78	1.69	9.09
	Lettuce--spring	11/1-3/31	19.94	.65	12.96	4.48	8.48
	Melons	3/10-7/31	33.63	.65	21.86	1.84	20.02
	Misc. hay & pasture	3/10-11/19	56.93	.80	45.54	4.78	40.76
	Misc. hay & pasture	11/20-3/9	13.83	.60	8.30	3.45	4.85
	Miscellaneous truck	8/15-3/31	32.41	.70	22.69	6.21	16.48
	Potatoes--sweet	3/10-11/19	56.93	.70	39.85	4.78	35.07
	Potatoes--white	3/1-5/31	18.05	.70	12.64	.79	11.85
	4 Small grains	10/1-4/30	31.35	.70	21.95	4.48	17.47
	Small grains	12/1-4/30	21.67	.70	15.17	3.74	11.43
	4 Sorghums	7/1-10/31	29.60	.70	20.72	3.75	16.97
	Tomatoes	3/10-7/10	27.60	.75	20.70	.97	19.73
A-17-G	Black River--Upper Salt River						
	Misc. hay & pasture	5/20-10/11	28.68	.75	21.51	12.09	9.42
	Misc. hay & pasture	3/16-5/19 & 10/12-11/14	12.59	.60	7.55	4.09	3.46
	Small grains	5/1-7/31	18.79	.70	13.15	5.68	7.47
A-18-G	Fort Apache Indian Reservation--Upper Salt River						
	Alfalfa	5/4-10/16	33.82	.85	28.75	8.04	20.71
	Alfalfa	3/7-5/3 & 10/17-11/10	11.45	.70	8.01	3.07	4.94
	Beans	5/15-8/15	20.42	.60	12.25	4.15	8.10
	Corn	6/1-9/30	26.24	.70	18.37	7.51	10.86

Table 8. Summary of estimates of normal consumptive use of water rates for native vegetation and incidental areas in the Lower Colorado River Basin (Continued).

Area and type 1/	Period 2/	Volume density 3/	K 100% volume density	Consumptive use			Effective precipitation 4/ (R)
				Factor (F)	Coefficient (K)	Use rate (U)	
	Dates	Percent				Inches	Inches
ARIZONA (Continued)							
Bartlett Reservoir							
Cottonwood	1/1-12/31	50	1.15	71.03	0.58	41.20	13.52
Mesquite	1/1-12/31	56	.65	71.03	.36	25.57	13.52
Bartlett Dam to mouth of Verde River							
Cottonwood	1/1-12/31	50	1.15	71.03	.58	41.20	13.52
Mesquite	1/1-12/31	47	.65	71.03	.31	22.02	13.52
Lake Pleasant (Agua Fria River)							
Mesquite	1/1-12/31	38	.65	70.63	.25	17.66	7.03
Maricopa County upstream from Gillespie Dam							
Salt cedar	1/1-12/31	75	1.40	70.11	1.05	73.62	7.41
Salt cedar	1/1-12/31	56	1.40	70.11	.78	54.69	7.41
Salt cedar	1/1-12/31	50	1.40	70.11	.70	49.08	7.41
Salt cedar	1/1-12/31	38	1.40	70.11	.53	37.16	7.41
Salt cedar	1/1-12/31	25	1.40	70.11	.35	24.54	7.41
Salt cedar	1/1-12/31	19	1.40	70.11	.27	18.93	7.41
Cottonwood	1/1-12/31	75	1.15	70.11	.86	60.29	7.41
Cottonwood	1/1-12/31	50	1.15	70.11	.58	40.66	7.41
Cottonwood	1/1-12/31	25	1.15	70.11	.29	20.33	7.41
Baccharis	1/1-12/31	50	.90	70.11	.45	31.55	7.41
Baccharis	1/1-12/31	38	.90	70.11	.34	23.84	7.41
Baccharis	1/1-12/31	25	.90	70.11	.22	15.42	7.41
Baccharis	1/1-12/31	12	.90	70.11	.11	7.71	7.41
Mesquite	1/1-12/31	75	.65	70.11	.49	34.35	7.41
Mesquite	1/1-12/31	56	.65	70.11	.36	25.24	7.41
Mesquite	1/1-12/31	38	.65	70.11	.25	17.53	7.41
Mesquite	1/1-12/31	19	.65	70.11	.12	8.41	7.41
Gillespie Dam to Dome--Gila River							
Salt cedar	1/1-12/31	56	1.40	73.44	.78	57.28	2.88
Salt cedar	1/1-12/31	38	1.40	73.44	.53	38.92	2.88
Salt cedar	1/1-12/31	19	1.40	73.44	.27	19.83	2.88

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By Henry P. Walker and Don Bufkin

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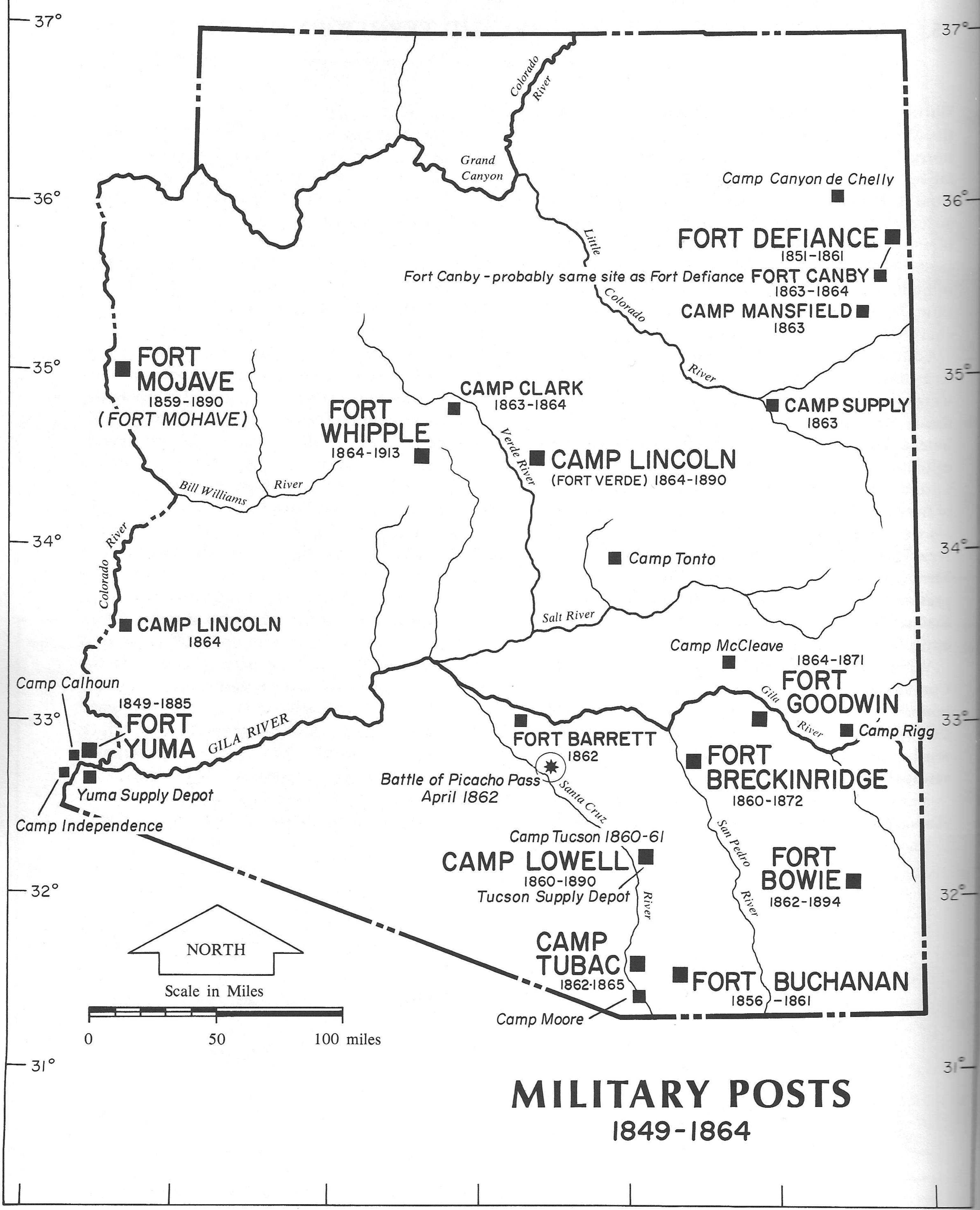

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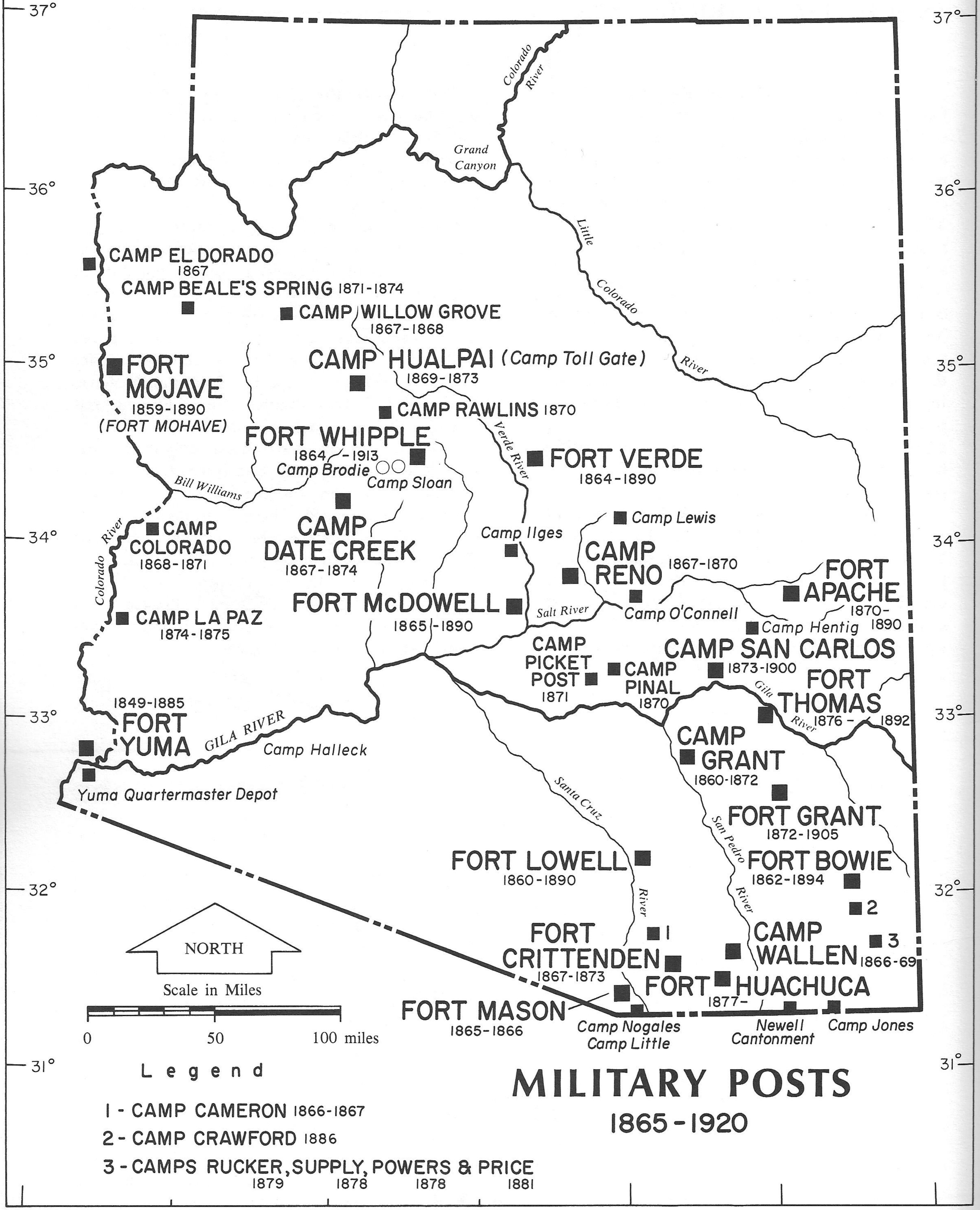

