TUCSON'S SANTA CRUZ RIVER
AND THE ARROYO LEGACY

by

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Dissertation Director Paul S. Martin — Date 11/21/88

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Signed Julio L. Betancourt

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ABSTRACT

Between 1865 and 1915, arroyos developed in the southwestern United States across diverse hydrological, ecological and cultural settings. That they developed simultaneously has encouraged the search for a common cause--some phenomenon that was equally widespread and synchronous. There are few southwestern streams for which we have even a qualitative understanding of timelines and processes involved in initiation and extension of historic arroyos. Tucson's Santa Cruz River, often cited in the arroyo literature, offers a unique opportunity to chronicle the arroyo legacy and evaluate its causes. The present study reconstructs both the physical and cultural circumstances of channel entrenchment along the Santa Cruz River. Primary data include newspaper accounts, notes and plants of General Land Office surveys, eyewitness accounts, legal depositions, and repeat photography.

On the Santa Cruz River, arroyo initiation and extension happened during relatively wet decades associated with frequent warm episodes in the tropical Pacific (El Niño conditions). Intensified El Niño activity during the period 1864-1891 may be symptomatic of long-term climatic change, perhaps indicative of global warming and destabilization of Pacific climate at the end of the Little Ice Age. During this period all but one of the years registering more than three days with rain exceeding 2.54 cm (1 in) in Tucson were El Niño events. The one exception was the summer of 1890, when the central equatorial Pacific was relatively cold but when prevailing low-surface pressures and low-level winds nevertheless steered tropical moisture from the west coast of Mexico into southern Arizona. In the twentieth century,

catastrophic channel widening was caused by floods during El Niño events in 1905, 1915, 1977 and 1983.

The Santa Cruz River arroyo formed when climatic conditions heightened the probabilities for occurrence of large floods in southern Arizona. Inadequate engineering of ditches that resulted in abrupt changes in the longitudinal profile of the stream further augmented probabilities that any one of these floods would initiate an arroyo. In the future, changing flood probabilities with low-frequency climatic fluctuations and improved flow conveyance due to intensified land use and channel stabilization will further complicate management of the arroyo in an increasingly urbanized floodplain.

CHAPTER 1: INTRODUCTION

Between 1865 and 1915, most major alluvial valleys in the southwestern United States experienced development of mainstem arroyos in previously unentrenched reaches. In a matter of decades, and sometimes during a single flood, streams that flowed across unincised alluvial fills became entrenched between vertical walls several meters below valley surfaces. The economic consequences of this seemingly synchronous and widespread event were devastating. Accelerated erosion resulted in destruction of farm and grazing lands, obliteration of irrigation and other water works, lowering of local water tables, loss of biotic diversity with deterioration of riparian and aquatic habitats, catastrophic silting of reservoirs, and depopulation of settlements.

Locally, arroyos were perceived as anomalous and undesirable, bringing economic ruin to what had been or might have become productive land. Initiation of arroyos received little national attention, however, in part because it reinforced "the forbidding image of an American Sahara" (Smith, 1975), and thus threatened railroad promotion and land speculation by Eastern capitalists. As with John Wesley Powell's (1878) warning that only a fraction of the West was irrigable, arroyo formation did little to discourage the tenacious Eastern dream of making that area west of the 98th Meridian, the Great American Desert, bloom.

Though there was immediate economic incentive for studying arroyos, the relevant disciplines, such as geomorphology, were only in their infancy and several decades passed before the origin and dynamics of historic arroyos attracted scientific attention. Powell's concept of base level, G.K. Gilbert's notion of the graded stream, and W.M. Davis' geographic cycle, born from early explorations in the West, were little more than a decade old when arroyos began to happen on a grand scale. Few geologists were on hand to witness or report on accelerated erosion before the turn-of-the-century. When arroyos first attracted scientific interest, beginning with Dodge's (1902) observations at Chaco Canyon, investigators were forced to rely on historical information, be it the recollections of a ranch foreman, a photograph, or a newspaper account. As such, arroyos made historians out of earth scientists (and vice versa), joining the archive with the equation (Cooke and Reeves, 1976).

Archives have long ceased being the exclusive domain of historians and social scientists. They have achieved special status in reconstructing landscapes and climates of the past where conventional or standard measurements are unavailable. In the Southwest, the historical record would seem indispensable for arroyo studies, more so as critical eyewitnesses passed away during the first half of this century. Surprisingly, only a few classic studies, such as Burkham (1970) for the Gila River, Cooke and Reeves (1976) for streams in southern Arizona and coastal California, and Williams (1978) for the Platte and North Platte in Nebraska, fully exploit the archives. Insufficient documentation in what were and have remained remote areas of the Southwest may partly explain this oversight. Nevertheless, several southwestern cities evolved on the banks of changing rivers and with them accumulated a rich historical record.

The present study, focused on the Santa Cruz River in southern Arizona, grew out of appreciation for the vast archives that accrued as the valley's largest settlement, Tucson, evolved from mud-walled village to modern metropolis (Figure 1). The stream rises in the San Rafael Valley near the

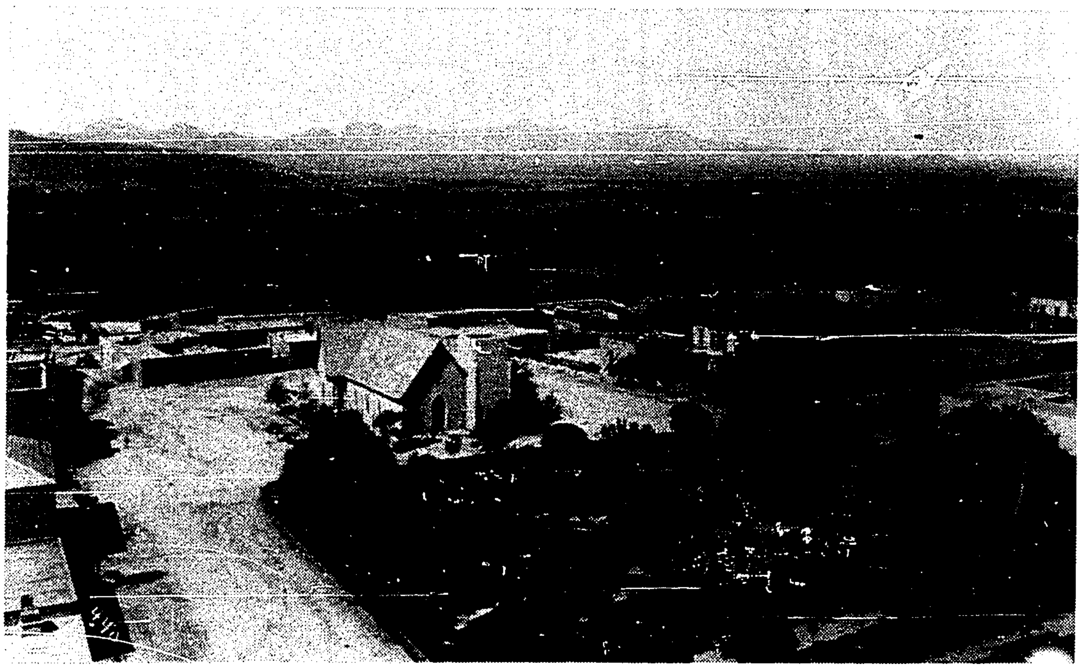


Figure 1. Tucson and the Santa Cruz Valley looking northwest ca. 1890, taken from the Pima County courthouse with the Plaza de Armas (now Presidio Park) in the foreground. Happenings on the river were chronicled by the *Arizona Daily Star* and *Tucson Citizen*, local newspapers whose offices were just a few hundred meters west of the Santa Cruz floodplain (Photograph taken by Henry Buehman, Arizona Historical Society, Negative No. 45079).

Arizona-Mexico border and sputters northeast past Tucson to an occasional union with the Gila, a total basin area of 23,300 sq km. The Santa Cruz has been often cited as an example by some of the major protagonists in the arroyo-cutting debate (Huntington, 1914; Bryan, 1925; Antevs, 1952; Hastings, 1959; Hastings and Turner, 1965; Cooke and Reeves, 1976; Dobyns, 1982; Hendrickson and Minckley, 1985). However, a full accounting of how the stream has changed does not exist.

Here, historical data are developed to reconstruct both the physical and cultural circumstances of arroyo formation along the Santa Cruz, and to evaluate potential causes, principally those having to do with land use and climate. The stream's history is chronicled from Spanish Colonial times to the present day to determine what pre-arroyo conditions were like, to show how and when the arroyo developed relative to land use and precipitation-runoff events, and lastly how the arroyo legacy relates to floodplain management in the modern, urban setting.

The genesis of historic arroyos is of broad interest to alluvial geologists and geomorphologists. Arroyo formation is recognized as a fundamental process by which sediment is transported episodically along ephemeral streams through a series of cut-and-fill cycles (Patton and Schumm, 1981). Much uncertainty remains over what causes a stream to cut or fill.

Regional synchroneity of arroyo formation (from one drainage to the next) implies shifts in regional climate (or pervasive human actions), whereas asynchroneity reflects differences in the physical characteristics and history of each drainage basin. The standard for synchroneity is the most recent cutting, which happened along several southwestern streams within a few decades. Regional synchroneity has also been claimed for prehistoric arroyo-cutting episodes (e.g., Haynes, 1968; Euler et al., 1979), though tests of synchroneity are complicated by the fragmentary nature of stratigraphic evidence and the large uncertainties associated with radiocarbon dating. In the stratigraphic record paleoarroyos are dated to the interval between the youngest obtained age of deposition before cutting and the oldest obtained age of fill in the arroyo. The resolution is usually no better than a few hundred years, though such a lengthy interval may in fact define the time it takes to complete a single cut-and-fill cycle. Nevertheless, there is little assurance that the close synchroneity of 19th century arroyos was duplicated at other times during the Holocene. Despite this, understanding how historic arroyos developed may contribute to knowledge about how they may have formed in the prehistoric past or how they may behave in the future.

By necessity, I have taken a relatively unorthodox approach to what is essentially a geomorphic problem, relying on written observations and photographs as primary evidence. Modern field evidence amounts to little more than a deep trench dissecting a highly disturbed floodplain. Widening of the historic arroyo during recent floods, particularly in 1977 and 1983, removed much of the stratigraphy indicative of pre-entrenchment conditions (Waters, 1988). A few qualifications are perhaps warranted in the use of historical sources. Second-hand accounts, newspaper coverage, reminiscences, correspondence, and legal depositions must be evaluated for personal, economic, or political motives that may taint the accuracy of observations. For example, to drum up support for establishing a mission in the Tucson Basin, the Jesuit missionary, Eusebio Kino, likened the irrigation potential along the Santa Cruz to that of Mexico City, a hyperbole that casts suspicion on other observations by Kino.

One popular source of historical data is the cadastral surveys commissioned by the U.S. General Land Office (e.g., Burkham, 1972; Cooke and Reeves, 1976). The GLO surveys can be trusted, with a few notable exceptions. During Henry Atkinson's tenure (1876-1884) as Surveyor General of New Mexico, false applications for township surveys and manufactured field notes were a common affair. In his chaining notes, one surveyor described dense mesquite growing on coppice dunes in what was actually a barren, gypsiferous playa. This playa is the sediment source for the White Sands and now serves as an alternate air strip for the space shuttle (Eidenbach and Wimberly, 1980). Fictitious surveys and gross errors during the Atkinson administration also rendered the GLO surveys worthless for Bryan's (1954) study of channel trenching in Chaco Canyon.

Another problem in interpreting historical data is the reliability of negative evidence. Nineteenth-century surveyors faithfully recorded channel widths, but were more lax about channel depths. Along the San Pedro River in southern Arizona, the journals of itinerants between 1849 and 1884 describe discontinuous arroyos, with perpendicular banks 3 to 6 m deep (Hendrickson and Minckley, 1985). In 1873, however, GLO surveyor Theodore White failed to report any channel depths along these reaches (Cooke and Reeves, 1976). As such, the recording of channel depths in GLO surveys was obviously haphazard and cannot be taken as evidence for unincised floodplains.

Many historical sources, mainly the newspapers, tend to focus on extreme and rare events of economic consequence, such as floods. The detail of such reports is understandably proportional to proximity to the nearest settlement or costly damage to waterworks and farmland. Where erosion occurred in fallow or unoccupied land, it seldom made the newspapers. This uneven coverage may give the false impression that some reaches were more afflicted than others.

Old photographs add clarity to the written word, as will hopefully become evident in pages to follow. They can be thought of as benchmarks, as anyone appreciates who has reoccupied the original camera station and documented changes between then and now (Rogers et al., 1984). Finding old pictures is relatively easy in any southwestern town, where archival efforts are fueled by public nostalgia for the past and the inevitable historical society.

In the Southwest, environmental historians tend to generalize about so-called presettlement conditions- what were they like before the onslaught of human impact? Observations made over decades, if not centuries, are conveniently lumped with the underlying assumption that presettlement landscapes were relatively stable until disrupted by European settlement. At the risk of redundancy, a different tack was taken to reconstruct pre-arroyo conditions along the Santa Cruz. Repeated observations of the same phenomena, be they unincised floodplains or groundwater outcroppings along the streambed, were duly noted to infer long-term stability. Equal attention was given to the possibility that perennial reaches may have elongated or shortened, or that discontinuous arroyos developed during the two centuries prior to accelerated erosion.

Though some readers may find the style cumbersome, the historical narrative about the Santa Cruz (Chapters 4, 5, and 6) is liberally doused with timely quotes from the newspapers of the day or other relevant sources. Paraphrasing was avoided, in part because the accounts constitute primary data and should be subject to the reader's own interpretation, but also because the prose often was fresher than mine. The narrative, which attempts to weave observations about the Santa Cruz in the cultural and historical context of the times, is organized chronologically. Wherever possible, great care was taken to record the reactions of Tucsonans to the river's metamorphosis, particularly when an opinion was rendered as to the causes.

In considering climate, it is indeed fortuitous to be writing at a time when knowledge about the complex link between global and regional climates is unfolding. The El Niño event of 1982-83, the most catastrophic version of this phenomenon in recent times, heightened scientific and public awareness worldwide. Drought was the case in many parts of the world, most severe over southern India, southeast Africa, eastern Australia, and the Amazon Basin. Elsewhere, there was record rainfall. The Peruvian coastal desert experienced the heaviest rains of the past few centuries, while flooding and rises in sea level wiped out the entire seabird community of Christmas Island in the equatorial Pacific (Rasmusson, 1985).

El Niño conditions during 1983 also got the attention of floodplain dwellers and managers throughout southern and central Arizona, as some of the largest floods on record caused damage approaching half a billion dollars. The El Niño of 1982-83 captured the imagination of those embroiled in the arroyo debate, many who now recognize the coincidence between the catalogue of warm events in the tropical Pacific and floods that produced significant channel changes during the past century (Wells et al., 1988). Such a coincidence could hardly be ignored for the Santa Cruz. Hence, much of the climatic discussion revolves around El Niño-Southern Oscillation (ENSO) conditions and their relation to southwestern weather.

To identify climatic patterns, I have chosen to work primarily with the Tucson precipitation record from 1868 to 1984. This is not to assume that Tucson faithfully represents point rainfall throughout the watershed. It does not. It does, however, serve as a useful guide to precipitation patterns through time that are generally representative of southern Arizona. In several instances, I have relied on qualitative observations from the archives to infer sources of moisture and types of storms that contributed to major flooding and erosion. These inferences are not trivial to the overall effort.

It will be argued here that, for large southwestern watersheds (>1000 sq km), certain types of storms produce the most extreme runoff events. These storms are generated by large-scale atmospheric circulation and sea surface temperature anomalies that tend to persist or recur during "wet" decades. A major implication of this pattern is that major erosional floods do not occur randomly in time, but are imbedded in the persistent atmosphere-ocean interactions associated with "wet" periods.

Finally, no matter what the climate, historic arroyos coincided with intensified land use as the West was being settled. Hence the question of what caused these arroyos only duplicates the dilemna now facing most environmental scientists. In considering change, be it global or local, we first must disentangle natural from cultural factors.

CHAPTER 2: THE GREAT ARROYO DEBATE

Much debate has focused on the regional and local causes for historic arroyo-cutting, the most recent summaries furnished by Cooke and Reeves (1976) and Graf (1983). In many respects, the various explanations for why arroyos happened have reflected professional interests (Bailey, 1935; Cooke and Reeves, 1976; Graf, 1983). Range managers have been quick to suggest removal of plant cover by livestock, whereas climatologists have naturally looked to the skies for an explanation. The geologist, accustomed to the products of erosion over long periods of time, sees arroyos as symptomatic of inherent instability in arid landscapes, while acknowledging that geomorphic thresholds may be exceeded with changes in climate and vegetation. The engineer, entrusted with flood control and design of structures spanning alluvial channels, is much less interested in why arroyos were initiated than in how they behave once established.

Arroyos continue to be studied today with increasing sophistication; nevertheless, the various specialists have yet to reach a concensus. In 1969, a judge ruling on a controversy over the geomorphic consequences of logging in California redwood forests summed it up as follows:

> While numerous expert witnesses in the field of geology, forestry, engineering, and biology were presented, their conclusions and the opinions they derived from them are hopelessly irreconcilable in such critical questions as how much and how far particles will be moved by any given flow of surface water. They were able to agree only that sediment will not be transported upstream (State of California, Marin County versus E. Richeletti and others, 1969, cited in Wolman, 1977).

In the arroyo controversy, there are multiple indictments, a veritable army of expert witnesses, insufficient evidence, and no real verdict. The moral of this story, certainly the one that is acknowledged by now, is that historic arroyos are a far better subject for study than for debate.

Explanations for arroyo-cutting fall into five general categories: livestock grazing, direct and indirect manipulation of streamflow by man, climatic change, extraordinary floods, and intrinsic geomorphic factors. The most long-lived indictment, leveled by scores of researchers from Dodge (1902) to Alford (1982), involves the role of livestock in compacting soils, focusing runoff in well-worn trails, and stripping vegetation from hillsides and valley floors.

Cows and Gullies

There are two key objections to grazing as a regional cause for historic arroyos. First, what Gregory and Moore (1931) termed epicycles of erosion, evinced by alluvial terraces, erosional unconformities, and buried paleochannels, occurred many times over prior to the introduction of cattle (and after extinction of native megaherbivores some 11,000 years ago). This reasoning led Tuan (1966) to omit grazing from his widely-cited review of New Mexican gullies. Though geologic evidence establishes that arroyos can form naturally, however, it does not exclude grazing as the primary reason for the most recent episode of erosion. If past vegetation changes induced by climate account for development of paleoarroyos, perhaps a case can be made for historic overgrazing as causing the most rapid and pervasive deterioration of western grasslands over the last 10,000 years. The uncertainty about overgrazing as a cause for arroyo-cutting is actually twofold: will livestock alter vegetation in such a manner that erosion is enhanced and does erosion intensity depend on vegetation cover? Neither question has been resolved.

A second objection to the livestock hypothesis has to do with grazing history relative to dates of arroyo initiation. Hastings and Turner (1965) point out that arroyos were initiated at the same time in Sonora and southern Arizona, even though extensive stock raising began two centuries earlier in Sonora. They concede that, while the ranges of Sonora might have been as crowded two centuries earlier, range conditions then might have been more favorable. For the upper Rio Grande, Denevan (1967) documented high livestock numbers in the period 1788-1848 with little or no gullying. Dobyns (1981) counters that this early grazing and trampling had a lagging effect on the landscape, with the final blow dealt by large flocks and herds of the 1870s and 1880s. Modern studies of rangeland hydrology relative to grazing pressure have been far from conclusive (Branson et al., 1981), and the relationship between livestock and gullies remains tenuous at best. Relevant hypotheses have gone untested - e.g., Melton's (1965) suggestion that sediment contributed from grazed hillsides steepened transverse gradients across valley floors, increasing flow depths and velocities.

Other Human Actions

Consequences of human land use other than livestock grazing have received little attention in the arroyo literature. Artificial concentration of streamflows increases hydraulic radii (the channel's cross-sectional area divided by its wetted perimeter) and flow velocities, resulting in greater stream power. Ways in which this can be accomplished include constriction of flows at bridge sites, artificial embankments, ditches, roads, and of course, stock trails (Cooke and Reeves, 1976). Historical anecdotes establish the link between initial arroyos and these artificial features on southwestern floodplains. In many cases, headcut migration followed the path of an abandoned wagon road, a ditch, or a railroad grade. Other human actions linked to arroyos include placer mining, deforestation of uplands and floodplains, extermination of beaver populations, draining of natural marshes or cienegas, and fire suppression in encouraging shrublands over grasslands (Dobyns, 1981).

Overall, human activity has been linked to concentration of flows, decreased hydraulic roughness, increased peakedness of flood hydrographs, and increased tractive forces. As with the grazing hypothesis, evidence for previous epicycles of erosion figure prominently in the counterargument. Several authors reason that widespread erosion during A.D. 1100-1400, dated mostly by archeological evidence, was clearly unrelated to man's activities, be it overgrazing or the artificial concentration of flows (Bryan, 1927; Miller and Wendorf, 1958; Leopold, 1976; Tuan, 1966). Ironically, prehistoric farmers during this period, be they the Anasazi on the Colorado Plateau or the Hohokam in the Sonoran Desert, may have outnumbered the rural population of the Southwest in the late 19th century. These prehistoric farmers harnessed streamflow to grow crops in ways not radically different from European practice. Their activities invite our attention.

It is curious that prehistoric human impact has been largely overlooked as a potential explanation for 12th-15th century arroyo-cutting. This oversight may be deeply rooted in the romanticized concept of the Noble Savage and his presumed conservation ethic, a sort of ecological hero who could walk through the forest without snapping a twig (Diamond, 1986). Scientists have not been immune from such sentiments, as reflected by Tuan's (1966) statement that, "Since prehistoric Indians lacked livestock, and since it is commonly believed that they did not despoil nature, the origin of the fossil trenches cannot readily be attributed to humans." This assumption was challenged initially by Calkins (1941, p. 77-78) in reviewing one of Bryan's (1941) papers:

> It is rather interesting to note that Doctor Bryan has used the evidence of human occupation found in ancient buried channels to strengthen his theory of an arid period causing erosion....With equal force, the available evidence can be used to support a belief that the ancient channels may have been caused by accelerated erosion directly related to human occupation.... It seems to be the general conclusion that these ancient peoples practiced some method of flood irrigation, diverting water from ephemeral streams to irrigate their crops. The effect of this practice would be that only the infrequent, high discharges would be allowed to pass down the valley. That lower portion of the valley, deprived of its plant sustaining low flows, would be subjected to a much greater erosion hazard than would have been the case naturally.... It would seem to be more remarkable if erosion did not occur with human occupation than that it did.

It would seem even more remarkable if prehistoric farmers understood arroyos well enough to avoid them, as Tuan implied, while the causes of arroyo-cutting still elude the modern-day geomorphologist.

Cyclical Drought and the Erosion-Deposition Seesaw

To many geologists, the synchronous and widespread nature of historic arroyo formation implies regional climatic change as a principal cause. For the alluvial geologist, there is much at stake in this interpretation. Were it true, it would give climatic meaning to a chronology of geomorphic and stratigraphic details, presumably in phase over a vast area. This task would seem relatively straightforward if not for polarized views of how climatic change figures in alternating phases of erosion and deposition. Both processes have been linked to cyclical drought. Underlying climatic interpretations of cutting and filling is the assumption that vegetative cover is the immediate factor affecting erosion, which in turn is controlled by precipitation. The debate took place in the early part of this century.

As Dutton (1882) and Davis (1902) saw it, stream gradients represent a balance between the erosion and transportation of sediments, with the volume and character of the sediment strongly adjusted to climate. Aridity would steepen stream gradients and produce aggradation, while a shift to humid conditions would reduce the gradient and lead to entrenchment. Huntington (1914) later applied this rationale to explain alluvial terraces and arroyo cutting in the Southwest, no doubt influenced by Davis during their joint expedition to Russian Turkestan.

According to Huntington, loss of vegetative cover during dry episodes promotes rapid removal of soil on hillslopes, overloading streams and bringing on alluviation. A shift towards more humid conditions would have the opposite effect. Improved vegetative cover on hillslopes would tend to reduce fluvial sediment loads, resulting in clearer, more erosive flows. This model, associating entrenchment with wetter conditions, remained the minority opinion until recently (Tuan, 1966; Hall, 1977; Knox, 1983; Love, 1983), even though historic arroyos appear to have been initiated by large floods during a sequence of wet years (e.g., 1884-1891, 1904-1920).

The flipside of the erosion-deposition seesaw was first championed by Bryan (1928), on whose Ph.D. dissertation committee Huntington served. Bryan reasoned that prolonged drought would deplete vegetation, reduce infiltration, and thus amplify the effect of storm runoff. Greater discharge along valley bottoms would initiate gullying in critical reaches with discontinuous arroyos integrated by headcut migration during subsequent floods. Bryan claimed that arroyo-cutting was already imminent when cattle were first introduced, that the gun was already loaded when triggered by overgrazing. In fact, it was Huntington (1914) who first alluded to overgrazing as the trigger-pull that initiated an already impending change, a turn-of-phrase now attributed to his student.

More recently, some authors (Haynes, 1968; Euler et al., 1979) have argued that greater aridity lowers ground-water levels and thus increases the erodibility of fine-grained, unconsolidated sediments overlying water-saturated strata along axial drainages. Leopold (1976) further maintained that arroyos near Santa Fe, New Mexico experienced alluviation during 1960-1975, a period characterized by cooler and wetter conditions. However, he failed to demonstrate that the rates of alluviation during this time exceeded those in the previous three decades that were dominated by drought.

Bryan's hypothesis was embraced by alluvial stratigraphers, particularly those working closely with archeologists (e.g., Hack, 1939; Antevs, 1952; Leopold and Miller, 1954; Haynes, 1968; Euler et al., 1979). Their enthusiasm for the desiccation-erosion hypothesis arose not from analysis of historic arroyos, but from the coincidence of prehistoric erosion during a "hot-dry Altithermal" (5500-2000 B.C.) throughout the West (Antevs, 1955) and the "Great Drought" (A.D. 1266-1299) on the Colorado Plateau. This influence is readily apparent in stratigraphic summaries for the Colorado Plateau, where three depositional layers, the Jeddito, Tsegi, and Naha formations, are thought to have been punctuated by the aforementioned droughts and their attendant erosion (Hack, 1939). Haynes (1968) found further support for the model from a systematic evaluation of radiocarbon dates in Holocene alluvium.

Light vs. Heavy Rains

Several authors have recognized the need to quantify climatic change and its possible effects on geomorphic processes. Leopold (1951) undertook analysis of rainfall data in New Mexico to dispute a claim by Thornthwaite et al. (1942) that no significant trends were obtainable in climatic records from the Southwest. While no trend was apparent in annual rainfall, Leopold maintained that the period of heaviest grazing between 1850-1880 was characterized by higher daily rainfall intensities than have been measured since (see also Leopold et al., 1966).

Leopold maintained that light rains (daily rainfall of <1.27 cm) favored plant productivity, so that fewer light rains and more frequent heavy rains (daily rainfall of > 1.27 cm) would result in greater runoff and perhaps the erosional episode of the late 1800s. Leopold and Miller (1954) later invoked an intensified summer monsoon as the mechanism for increasing heavy over light rains. Martin (1963), in trying to explain palynological evidence for a wet Altithermal in southeastern Arizona, also suggested increased summer rainfall to account for both mid-Holocene and historic arroyos. In southern Arizona, Cooke and Reeves (1976) found no significant trends in annual or warm and cool season precipitation from 1868-1966. However, Knox (1978) has pointed out that a significant discontinuity in the 1890s was missed because of their inadequate grouping of data for statistical analysis. Cooke and Reeves (1976) did find that heavy (in this case, defined as >2.54 cm) rains increased over light (<1.27 cm) in summers of the 1870s and 1880s. Similar trends in rainfall intensities were also noted in central California by Bull (1964), who associated arroyo-cutting with periods of above normal daily and annual rainfall (1875-1895 and 1935-1945).

Assuming that daily rainfall totals correlate well with actual rainfall intensities and that early records of light rains are accurate, it is still unclear how a secular trend in light vs. heavy rains might affect productivity of southwestern vegetation and, ultimately, alluvial processes. Given the wide range of physiological and demographic responses of southwestern species to precipitation events, timing may be a far more important factor than intensity. At the Santa Rita Experimental Range south of Tucson, precipitation during a relatively brief period in summer accounts for most of the year-to-year variability in grass biomass of uplands (Cable, 1975). In the warm season, a series of light rains might not be as effective as heavy rains in penetrating to the root zone.

The rainfall intensity hypothesis remains inconclusive because of uncertainties in how light vs. heavy rains affect vegetation across the broad range of ecological settings that experienced arroyo cutting. More importantly, such secular trends may not be unique to the last hundred years, the only period for which we have adequate climatic data, and may characterize other times when arroyos failed to develop. Lastly, because the secular trends in daily rainfall intensity seem real, a more fruitful approach would be to study air mass phenomena potentially responsible for shifting the proportion of heavy to light rains. This issue is at least partly addressed by the current literature dealing with probable maximum precipitation in the Southwest (e.g. Hansen et al., 1977).

Perhaps there has been undue emphasis on vegetation effects all along. The real issue may be whether or not high rainfall intensities recognized for the late 19th century produced unusually large floods, irrespective of changes in plant cover.

Catastrophic Floods

If a concensus exists in the arroyo controversy, it is that initial downcutting was associated with extraordinary floods. Since Davis (1903), large floods in and of themselves have been considered as a principal cause of local stream degradation (Huntington, 1914; Gregory, 1917; Thornthwaite et al., 1942; Tuan, 1966; Love, 1983; Webb, 1985; Hereford, 1985). This conclusion stems from recognition that significant channel changes occur when discharge exceeds some threshold and produces channel instability. Catastrophic floods may not be sufficient to explain synchronous arroyo development across a broad region if they represent random events in space and time, as assumed in probabilistic treatments of hydrologic processes. However, large floods over a large region tend to cluster in time because large-scale atmospheric circulation conducive to unusual rainfall events normally persists for several years before dissipating (Knox, 1983; Hirschboeck, 1987).

Over the past century, most channel erosion in the Southwest was accomplished by large floods during the relatively wet periods 1884-1891, 1904-1920, and 1965-1987. Unfortunately, most stream gages were not installed until long after arroyos had developed. Whether or not historic floods were extraordinary in geologic time, during, say, the last one to two thousand years, seldom can be determined. However, recent hydrologic analyses of dated slackwater deposits in bedrock canyons suggest that floods of the past century represent the largest events for periods of up to 2000 years (Baker, 1985). On the Escalante River in Utah, paleofloods measured in slackwater deposits within bedrock canyons coincide with formation of paleoarroyos in alluvial reaches (Webb, 1985).

The Climatic Setting for Large Floods

The climatic setting for large floods in the Southwest has recently become the focus of research. This work was not inspired by the arroyo debate, but by the economic consequences of disastrous flooding in the last two decades. Though the costlier damage may be traced in part to greater construction in hazardous floodplains, in some cases flood peaks appear to have actually increased in magnitude and frequency. Are watershed changes due to progressive channelization, intensified land use, and increased urbanization of southwestern floodplains now translating moderate rainfall into higher flood peaks, or has there been a recent shift in general atmospheric conditions that features heavier rainfall? Both phenomena impose certain restrictions on deriving design and regulatory floods from standard methods of flood frequency analysis. In computing recurrence probabilities for flood events, these methods assume that the annual flood series is stationary (that the means and moments of the distribution do not change do not change with time).

Recent hydroclimatological research in the Southwest links various flood-producing storm types to configurations in large-scale circulation patterns (Maddox et al., 1980; Hirschboeck, 1985, 1987; Smith, 1986). Summer precipitation due to monsoonal circulation, which essentially repeats itself every year, is highly variable from station to station in a given year, but fairly consistent from year to year at a given station (McDonald, 1956). Summer monsoon floods exhibit similar characteristics. Tropical storms, cutoff lows, and winter frontal activity associated with heavy flooding result from unique atmospheric conditions, linked to high sea-surface temperatures in the northeastern Pacific and broadscale circulation anomalies. These storms appear to be the source of most significant increases above the mean in annual rainfall totals. Precipitation from one or more tropical storms may contribute more than half of the annual precipitation at a given station- e.g., Yuma, Arizona. Over half of the Pacific tropical storms that tracked inland during 1900-1983 produced significant flooding somewhere in the Southwest (Smith, 1986).

The relative importance of flood-producing storm types appears to vary through time. Like drought years, heavy rainfall events tend to cluster in time, suggesting that they are symptomatic of persistent anomalies in atmospheric circulation. The atmosphere generally shifts between two different states of large-scale motion, the stable one dominated by zonal flow, and the unstable one by meridional circulation (Fig. 2). Shifts between these two states have been linked to decadal differences in global temperature trends and regional climate (Dzerdzeevski, 1969; Kalnicky, 1974).

Persistent circulation anomalies are most often associated with meridional flow and blocking, defined as large-scale obstructions in the typical west-east flow of high and low pressure systems that take the form of a quasi-stationary long, Rossby wave (right lower panel in Fig. 2A). Blocking allows massive low pressure systems to develop along the Pacific coast, steering tropical storms and cyclones into the Southwest. During decades characterized by meridional flow, frequent blocking activity may produce temporal clustering of heavy rainfall and catastrophic floods. This blocking activity seems to be at least partly related to the ENSO phenomenon (Horel and Wallace, 1981).

Figure 2. Relationship between major circulation types and temperature trends in the twentieth century for the Northern Hemisphere. Broadscale movements of warm and cold air masses poleward or equatorward act to balance energy deficits at high latitudes and surpluses at low latitudes. The persistence of two types of broadscale circulation (zonal vs. meridional) is often used to characterize decadal climates: a.) The wave pattern of the upper air of the jet stream varies from 3 to more than 10 waves with a decrease in waves leading to zonal circulation (nearly direct west to east: upper panel) and an increase in waves to meridional circulation (more sinuous: lower panels). Meridional circulation tends to develop when the temperature deficit between high and low latitudes is greatest. The amplitudes of the waves increase until they break, leaving pools of cool air (cut-off lows) at low latitudes (right lower panel), which may give rise to unusual weather. The net result of meridional flow should be general cooling of the northern hemisphere. b.) Time series for number of days with zonal cirulation type in the northern hemisphere (Dzerzeevskii 1969). Note that the circulation was predominantly zonal in the middle part of the century, matching c.) reconstructions of annual surface air temperature anomalies for the northern hemisphere (Jones et al., 1982; Vinnikov et al., 1980).

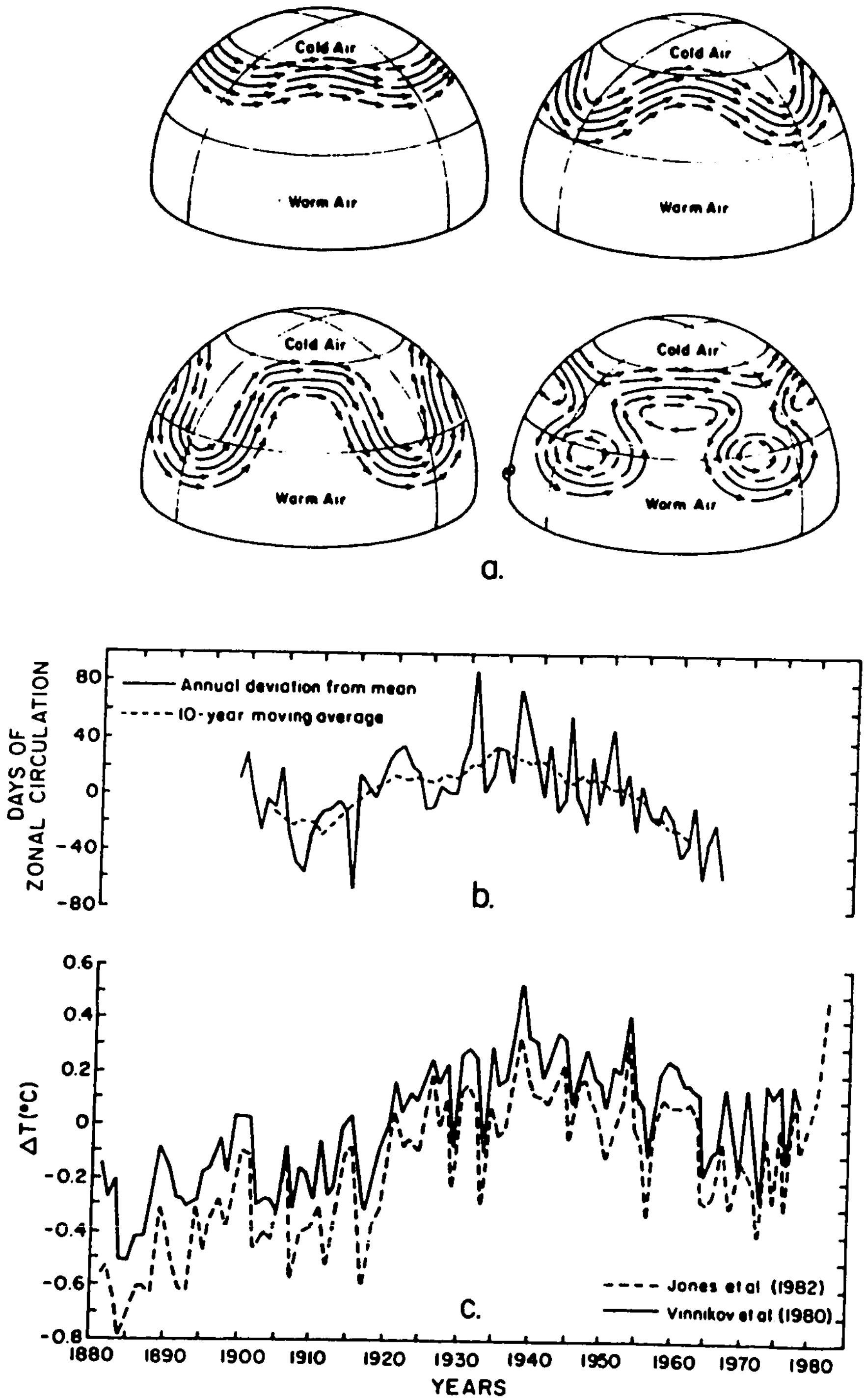

Cold Air
Warm Air
a.
DAYS OF ZONAL CIRCULATION
80
40
0
-40
-80
Annual deviation from mean
10-year moving average
b.
ΔT(°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Jones et al (1982)
Vinnikov et al (1980)
c.
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEARS

Figure 2

In Southern Hemisphere summers, a southward-flowing current brings warm waters to the normally-cold coast of Peru and Ecuador, signalling the end of the fishing season. Because it occurs around Christmas time, local fishermen named this current El Niño. Climatologists and oceanographers now reserve the term for an amplication of this seasonal warming, which occurs at intervals of 2 to 10 years and lasts for a year or more, crippling the local fishing industry, producing torrential rains in the Peruvian coastal desert, and more importantly, affecting weather worldwide. A number of authors suggest that the phenomenon exhibits two climatic (mainly opposite) states (ENSO vs. non-ENSO or El Niño vs. La Niña; Philander, 1985). At present, what forces ENSO phenomena is poorly understood.

The onset of a catastrophic El Niño is heralded in August-November by a reversal in the surface pressure gradient of the tropical Pacific (the so-called Southern Oscillation), with abnormally high pressure over Indonesia-northern Australia while that over the southeastern Pacific Ocean is abnormally low. In the tropical Pacific Ocean, salient features of an ENSO episode in its mature phase are: surface waters become unusually warm and the trade winds exceptionally weak over most of the area; the Intertropical Convergence Zone (ITCZ; where the southeast and northeast trades meet) is displaced southward and the Hadley circulation cell intensifies; the upward branch of the Walker circulation shifts from the western to the central Pacific Ocean; the normally-dry central and eastern Pacific experience precipitation surges, while the western Pacific is stricken by drought; intense eastward currents carry warm surface waters away from the western Pacific, where the sea level and depth of the thermocline drop sharply; and the tropical troposphere warms considerably, exciting large-scale planetary waves in the atmosphere that produce anomalies in extratropical circulation or large-scale teleconnections (Horel and Wallace, 1981; Philander, 1983; Rasmusson, 1984).

These air-ocean phenomena have been linked to anomalous weather not only in the tropics but also areas beyond. For example, during the intense ENSO episode of 1982-1983, links were established between heavy rains and flooding in coastal areas of northern Peru and southern Ecuador; severe drought in northeastern Brazil, much of Africa, Australia, Indonesia, and India, a relatively hurricane free season in the tropical Atlantic; and a wet, stormy winter over California, the southwestern U.S., and the Gulf states. On a global scale, El Niño may link the fates of a Peruvian fisherman, a farmer in Sri Lanka, and the owner of a condominium on a southern Arizona floodplain. However, the long-term stability of these apparent teleconnections is undetermined and, according to some authors, questionable (Ramage, 1983).

The ENSO phenomenon may partly explain why major floods would tend to cluster temporally in the southwestern U.S. Douglas and Englehart (1984) report a moderate correlation between El Niño activity in the tropical Pacific during the previous summer and heavy precipitation in the fall, and following winter and spring in the southwestern U.S. (see also Ropelewski and Halpert, 1986). It should not be surprising then to find some correspondence between the list of El Niño years and the roster of major southwestern floods over the past century. One of the more intriguing features of ENSO effects in the Southwest is the changing frequency of events over time and its correspondence to annual precipitation patterns. The droughty period between 1930-1960 is characterized by only three strong El Niño events (1932, 1940-1941 and 1957-1958), which produced marked precipitation surges and flooding in the region. A much higher frequency of ENSO episodes prior to

1930 and after 1960 coincides with relatively wet and flood-stricken periods.

Proponents of catastrophic floods as a cause for arroyos might argue that, under the climatic regime of the period 1860-1930, when arroyos were initiated and extended, a higher frequency of El Niño events heightened the probability for major floods and regional stream degradation. Conversely, fewer El Niño events between 1930 and 1960 resulted in fewer major floods and many of the arroyos tended to aggrade. A climatic cause for large floods and thus regional arroyo development remains fertile ground for more research.

Intrinsic Geomorphic Factors

Arroyo cutting and filling have long been recognized as the natural processes by which sediment is transported episodically along alluvial streams (Thornthwaite et al., 1942; Schumm and Hadley, 1957). Both field and experimental studies show that headcuts develop and erosion takes place when and where sediment stored in fluvial systems achieves a critical threshold slope and thus becomes unstable for certain discharge levels (Schumm and Hadley, 1957; Patton and Schumm, 1975, 1981; Schumm, 1979). A key point in this model is that intrinsic geomorphic processes can lead to local channel incision given adequate discharge (stream power). Because these processes vary, not only within a single drainage, but from one drainage to the next, short-term synchroneity of events on a regional scale should be the exception, not the rule. This constitutes one of the major criticisms of alluvial-climatic histories based on regional correlations of erosional and depositional episodes.

The concept of intrinsic geomorphic thresholds adequately explains discontinuous arroyos and poses a serious challenge to correlative schemes in alluvial stratigraphy. However, it does not explain how discontinuous arroyos coalesced to become continuous in the great variety of watersheds that became entrenched by the turn-of-the-century.

In summary, historic arroyos developed in a wide variety of hydrological, ecological, and cultural settings. That they developed more or less simultaneously has encouraged the search for a common cause-- some phenomenon that was equally widespread and synchronous. Despite the objections of alluvial geologists, it could easily be argued that development of coalescent arroyos, synchronized within a few decades and affecting most regional watersheds, happened only once in the last 10,000 years. Uncertainties of a few to several centuries cast doubt on regional correlations claimed for the erosional episodes of the middle Holocene (Haynes, 1968) and between A.D. 1100-1400 (Hack, 1942; Lance, 1963; Leopold, 1976; Euler et al., 1979). In southern Arizona, where the alluvial stratigraphy of several watersheds has been well studied, periods of degradation and aggradation are characteristically out of phase in number, character, and timing from one valley to the next (Waters, 1985). Even though arroyos are a natural part of the Holocene landscape, their most recent development probably has a unique origin, or at the very least, happened under a unique set of circumstances.

However suggestive this might seem, the genesis of historic arroyos remains unresolved. Some authors have been content to recognize equifinality, or probability of multiple causes (Cooke and Reeves, 1976), giving up the notion of a unique and singular regional explanation. Some 20 years later, Tuan's (1966, p. 595) reflections still hold: "In spite of prolonged interest, some careful work, and an extensive literature, our understanding of gullies in the American West lacks the tantalizing clarity of the landforms themselves." Perhaps part of the problem is that we have failed to become good historians, that our understanding of how and when particular arroyos formed is anecdotal, incomplete, and inaccurate. Certainly it is true that the historical record itself is scant, incomplete, and occasionally misleading. For whatever reasons, there are few southwestern streams for which we have even a qualitative understanding of timelines and processes involved in the initiation of coalescent, mainstem arroyos. Tucson's Santa Cruz River offers perhaps our best opportunity to chronicle the arroyo legacy.

CHAPTER 3: PROFILE OF A DESERT STREAM- THE SANTA CRUZ RIVER AND ITS ENVIRONMENTAL SETTING

The Santa Cruz rises in oak woodlands above 1600 m on the east slope of the Patagonia Mountains, the south slope of the Canelo Hills and the west slope of the Huachuca Mountains (Fig. 3). Sonoita Creek drains the west slopes of the Canelo Hills, passes between the Patagonia and Santa Rita Mountains, and joins the Santa Cruz at Calabasas. The north slope of the Hills drains into Cienega Creek and, via Pantano Wash, into the Rillito River, which joins the Santa Cruz in north Tucson. During a single storm, contributions from the three subwatersheds, each with its origin in the Canelo Hills, may accumulate as one peak at the confluences.

The Santa Cruz headwaters are gathered into a shallow, perennial channel that courses south through the rolling grasslands of the San Rafael Valley and on into Mexico. The river makes a 56-km loop past the old Sonoran settlement of Santa Cruz before re-entering Arizona 10 km east of Nogales. A short discontinous arroyo above Santa Cruz is the only entrenched segment of the river upstream of the Tucson Basin. In Sonora, the river's perennial flow is captured by wells and infiltration galleries for agricultural and minor municipal use. The flow is again perennial from the mouth of Potrero Creek to Tubac, as it was historically. The current flow, though, may owe its permanence to effluent discharged since the late 1960s from the Nogales Wastewater Treatment Plant at the mouth of Potrero Creek (Applegate, 1981). Downstream from Tubac, infiltration into the sandy streambed occurs at a rate of about 230,000-390,000 cubic meters per km and the stream is normally dry (Condes de la Torre, 1970). In winter, the stream frequently flows to just south

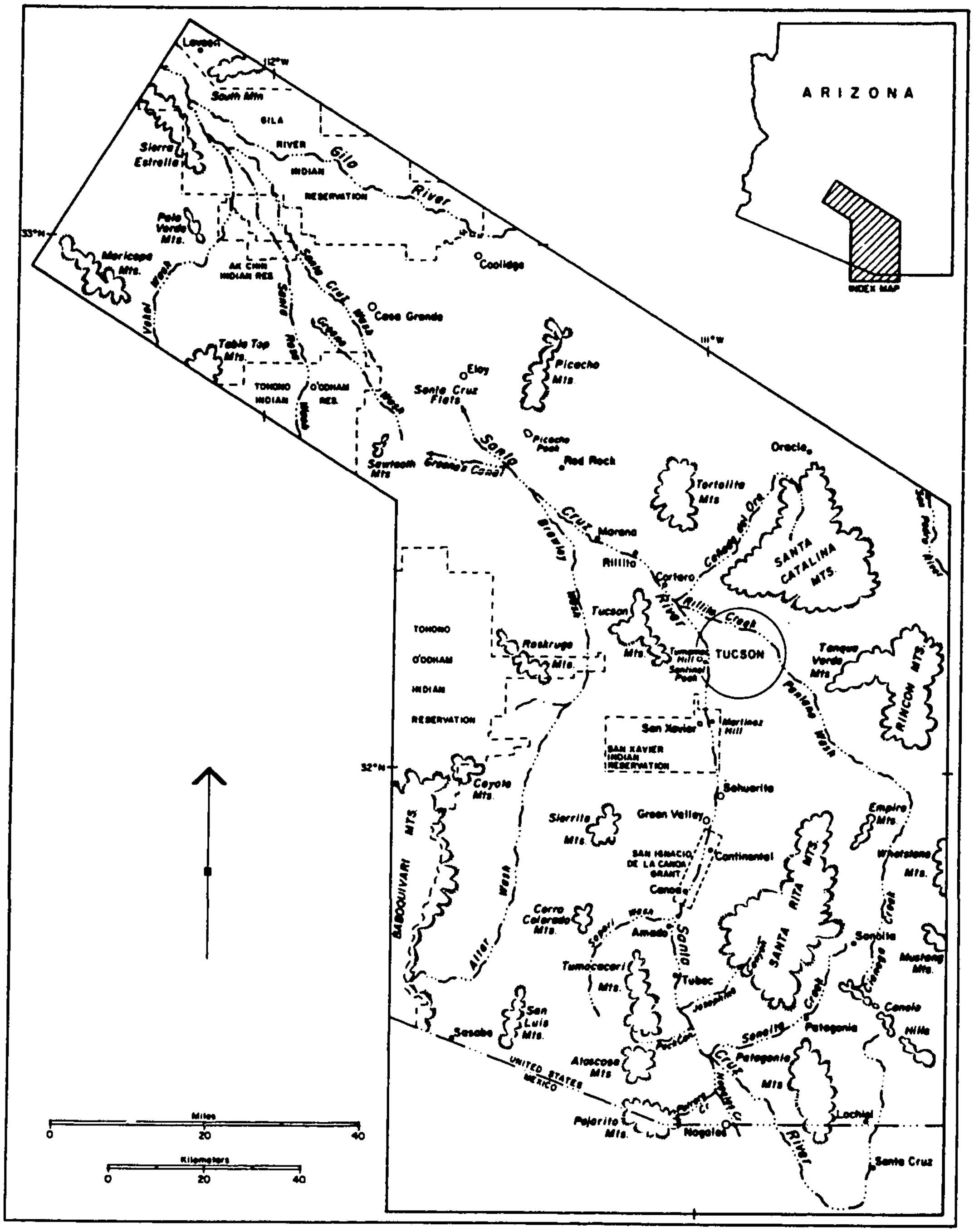


Figure 3. Map of the Santa Cruz River valley, with places mentioned in the text.

of Continental due to less water consumption by phreatophytes upstream.