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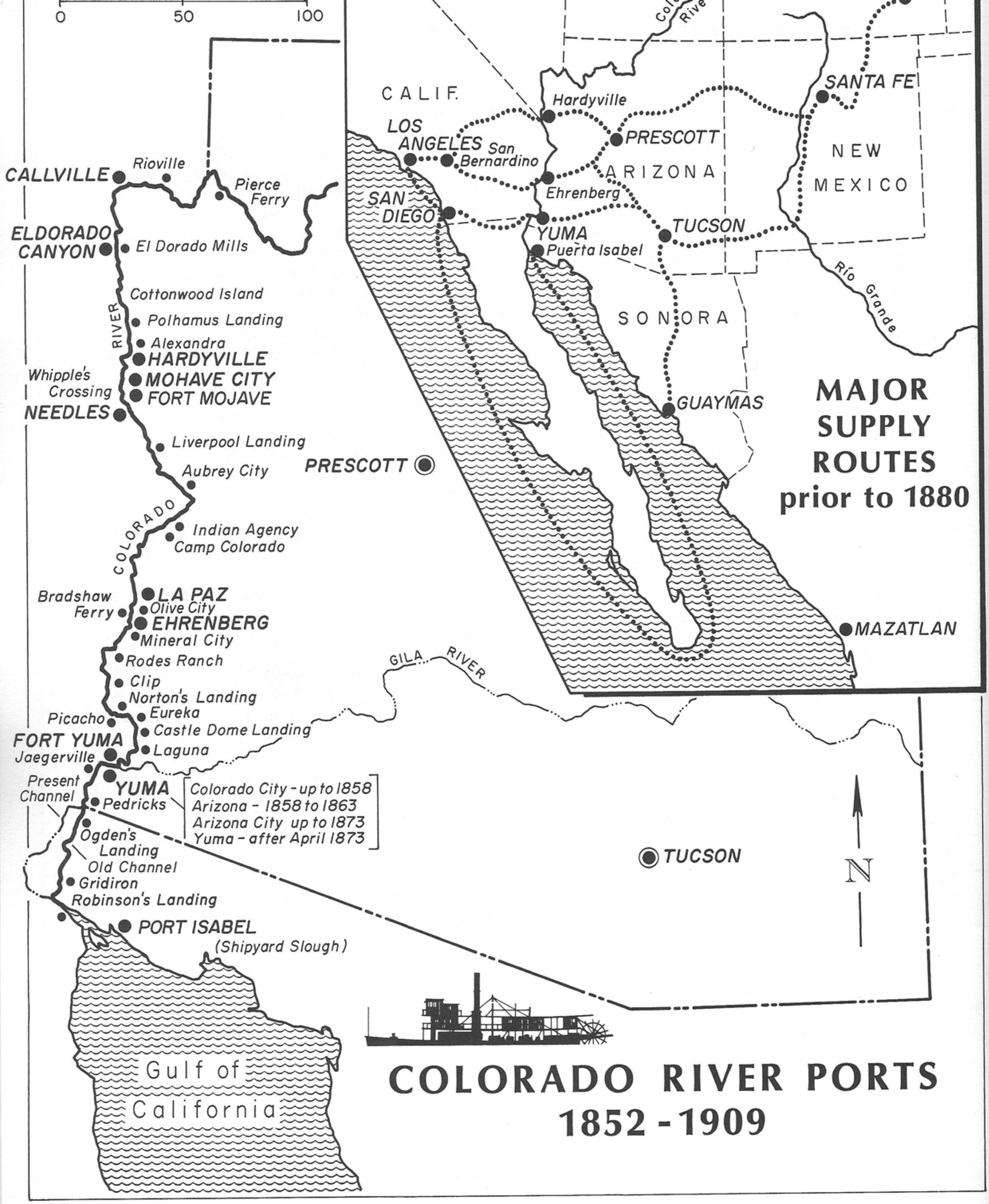
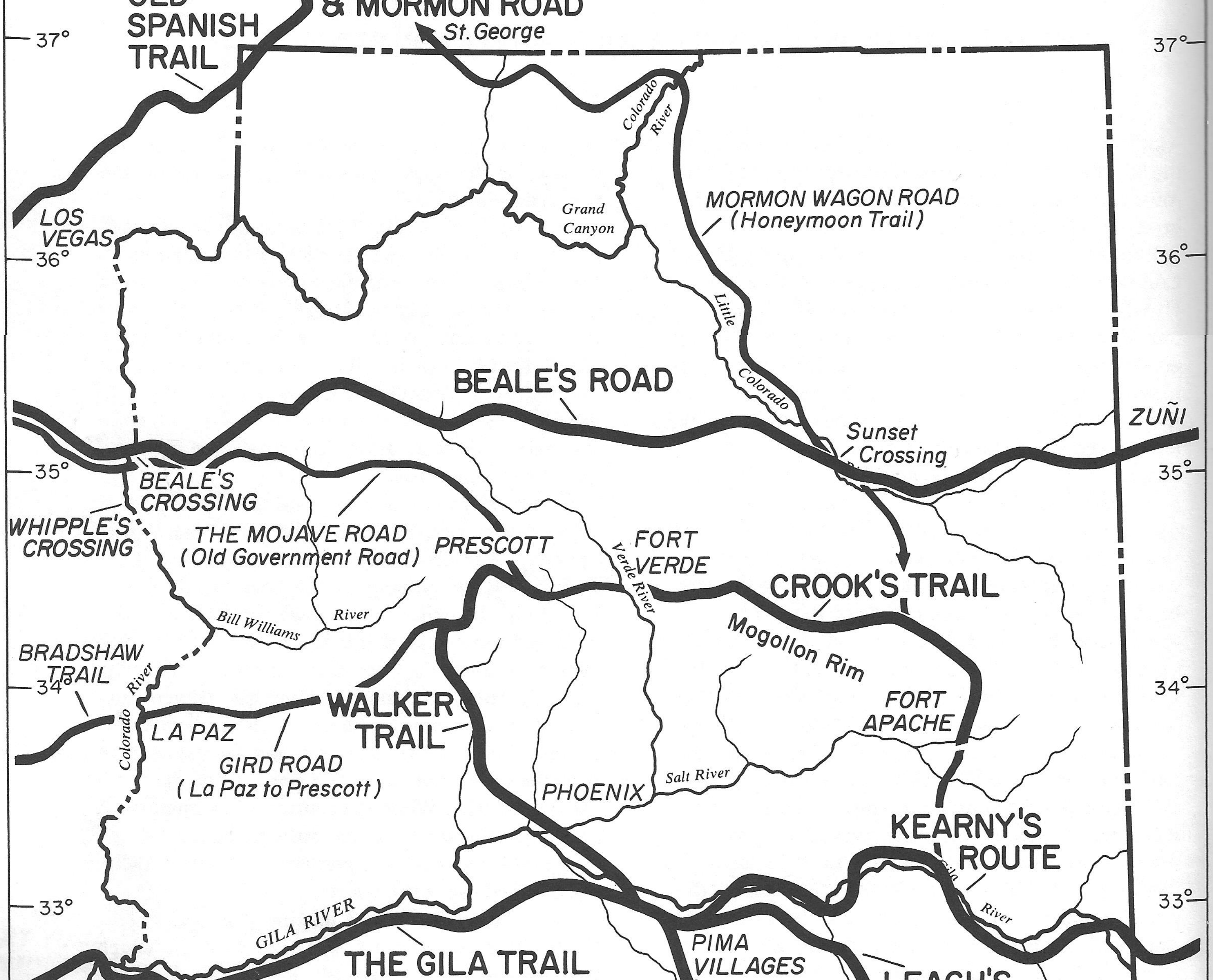


COLORADO RIVER PORTS 1852 - 1909



MAJOR TRAILS

Figure 5. Photograph of the Gila River taken near Olberg in March 1915. View is looking downstream with Sacaton visible to the left in the distance. At least 50 Akimel O'odham men assisted by 21 two-horse powered wagons repair a brush intake weir on the streambed of the Gila River. They are trying to divert water into the historic Santan Canal. The Gila River channel is about one kilometer wide in this view. (Homer Shantz Collection, Herbarium, College of Agriculture, University of Arizona, Tucson).

change in community organization has been tentatively defined and dated as the Polvoron phase or the terminal period of prehistoric occupation in the Gila and Salt River Valleys (Sires 1983). The Polvoron phase was characterized by dispersed ranchería-style villages, shallow pithouses, "degenerate" red ware, and a mixed subsistence strategy (Chenault 1993; Crown 1991; Doyel 1991; Hackbarth 1995; Sires 1983; Teague and Crown 1984). No major landscape change along the middle Gila River is documented for this time period (Figure 4e). Thus, the demise of the Classic-period Hohokam in the middle Gila River valley cannot be linked to landscape changes.

The Protohistoric period (ca. A.D. 1450 and 1700) marks the time between the end of the Hohokam and the beginning of the Spanish colonization of the Southwest. Historic descriptions of this area record the presence of Piman-speaking groups that pursued floodwater and small-scale irrigation farming on the active floodplain of the Gila River. Protohistoric fields were located on the T-1 and T-2 surfaces. By this time, the Gila River had returned to its original narrow channel configuration with a fully developed riparian zone and a broad floodplain that was regularly flooded. Due to a multitude of factors (e.g., introduction of wheat, warfare between the Akimel O'odham and Apache, and subsequent aggregation of settlements), irrigation agriculture became more intensified after the beginning of the historic period (Wilson 1999). The period of channel downcutting and widening documented on the middle Gila River in the late nineteenth century decimated the traditional farming lifeway of the Akimel O'odham (Rea 1997).

Cultural and Landscape Changes along the Salt River

The Salt River is a major tributary of the Gila River that lies directly north of the middle Gila River. Like the Gila, it was a core area of Hohokam settlement

LANDSCAPE CHANGE AND THE CULTURAL EVOLUTION OF THE HOHOKAM ALONG THE MIDDLE GILA RIVER AND OTHER RIVER VALLEYS IN SOUTH-CENTRAL ARIZONA

Michael R. Waters and John C. Ravesloot

Changes in river floodplain morphology can have devastating consequences for irrigation agriculturalists. Channel erosion occurred in the late nineteenth century, on the floodplain of the middle Gila River, Arizona and severely impacted the native Akimel O'odham (Pima) farmers. Prior to the Akimel O'odham, the prehistoric Hohokam also pursued irrigation agriculture along this river. Geoarchaeological investigations of the Gila River floodplain document a major period of channel cutting and widening sometime between A.D. 1020 to 1160. This channel erosion is coincident with the partial abandonment of large Hohokam villages and significant population rearrangements. It also marks the beginning of a major social reorganization when ballcourts were replaced by platform mounds as the social integrative structure and the Hohokam sphere of influence contracted. Other rivers utilized by the Hohokam—the Santa Cruz River, San Pedro River, and Tonto Creek—also experienced channel cutting between A.D. 1050 and 1150. Thus, a regional episode of channel erosion appears to have been a major factor that contributed to the reorganization seen in the Hohokam archaeological record. These synchronous landscape changes would have severely impacted Hohokam irrigation systems and food production capabilities. This undoubtedly created stresses within Hohokam society which in turn may have accelerated social, political, economic, ideological, and demographic changes that were already underway.

Cambios morfológicos en el cauce de un río pueden tener consequencias devastadoras para la agricultura de irrigación. La erosión del Río Gila Medio, que ocurrió al final del siglo IXX impactó severamente a los agricultores nativos Akimel O'odam (Pima). Antes de éstos, la población prehistórica Hohokam practicó agricultura de irrigación en este río. Investigaciones geoarqueológicas en el cauce del Río Gila documentan un período de gran entrenchamiento y ensanchamiento entre 1020 y 1160 d.C. Esta erosión coincidió con el abandono parcial de extensos asentamientos Hohokam en esta área del río y con un movimiento demográfico significativo. Este proceso también marca el principio de una reorganización social, cuando se reemplazaron las canchas de pelota por los montículos de plataforma como formas arquitectónicas integrativas y se contrajo la esfera de influencia Hohokam. Otros ríos utilizados intensamente por la población Hohokam, incluyendo el Río Santa Cruz, Río San Pedro, Quebrada Tonto, y Río Salt, también experimentaron entrenchamiento entre 1050 y 1150 d.C. Por lo tanto, un episodio regional de erosión del cauce parece haber sido un factor principal que contribuyó a la reorganización observada en el registro arqueológico Hohokam. Estos cambios sincrónicos en el paisaje habrían impactado severamente los sistemas de irrigación y capacidad de producción de alimentos. Esto sin duda creó presiones dentro de la sociedad Hohokam , la que entonces habría acelerado los incipientes cambios sociales, políticos, económicos, ideológicos, y demográficos de ese tiempo.

Prehistoric agriculturalists known as the Hohokam intensively occupied the middle Gila and Salt River Valleys of Arizona for hundreds of years (Gumerman 1991; Haury 1976). Characteristics of the Hohokam cultural pattern (i.e., red-on-buff ceramics, distinctive iconography, pithouse architecture, village layout, ballcourts, mortuary practices, and irrigation agriculture) are identifiable in the archaeological record around A.D. 700–750 (Doyel 1991; Wallace et al. 1995). Over the next three centuries, the Hohokam sphere of influence expanded to include almost all of south-central Arizona (Figure 1). After this long period of sustained growth, expansion of the size and complexity of villages, and cultural elaboration, the Hohokam experienced a period of major reorganization. Between A.D. 1050 and 1150 settlements that had been occupied for centuries were partially abandoned, the geographic range of the Hohokam pattern decreased, and the regional system of more than 125 ballcourts was gradually replaced

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The Ribbon of Green

Change in Riparian Vegetation in the Southwestern United States

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Principal photography by Dominic Oldershaw

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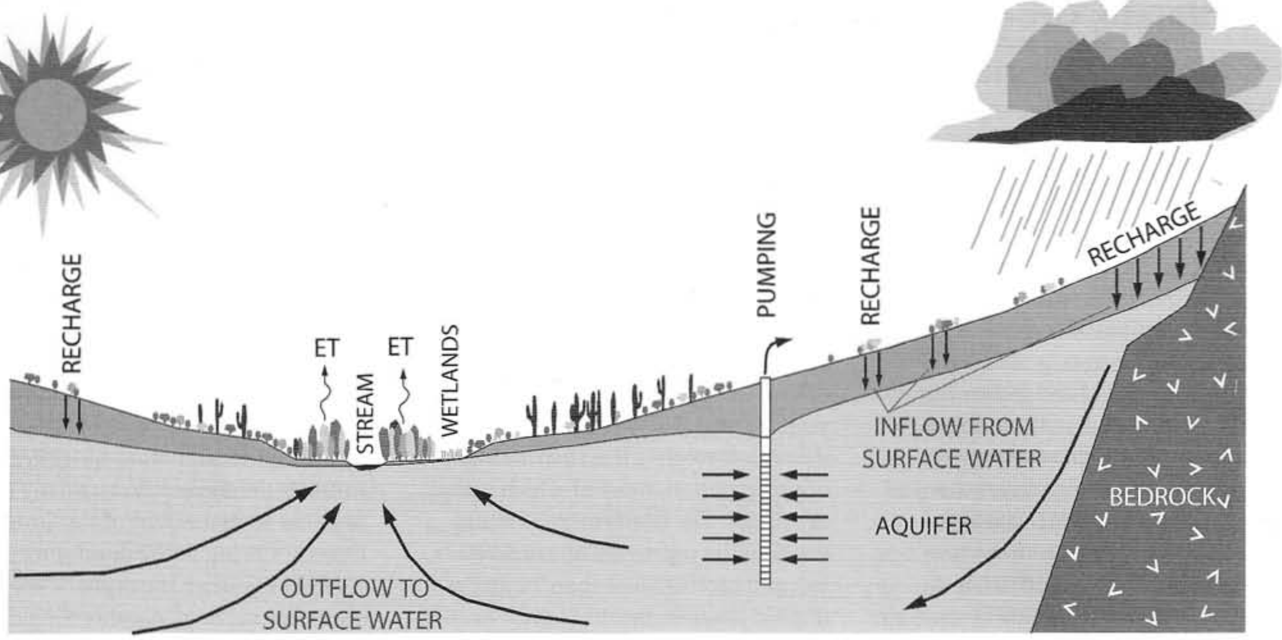

Figure 2.1 Generalized hydrologic cycle in the Southwest depicting groundwater–surface water interactions typical of many alluvial aquifer systems in the Basin and Range.

dissipating tropical cyclones coincide with cutoff lows or frontal systems from the North Pacific Ocean.[3]

Beginning at the Mogollon Rim, the climate of the Southwest changes significantly northward. The rim elevations of 7,000 feet and higher generally strip low-level moisture (below the 700-millibar pressure height) from storms, causing the highest regional storm intensities on the southern flanks of the mountains south of the rim. As a result, storms moving from the southwest and passing into the Four Corners Region may be diminished by the rainshadow effect of the rim, reducing storm amounts for some winter storms and most tropical cyclones. Similarly, storms approaching from the west encounter numerous mountains and plateaus in Nevada and southwestern Utah, creating another rainshadow effect for the plateau region of southeastern Utah.

Summer precipitation generally decreases and becomes unreliable on the Colorado Plateau in southern Utah.[4] The amount of moisture during summer is strongly dependent on the location and magnitude of those persistent steering features in the atmosphere. If, in particular, the Four Corners High does not develop or is not in its usual position for a significant period or is stronger than normal, moisture entry into the region may be blocked. During the summer, moisture recycled into the atmosphere following storms is added to the moisture advected from the oceans.

The headwaters of the Mojave River generally respond to winter precipitation. Owing to the strong orographic precipitation associated with the interaction of storms with the Transverse Ranges, rainfall may be relatively light in the desert but strong in the headwaters, leading to large amounts of runoff. Little runoff in this river system is generated during summer storms, making the Mojave River unique in the Southwest.

The El Niño–Southern Oscillation (ENSO) phenomenon of the Pacific Ocean strongly affects interannual variation in precipitation in the Southwest.[5] ENSO effects can be separated into three general categories: warm ENSO events (commonly known as El Niño conditions), cool ENSO events (commonly known as La Niña conditions), and other conditions. Precipitation during El Niño conditions generally is high, although notable dry periods have occurred under these conditions. Winter precipitation is the most affected; the effect of El Niño on summer precipitation is weak at best. Precipitation during La Niña conditions is reliably low, and most significant regional droughts are associated with this state. Anything can occur during other conditions, although extreme wet or dry periods are unlikely.

Despite geographic variation in processes, decadal-scale climatic fluctuations appear to affect the region in a relatively uniform fashion. Although all of the region may simultaneously experience dry or wet conditions, the magnitude and persistence of unusual climatic conditions varies. Whereas wet conditions generally are uniform from the Mojave River through southern Arizona, droughts seldom are uniform in severity or length. Orographic effects and seasonality of precipitation add to the complexity, making general statements about climatic variability difficult. Finally, average temperatures are related to precipitation; temperatures tend to be annually or seasonally high during droughts and may be relatively low or high during wet periods. This complex interaction affects riverine riparian vegetation.

The riparian vegetation encountered by early explorers undoubtedly reflected some aspect of prehistoric climatic conditions. The climate of the nineteenth century was strongly affected by cessation of the Little Ice

Age, which extended from around A.D. 1500 to around 1850.[6] The impact of this period on the Southwest is known only from tree-ring records at higher elevations, although, in general, average temperatures were lower than at present with uncertain impacts on regional patterns of precipitation. Landscape observations by Spanish explorers reflect, in part, ecosystems affected by the Little Ice Age.

Recorded observations of climate and weather began with settlement of the region by nonindigenous peoples, starting with the establishment of Spanish missions south of present-day Tucson in the late seventeenth and early eighteenth centuries.[7] The colonization of Utah by Mormons, beginning in 1847, led to settlement of the southwestern part of that state in 1860 and extending southeastward until 1880. An influx of prospectors, spurred by the California gold rush, led to boom-bust mining throughout the region; hostilities with American Indians led to the establishment of numerous army outposts throughout the region. Those outposts provided the first instrumental records of climate, although many climatologists discount most of these records as inaccurate. Reliable measurements that provide a regional perspective on climate began in the late 1880s.[8]

Analyses of climatic trends provide a general framework of decadal climatic fluctuations in the Southwest, and these analyses[9] are discussed further in chapter 30. The period 1880–1891 was generally wet, with numerous regional-scale storms that caused channel downcutting and generally led to the observation that "rainfall follows the plow." The most severe drought, and the one that affected the largest part of the region, began in the summer of 1891 and ended in 1904. In combination with overstocking of the range, the early-twentieth-century drought caused the death of half of the cattle in the region between 1891 and 1896. El Niño conditions in 1904 and 1905 ended this drought.

The wettest period in the region's history began in 1909 and extended through about 1920. The early-twentieth-century wet period had a number of lasting effects, including its influence on the overallocation of Colorado River water and the widening of arroyo channels throughout the region. This combination of extreme events and human settlement had major effects on the stability and extent of woody riparian vegetation in the region, in particular the elimination of much of the established vegetation along alluvial channels.

Climate was regionally variable between 1920 and the early 1940s, ending with the strong El Niño conditions of 1941 through 1942. In southern Arizona, conditions were relatively dry with few significant winter storms. From the Mojave Desert through southern Utah, conditions were generally wet, punctuated with a mild drought during the Dust Bowl years of the early 1930s. Between the mid-1940s and the early 1960s, drought conditions prevailed with strong regional variation in intensity. The mid-twentieth-century drought, centered on the La Niña conditions of 1954 through 1956, was most severe in the Mojave Desert, in southern Utah, and to the east in New Mexico. Near-normal summer precipitation mitigated this drought in central and southern Arizona.

Beginning in the early 1960s and fueled by several significant El Niño periods, the climate of the region became significantly wetter and warmer. Numerous strong storms in fall and winter occurred between 1970 and 1995, leading to significant floods in central and southern Arizona and to above-average precipitation in the Mojave Desert and the Colorado Plateau. Notable periods of El Niño conditions occurred from 1978 through 1980, 1982 and 1983, and 1993 through 1995. Brief droughts interrupted this intermittent wet period in 1986 and 1989 through 1991, with the latter event having severe effects in the Mojave Desert. The current extent of woody riparian vegetation was strongly affected by this climate period, which we refer to as the *late-twentieth-century wet period*.

Despite El Niño conditions in 1997 through 1998 and 2002 through 2003, drought generally prevailed at the end of the twentieth century and the beginning of the twenty-first century. The early-twenty-first-century drought, centered on 2002, has created several record extremes, including the lowest flow ever recorded in the Colorado River in southern Utah[10] and record low annual rainfall at many stations. The reasons for the switching of interdecadal periods between generally wet and generally dry conditions remain speculative, but research on the subject centers on hemispheric-scale, low-frequency oceanic processes in the North Pacific and North Atlantic Oceans.

Temperatures fluctuated through the twentieth century, leading to several distinct precipitation-temperature regimes. Annual temperatures generally were low from 1900 through 1930, creating a high precipitation–low temperature combination.[11] Severe freezes were common during this period,[12] with potential negative impacts on some species of riparian vegetation that otherwise would have germinated and established following winter floods. Temperatures peaked during the midcentury drought, creating a warm, dry period. Declining temperatures accompanied the earliest part of the late-century wet period, although temperatures steadily rose during the 1980s and 1990s, meaning that the late-twentieth-century wet period was also warm.

The most important characteristics of the late-twentieth-century wet period were an increase in winter floods, which create ideal conditions for germination and establishment of native riparian vegetation on larger rivers (chapter 3), and an overall increase in the length of the growing season,[13] which encourages rapid plant growth. This latter period therefore created ideal climatic conditions for germination and establishment of riparian vegetation. The early-twenty-first-century drought, which is ongoing at the time of this writing, has resulted in relatively dry conditions that are adverse to germination and establishment of native riparian vegetation, killing seedlings and even established trees in some marginal reaches.

Geomorphic Configuration and Riparian Vegetation

Riparian ecosystems are draped over a variety of geomorphic configurations in the Southwest. These settings determine how groundwater and surface

17 The Upper Gila River

Summary. The Gila River is the primary drainage for most of Arizona. With its headwaters in New Mexico, the Gila River upstream from Safford, Arizona, is largely unregulated, although flow diversions affect base-flow discharges at least locally. Below Coolidge Dam, the Gila River becomes fully regulated until the entire surface-water flow is diverted from the channel upstream of Florence, Arizona. Historically, the upper Gila River generated large, damaging floods while providing irrigation waters for fertile agricultural lands downstream. This river appears to respond strongly to regional climatic fluctuations, and flood frequency has been inferred to be low before 1891, high between 1891 and 1920, low through the middle part of the twentieth century, and high again after 1964. Despite considerable agriculture, groundwater levels near the river remain high. Cottonwood gallery forests once present in wide reaches were swept away in channel-widening floods in the early decades of the twentieth century. Cottonwood has increased in narrow reaches and bedrock canyons but has decreased in the wide valleys where it once was common. Channel narrowing during the middle of the twentieth century allowed establishment of dense tamarisk, but native species, such as mesquite, increased as well. Extremely large floods in the last third of the twentieth century failed to reduce tamarisk significantly, and tamarisk eradication with no follow-up maintenance resulted in reestablishment.

We discuss the Gila River in two chapters because of its importance to Arizona hydrology, its length, and changes along its course. We present changes in the reach from the Arizona–New Mexico border to the Ashhurst-Hayden Diversion Dam upstream from Florence in this chapter, and we consider the reach downstream to the confluence with the Colorado River near Yuma in chapter 26. The intervening chapters discuss changes in important tributaries, including the San Francisco and San Carlos Rivers (chapter 18); the San Pedro River and its tributaries (chapters 19 and 20); the Santa Cruz River and its tributaries (chapters 21 and 22); and the Verde and Salt Rivers and their tributaries in central Arizona (chapters 23 through 25).

The Gila River has its headwaters in the Gila Wilderness of western New Mexico (fig. 17.1). Several forks of the river combine upstream from Cliff, New Mexico, and the river plunges through a bedrock canyon of granite, locally called the Connor Box, before reaching the Arizona border. Beginning at Duncan, the river flows northwesterly through a relatively wide alluvial valley supporting agriculture—primarily hay production—before entering a canyon developed in volcanic rocks called the Middle Box. Upstream from Safford, Arizona, the river enters a broad valley with extensive agricultural production and flows northwesterly to San Carlos Reservoir. Downstream from Coolidge Dam, the river enters a series of short bedrock canyons through the Galiuro Mountains to emerge at Winkelman, Arizona. A short and relatively narrow segment through alluvium ends near the small town of Kelvin and enters yet another bedrock canyon, through which the river flows for 18 miles to emerge at Ashhurst-Hayden Dam upstream from Florence, Arizona.

The Gila River is an extremely important source of irrigation waters in eastern and central Arizona, and small diversion structures are common along its length. This river has also had extremely large floods in its history, resulting in construction of Coolidge Dam, which serves as both a flood-control structure and a flow-regulation dam for surface-water irrigation projects downstream of this reach. Upstream from San Carlos Reservoir, the Gila River is a free-flowing watercourse that remains subject to large floods; downstream of Coolidge Dam, the river is operated as an irrigation canal with the exception of certain periods, such as January 1993, when headwater floods overwhelmed the dam and reservoir's ability to contain all the runoff.