At Continental, a well-defined arroyo marks the river's entry into the Tucson Basin, a northward-trending, structural depression of about 2600 sq km. The Santa Cruz is entrenched most dramatically within the San Xavier Indian Reservation, with vertical banks up to 10 m high and 100 m apart where the river meanders around the base of Martinez Hill. To the north, even the largest floodflows are confined within sloping banks of soil cement, a recent precaution against flood damage in a heavily urbanized floodplain (Fig. 4).

In northwest Tucson, where the Rillito River and Cañada del Oro join the Santa Cruz from the east, the river channel gradually becomes shallower. Immediately downstream of the Cañada del Oro confluence, at the Cortaro gage, sewage effluent provides a constant daily streamflow of no more than 3 cms (Hays, 1984). At the downstream end of the Tucson Basin, beyond the northernmost ridges of the Tucson Mountains, the river bottom merges with the floodplain and floodwaters spread out onto a broad and deep alluvial plain, where deposition has gone uninterrupted for centuries if not millennia. This featureless plain, typified by the Santa Cruz Flats near Eloy, is interrupted only by the deep arroyo emanating from Greene's Canal, a ditch which was built ca. 1910 and became an active headcut during winter of 1915. From the Flats to the Gila, the Santa Cruz is only a subwatershed of Santa Rosa Wash. The river ends its 360-km course and 1300-m elevational transect through the region of the Sonoran Desert as it joins the Gila River on the outskirts of Phoenix.

Little or no sediment entrained upstream of Marana ever makes it to the Gila. As such, the lower Santa Cruz valley is functionally a closed basin, partially open at Marana, where it receives sediment from the Tucson Basin

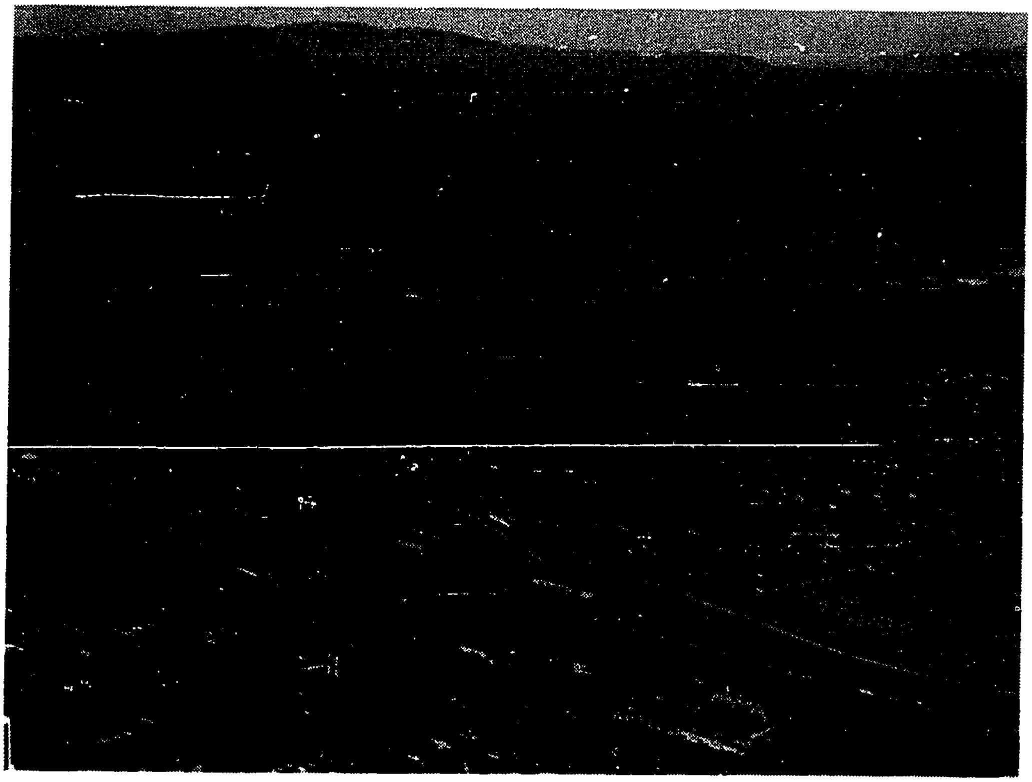


Figure 4. Aerial view of Tucson reach of the Santa Cruz River, looking southeast on October 9, 1983. Downtown Tucson is at lower left. Identified features are: A. Congress Street Bridge, B. Sentinel Peak, C. Tucson Mountains, D. Sierrita Mountains, E. Black Mountain, F. Former site of Silver Lake, G. former site of Warner's Lake, H. West Branch of the Santa Cruz River (Photograph by Peter Kresan).

and points upstream. One could speculate that the sediment budgets of the Gila and the Santa Cruz are linked only when stream power is sufficient to carve out and maintain a channel through the lower Santa Cruz.

Geologic History of the Tucson Basin Reach

The Tucson Basin was formed by uplift of mountain blocks and downthrow of intermontane areas during the early Tertiary, giving the region its distinctive Basin and Range character and youthfulness (Anderson, 1987). Infilling during the middle Tertiary was reversed by renewed uplift and volcanic extrusions in the late Tertiary and early Pleistocene. Tilting of the valley fill during the Miocene accounts for the dipping beds of the Pantano Formation. Probably during the middle Pleistocene, the heretofore closed basin was breached by an ancestral form of the Santa Cruz River. Either due to climatic change or crustal movement, several erosional cycles carved out some of the original fill, leaving a series of terraced surfaces sloping down to the present floodplain. The modern floodplain represents the height to which the inner valley was refilled during the Holocene or past 10,000 years (Davidson, 1970). Downstream from Marana, Holocene alluvium has buried the youngest Pleistocene surface, known locally as the Jaynes terrace (Smith, 1938). The depth of this unconsolidated fill ranges from 30-40 m along the central axis of the valley.

The alluvial history of at least the upper 10 m of Holocene fill, essentially the last 8000 years, is exposed along the cut banks of the modern arroyo and has been studied intensively in the area of Martinez Hill, (Haynes and Huckell 1986; Waters, 1988). Figure 5 summarizes this alluvial history. Prior to 8000 years ago, the Santa Cruz was a braided stream flowing across

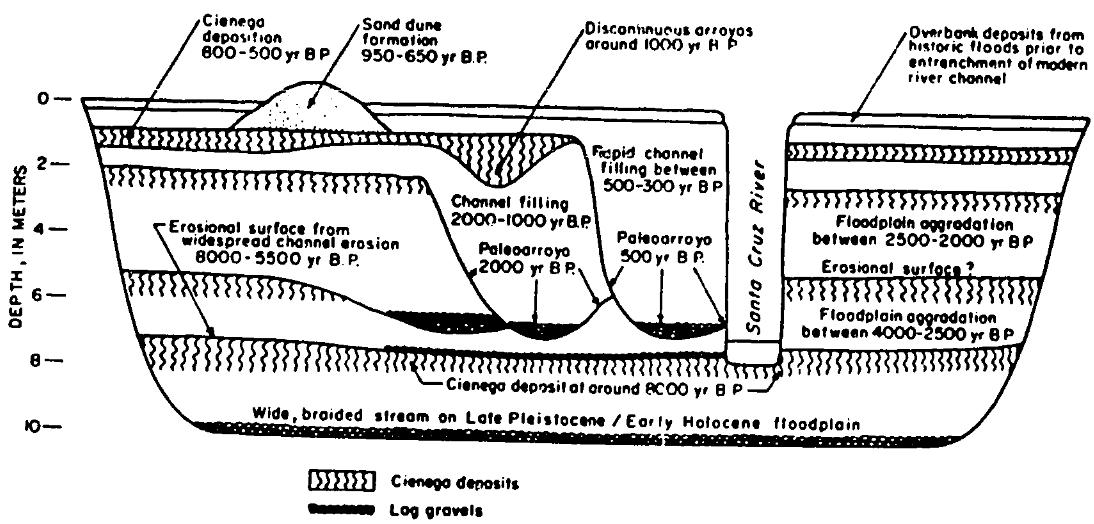


Figure 5. Representative Holocene stratigraphy of the Santa Cruz Valley, near Martinez Hill (not to scale; modified from Waters, 1988).

bottomlands 8 m below the present inactive floodplain (Waters, 1988). At about 8000 years ago, a cienega developed in this reach due to outcropping of ground water. The early Holocene floodplain was removed by downcutting and channel widening between 8000 and 5500 years ago (Haynes and Huckell, 1986). Reconstruction of this floodplain began before 5500 years ago, with a braided stream, high water tables, and cienega development characterizing the period from 4000 and 2500 years ago. Around 2500 years ago, the floodplain was still 7 m below the present bottomlands.

The last 2500 years represent vertical aggradation of some 7 m, punctuated by short periods of arroyo-cutting, when channels developed but removed only a fraction of the aggraded floodplain. Two of these arroyos, on the western side of the valley, were discontinuous. Waters (1988) was able to follow their course as they shallowed onto the then existing floodplain. Between 950 and 650 years ago, when these arroyos were extant, sand derived from their floors accumulated downwind to form low dunes on the floodplain (Haynes and Huckell, 1986; Waters, 1988). These dunes now outcrop near the historical source of the Spring Branch or Agua de la Mision, to be discussed later in the text. Two other arroyos, of comparable size to the modern arroyo and following a similar course, were incised into the floodplain around 2000 and 500 years ago. The latter paleoarroyo was about 170 m wide and 5.5 m deep. Its continuity downstream is undetermined, but this paleochannel possibly extended through Tucson and represents a cutting episode analogous to formation of the modern arroyo. The paleoarroyo filled rapidly. The stream again ran on the surface of the valley by the time that Kino first visited the San Xavier area, or about 300 years ago.

Waters (1988) sees a close correspondence between the intensity of

Hohokam agriculture, including shifting settlement patterns in the Martinez Hill area, and floodplain stability. Maximum Hohokam activity corresponded with periods of net aggradation and cienega development-- e.g., during the Rillito and early Rincon phases between 1150 and 950 years ago. The location of several village sites shifted during the middle Rincon phase (950-800 years ago) to the fans of newly-formed discontinuous arroyos. As these arroyos filled and cienegas developed during the Tanque Verde phase (800-650 years ago), the number of villages increased, particularly in the eastern sector of the floodplain which remained undissected. The paleoarroyos that developed about 500 years ago may account for abrupt abandonment of the area. As this paleoarroyo healed between 500 and 300 years ago, prehistoric farmers returned to the Santa Cruz Valley. When Kino first visited San Xavier and Tucson in the 1690s, the Indian population in the Santa Cruz Valley was greater than any other area in southern and central Arizona, although still much reduced from the Hohokam maximum.

General Rainfall Patterns

The sources and mechanisms for seasonal rainfall in southern Arizona are quite variable, as might be expected for a region that is intermediate between temperate latitudes and the tropics. In North America, month-to-month persistence of atmospheric flow pattern and precipitation are related to time of year. Persistence is greatest in winter and summer and undergoes sharp regime breaks during or just after the equinoxes. Spring and fall, when the thermal role of the continents is changing in respect to the oceans, are characterized by the greatest change in the zonal westerlies (Namias, 1986).

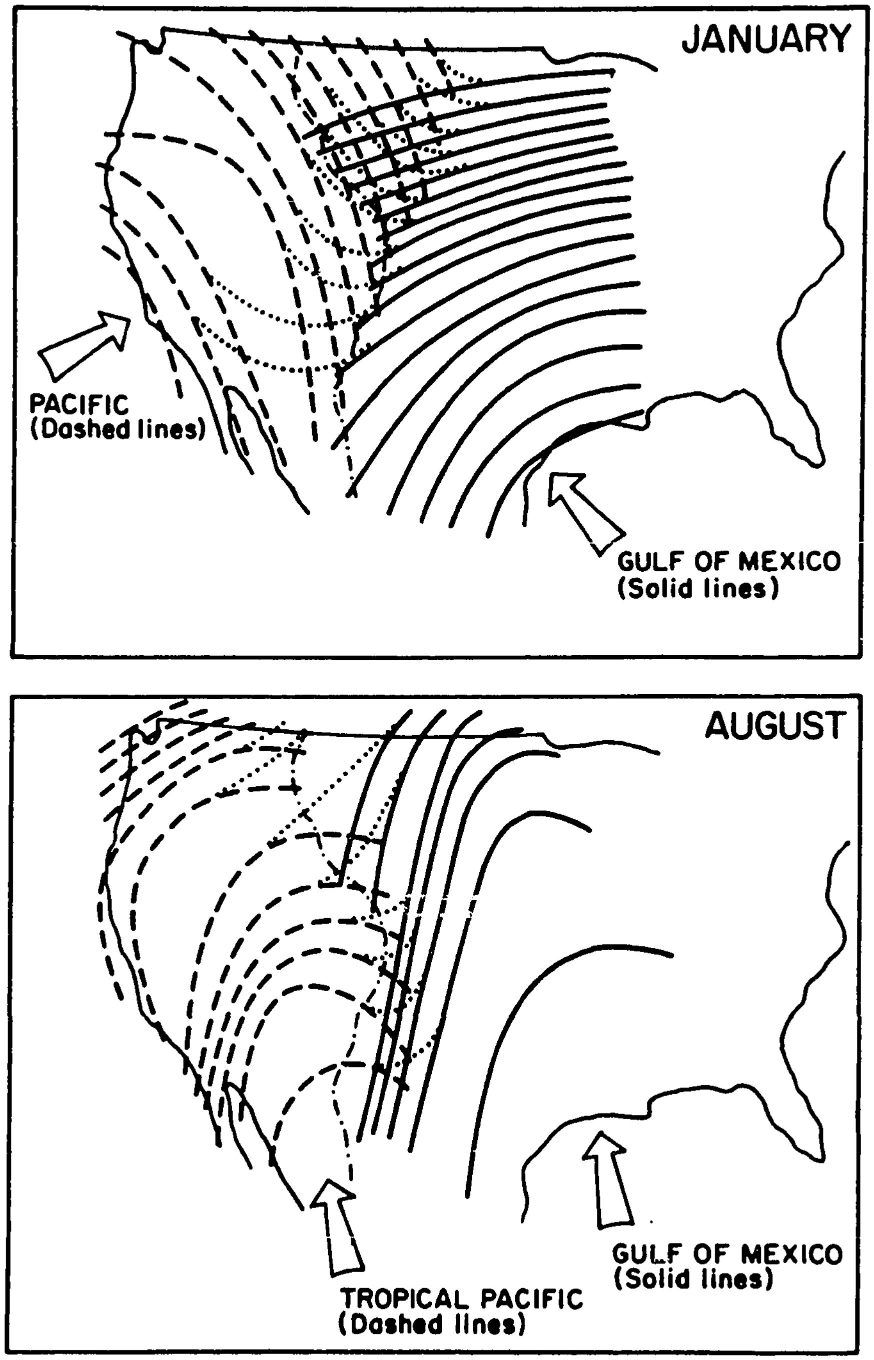
Precipitation in southern Arizona has been characterized as bimodal, with separate peaks in summer and winter (Sellers and Hill, 1974). This characterization is somewhat misleading. The primary peak occurs in July and August, which account for about 40% of the annual mean. Winter rainfall contributes another 40% spread over five months (November-March). A third peak, about 15% of the annual mean, occurs in the fall (September-October). The driest months of the year are April, May and June, which contribute only 5%.

The winter rains originate from large-scale low-pressure systems embedded in the westerlies, as the Pacific cyclone track moves south in conjunction with seasonal expansion of the Aleutian low-pressure center. During dry winters, the westerlies follow a path around the north side of a semi-permanent ridge of high pressure, located off the West Coast, into the Pacific Northwest. In wet winters, this ridge is displaced westward and a semipermanent low-pressure trough develops over the western U.S. Storms then tend to follow the prevailing winds along the West Coast, entering the continent as far south as San Francisco. When this happens, the Pacific Northwest is dry and the Southwest is wet. On rare occasions when the Pacific high pressure ridge is well developed, low pressure systems may stagnate (forming cutoff lows) and intensify off the California coast before moving inland into Arizona, where they produce record rainfall (Sellers and Hill, 1974; Pyke, 1972; Hansen and Schwarz, 1981).

During the arid spring and foresummer, the Southwest experiences strong westerly flow under direct influence of subsidence from the subtropical high-pressure cell in the Pacific, which is still far to the south. The aridity of May and June can be attributed both to subsidence with westerly flow and the relatively low ocean temperatures associated with upwelling off the California coast.

Around the end of June and first of July, the subtropical high cells rapidly shift to the north, inducing more easterly and southeasterly flow and intrusions of moist tropical air. These synoptic-scale surges, abruptly breaking the arid foresummer, have been likened to monsoonal circulation elsewhere in the globe (Tang and Reiter, 1984). Traditionally, the Arizona monsoon has been credited to flow around the Bermuda High entering through the Gulf of Mexico and reaching into the Southwest (Bryson and Lowry, 1954). The Gulf of Mexico is probably the source of many of the weak, upper-air disturbances that trigger thunderstorms in the area. However, it is an unlikely source for low-level moisture during summer-- over half of the precipitable water vapor over southern Arizona is below 800 mb, which is lower than the Mexican highlands that separate the area from the Gulf of Mexico.

Analyses of broadscale patterns in precipitable water (Reitan, 1957), water vapor flux (Rasmusson, 1967), low-level winds (Tang and Reiter, 1984), and regional precipitation (Hales, 1972; Pyke, 1972) suggest that most of the low-level moisture originates from the Pacific Ocean and Gulf of California. Hansen et al. (1977) present further evidence for the influence of the Pacific Ocean in the form of charts depicting maximum persisting 12-hr 100-mb dewpoints for the conterminous U.S. These charts show the broadscale moisture patterns influencing the Southwest. In August, the Continental Divide acts as a natural boundary between regions influenced by the tropical Pacific vs. the Gulf of Mexico (Fig. 6). Hansen et al. (1977) assert that, while the Gulf of Mexico may be the source for much of the day-to-day summer



-·-·-· Continental divide
·········· Transition lines

Figure 6. Moisture sources for the 48 conterminous states in January and August, implied by gradients of 12-hour persisting 1000-mb dew points. Tropical Pacific, and not Gulf of Mexico, moisture represents conditions necessary for extreme precipitation in August (From Hansen et al., 1977).

precipitation in the Southwest, such rainfall occurrences are not representative of conditions for extreme precipitation.

Carleton (1986) examined the synoptic climatology associated with bursts (surges) and breaks (retreats) of monsoon moisture in the Southwest. He found that bursts are associated with intrusion into the subtropics of upper-level troughs in the westerlies, promoting atmospheric destabilization, with convergence of moisture from both gulfs. For breaks, the subtropical ridge is displaced farther south, leading to subsidence and drier southwesterly flow over the region (anticyclonic conditions aloft). More recently, Reyes and Cadet (1988) have suggested that intensification of the South Pacific anticyclonic gyre in late summer shifts the source of the moisture to the Pacific. During ENSO events, the ITCZ moves south, the South Pacific anticyclonic gyre weakens, and low-level moisture advection into the Southwest is reduced. However, this may be offset by warm sea surface temperatures and greater equatorial moisture, increasing the probability of hurricane formation off the west coast of Mexico. Hypothetically, this could be expressed in the Southwest as a reduction in day-to-day convective activity and an increased probability for intense rainfall events associated with Pacific tropical storms.

In late summer and early fall, the Pacific Ocean occasionally becomes a dramatic source of rainfall over southern Arizona with northeastward penetration of tropical storms and hurricanes that originate off the west coast of Mexico. In Mexico, these storms are called "chubascos" (literally, squalls) or El Cordonazo de San Francisco (the Lash of St. Francis), the latter in reference to their occurrence around the feast day of St. Francis on October 4.

The main area of cyclogenesis is between 10-15°N and 95-100°W, the highest frequency of tropical storms originating about 200 km south of Cabo San Lucas, the southernmost point in Baja California. Upon leaving their area of origin, most tropical cyclones track west-northwest and are dissipated by wind shear and colder water. Some cyclone tracks recurve (anticyclonically) towards the north and east, steered by southerly winds ahead of a large amplitude trough centered over the Pacific Northwest or a weak trough between two subtropical high-pressure cells. The tropical cyclone season runs from June to October, with September being the month of maximum frequency. The recurving cyclones that would affect southern Arizona occur most frequently in September and October (74%), compared to July and August (22%). The greater incidence of recurvature in the fall is associated with the weakening and southern migration of the Pacific subtropical high and the more frequent appearance of middle latitude troughs at lower latitudes (Eidemiller, 1978). However logical this may seem, the higher frequency in September was calculated based on the period 1954-1976 and may misrepresent the seasonal frequency of recurving tropical cyclones in the late 19th and early 20th centuries. Dissipating tropical storms may also contribute moisture to the first extratropical Pacific cyclones in the fall. Record rainfall may result when these cyclones are associated with cutoff lows or sharp troughs (Hansen and Schwarz, 1981).

CHAPTER 4: PERENNIAL FLOW AND DISCONTINUOUS ARROYOS 1697-1870

Initially, the Santa Cruz was known as the Rio Santa Maria de Soamca, a name bestowed by its first European explorer, Eusebio Kino. It acquired its present name when the Spanish presidio of Santa Cruz de Terrenate, formerly at the confluence of Babocomari Creek and the San Pedro River, was moved, first to Las Nutrias and in 1787, to Santa Maria de Soamca, an abandoned settlement at the southern end of the Patagonia Mountains. The name Santa Cruz was applied to the revived village and, in keeping with the change, the Rio Santa Maria became the Rio Santa Cruz (Fontana, 1971).

The River During Spanish Colonial Days

Kino was the first non-Indian to trek the Santa Cruz from its source to the Gila. On several occasions in the 1690s, he visited six Indian settlements between San Xavier and Rillito. Although they lack detail, the diaries kept by Kino and his military escorts lend considerable time depth to the picture that emerges by 1870. Fields were irrigated from the mainstem (near the Indian settlements), suggesting that perennial flow could be directed across the floodplain with minimal effort. In 1697, Kino and Capt. Juan Mateo Manje traveled south along the Santa Cruz, reaching a sizeable settlement in the vicinity of Tucson on Nov. 23rd:

> ...after going six leagues [ca. 24 km], we came to the settlement of San Agustin de Oiaur where we were lodged in a big house they had built for us and big enough for all.... Here the river runs a full flow of water, though the horses forded it without difficulty. There are good pasture and agricultural lands with a canal for irrigation.... We counted 800 souls in 186 houses.... On the 26th, after having heard mass and saying goodbye to the Indians, we continued south over the plains, passing along the river bed which submerges here (Manje, 1954, p.

92-93).

Kino described the agricultural potential at San Xavier on October 29, 1699:

> The fields and lands for sowing were so extensive and supplied with so many irrigation ditches running along the ground that the father visitor said they were sufficient for another city like Mexico (Bolton, 1919, p. 205).

On April 11, 1701, Kino and Manje traveled south from San Xavier, "... over plains and meadows covered with pasture." (Manje, 1954, p. 168).

Spanish explorations into southern Arizona continued into the eighteenth century. By 1752, a presidio had been established at Tubac and in 1767, Franciscans replaced Jesuits in the proselytizing effort. To outdo their predecessors, Franciscans pushed to explore an overland route to California, setting up a line of missions along the way. In late October 1775, Pedro Font, a Franciscan with the de Anza expedition, described the initial days of the journey north from Tubac:

> We set out from La Canoa at two in the afternoon, and at five halted at Punta de los Llanos, having traveled 3 leagues [12.5 km] to to the north-northwest. At the campsite and in the plains which follow there is grass, but no water.... [At San Xavier] This is a large pueblo of Sobaypuri Pima Indians. Once it was very large, but now it is much depleted by the hostilities of the Apaches, and more especially because of its waters, which are very injurious, for they are very turgid and salty, so much indeed that a Jesuit father showed by experiment that a bottle distilled by alembic left two ounces of salt and sediment (Bolton, 1931, p. 26-27).

Punta de los Llanos, or Point of the Plains, refers to the opening up of the valley north of Continental. Consistent with later reports, in 1775 there was no perennial flow in the 30 km stretch between the Canoa Ranch and the springs south of San Xavier.

By the end of the 18th century, the Spanish Colony in the New World suffered from financial difficulties in the mother country. A series of evaluations by the Real Consulado, an official government tribunal, focused on the status of marginal outposts such as Tucson and Tubac. In August 1804, questionnaires were received by Manuel de Leon, second ensign at Tubac, and Jose de Zuñiga, captain of the Tucson presidio. Their responses contain general descriptions of the Santa Cruz. From Tubac, de Leon gave the following portrayal:

> Our river is the Santa Cruz, which takes its name from the Santa Cruz presidio at its headwaters, [110-130 km] to the southeast of us. Only in the rainy seasons does it enjoy a steady flow. During the rest of the year, it sinks into the sand in many places. Another, which we call the Sonoita River, takes its name from the abandoned Pima mission of the same name. It flows steadily for the first fifteen miles [8 km] of its westward course, but sinks beneath the sand seven to eight miles [12.2 km] before joining the Santa Cruz. This confluence provides water for Tumacacori and Tubac and collects in the marsh lands around San Xavier in great abundance (McCarty, 1976, p. 84).

Zuñiga gives a similar account from Tucson:

> The rivers of the region include the Santa Catalina [Rillito River], five miles (8 km) from the presidio, which arises from a hot spring [Agua Caliente] and enjoys a steady flow for ten miles in a northwesterly direction, but only in the rainy seasons. It is 33 feet [10 m] wide near its headwaters. Our major river, however, is the Santa Maria Suamca [Santa Cruz River], which arises 95 miles [152 km] to the southeast from a spring near the presidio of Santa Cruz. From its origin it flows past Santa Barbara, San Luis, and Buenavista, as well as the abandoned missions of Guevavi and Calabazas, the Pima mission at Tumacacori, and the Tubac presidio. When rainfall is only average or below, it flows above ground to a point some five miles [8 km] north of Tubac and goes underground all the way to San Xavier del Bac. Only during years of exceptionally heavy rainfall does it water the flat land between Tubac and San Xavier (McCarty, 1976, p. 87).

The Mexican Period

The early years of the nineteenth century brought prosperity to southern Arizona, the product of a concerted military offensive and subsequent treaties that kept the Apache content with gifts and rations. Some of the more peaceful groups settled near presidios such as Tucson. As the economy began to prosper, unfettered by Apache pressure, a number of ranchers scrambled to occupy the choice locations in the Santa Cruz Valley. On the eve of Mexican Independence, Tomas and Ignacio Ortiz of Tubac petitioned for four sitios (a sitio is about 710 ha) in the vicinity of La Canoa. A survey party including Manuel de Leon, now commanding officer at Tucson, measured the property in July 1821. Ignacio Elias Gonzales, commander of the Tubac garrison and Tomas Ortiz' father-in-law, gave the following account of the San Ignacio de la Canoa Land Grant:

> .... it is a place that contains ample level land through which runs the River of this military post, although without water due to the many sandy places that impede its current half a league to the north [of Tubac]. Only during the rainy seasons, when it receives water from its tributaries does the river flow. Its vast extent is covered by shrubs such as mesquite, acacia, tamarisks [teraques?], paloverde, saguaro, and very few cottonwoods and willows, it has pasture in all its circumference although not in great abundances, and also sacaton grass along the floodplain and I consider it of some utility for the raising of cattle and horses.... putting upon it a well.... which may be done at all times by digging a short distance (U.S. Court of Private Land Claims, 1881).

The Mexican War and the Forty-Niners

In 1846, war broke out between the United States and Mexico. Colonel Stephen W. Kearny and his Army of the West were dispatched to occupy the weakly-garrisoned borderlands of Mexico. Some 500 Mormon youths were recruited at Council Bluffs, Iowa and mustered into a special unit. The Mormon Batallion under Captain Phillip St. George Cooke was organized, not as a combat unit, but as a supply train to blaze a wagon trail to California. Leaving the Rio Grande, Cooke crossed the Continental Divide to the upper San Pedro, and then west to Tucson, camping just north of the town on Dec. 17, 1846. Cooke described the vegetation along the valley floor on a brief reconnaissance from Tucson to San Xavier:

> The thicket soon became a dense forest of mesquite two feet [0.61 m] in diameter. After marching four or five miles [6.4-8.0 km], we came to water; and while waiting some time for the footmen to come up, I for the first time spoke freely to the officers and asked their opinion on the prudence of continuing farther in the dense covert which we had found and which the guide stated became worse all the way to the pueblo (Cooke, 1878, p. 154).

Departing Tucson for the Gila, Cooke also described the road to the Point of the Mountains (near Rillito):

> To my surprise, I found water seven miles [11.2 km] from town [Nine Mile Water Hole] and plenty of it, instead of an insufficiency for miles reported by Weaver, whom I sent yesterday to examine (he took a different path).... The next three miles [4.8 km] down the dry creek of Tucson were excessively difficult, with deep sand and other obstacles. Then our beautiful level prairie road was much obstructed by mesquite (Cooke, 1878, p. 161).

After the war was over, a column of U.S. Army Dragoons visited the Santa Cruz en route from Monterrey to Los Angeles. Record of this journey (Sept. 1848) was kept by Lieut. Cave J. Couts:

> The river, or more properly, branch or creek, disappears in its sandy bottom a little below Ft. Tubac and probably does not rise again, its course is northeast, and probably turns to the San Pedro, that or Gila, as it was left to our right. The whole country between the mountains, and from Tubac to Tucson, is remarkably sandy and requires very strong streams to run any distance. Cannot find the Santa Cruz River in any map, reason for thinking it does not rise again (Couts, 1961, p. 67).

Each page of Couts' diary is accompanied by a hand-drawn sketch showing the day's route. The river's flow is shown to disappear just below the ford near La Canoa. Approaching San Xavier, he notes an increase in the size and density of mesquite and is forced to amend his earlier conclusions about the river's flow:

> Rio is called San Xavier, though the same as Santa Cruz, which disappears near Ft. Tubac and rises in a spring above Xavier del Bac from whence is called San Xavier....Marched from Ft. de Tucion [sic] about 8 on the morning of 27th. The Church, or Mission as it was at one time, stands some 1/2 mile [0.8 km] from the town, on the other side of the branch of San Xavier [then the mainstem of the Santa Cruz]. The town itself is called San Augustine, this mission Tucion [sic].

> About here, is where the branch disappears into the sandy desert which we have passed since leaving. The bed of it can be traced very little farther (Couts, 1961, p. 70).

Two months after Couts' visit, Tubac was razed by the Apaches, forcing evacuation of all the settlers. Tomas Ortiz' home burned to the ground, destroying the original title papers to the Canoa property. Most of the settlers moved north to the villages of San Xavier and Tucson. That same month (Dec. 1848) President Polk's annual message to Congress verified newspaper stories about the fabulous gold strike in California. Wagon trains of gold seekers soon headed west, following Cooke's road and other established trails across southern Arizona. John E. Durivage, a correspondent with the New Orleans Daily Picayune, was one of the argonauts:

> We camped eight miles [12.8 km] from the last rancho [Tubac] having traveled twenty-five miles [40 km] during the day. Just below this point river sinks into the sand and appears again only at intervals for many miles. Here the river is crossed for the last time for fifteen leagues, although the cottonwoods marking its course are frequently in sight.... It [Tucson] is eight miles [12.8 km] from San Xavier and a miserable old place garrisoned by about one hundred men. Flour and a small quantity of corn were all that could be procured. The Santa Cruz river flows within half a mile [0.8 km] of the town and then takes a southerly bend [actually the bend is to the northwest]. Near the town are the remains of an old mission [San Agustin], the gardens of which are well stocked with fruit. The whole valley is exceedingly fertile (Durivage, 1937, p. 209, 211).

A.B. Clarke, who was traveling with Durivage, describes the river just south of San Xavier on May 29, 1849:

> Coming to a grassy meadow, where judging from the nature of the ground, as well as we could in the darkness, that there must be water not far off, we camped. Several men went out in different directions and soon found a small creek with high banks [probably the stream emanating from the spring at Punta de Agua] (Clarke, 1852).

In October 1849 another argonaut, Lorenzo D. Aldrich, depicts the valley between San Xavier and Tucson as a barren plain, contradicting repeated references to a mesquite thicket connecting the two settlements:

"Driving over a barren plain some five miles [8 km] in extent, we encamped for the night by the side of a running stream about one mile [0.8 km] from the town of Tucson (Aldrich, 1950, p. 52)."

One of the more detailed journals was kept by H.M.T. Powell, who followed the Santa Cruz on the same month as Aldrich. Powell describes the valley north of Tubac and at Tucson:

> [14.5 km north of Tubac]....we crossed the river to left bank.... three or four hundred yards below where we crossed the river sinks into the sand, and where it rises again we do not know. It sinks in the bend northeast of the point of the double peak mountains.... The road from San Xavier to camp, 1 mile [1.6 km] short of Tucson, was very level, running throughout mesquite, etc. We encamped in a grassy bottom, much covered with saline efflorescence. The river has divided to a mere brook, the grassy banks of which are not more than 2 yards [1.8 m] apart (Powell, 1931, p. 141, 143).

In February 1851 Jose Maria Martinez, who had moved from Apache-torn Tubac to San Xavier, filed for a small land grant abutting the mission to the east. Since 1849 Martinez had been clearing the land, which was formerly covered with mesquite and sacaton and used by the mission as summer pasture. He also cut a ditch to the spring on the western side of the valley (Fig. 7). Though the Spring Branch (Agua de la Mision) ran across Martinez' land, the Indians maintained that he only had the right to use, "for irrigation the water of the 'rebenton de la Sanja' [Punta del Agua] without using the water of the 'acequia del ojo de agua' [later called Agua de la Mision or the Spring Branch], which flowing from the east irrigated the land of the Mission Indians" (U.S. Court of Private Land Claims, 1882). The Papagos agreed to the terms of the land grant, in part because they had grown accustomed to using Martinez' oxen for their own plowing.

Under the Treaty of Guadalupe Hidalgo, signed February 2, 1848, the southern boundary of the Mexican Cession was to be surveyed by a Joint

Figure 7. Upstream view in 1912 of Acequia de Punta de Agua, a streambed spring along the Santa Cruz River south of the San Xavier Mission (from Olberg and Schanck, 1913).

Boundary Commission. John Russell Bartlett, a prominent bibliophile and amateur ethnologist from Rhode Island, was selected to head the Commission. His survey in 1851-52 would be hotly contested in the U.S. Senate, the charge being that perhaps no more than a fifth of the appropriations were actually used for the intended survey. The majority of the funds were spent tracking Bartlett's interests in the Indian cultures of the desert. This produced a classic tome in American ethnology, which was initially refused publication by the government press. In July 1852, Bartlett followed the old trail along the Santa Cruz south from the Maricopa and Pima villages on the Gila:

> .... camped eight miles [12.2 km] from Tucson [at the Nine Mile Water Hole].... en route to Tucson, wagons mired in crossing arroyos; in Tucson camped on the banks of the Santa Cruz River, where there was an abundance of grass.... In addition to the river alluded to, there are some springs near the base of hill [Sentinel Peak] a mile west of the town, which furnish a copious supply of water.... the bottomlands are here about a mile [1.6 km] in width. Through them run irrigating canals in every direction, the lines of which are marked by rows of cottonwoods and willows, presenting an agreeable landscape.... [left Tucson, heading south and] soon entered a thickly wooded valley of mesquite.... Near [San Xavier] is a fertile valley, a very small portion of which is now tilled, although from appearances, it was all formerly irrigated and under cultivation.... Leaving the village, we rode on a mile [1.6 km] further and stopped in a fine grove of large mezquit [sic] near the river, where there was plenty of grass.... we resumed our journey along the valley as before, through a forest of mezquit trees.... The rain having continued the whole night, we were much delayed in getting off this morning. The whole country was drenched with water and the road almost impassable for heavily- loaded wagons. After a hard journey of eighteen miles [30.8 km], we stopped at the banks of the river [14.4 km north of Tubac] and strange as it may appear, notwithstanding all the rain that had fallen, the river, such is the uncertainty of the streams in this country, was quite dry. Fortunately, in some cavities in the river's bed we found water enough for our present wants (Bartlett, 1854, p. 292-302).

Two other developments deeply affected Tucson on the eve of its annexation by the United States. The first was a cholera epidemic in 1850 and 1851 spread by the itinerant gold seekers. In 1851, one out of ten Tucsonans died from the dreaded disease. A morass of land tenure conflicts also plagued the settlement. In 1848, the Mexican government had sought to protect its northern frontier by establishing military colonies. To attract volunteers, a law had been passed promising plots of farmland near garrisons to six-year veterans. In Tucson several settlers were dispossesed of their bottomland to accomodate the military. Traditional patterns of land use, involving the history of existing berms and ditches or what to do when the river flooded, were disrupted. This turnover in land tenure would accelerate after the Gadsden Purchase.

Additional territory was purchased from Mexico in 1854, lands needed to chart a transcontinental railroad to the Pacific by way of the 32nd Parallel. When it was realized that Bartlett's boundary missed the good railroad route, James Gadsden, a railroad promoter, was commissioned to convince Mexico that the Treaty of Guadalupe Hidalgo had been drawn hastily. Still another survey was needed to determine the international boundary as prescribed by the Gadsden Purchase. This time the Chief Surveyor was Major William Emory, the topographer for Kearny's Army of the West and Chief Astronomer and Commander of Bartlett's military escort. He knew the country well:

> After leaving Tubac, which is situated about midway between Santa Cruz and Tucson, the valley expands into a wide open basin, the mountains receding on either hand, and the dry valley now almost exclusively occupied by mesquite, is bordered by a wide stretch of gravelly table land.... Approaching the town of San Xavier, noted for its superb church, contrasting strangely with the mud hovels surrounding it, we again come upon running water, with its constantly associated fertility and verdure.... The settlement of Tucson occupies the lowest line of constant running water and consequently, the last fertile basin lying in the course of this valley (Emory, 1857, p. 19).

After the Gadsden Purchase

Mexican troops remained in Tucson until 1856, when they were replaced by four companies of the First United States Dragoons. That year, Tucson was introduced to Solomon Warner, whose future livelihood would greatly depend on the vagaries of streamflow along the Santa Cruz River. A native of New York, he had worked his way around the continent until 1855, when he helped construct Fort Yuma. In February 1856, Warner secured a stock of general goods and set out for Tucson, accompanied by William Rowlett of Virginia. Upon arrival Warner established Tucson's first mercantile store in partnership with Mark Aldrich. Rowlett and his brother Alfred began construction of a low earthen dam downstream of a spring-fed cienega near Sentinel Peak. The following year, the Rowletts built Tucson's first water-powered flour mill west of the reservoir, in later days known as Silver Lake (Figs. 8-9).

The millrace probably did not originate at the dam. A complicated, somewhat muddled account of the waterworks at Silver Lake was given as testimony in an 1885 water rights case (Drake 1885; testimony of Juan Romero). Presumably, three ditches were developed from springs in the southern half of Section 26, T14S, R13E and were gathered up into a single stream that turned the water wheel. The tailrace emptied east into the reservoir and water would be let out into the main acequias when needed downstream for irrigation. The purpose of the lake was to avoid having to synchronize operation of the mill with the irrigation schedule for fields immediately west of Tucson.

Continued growth of California increased needs of overland transport leading to the establishment of a stagecoach service through Tucson in July 1857. Phocion Way, one of the Jackass Mail Route's first passengers, stopped in Tucson, apparently in summer, and rendered this colorful verdict:

Figure 8. Looking west across Silver Lake in the 1880s. Structure on the right was a hotel (Arizona Historical Society, Tucson, Negative No. 18335; U.S.G.S. Stake 1060).

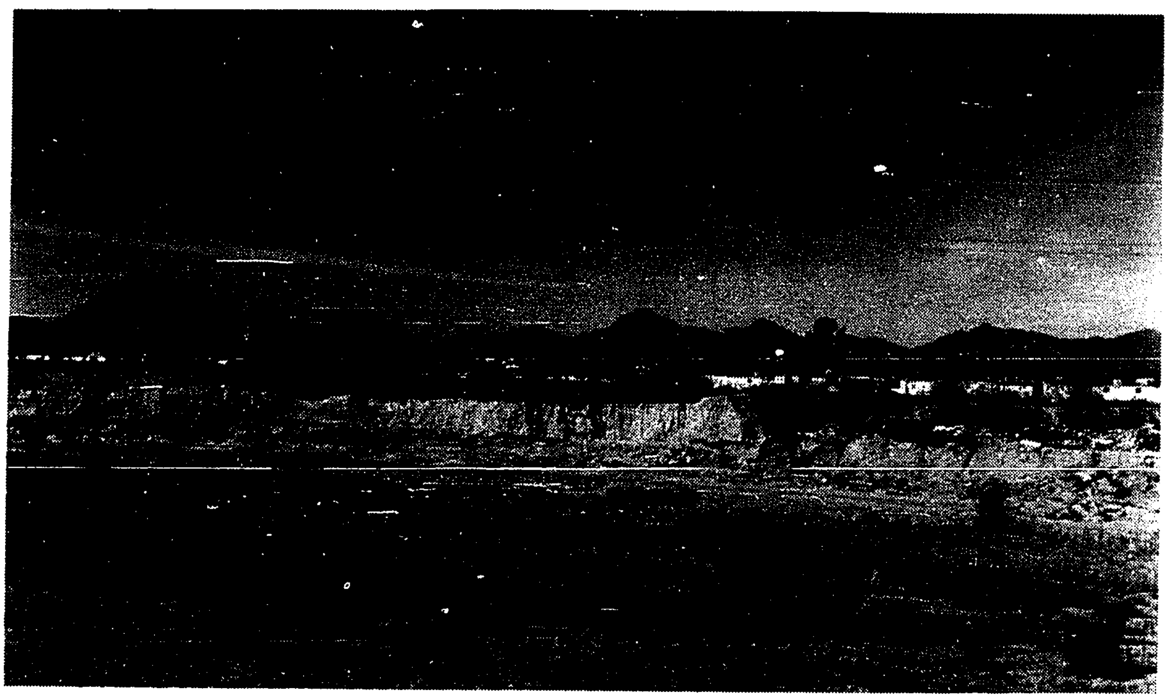


Figure 9. Same view as Figure 8, taken on December 16, 1981 (Photograph by R.M. Turner, U.S.G.S. Stake 1060).

> There is a small creek that runs through the town. The water is alkaline and warm. The hogs wallow in the creek, the Mexicans water their asses and cattle and wash themselves and their clothes and drink out of the same creek. The Americans have dug a well and procure tolerably good water, which they use. There are a few acres of land along the bottom cultivated by irrigation. It never rains there, only in the rainy season and sometimes not then. There is very little air stirring, and if hell is any hotter than this I don't want to go there (Way, 1960, p. 160).

Another of Tucson's early businessmen, Sam Hughes, arrived on March 25, 1858. A native of Wales, Hughes arrived via the California gold fields to establish a thriving butchering business in Tucson. Here, he met Mose Carson (Kit's brother), who had spent the last winter trapping beaver on the Santa Cruz and Rillito Rivers (Hughes, n.d.). According to Hughes, the winter of 1858-1859 was colder than usual and some 3.3 cm of snow fell in Tucson. Recollecting that winter, he claimed that, "the waters of the Santa Cruz were so deep that a flat boat could be navigated probably clear to the Gila at Maricopa, and that the Rillito was a mile wide" (*Arizona Mining Index*, Feb. 27, 1886). In 1859 a German itinerant described the Santa Cruz just south of Tucson as, "a rapid brook, clear as crystal and full of aquatic plants, fish and tortoises of various kinds...[flowing] through a small meadow covered with shrubs" (Froebel, 1859, p. 503).

In 1860, the Rowletts sold their mill to William S. Grant and T.W. Taliefero for a considerable profit. By the end of the year, Grant had bought out his partner and the Rowletts were panning for gold in the Cañada del Oro. As government contractor, Grant supplied Forts Buchanan, Breckenridge, and Fillmore with flour. He built another mill on the shores of Silver Lake at a cost of $18,000 just prior to the Civil War. In 1862, the ditch headings that fed the millrace were enlarged by several Mexican farmers hoping to increase flow to beyond what is now St. Mary's Road (Drake, 1885).

U.S. Military Occupation During and After the Civil War

At the onset of the Civil War, the Territory of New Mexico, which included Arizona and New Mexico, was sympathetic to the South. In March 1861 conventions in Mesilla and Tucson voted for secession although the territorial government in Santa Fe remained loyal to the Union. That year, Union forces arrived in Tucson and set fire to Grant's mill to keep it from falling into Confederate hands. In February 1862, Confederate troops marched into Tucson, meeting no opposition. Union men, such as Sam Hughes and Solomon Warner, were forced to flee. Warner left for Santa Cruz, Sonora, where he erected a flour mill, raised cattle and became engaged in freighting between Guaymas and Tucson. Hughes headed for California, only to return in June with Carleton's Union forces. A month earlier, Colonel Joseph R. West had raised the Union flag in Tucson and repaired one of Grant's mills to supply the incoming troops with flour.

To determine which properties should be confiscated, West ordered the town mapped by Major David Fergusson. One of the resulting maps shows the ownership of cultivated fields in the bottomlands west of town. According to the map the perennial flow of the Santa Cruz vanished underground between present Congress Street and St. Mary's Road. Surprisingly, documents from 1862 failed to mention floods along the Santa Cruz that winter, which produced catastrophic floods throughout southern California and northern and central Arizona (Dobyns, 1981).

In October 1862 Fergusson reconnoitered a route from Tucson to the Gulf of California, hoping to find a suitable gateway for transporting supplies to mines in southern Arizona. Three kilometers south of San Xavier, he passed

El Rancho Viejo. The road to the ranch was through a meadow, with running water 200 m to the east. One kilometer south to Struby's Ranch (Punta de Agua), the road ran through dense mesquite, again flanked by running water to the east. Upstream of this point, water could only be found by digging shallow wells in the stream bottom (Fergusson, 1862, p. 14).

By the late 1860s, surveys for a southern railroad to the Pacific Ocean were underway. Traveling with a survey party in 1867, Bell (1869) noted that some 40 ha were cultivated at San Xavier and another 800 ha in Tucson. He alludes to the river's intermittent flow in a particularly lucid summary:

> One word about the Rio Santa Cruz, the eccentric course of which can be traced at a glance on the map. For the first 150 miles [240 km] from its source it is a perennial stream; but four miles [6.4 km] south of Roade's Ranch, at a spot called Canoa, it usually sinks below the surface; it then flows underground almost to St. Xavier, and again reappears at a spot called Punta de Agua. The Papagos are thus supplied with water, and are enabled to raise what crops they require around their huts by means of irrigation. Beyond St. Xavier it usually sinks again, rising for a third time as a fine body of water near Tucson, enriching a broad piece of valley for about ten miles [16 km] around that town, turning the wheel of a fair-sized flour mill, and then sinking forever in the desert to the northwest. During some seasons, it flows further than others, so that the length of the stream above ground is subject to considerable variation; but it never suceeds in reaching the Rio Gila on the surface, although I believe it flows over the bedrock and under the drift which covers it for the remaining one hundred miles [160 km] from Tucson to Maricopa Wells, where a large spring, the waters of the Rio Santa Cruz, it is believed- comes to the surface and flows into the Gila. Wherever water can be obtained, the valley is exceedingly fertile and might, under cultivation, be made very productive. South of Tucson, fine pasturage clothes the high lands on either side (Bell, 1869, p. 99-100).

In 1866, Camp Lowell was established on the eastern outskirts of Tucson, overlooking the Santa Cruz River. The Post Surgeon also assumed the role of weatherman and maintained daily temperature and precipitation records for the U.S. Signal Corps. John Spring, a member of the Regular Army stationed at Camp Lowell, stated that, "the Santa Cruz River.... had a few places where the water was perhaps a little over four feet [1.2 m] deep" (Spring, 1966,

p. 47). In 1870, the Surgeon General's Office of the War Department expressed concern over the high incidence of malaria among local Mexican farmers:

> The Santa Cruz....runs northward from the Sonora line past the west side of the town and post, and continues its course to a point about four miles [6.4 km] below, where its water cease to run above ground, on account of the porous character of the soil.... For a distance of about three miles [4.6 km] north and south, and on both banks of the river to the west of the town, are the fields which are cultivated by the Mexicans, producing yearly two crops, one of small grain, such as barley or wheat, sown in November and harvested in May, the other of corn, planted in June and harvested in October. As cultivation can only be carried on successfully by irrigation, it follows that more or less of the fields are constantly under water, which, combined with the heavy rains in July and August, the tropical vegetation and its rapid decay, favors the development of the malarial poison and accounts for the cases of remittent and intermittent fevers and diseases of the liver which prevail among the Mexican inhabitants during the months of August, September, and October. The camp, however, being separated from these fields by the town, and being on a somewhat higher level, is almost exempt from these malarial visitations (U.S. Surgeon General's Office 1870, p. 462-463).

Intermittent Flow, Discontinuous Arroyos and Other Truths About the Land of Milk and Honey

In recent years myths about the "good ole days" along the Santa Cruz have become public dogma. They say that a perennial stream meandered through grass belly-high to a horse, nothing short of the biblical land of milk and honey (Hastings, 1959). Contrary to this popular notion, historical sources indicate that 80% of the 72-km stretch between Continental and Rillito was predominantly dry before 1870. Two perennial reaches, in total about 15 km, occurred near Tucson and the San Xavier Mission. These choice locations may have indeed resembled the Santa Cruz of legend.

At San Xavier, perennial flow has been attributed to a subsurface dyke of flat-lying basaltic extrusions. Pleistocene erosion breached a wide gap through these Late Tertiary volcanics, leaving Martinez Hill and Black

Mountain as remnants on either side of the valley. The buried dyke functions as a barrier to the northward flow of ground water, a relationship recognized as early as 1883 by Solomon Warner (*Arrizona Weekly Citizen*, November 17, 1883). At Tucson, Pleistocene terraces from the east nearly converge with the western mountain front at Sentinel Peak and Tumamoc Hill. An impervious stratum in the narrows of the valley also acted as a barrier, forcing the underflow to the surface (Hinderlider, 1913).

All accounts agree that the flow of the Santa Cruz first disappeared not far north of Tubac, near the ford at La Canoa. In December 1872, Theodore White noted that, "about a mile [1.6 km] south of where this line (southern boundary of T18S, R13E) crosses, the Santa Cruz is a large, ever running stream of water, but sinks into the sand in a short distance" (Fig. 10C:26 & 27). Directly west of this point are the present headquarters of the Canoa Ranch. The flows from the Punta de Agua and Agua de la Mision springs disappeared at San Xavier and the eastern base of Martinez Hill, respectively. Permanent water reappeared 3.5 km north of Martinez Hill, quitting again in less than 2 km. Another brief stretch of perennial flow existed half way to Tucson in the northern half of Section 2, T15S, R13E (shown on USGS topographic map, 15' Tucson quadrangle, edition of 1905). The evidence for where the flow disappeared north of Tucson is less clear.

In 1871, S.W. Foreman recorded an irrigation ditch with its heading at the river in the southeast corner of Section 20, T13S, R13E (Figure 10B:7). A tentative interpretation is that there was perennial flow at this location, disappearing a short distance to the north. However, the ditch may have been constructed in response to a series of very wet years that extended the river's flow farther than usual. In the 1885 water rights case involving all of the

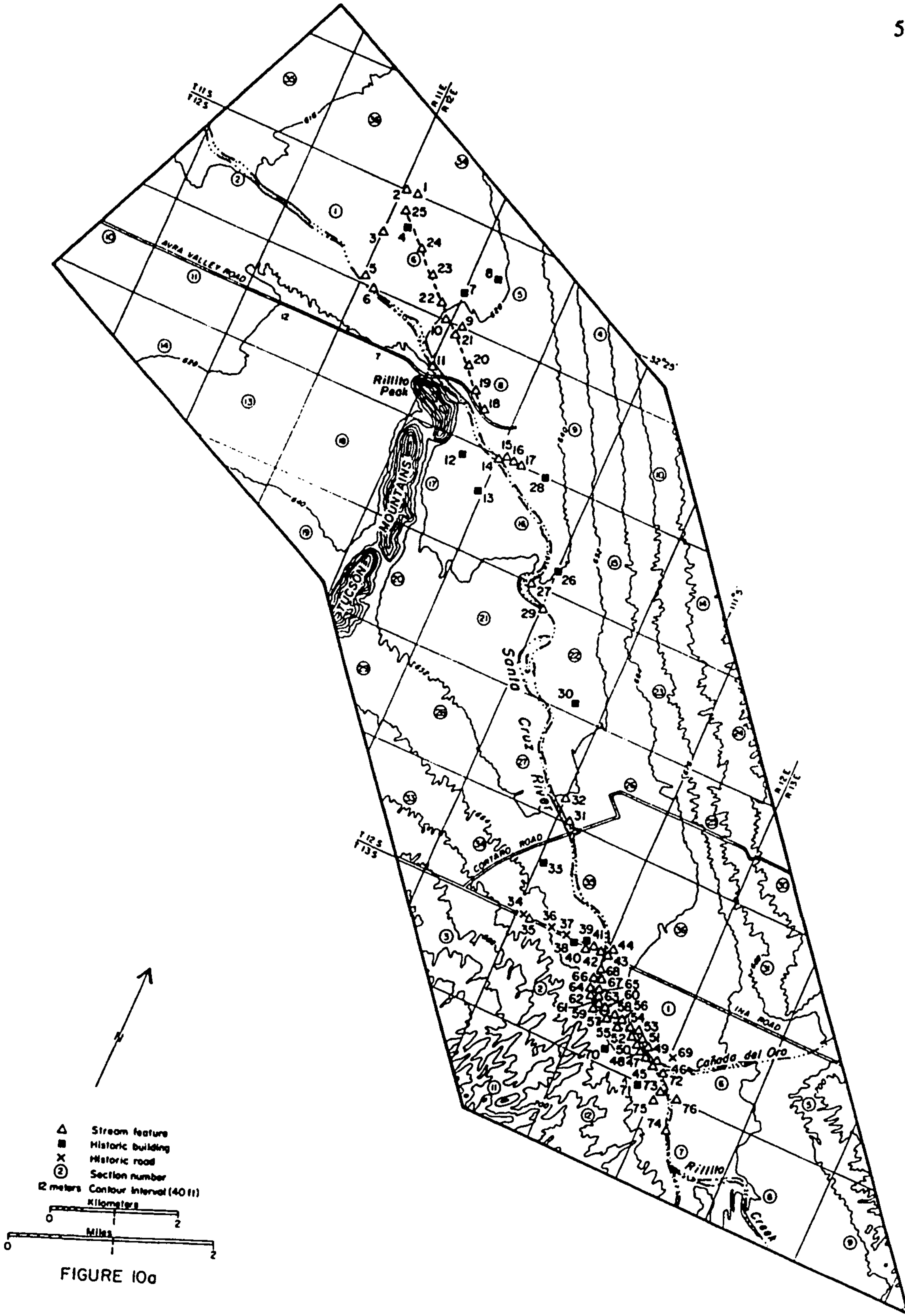

Rillito Peak
TUCSON MOUNTAINS
Santa Cruz River
AVRA VALLEY ROAD
CORTARO ROAD
INA ROAD
Cañada del Oro
Rillito Creek
Stream feature
Historic building
Historic road
Section number
12 meters Contour interval (40 ft)
Kilometers
Miles
FIGURE 10a

Figure 10 A

Figure 10A. Historic features noted in cadastral surveys of the Santa Cruz River Valley from confluence with Rillito River to Point of the Tucson Mountains. Numbers refer to features on map.

1. irrigation ditch, 3 m wide (Contzen, 1895).
2. plowed fields just west of this point (Contzen, 1895).
3. plowed fields west of line between Sections 1 and 6 ; irrigation ditch, 1 m wide, course NW (Contzen, 1895).
4. house belonging to J. Landis (Contzen, 1895).
5. dry bed of Santa Cruz River (SCR), 44.3 m wide, course W (Contzen, 1895).
6. dry bed of SCR (Contzen, 1895).
7. Rillito Station (Contzen, 1895).
8. house beloging to Flores (Contzen, 1895).
9. irrigation ditch, 3 m wide (Contzen, 1895).
10. irrigation ditch, 3 m wide (Contzen, 1895).
11. dry bed of SCR, 30.2 m wide, course NW (Contzen, 1895).
12. house belonging to S. Ruelas (Contzen, 1895).
13. house belonging to F. Ruelas (Contzen, 1895).
14. irrigation ditch, course W (Contzen, 1895).
15. irrigation ditch, 2 m wide, 0.3 m deep, course NW (Contzen, 1895).
16. dry bed of SCR, 30.2 m wide, course NW (Contzen, 1895).
17. irrigation ditch, course NW (Contzen, 1895).

18-25. course of irrigation ditch (Contzen, 1895).

26. house of A. Alvarez (Contzen, 1895).
27. dry bed of SCR, 30.2 m wide, course N (Contzen, 1895).
28. Weaver's well bears 100 m south of this point (Contzen, 1895).
29. dry bed of SCR, 40.2 m wide, course W; timber of tesota (ironwood, *Olneya tesota*), mesquite and jano (?); undergrowth of tesota (Contzen, 1895).
30. house belonging to Molina (Contzen, 1895).
31. dry bed of SCR, 50.3 m wide, course N (Contzen, 1895).
32. dry bed of SCR, 60.4 m wide, course N (Contzen, 1895).
33. Ruiz and Aguirre Ranch, formerly belonging to Juan Bafarquez (Contzen, 1895).
34. road to Yuma Mine Co., bears NE and SW (Wright, 1907).
35. dry wash, 4 m wide (Wright, 1907).
36. road bears NW and SE (Wright, 1907).
37. wagon road, Tucson to Red Rock, bears NW and SE (Wright, 1907).
38. deserted ranch house, bears south 40 m (Wright, 1907).
39. house of Antonio Canas (Contzen, 1895).
40. irrigation ditch, course N (Wright, 1907
41. irrigation ditch, course N (Contzen, 1895) [in comparing points 38 with 39, 40 with point 41, note slight offset of survey points for features that are probably the same]
42. dense mesquite brush to the west (Wright, 1907).
43. SCR, 90.5 m wide, west bank 0.6 m hight (Wright, 1907).
44. right bank of SCR, course N-NW; heavy timber and undergrowth to the N (Contzen, 1895).
45. west bank of SCR, course N-NW; heavy timber and undergrowth to the N (Contzen, 1895).
46. east bank of SCR, 0.6 m high (Wright, 1908).
47. west bank of SCR, 0.9 m high (Wright, 1908).
48. west bank of SCR, 0.9 m high (Wright, 1908).

Figure 10A (continued)

49. east bank of SCR, 1.2 m high (Wright, 1908).
50. west bank of SCR, 0.6 m high (Wright, 1908).
51. east bank of SCR, 1.2 m high (Wright, 1908).
52. west bank of SCR, 0.9 m high (Wright, 1908).
53. east bank of SCR, 1.2 m high (Wright, 1908).
54. east bank of SCR, 0.6 m high (Wright, 1908).
55. west bank of SCR, 0.6 m high (Wright, 1908).
56. east bank of SCR, 1.2 m high (Wright, 1908).
57. west bank of SCR, 0.6 m high (Wright, 1908).
58. east bank of SCR, 1.2 m high (Wright, 1908).
59. west bank of SCR, 0.3 m high (Wright, 1908).
60. east bank of SCR, 1.2 m high (Wright, 1908).
61. east bank of SCR, 1.2 m high (Wright, 1908).
62. west bank of SCR, 3 m high, being against edge of mesa (Wright, 1908).
63. east bank of SCR, 1.2 m high (Wright, 1908).
64. west bank of SCR, 1.2 m hight (Wright, 1908).
65. east bank of SCR, 0.9 m high (Wright, 1908).
66. west bank of SCR, 0.9 m high (Wright, 1908).
67. east bank of SCR, 0.9 m high (Wright, 1908).
68. east bank of SCR, 0.9 m high (Wright, 1908).
69. old road (Wright, 1909).
70. pumping plant belonging to DeBascano (Wright, 1907).
71. house belonging to Julian Rodriguez (Wright, 1907).
72. SCR runs NW, 20 m wide, no timber between sections 1 and 6 ; often prairie (Foreman, 1871).
73. SCR, 12.1 m wide, runs NW (Foreman, 1871).
74-75. irrigation ditch through cultivated field (Foreman, 1871).
76. land immediately to the east is plowed land (Foreman, 1871).

References: The cadastral survey notebooks and plants for the state of Arizona are stored at Records Division, Bureau of Land Management, U.S. Department of the Interior in Phoenix. Individual notebooks can be retrieved by their call number:

Contzen, Phillip (1895). Notebooks 756, 757, 758, 1511.
Foreman, S.W. (1871). Notebook 1457
Wright, J. B. (1907-1908). Notebook 2072

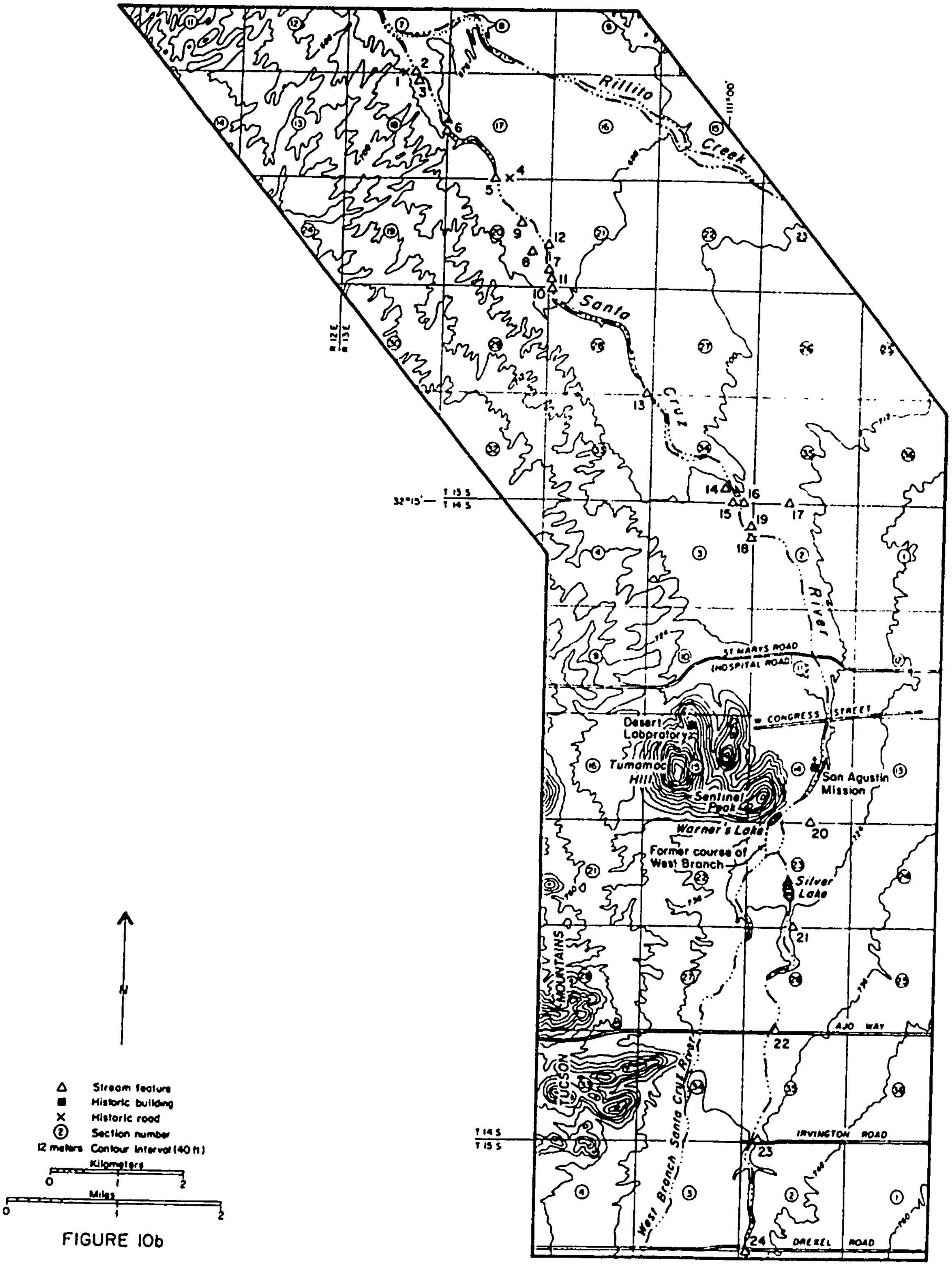

Rillito
Creek
Santa
Cruz
River
111°00'
R 12 E
R 13 E
32°15'
T 13 S
T 14 S
T 15 S
ST MARYS ROAD
(HOSPITAL ROAD)
W CONGRESS STREET
Desert Laboratory
Tumamoc Hill
Sentinel Peak
San Agustin Mission
Warner's Lake
Former course of West Branch
Silver Lake
TUCSON MOUNTAINS
West Branch Santa Cruz River
AJO WAY
IRVINGTON ROAD
DREXEL ROAD
N
Stream feature
Historic building
Historic road
Section number
12 meters Contour interval (40 ft)
Kilometers
0 1 2
Miles
0 1 2
FIGURE 10b

Figure 10B

Figure 10B. Historic features noted in cadastral surveys of the Santa Cruz River Valley from Drexel Road to the confluence with the Rillito River. Numbers refer to features on the map.

1. road to Ft. Yuma, runs NW, land along river mostly under cultivation (Foreman, 1871).
2. SCR, 5 m wide, runs NW (Foreman, 1871).
3. Nine Mile Water Hole (Foreman, 1871).
4. road to Ft. Yuma runs, NW, (Foreman, 1871).
5. SCR, 1 m wide, course NW (Foreman, 1871).
6. SCR, 1.6 m wide, runs NW (Foreman, 1871).
7. water ditch runs NW (Foreman, 1871).

7-9. straight course of SCR (Foreman, 1871).

10. SCR, 10 m wide, runs NW, mesquite timber (Foreman, 1871).
11. SCR, 10 m wide, runs NW (Foreman, 1871).
12. plowed lands immediately to the N (Foreman, 1871).
13. SCR, 10 m wide, rus NW, no timber (Foreman, 1871).
14. cultivated fields on west side of SCR, pasturage on east side (Foreman, 1871).
15. cultivated lands immediately to the W (Foreman, 1871).
16. SCR, 16.1 m, runs N (Foreman, 1871).
17. no timber on line betweeen sections 2 and 35 (Foreman, 1871).
18. SCR, 48.3 m wide, runs N (Foreman, 1871).
19. cultivated fields immediately south but not to the north of this point (Foreman, 1871).
20. SCR, 3 m wide, runs NE (Foreman, 1871).
21. SCR, 40.2 m wide, runs N (Foreman, 1871).
22. SCR, 24.1 m wide, runs N, mesquite timber along line between Sections 26 and 35 (Foreman, 1871).
23. SCR, 16.1 m wide, runs N (Foreman, 1871).
24. SCR, 10 m wide, runs N (Foreman, 1871).

References: The cadastral survey notebooks and plants for the state of Arizona are stored at Records Division, Bureau of Land Management, U.S. Department of the Interior in Phoenix. Individual notebooks can be retrieved by their call number:

Foreman, S.W. (1871). Notebooks 818, 821, 1507.

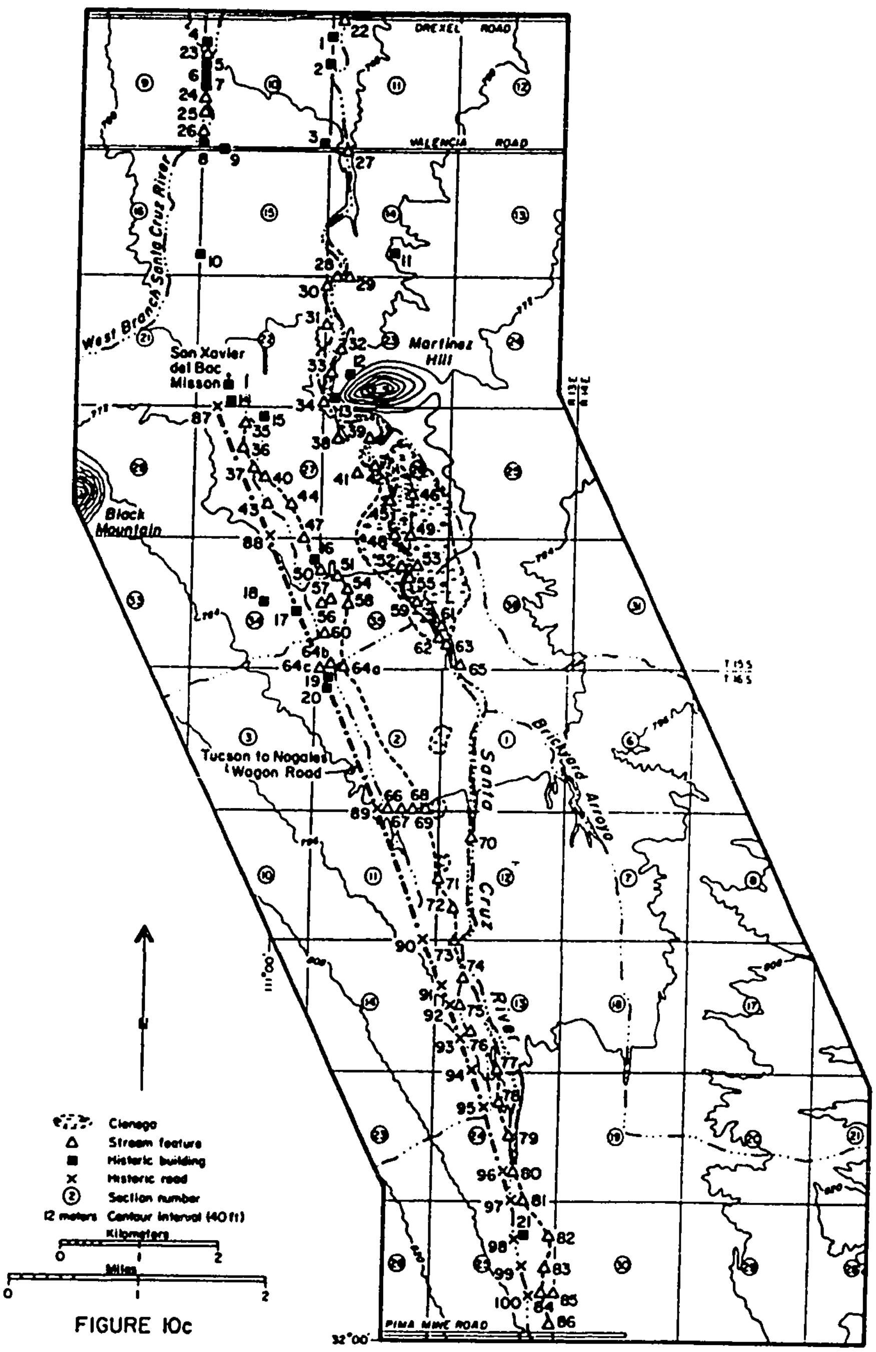

DREXEL ROAD
VALENCIA ROAD
West Branch Santa Cruz River
San Xavier del Bac Misson
Martinez Hill
Black Mountain
Tucson to Nogales Wagon Road
Santa Cruz River
Brickyard Arroyo
PIMA MINE ROAD
T15S
T16S
111°00'
32°00'
Cienega
Stream feature
Historic building
Historic road
Section number
12 meters Contour interval (40 ft)
Kilometers
Miles
FIGURE 10c

Figure 10C

Figure 10C. Historic features noted in cadastral surveys between 1871 and 1915 within San Xavier reach of the Santa Cruz River (SCR). Numbers refer to features on map.

1. house (Foreman, 1871)
2. adobe house (Foreman, 1871).
3. house (Foreman, 1871).
4. old arrastra (Foreman, 1871; house with corrals (L.D. Chillson, 1888).
5. row of our houses (Chillson, 1888); settlement of Upper Reales.
6. two houses (Chillson, 1888).
7. lime kiln (Foreman, 1871).
8. house (Foreman, 1871); ruins of adobe house (Chillson, 1888).
9. adobe house (Foreman, 1871).
10. Mexican hut with corral on north side (Chillson, 1888).
11. settlement of New Los Reales (Chillson, 1888).
12. Indian house (Leedy, 1915).
13. house belonging to Manuel Atondo (Roskruge, 1882).
14. Trojel's house (Chillson, 1888).
15. three houses along western boundary of Martinez land grant (Foreman, 1871).
16. Raglan's house (Foreman, 1871).
17. ruins of Carrillo's house (Chillson, 1888).
18. lime kiln (Chillson, 1888).
19. house (White, 1872).
20. Punta de Agua ranch (White, 1872).
21. Lime kiln (Chillson, 1888).
22. Santa Cruz River (SCR), 10 m wide (Foreman, 1871).
23. arroyo, 4 m wide, course NE (Chillson, 1888).
24. arroyo, 20 m wide, course NE (Chillson, 1888).
25. arroyo, 20 m wide, course NE (Chillson, 1888).
26. road, course NE (Foreman, 1871); arroyo 20 m wide, course NE (Chillson, 1888).
27. SCR, 20 m wide, no water in May, bluff banks 3 m high (Foreman, 1871).
28. left bank of SCR, 4.6 m high (Leedy, 1915).
29. right bank of SCR, 4.6 m high (Leedy, 1915).
30. left bank of SCR, 3.6 m high (Leedy, 1915).
31. left bank of SCR, 3 m high (Leedy, 1915).
32. right bank of SCR, 2.4 m high (Leedy, 1915).
33. right bank of SCR, 3 m high (Leedy, 1915).
34. SCR, banks 4.6 m high (Leedy, 1915).
35-37. These points define marshy oxbow of SCR (Chillson, 1888).
38. west bank of barranca, 3 m high, documenting early side gullying on west side of SCR, formerly the Spring Branch, as early as 1915 (Leedy, 1915).
39. SCR, banks 3 m high (Leedy, 1915).
40. SCR, 6 m wide, course N (Chillson, 1888).
41. barranca, 12 m wide, 2.5 m deep, course N30°W (Leedy, 1915).
42. Spring Branch (now course of SCR), 12 m wide, running water, course NW (Chillson, 1888).
43. marshy branch of SCR related to oxbow feature (35-37)(Chillson, 1888).
44. SCR, 8 m wide, course NW (Chillson, 1888).
45. Spring Branch, 6 m wide, running water, course N (Chillson, 1888); SCR banks, 3 m high, course N30°W (Leedy, 1915).

Figure 10C (continued)

46. Spring Branch (Foreman, 1871).
47. SCR, 8 m wide, banks 2.4 m high, runs N (Foreman, 1871); Santa Cruz River, 8 m wide, course NW (Chillson, 1888).
48. Spring Branch, 8 m wide, running water, course N (Chillson, 1888); left bank of SCR, 3.7 m high, course N (Leedy, 1915).
49. Spring Branch, 2 m wide, runs N (Foreman, 1871); discrepancy with (48) may mean error in surveys of that the Spring Branch moved 200 m to the west between 1871 and 1888.
50. SCR, 10 m wide, bluff banks, 4.6 m high, runs NW (Foreman, 1871); SCR, 10 m wide, course N (Chillson, 1888).
51. SCR, 20 m wide, banks 3 m high, course N (Chillson, 1888).
52. left bank of SCR, 3 m high, course N30°W (Leedy, 1915).
53. right bank of SCR, 3 m high, course N30°W (Leedy, 1915).
54. SCR heads west at this point (Foreman, 1871).
55. Spring Branch, 18 m wide, course N (Chillson, 1888).
56. SCR, 16 m wide, banks 4.6 m high (Chillson, 1888).
57. dry wash, 5 m wide, course NW (Chillson, 1888).
58. SCR, 44 m wide, banks 3 m high (Leedy, 1915).
59. Spring Branch, 20 m wide (Chillson, 1888).
60. SCR, 17.5 m wide, course N (Chillson, 1888).
61. right bank of SCR, 3 m high (Leedy, 1915).
62. Spring Branch, marshy bed, 20 m wide (Chillson, 1888).
63. gulch, 10 m wide, 4.6 m deep, course NW (Chillson, 1888).
64a. SCR, 10 m wide, runs N (Foreman, 1871).
64b. SCR (Chillson, 1888); old channel of SCR (Leedy, 1915).
65. right bank of east channel of SCR, 3.6 m high (Leedy, 1915).
66. ditch with running water, 4 m wide, runs NW (White, 1872).
67. present swale above and below this point shown as ditch in survey plat (White, 1872).
68. arroyo, 2 m wide, 1.2 m deep, course NW, may be same location as (67)(Leedy, 1915).
69. dry bed of SCR, 30 m wide, course NW (Leedy, 1915).
70. The present straight channel of the SCR above and below this point was engineered in 1913 to join the arroyo of the SCR on the west side of the valley with the newly entrenched Spring Branch on the east side (Olberg and Schanck, 1913).
71. dry bed of SCR, 11 m wide (White, 1872); arroyo, 2 m wide, 1.2 m deep, course NW (Leedy, 1915).
72. dry bed of SCR, 12 m wide (White 1872).
73. dry bed of SCR, 9 m wide, course NW (White, 1872); dry bed of SCR, 10 m side, course NW (Leedy, 1915).
74. dry bed of SCR, course NW (White, 1872).
75. dry bed of SCR, 14 m wide, course NW (White, 1872).
76. dry bed of SCR, 10 m wide, course NW (White, 1872).
77. dry bed of SCR, 12 m wide, course NW (Chillson, 1888).
78. dry bed of SCR, 12 m wide, course NW (Chillson, 1888).
79. dry bed of SCR, 10 m wide, course N (Chillson, 1888).
80. dry bed of SCR, 13 m wide, course N (Chillson, 1888).
81. dry bed of SCR, 16 m wide, course N (Chillson, 1888).
82. dry bed of SCR, 20 m wide, course N (Chillson, 1888).

Figure 10C (continued)

83. dry bed of SCR, 20 m wide, course N (Chillson, 1888).
84. dry bed of SCR, 23 m wide, course N (Chillson, 1888).
85. gulch, 11 m wide, course E to W (Chillson, 1888).
86. dry bed of SCR, 23 m wide, course N (Chillson, 1888); dry bed of SCR, 40 m wide (Leedy, 1915).
87-100. Route of wagon road from Tucson to Nogales between 1871 and 1888 (Foreman, 1871; White, 1872; Chillson, 1888). Points 87-100 show a coincidence between the route of the old wagon road and the modern arroyo of the SCR. It is likely that, once the road was abandoned, the ruts eroded into an arroyo that migrated along the junction of the bajada and floodplain. This arroyo eventually captured the Santa Cruz at a point upstream.

---- Areas enclosed by dashed lines denote clearings in sacaton grass (*Sporobolus airieoides*) and surrounded by mesquite brush and timber, some of the trees attaining heights of 10 to 20 m. In some instances, the surveyors noted marshy conditions in these grassy flats, particularly in Sections 26, 35 and 36, T15S, R 13E. There is little mention of cottonwood, a tree that begins to dominate streamsides in southern Arizona following channel entrenchment. Areas not enclosed by dashed line are denoted by the surveyors as being either heavy mesquite brush or cultivated fields, the latter concentrated around the San Xavier Mission (Foreman, 1871; White, 1872; Roskruge, 1882; Chillson, 1888; Leedy, 1915).

General Descriptions of Townships: Each survey notebook contains a section entitled "General Description." This section frequently contain important information about the condition of the surveyed land, including state of cultivation, erosion, availability of surface water, etc. Below are some examples for T15S & T16S, R13E:

T15S, R13E

Chillson, 1888- "In fractional sections 25, 26, 35, and 36, there is heavy mesquite timber and with the exception of the enclosure in fractional townships 21, 22, 23, 25, 26 and 27, there is scattering mesquite timber and brush throughout the township. The white settlers on the Reservation in this fractional township are I. M. Berger and Trojel. The latter claims his right of settelement by marriage to an Indian squaw. I. M. Berger claims his right of settlement under claim known as the Martinez private land grant.... containing approximately [27 ha]. The wire fence in the fractional sections 21, 22, 23, 25, 26 and 27 encloses about[786 ha]; of this amount, about [370 ha] in Sec. 26 and fractional sections 23 and 27 are pasturage lands. Martinez Mountain in fractional sections 23 and 26 covers about [72 ha], and there are about [54 ha] of mesa land in section 23, which leaves approximately[288 ha] of fields in fractional sections 21, 22 and 23, of which about [180 ha] are in actual state of cultivation. There are no lands cultivated outside of the wire fence above mentioned."

Figure 10C (continued)

Leedy, 1915- "The river in this township is from 44.3 to 96.6 m wide; banks at present are well-defined: cut banks from 3.7 to 6.1 m height.. About [1.6 km] south of the standard parallel in T16S, R13E, the stream disappears entirely, the flow being underground... there are about [540 ha] under cultivation...probably [540] more would be equally productive if sufficient water for irrigation was available... barrancas are cutting back into the Martinez claim which will greatly depreciate its value unless stopped and if not checked, will eat away at the best part of the claim."

T16S, R13E

White, 1872- "Scattering timber over the township, but along the east side and over the northeast corner, the mesquite is very heavy and the brush very thick, in places almost impenetrable, with pretty grass flats of from [3.6 to 7.2 ha] in extent, in the midst of the timber. Water is found in wells in the bottom along the road and there is a running stream in sections 2 and 11."

Leedy, 1915- "The Santa Cruz River runs through the eastern half of the township mostly on top of the ground with no definite channels before it crosses the third standard parallel south (northern boundary of section 2), the west fork being the old channel and the east fork being the newer, which is well-defined and will probably become the main channel, having started about 15 years ago cutting back from Tucson."

References: The cadastral survey notebooks and plats for the state of Arizona are stored at Records Division, Bureau of Land Management, U.S. Department of the Interior. Individual notebooks can be retrieved by their call numbers:

Chillson, L.D. (1888). Notebooks 1975, 1976, 1985, 1986, 1987, 1997.
Foreman, S.W. (1871). Notebooks 818, 1456, 1457, 1566, 1507.
Leedy, C.M. (1915). Notebooks 3418, 3419, 3422, 3425.
Roskruge, G. (1882). Notebook 1747
White, T. (1872). Notebook 809.

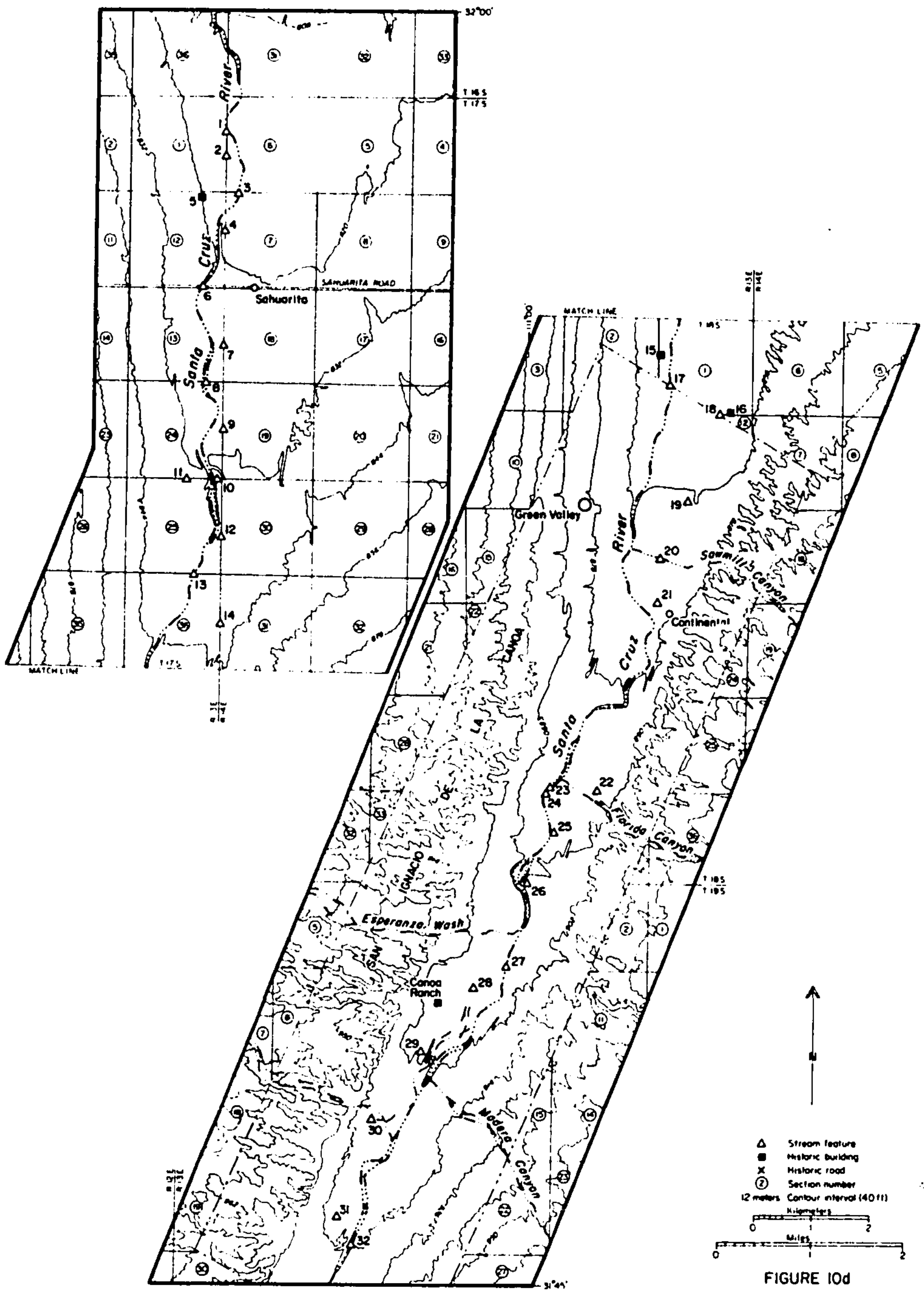

Santa Cruz River
Sahuarita
Sahuarita Road
Match Line
Green Valley
Continental
Sawmill Canyon
Florida Canyon
Esperanza Wash
Canoa Ranch
Madera Canyon
Stream feature
Historic building
Historic road
Section number
12 meters Contour interval (40 ft)
Kilometers
Miles
FIGURE 10d

Figure 10D

Figure 10D. Historic features noted in cadastral surveys of the Santa Cruz River Valley from the southern end of the Canoa Grant to the southern boundary of the San Xavier Indian Reservation. Numbers refer to features on the map.

1. dry bed of SCR, 160 m wide, runs NE (White, 1872).
2. along section line between sections 1 and 6, there is heavy timber and brush with occasional clearings covered with grass (White, 1872).
3. dry bed of SCR, 107 m wide, runs N (White, 1872).
4. along section line between sections 7 and 12, there is heavy timber and brush with occasional clearings covered with grass (White, 1872).
5. Ochoa's Ranch (White, 1872).
6. dry bed of SCR, 5 m wide, runs N (White, 1872).
7. along section line between sections 13 and 18, there is heavy timber with occasional clear grass flats (White, 1872).
8. dry bed of SCR, 4 m wide, runs N; to the west there is some grass and scattering trees (White, 1872).
9. along section line between sections 19 and 24, there is heavy timber, very brushy (White, 1872).
10. dry bed of stream, 16 m wide, runs N (White, 1872).
11. dry bed of SCR, 4 m wide, runs NE (White, 1872).
12. fine grass flat with a north-south width of 100 m, bordered on the north by heavy timber, very brushy (White, 1872).
13. dry bed of SCR, 20 m wide (White, 1872).
14. along section line between sections 31 and 36, it is very brushy with scattering timber (White, 1872).
15. Seward Brown's Ranch (White, 1872).
16. Rancho Nuevo and old corral (Contzen, 1900).
17. deep wash, 13 m wide (Contzen, 1900).
18. deep gulch, 3 m wide, runs W (White, 1872); SCR, 5 m wide, course NE (Harris, 1880); SCR channel banks 1.2 and 3 m high, course N and flanked on the west by wash, 7 m wide; soil is black loam (Contzen, 1900).
19. land very marshy in bottom (White, 1872).
20. SCR, 60 m wide, marshy bottomlands (White, 1872).
21. SCR, 40 m wide, dry, runs N, no timber along section line between sections 13 and 24 (White, 1872).
22. SCR, dry bed, 40 m wide, runs NE (White, 1872).
23. SCR, 50 m wide, runs NE (White, 1872).
24. SCR, 60 m wide, marshy bottomlands (White, 1872).
25. scattering cottonwood and mesquite trees (White 1872).
26. about 1.6 km of where the southern boundary of sections 34 and 35 crosses, the SCR is a large ever running stream of water, but sinks in the sand in a short distance (White, 1872).
27. upstream of this point the SCR is a large ever running stream of water, but sinks into the sand in a short distance downstream (White, 1872).
28. SCR bottom at this point cultivated on both sides of river (Contzen, 1900).
29. canal runs NE (Contzen, 1900).
30. old house (Contzen, 1900).
31. stage station (Contzen, 1900).
32. SCR, 27 m wide (Harris, 1880).

Figure 10D (continued)

General Descriptions of Townships:

T17S R13E

White, 1872- "Water runs along this portion of the Santa Cruz in the rainy season and now rises in holes along the valley but can be procured anywhater in the bottom by sinking wells a short depth."

T18S R13E

White, 1872- "River bottom possesses very rich soil covered with rank grass and weeds. There are some cottonwood and mesquite trees along the bottom... water can be had by digging along the water bottom."

San Ignacio de la Canoa Grant

Harris, 1880- "With the exception of the two houses and improvements owned by the claimants of the grant there are no improvements and no one else living upon the ground eclosed in the survey....some good agricultural land in the bottom but very little running water....there is heavy sacaton grass in the bottoms.

Contzen, 1900- "The Santa Cruz runs through the center and lengthwise of the grant. There is some fine land within this grant which is capable of producing an abundance of crops by irrigation. There is only running water in the Santa Cruz River during the rainy season....an abundance of cottonwood timber grows along the banks of the Santa Cruz River.... there are about 400 acres [143 ha] in cultivation on this grant. The improvements consist of a number of ranch houses, with enclosures, walls, etc. which are occupied by some of the claimants. No settlers save owners of the grant live on this grant .

References: The cadastral survey notebooks and plants for the state of Arizona are stored at Records Division, Bureau of Land Management, U.S. Department of the Interior in Phoenix. Individual notebooks can be retrieved by their call number:

Chillson, L. D. (1888). Notebook 1977.
Contzen, Phillip (1900, 1902). Notebook 1753, 1755.
Harris, J. L. (1880). Notebook 1752.
Leedy, C.M. (1915). Notebook 3418.
White, T. F. (1872). Notebook 851, 952, 1515, 1530,

agricultural lands opposite Tucson, E.N. Fish testified that during the wet years of 1868 and 1869, the river ran clear down to the Nine Mile Water Hole (Fig. 10B:3), allowing irrigation of the valley bottom north of town (Drake 1885). Along the Rillito River, a flood in September 1868 was one meter higher than a similar flood in September 1887 (*Tucson Citizen*, September 12, 1887). According to Hughes, the flood inundated the lower Gila destroying a gallery forest of cottonwoods east of Yuma (*Arizona Daily Star*, February 28, 1891).

By 1869 there were about 200 ha cultivated around the Nine Mile Water Hole, with some 80 or 90 pioneers clustering around the stage station (Weekly Arizonan, May 22, 1869). According to Sam Hughes: .

> [In 1868].... The Santa Cruz and other rivers which empty into the Gila were all running high and so great was the snow and rainfall during that season [winter] and the two years following that the Santa Cruz flowed a surface stream from its source to the Gila during 1868, 1869 and 1870, something unheard of since, as the stream is subterranean more than three-fourths of the length of the valley through which it flows (*Arizona Daily Star*, February 28, 1891).

Though there certainly were cienegas south of San Xavier and at the base of Sentinel Peak, references to beaver are scant for the Santa Cruz River, particularly in the Tucson Basin. Carmen Lucero, who resided at Tucson in the 1850s and 1860s, reminisced that, "I was telling you about the days before the Americans came. At that time the river did not have a deep channel but was just a creek running all over the valley, and there were lots of beaver at Silver Lake" (Lucero, 1928). Remains of beaver are unknown from excavated Hohokam sites along the Santa Cruz River. Yet these same sites yielded muskrat, an aquatic mammal of marsh habitats that was never noted in historical accounts of the middle Santa Cruz valley (Fish and Gillespie, 1987). Historical references to beaver in this reach of the Santa Cruz may be a case of mistaken identity. Muskrats do not build dams and thus would have played a different role than beavers in the maintenance and perpetuation of local cienegas.

Accounts prior to 1870 seldom mention the depth of the river channel. In 1849, Clarke (1852, p. 85) describes a small creek with high banks on the western side of the valley south of San Xavier. Some 22 years later, Foreman observed that the bluff banks of the Santa Cruz River were from 8 to 10 m apart and from 2.4 to 4.6 m deep in the same general area (Fig. 10C:47, 50). Upstream, about 2 km to the south, was the spring at Punta de Agua (Fig. 10C: 20) which had been developed by Martinez no earlier than 1849. As late as 1915, land surveyor C.F. Leedy noted that, "The Santa Cruz River runs through the eastern half of the township mostly on top of the ground with no definite channels before it crosses the Third Standard Parallel South (Fig. 10C: northern boundary of Section 2, T16S, R13E)." Punta de Agua is located about 200 m south of the Third Standard Parallel (Fig. 10C). The springs at Punta de Agua probably emanated where a steep headcut intercepted the water table.

On the eastern side of the valley, at the present site of the Valencia Road Bridge, Foreman recorded bluff banks 3 m high and about 20 m apart (Fig. 10C:27). In 1882, the newspapers described a headcut at this locality:

> Some six miles [9.6 km] south of the city, the Santa Cruz seems to spring directly from a steep clay bank, rising on the three sides about 20 feet [6.1 m] from the bed. Above that point the river is lost under the dry mesa, not reappearing again for miles beyond. Here is found a deep pool of pure cold water, bubbling through the earth from the sides and bottom (*Arizona Daily Star*, September 24, 1882).

The location of the Valencia Road headcut relative to the mainstem of the Santa Cruz River is somewhat problematical. The headcut was directly in line, not with the mainstem which then ran on the west side of the valley, but with the Spring Branch, the stream emanating from the spring at Agua de la Mision. Note that the present channel coincides with the former course of the

Spring Branch. Maps of this area in 1882 (Fig. 11), 1888 (Fig. 12), and 1891 (Fig. 13) show that the Spring Branch was diverted from the base of Martinez Hill west towards the Santa Cruz mainstem. North of Martinez Hill, the maps suggest that floodflows followed the irrigation system rather than natural channels. This pattern probably existed back to Kino's time, but may have been atypical of conditions about 500 years ago, when the Santa Cruz probably flowed in a deep channel along the historic course of the Spring Branch.

Recent alluvial stratigraphic work at the base of Martinez Hill has revealed a large paleoarroyo in the exposed banks of the present Santa Cruz River channel. Waters (1988) suggests that this paleochannel, of comparable dimensions as the modern arroyo, cut and filled between 300 and 500 years ago (Fig. 5). The Valencia Road headcut developed in a floodplain that was only 300 years old, at a time when the main floodflows followed the eastern margin of the valley. The exact age of the Valencia Road headcut remains uncertain, but its development may have influenced upstream diversion of floodwaters by the Hohokam or their progenitors. This is suggested by what appears to be the anomalous location of the Santa Cruz on the western side of the valley, and the lack of continuity of the Spring Branch upstream of Ojo de la Mision.

Judging from the pre-1870 accounts, similar headcuts had not developed near Tucson. As it approached the town in 1849, the river, "divided to a mere brook, the grassy banks of which are not more than 2 yards (2 m) apart" (Powell, 1931, p. 145). As late as 1907, the river banks immediately below the confluence with the Cañada del Oro (Section 1, T13S, R12E) averaged less than 1 m high (Fig. 10:46-68). In 1871, the channel was about 5 m wide at the Nine Mile Water Hole, a few hundred meters above the Rillito confluence (Fig. 10B: 2).

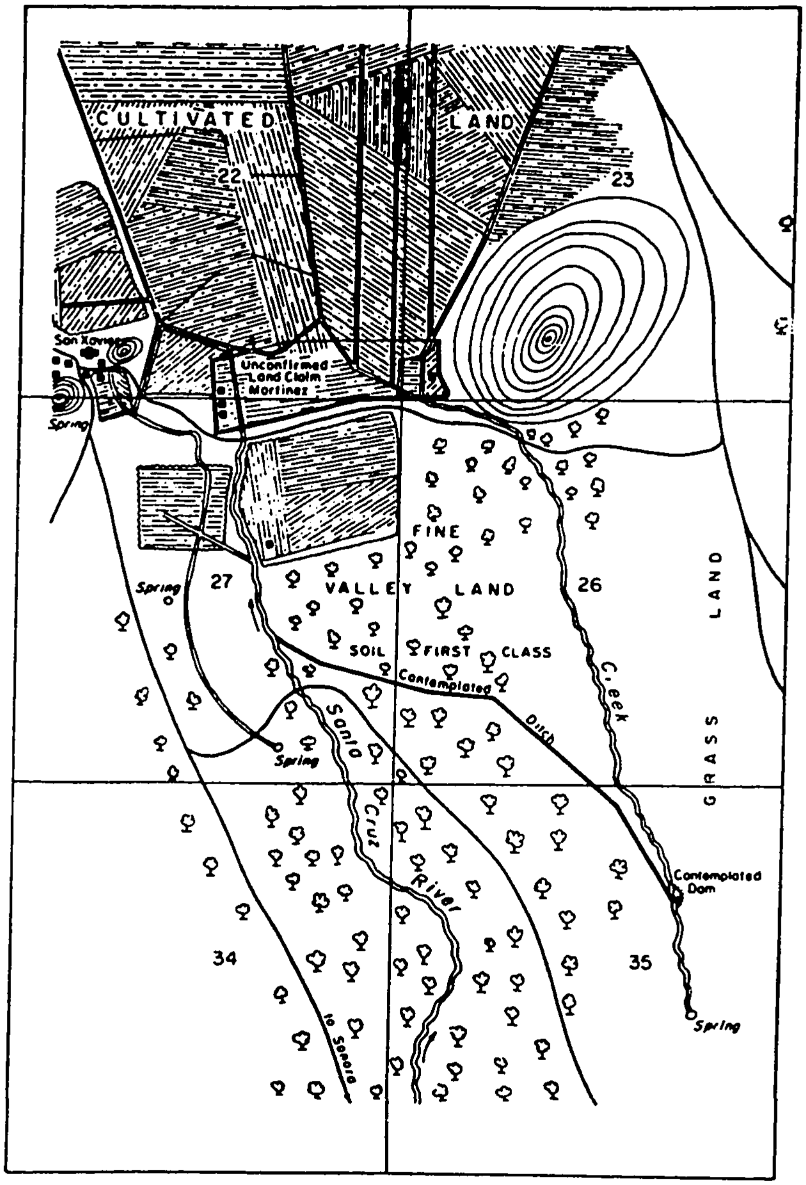


Figure 11. Map of the northeast portion of the San Xavier Indian Reservation in 1882 (after Roskruge, 1882). In this map, and on later ones (Figs. 12-13), the course of the Santa Cruz north of Martinez Hill is not indicated, suggesting that the channel had long been replaced by ditches in carrying floodflows.