Early Observations of the Upper Gila River

Early Spanish explorers, such as Francisco Coronado, crossed the upper Gila River but made no mention of its resources. The first description of the Gila appears in the narrative account of James Ohio Pattie, who ranged widely through the western United States between 1824 and 1830. Pattie and his party of trappers first reached the Gila River upstream from the present-day Arizona–New Mexico border on December 14, 1824, and immediately caught thirty beaver.[1] He described downstream travel through one bedrock-confined canyon with tangled growth of wild grape and shrubs and another reach—probably near present-day Cliff, New Mexico, with "banks covered with tall cottonwoods and willows."[2]

Pattie's group found that beaver had already been trapped from the river just downstream from the present-day Arizona–New Mexico border, so they continued downstream. Pattie described the river bottomlands near present-day Safford as thickly vegetated with mesquite; he made no mention of cottonwood. After a brief excursion up the San Pedro River, the trapping party regained the Gila River upstream from present-day Safford, where Pattie trapped and killed an otter.[3]

Pattie returned to the Gila River several times, always trapping for

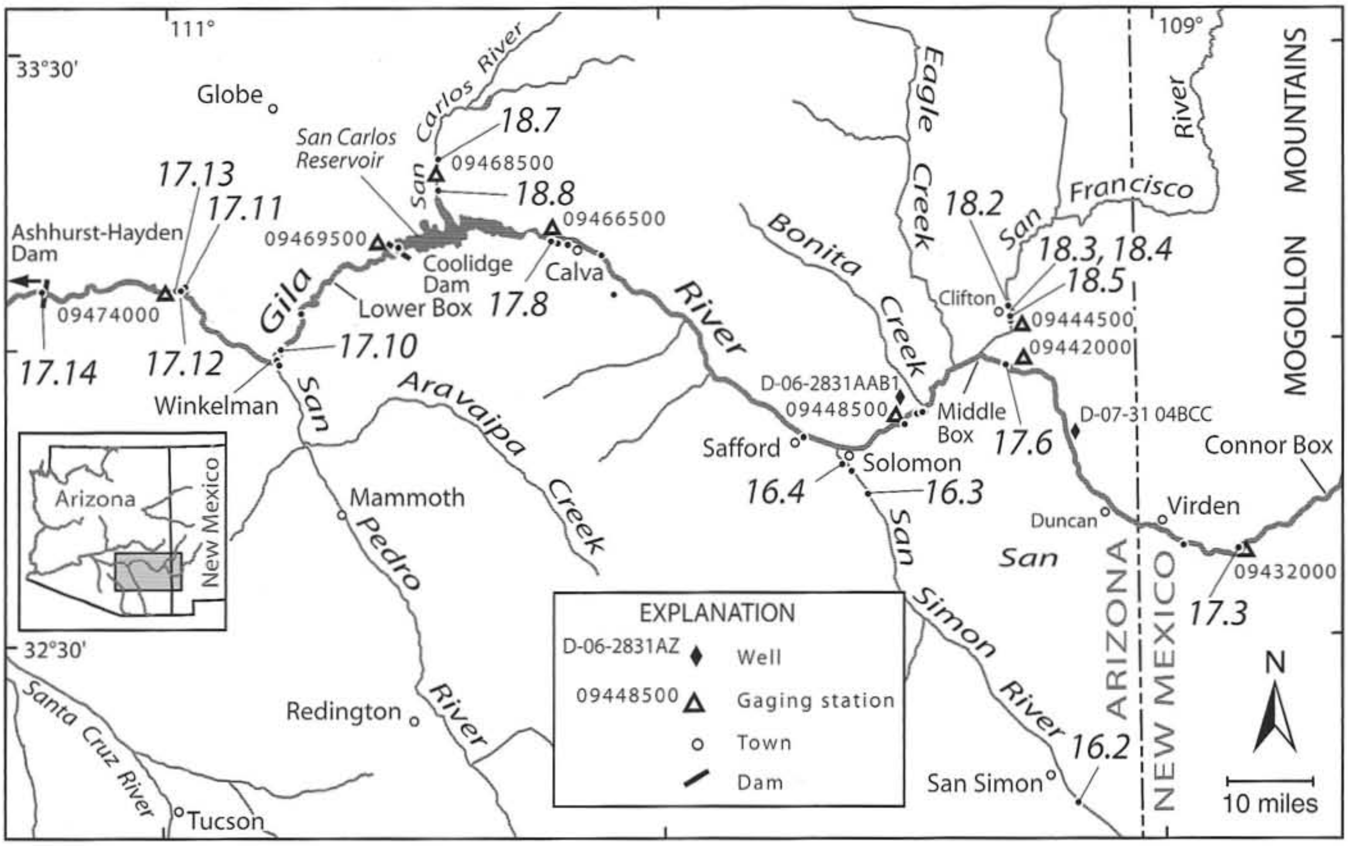

Figure 17.1 Map of the Gila River from the Arizona–New Mexico border to Florence, Arizona.

beaver. In January 1826, his group traveled down the Gila and observed that "there is here little timber, beside musqueto-wood, which stands thick" near the site of present-day Coolidge Dam.[4] In September 1829, Pattie made his final trip to the Gila and found that most of the beaver had been trapped out upstream from the San Pedro River.[5] As Pattie's account shows, the Gila River was a frequent destination for all the pre-1850 trappers in the West.[6] As late as 1884, beaver were reported to be abundant on the Gila River near the confluence with the San Carlos River.[7]

The 1846 war with Mexico caused the next incursion of Gila River observers. The Army of the West, guided by Kit Carson and led by Lieutenant Colonel W. H. Emory, came to the upper Gila River near the present-day Arizona–New Mexico border and traveled along its channel en route to California. Near the Arizona–New Mexico border, Emory observed that "[t]he growth of trees and weeds was very luxuriant; the trees chiefly cottonwood, a new sycamore, mesquite." At the mouth of the San Pedro River, the Gila River had a "bottom three miles wide . . . principally of deep dust and sand, over grown with cotton-wood, mezquite, chamiza, willow, and the black willow."[8] Dr. John S. Griffith, a physician and naturalist accompanying the expedition, described the riverine setting as a river filled with fish and lined with coyote willow and cottonwood trees.[9] Other descriptions noted the occurrence of mesquite bosques along the river.[10]

Groundwater conditions were high along the river, and malaria forced abandonment of several early towns.[11] Settlers affected riparian vegetation by clearing floodplains—mainly mesquite—for fields and using the wood for construction and fuel. Safford was established in 1872 by Mormon farmers, some of whom soon began to cut the bosques of mesquite just upstream to fuel smelters associated with local mines.[12] With the discovery of copper locally in the mountains near Safford and on a large scale near Clifton, woodcutting accelerated to fuel those smelters as well.[13] Undoubtedly, the same pattern was repeated between Winkelman and Kelvin with the discovery of extensive copper ore bodies.

Floods, Flow Regulation, and Channel Change

Because of the Gila River's importance for water supply and its propensity for generating large floods, six streamflow gaging stations record flow on the river from just upstream of the Arizona–New Mexico border to Ashhurst-Hayden Dam (fig. 17.1). The gaging stations below Blue Creek and near Clifton record average daily discharges of 215 and 197 ft^3/s, respectively. The gaging stations at the head of Safford Valley and near Calva, both downstream from the San Francisco River (fig. 17.1), have average daily discharges of 512 and 376 ft^3/s, respectively. The gaging station below Coolidge Dam has an average daily discharge of 401 ft^3/s, and the gaging station at Kelvin, which is below the confluence with the San Pedro River, has an average daily discharge of 542 ft^3/s.

The upper Gila River is subject to extremely large floods (figs. 2.2, 17.2), most of which occur during warm-winter storms or fall storms, the latter typically spawned from dissipating tropical cyclones. The earliest known

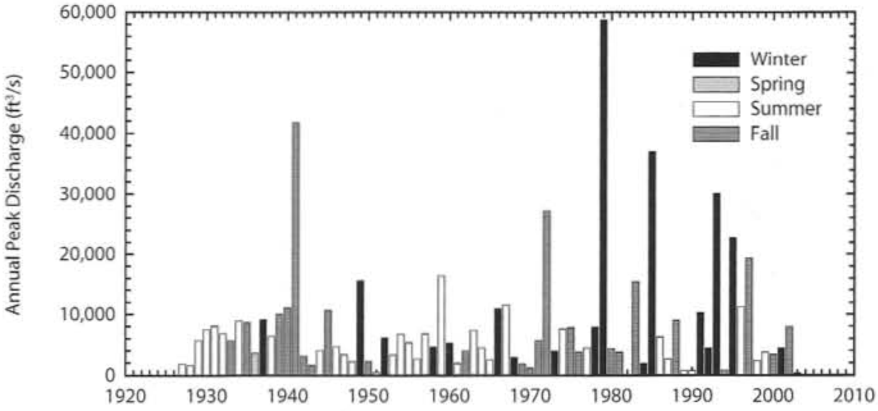

Figure 17.2 Annual flood series for the Gila River below Blue Creek, New Mexico (station 09432000; 1927–2003).

floods occurred before settlement of the Safford Valley and are discussed in chapter 26 in reference to the lower Gila River. The February 1891 flood, which peaked at around 100,000 ft^3/s at Florence, is one example of a large nineteenth-century flood on the upper Gila River.[14] The November 1905 flood reportedly peaked at 150,000 ft^3/s at San Carlos (now beneath San Carlos Reservoir) and 190,000 ft^3/s at Florence.[15] Other large floods occurred in 1906, 1915, 1916, and 1941.[16]

Cadastral surveys made from 1875 through 1894 show that the Gila River in the Safford Valley was relatively narrow and lined with willow, cottonwood, and mesquite.[17] Most of this vegetation was destroyed during channel widening associated with large floods between 1905 and 1916. Over a fifty-year period during the middle part of the twentieth century, the channel narrowed appreciably to about its pre-1905 conditions,[18] in part because of low peak discharges during floods. Near Safford, the channel was widest in 1935.[19] Riparian vegetation took advantage of the new openings on the margins of the channel and encroached on low floodplains.

Relatively small annual floods occurred in the middle part of the twentieth century, notably in the 1950s, but large floods occurred in the 1970s through 1990s, including the 1983 flood,[20] which peaked at 132,000 ft^3/s at the head of the Safford Valley gaging station (fig. 2.2) and is the largest recorded flood on the upper Gila River. In January and February 1993, three flood peaks exceeding 100,000 ft^3/s at the Calva gaging station coursed through the Safford Valley, filling San Carlos Reservoir and causing major flow releases downstream.

The annual flood series shows that floods on the upper Gila River are nonstationary in time and follow the same pattern of climatic fluctuations described for other sites in southern Arizona.[21] Even the lesser floods of the 1930s and 1940s caused significant damage. The 1941 flood reportedly inundated Duncan, Arizona, with 4 feet of water. The bridge over the Gila River at Duncan was destroyed during the January 1949 flood, which also forced evacuation in all the major towns downstream to San Carlos Reservoir.[22]

As with most nineteenth-century flow-regulation structures, the first low dams across the Gila River failed during the first flood after construction was completed. The first permanent structure built on the Gila River was the Ashhurst-Hayden Dam, a low-head dam completed in 1922 by the U.S. Indian Service.[23] Located about 20 miles upstream from Coolidge, Arizona, this dam diverts base flow into canals that supply the extensive agricultural development of the Eloy basin. The Ashhurst-Hayden Dam did nothing to control floods, which were common in the first three decades of the twentieth century. Smaller diversion dams are common along the river from the Arizona–New Mexico border to San Carlos Reservoir. Coolidge Dam, completed in 1929, impounds San Carlos Reservoir, which has highly variable water levels. This structure has the dual purpose of flood control and delivery of irrigation water downstream to extensive agricultural areas in the Eloy basin.

Riparian Vegetation Change on the Upper Gila River

Much of the upper Gila River flows in remote bedrock canyons that do not have a recorded history of riparian vegetation. Moreover, either few people ventured into these canyons to take photographs, with the exception of U.S. Geological Survey hydrographers, or those photographs were not preserved. Nonetheless, 127 repeat photographs document vegetation change on the Gila River between Blue Creek (just upstream of the Arizona–New Mexico border) and the Ashhurst-Hayden Dam.

Arizona–New Mexico Border to Safford

Just upstream from the Arizona–New Mexico border, the Gila River passes through a series of short bedrock canyons and high alluvial terraces. Photographs associated with the gaging station document change in riparian vegetation in a wide reach upstream from one of these short canyons below Blue Creek, a major tributary (fig. 17.3). This wide reach shows considerable channel shifting that occurred during large floods in the last third of the twentieth century, resulting in removal of a band of Frémont cottonwood, which were replaced with tamarisk and coyote willow. Within the bedrock-confined reach just downstream, riparian native vegetation—primarily in the form of mesquite bosques—is locally dense, and tamarisk is less common. Bosques in this reach are notable for their wildlife, including javelina, turkey, coatimundi, deer, and other large vertebrates. Twenty-three photographs show that native riparian vegetation has increased in this reach despite repeated channel shifting across the wide floodplain. Tamarisk is not widespread here.

In the vicinity of Duncan, the corridor opens into a relatively wide bottomland supporting agriculture. Despite use of groundwater for agriculture, long-term records of water level downstream from Duncan (fig. 17.4) show that no significant trends have occurred other than a general decline during the midcentury drought and rises of 11 and 4 feet following the 1970 and 1993 floods, respectively. Several historical photographs, notably ones that document a bridge that repeatedly failed during floods in this reach, also show increases in riparian vegetation, in particular cottonwood. Analysis of aerial photography taken between 1935 and 1997 shows the combined effects of initial channel narrowing, agricultural clearing of floodplain vegetation, and increases in riparian vegetation, followed by channel widening during the 1993 flood.[24] The amount of tamarisk along the Gila River increases substantially downstream from Duncan.

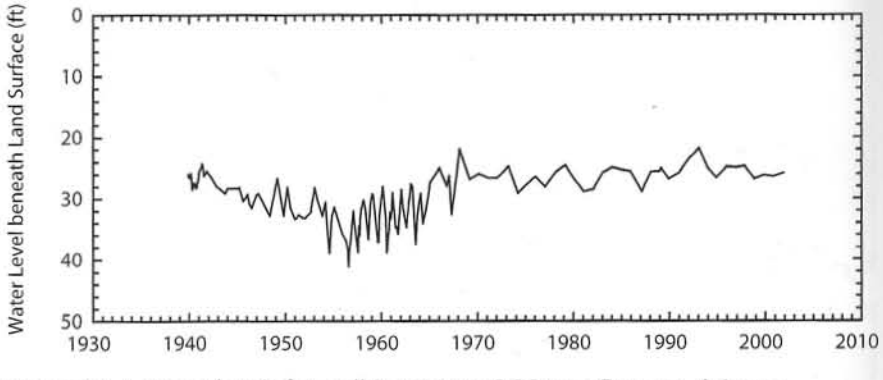

Figure 17.4 Water levels for well D-07-31 04BCC near Duncan, Arizona.

Between Guthrie and Safford, the river flows through the Gila Box Riparian National Conservation Area, where grazing has ceased but off-road vehicle use and hunting persist.[25] At the upstream reach, a U.S. Geological Survey gaging station has recorded flows since the early twentieth century (fig. 17.5). Twenty-one photographs associated with the gaging operation have been taken at this site. In general, these photographs show a steady increase in riverine riparian vegetation despite the recent occurrence of large floods (fig. 17.6).

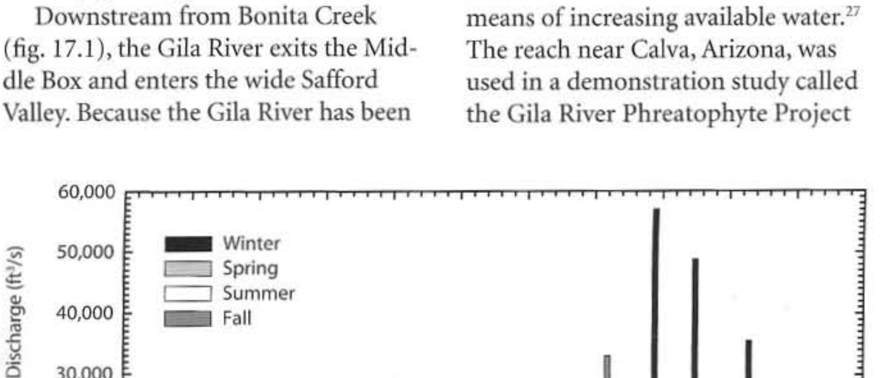

Figure 17.5 Annual flood series for the Gila River near Clifton, Arizona (station 09442000; 1911–1917, 1928–2003).

Downstream from Bonita Creek (fig. 17.1), the Gila River exits the Middle Box and enters the wide Safford Valley. Because the Gila River has been subjected to climatically induced fluctuations in flood frequency (fig. 17.2), damage to floodplains and bosques at the start of this reach was frequent in the 1970s through the 1990s.[26] Overall, however, eleven photographs upstream from Safford show increases in native species and nonnative tamarisk. At Safford, another ten photographs that have been matched show increases as well, although the relative proportion of the increase in nonnative vegetation, primarily tamarisk, is higher.

Reaches Affected by San Carlos Reservoir

The reach of the Gila River upstream from San Carlos Reservoir to the eastern edge of the San Carlos Apache Indian Reservation has long been a place where elimination of riparian vegetation once was considered a viable means of increasing available water.[27] The reach near Calva, Arizona, was used in a demonstration study called the Gila River Phreatophyte Project to determine the effect of tamarisk removal on reducing evapotranspiration losses in the 1960s and early 1970s.[28] In the late 1940s, about 9,300 acres of riparian vegetation were present between Thatcher and Calva, and tamarisk used an estimated 75 percent of the 23,000 acre-feet per year of water consumed by riparian vegetation in this area.[29]

Groundwater in this reach moves between basin-fill deposits and the alluvial aquifer, and water levels are highly influenced by flows and floods in the Gila River.[30] As discussed in chapter 2, groundwater levels under these conditions are generally shallow, vary seasonally in accord with streamflow variations, and may show diurnal fluctuations owing to withdrawals by riparian vegetation (fig. 2.3).

The San Francisco River (chapter 18) is the largest tributary of the upper Gila River, and this tributary strongly affects flood magnitudes in this reach (figs. 2.2, 17.7). The alluvial channel of the Gila River has widened historically and shifted in this reach, in some places by large distances, thus affecting the riparian vegetation.[31] The change in riparian vegetation has been substantial; where closed gallery forests of cottonwood once grew, tamarisk has become the primary species lining the Gila River.[32] Although floods and channel change are directly involved in causing loss of the cottonwood gallery forests along the upper Gila River, livestock grazing is not directly implicated.[33]

In the mapped area of the Gila River Phreatophyte Project, change in the area occupied by several species of riparian vegetation can be determined from 1914 to 1994.[34] Not surprisingly, the area occupied by tamarisk increased from zero percent in 1914 to 7 percent in 1937, 26 percent in 1944, 44 percent in 1964, and 61 percent in 1994. Cottonwood declined precipitously, from about 1,023 mapped trees in 1914 to 49 trees in 1994, although young trees that germinated during the 1993 floods are not included. The loss of cottonwood probably resulted from inundation during record high water levels at the San Carlos Reservoir.[35] Besides cottonwood, seepwillow lost the most area of the mapped native species; its loss might be a reflection of stability as the larger trees assume dominance of a more stable riparian ecosystem.

Changes in the area occupied by mesquite are interesting, given the divergent claims that mesquite bosques have been destroyed along the Gila River[36] and that mesquite has increased throughout southern Arizona.[37] Mesquite at all density levels occupied 21 percent of the area in 1914 and increased to 24 percent in 1937, 39 percent in 1944, and 44 percent in 1964, finally decreasing to 34 percent in 1994. The decrease between 1964 and 1994 is related to a renewed channel widening associated with floods from 1972 through 1993. Particularly in light of the later event, which consisted of multiple flood pulses, the increase in tamarisk and decrease in mesquite do not suggest that floods, whether artificially released from dams or naturally occurring, would help reduce the prevalence of nonnative vegetation in this setting.

Repeat photography of this area from the Calva railroad bridge (twelve views matched; e.g., fig. 17.8) shows another problem with restoration of floodplains, particularly with respect to eradication of tamarisk. In 1932, cottonwood and willow were still obvious on the floodplain. By 1964, tamarisk was ubiquitous, and native species could not be seen. All woody riparian plants, mostly tamarisk, were removed by 1974, but no additional channel maintenance was performed after the Gila River Phreatophyte Project ended. As a result, tamarisk steadily encroached onto the floodplain, despite large floods and attempts at eradication.

Downstream from Coolidge Dam, the river enters a series of bedrock canyons en route to Winkelman. Coolidge Dam is operated as a flood-control dam, and, except in 1993, this operation has been highly successful (fig. 17.9A). Flow releases from Coolidge Dam are generally highest during the summer months and low during the winter, which creates prime conditions for the growth of riparian vegetation. In the 1980s, reports from river runners downstream from the dam described a dense tamarisk thicket with water running through groves of trees.[38]

Nine historical photographs document changes in this reach, although most of the views show channel changes associated with construction activities at the base of the dam. Several photographs show conditions downstream from the disturbed areas, and cottonwood, black willow, and tamarisk have increased in this reach despite destruction of riparian vegetation during the 1993 high releases (fig. 17.10). Cottonwood trees along this reach provide nesting habitat for Bald Eagles.

Winkelman to Florence

The San Pedro River (chapter 19) enters the Gila River downstream from Winkelman and partially negates the flood-control effectiveness of Coolidge Dam (fig. 17.9B). Floods in 1983 and 1993 were of approximately the same magnitude as the 1891, 1916, and 1926 events, the latter also originating from the San Pedro River. The wide, denuded reach that existed before completion of Coolidge Dam has narrowed significantly (figs. 17.11, 17.12). During the midcentury drought and persisting through 1992, tamarisk created a closed canopy over much of the river in this reach, but at least part of this dense tamarisk was swept away during the 1993 releases from Coolidge Dam. However, as shown in eighteen sets of repeat photographs, cottonwood, mesquite, and tamarisk have increased near the gaging station at Kelvin (fig. 17.13).

The Ashhurst-Hayden Dam, which diverts most of the surface flow into irrigation canals, provides a convenient place to divide the upper from the lower Gila River. This small structure allows the passage of large floods while completely shifting small flows out of the channel. A small reservoir upstream from the dam has silted in and periodically dries, allowing encroachment of riparian vegetation (fig. 17.14). Nonnative vegetation, including both tamarisk and Athel tamarisk, dominates the banks of the river at this point, although dense mesquite also has been increasing.

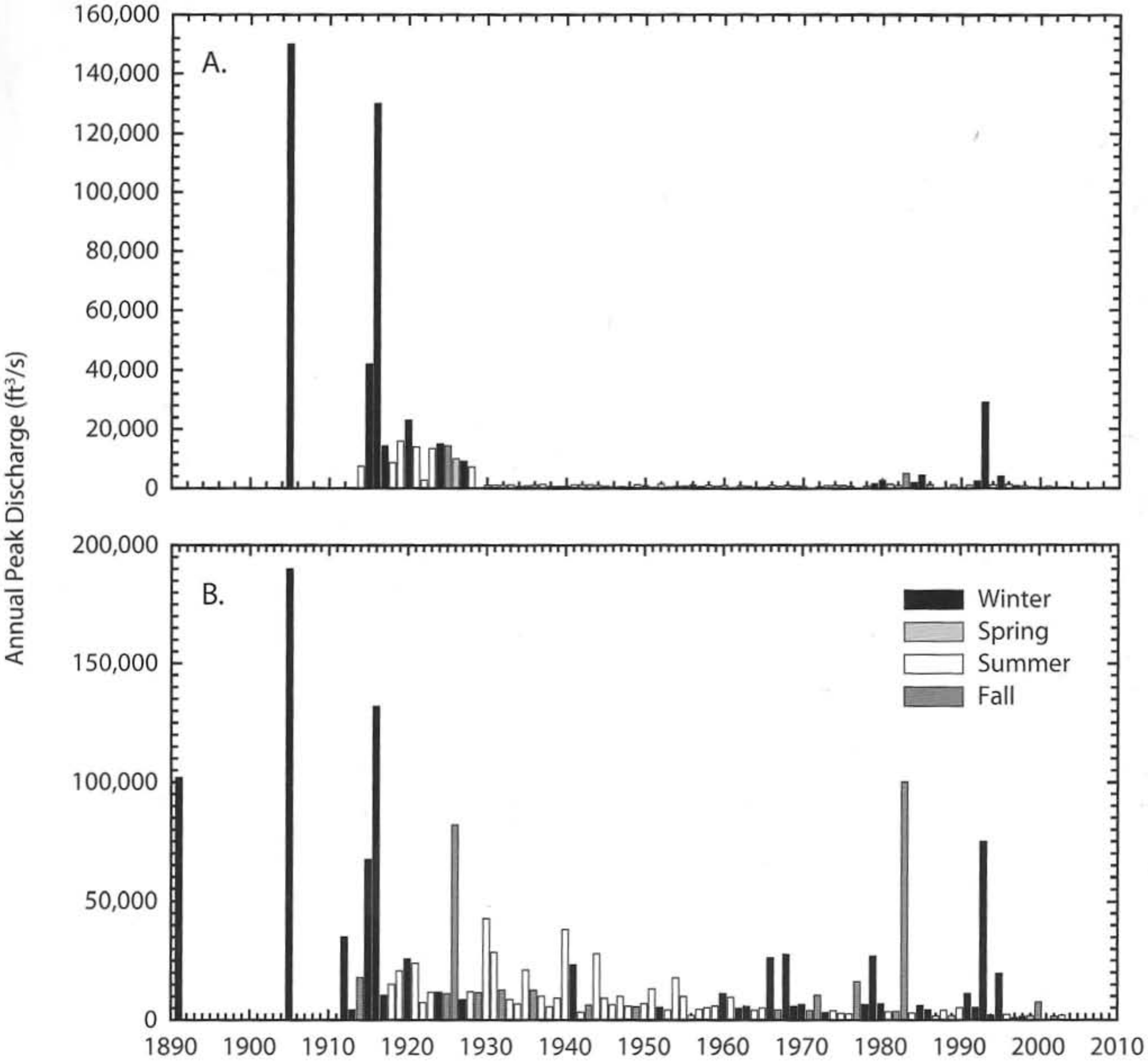

Figure 17.9 Annual flood series for the Gila River.