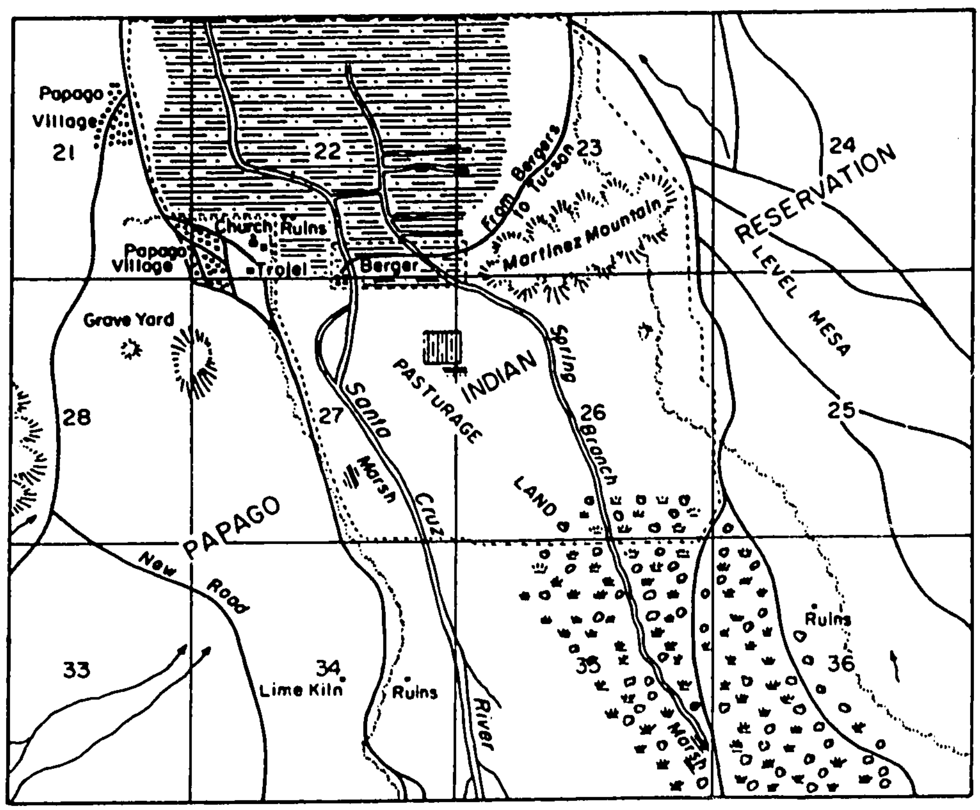


Figure 12. Map of the San Xavier Indian Reservation in 1888 (Chillson, 1888).

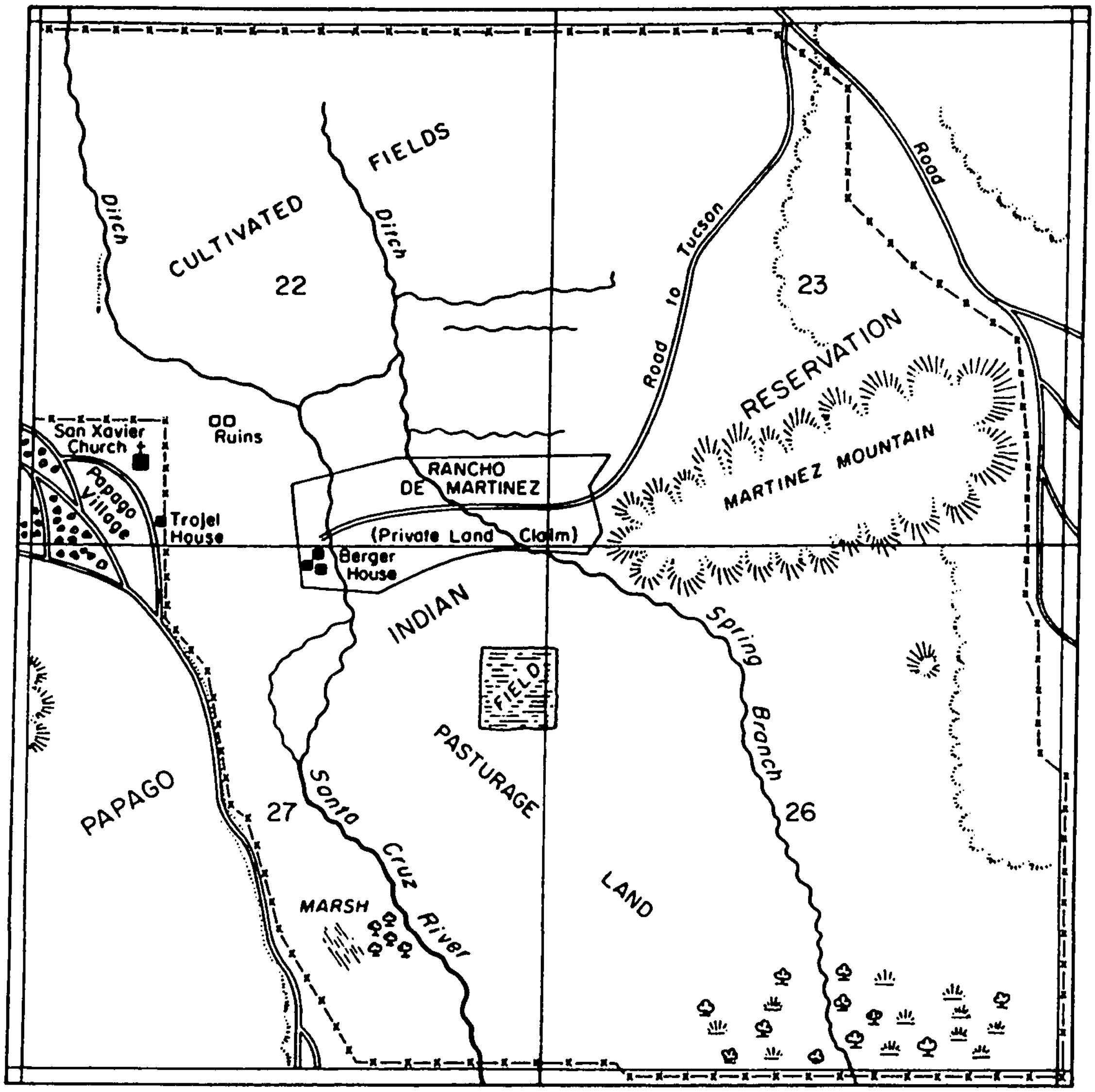


Figure 13. Map of San Xavier Indian Reservation in 1891 (Surveyor General's Office, 1891).

Early accounts provide general descriptions of the vegetation in the valley. Dense mesquite growth occupied the dry reaches above and below the perennial stretch through Tucson. Across from town, cottonwoods and willows marked the course of the various irrigation ditches. A grassy marsh covering about 2.5 sq km spread out on either side of the Spring Branch above San Xavier (Fig. 10C). An impressive mesquite (*Prosopis velutina*) forest, interspersed with small meadows, was restricted mostly to the western side of the valley, between Punta de Agua and the Mission (Fig. 10C). In 1902 and 1903, ornithologist Harry Swarth described the forest:

> South of Tucson, Arizona, along the banks of the Santa Cruz River, lies a region offering the greatest inducements to the ornithologist. The river running underground for most of its course, rises to the surface at this point, and the bottomlands on either side are covered, miles in extent, with a thick growth of giant mesquite trees, literally giants, for a person accustomed to the scrubby bush that grows everywhere in the desert regions of the southwest, can hardly believe that these fine trees, many of them sixty feet [18.3 m] and over, really belong to the same species. This magnificent grove is included in the Papago Indian Reservation, which is the only reason for the trees surviving as long as they have, since elsewhere every mesquite large enough to be used as firewood has been ruthlessly cut down, to grow again as a straggly bush (Swarth, 1905).

In 1911, another ornithologist visited the area and reported:

> The mesquite trees are wonders of their kind....There were some whose trunks at the base scaled over four feet [1.2 m] in diameter. The large bases branched a few feet from ground into several limbs fifteen or eighteen inches [38-46 cm] in diameter. The tallest reaches a height of over sixty feet [18.3 m]. The undergrowth is a thick mass of hackberry, etc. with various thorny bushes growing close to the ground. Meandering wood roads lead in every direction and one can never be quite sure that he is on the right one (Willard, 1912).

Within the Canoa land grant near present Green Valley, surveyors in 1821 referred to "teraques" in listing the local flora. In 1876, the document was translated by the U.S. Surveyor General's Office and "teraque" was taken to mean "tamarisk." Tamarisk or saltcedar (*Tamarix* spp.) was introduced to the New World as an ornamental supposedly in the mid-19th century. The feral species (*T. chinensis*) was first reported along the Salt River in 1901 (Robinson, 1965), while cultivated plants (*T. aphylla*) in Arizona may be derivatives from a few cuttings secured by J.J. Thornber, a botanist with the University of Arizona, at the beginning of the 20th century.

Due to prolific seed production, effective seed dissemination, rapid growth and early maturation, saltcedar has become established along water courses, reservoirs and irrigation ditches in western North America, often to the exclusion of native phreatophytes. For example, between 1937 and 1964, there was a seven-fold increase in the area dominated by saltcedar along a 21-km stretch of the Gila River (Turner, 1974).

Relying on historical photographs, wholesale replacement of native riparian species by saltcedar did no occur along the Santa Cruz River until after 1940. Unlike cottonwood and seepwillow, saltcedars commonly survive in habitats where ground water is unavailable. After 1940, radical lowering of the water table and channel entrenchment helped eliminate native phreatophytes to the advantage of saltcedar. If indeed saltcedar was present along the Santa Cruz in 1821, the lag time it took to get established defies explanation.

CHAPTER 5: FLOODS AND LAND USE 1871-1889

By 1870, Tucson had become a bustling community of 3,224, including 200 Anglos. Pima County alone accounted for more than half of Arizona's population. Excluding the Fergusson map of 1862, there had been no surveys of the fertile lands in the valley. This posed a significant obstacle to obtaining title to property and precluded establishment of Tucson as a formal townsite. Apache hostilities postponed the sorely needed surveys, even though Levi Bashford had been appointed Surveyor General of Arizona in 1863 with offices in Tucson. In July 1864, Bashford and his records were transferred to Santa Fe, slated as the new headquarters of the General Land Office for Arizona and New Mexico. John Clark, the new Surveyor General in 1865, warned that surveying parties would remain inactive until the Indian menace was dealt with. Jurisdiction over Arizona shifted to California in 1867 and, three years later, Arizona was finally granted its own district with John Wasson as Surveyor General.

In January and February 1871, the survey of T14S, R13E, including the proposed townsite of Tucson, was completed (Fig. 10B). By 1872 every township in the valley between Rillito and Continental (except T12S, R12E) had been surveyed by either S.W. Foreman or Theodore F. White, in spite of Apache pressure (Fig. 10A-D). In fact, Foreman's 1871 survey of the San Xavier district followed closely on the heels of a raid on the Punta de Agua Ranch.

Attracted to California by the gold rush, Foreman first settled in Nevada City and later served as Deputy Surveyor General in San Francisco. By the late 1860s, he had been granted several subcontracts to survey in Arizona.

White had lived in the Santa Cruz Valley since 1850, starting out as a government contractor in Fort Buchanan. Both surveyors recorded site-specific information concerning the course and dimension of the river channel, vegetation, and cultural features (houses, fences, irrigation ditches, roads, etc.,) in the early 1870s (Fig. 10A-D).

Flour, Fires and Floods: Events of the 1870s

The early 1870s were years of drought. In March 1873 Camp Lowell was moved from the military plaza to the confluence of the Tanque Verde with Pantano Wash. Also in 1873, the telegraph was connected in Tucson. After three years of trying to evict Mexican settlers from the San Xavier area, Indian Agent R.A. Wilbur and local Papagos were finally rewarded in 1874, when Congress agreed to set aside an Indian reservation along the Santa Cruz River.

The winter of 1874 was exceedingly wet throughout central Arizona and flooding occurred throughout the Gila River Basin. On the lower Gila, the floods matched the high water mark reached in winter of 1868 (Dobyns, 1981). Heavy rains in July inflicted damages at San Xavier and Tucson:

> The late heavy rains were a little too heavy for vegetables and vines in the valley in front of town, but most of them will be covered and the damage sustained. Levin's park and garden was pretty generally overflowed and some injury done to plants and vines, but not so much as first appeared to be. He still will have a very large crop of vegetables.... William Zeckendorf was out among the ranchers towards San Xavier on Wednesday and he informs us that much wheat has been ruined by the late heavy rains. One man loses thirty thousand pounds and at least one hundred thousand pounds are damaged in that neighborhood (*Arizona Citizen*, July 18, 1874).

The early 1870s also marked the return of Solomon Warner to Tucson. Warner's plans for building a flour mill at the foot of Sentinel Peak were conceived before May 1872 (Figs. 14-16). It was then that Tomás Elias authorized access for an irrigation ditch across his land near the northeast corner of the garden at the San Agustin mission. Warner faced stiff competition from two other local mills, Lee and Scott's Pioneer Mill at Silver Lake and the Eagle Steam Flour Mill at the corner of Main and Broadway. In 1874 Lee and Scott dissolved their partnership and the Eagle Mill was sold to E.N. Fish.

In October 1874 Warner endeavored to obtain water rights and rights-of-way for his canal system to and from the mill. Bishop J.B. Salpointe, trustee for the Catholic Church, granted Warner the right to build ditches across church lands. Warner enlisted Alex McKey for construction of the millrace at a cost of over $1000 (*Arizona Citizen*, August 22, 1874). Beginning near the Pioneer Mill, the millrace ran for 1.5 km. The tailrace took waste water and returned it to the Acequia Madre directly east of the San Agustin Mission (Figs. 17-18). The amount of water claimed by Warner was 0.35 cms. A portion of the tailrace was diverted to run through Leopoldo Carrillo's cooling house directly across from the mission building. By October 1875 Warner had completed construction of his mill at an expense of between $15,000 and $16,000, a considerable sum in those days:

> The mill wheel is a twenty-five inch American turbine, producing a 9 horsepower which will make a grind of about eight bushels an hour. The driving force is some six hundred cubic feet [17 cm] of water with an average fall of eleven and a half feet [3.5 m].... Mr. Warner had to construct a ditch.... which is quite a piece of engineering, but as Mr. Warner says, [it is] the only badly constructed thing about the mill [in July 1875 McKey had to sue Warner to recover the cost of building the millrace] (*Arizona Citizen*, October 30, 1975).

In 1876 several parties from Tucson began investing heavily on grazing lands in the Santa Cruz Valley. In November, Tomas Ortiz sold his half interest in the Canoa Land Grant to Fred Maish and Thomas Driscoll for $1100.

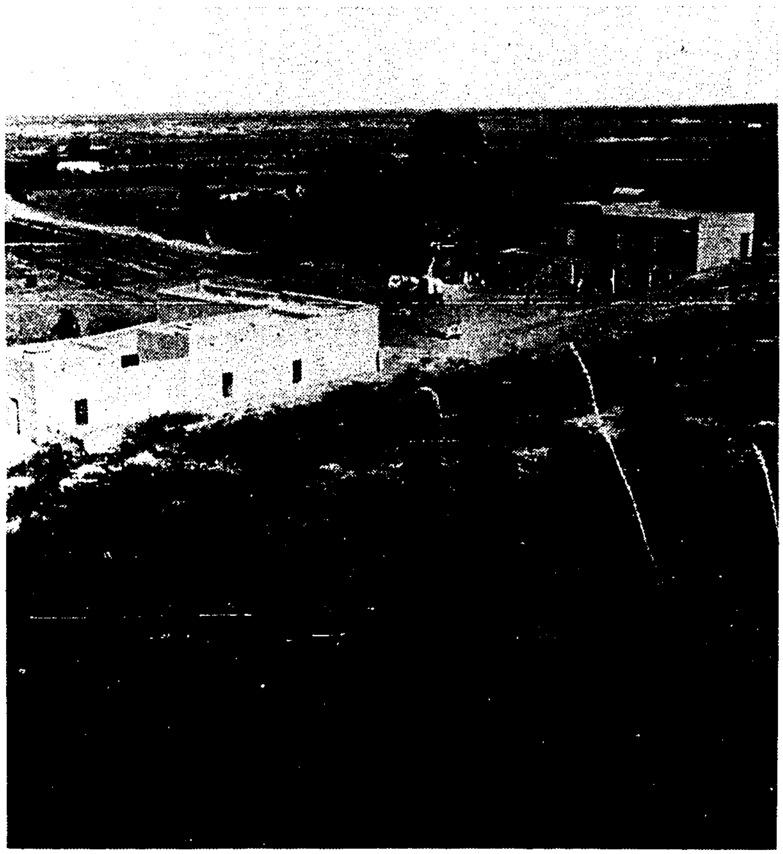


Figure 14. Solomon Warner's house and mill in 1880, looking southeast from lower slope of Sentinel Peak, with the Santa Cruz Valley in the background (Photograph by Carleton Watkins, Arizona Historical Society, Tucson, Negative No. 14846).

Figure 15. The Santa Cruz Valley from the base of Sentinel Peak looking east ca. 1880. Warner's Mill is the structure at left margin of photograph. White structure at center right is Leopoldo Carrillo's ice house, which was cooled by water from the mill's tail race (Arizona Historical Society, Tucson, Negative No. 6608; U.S.G.S. Stake 1052).

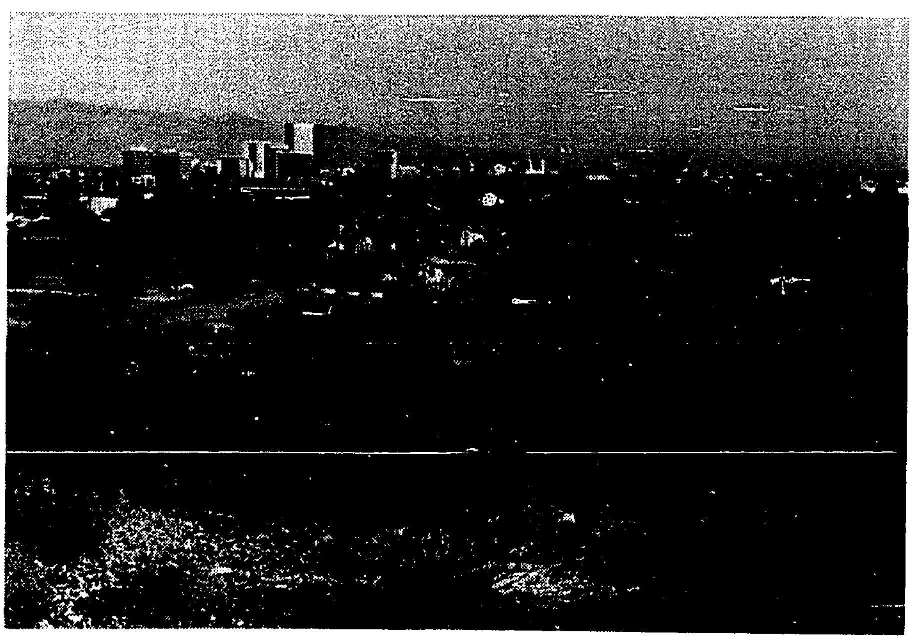


Figure 16. Same view as Figure 15 on December 1, 1981 (Photograph by R.M. Turner, U.S.G.S. Stake 1052).

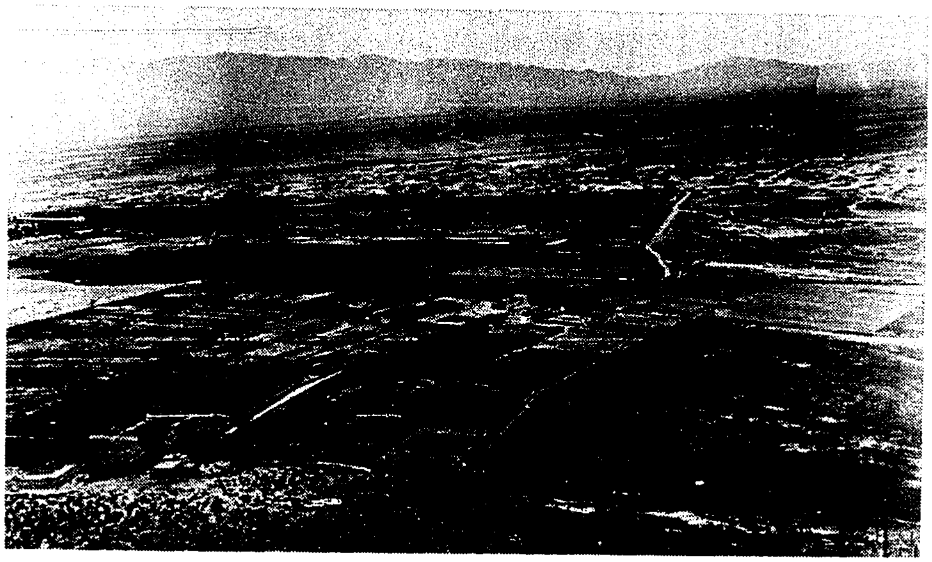


Figure 17. East view of Santa Cruz River Valley and Tucson from Sentinel Peak in 1882, showing the San Agustin Mission (center) and Warner's Mill Complex at lower left. The Acequia Madre, which was fed by Silver lake, runs from right to left across center of photograph. The Acequia may have followed the mainstem of the Santa Cruz River, which at that time had no discernible channel (Arizona Historical Society, Negative No. 18233; U.S.G.S. Stake 1053).

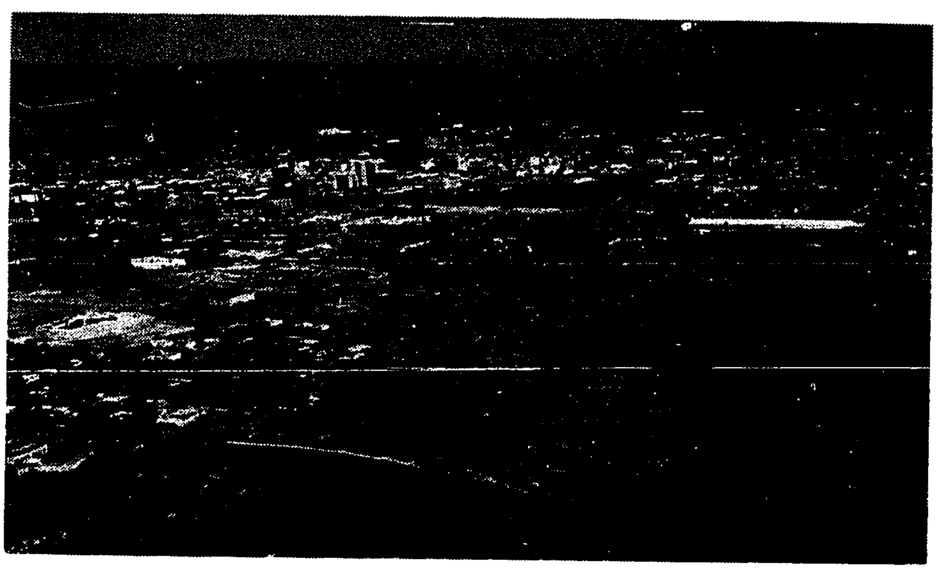


Figure 18. Same view as Figure 17 on December 1, 1981. The only recognizable feature in both photographs is Solomon Warner's house in lower left corner. Most of the modern floodplain has been elevated a few meters by landfills (Photograph by R.M. Turner, U.S.G.S. Stake 1053).

In summer 1877, widespread fires broke out along the eastern margin of the Tucson Basin, destroying valuable pasture:

> For the last month the country north, south and east of Tucson has been in a constant blaze. The grasses on the mesas, mountains, and valleys have been eaten up by the flames; during the past two days the fire has traveled over the Santa Catalina Mountains and is burning now miles beyond. It has climbed almost to the summit of the Santa Ritas (*Arizona Weekly Star*, June 23, 1877).

Overall, large fires in the Santa Cruz watershed happened in 1874, 1877, 1879, 1880, 1882, 1887 and 1889 (Bahre, 1985). Whether or not fires were unusually frequent and extensive in the 1870s and 1880s cannot be evaluated at present. The 1877 fires were associated with a prolongued winter-spring drought, which continued into the late summer, causing much alarm in Tucson. No rain fell in August 1877, an unusual occurrence in the Tucson area:

> Contractors are already feeling uneasy over their prospects, and a sufficient amount of rain seems to be as far off now as it was in June. This state of things, which we are informed by old residents has never been known before, is to be deeply regretted just at this time, owing to the fact that the Territory of Arizona will be visited this fall and winter by a greater number of people than ever before in any one year, and the appearance of the country will not be so favorable (*Arizona Weekly Star*, August 9, 1877).

Combined fire and drought during the summer of 1877 probably destroyed much of the grass cover in the upper watersheds of minor tributaries. Just how much of the area was denuded or whether the lack of vegetative cover was sufficient to increase runoff significantly is uncertain. Because of the summer drought in 1877, recovery of grasses dependent on summer rainfall would have been delayed until arrival of late summer rains in 1878. On July 11, 1878, unusual flooding occurred along tributaries that originate in the eastern part of the Tucson Basin and flow through town, fully a month before the burned and drought-strickened grassland could have recovered. This storm contributed to the second wettest July in history (the wettest occurred in 1921):

> On Thursday afternoon of last week, the most violent rainstorm that has occurred in Arizona during the recollection of the oldest settlers visited Tucson and vicinity, doing an immense amount of damage to property. The clouds began to gather at about 3:00 in the afternoon and two were plainly visible, coming from an opposite direction, which were heavily laden with water.... At about 5:00 the crash came, although rain was falling slightly for a little time before. But darkness came with the two black clouds, and meeting, they burst. Being over an elevated position of the country, the water started within one mile [1.6 km] of the city, and soon the streets of Tucson leading to the bottomlands, were a roaring sea of water. Buildings were washed out, walls torn down and families were fleeing for safety in great alarm. In the lower end of the city the damage was more severe, as the water came tearing down in great volume among the buildings on the lower side of Main Street. The valley was flooded, the fields being covered to a depth of two and three feet [0.6-0.9 m], gardens were destroyed, trees taken out by the roots and swept away with the current, carrying devastation in their course. The vegetable gardens, and they are numerous on the bottom, were destroyed, and the houses flooded with water, so much so that the people had to seek places of safety on more elevated ground.... There were forty-two buildings, as far as we have investigated, which have been damaged or washed away, and the scene of wreck and ruin is beyond description. The storm lasted about 3/4 of an hour and rain fell to a depth of six inches [15.3 cm] on the level (*Arizona Weekly Star*, July 18, 1878).

Lakes in the Desert

In spring of 1879, Leopoldo Carrillo purchased about 5 ha of uncultivated land south of the road to the San Agustin Mission and Warner's Mill, near the artesian well at El Ojito on the east side of the floodplain:

> Just at the lower edge of Tucson a little enterprise has been going on this spring which has now advanced far enough to deserve mention. Leopoldo Carrillo some time back, took possession of several acres of waste land, then covered with the usual growth of bushes, and so far this side of the valley, being just at the edge of the mesa, that it could not be irrigated with the present system of sluices. He boldly planted a lot of fruit trees, procured from Armstrong, and then set to work to provide them with water. A ditch parallel with and close to the mesa line, with short lateral ditches running from the main ditch into the side of the mesa hill, soon filled with water and showed that the neighborhood there was full of springs. Mr. Carrillo then built a stone tank about 50 feet [232 sq m] and added thereto a simple pumping apparatus, and the thing was done. The trees have flourished and

> there seems to be no reason why the place, which was before a mere alkali patch, may not in the future be a fruitful orchard (*Arizona Citizen*, May 2, 1879).

The year 1880 opened with an unusual snow storm in Tucson. Earlier in the year, Carrillo bought or built a hundred houses to keep up with Tucson's burgeoning population, which had doubled during the previous decade. Arrival of the Southern Pacific Railroad in March ensured Carrillo of turning a handsome profit and furthering his status as Tucson's foremost landlord and wealthiest resident. Carrillo also developed four large springs at his Sabino Canyon Ranch in the Catalina Mountains, running the water into a reservoir. Apparently, this was done in preparation to opening a resort the following summer (*Arizona Daily Star*, August 9, 1880). A similar resort was already available at Silver Lake (Figs. 8-9). The Silver Lake facilities were improved in 1881:

> Silver Lake.... is caused by a dam of masonry in the Santa Cruz River and extends over several acres. Several boats for sailing and rowing up the river beyond the lake.... A row of commodious bath houses for bathers and a stout rope extends across of the lake for the convenience of persons learning how to swim. The hotel, bath houses, pavilion, lake and grove occupy a space of 20 acres [8.1 ha], leased and controlled by Richey and Bailey, who also own the mile racetrack [now Cottonwood Road] adjacent thereto and where the annual races are held. This is the only racetrack near Tucson and only swimming baths in Arizona (Barter, 1881).

Flooding occurred in July 1881, but its impact on Silver Lake is undetermined:

> At Brown's station the crossing constructed by Mr. Brown was carried away and a washout eight feet [2.4 m] deep was made. The Santa Cruz below Brown's was a sheet of water half a mile [0.8 km] wide and in places 6 feet [1.8 m] deep and holes washed out in every direction making the whole country a whole lake (*Tombstone Daily Nugget*, July 27, 1881).

Sometime in the 1870s, Solomon Warner built a small pond covering ca. 2 ha of land. The pond captured water that escaped Silver Lake during the night. In January 1880 Francisco Leon and other farmers downstream became dissatisfied, claiming that there was a sink in the bottom promoting loss of water. Accordingly, Warner cut a ditch on the side of the pond a couple of months later, acquiescing to Leon's demands to run the water past the pond. The Water Overseer, Lorenzio Reubaria, "turned the water back and turned it loose in the morning and continued to do so until the high water washed the dam away" (Warner, 1884).

By the close of the decade, it was evident that Tucson was running short of domestic water. Although the fields across from town could be easily irrigated, demand for domestic water had outgrown the days of the presidio. Most of the domestic water then came from El Ojito, an artesian well located where the floodplain abutted the Pleistocene terrace on the east side of the valley. In the 1870s, Adam Sanders and Joseph Phy owned a hand-dug well on South Main Street, from which they filled a large square iron tank fitted on a wagon. Each day they would drive through the streets selling water at five cents a bucket (*Tucson Magazine*, Dec. 1948). T.J. Jeffords, a former Butterfield stage driver and the man who brought Cochise to peace terms, finally tackled the problem in May, 1879. Jeffords signed a contract with the city of Tucson to develop enough artesian flow to supply local water needs for 25 years. The artesian flow never materialized (*Arizona Weekly Star*, April 17, March 24, May 1, May 8, 1879; March 24, August 11, 1881).

The organization of a volunteer fire department in 1881 once again highlighted Tucson's pressing water needs. Then Mayor of Tucson, Robert N. Leatherwood, devised a scheme whereby gravity flow from the river 10 km upstream could be piped up on the west terrace to town. In the spring of 1882, he enlisted the aid of Sylvester Watts and J.W. Parker, capitalists from the Midwest who had experience in such affairs. Their plans were to develop the springs at the Valencia Bridge headcut:

> Mr. R.N. Leatherwood was to obtain water from the Santa Cruz above Gay's ranch, at an elevation that would insure the fluid being forced to all prominent points in the town. Not being able to obtain sufficient capital at home to complete the undertaking he went abroad, and fortunately came into contact with Sylvester Watts, a St. Louis capitalist who had extensive and successful experience in like enterprises. Early in April, Mr. Watts visited Tucson.... and examined the survey made by City Engineer John P. Culver. The first material move toward perfecting the plans adopted by them was the purchase of 1000 acres [405 ha] of land surrounding the source of water supply. By the 20th of May, several carloads of heavy sheet iron were on their way from St. Louis and early June the work of constructing the water mains were begun in the old government corral. By August 1, a sufficient number were finished to justify excavation of trenches between this city and the forbey [forebay] beyond Gay's ranch and a few days afterward, the first pipe was placed in position. From that time to the 15th of September, the largest available force of laborers were employed in digging tunnels and cementing mains, and on this latter date, as the reader must be aware, the Santa Cruz was forced into Main Street....[From the Valencia Road Bridge headcut] for a half mile [0.8 km] northward, a wide ditch has been excavated four feet [1.2 m] wide in its bed being clean gravel. Through this, water from the underground springs is constantly rising to the surface. Over the entire length of the ditch a triangular aqueduct of redwood has been constructed, completely watertight, thereby preventing any surface water from entering. The aqueduct gathers all water reaching the surface along the whole distance and pours it into a huge forebay, 20 feet [6.1 m] deep. This is a compartment built of strong timbers, which acts as a receiver for the aqueduct water and from which the water is discharged into pipes 20 inches [50.8 cm] in diameter. These extend probably 100 feet [30.5 m], leading to the corner of Main and McCormick Streets (*Arizona Daily Star*, September 24, 1882).

By 1883, there had been a noticeable drop in the water level at Silver Lake. According to Solomon Warner, upstream development of the underflow by Watts and Parker effectively lowered the lake level. He lamented that:

> It is impossible to run a flour mill with the natural flow of the river except two or three months in the winter.... I run my mill from Lee's pond [Silver Lake] and as long as he was running his mill it was very satisfactory. But after he stopped running his mill [ca. 1882], the water came very irregular both in quantity and time and it became necessary for me to get the full benefit of the water (Warner, 1884).

Early in 1883, Warner began buying up lands along the West Branch of the Santa Cruz River. In summer, he started construction of a large earthen dam that would impound the West Branch cienega at the foot of Sentinel Peak (Figs. 19-20):

> I put the flood gates in my present pond some time in July last year and commenced damming the water that was running from my own cienega with but little success at first, the water leaking through nearly as fast as it came in. About the first of December, the embankment gave way near the flood gates and let almost all the water out of the pond. In repairing that I succeeded in stopping nearly all the leaks and about the first of January, the water in the pond was on a level with the water in the flume. I then made a connection with the flume and the pond and commenced using the water from them both. The water in the Santa Cruz near Tucson has been much less during the past two years than formerly. Both years being very dry and the Tucson Water Company using a large amount of water in Tucson. They have taken it for about two years. The watershed that supplies the cienega is quite extensive. It commences on the west side of the Sierritas, 30 or more miles [40 km] in length and 10-15 miles [16-24 km] in width. In some seasons the quantity of water running from the cienega is equal to one-quarter to one-half enough to run the mill several months a year. The pond is situated at the foot of a mountain [Sentinel Peak] and there are several springs at the base, and for a considerable distance water oozed out so much that the cattle to avoid it made a trail through the mesquite and over the rocks at the base of the mountain. Tullies [*Typha* sp.] and water grasses grew on all the land the pond covers with the exception of three or four acres on the south and east side. Beside the stream of water that continuously ran in the lower part of the land which the pond covers there were other depressions where the water remained all the time (Warner, 1884).

The newspapers also provide descriptions of Warner's Lake:

> Yesterday morning the Citizen local accepted an invitation to take a ride into the country with Mr. Robert Miller, of Warner's Mill and view the great work that has been accomplished by the Warner brothers in the creating of an immense artificial lake in order to insure a continually full race for the mill, and also afford a place for the breeding and rearing of carp.... One difficulty Messrs. Warner and Miller have experienced in running their mill has been to always have a constant and steady full head of water in the mill race. Of a morning the race might be full and by noon have fallen a couple of inches, caused by the distribution of water among the farmers in the valley above the mill by the sanjeros (ditch bosses). This annoyance for a while seemed to be an obstacle they could not possibly overcome. The farmers below the mill never gave any such occasion of trouble, for they use the water after it has passed through the race, and turned the mill. Work was begun upon the dam along the early part of the last summer, but the season and other causes combined compelled a temporary suspension of the work. It was resumed some four weeks ago, and will be completed in about two more weeks. The dam begins at that point on Sentinel Peak where the mill race first touches the hill

> and runs for a quarter of a mile alongside of the race towards Silver Lake, ending at a point of ground sufficiently high to hold all the water needed. It will be wide enough for a roadway on its top to connect with one by the mill race. At the hill is a bulkhead ten feet [3 m] wide and provided with strong gates to let out the surplus waters in case of a flood. The work of construction is simple in its character, but massive and extensive. At present six men with scrapers are employed in putting the finishing touches to the dam. The result of this big dam has already been wonderful. The waters of the many springs of the different cienegas on the Warner land have been held back by the dam and have risen till they have covered some 20 acres [8 ha] of land, creating a sheet of water that is beautiful to look upon. Already the wild fawn have made it their resort, and an organization of hunters have obtained the exclusive right to shoot upon its waters. A flat-bottomed boat sails over its surface. The different kinds of ducks killed there are the gray and spoonbill, the green and red winged teal, mallard, canvass back, widgeon, spring tail, the butter and a new kind never seen before called the fish duck.... The snipe, curlew and plover appear abundantly. When the dam is completed and the waters have occupied all their space, about 50 acres [20 ha] will be covered (*Arizona Citizen*, November 18, 1883).

No sooner had the dam been constructed than Warner began drawing up plans for bath houses to compete with the resort at Silver Lake. He had completed the foundations for the houses and was about to erect the structures when Hudson and Company failed. Warner was a creditor to the amount of $2300, the loss compelling him to cease all improvements. Foreclosure on his credit marked the beginnings of troubled times. In July 1884, he received legal notice from Hereford Lovell, attorneys for the Water Overseer and landowners immediately downstream of the lake. According to Lovell, Warner was obstructing streamflow from flowing into the public acequia without consent of the water overseer.

Two weeks after Warner received this legal notice, certain landowners in the valley adopted measures to secure a more efficient distribution of water. At the meeting, Water Overseer C.A. Dalton was accused of not distributing

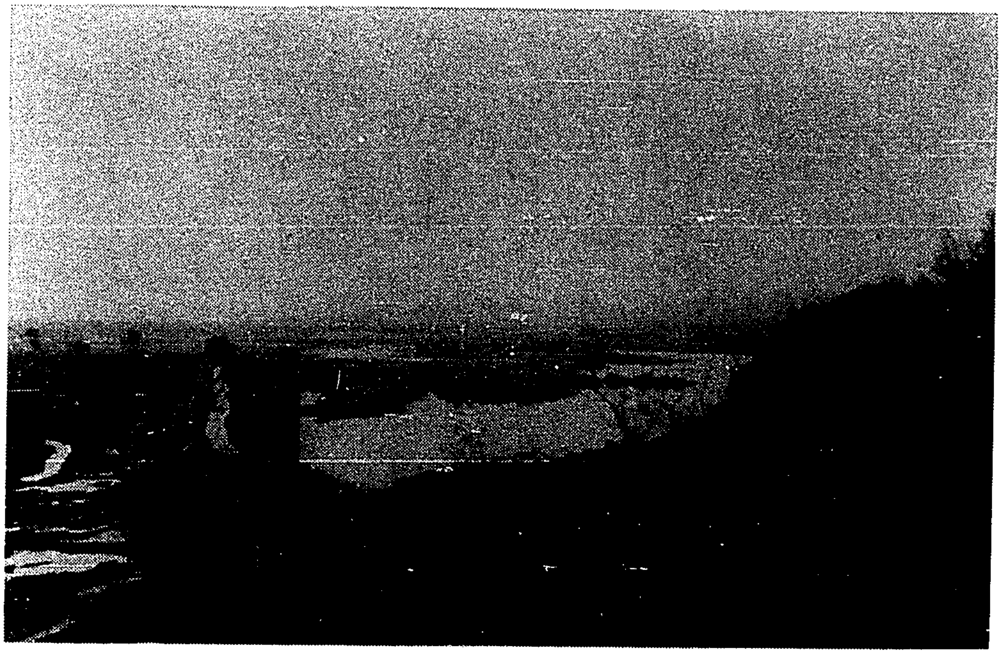


Figure 19. Southeast view of Warner's Lake in 1883. The shallow channel of the Santa Cruz River is visible downstream of the dam at extreme left of the photograph (Arizona Historical Society, Tucson, Negative No. 12565; U.S.G.S. Stake 1055).

Figure 20. Approximately the same view as Figure 19 on December 31, 1988. The course of the Santa Cruz is obscured by saltcedars at lower left. Elevated road is 22nd Street (Photograph by R.M. Turner, U.S.G.S. Stake 1055).

water to the satisfaction of these landowners. Because he would not commence proceedings against Warner, Dalton immediately resigned and was replaced by Joe Holt.

Litigation over the Santa Cruz: The Water Rights Case of 1884-1885

As new lands were cleared for cultivation downstream of Tucson, the irrigation issue escalated into serious litigation between landowners north and south of the hospital road (now St. Mary's Road: see Fig. 10B). Fields north of the road received their water after it had turned Warner's waterwheel. Landowners south of the road felt that the set-up at Warner's lake and mill deprived the oldest fields of irrigation water. Warner himself narrates the power struggle over the lake:

> The day before J. Holt opened the gate at the pond he was there to take charge of the water. I asked him by what authority he was going to take the water. He said by the authority of the Committee. I asked him who were the Committee. I asked him to wait until I could see the Committee. He told me to see Gleason. Everything remained that day as it formerly had been. I went and saw Mr. Gleason. I asked him if we could not make some arrangement and continue the running of the mill. By his drawing down the pond, I would soon have to stop. I proposed to get a hydraulic engineer and measure the water above the pond and then measure the water taken out of the pond and see if there was any loss of water. I told them to draw water down in the pond and ascertain in that way if the pond was any injury to them. He said that he was going to draw the water down to establish their right. He said that if they would let me go, that in two years, I would establish my right by limitation of law and after they had established their right they would then destroy the old contract between myself and them and make a new one. The day Holt opened the water gate at the pond I made no objection to his doing so as he had told me the day before that if I interfered with him he would cut the ditch. That the Committee had ordered him to do so. There were a number of men present when Holt opened the gate. I afterward asked Holt what he would have done had I shut down the gate he had raised. He said he would have raised it again and would have left a man in charge of it (Warner, 1884).

By May 1885 the conflict between farmers north and south of the St.

Mary's Road was being settled in the county court before Judge Gregg. The transcript of the proceedings (Dalton et al. vs. Carrillo) as recorded by then court recorder Charles Drake reveals a complex scenario of water and land use in the bottomlands west of Tucson. The plaintiffs were several landowners north of the road, including W.A. Dalton, Emilio Carrillo, Joaquin Telles, E.N. Fish, Lauterio Acedo, Ramon Pacheco, Cerilio Leon, and Francisco Munguia. Their attorney was C.C. Stephens. The primary defendants were Leopoldo Carrillo, Sam Hughes and W.C. Davis, all owning agricultural lands south of the road. According to Dalton's testimony, about 580 ha of irrigated land were involved in the litigation. The vast majority of these fields supported wheat and barley. A second crop during the dry summer could not be grown on fields north of the road because of heavy use upstream and the scant flow of the Santa Cruz. As early as 1862, Fergusson's map of cultivated fields had indicated that fields just beyond Congress Street were worked only when there was an abundance of water.

In summer 1884 landowners south of the road provoked the lawsuit by cutting off flow to the north, promising to evenly distribute surplus water in the future. Landowners to the north were skeptical, anticipating heavier use to the south and the unlikely prospect of a surplus in the immediate future. Traditionally, water was diverted to the field that needed it the most, regardless of the owner or his position in the irrigation schedule. This pattern was now being disrupted by unusually heavy water use just downstream of Silver Lake. Since the coming of the railroad, several Chinese families had begun leasing fields from Sam Hughes, Lepoldo Carrillo, and Warner. By 1885, land in Chinese gardens amounted to about 60 ha. In cross-examination, Dalton was asked to differentiate between Chinese and Mexican gardens:

> The difference is this. The Chinaman raises cabbages, garlic, and in fact, everything in the vegetable line from an artichoke to the biggest cabbage and the Chinaman makes it a matter of business and he produces all he possibly can, and as often as he possibly can. The Mexican garden produces a few chili peppers, onions, garbanzos, beans, watermelons, etc. The gardens are from about 25 or 30 feet square [58-84 sq m] to as much as an acre [0.4 ha]. They are called huertas (Drake, 1885).

Whereas fields in wheat and barley required irrigation only once in a month, Chinese gardens needed water every week, and on a daily basis if at all possible. Dalton accused the Chinese of stealing water from the ditches:

> Some have seed beds for raising plants. They water them with pots. They keep the ditch full of water and take a pot holding 5 gallons [19 l]. They take, two of these pots one in each hand and walk along and water on each side at the same time (Drake, 1885).

In June 1885 Judge Gregg rendered a judgment in favor of Carrillo and the landowners south of the hospital road. Lands north of the road would receive surplus waters only after fields to the south had been fully irrigated, including the Chinese gardens (*Arizona Daily Star*, June 11, 1885). For the landowners north of the road, the unfavorable judgment was compounded by severe drought in summer of 1885. In February 1886, the newspapers provide a brief sketch of the valley:

> Our ditches- eight streams of water run through the Santa Cruz Valley opposite Tucson. Five of these ditches are 7 feet [2.1 m] wide that now contain a foot and a half of running water. The other three are narrower, and contain less. Besides there are many smaller ditches taken from the larger ones and running nearly parallel with them. The source of all this water is Silver Lake and the Santa Cruz, the spring at Carrillo's Garden and the natural springs at Warner's Lake. About 6 miles [10 km] below the city these ditches cease, the water sinking into the plain where it is reached at a distance of from 100 to 300 feet [33-91 m] below the surface (*Arizona Mining Index*, February 13, 1886)..... The water not only shows on the surface for miles in a running stream but also in many bubbling springs at San Xavier, at Carrillo's Garden, and other places, including those ranches where there is no surface water. All along the valley, whether the stream appears or not, are wells, such as those at Verdugo's or Osborn's, giving abundant water at from 4 to 6 feet [1.2-1.8 m] below the surface (*Arizona Mining Index*, February 20, 1886).

Early in 1886, Warner leased his lake to parties wishing to improve the resort. Maish and Driscoll, who acquired the Silver Lake property in 1884, renovated the hotel that same year. In May 1886, Warner sold all of his 127 ha, including the mill and lake property, to a Mrs. T.L. Shultz for $6000. To keep up with the competition, Leopoldo Carrillo improved the gardens on the edge of town and waged an impressive advertising campaign in the newspapers (*Arizona Daily Star*, May 12 and 26, 1886; *Arizona Citizen*, June 2, 1886).

More Floods, an Earthquake and Sam Hughes' Intercept Ditch

Newspapers reported in June 1886 that, "There is a scarcity of water in the Santa Cruz Valley and Silver Lake has spared the settlers all the law allows" (*Arizona Mining Index*, June 19, 1886). Despite the drought of the past few months, local residents knew that heavy rains would come sooner or later. The *Arizona Mining Index* warned of the impending danger of building on the floodplain of the Santa Cruz River:

> The bottom of the Santa Cruz is an unsafe place for dwelling houses, and there are a good many such along through it. In 1872, and several times previously, old don Juan Warner of Los Angeles published several articles in the papers cautioning the incoming population about the dangers of building along the river valley and has often advised the city authorities to build certain embankments and take other precautionary measures for protection. To his advice and statements they gave no heed, and within the past three years the floods came again, as of yore, and destroyed many lives, houses and other properties. We state this as a hint to those who build in the Santa Cruz Valley bottom. The upland mesa is the place for homes and hearth (*Arizona Mining Index*, February 27, 1886).

Just five months later, in August 1886, heavy floods wrecked havoc on the Santa Cruz floodplain:

> The Santa Cruz river was booming yesterday. At some points it was about one half mile [0.8 km] wide. Silver Lake dam was damaged and Warner's Lake is badly wrecked. A considerable portion of the county

road leading across the valley to Silver Lake has been damaged. Nearly all the irrigating ditches have been submerged. It is feared the carp of Warner's Lake has been carried away (*Arizona Daily Star*, August 4, 1886).