A. The Gila River below Coolidge Dam, Arizona (station 09469500; 1905, 1914–2003).

B. The Gila River at Kelvin, Arizona (station 09474000; 1891, 1905, 1912–2003).

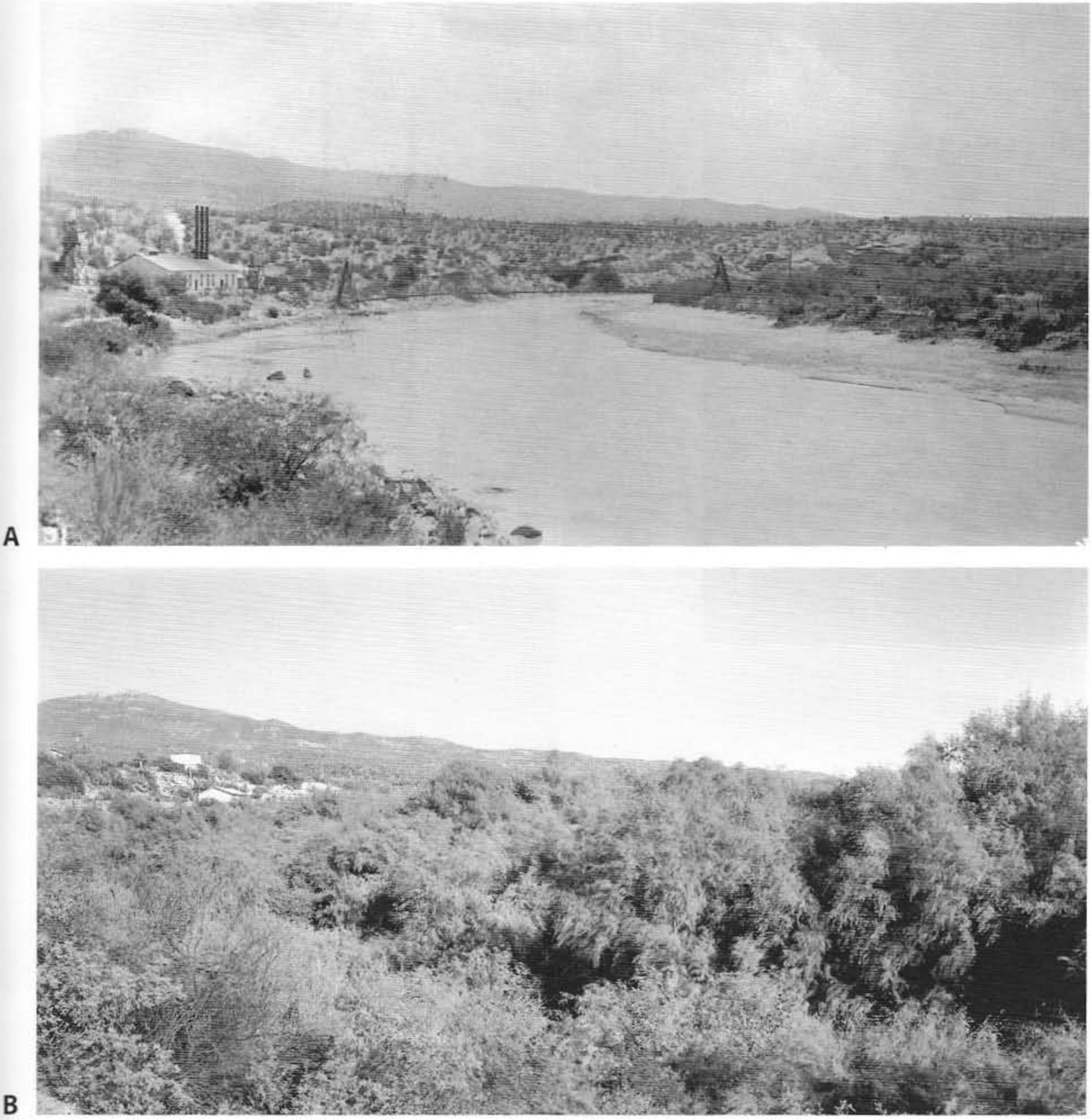

Figure 17.11 Photographs of the Gila River near Kelvin, Arizona.

A. (September 2, 1915.) This upstream view from a railroad grade shows a mill associated with copper-mining operations along the Gila River in this reach. Wooden A-frame structures suspend a pipeline across the river in the midground. The channel is wide and barren, and a nearly continuous, although thin, line of mesquite is present on the left bank. (Photographer unknown, courtesy of the U.S. Geological Survey.)

B. (October 2, 2000.) The mill has been abandoned, but the railroad remains active. The channel has narrowed substantially owing to flow regulation and encroachment of riparian vegetation. Creosote bush appears in the immediate foreground, and mesquite and tamarisk form the wall of vegetation blocking most of the view of the channel. The upper branches of Frémont cottonwood, which are common in this reach, appear at right. (D. Oldershaw, Stake 433.)

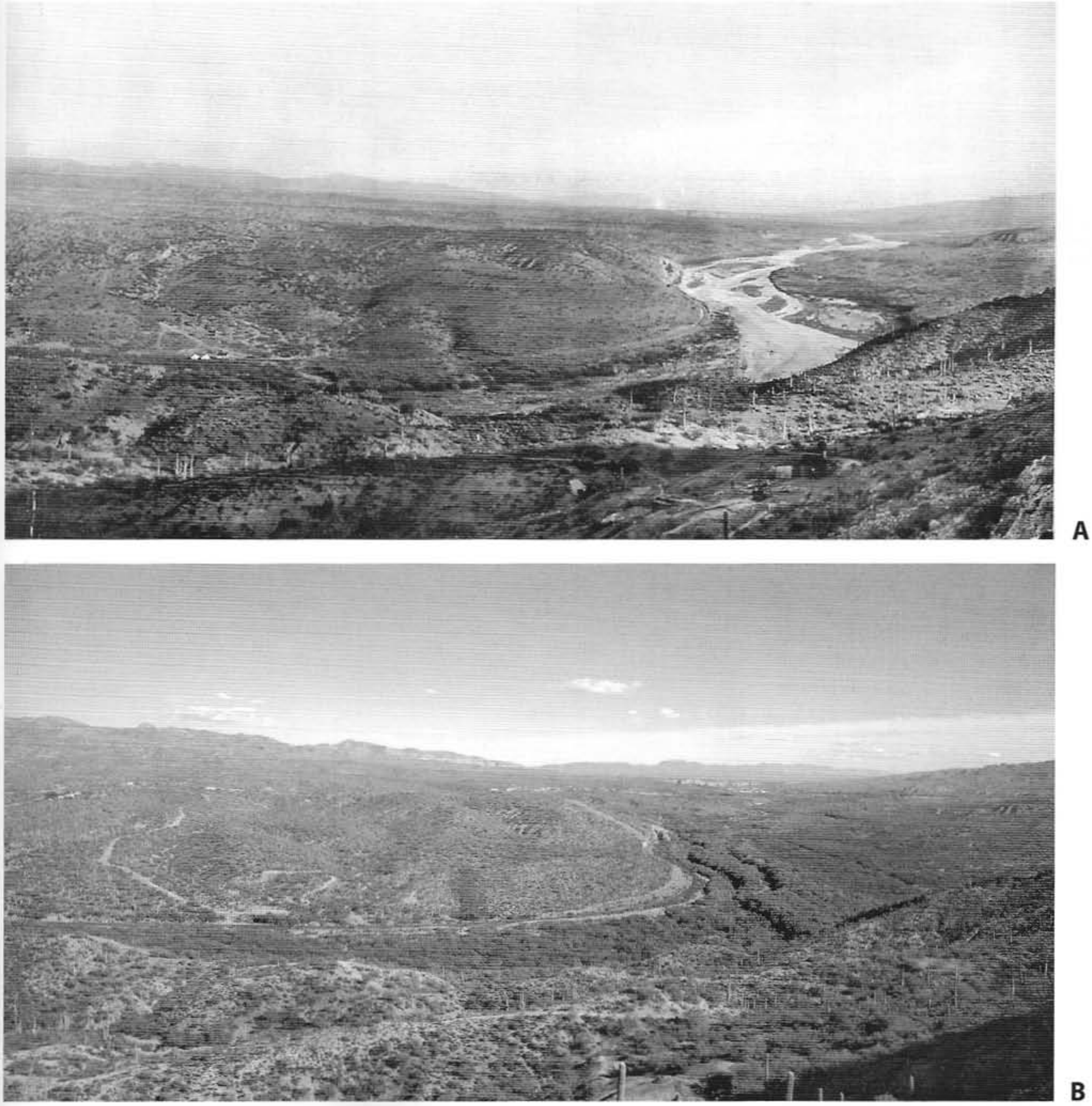

Figure 17.12 Photographs of the Gila River near Kelvin, Arizona.

A. (Ca. 1908.) This view, the right *(upstream)* quarter of a panorama, shows the Gila River in the vicinity of Kelvin. The wide channel is denuded, and low terraces sustain dense stands of mesquite. No Frémont cottonwood trees are obvious. (Photographer unknown, PAN US GEOG-Arizona No. 3, courtesy of the Library of Congress, Washington, D.C.)

B. (October 1, 2004.) The once-wide channel has narrowed considerably in response to regulation by Coolidge Dam, although occasional large floods emanate from the San Pedro River, a major tributary that joins the Gila River in the distance. Riparian vegetation consists of well-established Frémont cottonwood, tamarisk, black willow, catclaw, and mesquite. (D. Oldershaw, Stake 1429d.)

26 The Lower Gila River

Summary. The Gila River between Florence and its confluence with the Salt River is one of the few reaches where riparian vegetation has markedly declined. The evidence for this decline consists of written descriptions of channel conditions in the sixteenth through nineteenth centuries compared with written descriptions from the early twentieth century and current conditions. The Gila River in this reach is fully regulated and managed primarily for delivery of irrigation water and for minimization of damage from infrequent, large floods. Complete diversion of surface water and heavy groundwater use have prevented reestablishment of the once extensive riparian vegetation near Maricopa, which was largely eliminated by large floods at the end of the nineteenth century. Wastewater effluent from the city of Phoenix and irrigation returns sustain incipient to fully developed stands of woody riparian vegetation downstream from the confluence of the Salt and Gila Rivers. Dense tamarisk thickets are the basis for several wildlife areas west of the Salt-Gila confluence; historic descriptions indicate widely divergent vegetation in this reach, ranging from cottonwood-willow forests to dense carrizo grass. Riparian vegetation has increased downstream from the Salt-Gila confluence, although tamarisk accounts for most of the increase. Sparse photographic evidence and vague written accounts diminish the reliability of any conclusions concerning change in riparian vegetation downstream from the confluence beyond the increase in tamarisk. Near the Colorado River, irrigation returns to the Gila River again sustain woody riparian vegetation.

The lower Gila River, especially downstream of its confluence with the Salt River, is arguably the most important river in Arizona (fig. 26.1). With the exception of the Little Colorado and Bill Williams Rivers, all of the major river systems in Arizona converge here, making the Gila the primary drainage system for Arizona. The watershed area upstream of Dome, Arizona, is 57,850 square miles and includes parts of western New Mexico. The Gila River once provided sustenance for the Pima, then was the lifeline for southern travelers from the East to California, and now is little more than a drainage ditch across the south-central Sonoran Desert of Arizona. As a result, some have called it a "dead" river.[1] Despite large losses in some reaches, however, significant and valued stands of riparian vegetation are present along this archetypal desert river.

Early Observations of the Lower Gila River

Spaniards first arrived at the Gila River in 1694 and found a thriving village of Pima near present-day Maricopa (fig. 26.1).[2] These native people had occupied the Gila River floodplain since around A.D. 1540, or about 150 years before the arrival of the Spaniards. They practiced irrigated agriculture and, following the Hohokam, partially regulated the low-water flow of the Gila River. They also included fish from the Gila as a major part of their diet.

Spanish missionaries and travelers noted the riparian vegetation, which was a beacon across an otherwise waterless desert. Father Eusebio Kino, during his second visit, traveled from the mouth of the San Pedro to the Piman villages following the Gila River and "its very large cottonwood groves." In 1744, the confluence of the Salt and Gila Rivers had "an abundant growth of [willows] and cottonwood."[3] These observations are mostly limited to about a 30-mile reach of the river centered on the Piman villages.

In February 1826, at the Salt-Gila confluence, James Ohio Pattie wrote that the Gila River was "about 200 yards wide, with heavily timbered bottoms."[4] Descriptions of river width varied from this figure to as little as 40 feet in the nineteenth century, which reinforces the idea that the amount of flowing water depended on where the river was viewed in the alternating effluent-influent reaches. There is also little doubt that the channel consisted of braided, weaving strands through sandy islands in the center. Several marshy areas, possibly sustaining alkali sacaton, were present, including near present-day Sacaton, at the Santa Cruz–Gila confluence and near the mouth of the Salt River.[5]

Lieutenant Colonel W. H. Emory, of the Advanced Guard of the Army of the West, traveled down the Gila River in 1846 en route to California, all the way commenting on flora and fauna. Near present-day Florence, he mentioned dense growth of willows but not cottonwood. He estimated the population of Pima and Maricopa to be up to ten thousand people near the confluence of the Gila and Salt Rivers and stated that "a great deal of the land is cultivated." Near present-day Gila Bend, the course of the river could readily be discerned from the line of green cottonwood lining its banks, but to the west, near present-day Painted Rock Dam, "the bottoms of the river are wide, rich, and thickly overgrown with willow" and "the river spread over a greater surface, about 100 yards wide, and flowing gently over a sandy bottom, the banks fringed with cane, willow, and myrtle."[6]

In December 1846, the Mormon Battalion traveled from the Piman villages north of present-day Maricopa, Arizona, to the Yuma crossing of the Colorado River.[7] Their descriptions,

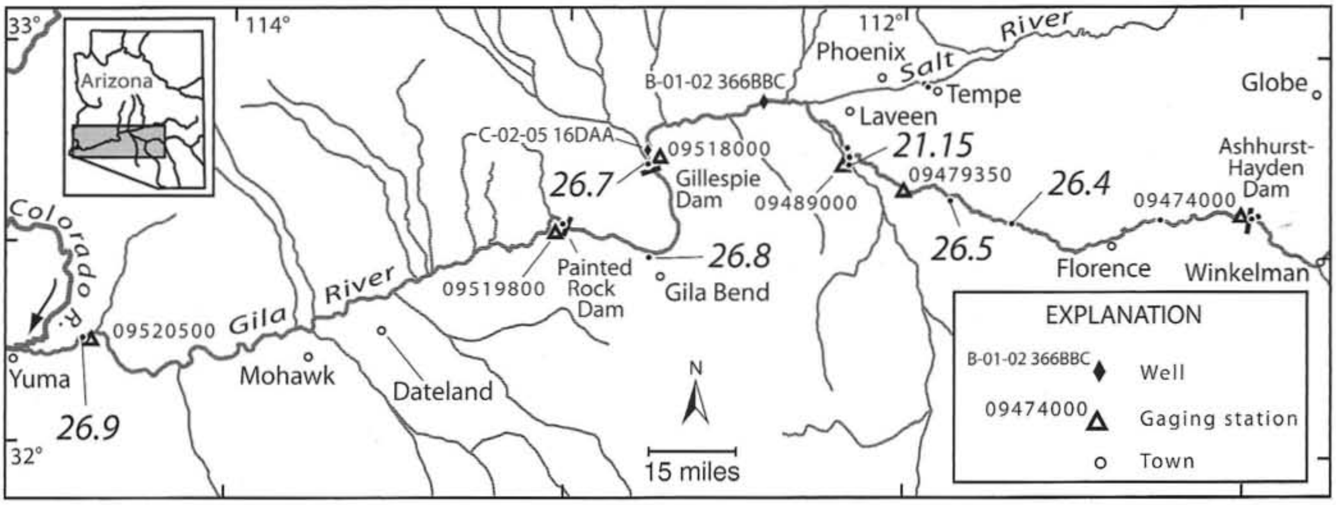

Figure 26.1 Map of the Gila River from Florence to Yuma, Arizona.

combined with later visits by Forty-niners, suggest that the Gila River was lined with a thin band of cottonwood and black willows; seepwillow was common nearest the permanent water sources. Dense mesquite bosques were common near the floodplain;[8] in 1938, the confluence of the Gila and Santa Cruz Rivers was described as a dense mesquite thicket (both screwbean and velvet mesquite). In 1854, John Bartlett found the Gila River to be dry at this point owing to complete diversion of low flow to Piman crops.[9] Upstream from the Piman villages, and presumably upstream from the flow diversions, the river had 15-foot-high banks and a closed-gallery cottonwood-willow forest.

In the late nineteenth century, the lower Gila River was perennial—or at least intermittent—in this reach, sustaining open cottonwood galleries punctuated with bottomlands vegetated with grasslands and willows.[10] In 1864, Pratt Allyn described the Gila River near its confluence with the Salt River as having a margin of willows and cottonwood.[11] Near Powers Butte, one observer in 1889 found the river lined with "cottonwoods and bushes."[12] Downstream from the Salt-Gila confluence, the Mormon Battalion found grass to be scarce and instead fed cottonwood bark to their stock. Lieutenant Cave Couts, en route to California, wrote a cryptic note in 1848, stating that the river had "salt grass. . . . The remainder is nothing but cottonwood (thinly scattered along the margin), coarse chaparral bushes and weeds, and the water willow."[13] Others noted the presence of Arizona ash in small numbers.

In 1894, Edgar Mearns visited the Gila River and described riparian vegetation along its lower 20 miles above the confluence with the Colorado River. He stated later: "The stream, as usual, is bordered by cottonwood and willow trees. Mesquite and screw bean are the common trees of the river bottom . . . [and there are] numerous sloughs, bordered with cat-tail, tule, cane, sedge and rush."[14] By the 1920s, arrowweed dominated floodplain vegetation,[15] to be supplemented with (or replaced by) nearly monospecific stands of tamarisk by the early 1950s.

Some observations are baffling in their seeming contradictions. One report from 1879 said the Gila River near Florence was nothing but a channel of dry sand, yet a ferry operated at this town, linking it to other towns in the Salt River Valley.[16] Presumably, this ferry operated during the predictable spring runoff and during unpredictable floods. At the end of the nineteenth century, all rivers in the region were experiencing alternating periods of extreme floods and extreme droughts. Although it is convenient to blame the apparent initial decline in riparian vegetation on water diversions, floods likely had at least as much of an impact.[17]

At the start of the twentieth century, a dense stand of carrizo grass was present near the Salt-Gila confluence.[18] Maps made around 1900 show extensive stands of "mesquite timber" lining both sides of the Gila River from its confluence with the Salt River upstream and past its confluence with the Santa Cruz River.[19] Groundwater levels were less than 50 feet below land surface in a broad swath centered on the river from the Salt-Gila confluence upstream to Florence, and effluent conditions were reported in the river at two points, near Sacaton and in the vicinity of the current Interstate 10 crossing. However, few cottonwood and willow trees remained, despite the fact that large-scale water development would not begin for another decade. Descriptions such as "cottonwood occurs in a thin fringe . . . here and there a grove along the Gila and Salt Rivers" are consistent with other nineteenth-century observations. By 1923, the river was described as intermittent, and settlers described the cottonwood as having disappeared forty years earlier (1880s), but fish were reportedly still present in the river.[20]

Before extensive urbanization in the Salt River Valley, mesquite grew in extensive stands in the vicinity of and downstream from the confluence of the Salt and Gila Rivers.[21] Many of these bosques, in particular those downstream from the present-day site of Painted Rock Dam (fig. 26.1), have been cleared for agricultural lands.[22]

Others died owing to water-level declines in the alluvial aquifer by the 1970s.[23]

The native fisheries of the Gila River have been largely eliminated. In the middle of the nineteenth century, many native species, in particular Colorado River pikeminnow, were common in much of the river basin.[24] Many species of birds occur along the lower Gila River, particularly where riparian habitat remains. On the Gila River Indian Reservation, where a perennial stream supporting a cottonwood-willow forest is now a xerophytic riverbed, twenty-nine bird species are thought to have been locally extirpated.[25] Although bird life along the lower Gila River was abundant, aquatic mammals were relatively sparse, as in most other riparian areas in the region. Beaver became much less numerous along the lower Gila River following the 1891 flood (see the next section), although a colony was reported to be at Mohawk in 1894.[26] Few trappers reported beaver in abundance on the lower Gila River, although beaver and muskrat, now uncommon in most Arizona rivers, remain.[27]

Floods and Channel Change

The first evidence of large floods along the lower Gila River are preserved in paleoflood records in damaged irrigation canals once used by the Pima and show variation in flood occurrence in the late Holocene.[28] In particular, flooding was relatively low from around four thousand to one thousand years ago, followed by a period of high flood frequency, channel instability, and damage to irrigation canals. Lack of evidence suggests a period of low flood frequency and high channel stability leading to the nineteenth century.

As the first observations suggest, the Gila River was a shallow, braided stream, particularly between Florence and the confluence with the Salt River.[29] Some researchers erroneously believe that the Gila River once flowed with a volume sufficient to sustain steamboat traffic.[30] The origin of this myth may be W. H. Emory's report, which stated that "[t]he Gila, at certain stages, might be navigated up to the Pimos [Pima] village."[31] Although this claim is clearly an exaggeration, two early expeditions built boats to float from near the present site of Gila Bend to the Colorado River. The first attempt was made by the Mormon Battalion in 1845.[32] In a failed attempt to avoid slow travel through deep sands, they converted a wagon into a boat, but flow was shallow, and the wagon was repeatedly stranded on sandbars. The second attempt, this time successful, was made by a Forty-niner group who turned their wagon into a scow.[33] After the *Explorer* (see chapters 12 and 27) was salvaged in the late 1850s, it reportedly was used to haul firewood down the Gila River near its mouth.[34] Clearly, seasonal flow in the river was sufficient to tempt river traffic and to sustain native fish populations, but insufficient to allow regular boat traffic.

Floods were once common on the lower Gila River and are known mostly because of damage at Yuma (see chapter 27). Some floods, such as an 1833 event, are thought to be larger than twentieth-century floods but are poorly known because written records were not made and discharge measurements are not available.[35] Two floods, in September 1868 and again in 1869,[36] also caused significant inundation along the lower Gila River; the 1868 flood reportedly was 4 miles wide. The 1891 flood, one of the most significant floods in Arizona history, had peak discharges of 250,000 ft^3/s at Gillespie Dam and 280,000 ft^3/s at Dome (fig. 26.2). With the construction of bridges and other floodplain structures, flood damage became a serious problem. For example, in October 1895, a flood on the Gila River destroyed a railroad bridge near Maricopa;[37] another flood in July 1898 destroyed a stagecoach. The 1905 flood, a relatively small event at Dome, widened the Gila River and converted it into a braided form.[38] More damage occurred during the January 1916 floods. Channel width increased by a factor of four to five between 1868 and 1923.[39]

Since construction of Coolidge Dam in 1928, only two significant floods have occurred in the reach upstream from the Salt-Gila confluence. The 1983 flood came from the combination of the San Pedro and Santa Cruz Rivers (chapters 19 and 21), and the 1993 flood also came from these tributaries, combined with emergency releases from Coolidge Dam. Downstream from the Salt-Gila confluence, floods have been more frequent owing to the effects of large regional storms on the Verde and Salt Rivers (chapters 23 and 24). Extremely large events that rivaled the size of predam floods occurred in 1978 (March and December), 1980, and 1993 (fig. 26.2b).

The channel of the Gila River upstream from the Salt-Gila confluence responded differently to the 1983 and 1993 floods. The 1983 flood, with a peak discharge of 35,000 ft^3/s, was not sustained and caused little channel change.[40] In contrast, the 1993 flood peaked at 41,600 ft^3/s, and the sustained flows in the late winter and spring of 1993 caused significant channel widening. The post-1993 channel reverted to its appearance following the 1905 floods (see fig. 26.4).

Flow Regulation

For several hundred years, the Pima diverted water from the Gila River for irrigation purposes. As others moved into the region in the 1870s, diversions increased, but the dams frequently washed out. The 1891 flood reportedly destroyed all the irrigation dams along the Gila River; a small flood in 1900 cut a 20-foot-wide breach in the irrigation dam at Florence.[41] The joint needs for flood control and irrigation diversion prompted a basinwide development of water resources in the early twentieth century.

Roosevelt Dam, completed in 1911, regulates much of the flow on the lower Gila River (chapter 24). As noted in chapter 17, Ashhurst-Hayden Dam (1922) was the first concrete-and-steel dam to regulate at least partially the Gila River upstream from its confluence with the Salt River. The lower Gila River has been fully regulated by dams on its main stem and principal tributaries since completion of Coolidge Dam in 1928. Releases from Coolidge Dam are typically diverted into a canal network at Ashhurst-Hayden Dam upstream from Florence, leaving the channel downstream dry most of the time. This dam is designed to pass flood releases from Coolidge Dam—as occurred in 1993—and occasional large floods from the San Pedro River.

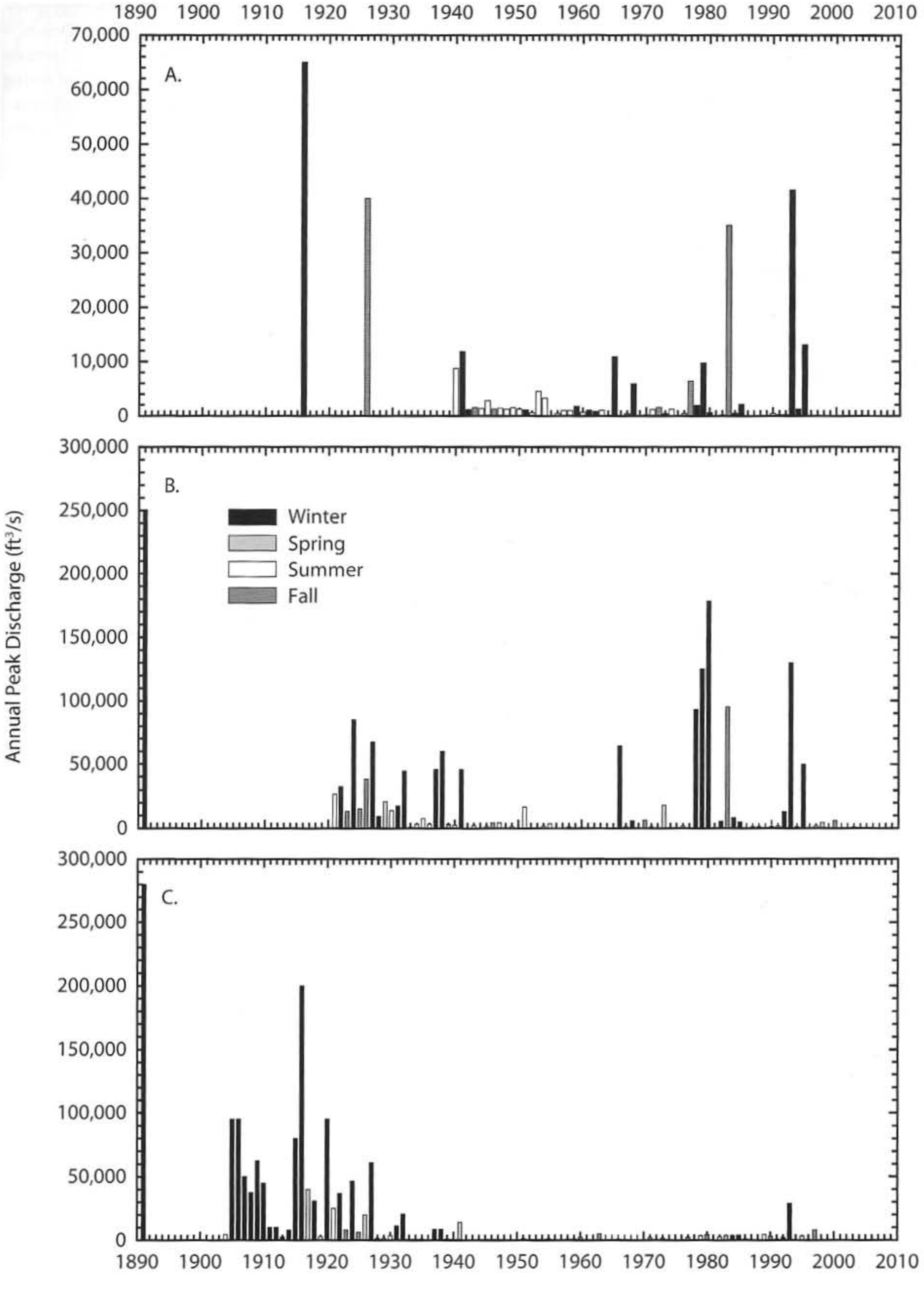

Figure 26.2 Annual flood series for the Gila River. Many years have no flow.