There was quite a river flowing down the Santa Cruz Valley yesterday, probably the result of the floods of Sunday night in the Sonoita Valley and Santa Cruz (*Arizona Daily Star*, August 4, 1886).

The recent heavy rains in the vast watershed of the Santa Cruz, culminated in a flood near Tucson on Tuesday last. The rise in the valley above the city was unexpected and could not be controlled. It appeared with suddenness at Silver Lake and Warner's Lake, two sheets of water above town, and breaking through the dams of each so formed a junction and swept down the cultivated valley for several miles below. When it appeared rolling over the waters of Warner's Lake the parties in charge there attempted to hoist the floodgate at the dam but the accumulated sediment on the upper side prevented them from making use of the safety valve and the rushing flow swept away 30 feet [9.1 m] of the dam clear to the bottom level of the lake. At Silver Lake, the flood did not break the stone work, but swept over the bank east of the bath houses and soon cut a wide passage way. Pouring rapidly into the field it swept out a culvert in the graded highway and soon met the flood coming down from Warner's Lake where they united and covered the whole valley, damaging fences and filling the ditches with sand. The flood covered the valley to a point four miles [6.4 km] below the town and its mainstream and some of the boards of the fences as far as the Nine Mile Water Hole. The vegetable crops, fortunately, were but little damaged, as all the water subsided by the next morning, but it is said to have injured the alfalfa which cannot stand too much water. The carp were pretty well let out of Warner's Lake, but the ducks and other wild fowl bravely held their own. The boats of the Gun Club were only slightly warped by the catastrophe. The estimates of the total damage to the lakes, the crops and the ditches is placed at $4000. Repairs have already been made at Silver and Warner's Lakes as well as on the fences of this valley. It will require some time to restore the ditches to their former capacity (*Arizona Mining Index*, August 7, 1886).

The Santa Cruz is booming again. The flow is from the upper Santa Cruz and the Sonoita Valley. The dam at Silver Lake was washed away again yesterday and a great deal of damage has been done to the lake (*Arizona Daily Star*, August 14, 1886).

The county bridge across the Santa Cruz near Silver Lake was washed away by the roaring flood (*Arizona Daily Star*, August 17, 1886).

On May 3, 1887 a tremendous earthquake with an estimated magnitude of 7.2 (Richter scale) affected an area of nearly 2,600,000 sq km in the southwestern United States and northern Mexico. The earthquake, with its epicenter just north of Bavispe, Sonora, left an impressive 50-km fault scarp with its northern terminus 8 km south of Douglas, Arizona (DuBois and Smith, 1980). It levelled several villages in Sonora and Arizona, including Charleston on the San Pedro River (Goodfellow, 1888). Several buildings in Tucson were damaged and certain springs and wells, including the deep well in back of Alex McKay's house, ceased flowing (Bennett, 1977). At San Xavier, the walls of the Spanish cemetery were demolished and the church building itself suffered extensive damage. Viewed from Tucson, the dust raised by rock avalanches in the Santa Catalina Mountains were mistaken for forest fires.

After the earthquake, significant changes in ground-water and surface flow were reported within 160-km radius of the epicenter (Dubois and Smith, 1980). The principal hydrological effects included a sudden rise or fall in area wells, increases in natural spring discharge, rise of ground water to the surface because of subsidence or opening up of new fissures, and forcible ejection of water and mud from fissures (Fig. 21).

A fissure 32 km long was reported along the San Pedro River north of Benson, and it issued a considerable stream of water. Throughout southern Arizona, there were reports of increased stream discharge, this during the driest month of the year. At St. David on the San Pedro, the earthquake alerted Mormon settlers to the presence of artesian water. Nearby, the San Pedro suddenly ceased flowing and for a short time was entirely dry, only to resume its course again with a volume at least two feet higher than before (*Tucson Weekly Citizen*, May 7, 1887). According to second-hand accounts, the earthquake destroyed the source (Agua de la Mision) of the Spring Branch near San Xavier and forced the water to the surface farther up the valley (Olberg and Schanck, 1913; Castetter and Bell, 1942). Papagos built a dam at the

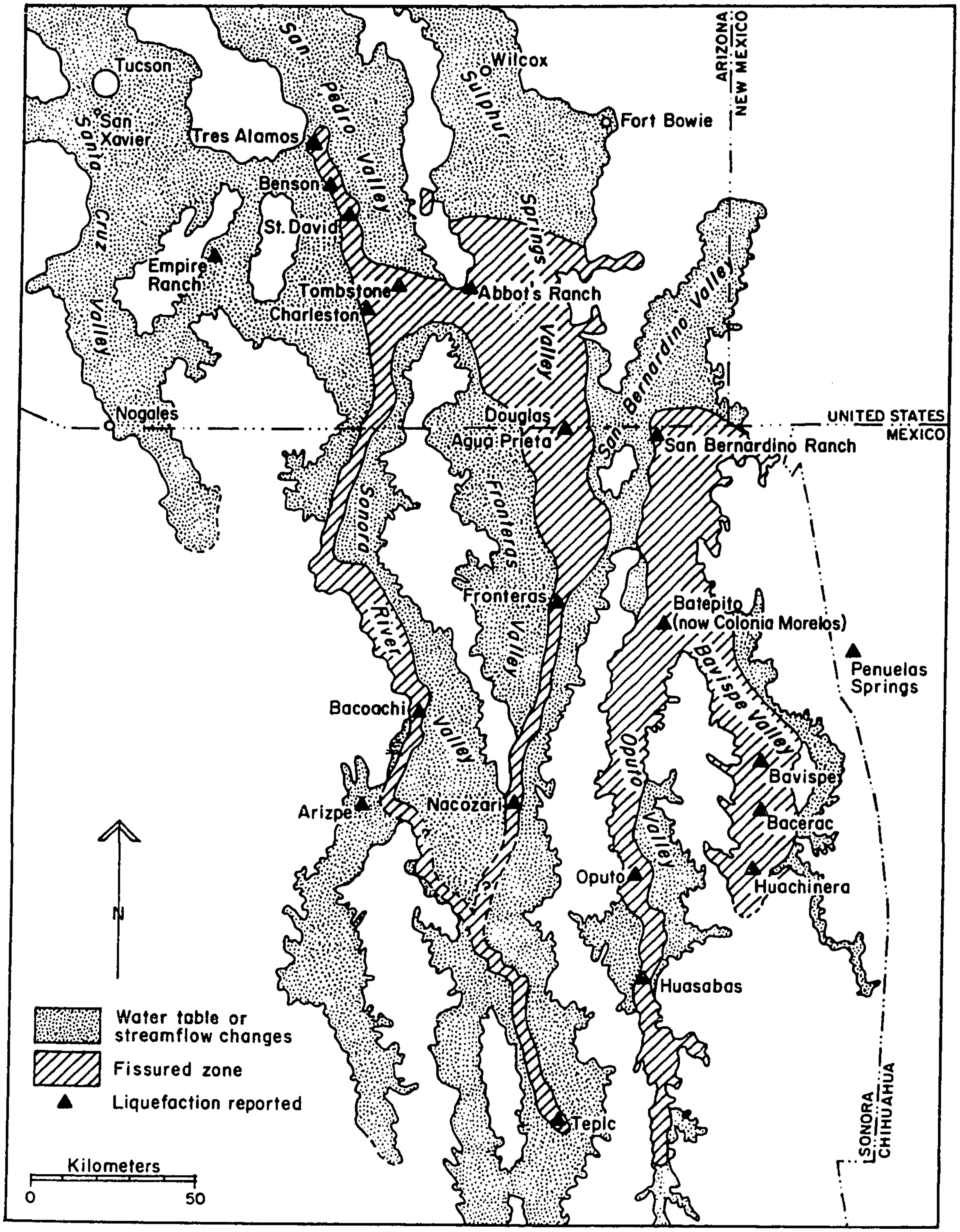


Figure 21. Map of northern Sonora and southern Arizona, showing hydrological effects of the 1887 earthquake (after Dubois and Smith 1980).

new spring source before the onset of the summer monsoon. Though it has not been demonstrated, the 1887 earthquake could have produced permanent deformation of unconsolidated alluvium in southern Arizona valleys like the San Pedro and Santa Cruz. As such, the earthquake could have played a crucial role in arroyo development in years to follow.

According to Tevis (1954), similar hydrological phenomena occurred during an earthquake at the beginning of the 19th century. His informant, the Apache chief Esconolea, an old man when interviewed in the 1850s, recalled that:

> The whole earth split open from one side of the valley to the other, sending forth a blue smoke [ejection of water?] heavenward for a mile. The same day it began to rain and continued for several days. When the storm ceased all of the earth on this side of the San Pedro River had closed together again, while a crack in the earth about a mile [1.6 km] long, five feet [1.5 m] wide, and from ten to twenty feet [3-6.1 m] deep remained (Tevis, 1954).

In mid and late summer of 1887, flooding again took its toll in the Tucson Basin, most dramatically along the Rillito River:

> There is a considerable volume of water coming down the Rillito from the watersheds of the Rincon and Santa Catalinas. It has been reported that the recent flood carried away the bridge between here and Silver Lake across the Santa Cruz River. The late heavy rains to the southward have caused the Santa Cruz to boom. The water is now coming down the valley in three large streams (*Arizona Daily Star*, July 12, 1887).

> The Santa Cruz River is more than a mile [1.6 km] wide and deep enough to float a mammoth steam boat.... The big rain yesterday afternoon filled the arroyo in North Tucson [Tucson Arroyo] full to the brim, the angry waters roared like a young ocean turned loose through a new channel. It swept everything before it, flooding the valley below (*Arizona Daily Star*, July 13, 1887).

> The flood in the Rillito on Friday last (September 9) was much worse than was thought. Many cattle being taken unaware by the sudden overflow of the stream were swept away and drowned. Trees of good size, bridge timbers and other debris were found scattered along the banks yesterday.... The waters north of town are reported to have stood about 2 miles [3.2 km] wide (*Arizona Daily Star*, September 11, 1887).

> The Santa Cruz River is running higher now than ever before this season. For the first time in many years, it is navigable from Tubac to the Gulf (*Tucson Citizen*, September 12, 1887).

> The Santa Cruz northwest of town is running a big body of water (*Arizona Daily Star*, September 16, 1887).

The 1887 floods washed out the newly-built dam along the Spring Branch and scoured a channel immediately downstream. In February 1888, Surveyor L.D. Chillson recorded a gulch 10 m wide and 4.6 m deep near the former source of the Spring Branch (Fig. 10C:63). The wet summer and flooding that followed closely on the heels of the Bavispe earthquake and its hydrological effects may have also produced local channel degradation along the San Pedro. Hastings (1959) cites legal testimony that, near Tres Alamos north of Benson, the river deepened 3.5 m between 1885 and 1889.

In September, 1887 Sam Hughes saw a remedy to the lack of irrigation water available for fertile bottomland north of the hospital road. He bought a narrow strip of land centered on the road and following the river. Just north of the road, Hughes planned to excavate a ditch to tap the underflow in the alluvium. The ditch was to be 6 m wide at the heading and a total of 24 km long (*Arizona Daily Star*, September 3, 1887). Apparently, the capital for Hughes' venture was not forthcoming and he dug a smaller ditch in 1888, leaving it up to the next year's floods to excavate a larger heading. A similar intercept ditch was also dug at the Canoa Ranch near Continental that same year by Maish and Driscoll, owners of the Silver Lake resort (*Arizona Daily Star*, November 3, 1887). This type of ditch, essentially an artificial headcut, was probably the most popular method to secure near-surface underflows before the turn-of-the-century.

By 1888 Frank and Warren Allison had purchased the Warner property and rebuilt the lake, stocking it handsomely with carp. In early summer, they were selling up to 230 kg of fresh fish a day (*Arizona Daily Star*, June 7, 1888). The Tucson city council and the Tucson Water Company entered an agreement, whereby all who planted trees along the streets were allowed free water for irrigation. To the south, in the San Xavier area, Lorenzo D. Chillson, discoverer of the famous Comstock Lode in 1859, undertook cadastral surveys and kept excellent notes on the condition of the floodplain (Fig. 10C).

In October 1889, Henry Buehman strolled from his photographic studio on Congress Street to observe minor flooding at the hospital road. Buehman had an excellent eye for landscapes, as shown in his photographs of the eroded heading of Sam Hughes' intercept ditch (Figs. 22-23). This artificial nickpoint would later figure heavily in development of the Santa Cruz arroyo.

In summary, ample documentation exists for the period between 1871 and 1889. By the 1880s demand for irrigation and domestic water exceeded the supply afforded by the perennial flow of the Santa Cruz. In 1884, City Engineer J.P. Culver summarized the discharge at the various springs in the valley. The flow was measured at 0.5 cms at Punta de Agua, 0.13 cms at the Valencia Road headcut and 0.01 cms at a spring in the riverbed 1 mile downstream, between 0.35 and 0.5 cms through the flume at Lee's Mill on Silver Lake, and about the same through Warner's mill race (*Arizona Daily Star*, February 12, 1884).

In the 1880s, two major dams at Silver Lake and Warner's Lake blocked the normal flow of the river and water was released at their headgates to irrigate about 180 ha of land. J.M. Berger, heir to the Martinez land grant and Farmer-in-Charge on the Papago Indian Reservation, estimated that another 320 ha of land were irrigated near San Xavier in 1890 (Castetter and Bell, 1942). A major conflict developed over water rights between landowners upstream and downstream of St. Mary's Road, eventually settled in favor of upstream irrigators.

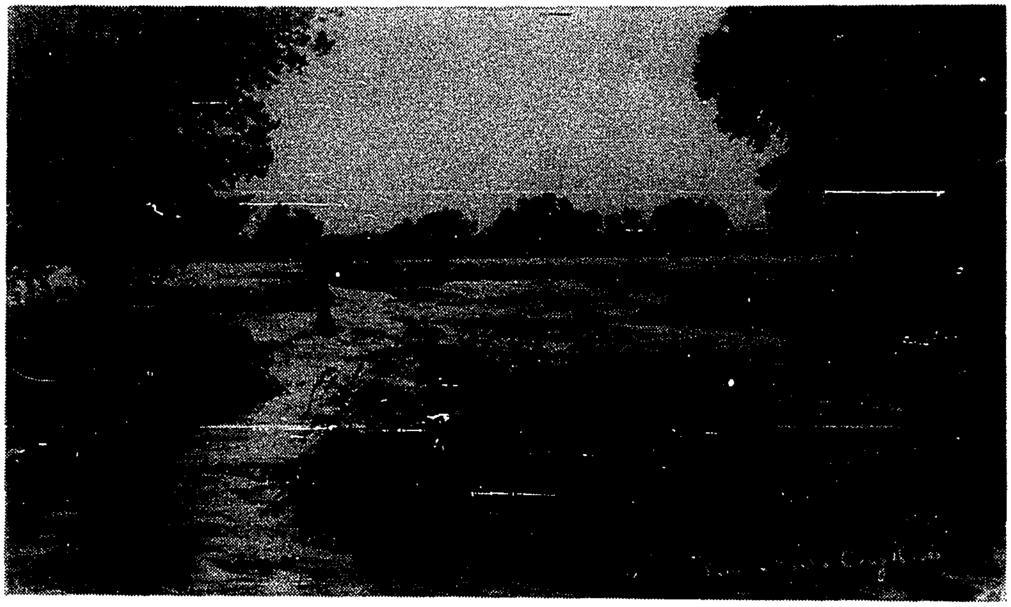


Figure 22. Upstream view of the heading of Sam Hughes' intercept ditch at the St. Mary's Road crossing in October 1889. The heading here behaved as a headcut actively eroding even with minor flooding. Note that in 1889, this reach was unentrenched and even moderate flows would inundate the valley (Photograph by H. Buehman, Special Collections, University of Arizona Library, Tucson).

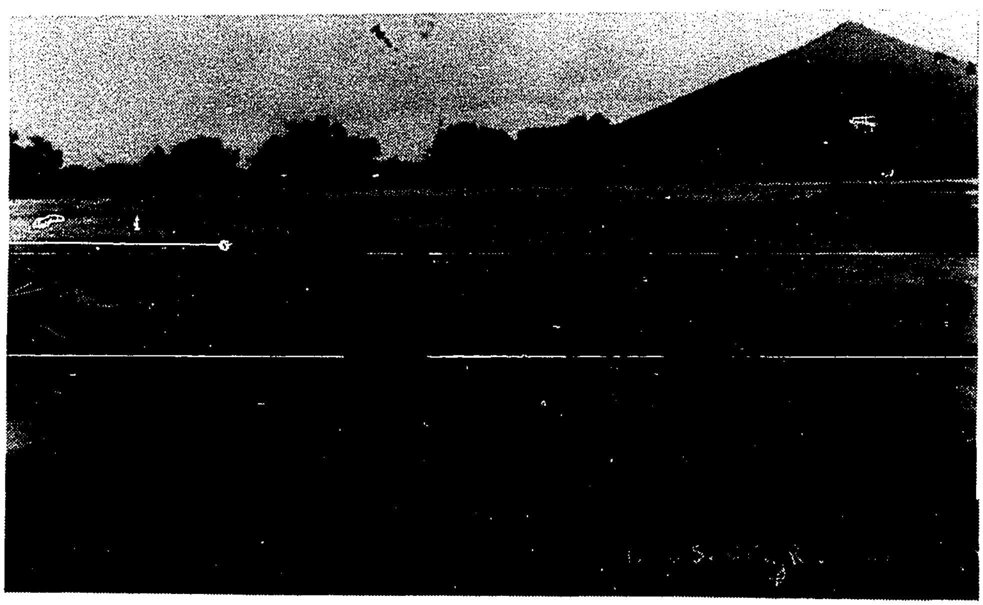


Figure 23. Taken on the same day, a slightly different view of the headcut in Figure 22, with Sentinel Peak at upper right (Photograph by H. Buehman, Arizona Historical Society, Tucson, Negative No. 2922).

CHAPTER 6: ARROYO-CUTTING AND THE AFTERMATH 1890-1950

In the summers of 1886 and 1887, floods breached the dams of Warner's Lake and Silver Lake. The May 3, 1887 earthquake displaced the head of the Spring Branch 1 km to the south and accounted for significant, although temporary, increases in discharge throughout southern Arizona and northern Sonora. Permanent deformation of alluvium happened in southern Arizona valleys, possibly altering surface profiles of streams and hence, setting the stage for arroyo-cutting during major floods in 1887, 1889, 1890, and 1891. In 1888, Sam Hughes excavated a ditch to intercept the underflow at St. Mary's Road. This would become the locus of arroyo-cutting in the following summer. Figure 24 indicates the location of headcuts and other features of interest for the period prior to 1890.

Sam Hughes' Ditch Takes a Walk to Silver Lake for Water

The summer of 1890 contributed yet another season of heavy flooding in the Santa Cruz Valley. The newspapers describe the initial period of flooding between July 27 and August 1:

> Sunday [July 27] the Santa Cruz overflowed its banks at Silver Lake, passing around the hotel. The overflow carried out a large number of carp, many of which Mr. Swart gathered up and found a ready market for them in this city (*Arizona Daily Star*, July 29, 1890).

> A huge volume of water came rushing down the valley below town, sweeping everything before it and doing great damage. The track of the water is about 100 yards [91 m] wide. Gardens, trees, fences, etc., all washed out and the loss caused by it will run into the thousands (*Arizona Citizen*, July 30, 1890).

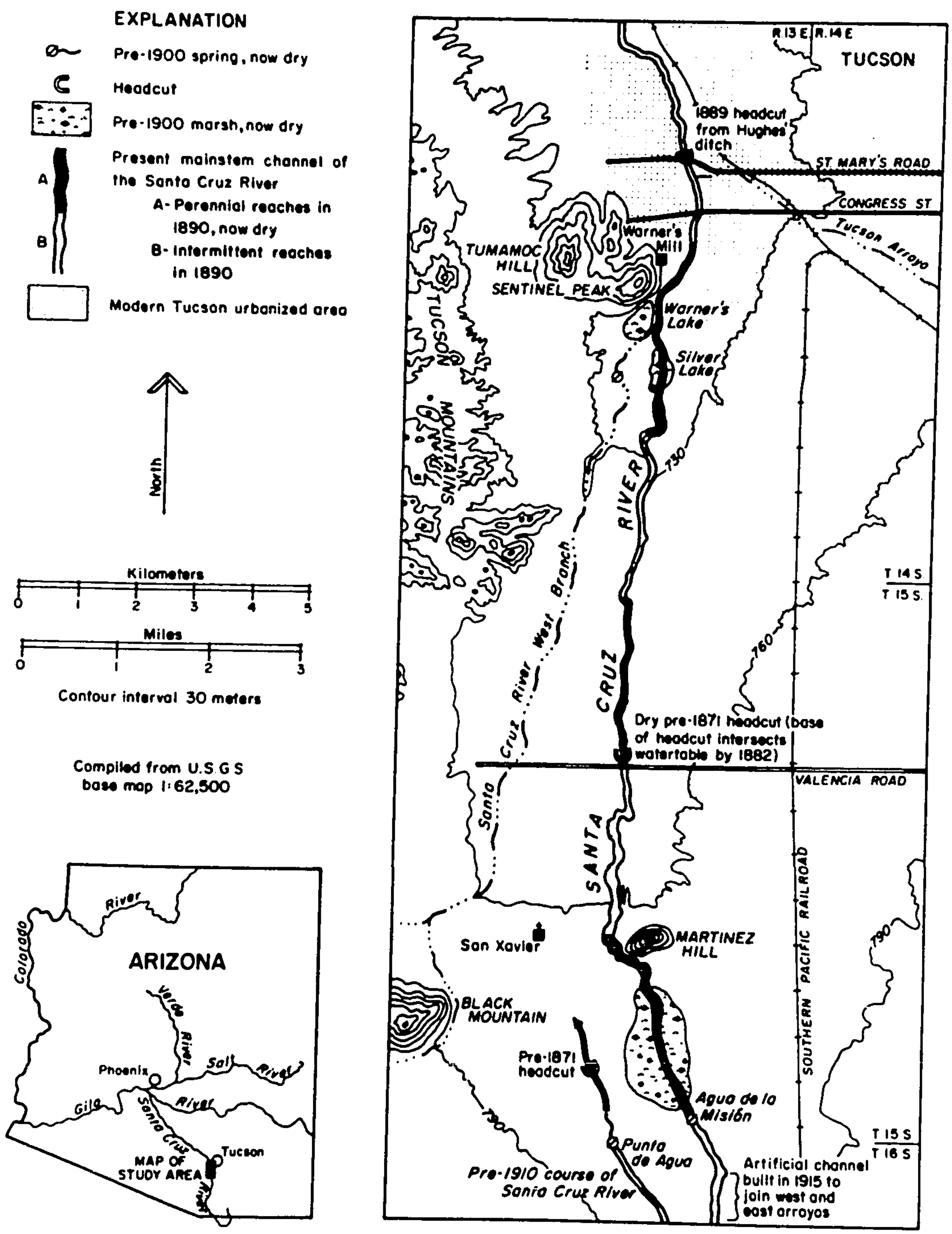


Figure 24. Historic map of the Santa Cruz Valley in the Tucson-San Xavier area, summarizing some of the principal features that played a role in arroyo development.

> Many adobe buildings have melted down, fences are gone, irrigation ditches cut up and gardens are ruined. Rillito Creek is doing its full share of the damage. Chinamen seem to be the principal sufferers. Steamers will leave Levin's landing daily, at 2 p.m., for Yuma (*Arizona Citizen*, August 1, 1890).

> The rainfall has been quite general lately in this section. The heaviest rains occurred day before yesterday. There seemed to be two storms--one traveling towards the southeast and the other towards the southwest- and seemingly met at the Coyote Mountains, hence the overflow of the Santa Cruz at the present time. The San Pedro, the Gila and the Rillito also reported full. The width of the overflow of the Santa Cruz is about 700 yards [640 m] and the deepest part is over twelve feet [3.7 m] (*Arizona Daily Star*, August 1, 1890).

On August 4, the floods widened the heading of Hughes' canal near the St. Mary's Road. By the end of the month, the resulting headcut had eroded 3 km upstream to a point near Silver Lake. Tucson surveyor George Roskruge photographed the new channel from the east bank at the hospital crossing (Figs. 25-28). On August 13, he was quoted by the newspapers as saying that the new channel was, "Sam Hughes' ditch taking a walk to Maish's lake [Silver Lake] after water" (*Arizona Daily Star*, August 13, 1890). The *Arizona Daily Star* continued to report on flooding and headcut migration between August 4 and September 7:

> The flood yesterday washed a deep cut across the hospital road, so that the road now is not only impassable but extremely dangerous for teams or travel as the embankment of the cut is perpendicular and the water below deep, and pedestrians might easily endanger their lives (*Arizona Daily Star*, August 5, 1890).

> Another flood came down the Santa Cruz yesterday afternoon. Nogales stage has not arrived. Hon. James O'Brien reports some of Maish's carp fish at Picacho, taken down by the flood.... It is thought that the washout in the Santa Cruz, opposite the city, will reach Stevens Avenue [Congress Street] this morning. Boss Levine says that the Santa Cruz was higher last night than at any time during the last twenty-five years, and he ought to know as he has lived on its banks during that time (*Arizona Daily Star*, August 6, 1890).

> A terrible cloud burst is reported southeast of the city, some 20 miles [32 km] away. Look out for another big flood in the Santa Cruz. Wetmore, the signal service man says that 2 and 1/4 inches [5.7 cm] have fallen during the last ten days. The floods, however, have come

from storms outside of the Tucson Basin. The channel or cut being made by the overflow of the Santa Cruz River, is now one mile and a half [2.4 km] long, by from one to two hundred yards [91-183 m] wide-in other words, it extends from the smelter to about two hundred yards [183 m] this side of Judge Satterwhite's place. Constant and heavy rains reported from Nogales for last ten or twelve days (*Arizona Daily Star*, August 7, 1890).

More than fifty acres [20 ha] of land which has formerly been under cultivation in the Santa Cruz bottom, has been rendered worthless by being washed out so as to form an arroyo. J.D. Swart of Silver Lake, was in the city yesterday for the first time since the floods. He says that the first flood was two and a half feet [0.8 m] higher than the dam and covered the first floor of the hotel. The water has subsided so that travel to and from Silver Lake has been resumed. Mr. Maish will put on a force of men to work this morning repairing that part of the road leading from the county road to the hotel. The bathing pond of the hotel is full of clean, fresh water. This pond is 14 feet [4.3 m] deep and a springboard has been erected to accomodate bathers (*Arizona Daily Star*, August 8, 1890).

Mr. H.H. Doe informed the Star yesterday that the water in the Rillito was a foot [0.3 m] higher last Tuesday night [August 5] than the highest water mark of past years, and he thinks there was at least one third more water, as the recent flood had so cleaned out and deepened the channel that a third more water could be carried without it reaching the height of Tuesday night. Mr. Doe lives out a short distance east of Fort Lowell. Nearly all his garden and corn crop was destroyed, being either washed out or covered two or three feet [0.6-1.0 m] with sand. He stated that the sand deposit on the overflowed land is from two to four feet [0.6-1.2 m] (*Arizona Daily Star*, August 8, 1890).

The single channel which was being washed out through the fields of the Santa Cruz by the floods, resulted in considerable damage but this danger has been greatly increased from the fact that the wash or channel has forked at the head [see Fig. 29], and there are now several channels being cut by the flood, all of which run into the main channel. If the flood keeps up a few days longer there will be hundreds of acres of land lost to agriculture. As these new channels or washes are spreading out over the valley, they will cut through and greatly damage the irrigating canals. Those who have visited the spot say that it is not too late yet to direct the water so as to cause it to cut a single channel and thus confine the flow. In view of the probable great destruction it would be well for some one to lead off in this matter (*Arizona Daily Star*, August 9, 1890).

There must have been heavy rains along the watershed of the Santa Cruz last Monday night, for the river rose several feet yesterday (*Arizona Daily Star*, August 13, 1890).

The raging Santa Cruz continues to wash out a channel and the head of it is now opposite town. It may reach Silver Lake before the rainy season is over (*Arizona Daily Star*, August 14, 1890).

Several suits for large sums are threatened, on account of dangers resulting from the recent floods in the Santa Cruz (*Arizona Daily Star*, August 14, 1890).

Silver Lake dam, gates open, was washed away for about 40 feet [12.2 m] in the bank of sand at one side. Many Tucsonans visited scene. Fields flooded, stage passengers detained, fences gone, four acres [1.6 ha] of fine bottomland in W.C. Davis' field washed down. A man on horseback rode into newly made waterhole on hospital road, going down out of sight for some seconds (*Arizona Daily Star*, August 17, 1890).

The Santa Cruz River at the crossing of the hospital road, from bank to bank, is something over 100 yards [91.4 m] wide (*Arizona Daily Star*, August 20, 1890).

The Santa Cruz was rising last evening at 6 o'clock. Evidently there must have been heavy rains along its watershed (*Arizona Daily Star*, August 24, 1890).

The Santa Cruz River was higher yesterday afternoon than it has been this summer. It is doing much damage and has before now, perhaps reached several adobe houses along its banks and carried them away. As soon as the waters subside some steps should be taken towards preventing the river from continuing its ravages again next summer (*Arizona Daily Star*, August 26, 1890).

The water in the Santa Cruz is falling rapidly. Up to sunset last evening it had gone down about two feet [0.6 m] from the highest point attained during the last storm. The Santa Cruz River was reported to have been over waist deep yesterday noon, at the crossing going to Warner's mill, and somewhat dangerous on account of the large amount of quicksand (*Arizona Daily Star*, August 28, 1890).

The Santa Cruz is getting down to its little bed. The head of the new channel of the Santa Cruz River is now opposite Judge Osborne's place on the road to Silver Lake (*Arizona Daily Star*, August 29, 1890).

Similar events were reported on the San Pedro:

Recent floods at Mammoth washed the soil out places 30 feet [9.1 m] deep along the river bottom. Exposed area at bottom brought out in many places evidence of ancient civilizations. Trunks of huge trees cut with stone axe; old pottery and implements. Giant human bones. A scientific expedition should investigate before covered again (*Arizona Daily Star*, October 2, 1890).

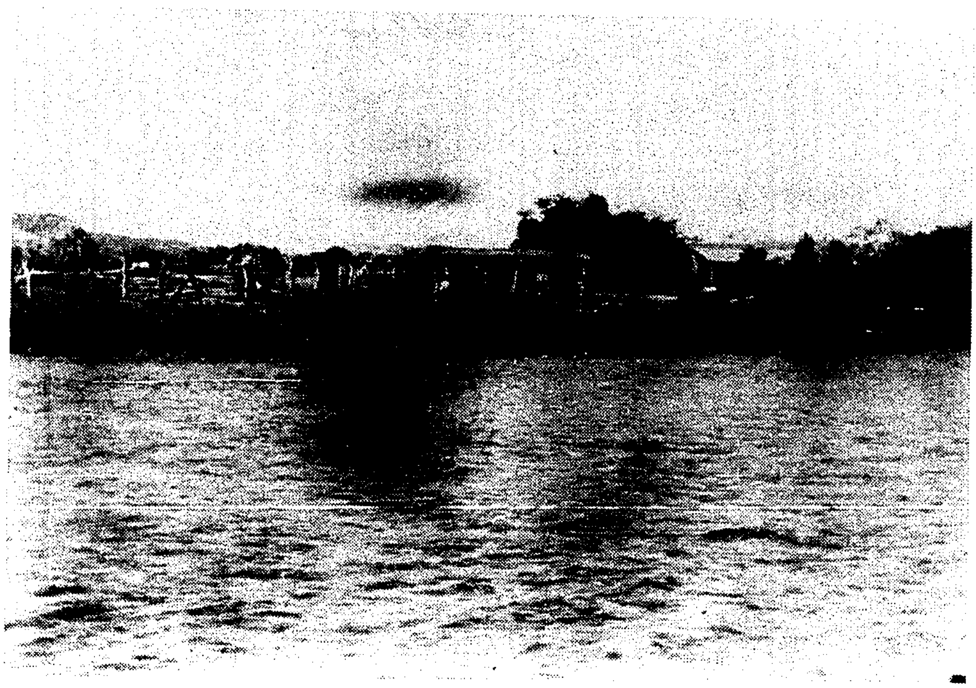


Figure 25. View looking directly west across the St. Mary's Road crossing in August 1890, with newly formed arroyo threatening homestead on opposite bank (Photograph by G. Roskruge, Arizona Historical Society, Negative No. 45854; U.S.G.S. Stake 1065A).

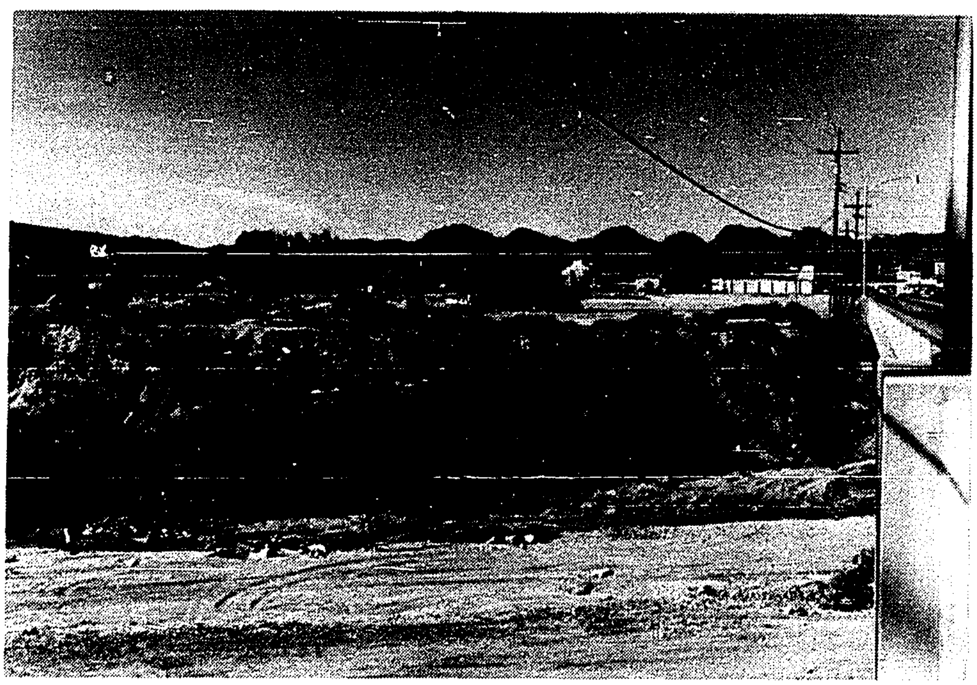


Figure 26. Same view as Figure 25 on February 4, 1982. St. Mary's Road Bridge appears on extreme far right. Landfill occupies the upper 1-2 m of the floodplain (Photograph by R.M. Turner, U.S.G.S. Stake 1065A).

Figure 27. Downstream view of the Santa Cruz river during the flood of August 1890, taken from east bank at the St. Mary's Road crossing. Note erosional remnants in the middle of the newly-formed arroyo (Photograph by G. Roskruge, Arizona Historical Society, Tucson, Negative No. 45851).

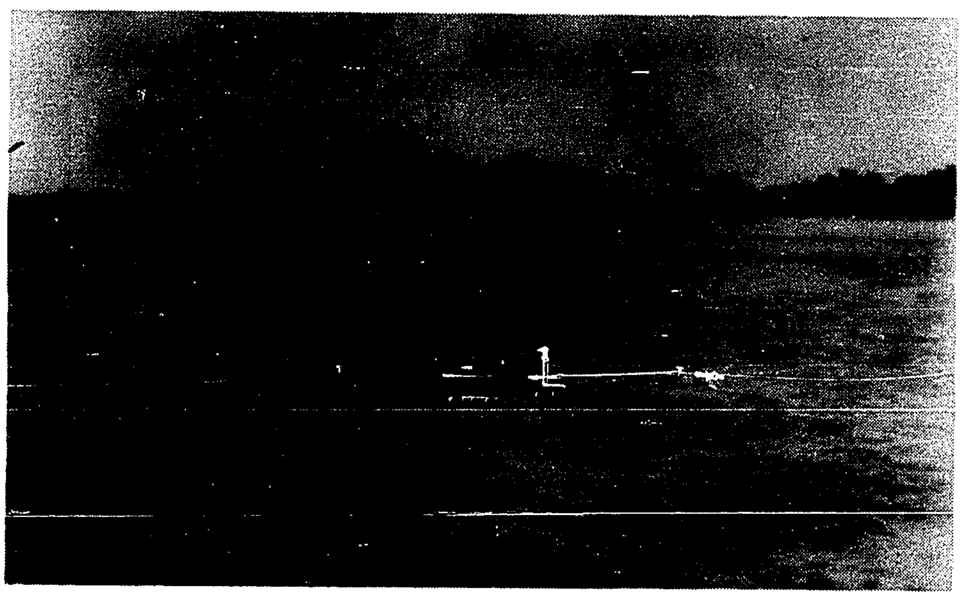


Figure 28. Upstream view of the Santa Cruz River on the same day and from same location as Figures 26 and 27. On August 8 or 9, the headcut forked into two channels, their confluence shown in this photograph. Note cottonwood with distinctive, asymmetrical crown on right bank. The same tree appears in Figure 31. Also, compare with Figure 22, which was taken only 10 months before (Photograph by G. Roskruge, Arizona Historical Society, Tucson, Negative No. 45852).

Tucson's Reaction to the Arroyo

Tucson's reaction to the new channel was mixed. A few residents suggested that there was something to be gained from the erosion: "The big arroyo cut through the Santa Cruz Valley will afford the means of drainage for the city. It is an ill wind that does not bring good to someone" (*Arizona Daily Star*, August 9, 1890). In October, a petition circulated urging the Pima County Board of Supervisors to build a bridge at the hospital road: "The mooted question now is whether there is solid ground enough at the banks of the Santa Cruz, to anchor abuttments sufficiently strong for a bridge." (*Arizona Daily Star*, October 5, 1890). The petition failed in its original purpose and the bridge was not built until 1899 (*Arizona Daily Star*, October 25, 1899).

In retrospect, many Tucsonans blamed Sam Hughes for the events in summer of 1890. Volney Spalding of the Carnegie Desert Botanical Laboratory on Tumamoc Hill explained some years later that:

> According to statements of residents, this extensive erosion is of recent date. Previous to the advent of cattlemen some 20 years ago, and the destructive effects of over-pasturing, the valley of the Santa Cruz had a luxuriant growth of sacaton and other vegetation, which prevented the cutting of the channels, and the water spread out over the whole valley instead of flowing through the deep cuts it has since made; tules grew thickly in the springy places, and a fine forest of mesquite covered the ground. I have given the commonly received version of the cause of the cutting of the channels of the Santa Cruz, but have since been told by Mr. Herbert Brown, of the Tucson Post, that about 20 years ago, certain old settlers undertook to develop water at a point about two miles down the river, where there were springs, and in order to accomplish this most easily cut a channel for a little distance, expecting the river when it rose to do the rest. Their expectations were fully realized, for the river scoured out the cut and kept on with its work, as already indicated. At present the effects of such erosion are seen most plainly from the point below Tucson already indicated to one about two miles [1.6-3.2] above the city (Spalding, 1909, p. 9).

In 1934, another pioneer, Rollin C. Brown, recalled the events of 1890:

> Tucson was a great old place when I first came here in 1873.... In 1873 Tucson was situated down around Meyer and Main Street extending west as far as the Santa Cruz. And, by the way, there was no big river bed down there then. All that country was a beautiful garden spot, smooth and covered with grass and big cottonwoods. That was where Levin's beer garden used to be. There was no finer place in the town.... Then a man by the name of Hughes had one of these new fangled ideas of digging a ditch in the little brook that was then the Santa Cruz and when the flood season came he could bring the water in by gravity. Well, all in all, his gravity idea did not work so well, and when the rainy season came on that ditch got bigger and bigger until you have that big dry river bed that you see today. I can remember the many times when Main Street was completely covered with water during the flood time (*Arizona Daily Star*, June 10, 1934).

Cirilio Solano Leon, who was born around 1850, the son of a lieutenant in the old Mexican garrison, reminisced that:

> When I was boy there were no river banks. I remember the time the banks were washed out. It isn't very long that the present channel has been here. Mr. Hughes used to own a small piece of land where the Deaf and Blind School is now [on the west bank, just downstream of Speedway Avenue], and he dug a channel about five or six feet [1.5-1.8 m] wide, and when the floods came along the waterfall began to cut away the land greatly, clear back to San Xavier. This lowered the water level all over the whole valley. Much of the land that is dry now had water before this (Leon, n.d.).

At the 1924 dedication of Tucson's Sam Hughes Elementary School, Mrs. George F. Kitt handed down still another indictment. Speaking of the school's namesake, she stated that, "He started one of the early irrigation ditches in this part of the country-- the ditch which when the floods came cut back and formed the channel of the Santa Cruz River."

Flood Control and Development of Water Supplies in the Aftermath of the Arroyo

In summer of 1891, flooding resumed in the Santa Cruz Valley. On July 2, bankfull discharge was observed and the newspapers reported that the river was as high as any time during the previous summer (*Arizona Daily Star*, July 2, 1891). In August, the dam at Silver Lake was repaired. Later that month, the river was once again running full and level with its banks, causing great damage to the irrigation network west of town (*Arizona Daily Star*, August 19, 1891). By August 29, "Silver Lake is again full of clear and limpid water, and much deeper in places than before" (*Arizona Daily Star*, August 29, 1891).

The 1890-1891 floods extended the headcut at Sam Hughes' Ditch from St. Mary's Road past Congress Street (Figs. 29-31), the San Agustin Mission (Figs. 32-34), and along both streams above the confluence of the West Branch and the Santa Cruz (Figs. 35-36). The damage to agricultural land in the summers of 1890 and 1891 raised special concerns about the future:

> The land owners along the Santa Cruz Valley held a meeting last evening in Judge Lovell's office for the purpose of devising means to prevent further damage to their lands in the future by floods. It was proposed that a fund be raised and build breakwaters, which plans were adopted (*Arizona Daily Star*, July 16, 1891).

The situation was aggravated by the minimal flow in the fall of 1891. Once again, a conflict developed between landowners in the bottomland. This time a deep channel divided the factions on either side of the valley:

> There is much complaint among the ranchmen in the valley west of the city that there is an unfair distribution of water. It is claimed that the land on the west side of the river is receiving but half rations, while the ranches on the east side are receiving double the quantity to which they are entitled (*Arizona Daily Star*, October 22, 1891).

> The Santa Cruz River has never been as low since 1872 as it is now. At that time the people had to dig in the bed of the river for water, and barely obtained enough for home consumption. It is feared that the same conditions will come to pass this fall (*Arizona Daily Star*, October 24, 1891).

The deep channel called not only for flood control, but also a suite of new irrigation schemes in the early 1890s:

> Since the recent floods leave greatly demoralized the irrigating system of the Santa Cruz valley, it is an opportune time to reorganize the entire water system of the valley to the end that better irrigating facilities and a vast amount of water which has gone to loss under the old system may be utilized (*Arizona Daily Star*, August 26, 1891).

Figure 29. View looking upstream at Congress Street in 1902. The deep arroyo that eroded in 1890 and 1891 made river crossings more difficult. By 1902, a Pratt Truss steel bridge had been erected to span the river at Congress Street. This photograph shows a young stand of willows and cottonwoods that were probably established after the 1890 flood (Arizona Historical Society, Tucson, Negative No. 26698).

Figure 30. Downstream view of the Santa Cruz river in 1902. This photograph shows active erosion where the meandering thalweg strikes the right bank. Congress Street is on far left and is seemingly in a precarious position should the meander continue eroding downstream. The Santa Catalina Mountains are in the background (Arizona Historical Society, Tucson, Negative No. 26699).

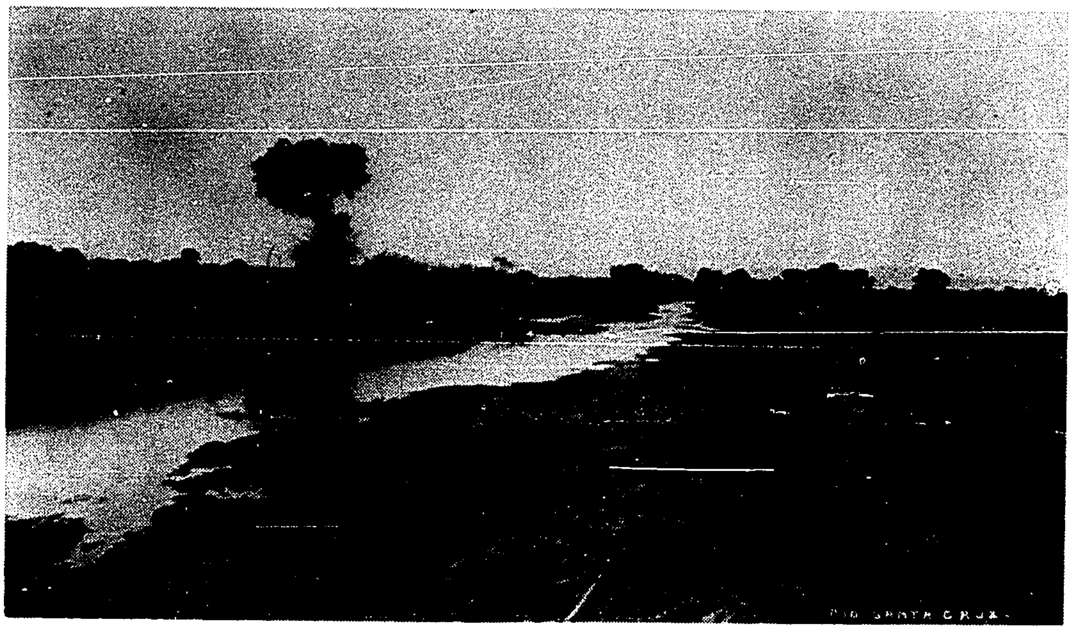


Figure 31. Downstream view of Santa Cruz arroyo between Congress Street and St. Mary's Road ca. 1900. Cottonwood with distinctive crown also appears in Figure 28 (Photograph by H. Buehman, Arizona Historical Society, Negative No. 1902).

Figure 32. The San Agustin Mission or Convento Ruins as sketched by John Spring in 1871, looking west across the Acequia Madre. In 1890-1891, the arroyo from Hughes' ditch extended headward along the Acequia Madre. Compare with Figures 33 and 34.

Figure 33. The San Agustin Mission in 1903, looking across to the west bank of the Santa Cruz River. The ditch at left center was the tail race or waste channel from Warner's Mill into the Acequia Madre. The tail race postdates John Spring's 1871 sketch (Figure 32) (Photograph by B.R. Bovee, Arizona Historical Society, Tucson, Negative No. 52644).

Figure 34. The San Agustin Mission, most likely in the the 1910s, from roughly the same vantage point as Figures 32 and 33 (Arizona Historical Society, Tucson, Negative No. 24802).

Figure 35. Downstream view of the confluence of the West Branch and the Santa Cruz River, looking northeast from the lower slope of Sentinel Peak in 1904. The lower half of the photograph incorporates the former area of Warner's Lake (see Fig. 19). A remnant of Warner's Dam is visible at left center, just upstream of the confluence. By 1904, the headcut from Sam Hughes' Ditch had extended along the Santa Cruz mainstem and the West Branch (Photograph by Walter Hadsell, Arizona Historical Society, Tucson, Negative No. 24868; U.S.G.S. Stake 1026).

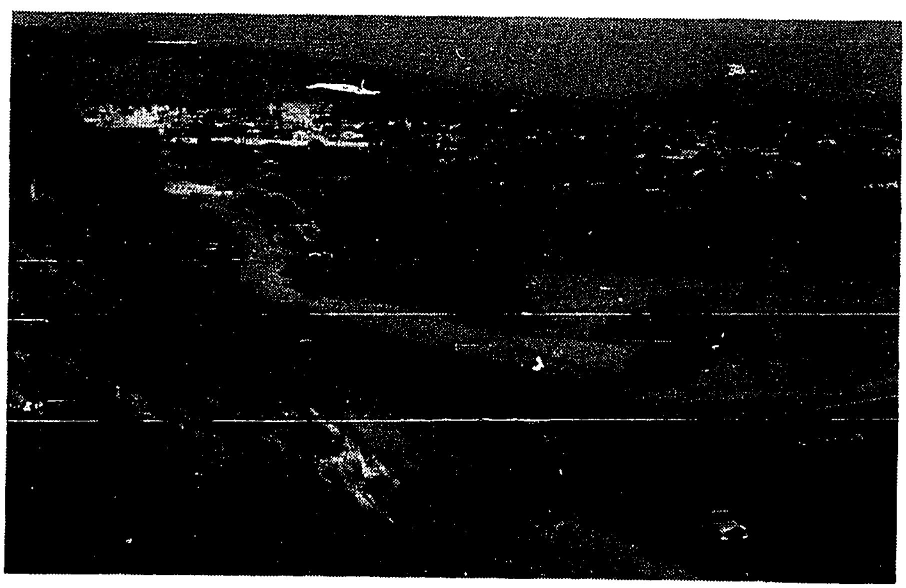


Figure 36. Same view as Figure 35 on December 17, 1981. The West Branch was filled in artificially in the 1960s and is now marked only by a shallow depression lined with a few mesquites. The Santa Cruz proper is bordered by taller saltcedars. The intersection of Mission Road and 22nd Street is in lower right (Photograph by R.M. Turner, U.S.G.S. Stake 1026).

In 1891, W.A. Hartt developed one of the first farms that depended entirely on pump-well technology (Section 6, T17S, R14E) (*Arizona Daily Star*, February 5, 1891). S. W. Grossetta followed suit in the same year by installing pump wells on his farm in Section 34, T13S, R13E, just north of present Grant Road (*Arizona Daily Star*, April 14, 1891). Just south of Hartt's ranch, J.K Brown constructed a dam 4 m high and 152 m long that would impound 300 million liters of water fed into the reservoir by tributaries that drain the northeast slopes of the Santa Rita Mountains (*Arizona Daily Star*, October 6, 1891). Also underfoot was an impressive plan to dam the Santa Cruz near Nogales making possible the irrigation of some 120,000 ha of bottomland as far north as the San Xavier Indian Reservation. The plan never came to fruit. In 1892, Frank and Warren Allison set out to rejuvenate fields that were left high and dry by entrenchment of the channel. According to the *Arizona Daily Star*, they began developing the water by first draining the marsh contiguous to the former site of Warner's Lake:

> Our people are just beginning to realize that a vast stream of water flows underground in the Santa Cruz Valley. Allison Brothers are now taking out a ditch which skirts the mountains west of the valley, opposite Tucson. They have opened it for a distance of nearly a mile [1.6 km]. Starting without any water, they have developed four times as much before they complete their plans of development. They will run this ditch at least a mile [1.6 km] above the old Warner mill which will tap a large area of swamp land, as well as catch the underground currents which flow out from under the mountain (*Arizona Daily Star*, January 16, 1892).

> Work on the Allison ditch is progressing rapidly. A large force of men is at work and the ditch has been constructed to a point some distance beyond the hospital. It is one of the biggest irrigation enterprises now under way in this section of the county. The ditch commences at Warner's Lake, where the water supply will be had, and winds its way along the foot of the mountains to the land beyond the hospital. The object in constructing the ditch is to supply the vast acreage of rich land lying between the city and the foot of the mountains with sufficient water for irrigation purposes. Much of the land there which is capable of a high state of cultivation is devoted to raising hay and alfalfa where if water could be set to fruit trees and would soon

> become one of the largest fruit growing sections in this part of the territory. Large forces of men have been at work on the ditch for several months. The expense attached to carrying out such an enterprise is enormous. In many places the line of ditches passes though solid rock and large quantities of powder had to be used to blast out the rock. In some places they had to go down as deep as sixteen feet [4.9 m] to keep the right grade. This would be easy enough to do in soft earth, but when it comes to working in rock it is quite another thing. The Star reporter visited the ditch yesterday morning to see what progress was being made. The upper part of the ditch as far down as the hospital was full of water. A short distance northwest of the hospital a big force of men was at work. It will be built some distance further on yet in order to supply the rich land in the flat with water (*Arizona Daily Star*, July 21, 1892).

> Steadily work goes forward on the Allison canal below the city. The canal is now a considerable distance below the hospital. A reservoir [SW1/4 of SE1/4 of Section 3, T14S, R13E] has been made, with banks in places twenty feet [6.1 m] high.... It will cover about ten acres [4 ha] (*Arizona Daily Star*, January 20, 1893).

Tucson's industrial technology was powered by steam, requiring an ample and convenient wood supply. Demand for fuelwood impinged upon the vast mesquite growth anchoring the Santa Cruz alluvium. By 1892, the fuel supply on nearby ranches had been exhausted, leaving the San Xavier Indian Reservation as the only convenient source of wood in the area:

> Ten years from now will see wood scarce and hard to get. Mr. Shortridge, in the wood business, tells that already for ten miles [16 km] around, with the exception of the Etchells, S. Hughes, Buckalew and Shortridge ranches, the supply is nearly ended. Mexicans are now bringing in roots and stumps, dug up and cut up into stove size. Many Mexicans, he says, go as far out as twenty or thirty miles [32-48 km], taking two or three days for the trip. Others make a precarious livelihood by stealing what they can from ranches or government land. The San Xavier Reservation has a fine wood supply. This the Papagos are becoming aware of, and are raising the prices accordingly. When the wood from the surrounding ranches is gone, which it will be at the present rate in five years, they will have enough to keep Tucson going for another five years. But the outlook is not as gloomy as it might be. Long before that time coal will be obtainable, for new railroads will place the product of the coal fields of New Mexico, Colorado, and San Marcial, Mexico at rates that will probably lengthen indefinitely the ten years' limit for wood Mr. Shortridge names (*Arizona Daily Star*, December 20, 1892).

In 1893, the Tucson Water Company was struggling to supply the town with domestic water, particularly during the dry season. Drinking water also irrigated the shrubbery and lawns that were fostered to beautify the city in the 1880s:

> It has been suggested that some plan should be adopted by which all irrigation of gardens, lawns and trees in Tucson should be done from 6 pm to 4 am. This plan would be much better for the gardens and lawns and would make the water supply ample during the dry season of the year (*Arizona Daily Star*, February 15, 1893).

Modern Tucson has adopted a similar plan of action in recent years, fueled by the popular slogan, "Beat the Peak," in reference to maximum water use during the hot summer. An additional misuse of drinking water in the 1890s involved the sprinkling of Tucson's dusty streets. The unpopular sprinkling carts consumed an average of 38,000-45,000 liters of water per day. To counter water deficits, the Tucson Water Company was forced to dig new wells inside the San Xavier Reservation, a short distance upstream of the original gravity flow system:

> A change in the waterworks of the city will soon be made, which will do away with all the old trouble of scarcity of water in time of need. This will be done in part by supplying water from a new source. The Santa Cruz has been pretty faithful but an unfailing supply is demanded. This will be obtained from a well which has been sunk at San Xavier, near the head of the present pipe system going down twenty feet [6.1 m] to the bedrock. This water will be pumped into a huge tank, from which it will be drawn into the water main as fast as needed, from a pump capable of supplying 1 million gallons [3.8 million liters] a day. The pumping plant will be run by a sixty-horse-power boiler. The water from the well will differ somewhat from the present supply, containing none of the matter in solution which the present supply causes to have a coating within boilers. The consumption of water in Tucson is over 100 gallons [380 l] per day to each person. This is above the average consumption the country over, and is due largely to irrigation. The water company is talking of putting in meters and making charges according to the amount consumed (*Arizona Daily Star*, February 17, 1893).

> At San Xavier the new well system, the Cook Well, a perforated tube, driven in gangs within a radius of 50 feet [15.2 m] is going forward satisfactorily, the first being now done.... Five will be driven and their flow concentrated and pumped into the water main (*Arizona Daily Star*, March 21, 1893).

Pumping will begin at the new plant at San Xavier today, the connections having all been made and the boiler fired up. The water head has been very light for a day or two, but it is hoped that with pumping it will be much augmented, and that residents in the eastern end of town will have no cause hereafter for grumbling (*Arizona Daily Star*, March 31, 1893).

The new system for irrigating the valley of the Santa Cruz at San Xavier is progressing. One well has been put down to water by digging, being now seventeen feet [5.2 m] deep. On arrival of Cook well strainers, wells of that class will be put down a considerable depth. Already a good water supply is had, the water coming up plentiful and clear. This well, it is thought will be sufficient to irrigate 640 acres [259 ha] owned by the water company. Something of the needs of water supplies may be judged from the fact that to cover an acre of land with an inch of water requires 27,000 gallons [102,330 l]. The new well will be under way in about a month. Ranchers in the valley will probably purchase water when the supply is sufficiently developed. Opinions are expressed that the supply in the valley will not last the summer through (*Arizona Daily Star*, April 27, 1893).

Even with the new wells, water became scarce in June:

Complaints against the water company are becoming numerous. Many people say there has been no water to be had before 8 o'clock for several days past and yesterday morning it was an hour later than that before water began to flow though the pipes. The water in the Santa Cruz is low and is not being used by the water company to supply customers. The pumps are running every day and will continue to do so till the summer showers (*Arizona Daily Star*, June 11, 1893).

Low flow conditions existed on area streams until January 1895, when the Rillito flooded over its banks:

The Rillito was the highest yesterday morning than it has been for a long time. It was out of the question for the Mammoth stagecoach to cross it, but the mail was taken on by a Mexican boy who forded the river on his horse. It was said in the afternoon that the water was out of the banks of the stream to the distance of a mile [1.6 km], and in some places more than two miles [3.2 km] (*Arizona Daily Star*, January 17, 1895).

In June 1895, J.R. Watts, superintendent of the Tucson Water Company, reported a significant lowering of the water table in the San Xavier district:

This fact is determined by the well from which the city supply of water comes. Originally the well was but 18 feet [5.5 m] deep and the process of sinking is still going on. Formerly the city supply came through submerged sluices in the river bed and to some extent these still furnish all that is necessary, but the company has been obliged to run their pump 27 months in the last two and a half years. To do this it required 1,782 cords of wood at an expense of $4500. Tucson uses an average of 13 million gallons [36 million liters] of water per month. Recent rains in the mountains will probably help matters with the company (*Arizona Daily Star*, June 13, 1895).

Heavy flooding resulting from local rains caused significant damage in August:

Tucson people have been wanting rain for some time and wanting it bad. Early yesterday morning they got all the rain they wanted and got it quick, too. Just about midnight the entertainment opened with a brilliant though silent electrical display. Later the deep music of rolling thunder was added and the lightning flashes became almost continuous. About one o'clock the flood gates were opened and a tremendous downpour set in. In about two hours time 2.75 inches [6.6 cm] of water were reported by a local observed to have fallen. Some of the citizens probably thought as many feet had come down. Among the many items of damage may be mentioned that the Fort Lowell Road wagon bridge [on the Rillito River] was carried away and part of it lodged against the Stone Avenue Bridge, which had two piers torn away, thus making it unsafe for travel. Part of the piers of the Southwestern Pacific Railroad Bridge was carried away and the eastbound passenger train was delayed several hours while the bridge was temporarily repaired to allow the train to cross, and left here at ten o'clock. Down in the city some lively scenes were being enacted. The streets were soon mini-rivers, and the rush of water so great that many residences, especially in the lower part of town, were flooded and several inches of mud on the floors this morning tell the tale of the downpour. On the corner of Meyer and McCormick Streets, Wing Ho kept a grocery. The end wall of this building fell out and half of the heavy mud roof fell in, badly damaging his stock of goods by the rain and mud (*Arizona Daily Star*, August 9, 1895).

Three months later, the prophesy of an impending fuel crisis became a reality for Tucson and surroundings:

Tucson is on the edge of a wood famine. Prices have already doubled in the last two weeks. Most that arrived yesterday was brought in burros. A load of this kind has a fixed market price of four bits. There is no scarcity of wood in the mountains, so the famine will only be temporary. The cause of it is that the Papagos who furnish most of the wood are engaged in planting their crops (*Arizona Daily Star*, November 17, 1895).

In March 1895, the Allisons, controlling about 470 ha of bottomland, expanded their irrigation works:

> The Allison ditch in the valley is full of water which is being used to good advantage for irrigation purposes on the rich land north of Stevens Avenue [Congress Street]. It is said that the Allison Brothers are thinking of taking water out of the river further up than they are now and that they will cut the ditch deeper thus being able to supply farmers in the valley with more water (*Arizona Daily Star*, March 8, 1895).

By the following year, the Allisons' canal on the west side of the valley had become unsatisfactory: "The land down on the west side had too much alkali and was no good, so we finally dug the present canal on the east side of the valley and located the land which is called the Flowing Wells (Allison, n.d.)."

At the former site of Warner's Dam, the Allisons constructed a flume that carried water across the channel into a newly-dug ditch referred to as the East Side Canal. This canal also turned the waterwheel at the new flour mill just south of the Tucson smelter (NW 1/4 of SE 1/4 of Section 2, T14S, R13E). By 1898, they were turning a handsome profit shipping watermelons along the Southern Pacific Railway. In 1900, the Allisons sold their Tucson property to L. H. Manning and other parties for $60,000, hoping to reinvest in agricultural lands between San Xavier and Tucson:

> After we sold this property we got a right of way from the Indian Department in Washington (Bureau of Indian Affairs), and dug another ditch, bringing water from the Black Mountain on the Indian Reservation, to land about 14 mi [22.4 km] north of the Black Mountain. We cleared the land of heavy mesquite and farmed it for several years (Allison, n.d.).

Drawing from the Allisons' experience, in 1902 L.H. Manning sought to develop artesian water at the base of Sentinel Peak:

> Some years ago the Allison brothers opened an irrigation canal on the west side of the Santa Cruz Valley with its source of supply at what is known as Warner's Lake at the east side of Sentinel Peak, southwest of Tucson. To increase the water supply at the head of the canal the Allison brothers put down several drain pump three-[7.6 cm] pipes to the depth of from ten to fifteen feet [3-4.6 m], resulting in several flowing wells, increasing greatly their water supply. It was noticed

that in every instance one or two strata of hard substance had to be penetrated to reach the underflow which would flow out of the pipes some inches above the surface.... There is good reason to believe that at depth a large and permanent supply of artesian water can be obtained. The successful experiment of Manning and Ives on the Allison ranch Tuesday in developing the underflow in the vicinity of the Allison brothers experiment some years ago is most encouraging. It is evident the water is still there and in large quantities. It is encouraging to know that Manning and Ives will make a thorough test by sinking to a great depth. They have employed an experienced well borer, James C. Fulton, to do the work. Mr. Fulton had had a long experience in boring for artesian water and oil. He believes the probabilities for a large supply of artesian water in the Santa Cruz Valley in the vicinity he has set his stakes on is good. The flow developed Tuesday keeps up its output of pure clean water. A large pipe will be put down with a view to increasing the volume of water from this underflow (*Arizona Daily Star*, May 1, 1902).

The artesian water question has been determined in the Santa Cruz Valley. Yesterday Captain Fulton, the manager for General L.H. Manning, struck the fifth flow of water, this about three quarters of a mile [1.2 km] up the valley from the first well opened. The flow was struck at twelve feet [3.7 m]. A four and one-half foot [1.4 m] pipe was put in. The cold, clear water spouts out with force. The flow from the four and one-half foot [1.2 m] pipe is 250,000 gallons [ca. 950,000 l] per twenty-four hours. The other four wells keep up their flow which added to this yield 1,500,000 gallons [5,700,000 l] daily. Three more eight-inch wells will be sunk in line with the new gusher from which a flow of over a million gallons is expected. General Manning is very much elated over the wonderful success which has resulted from Captain Fulton's work. He feels confident that he has struck a subterranean river, and the flow would seem to warrant the belief. He predicts that they will during the next six months develop 4,000 miner's inches [2.5 cms] through the artesian wells. This will equal more than one-half the entire water supply of Salt River Valley. One of the interesting features of these wells is that not one of them has depreciated in flow since developed yet this is our very driest season. General Manning and associates have done and are doing a great work for the Santa Cruz Valley and Tucson as well as for themselves (*Arizona Daily Star*, July 10, 1902).

The experiments made in developing artesian water in the Santa Cruz River in such large quantities, the water being encountered at an average depth of twenty feet [6.1 m], demonstrates the theory of a large underflow in this valley. It also demonstrates that this underflow can be brought to the surface with little cost or trouble. The most practical and inexpensive means is the simple canal system. The Allisons determined this fact by their canal. Now if the underflow can be tapped at twenty feet [6.1 m], it will not require a very long canal to carry out this water onto the mesa lands surrounding Tucson, or the lands of the lower Santa Cruz Valley. This underflow can be tapped at scores of points south of Tucson at most any point in the

> valley. Two, three or five miles [3.2, 4.8, 8.0 km] up the Santa Cruz Valley would no doubt develop water sufficient to supply the entire demand of the city. There is believed to be a very large underflow in the valley, sufficient to irrigate the many thousands of acres. This can be brought to the surface and made to do duty in the reclamation of lands. The fall of the valley is sufficient to carry out this water (*Arizona Daily Star*, July 30, 1902).

More Water Harvesting Schemes in Response to Declining Ground-Water Levels

Optimism over the potential of wells to supply all of Tucson's water needs was cut short when the most severe drought in southwestern history occurred between 1899 and 1904. The city, which had bought the Tucson Water Company in 1900, again urged citizens to schedule irrigation of lawns and gardens to minimize evapotranspiration:

> Owing to the increased consumption of water so far in excess of the present means of supply, and the decrease in the underground flow to the now existing wells, the installation of the new pump ordered by the city, and the completion of the new well now under course of construction.... Sprinkling and irrigation allowed only between the hours of 5 a.m. and 8 a.m. and between 5 p.m. and 8 p.m..... Trusting that the fairminded citizens of Tucson will bear with us in this proposition (*Arizona Daily Star*, June 19, 1903).

The severe drought at the turn-of-the-century was followed by the wettest year of record. In 1905, Tucson received a total of 614 mm of rain, with more than half of this coming in January, February, March and April. In early March, about 15 m of grade at the west end of the Jaynes bridge (on section line between Sections 7 and 18, T13S, R13E) was swept away by floods (*Arizona Daily Star*, March 12, 1905). A couple of weeks later, 0.2 ha of land washed away near the bridge (*Arizona Daily Star*, March 21, 1905). Perhaps it was this flood that spurred the Irrigation Department at the University of Arizona to install a stream gage at the Congress Street Bridge in November of that year (Schwalen, 1942).

In June 1905, an anonymous observer perceived the connection between the recent water shortages and the newly-developed arroyo:

> The shortage in the Tucson water supply is said to result from the deep wash in the Santa Cruz Valley which extends far above Silver Lake Hotel. The deep wash is drawing off the underflow which previously formed a vast underground reservoir and from which the city water wells drew their supplies (*Arizona Daily Star*, June 24, 1905).

Similar claims were made in the 1910s by hydrologists and engineers working in the Tucson area:

> Immediately at the Santa Cruz River to the southward from Tucson the [ground] water contours curve sharply upstream. Here the underflow inclines towards the river. The river bed is from five to ten feet [1.5-3.0 m] lower than the general water level of the bottomland and must act therefore exactly like a drainage canal in underdraining the valley. As late as 1890 there was little or no definite river channel along this course, but the surface waters during flood time were spread out over the bottomland. Between that date and 1906 the channel was cut down rapidly and thus far the time has been too short to drain the water far back from the channel. It is probable that as this underdraining continues the water level will be lowered considerably along the valley and eventually the sharp curves of the water contours will disappear (Smith, 1910, p. 177).

> As the barrancas [arroyos] become deeper they drain and lower the groundwater plane, compelling those dependent on the flow appearing in the bed of the barranca to go higher up the channel for their supply (Olberg and Schank, 1913, p. 8).

By the early 1910s, there were four main canals that irrigated lands west of Tucson:

> The oldest of these canals, the "Farmer's," originally had its heading on the east side of the river a short distance above Tucson, where the ground water originally appeared on the surface [at the site of the Silver Lake dam]. Its former heading is now 10 or or 12 feet [3.0-3.7 m] above the bed of the river and is supplied with water by means of a ditch leading along the river bed. That part of the "Farmer's" ditch in the bed of the barranca washes out with each flood, and frequently the heading is now several feet above the bed of the channel, and the ditch is supplied with water from the Manning Canal [Figs. 37-38] by means of a flume across the barranca. Water in the Manning Canal is developed in one of the side channels which enter the barranca from the west, about 2 miles [3.2 km] above Tucson. This flow, together with what appears in the bed of the channel at that point is collected and led into the canal by means of a ditch in the bed of the barranca about three-quarters of a mile [1.2 km] long. A fourth canal has been taken

> out of the river a short distance below the Papago Reservation. As the channel deepened the water came to the surface higher up the river bed. For this reason, the owner (Allison) of the canal was compelled to take out a new heading inside the reservation. This intake is on the east side of the river, and the water is conducted down the bed of the channel to the canal heading farther down the valley (Olberg and Schanck, 1913, p. 9).

In 1910 a group of Chicago and British businessmen, the latter drawing funds from the estate of Cecil Rhodes (the same estate that now supports Rhodes scholars), pooled their capital and formed the Tucson Farms Company. In 1911, they purchased some 500 ha from Manning and the Allison brothers. By 1913, the Company's holdings included some 2400 ha of valley land. Manning reinvested in the Santa Cruz Reservoir Project, a 10 million dollar boondoggle to impound runoff at the confluence of the Santa Cruz and the Aguirre Valley in Pinal County. Both the Tucson Farms Company and Santa Cruz Reservoir Project were investment schemes slated to attract farmers from the Midwest to the Santa Cruz River Valley.

The Tucson Farms Company project called for further development of the underflow at the base of Sentinel Peak, near San Xavier, and at Sahuarita, increasing the total area subject to irrigation. Developed parcels of land with partial water rights were then sold to farmers for $500-750 per hectare (James, 1917). The chief engineer of the project was H.C. Hinderlider, who some years later became State Water Engineer for Colorado.

At San Xavier, the Tucson Farms Company installed a number of electrically-operated pumping plants. From south of Sahuarita to the north end of the Canoa land grant, the Company drilled 24 wells. Most of these wells were 60-150 m deep, but one was drilled to a depth of 275 m (Schwalen and Shaw, 1957, p. 94). In 1912, Manning bought the Canoa land grant and developed gravity flow at the point where the perennial flow of the Santa Cruz

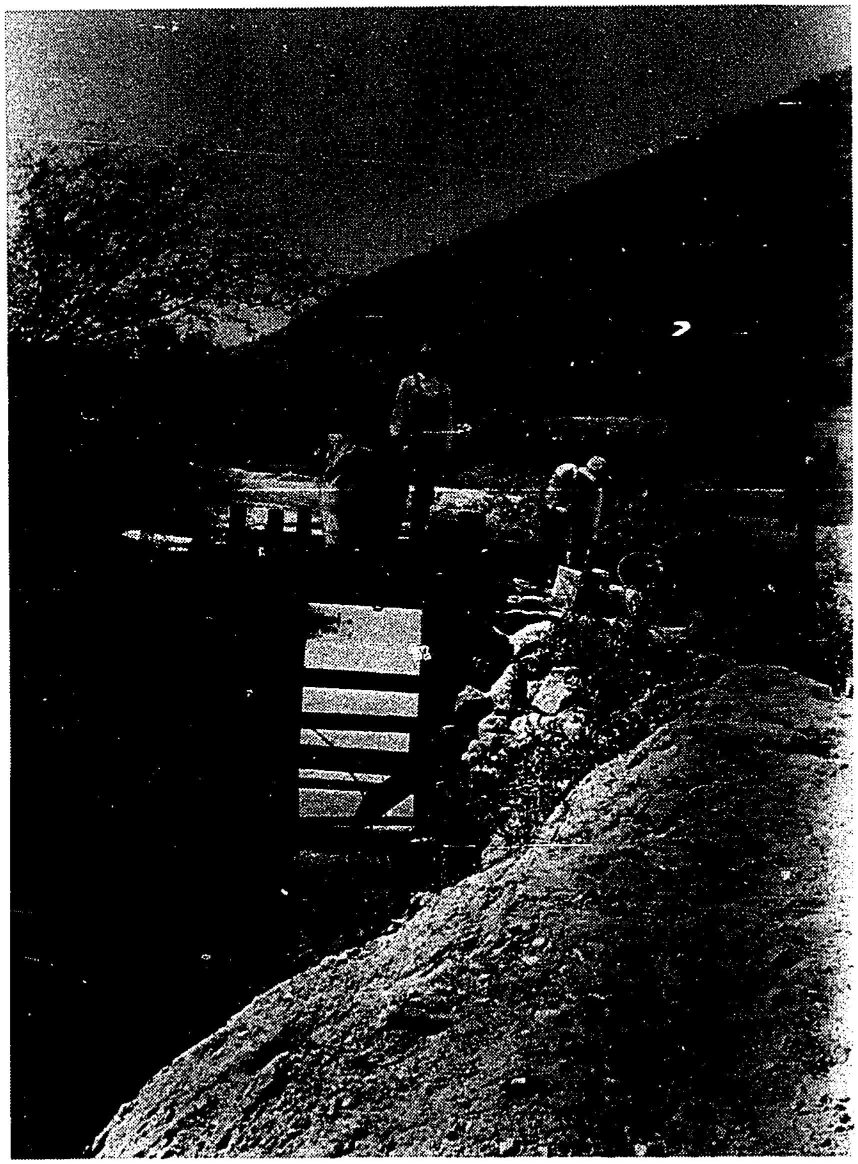


Figure 37. Head of the Manning Ditch in 1907, with the Santa Cruz River and Sentinel Peak in background. The men in the photograph are dumping copper sulfate in the ditch, presumably to retard accumulation of moss. Even though the stream had become entrenched throgh this reach in the 1890s, it remained perennial. In fact, the flow may have increased with deeper intercept of the water table (Special Collections, University of Arizona Library, Tucson, Negative No. 2709; U.S.G.S. Stake 1073).

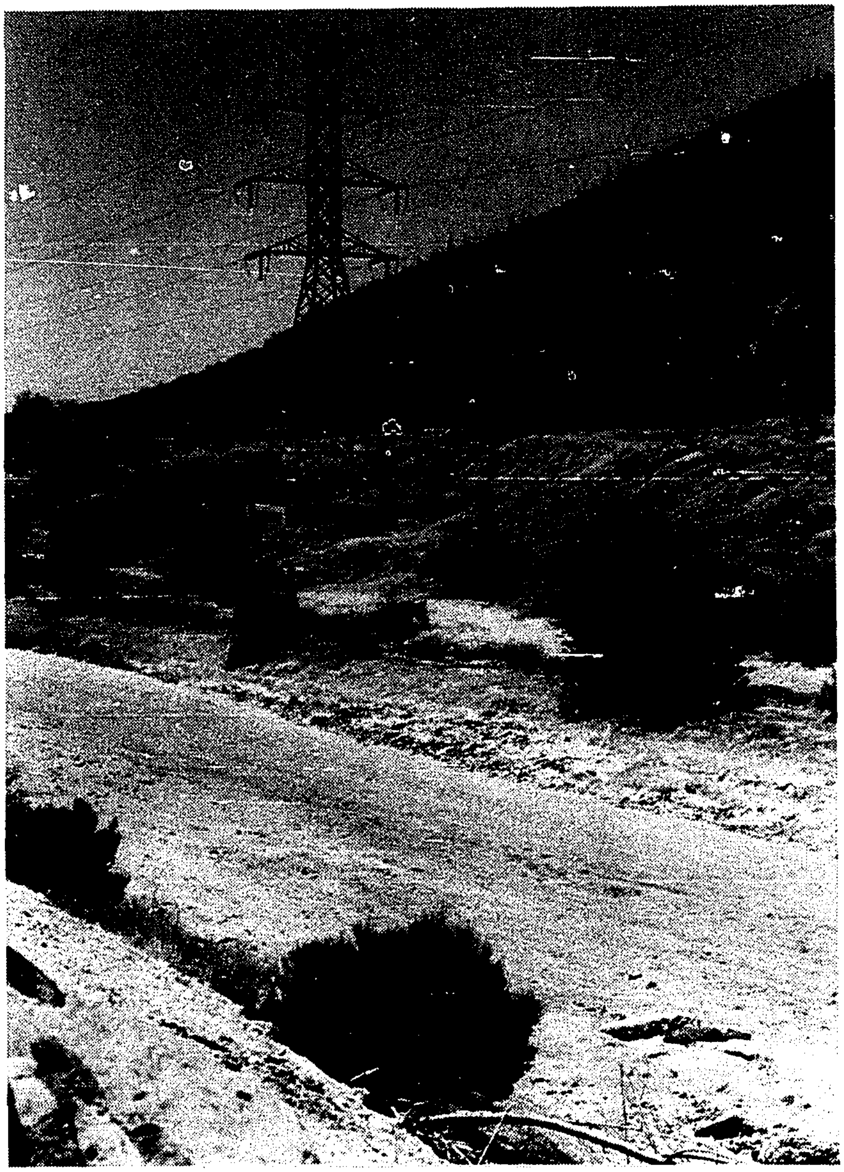


Figure 38. Same view as Figure 37 on February 4, 1982 (Photograph by R.M. Turner, U.S.G.S. Stake 1073).

disappeared:

> To tame this erratic stream and at the same time tap its water there was conceived the idea of creating an artificial ravine, which would draw off the underground flow. This ravine was excavated from higher lands at the headquarters of the Canoa Ranch, gradually deepening until at the head, the ravine was deep enough to draw seepage from the river (*Arizona Daily Star*, January 1, 1922).

The most elegant scheme to develop water by the Tucson Farms Company was implemented about 100 m downstream of the former dam at Silver Lake:

> The recovery and distributing system planned for a normal capacity of 40 sec. ft. [1.1 cms], consists of nineteen wells drilled in a straight line across the narrow part of the valley. These wells are connected by means of a gravity conduit of reinforced concrete, 4740 ft. [1444 m] in length, located and built from 5 to 12 ft. [1.5-3.7 m] below the water plane of the valley. The distributing system consists of a reinforced concrete pipe line 48 in. [122 cm] in diameter, 1500 ft [460 m] in length forming the outlet from the recovery system, a 48 in. [122 cm] concrete siphon under the Santa Cruz River, about 7 miles of ordinary earth canal, 12,650 ft [3860 m] which are lined with concrete, and 21 miles [33.6 km] of laterals of which about 3000 ft. [914 m] are lined with concrete. In addition there are numerous reinforced concrete drops, provided with steel measuring weir, steel flumes, 1200 ft [366 m] of 24 in. concrete siphons under the Santa Cruz and Rillito Rivers, one earth and one timber dam across the former river, a large number of check and division boxes, lateral head gates, drainage structures, etc., about 200 in number and common to most irrigation projects.
>
> Probably the most interesting feature of this project, and certainly the most important, is the recovery system of nineteen wells drilled across the valley to intercept the underground waters, together with the necessary pumping equipment and conduits for conveying the water recovered to the open canal system. The wells were drilled to various depths, ranging from 45 to 150 ft. [13.7-45.7 m] below the surface of the ground, each hole being sunk through the water bearing material well into the impervious material below, the profile of which was found to be quite irregular. One of the accompanying illustrations shows the general plan of this development [Fig. 39; also see Figs. 40-46]. It will be seen that at the point of drillings there are two channels of the Santa Cruz, the main channel being near the center of the valley at this point while the west branch occupies a position near the western extremity of the valley and enters the main channel about 1/2 mile [0.8 km] below, at the intake of the old Manning ditch, the control point for the distributing system.... Fortunately, the elevation of this point of outlet into the West Branch conduit coincided very well with the elevation of the Manning ditch some 3200 ft. [975 m] lower down the river.

> .... The main canal which conveys the water from the 48 in. [122 cm] outlet conduit of the recovery system is about 9 miles [14.4 km] long. There are no unusual features connected with construction of this canal with the exception of the structures along the upper 2-1/2 miles [4 km]. The first three miles [4.8 km] of this canal consist of an enlargement of the old Manning ditch [Fig. 37-38, 46]. This ditch was very crudely built a number of years ago. For the most part the gradient was very low and poorly equalized while the location of the ditch through a part of the city inhabited largely by Mexicans, running as it did through alleys, backyards, and under houses with poorly defined rights of way, made the relocation a rather troublesome matter (Hinderlider, 1913, p. 200-201, 244).

Percy Jones, who was concrete inspector and instrument man during construction of the Crosscut system described above, related that the "trouble with building the damn thing was too much water, and then it was never a success because they never had enough (Jones, 1973)." Close to a million dollars was spent on the project. Several suitcases of cash were needed to meet the payroll for the more than 500 workers. One result of the Crosscut was to displace the confluence of the West Branch and the Santa Cruz upstream, safeguarding the West Branch outlet against flooding. By 1915, the system delivered almost 30 million gallons [84 million liters] of water a day.

The downstream counterpart to the Tucson Farms Company was the Santa Cruz Reservoir project, an elaborate scheme near present Redrock (Fig. 47), which diverted streamflow from the Santa Cruz River (by way of Greene's Canal) and Aguirre Wash into a reservoir with a capacity of 300,000 acre feet (370,000,000 cubic meters). The reservoir site was a natural depression upstream from the confluence of the two streams. The engineer for the project, P.E. Fuller, describes the waterworks two years after Colonel Greene, the originator of the project, had died:

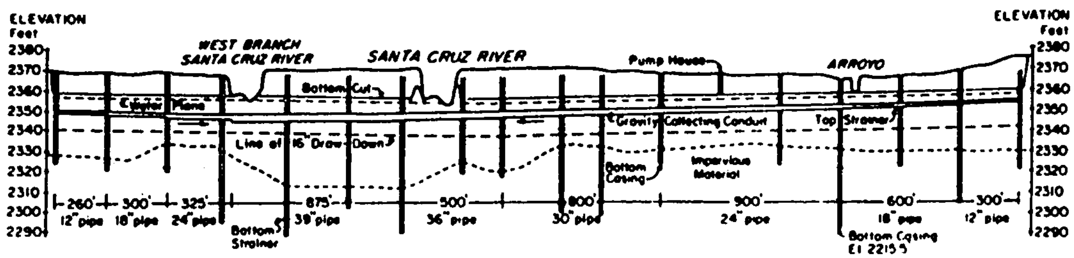


Figure 39. Vertical profile of the line of wells, pump houses and gravity collecting conduit associated with the Tucson Farms Company Crosscut. Note the intercept of the water plane by both the West Branch and the Santa Cruz River (from Hinderlider 1913).

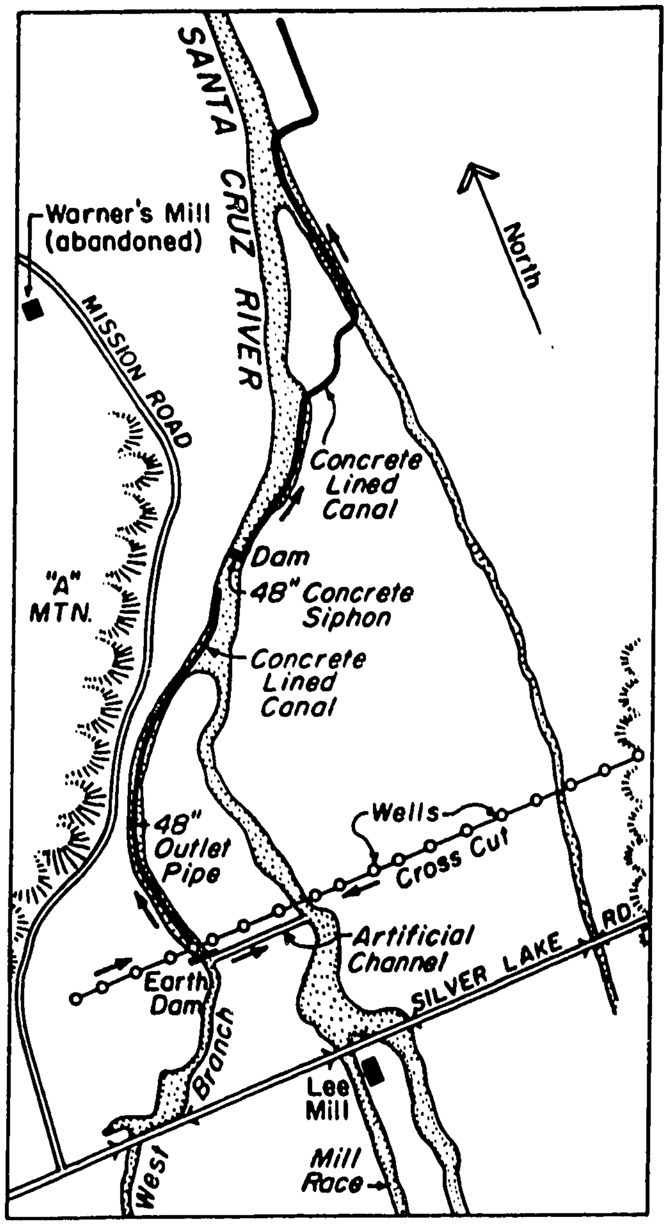


Figure 40. Plan of the Tucson Farms Company Crosscut and distribution system (Hinderlider 1913).

Figure 41. East view of the Crosscut in 1913, with trenching for concrete conduit in progress and well casing in foreground. The channel of the Santa Cruz River runs from right to left across center of photograph (Photograph by Percy Jones, Special Collections, University of Arizona Library, Tucson, Negative No. 2803).

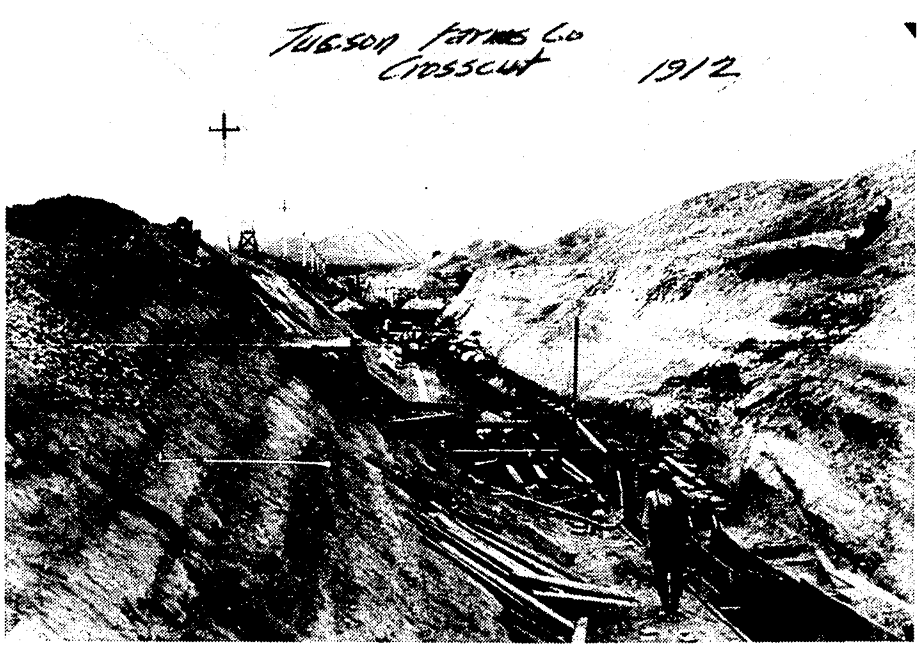


Figure 42. West view of the Crosscut under construction in 1912 (Photograph by Percy Jones, Special Collections, University of Arizona Library, Tucson, Negative No. 2758).

Figure 43. Outlet from the Crosscut in the streambed of the West Branch in 1913 (Photograph by Percy Jones, Special Collections, University of Arizona Library, Tucson, Negative No. 2709; U.S.G.S. Stake 1066).

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Tucson Farms Co
Santa Cruz Diversion 1912

Figure 45. Diversion point for water developed by the Crosscut, about 3 km downstream along the bed of the Santa Cruz River, in 1912. (Photograph by Percy Jones, Special Collections, University of Arizona, Tucson).

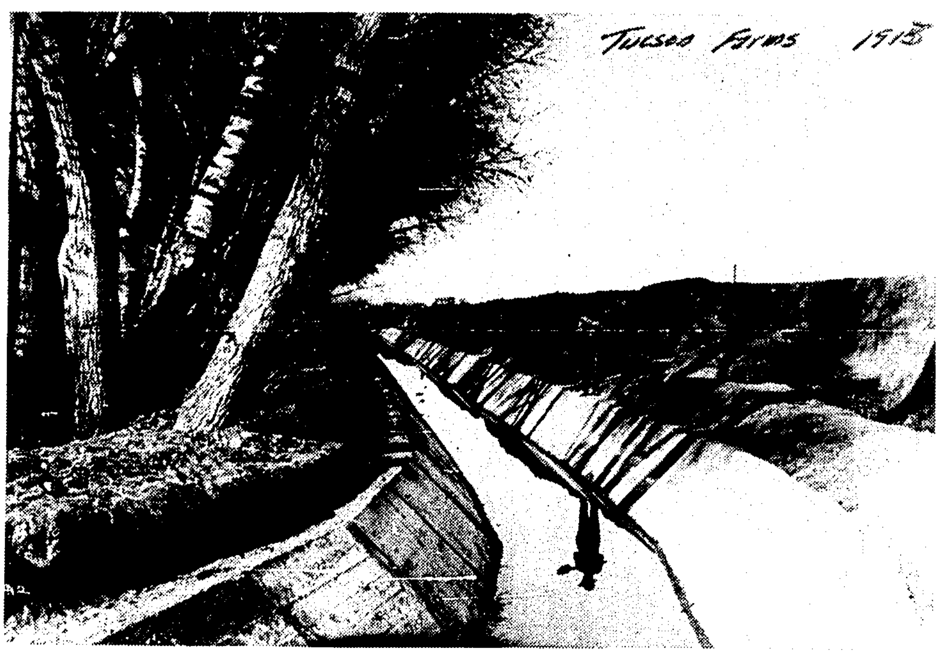
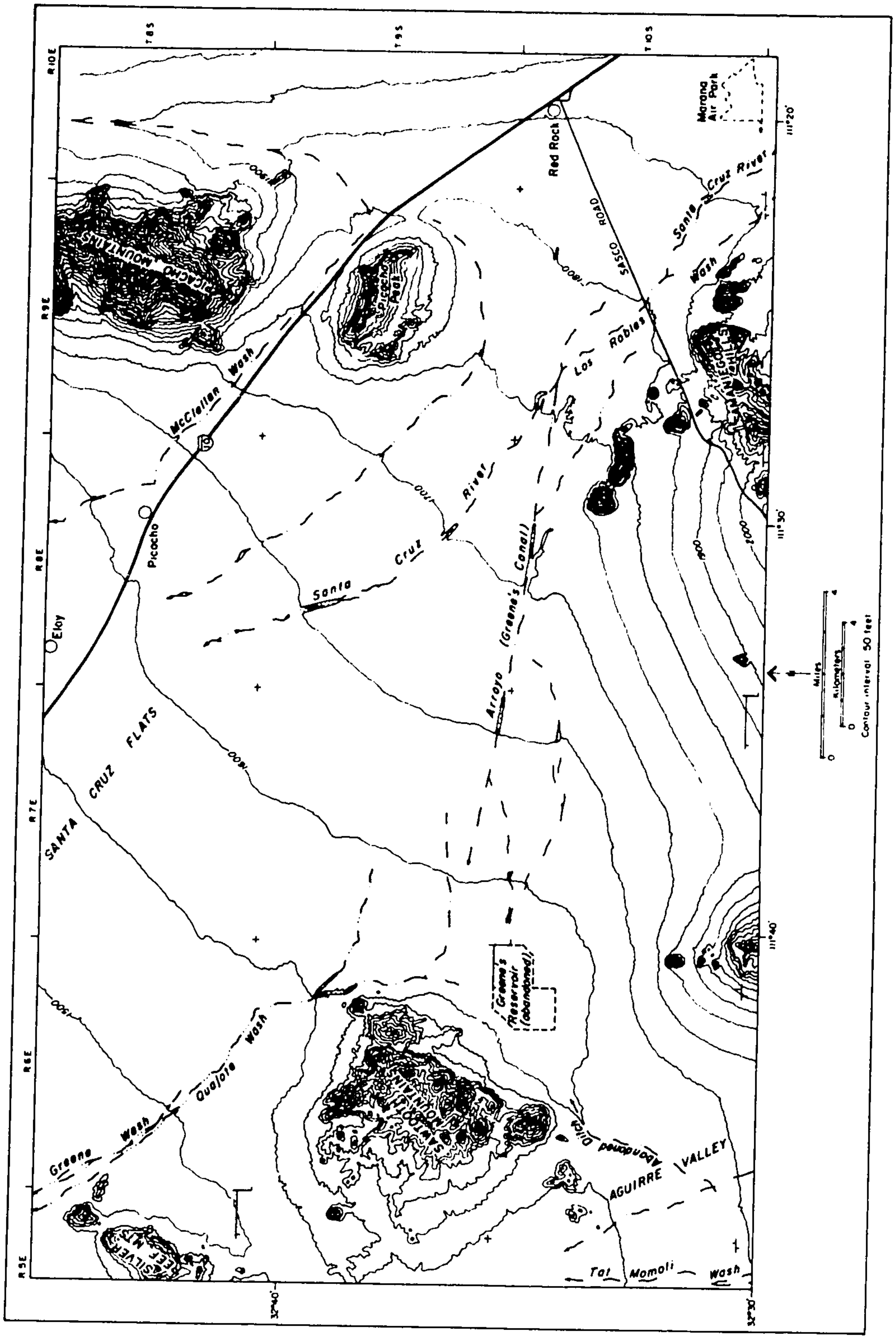


Figure 46. Sector of finished concrete lined canal inside the east bank of the Santa Cruz River in 1913 (Photograph by Percy Jones, Special Collections, University of Arizona Library, Negative No. 2713).

At the point of the interception of the Santa Cruz River by the diversion canal, an earth-fill diversion dam, some 2000 feet [610 m] long and 10 feet [3 m] high, has been constructed across the Santa Cruz River channel. Also, there is constructed a diversion canal, from this point to the reservoir, which has an average width of 20 feet [6.1 m], an average depth of 5 feet [1.5 m] and a gradient of 14 feet [4.3 m] per mile. At the extreme west end of the Santa Cruz diversion dam there is constructed a waste-way with gates, having a waste-way area of close to 100 square feet [9.3 sq. m]. The water discharged through these waste gates flows into the old channel of the Santa Cruz River below the point of diversion.... The diversion dam of the Santa Rosa River [actually the Aguirre Valley] is in the form of a levee which continues and forms the south bank of the Santa Rosa [Aguirre] diversion canal which has been constructed for a distance of some 6 miles [9.6 km]. The gradient of this canal is 12 feet per mile [2.3 m/km] and the width is about [6.1 m], with a depth from 1 to 1.5 feet [0.3-0.5 m].... From the outlet gates of the Santa Cruz reservoir there has been constructed a main supply canal to a point some 9 miles [14.4 km] north. This canal is 15 feet [4.6 m] in width, 4 feet [1.2 m] in depth, with a maximum gradient of 7 feet per mile [1.3 m/km]. Branching from this main canal there are about 30 miles [48 km] of laterals and distributing canals, varying in width from 8 to 12 feet [2.4-3.7 m] and in depth from 2 to 3 feet [0.6-0.9 m]....The maximum capacity of this canal, upon its present gradient and cross-section, is 600 second-feet [17 cms]. Capacity will be automatically greatly increased by erosion as it is called upon to carry the flood flows, though it is doubtful if its course will remain in the present alignment since the old course of the river, below the point of diversion, is a tortuous one, presenting a greater length upon the gradient as the present canal.... The Santa Rosa diversion canal has a present capacity of of 50 cubic feet per second [1.4 cms] in its excavated channel, but this canal will similarly increase in capacity as it is called upon to convey flood flows. Further, the excavated material has been deposited upon the lower side slope, producing banks several feet in height; hence its true carrying capacity is much in excess of that given for the excavated area--probably 200 second-feet [5.7 cms]. This is still further augmented by the Quajote Wash, which is an independent water-way....To carry the maximum flood flow of the Santa Cruz of which there is record; i.e., 6780 second-feet [192 cms], it would require that the canal be widened about 200 feet [61 m] or approximately the present width of the river channel, at the point of diversion. This might readily be accomplished during one flood flow, as a channel of nearly equal area was eroded within a few days at a point above Tucson upon the Santa Cruz River, when it was desired to change the course of the river (Fuller, 1913, p. 8-9, 28-29).

Figure 47. Map of Greene's Canal and lower Santa Cruz River, based on U.S.G.S. 15' Quadrangles.



Erosion Control on the Indian Reservation: Joining the West and East Barrancas

By 1912, the Tucson channel had migrated upstream to join the headcut at Valencia Bridge, eventually reaching 5 km into the San Xavier Reservation and within 1 km of capturing the entrenched segment of the Spring Branch (Figs. 48-49). By 1912 a channel 30-60 m wide and 5-6 m deep marked the course of the Spring Branch two miles downstream of the spring source. Another earth dam was thrown across the mouth of the channel to collect water and prevent further erosion:

> This dam washes out with every flood, but it probably prevents a certain amount of erosion. One-half mile below the dam is the head of the channel leading up from Tucson. It is about 30 feet [9.1 m] deep and divided into several branches which will eventually combine into several hundred feet in width. The grade drops rapidly from the base of the dam to the bed of the Tucson channel, which begins opposite a small mountain of volcanic formation known as Sahuarita Butte [Martinez Hill]. At this point a stratum of clay overlies the water bearing sand and gravel, which has checked erosion to a certain extent. Practically all of the irrigable land now under cultivation, possibly a total of 500 acres [200 ha], lies on the west side of this barranca, about half of which is irrigated by a canal heading at the dam. If the main channel erodes back to the dam, the heading of the Indian ditch will become similar to those of the canals lower down the valley (Olberg and Schanck, 1913, p. 10).

On the west side of the valley, an entrenched segment downstream of Punta de Agua had developed as early as 1849. By 1912, erosion along this segment had forced local farmers to construct a ditch heading at the mouth of the channel:

> This channel varies from 60 to 100 feet [18.3-30.5 m] in width and at the ditch heading is 6 feet [1.8 m] in depth. As the channel ascends the valley it becomes progressively deeper, until at a point 2 miles [3.2 km] above, it is about 20 feet [6.1 m] deep. Here it encounters a deposit of indurated sand and gravel, or caliche. This harder material has checked the cutting and a broad sandy channel continues up the valley. Water occurs in the bed of the channel mentioned above. Owing to a peculiar perversity of nature this barranca fills up with a deposit of sand from 6 to 8 feet [1.8-2.4 m] deep after each flood,

> requiring the equivalent of one man doing from 1000 to 1200 days of hard toil on the part of the Papagos before the water is again available. What probably occurs is that the barranca is scoured deeper with each flood, which on receding deposits its great burden of sand (Olberg and Schanck, 1913, p. 10).