A. The Gila River near Laveen, Arizona (station 09479500; 1916, 1926, 1940–1995) combined with Gila River near Maricopa (station 09479350; 1995–2000).

B. The Gila River below Gillespie Dam, Arizona (station 09519500; 1891, 1921–2003).

C. The Gila River near Dome, Arizona (station 09520500 1891, 1904–2003).

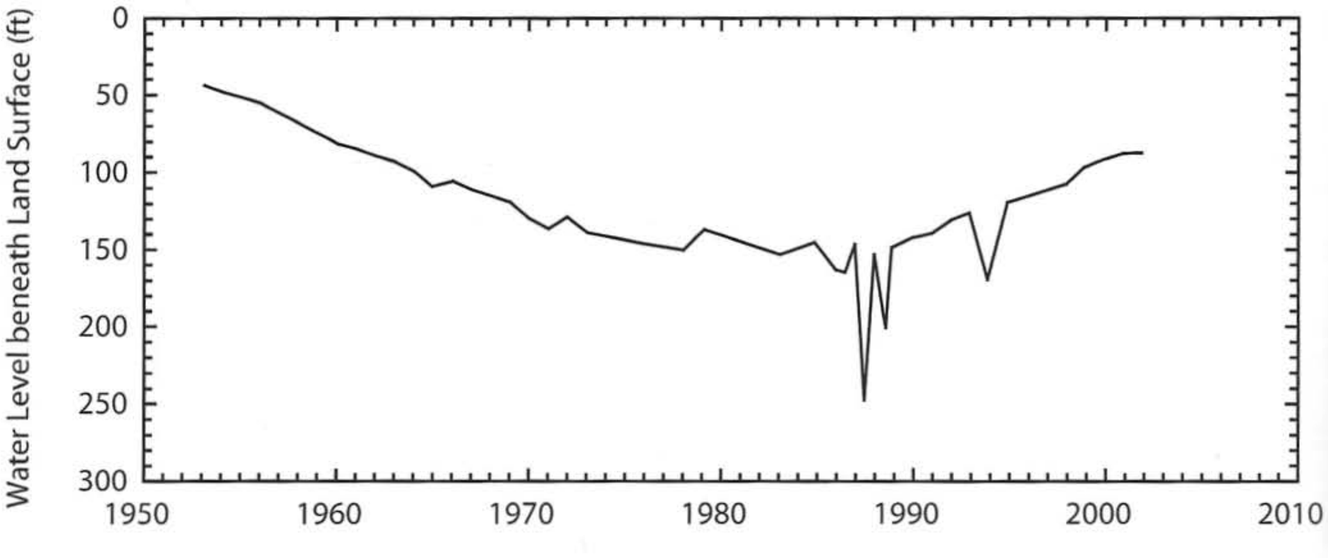

Figure 26.3 Groundwater levels for well D-04-03 16CBB along the Gila River near Maricopa, Arizona.

Widespread development of the Gila River below present-day Painted Rock Dam began in 1857 with small-scale diversions. Floods destroyed these early dams, but the fertile valleys remained magnets to farmers. The first solution was drilling of irrigation wells in the 1910s, but ultimately surface water from the Gila and Colorado Rivers was needed. The Wellton-Mohawk Irrigation District was formed in the 1940s to irrigate 75,000 acres along the Gila River.[42] Painted Rock Dam, 181 feet high, was completed in 1960 to provide flood control for the lower Gila River.[43] This dam potentially impounds one of the largest reservoirs wholly within Arizona (by volume, 2.5 million acre-feet), but the 53,200-acre reservoir usually is dry. The largest discharge entering the reservoir was 220,000 ft^3/s during the February 1980 floods in central Arizona; the dam and spillways released 26,500 ft^3/s in February 1993 into a channel designed to pass 10,000 ft^3/s.[44] The sustained releases from Painted Rock Dam in 1993 damaged levees and inundated farmland, but the releases were an order of magnitude smaller than historical flood peaks in this reach.

Changes in Riparian Vegetation

Florence to the Salt-Gila Confluence

Although once lush with woody riparian vegetation, at least within certain specific reaches of perennial flow, the Gila River between Florence and its confluence with the Salt River is now usually dry. Flood flows from the Santa Cruz River basin have occasionally reached the Gila River near Laveen, notably in 1983 and 1993 (chapter 21). Otherwise, irrigation returns are the only sources of water in this reach. Groundwater levels near the river steadily declined as aquifers were pumped to supplement surface water (fig. 26.3). However, beginning in the early 1990s, water levels have rebounded, but not to heights sufficient to sustain riparian vegetation. The increase likely is the result of importation of CAP water extracted from the Colorado River combined with recharge of the alluvial aquifer during the 1993 flood.

Fourteen photographs at two locations document twentieth-century changes in riparian vegetation; no historical photographs show the riparian conditions orally described at the Piman villages. One of the few historical photographs in this reach shows an extremely wide and barren channel in 1915 (fig. 26.4A). Changes in the twentieth century, reminiscent of those in the San Juan River (chapter 8), are steady revegetation of the channel during the low-flow period of the midcentury drought (fig. 26.2A), but owing to groundwater declines and decreased surface flow the vegetation is mostly mesquite and tamarisk in xerophytic positions or plants typical of the Sonoran Desert. The 1993 flood release, which was sustained over a two-month period in February and March, simultaneously destroyed some of the xerophytic vegetation (fig. 26.4D) and caused some germination of cottonwood; several isolated individuals survive in this reach.

Where Interstate 10 currently crosses the Gila River, the channel already had become nearly devoid of riparian vegetation by 1903 (fig. 26.5A). The channel of the Gila River at the former gaging station at Laveen (fig. 26.1) sustains a nearly monospecific stand of tamarisk on flow that is either irrigation returns or infrequent floods on the Santa Cruz River (chapter 21). Downstream, the Gila River flows through a narrow valley between the Sierra Estrella and South Mountain, which may force groundwater toward the surface. Near the Gila's confluence with the Salt River, Frémont cottonwood has returned to the channel banks as a result of a change in both groundwater levels and Salt River flow regime.

The Gila-Salt Confluence to Gillespie Dam

The Gila River has perennial flow from its confluence with the Salt River to near Gila Bend owing to the combination of irrigation returns and sewage effluent from Phoenix and its suburbs

A

B

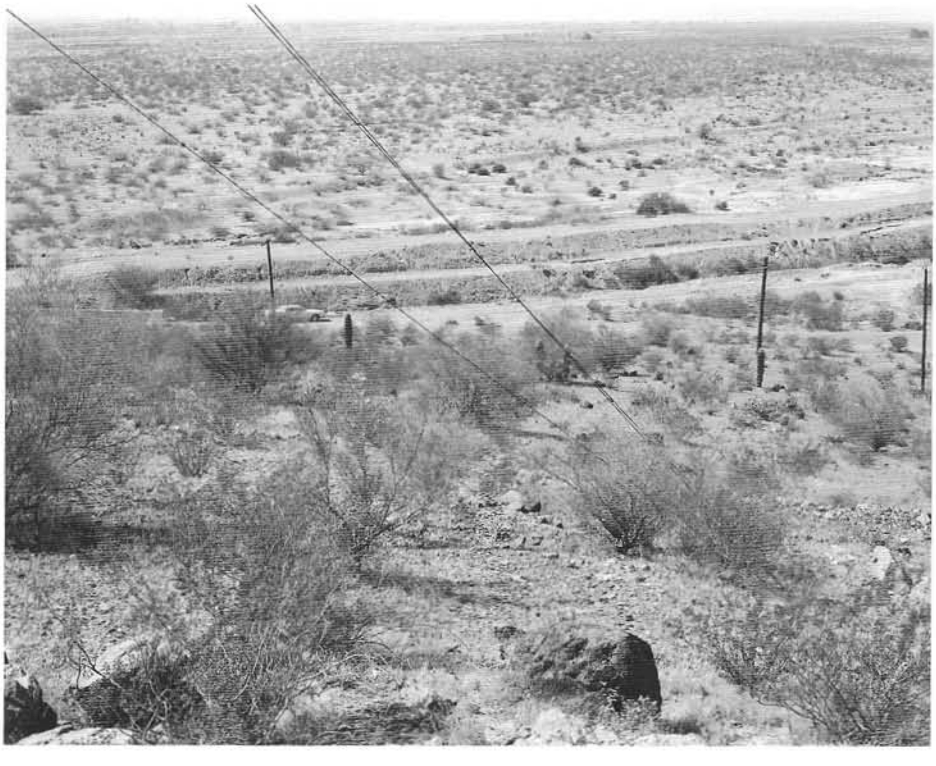

Figure 26.4 Photographs of the Gila River at Olberg, Arizona.

A. (March 17, 1915.) This downstream view on the Gila River, from a low butte adjacent to the right bank, shows an extremely wide, denuded channel with a thread of flow occurring in the right midground. The line of horse-drawn wagons is in place to repair a diversion dam that serves the canal leading to the right. An abandoned canal lies at the base of the butte below the camera station. This photograph was taken a few months after the devastating floods of February 1915 in the Gila River basin (see fig. 26.2C.) A few mesquite trees appear along the right bank, and an open grove of Frémont cottonwood appears on both banks in the background. (H. L. Shantz I-7-1915, courtesy of the Homer Shantz Collection, University of Arizona Herbarium, Tucson.)

B. (March 6, 1974.) The Gila River seldom flows in this reach owing to total diversion of surface water upstream at the Ashhurst-Hayden Dam, about 40 miles upstream. Xerophytic shrubs, including mesquite, catclaw, and creosote bush characteristic of the Sonoran Desert lowlands, appear where the river once flowed. A hint of obligate riparian trees remains in the background, although they may be trees planted around houses. (R. M. Turner.)

into the Salt River. Groundwater levels have been high at this confluence, both historically and currently, and a cottonwood-willow forest persists at this point within a sea of tamarisk in the wide floodplain. One analysis shows that riparian vegetation in the channel was nearly nonexistent around 1900 but peaked in the 1930s immediately following construction of Coolidge Dam.[45] In 1971, the area of tamarisk with greater than 50 percent cover was 5,900 acres in this reach, and a total of 11,540 acres had tamarisk.[46] This tamarisk grove is highly valued for its White-winged and Mourning Dove populations, as indicated by the establishment of the Robbins Butte and Arlington State Wildlife Areas in this reach. Thick groves of mesquite and catclaw are behind the tamarisk-dominated floodplain.

Gillespie Dam, built as an irrigation diversion structure in 1921,[47] almost immediately filled with sediment (fig. 26.6A). Nine photographs document changes in riparian vegetation at this site. Riparian vegetation began growing almost immediately in the wide delta area, and this environment became prime habitat for tamarisk. Gillespie Dam breached during the 1993 flood (fig. 26.6C), which caused the channel to downcut through the former delta, lowering its groundwater level. Fires here have burned some of the dense stands of tamarisk, which may not regain their former density owing to the lowered water table. The filled reservoir supports mostly dense groves of tamarisk, but some areas, closer to the active channel level, support cattail.

Gillespie Dam to Yuma

Downstream from Gillespie Dam, the Gila River flows south to Gila Bend and the delta of Painted Rock Reservoir. This reach—including the usually dry reservoir—is lined with agricultural fields that grow primarily alfalfa and cotton. These fields are irrigated with a combination of groundwater and surface water, and as in many other alluvial aquifers in the desert region of Arizona, groundwater levels have had precipitous declines (fig. 26.7). Water levels rebounded with the frequent floods between 1977 and 1983 (fig. 26.2B). Native and nonnative riparian vegetation is common along the river upstream from the reservoir.

At Gila Bend, the river's course swings westerly for its last reach of more than 100 miles to its confluence with the Colorado River. Its first 30 miles are within the boundaries of Painted Rock Reservoir. Four historical photographs document postdam changes in riparian vegetation here (fig. 26.8) and downstream from Painted Rock Dam. Owing to periodic inundation—the most recent occurred in 1993—the vegetation here is either tamarisk, riparian shrubs, or xerophytic species associated with disturbance.

Below Painted Rock Dam, the Gila River is mostly dry until irrigation returns associated with the Wellton-Mohawk Irrigation District add some flow to the channel. The combination of flow regulation upstream and agricultural clearing changed much of the riparian vegetation in this reach. Tamarisk encroachment was significant enough to prompt large-scale clearing of 2,700 acres along 142 miles of channel between 1958 and 1959.[48] By 1970, most of the vegetation in this reach was tamarisk within the floodplain and mesquite on the nearby uplands.[49] Riparian vegetation occupying 16,400 acres along the Gila River upstream from Dome was mapped on 1970 aerial photography.[50] At that time, tamarisk occupied half of the mapped area. Other nonnative species of note were giant reed, found in association with cattail assemblages adjacent to standing or slow-moving water, and tree tobacco, associated with tamarisk-arrowweed assemblages.

Twenty-two photographs associated with the gaging station on the McPhaul Bridge near Dome, Arizona, document changes in riparian vegetation (fig. 26.9). Flow regulation by Roosevelt and Coolidge Dams and the midcentury drought have drastically reduced the size of floods at this site (fig. 26.2C). The channel has narrowed considerably through the combination of reduced flow and channel stabilization (fig. 26.9B), and agricultural development of floodplains has reduced the amount of riparian vegetation, including both cottonwood and mesquite. Riparian vegetation now consists of the combination of a narrow line of cottonwood, with dense tamarisk behind and mesquite on the far margins of the channel.