The most serious erosion on the reservation resulted when overbank flow crossed from the west to the east side of the valley, and cascaded into the east side barranca near the base of Martinez Hill. This process was described during flooding in July 1908, with a peak of 190 cms at Congress Street:

> There is evidence that some water passed over the territory lying between the two [channels] which flowed into the east channel above the dam, cutting lateral branches to the west. This water probably debouched from some barranca higher up the valley, as there is no evidence that either channel overflowed its banks. The water passing down the east channel washed out the dam and entered the Tucson channel, doing little damage on the reservation except to enlarge the barranca immediately below the dam and to carry the true head of the Tucson channel farther into the reservation. The water coming down the west barranca flowed out over the country, practially inundating it. The greatest damage was due to this source. After passing over the country, making fields and roads a quagmire, it finally fell into the Tucson channel over a bluff of soft earth from 20 to 30 ft [6.1-9.1 m] high. The result can readily be imagined-- immense channels were cut in every direction. This flood ruined more land than it actually carried away, as it is impossible to cultivate the ground between the side barrancas (Olberg and Schanck, 1913, p. 11).

In 1909, J.H. Quinton, a consulting engineer, submitted to the Chief Engineer of the U.S. Indian Service a plan that would remedy the problem. Quinton proposed that a dike and canal be constructed across the upper end of the valley joining the west and east barranca above the reservation's best agricultural lands. Flood waters would then enter the east side channel just south of Martinez Hill. A major obstacle to this strategy involved litigation between the United States and the Tucson Farms Company, which had bought the Martinez land grant and installed expensive electrical pumps at several wells within the property. If carried out, Quinton's proposal threatened the Company's investment. An alternate plan was suggested in 1913 and carried

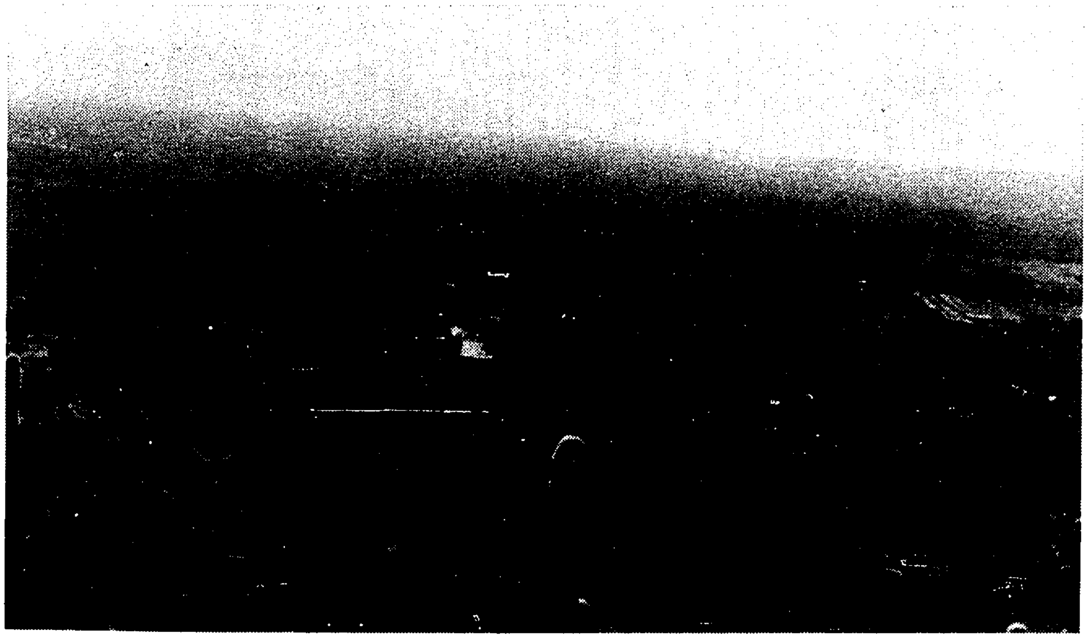


Figure 48. Upstream view from Martinez Hill in 1912, with dense mesquite growth in the valley bottom. By this date, a channel 9 m deep marked the course of the Spring Branch, with a steep headcut terminating just below the dam in the center of the photograph (from Olberg and Schanck 1913, National Archives, U.S.G.S. Stake 1057).

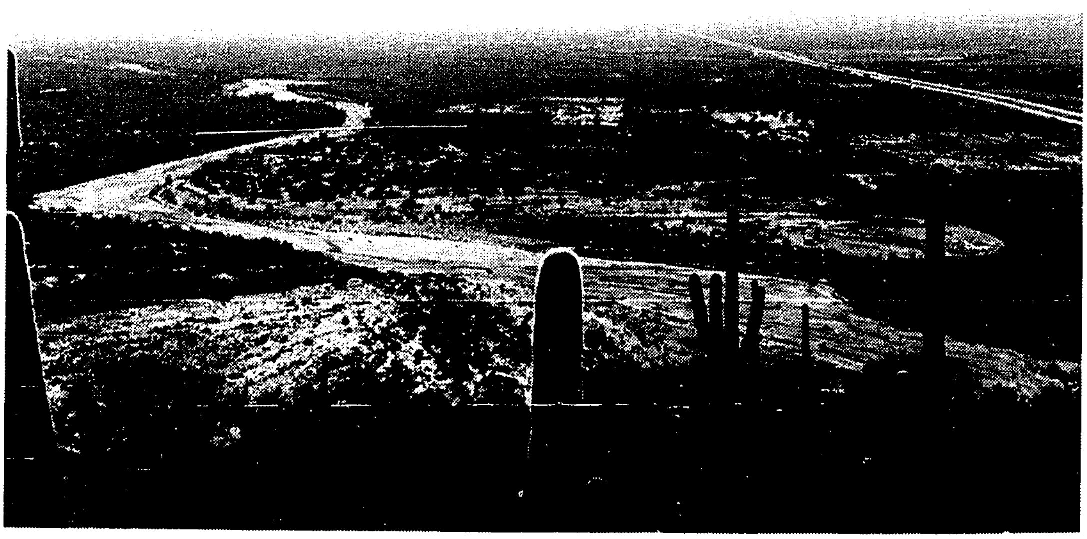


Figure 49. Similar view as Figure 48 on December 15, 1981. The floodplain is now sparsely vegetated due to a substantial drop in the water table, the consequence of heavy pumping since 1940. The Santa Cruz now courses along what was formerly the Spring Branch in a deeply entrenched and broad channel (Photograph by R.M. Turner, U.S.G.S. Stake 1057).

out in 1915:

> .... the west side barranca heads near the north line of section 13, township 16 south, range 13 east, while the heading of the east side channel occurs near the center of section 1, same township. A cut-off dike, extending across the valley along the north line of sections 14 and 13, would prevent flood waters from above from entering the west side channel. This dike will also form a flood storage reservoir with a capacity of 350 acre-feet [432,000 cubic meters]. The channel from this dike along the north and south center line of sections 1 and 12 would lead the water to the head of the east-side barranca. The proposed cut-off dike along the north line of sections 14 and 13 should be 7 feet [2.1 m] in height with side slopes of 2-1/2 to 1 and 2 to 1. To prevent the dike from being destroyed by the activity of burrowing animals, a close-mesh fence of galvanized wire should be built into the center of the earthwork. The channel leading to the head of the east-side barranca should be formed by two dikes, each 4 feet [1.2 m] in height with a 6 foot [1.8 m] crown and side slopes 2-1/2 to l. The two dikes should be 300 feet [91.4 m] apart. This will form a channel, the bottom 300 feet [91.4 m] wide and the side slopes 2-1/2 to 1, with a depth of 5 feet [1.5 m].
> The elevation of the surface of the valley is 2620 feet [199 m]. The ground elevation at the head of the east barranca is about, 2590 feet [180.3 m] while the bottom of the barranca is 20 feet [6.1 m] lower. This gives a total fall to the channel of 50 feet in a distance of about 1-1/3 miles (7.1 m/km) (Olberg and Schanck, 1913, p. 12).

Today, the deep channel of the Santa Cruz River follows the route of the 1915 dike into the former course of the Spring Branch (Figs. 10C and 24). This channel is now 6 to 8 m deep and more than 100 m across.

The Great Floods in Winter of 1914-1915

Winter of 1914-1915 contributed to the highest annual flow on record at Congress Street, with 68,000,000 cubic meters in December alone. The peak flow of 425 cms occurred on December 23 (Fig. 50):

> City wells destroyed-- loss of $10,000-- flood washing out sections of track and bridges on both main line and Nogales branch of the southern Pacific Railraod, destroying property estimated at thousands of dollars and ruining numerous wells and other irrigation equipment. Below Marana and Cortaro, track of main line inundated for about 4 feet [1.2 m], 25 miles [40 km] of track washed out.... Two people believed drowned at Sahuarita; 25 people marooned on housetops and windmills.... City pumping plant No. 2 five miles south of

the city, inundated and seven wells.... Tucson Farms Company, as well as other ranchers and farmers, suffered heavy damage.... Allison Bridge, 1/2 mile [0.8 m] south of the Manning Ranch went out. It was on the Valley Road to the mission.... Twin Buttes R.R. Bridge washed out and struck Congress Street Bridge.... Parts of houses and trees did considerable damage. West end worse than east end. Railings and girders broken. Five wells at Indian Training School ruined; motor and pump house washed away.... Dam below San Xavier swept out. Believed that all dams in river are out. Water said to be 15 feet [4.6 m] deep in flooded district (Sahuarita).... U of A expedition [to Saguarita] estimated velocity at 12 miles an hour [19.2 km an hour] (*Arizona Daily Star*, December 23, 1914).

About twenty acres [8.1 ha] of the city farms on the west side of the Santa Cruz River were washed away by the recent flood. The land was all in alfalfa and was a very valuable piece of ground being worth at least $400 per acre.... At present it is a pile of sand and uprooted trees.... uprooted trees and overturned houses are floating downstream. The crest of the flood is expected to reach Tucson late this afternoon. The river had already overflowed its banks (*Tucson Citizen*, December 24, 1914).

At 7 o'clock last evening water at Plant No. 2 still about three feet above wells and still flooding pumps. Late last evening river approximately 8 feet [2.4 m] below flood level of Wednesday [December 23] at 6 p.m. (*Arizona Daily Star*, December 26, 1914).

Four p.m Friday, river estimated at least 12 feet [3.7 m] below high mark of Wednesday (*Arizona Daily Star*, December 26, 1914).

Although the Tucson Farms Company Crosscut sustained damage estimated at $10,000, the bridge and abuttments at Congress Street remained intact until the following month, when persistent flows eroded the bank. As early as 1902 (Fig. 30), a precarious meander had developed on the east bank of the river upstream of the bridge. This meander had withstood peak flows in the winter of 1904-1905 and also on December 23, 1914. However, on January 31, 1915 the bank defining the meander finally gave way and breached the east approach to the bridge (Figs. 50-57):

Sudden destructive tendencies developed in the flood that swept down the Santa Cruz River yesterday morning and from about 10 o'clock until noon the river rapidly washed away a large section of valuable land enclosed within a wide curve on the east side of the stream just south of the Congress Street road and containing five or more acres [2 ha], finally about noon destroying more than a hundred and fifty feet

[45.7 m] of embankment that connected Congress Street with the east approach to the bridge and completely isolated Menlo Park [a neighborhood on the west side of the river] and the west side from the main part of the city. The work of destruction was continued steadily, but more slowly throughout the afternoon and by midnight the rushing water was creeping at the outside of the curve close to the row of cottages just east of the big concrete irrigation ditch and threatening to include the houses in the ruin. While the river did not rise any higher, it developed a terrific boring power that rapidly crumbled the soft dirt into the swirling current of the muddy Santa Cruz. The current worked with telling effect on the sandy subsoil of the rich arable land of the bottom and the total damage is estimated to be not less than $50,000 at midnight. The east approach to the bridge was swept away leaving 200 feet [61 m] of water between the road and the bridge. The piers of the bridge also sank.

Notwithstanding the precautions taken by City Manager Clark and City Engineer Ruthrauff with their large force of men, the sudden driving force that the stream acquired in the morning rendered useless the protective measures taken and there was little that could be done through the day to protect the embankment. Foot after foot went out and by midnight it was estimated that the gap between the bridge and the east end of the road was more than 200 feet [61 m].

In the evening a force of men filled about six hundred sacks with dirt which were dumped into the current at the end of the road, but like the filling of the Rillito the night before it was swept away by the terrific power of the flood water. Clark and Ruthrauff left about 11 o'clock, leaving patrols along the river and promising to renew the work of turning the river from its destructive course this morning. A point on the east side several hundred yards below the bridge was dynamited in order to allow a clear sweep for the river and prevent a repetition of the washing away of land above. This precaution was taken to save the land near the Paseo Redondo and the destruction of the point appeared to stop the cutting away of the stream on the north side of Congress Street.

The sudden cutting out of the embankment surprised several hundred people who were residents of the west side, or who happened to be on that side when the gap was opened. At the very last a railroad man who had to make a train, came running over the bridge and across the embankment. He was warned not to attempt to jump over the gap that had just appeared, but he insisted that he must take the chance, and succeeded. He was the last man over, for the rush of the water broke down the embankment rapidly after that.

At 1 o'clock this morning it was estimated that the stream at its nearest point was only about 35 feet [10.7 m] from the big concrete irrigation ditch which is just behind the houses on Mission Street [the outlet to the Crosscut]. The people in the houses were all ready to leave at short notice, but at the time of going to press they had not been ordered out by the patrols.

It is estimated that more than 5000 spectators visited the scene of the flood during the day. At one time in the afternoon it was estimated that there were more than 3000. The crowds were kept back by ropes stretched across the road and police patrolled the space in front. Automobiles were not allowed to approach within 500 feet of the end of the road and a rope was stretched across to keep them out of the prohibited area.

Dr. Townsend, who had gone to visit a patient at St. Mary's was unable to return.... Several men succeeded in fording the stream a quarter of a mile south of Congress Street, but the current was too strong for others and they were obliged to return back. The current was estimated to be running six miles an hour [9.6 km or about nine feet a second [2.7 m a second] at 6 p.m. Only meager reports were available from the Rillito bridge last evening but it appears that the bridge is still holding its own. The river is flooded heavily and about 200 feet [61 m] of embankment approaching the north side are washed out (*Arizona Daily Star*, February 1, 1915).

The flood waters which cut away the approach to the east end of the Congress Street bridge and which did various other damage which will amount to at least $50,000 are receeding and unless something unforeseen occurs the danger to the houses on the east bank and to the bank and to the concrete ditch of the Tucson Farms Company has passed.

Owners of property in the neighborhood of the river have formed a protective association and are raising a fund to install the necessary works to defend their lands against any further ravages of the treacherous Santa Cruz.

A number of people forded the stream yesterday and it is expected that within a short time regular communication between the city and the west side will be restored.

City manager Clark and Engineer Ruthrauff directed a force of workmen in cutting away the point which caused the river to lash over the east bank and cut its new channel at three o'clock Sunday morning. In addition they built a bulkhead at the point where the river cut through and by this means sent the greater portion of the water back into its old channel.

Since the Congress Street bridge was built the bed of the river has fallen six feet [1.8 m] and this has permitted the piers to project so that but eight feet [2.4 m] were imbedded in the soil, which unfortunately at this point is mostly shifting sand. Manager Clark says it will not be a particularly difficult matter when the water goes down to jack the bridge up and straighten the piers. The piers at the east end of the bridge are the ones which have gone out of line the farthest, although the bridge itself is down about two and a half feet [0.8 m] below its regular level (*Arizona Daily Star*, February 3, 1915).

Figure 50. The Santa Cruz River in flood at Congress Street on December 23, 1914. This was the peak flow (420 cms) for the 1915 water year. Heavy flows continued into January, eventually destroying the meander where the people in the foreground are standing (Photograph by H. Buehman, Arizona Historical Society, Tucson, Negative No. 93470).

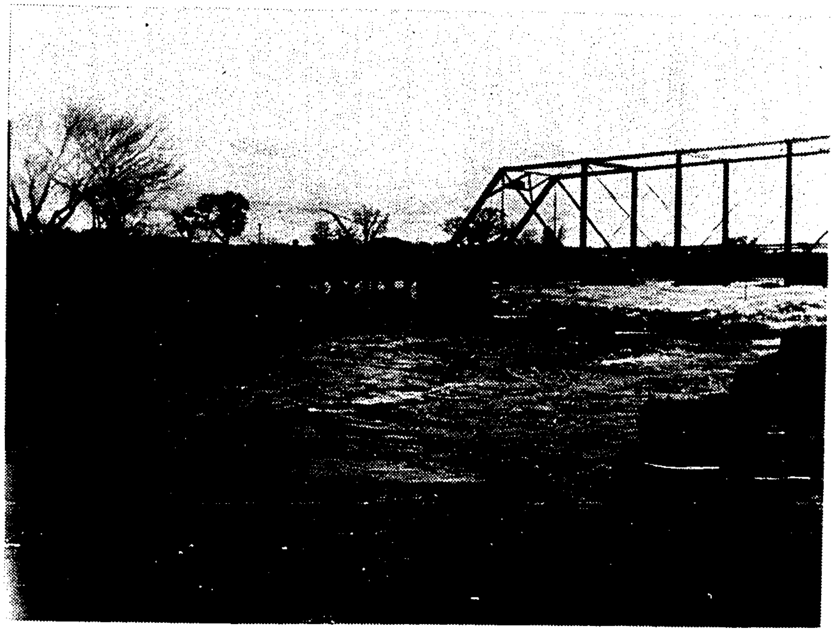


Figure 51. Upstream view of the Congress Street Bridge on the morning of January 31, 1915, as the east approach to the bridge began to give way. Note sinking piers of the bridge (Arizona Historical Society, Tucson, Negative No. 17439).

Figure 52. In this northwest (downstream) view of the 1915 flood, onlookers stand perilously close to the eroding east bank of the Santa Cruz River, just downstream of the Congress Street Bridge. Note undercutting of the east bank at right center of photograph (Photograph by H. Buehman, Arizona Historical Society, Tucson, Negative no. 38373).

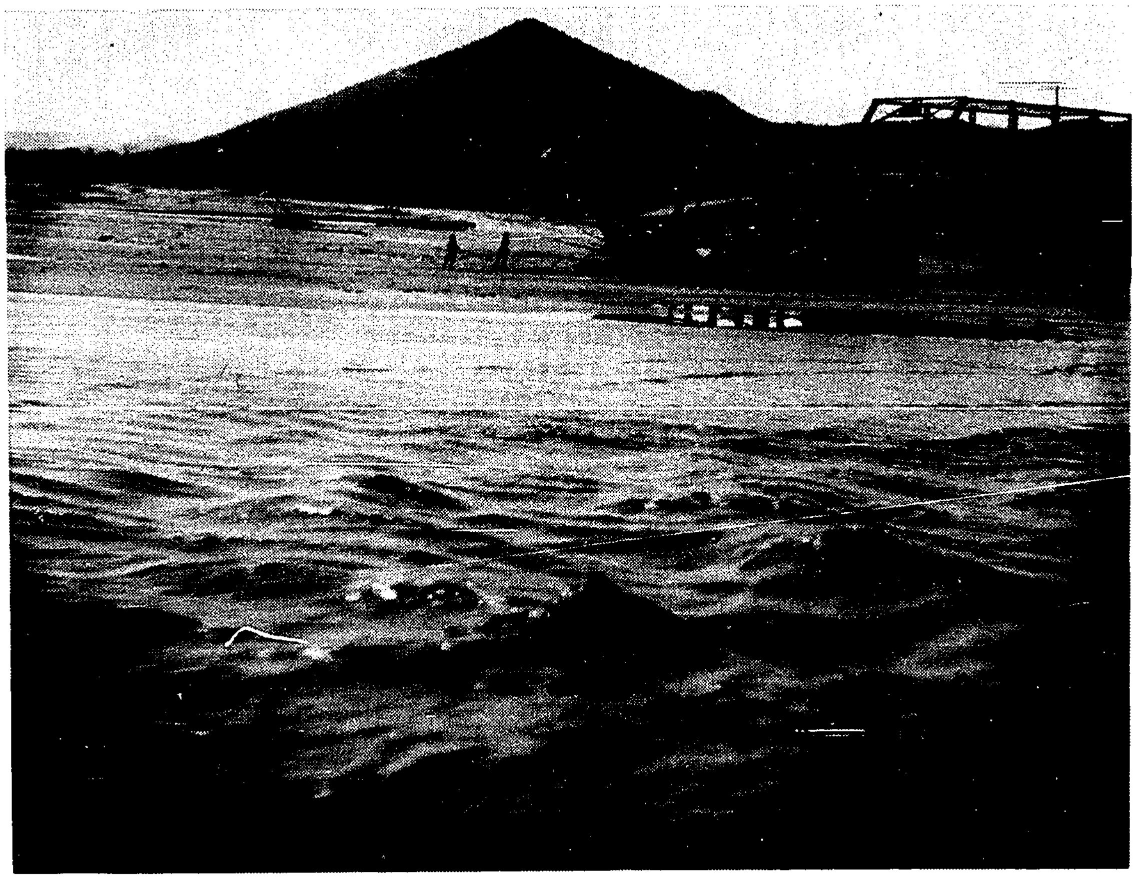


Figure 53. Southwest (upstream) view of Santa Cruz River in flood in February 1915. The thalweg shifted several tens of meters to the west bank, abandoning its former course under the Congress Street Bridge (Photograph by H. Buehman, Arizona Historical Society, Tucson, Negative No. 93468).

Figure 54. The Congress Street Bridge after erosion of east bank in January 1915, looking northwest. The cottonwood stand evident in 1902 (Fig. 29) was completely removed during the 1915 flood (Special Collections, University of Arizona Library, Tucson).

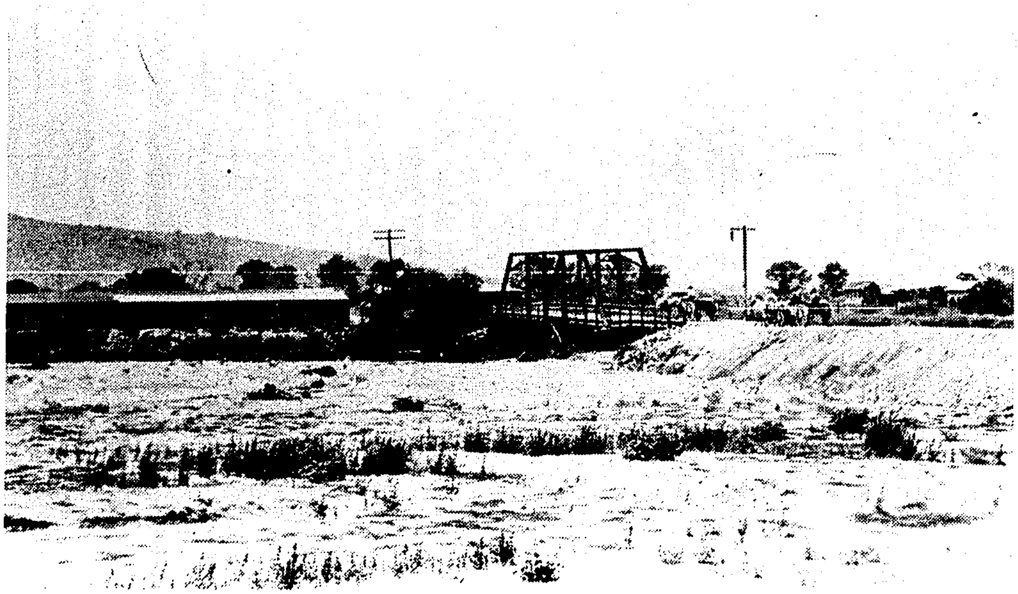


Figure 55. A similar view as Figure 54 in July 1915. A berm was built to join the east approach to the bridge (Special Collections, University of Arizona Library, Tucson).

Figure 56. North (downstream) view of the Santa Cruz River from the Congress Street Bridge in November 1907. Note narrow channel (Photograph by W.T. Hornaday, Arizona Historical Society, Tucson, Negative No. 11669).

Figure 57. Similar view as Figure 56 on July 29, 1916 after the 1915 flood widened the Santa Cruz River channel (Special Collections, University of Arizona Library, Tucson).

Downstream of Tucson, in the alluvial plains near Sasco (Redrock), the floodwaters of the Santa Cruz River spread out to a width of more than 8 km. Near Casa Grande, the overflow is said to have extended from the outskirts of town west to the alluvial fan of the Table Top Mountains, implying an inundated area of up to 15 km wide. As anticipated by Fuller (1913), the engineer for the Santa Cruz Reservoir Company, Greene's Canal eroded to a width of 61 m in places, but much to his dismay and that of company officials, the canal also deepened 6 m or more to form a discontinuous arroyo between the Santa Cruz River and the reservoir. The flood also transformed a sinuous, narrow channel (Figs. 58-59) into a broad system of braided channels near present-day Marana, in some places widening the channel by as much as six times its former width (Hays, 1984).

Upstream of the city, near San Xavier, the diversion dam along the old Spring Branch (SW 1/4 of SE 1/4 of Section 26, T15S, R13E) sustained considerable damage. The effects of the flood were recalled in 1937 by the Supervising Engineer of the Office of Indian Affairs Irrigation Service:

> It should also be kept in mind in connection with the San Xavier irrigation situation that the so-called diversion dam is not really a diversion dam but is a soil conservation dam built with funds allocated for the purpose of preventing further erosion and deepening of the San Xavier River channel in the immediate locality upstream from the dam. We were hopeful, of course, that it incidentally would act also as a diversion dam but in this particular there has been disappointment due to the fact that the largest flood in the history of the Santa Cruz River had to come within a week or ten days after completion of the dam and before the river channel had been adjusted to the change of the grade by normal flood flows. The erosion immediately below the dam as a result of this excessive flood, cut through the underlying clay stratum with a result that a considerable part of the water that heretofore would have been diverted into the canal by this dam flows through the gravel stratum which is below the clay and comes into the river channel below the dam (letter, C.A. Engle to E.W. Kramer, Jr., March 29, 1937).

Figure 58. In March 12, 1910, Ellsworth Huntington, the noted geographer, took this photograph and described it as follows in his unpublished journal, "looking northwest from end of Tucson Mountains [Rillito Peak] at Santa Cruz Valley, now dry, near where this river finally merges into a large playa....The dry channel of the river...here possibly 5 feet [1.5 m] below the terrace (Yale University Library, New Haven; U.S.G.S. Stake 1105).

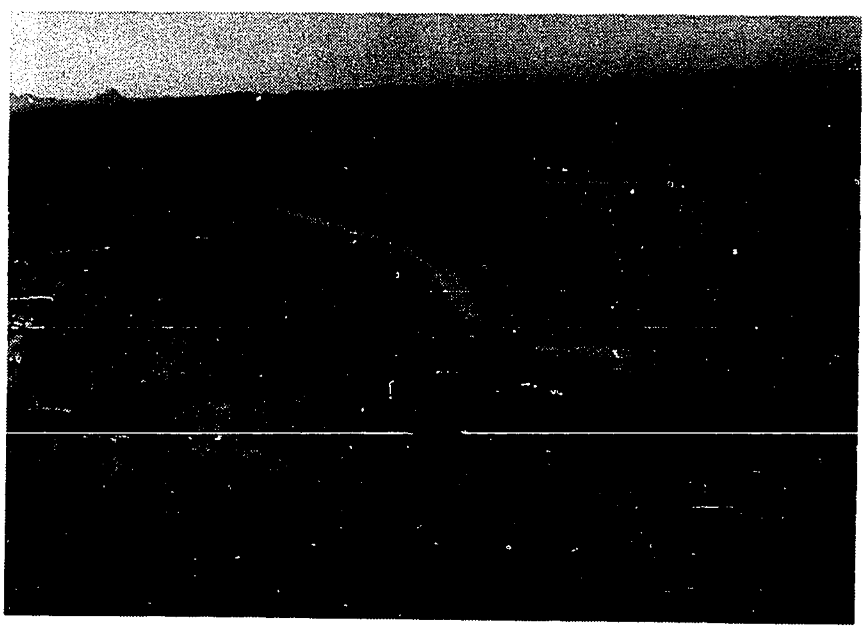


Figure 59. Same view as Figure 58 taken on November 30, 1983. Note the relatively narrow channel at extreme right and the widening that occured to the left of it during the flood of October 1983 (Photograph by R.M. Turner, U.S.G.S. Stake 1105).

Since its inauguration in 1903, the Carnegie Desert Botanical Laboratory on Tumamoc Hill was often cut off from Tucson when the Santa Cruz was in flood stage. The makeshift bridge at the hospital road crossing washed out in 1905 and after the Congress Street Bridge gave way in 1915 the staff had to improvise in fording the river. The correspondence of D.T. McDougal, Director of the Laboratory, reveals some interesting information, including rapid recharge of the water table during winter of 1914-1915:

> The rainfall here has taken such shape that the Santa Cruz has been in flood for a week and taking out bridges, and our only communication with town has been by rider and by wagon fording the river. The thing that concerns you, however, is the rise of the water table, which in this part of the valley amounts to from four to six feet [1.2-1.8 m]. It will probably come higher yet (letter, D.T. McDougal to W.L. Tower, February 4, 1915).

> .... our rainfall here this winter has reached up towards the maximum, and has been distributed in showers in such fashion that the Santa Cruz has been a raging river for the past week.... the water table in the lowlands has come up five or six feet [1.5-1.8 m] in most places (letter, D.T. McDougal to J.H. Harris, February 6, 1915).

> The Santa Cruz River in all of this stretch between the two tips of the mountains has broadened itself this winter and filled its channels with the floods. Do you remember the little old narrow bridge that we crossed in going in and out of town [Congress Street], and the comparatively narrow channel here? This channel was widened this winter by a cut which gives it a width of about three times the old one, and the banks are now not as high. This is true of pretty nearly all of the stretch between here and the tip of the mountain [near Rillito]. We were down to the extreme tip of the mountain two weeks ago and at that time a stream in two channels was going on out into the desert with a comparatively large volume of water, and the cutbank which you photographed and published [Plate 1A in Huntington, 1914], giving a record of its height is now no more than four or five, or possibly six feet [1.2, 1.5, 1.8 m] at any place in that region (letter, D.T. McDougal to Ellsworth Huntington, March 20, 1915).

In the summer of 1916, McDougal was at the Carnegie installation in Carmel, California and was kept informed on events about Tumamoc Hill by Godfrey Sykes. The floods of that summer were frequently the topic of their correspondence:

The Santa Cruz has been on a wild rampage for the last two days and even teams have had a very hard time in crossing, several outfits have been turned over and carried downstream and there have been one or two narrow escapes from drowning. The old long-legged yellow horse has proved to be invaluable as he is mighty reliable under a saddle. Strickland and Spoehr have very wisely not attempted to cross. I got a rig from Davis to bring Shreve across and more or less stood by on the horse to watch development; everything was all right, however, and he brought a very necessary replenishment to the family larder. We have had no rains here to speak of for the last few days but every shower or heavy dew up above maroons us (letter, Godfrey Sykes to D.T. McDougal, August 16, 1916).

The river is down to about six inches [15.2 cm] in depth this morning and so we are resuming normal intercourse with the enemy to our East (letter, Godfrey Sykes to D.T. McDougal, August 21, 1916).

Yours of the 16th and 17th at hand. The Santa Cruz is surely making things exciting and it is getting me in such a frame of mind that I have written two pretty stiff letters -- one to Estill and one to Cochran. I have noticed your genial effusions in the *Citizen*, but am inclined to believe that these gentlemen are so thick skinned that nothing but a tap on the jaw will bring them to (D.T. McDougal to Godfrey Sykes, August 23, 1916).

I went over to town yesterday afternoon.... I got caught again by the river, which came up in a few minutes to almost swimming deep. I was of course obliged to leave the car over there and had to get a long-legged team from Sam Davis, with a very badly scared Mexican driver, to bring me across again. The water went down again pretty well before night, but we heard that it is up pretty big again this morning and so I am going over on the old horse to get the mail. It is a beautiful state of affairs, isn't it? (letter, Godfrey Sykes to D.T. McDougal, August 24, 1916).

The news about the river is interesting scientifically but distressing in a business way. I have decided to go after the supervisors [to build a bridge] and have already had some correspondence with them. The latest from Estill is enclosed, also my reply. I am, as you will see, taking the ground that we shall hold our plans in abeyance until we see whether they are really going to give us decent communication with town. I am going after blood and meanwhile, perhaps it would be just as well not to write any more for the paper in your genial, sarcastic way or they may think we do not mean it (letter, D.T. McDougal to Godfrey Sykes, August 28, 1916).

Guayule, Cotton and the WPA: Events up to World War II

In July 1916, L.H. Manning sold the north half of the Canoa land grant to the Continental Rubber Company, which tried to grow guayule (*Parthenium argentatum*) for the manufacture of synthetic rubber. At about the same time, Manning encouraged the McGee colony of Mormons to settle on tillable lands. The remaining acreage of the Canoa property became a renowned breeding ranch for thoroughbred beef stock and Arabian horses in the 1920s. By 1920 approximately 450 ha of guayule were under irrigation. Later that year, the post-World War I drop in the price of rubber cut into the guayule profits and the farm was abandoned (Schwalen and Shaw, 1957).

In 1921, the Tucson Water Company expanded its system by drilling three wells east of the University. In June 1922, the newly-formed Flowing Wells Irrigation District assumed control of the Tucson Farms Company Crosscut. The Company's land just north of San Xavier were sold to Midvale Farms. Anticipating encroachment by Tucson, Papagos attempted to secure their water supply on the San Xavier Reservation in 1925:

> Completion of new gravity irrigation system will enable Papagos to abandon temporary pumping system installed by the government after 1914 when the erosion of the Santa Cruz River lowered the water level of the stream until the water would no longer flow over the Mission fields by gravity. Installation of a 30 in [76.2 cm] infiltration gallery.... will deliver 4500 gpm (912,550 lpm). Prior to the erosion of the river bed in 1914 the Santa Cruz was a very small and narrow channel, in many places not even well defined, and Indians secured gravity water for the irrigation of their lands by diverting the steady flow of the small stream above the Mission into irrigating ditches. The river at this point, due to an underground natural dyke that extends across the floor of this section of the Santa Cruz Valley from Black Butte, which lies to the west of the Mission, along a series of outcropping hills to another large rise on the east of the river bank, has always provided a flowing stream (*Arizona Citizen*, April 3, 1925).

The relatively wet summers of 1919, 1921, and 1923 were followed by prolonged drought through 1930, though occasional floods such as in November 1926 (Figs. 60-61) and late September 1929 were reported. On the San Pedro River, a tropical storm in September 1926 produced the largest peak

Figure 60. Santa Cruz River in flood, November 1926, showing road embankment on the east approach from Congress Street. As is customary for normally-dry rivers such as the Santa Cruz, the flood attracted a crowd of onlookers (Arizona Historical Society, Tucson, Tucson, Negative No. 28765; U.S.G.S. Stake 1084).

Figure 61. Same view as Figure 60 taken on September 12, 1983. The new bridge was constructed in 1972. The channel has been narrowed artificially, eliminating the embankment on the east approach. This narrowing contributed to renewed downcutting and a considerable lowering of the streambed in the period from 1950 to 1980. Note soil-cemented east bank (Photograph by R.M. Turner, U.S.G.S. Stake 1084).

on record in southern Arizona, estimated at 2830 cms near Charleston. Except in the headwaters, this storm had minimal effect on the Santa Cruz. However, floods in September 1929 destroyed the bridges at St. Mary's Road and at Continental. At Congress Street, the crest of the flood rose within 1 m of the top of bridge (*Arizona Daily Star*, September 24 and 25, 1929). The same tropical storm produced the second highest peak of record on the Rillito River (680 cms). On August 10, 1931 flooding was again reported along the Santa Cruz. Figures 62-69 show the condition of the channel upstream of Congress Street in the 1910s and 1920s

During World War I, Edwin R. Post purchased vast acreage in the floodplain between present Marana and the Rillito-Santa Cruz confluence. The Post Project, with headquarters at Cortaro, emulated the Tucson Farms Company in an attempt to lure immigrant farmers by drilling ten new wells and emphasizing the lucrative market in cotton. At the end of the war, cotton prices plummeted and several Post Project farmers went bankrupt. The project was eventually transferred to the Pima Farms Company and later to Cortaro Farms. By 1930, the cotton market had improved and land was leased to farmers on a share-crop basis. Pumping took its toll on ground water in the northern part of the Tucson Basin from 1920 to 1930, a trend that was arrested by the Great Depression:

> On the Cortaro Farms Project around Cortaro, Rillito and Marana, the water supply has apparently been overdrawn, as the water level has lowered since irrigation was started. The acreage under cultivation on this project has been decreased recently, and if it is held at or below the present acreage, the water supply will be sufficient (Youngs, 1931, p. 46).

In 1931, the U.S. Senate conducted extensive hearings concerning Tucson's plans to draw from the water supply on the San Xavier Reservation. Development of water by non-Indians on the reservation would require an Act

Figure 62. View south from summit of Sentinel Peak in 1919, looking upstream along the Santa Cruz River. Note the Tucson Farms Company Crosscut running from left to right across center of photograph. The entrenched channel of the West Branch is in lower right (Photograph by Godfrey Sykes, Arizona Historical Society, Tucson; U.S.G.S. Stake 1306).

Figure 63. Same view as Figure 62 on January 6, 1988. Note bank stabilization with soil cement and the modified confluence of the West Branch and the Santa Cruz. The bridge in the foreground is 22nd Street, which was routed across the former site of Warner's Lake (Photograph by R.M. Turner, U.S.G.S. Stake 1306).

Figure 64. View from Sentinel Peak on May 30, 1927, looking east across Santa Cruz River. The east bank is visible across bottom of photograph. Note secondary mesquite growth across formerly cultivated fields. Photograph is part of a panorama, which includes Figures 64-69 (Photograph by Norman Wallace, Arizona Historical Society, Tucson, Negative No. 518; U.S.G.S. Stake 1307d).

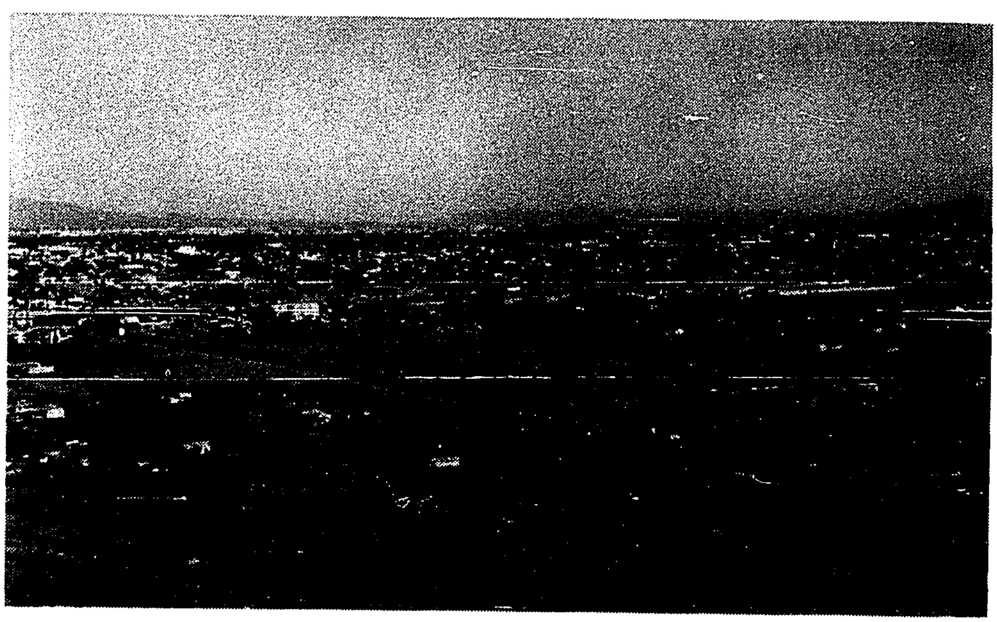


Figure 65. Same view as Figure 64 taken on October 6, 1987. Soil-cemented banks of the Santa Cruz River are visible across bottom of photograph and 22nd Street in center (Photograph taken by R.M. Turner, U.S.G.S. Stake 1307d).

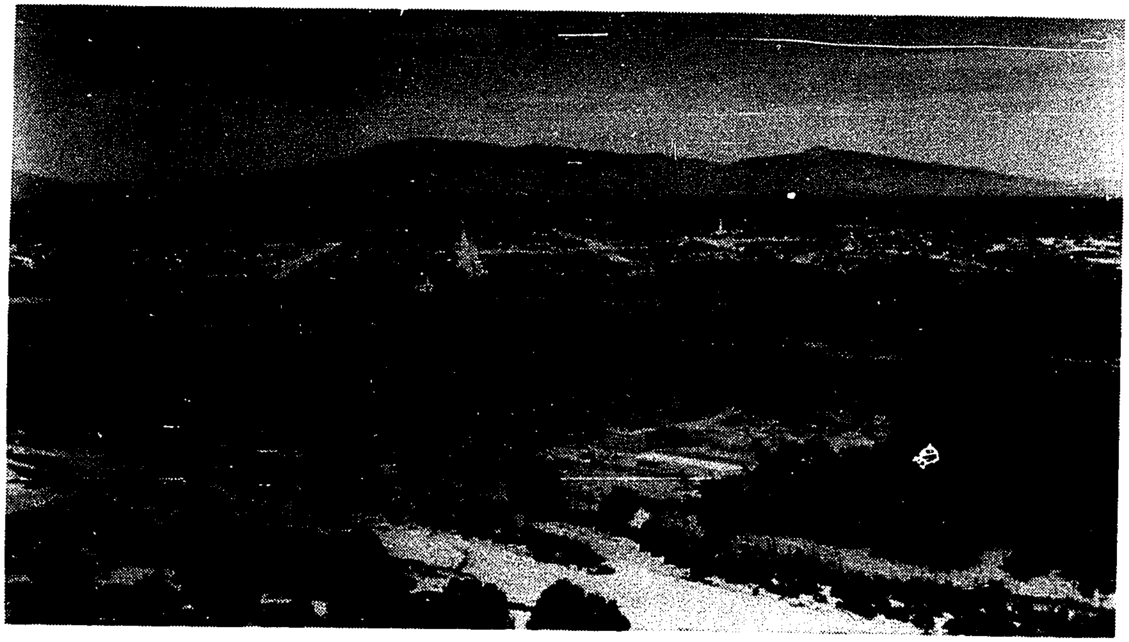


Figure 66. View east-northeast from Sentinel Peak on May 30, 1927, with Santa Cruz River in foreground (Photograph by Norman Wallace, Arizona Historical Society, Tucson, Negative No. 522; U.S.G.S. Stake 1307c).

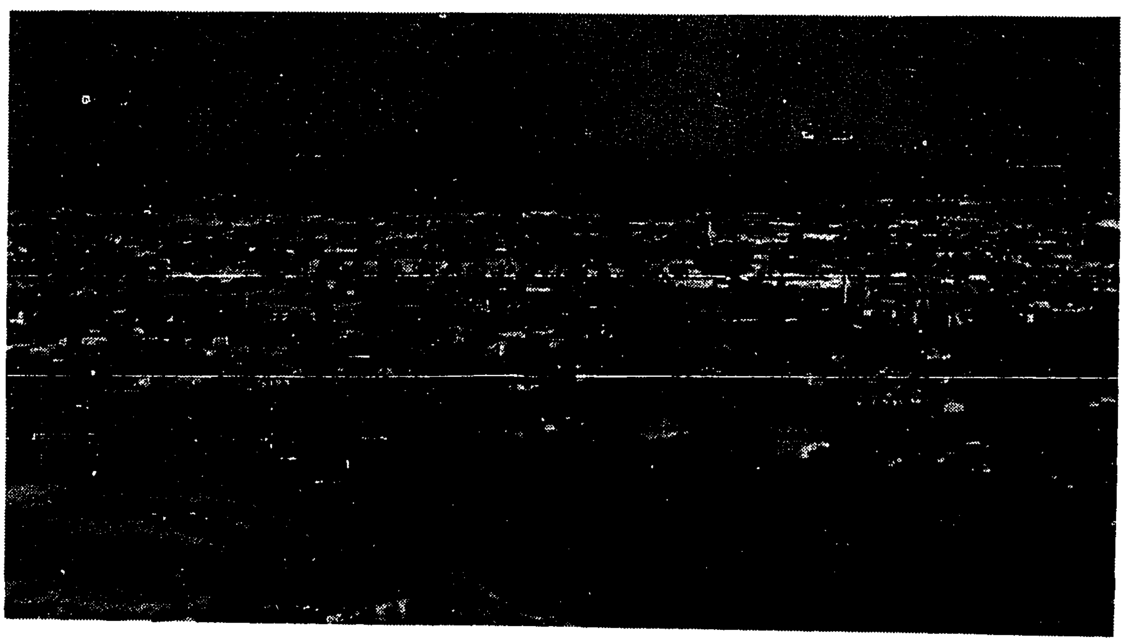


Figure 67. Same view as Figure 66 on October 6, 1987 (Photograph by R.M. Turner, U.S.G.S. Stake 1307c).

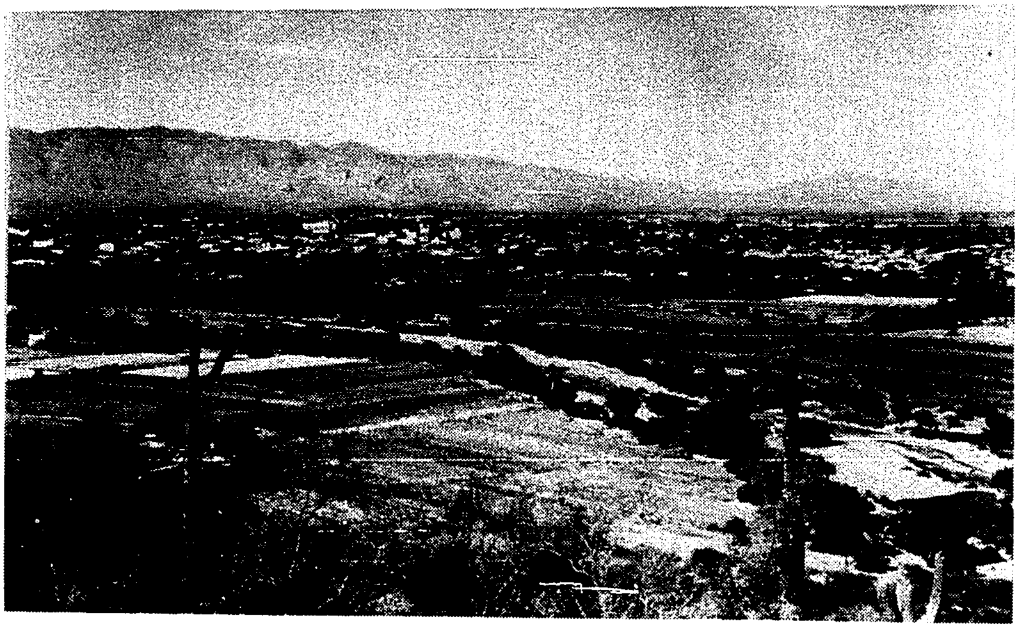


Figure 68. View northeast from Sentinel Peak on May 30, 1927 with Santa Cruz River running from right to left (Photogrpah by Norman Wallace, Arizona Historical Society, Tucson, Negative 502; U.S.G.S. Stake 1307b).

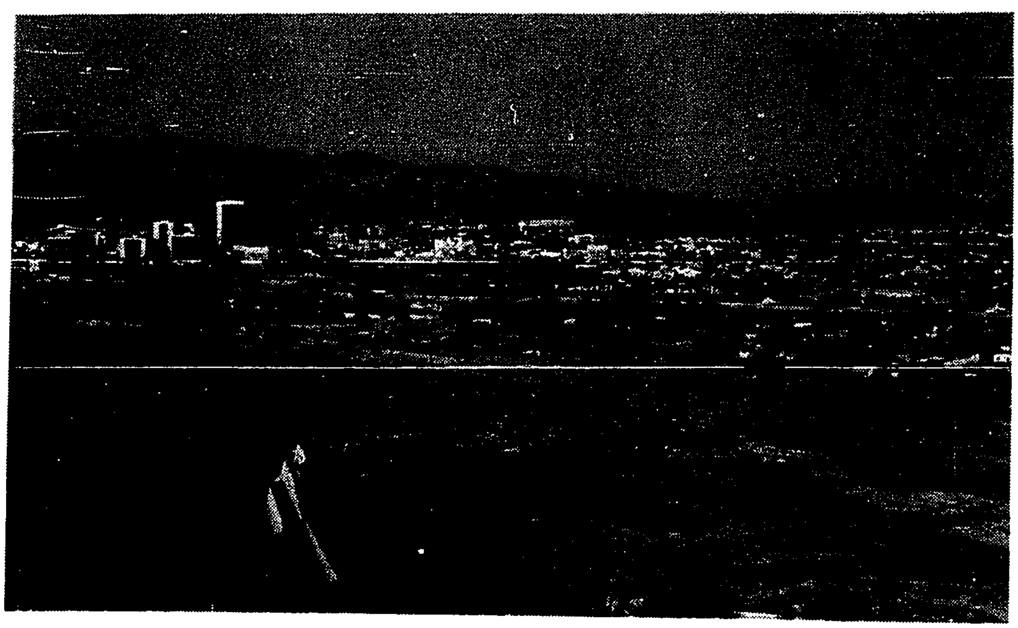


Figure 69. Same view as Figure 68 on October 6, 1987 (Photograph by R.M. Turner, U.S.G.S. Stake 1307b).

of Congress, but the idea was rejected on the strong objections of the Chief Irrigation Engineer at San Xavier. C.K. Smith, then mayor of Tucson, testified that:

> The city of Tucson has been scouting for some time to get a larger and more available water supply for the city. Our engineer employed for the purpose of finding what the available sources of water were came to the conclusion that the Santa Cruz Valley carries from its watershed the largest and most valuable source of water for Tucson. We are a growing community. We have an adequate supply for the present but we must look forward to the future. Eight or nine miles [12.8-14.4 km] up the river is the Indian Reservation. Two mountains come very close together and an underground formation or a ledge has formed for miles back and there is a water-bearing sand to such an extent that it often flows over between these two mountains. It is the most available place for water in the entire river course. Now, I want to offer a tentative plan that might be of benefit to the Indian Service and also to Tucson. Our engineers have investigated the claim that there is more water than the Indians can ever use and more than Tucson can use for 50 years to come (United States Senate, 1931, p. 8347).

In the early 1930s, the Works Projects Administration (WPA) focused its large work force on flood control along the river. In large measure, the recommendations of H.C. Schwalen, a hydrologist at the University of Arizona, were followed. According to Schwalen, sharp meanders in the channel subject to erosion could be eliminated by excavation of new channels through sand and gravel bars. The overburden should be piled on the lower side of the bars. Projecting points along the channel should be removed along with trees and other vegetation growing in the channel. The WPA implemented these recommendations for the Santa Cruz between San Xavier and Congress Street:

> Six long pilot channels were constructed across some of the more severe bends, the current being deflected into these channels by means of deflectors or revetments. These revetments were constructed of automobile frames in instances where the pressure was excessive and of double and triple lines of hog wire fence with posts of boiler tubes filled with cement. Current is deflected away from the big bends by means of boiler tube and hog wire fences placed in such a manner that the river current would do the greater portion of its own cutting, thus eliminating a great deal of the unnecesary labor. Projecting points were shaken up with dynamite so that they will be carried away

> by the first heavy flood. All heavy bends have been protected with tree planting behind jetties and revetments. Trees have also been planted along the entire river at points where it was desirable to maintain and hold existing banks. A recent survey indicates that about 95% of the trees planted have taken root and are growing (Baker, 1935, p. 3).

The revetments built by the WPA were sucessful and in several cases, they are now buried by point bars as originally intended (Figs. 70-71). The WPA works and low flow conditions probably explain why ratings at Congress Street showed a nearly constant zero flow elevation from 1929 to 1946 (Aldridge and Eychaner, 1984).

In 1936-37, the Soil Conservation Service (SCS) effected a survey of the entire Santa Cruz Valley, using aerial photography as the primary data base. Preliminary results served as a springboard for yet another investigation of water resources within the San Xavier Reservation. Because of a lack of water and accelerated erosion in agricultural fields, a large number of Papagos had turned from crops to fuelwood. A concerted attempt to develop new water and arrest erosion was attempted to encourage a return to farming on the reservation.

A major concern of the SCS was the growth of agriculture in the lower Santa Cruz Valley. In 1937, irrigated land from the international border to the Rillito confluence amounted to only 9000 ha, compared to 40,000 ha from the Rillito to the Gila (Knapp, 1937). This was a complete reversal from the agricultural dominance of the upper Santa Cruz before the turn-of-the-century. Development of a well-defined channel in the Tucson Basin also shifted hazards from flood inundation downstream. F.H. Knapp, a local engineer, reported that:

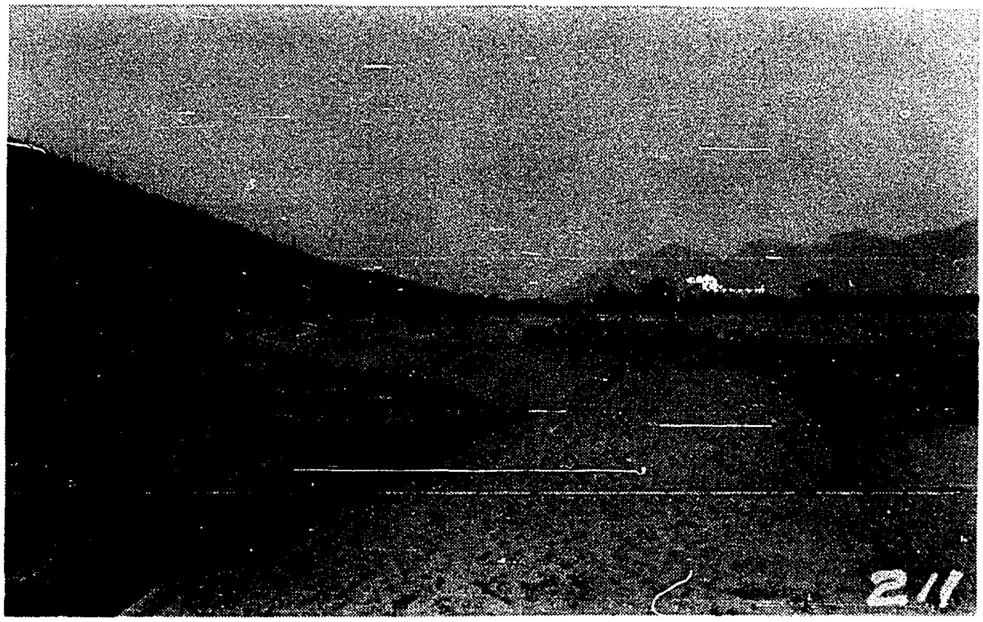


Figure 70. In 1935, the Works Projects Administration (WPA) constructed several flood control features along the Santa Cruz River River. In the reach just south of Sentinel Peak (left), the river's flow was deflected into pilot channels by means of revetments, in this case fashioned from old automobile frames (right). By the following year, summer flows had filled the area behind the revetment with about 1 m of sediment. The intent was to eliminate sharp meanders and to reclaim the areas they incorporated for cultivation (Photograph by R.C. Baker, State of Arizona Archives, Phoenix, U.S.G.S. Stake 1074).

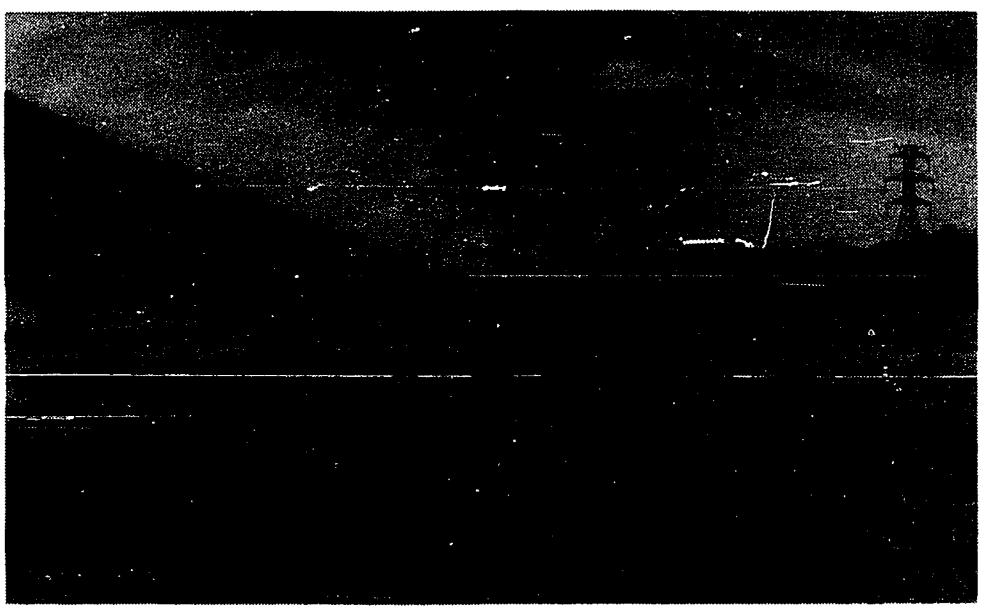


Figure 71. Same view as Figure 71 on May 11, 1982. The WPA measures were largely effective in eliminating the sharp meanders (Photograph by R.M. Turner, U.S.G.S. Stake 1074).

> The Santa Cruz above its junction with the Rillito has a deep, well-defined channel still in process of some bottom cutting in the immediate vicinity of Tucson. The Rillito, on the other hand, and the Santa Cruz below its junction are undergoing deposition of sand in the stream bed and, consequently, widening of the channel and changing of course-- This is aggravated by poorly located bank defense works built for local protection without regard to a comprehensive plan, and a crooked and meandering alignment.... As to deposition of the silt burden, most of the fine silts of the main stream find their way to the [Santa Cruz Plains], a part going with diverted water to the irrigated lands, the rest spread over the uncultivated plains. The larger part of the coarser sands are being deposited at a point about 2 miles [3.2 km] upstream from the road bed of the old Silver Bell Railroad near Sasco. General leveling of the plains is taking place here, resulting in the termination of the well- defined channel [the arroyo at Greene's Canal, Fig. 47] which moves upstream (report from 1/4 mile [0.4 km] to 1 mile [1.6 km] in past 10 years). Additional heavy silting is taking place upstream from this channel end [headcut] all the way to the mouth of the Rillito (Knapp, 1937).

On September 21 and 22, 1937, the War Department held flood control hearings at Casa Grande, Tucson, and Nogales, surely related to nationwide efforts to curb flood losses during the Depression years. The principal issues were the increase in flood hazard over past years, particularly to agricultural pursuits in the lower Santa Cruz Valley, and clear recognition that something like the 1914-15 flood would leave damages amounting to millions of dollars. Knapp and other local engineers recommended construction of a large dyke across the valley that would intercept a record flow with ample spillway to carry the overflow down the arroyo at Green's Canal to what used to be the Santa Cruz Water Company reservoir. One feature of the project was to prevent further headcut migration. At least the latter had been successful until recently.

By 1940, the old wagon road between Tucson and Nogales had eroded into a deep channel on the west side of the valley south of San Xavier (Section 25, T16S, R17E, Figure 10C). This channel would later erode upstream to capture the main flow of the Santa Cruz and complete the rerouting of the Santa Cruz to its present course in the valley.

On August 13, 1940 a storm of wide areal extent, uniformly heavy rainfall and high intensity affected the entire Santa Cruz watershed. Considerable damage was reported along Tucson Arroyo and in downtown Tucson. The Crosscut along the Santa Cruz was destroyed by the flood and subsequently abandoned.

Ground-water pumpage began to seriously dewater the Tucson Basin aquifer after 1940. Over 4 billion cubic meters of water were withdrawn from the aquifer in 1940-65 (Davidson, 1973). In 1940, the water table near Martinez Hill and Sentinel Peak was still within a few meters from the surface of the floodplain. The ecological consequences of lower water tables are illustrated in Figures 72-73. The cottonwood galleries and mesquite bosques south of Martinez Hill, a popular picnic spot for Tucsonans in the 1930s and 1940s, died out leaving the floodplain treeless. Ground-water overdraft also eliminated the influence of a near-surface water table in limiting channel downcutting. As a consequence, degradation propagated upstream to as far as Continental (Figs. 74-75). In the immediate Tucson area, the rate of downcutting was probably influenced by urbanization of the floodplain, especially its use as a landfill.

The city burned its garbage during the 1940s at an incinerator on the east bank of the Santa Cruz at St. Mary's Road. Since the incinerator closed in 1950, several million metric tons of garbage have been dumped either in the channel or on the adjacent floodplain. Between 1953-1962, the main landfill was at the base of Sentinel Peak, from the former site of the old San Agustin Mission upstream to that of Warner's Lake (Figs. 76-77). This landfill covered about 9 ha to an average depth of 15 m, in one case completely filling in the channel of the West Branch near the confluence with the Santa Cruz. Another inner city landfill was created at Congress Street, engulfing the channel widened by the 1915 flood (Figs. 78-79).

Landfills have also been operated near the former site of Silver Lake, near the confluence of the Rillito River and Cañada del Oro with the Santa Cruz, and at Marana. Landfills, bridge construction, urbanization of the floodplain, and sand and gravel mining of the river bed (Bull and Scott, 1974) have constricted the channel and promoted bed degradation. The elevation of zero flow at Congress Street dropped 3 to 4.5 m between 1946 and 1980 (Aldridge and Eychaner, 1984). Similar downcutting is evident in comparing photographs from the Rillito confluence (Figs. 80-81) to Continental (Figs. 74-75), taken in the 1940s and 1980s.

In effect, the formation of an arroyo, by improving drainage through the city, paved the way for urbanization of the Santa Cruz floodplain (Figs. 82-84). The land was no longer suitable for agriculture, but its proximity to the inner city made it valuable real estate for both housing and industrial developments. Much of this development has occurred piecemeal and without proper planning. Much of it also occurred during a period of low flow conditions and before local authorities could respond to federal legislation concerning floodplain hazards.

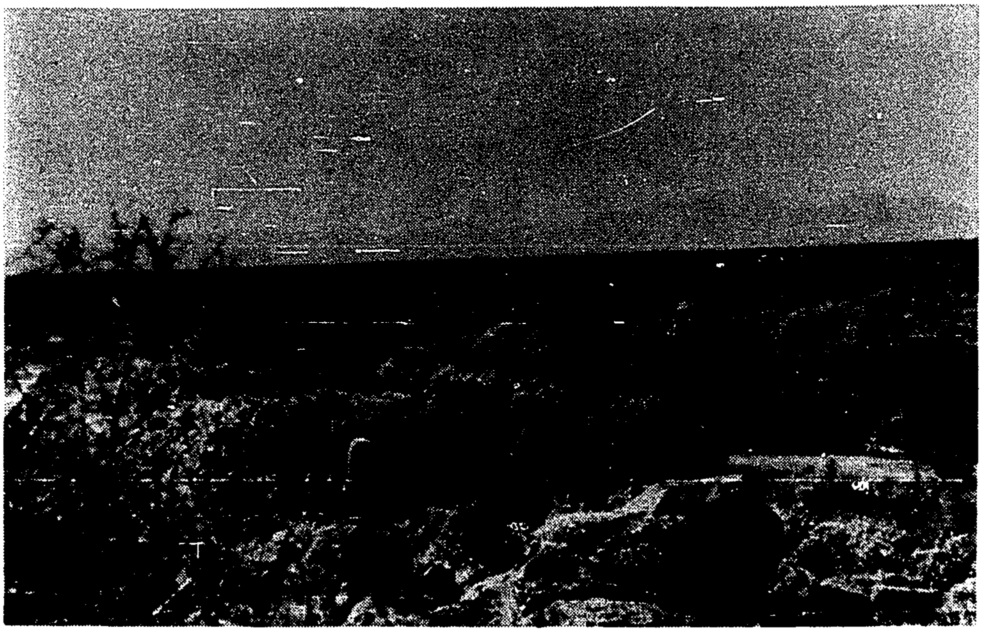


Figure 72. South view from Martinez Hill in June 1942. A gallery of cottonwoods flanks the river channel and dense mesquite occupied the bottomlands, then a haven for nesting and roosting whitewing doves. As late as 1942, one could dig by hand and find water in the streambed (Arizona Game and Fish Commission, Phoenix; U.S.G.S. Stake 937).

Figure 73. Same view as Figure 72 on May 29, 1981. Note the broad river channel and badly denuded bottomlands. The latter resulted from a considerable drop in the water table since 1940 (Photograph by R.M. Turner, U.S.G.S. Stake 937).

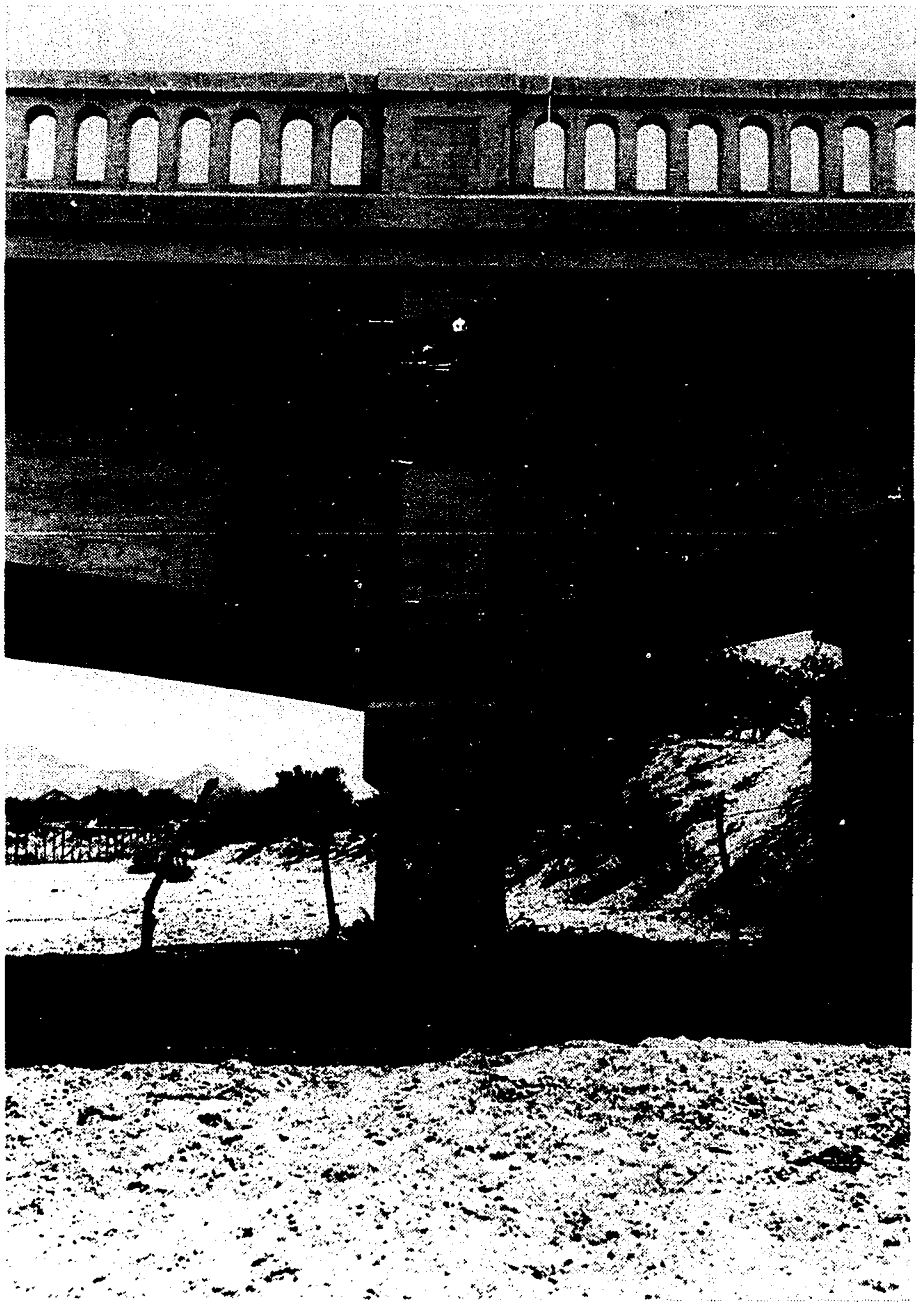


Figure 74. Upstream view of the Santa Cruz River bridge at Continental on June 4, 1940 (U.S.G.S. Stake 940).

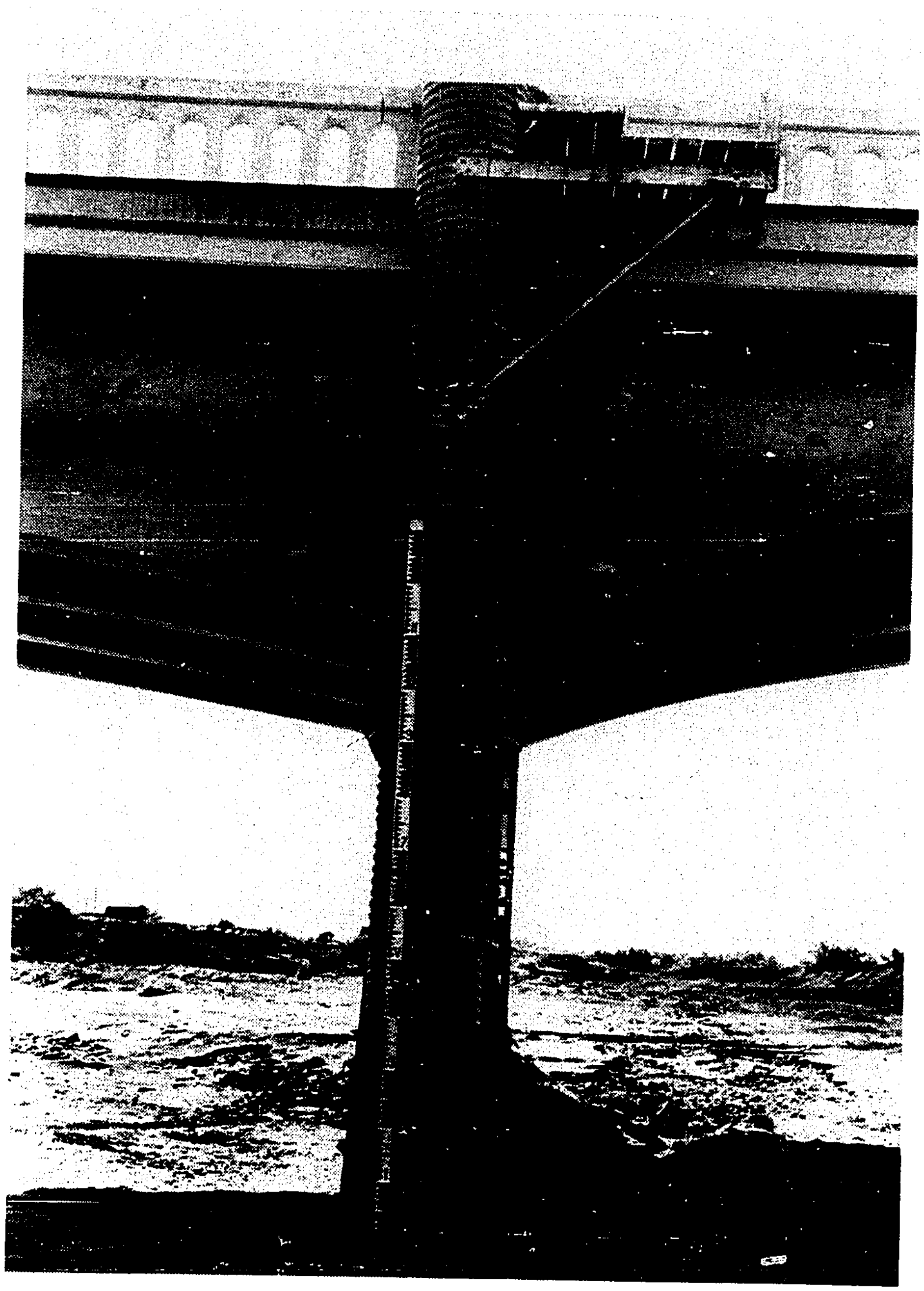


Figure 75. Same view as Figure 74 on November 16, 1978, showing deepening of the channel by ca. 1 m, as indicated by the exposed pier (Photograph by R.M. Turner, U.S.G.S. Stake 940).

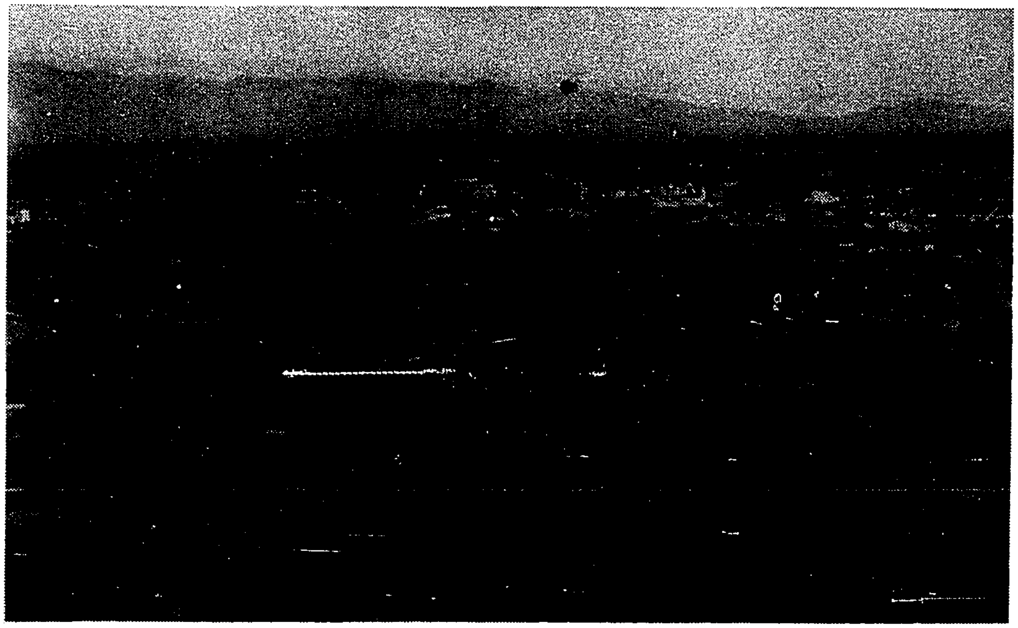


Figure 76. East view of the Santa Cruz River Valley and Tucson from Sentinel Peak in 1932. The river runs from right to left across center of photograph, with the Congress Street Bridge at far left. Note the broad entrenched channel lined with cottonwoods. Solomon Warner's house and the ruins of his mill are in lower left corner (Arizona Historical Society, Tucson, Negative No. 26758; U.S.G.S. Stake 1044).

Figure 77. Same view as Figure 76 on July 8, 1981. Since 1950, landfill operations and construction of an interstate highway have constricted the channel. Much of the floodplain surface has been elevated by landfill, in some places by 2-3 m. The only non-elevated part of the floodplain is the former Mission garden in the lower center of both photographs (Photograph by R.M. Turner, U.S.G.S. Stake 1044).

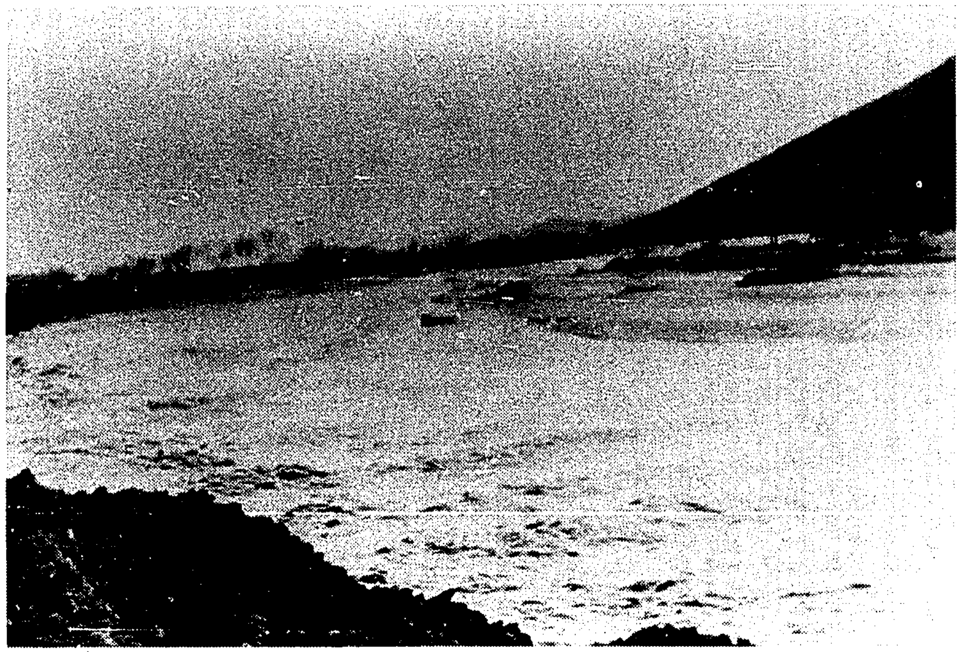


Figure 78. Southeast view of the Santa Cruz River, looking upstream from a point just south of the Congress Street Bridge. This photograph shows the sweeping meander along the east bank, as it eroded on January 31, 1915 (Special Collections, University of Arizona Library, Tucson, Negative No. 6518; U.S.G.S. Stake 1067).

Figure 79. Same view as Figure 78 on February 26, 1982. Landfill operations, which began in 1950, have narrowed the channel and thus promoted further downcutting (Photograph by R.M. Turner, U.S.G.S. Stake 1067).

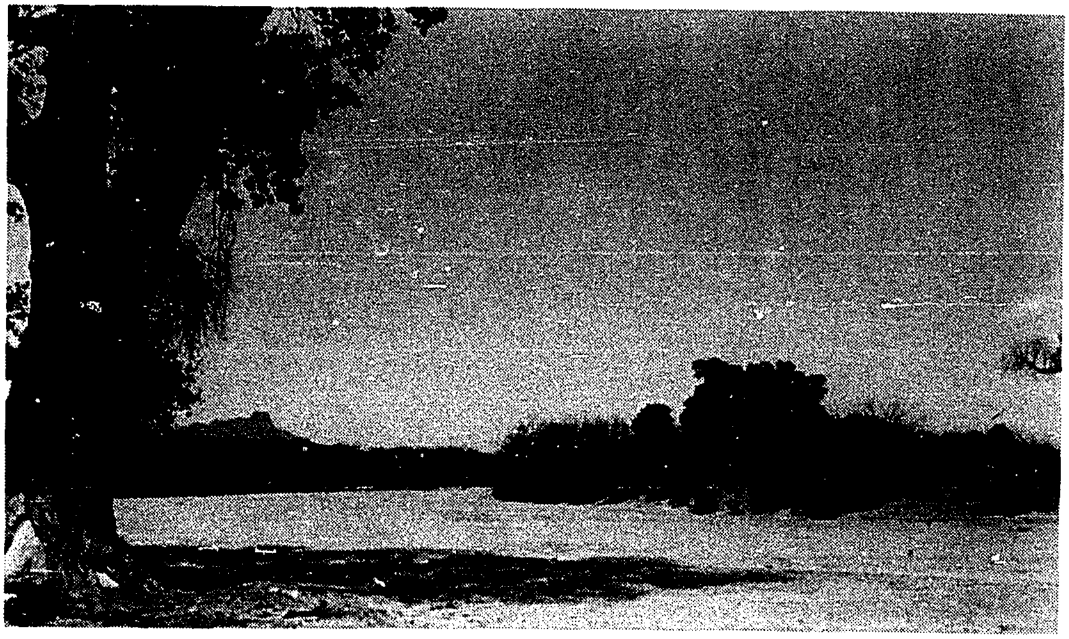


Figure 80. Downstream view of the Rillito-Santa Cruz River confluence, looking north in 1939 (Special Collections, University of Arizona Library, U.S.G.S. Stake 1102).

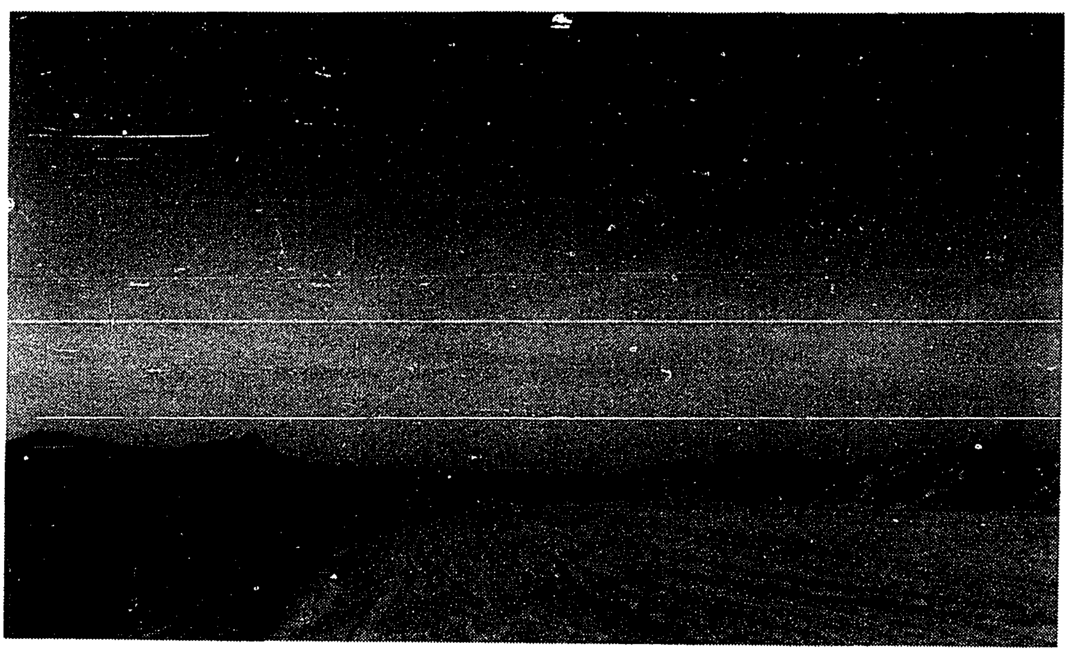


Figure 81. Same view as figure 80 on November 9, 1983. Note entrenched banks and the general lack of vegetation, compared to 1939 (Photograph by R.M. Turner, U.S.G.S. Stake 1102).

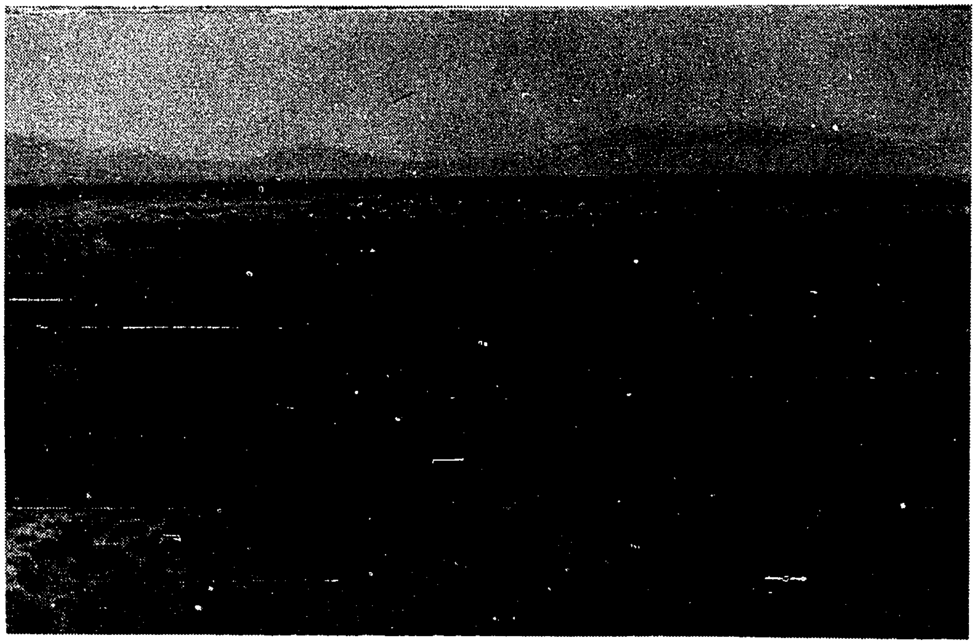


Figure 82. East view of Congress Street and the then active floodplain of the Santa Cruz River, taken from West Congress Terrace in the 1890s (Photograph by George Roskruge, Arizona Historical Society, Tucson, Negative No. 46397; U.S.G.S. Stake 1061).

Figure 83. Approximate view as Figure 82 in the 1930s. Entrenchment of the Santa Cruz arroyo enhanced drainage and thus encouraged urbanization of the inactive floodplain (Photograph by Ed Ronstadt, Special Collections, University of Arizona Library, Tucson, U.S.G.S. Stake 1061).

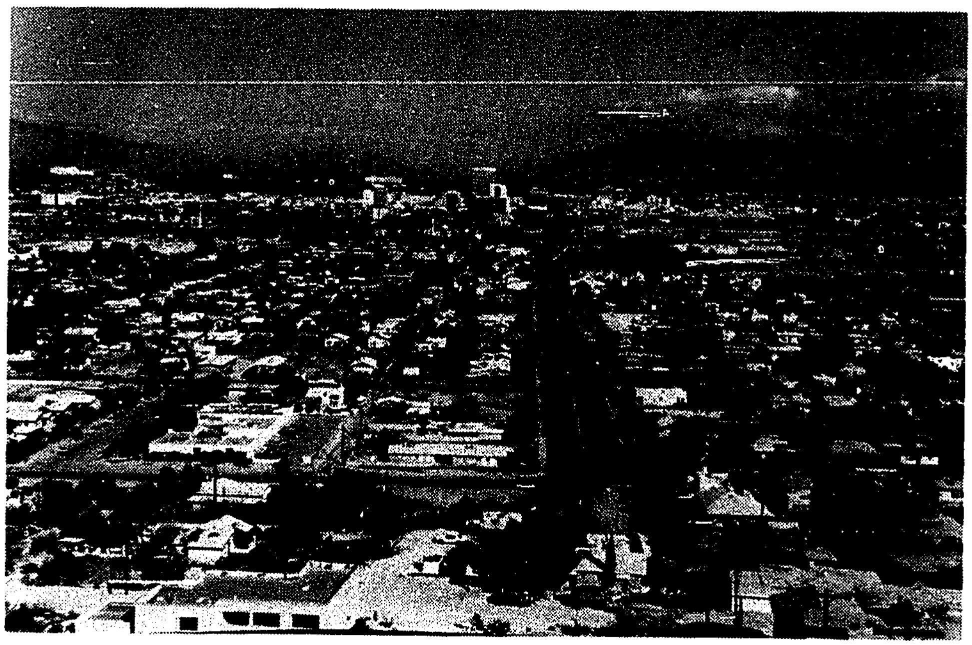


Figure 84. Same view as Figure 83 on February 26, 1982. The once-active floodplain is now completely urbanized within the downtown Tucson reach (Photograph by R.M. Turner, U.S.G.S. Stake 1061).

CHAPTER 7: TAMING OF THE ARROYO- FLOODS AND FLOOD CONTROL IN AN URBANIZED FLOODPLAIN

> The 100-year flood has come and gone, so, by all rights, Tucsonans should enjoy another century of great Southwest weather (message sent to national media by Metropolitan Tucson Convention and Visitor's Bureau after the flood of October 1983; cited in Saarinen et al., 1984).

For modern Tucsonans, many who hail from areas where even the smallest creek flows year-round, the Santa Cruz River was little more than a dry trench lined with the city's garbage. To county and city officials entrusted with local floodplain management and aware of the arroyo legacy, the river had become an accident waiting to happen. On September 12, 1981 the *Arizona Daily Star* echoed the conclusions of a preliminary report by the U.S. Army Corps of Engineers that, "damage would total at least 321 million dollars if a 100-year flood hit the Tucson area."

In a way, Tucson's attitudes towards flood hazards had been lulled by low flow conditions in the two decades before and after World War II. There had been no large floods like those in 1887, 1890, 1905, and 1915. The flood peak of December 23, 1914 was not exceeded until August 1961; it was exceeded again in December 1968, October 1977, and most dramatically on October 1 and 2, 1983 (Fig. 85). The 1983 event was 3.5 times greater in magnitude than the 1914 peak, 2.4 times greater than the previous flow of record (1977), and 2.3 times greater than the previously estimated 100-year flood. The flood damage throughout Arizona was estimated at half a billion dollars.

The 1983 flood redefined flood hazards along the Santa Cruz River. In the long run, this singular event also may influence national perception of floodplain management on ephemeral streams in the Southwest. It has spurred reevaluation of the critical assumption of stationarity that underlies recommended methods of flood frequency analyses to determine design and

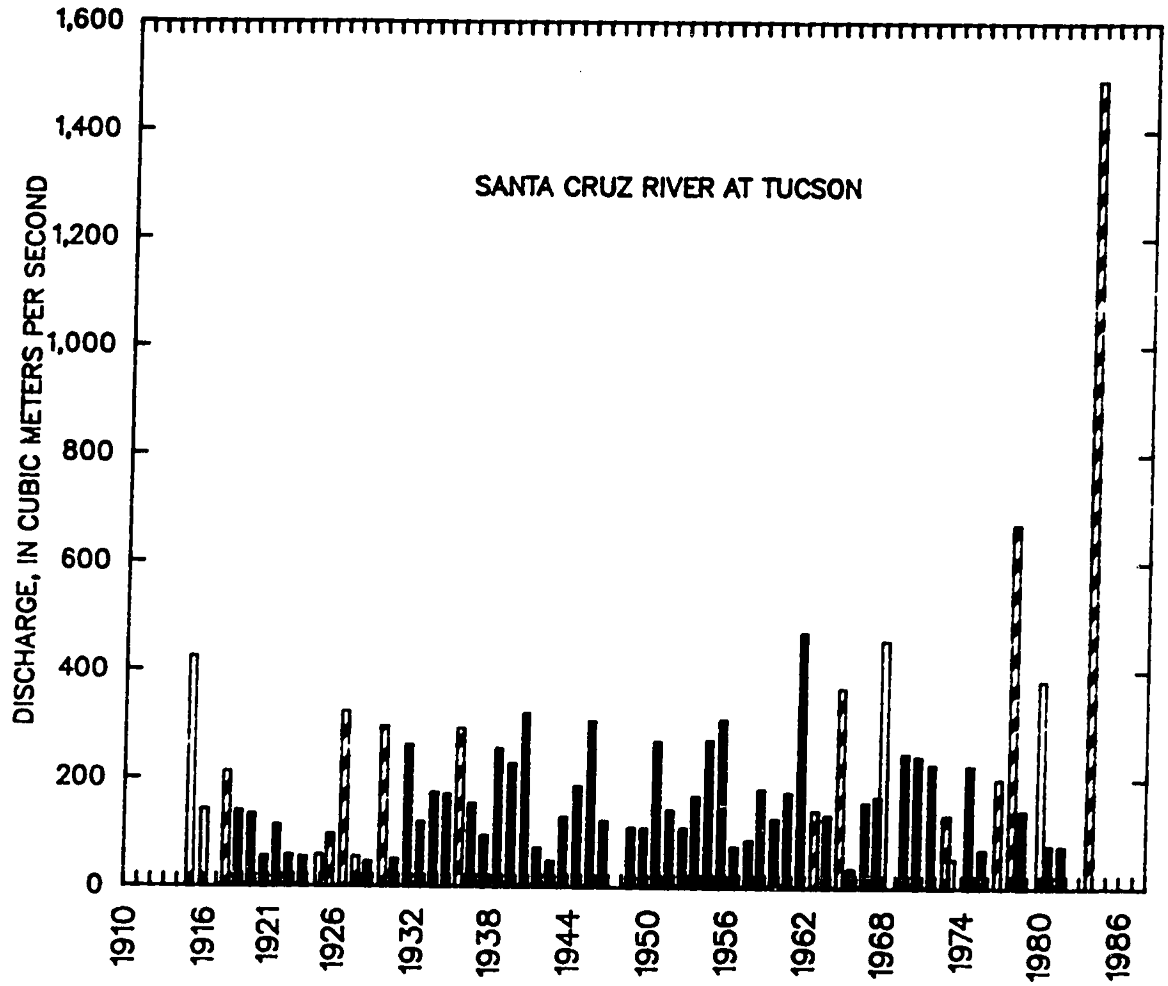


Figure 85. Annual peak discharge at the Congress Street gage, Santa Cruz River at Tucson. Open bars denote winter peaks (November through February), closed bars for summer peaks (June through August), and candy-striped bars for fall (September through October).

regulatory floods (Baker, 1984; Hirschboeck, 1985; Ponce et al., 1985; Reich, 1984, 1985; Saarinen et al., 1984; U.S. Geological Survey, 1985; Zeller, 1984).

Flood Frequency and Floodplain Management

In the 1970s, local authorities were making every effort in responding to federal floodplain legislation. The National Flood Insurance Act had been passed by Congress in 1968. This piece of legislation offered below-cost property insurance for buildings in flood-prone areas. These insurance subsidies were an inducement for local authorities to restrict new construction in the most risky areas and compel the use of better siting, design and construction practices. The gamble was that the subsidies would cost the National Treasury less than the disaster-relief grants and reconstruction loans handed out after floods. In 1973, Congress raised the stakes by passing the Flood Disaster Protection Act. Communities not participating in the National Flood Insurance Program were now ineligible for Federal disaster relief. Federally-insured lenders had to require borrowers to purchase flood insurance for loans secured by floodplain property. The Federal Emergency Management Agency (FEMA) was formed to administer the federal flood insurance programs and oversee Floodplain Insurance Studies by each community. Each study would identify the extent of flood hazards, determine flood-flow frequencies for discharges having 10, 50, 100, and 500-year recurrence intervals, develop water surface elevation profiles for each of those discharges, and produce a map of the floodway that would contain the 100-year discharge.

Methods of flood-frequency analyses had been in a constant state of development since 1914 (see review in Hirschboeck, 1985). In 1967, a Federal interagency work group recommended a log-Pearson type III distribution as a uniform technique for determining flood flow frequencies from a series of annual flood peaks (for a history of this process, see Thomas, 1985). This distribution accounts for the logarithmic mean, the standard deviation, and the skew of the data. When the data are log-normally distributed (when the skew coefficient is zero), the distribution will plot as a straight line on normal probability paper; otherwise, it plots as a curve. The method assumes that the hydrological characteristics of the stream have not changed over the period of flow measurements (i.e., that the mean and moments of the distribution are stationary). This assumption may not hold where significant watershed or climatic changes produce trends in the annual flood series. Also, inclusion of very low peaks, as is characteristic of desert streams, yield high negative skews in log-transformed data (Wallis and Wood, 1985). The distribution may flatten, so that differences between the 10-year and 100-year floods become imperceptible in fitting the distribution. In spite of these limitations, log-Pearson type III is currently the flood frequency distribution used by all federal agencies; however, Bulletin 17B (U.S. Water Resources Council, 1981) does allow for use of other techniques if the stationarity assumption is violated.

Once the 100-year flood, or the discharge which has a one in a hundred chance of occurring any year, has been computed, the normal procedure is to use aerial photography to map the area in and near the channel. Cross sections are then generated from the maps or from photogrametric methods. Water surface elevations for the 100-year flood are calculated from a step-backwater model and are mapped on the topographic base to yield 100-year floodplain maps. The principal assumptions of the step-backwater model are steady flow conditions and a fixed channel before, during, and after the flood. Flood boundaries must be recomputed as the hydraulics change, or the channel must be stabilized by artificial means.

Both flood frequency analysis and floodplain mapping were initially developed and have been most successful in humid regions with stabilized channels. However, the assumption of channel and floodplain stability may be violated for ephemeral, dryland streams. That the Federal program is provincial to humid regions also is implicit in the greater emphasis given to inundation compared to lateral erosion.

In 1973, the Arizona legislature passed House Bill 2010, naming the governing body of each city, town and county the Floodplains Board for their jurisdiction. The Bill required each Board to adopt floodplain regulations and delineate floodplain properties. Pima County entered the Emergency Phase of the National Flood Insurance Program and enacted its first floodplain management ordinance in 1974. Between 1975 and 1980, flood hazard areas were identified in Arizona communities, including Pima County and Flood Hazard Boundary Maps were issued. The Federal Insurance Administration held meetings with local authorities to determine specific areas for Flood Insurance Studies (FEMA, 1981). Pima County adopted a written policy requiring building setback requirements of 300 feet (91.5 m) for development of new residential units for sale and 100 feet (30.5 m) for rental units along major watercources (after the 1983 flood, the setbacks along the Santa Cruz were increased to 500 feet (152 m) from the primary channel bank of the the 100-yr floodway).

Prior to October 1983, there had been much controversy about the techniques for computing 100-year flood and the values derived from them.

In the 1930s, Knapp (1937) arrived at a value of 355 cms at Congress Street based on 20 years of record. Some 45 years later, FEMA (1982) adopted a 100-year flood discharge of 850 cms for floodplain mapping despite objections by some local hydrologists that this value might seriously underestimate actual flood hazards through Pima County. Using various techniques, different authors recommended 100-year flood values of 1090 cms (Roeske, 1978), 1811 cms (Malvick, 1980), and 2179 cms (Boughton and Renard, 1984). By comparison, direct application of the Log Pearson Type III distribution applied to annual flood peaks at Congress Street from 1915-1981 yielded a 100-year flood of 626 cms (Eychaner, 1984), which was exceeded during the October 1977 flood (Aldridge and Eychaner, 1984). Before October 1983, the contradictory estimates had confused the general public and had fostered some skepticism about the federal program among those entrusted with the task of enforcing floodplain legislation.

In 1982, the city of Tucson undertook plans to revitalize the downtown sector by constructing a small community of 1,100 homes on the west bank of the Santa Cruz River upstream of St. Mary's Road. City ordinances required the lowest finished floors of the houses to be one foot (0.3 m) above 100-year flood water surface elevations. Channel stabilization, in the form of 2.5-m thick retainer walls of soil cement to replace the river banks, was required to contain a design flow of 1274 cms. There was some uncertainty about the performance of the soil cement, particularly where it tied in to unprotected banks at both ends of the protected reach. A more severe test of local floodplain engineering than the flood of October 1983 could not have been imagined.

Tropical Storm Octave and the Flood of '83

Unusual weather conditions developed over southern Arizona in late September 1983. After a normal monsoon season, a thermal low developed near the head of the Gulf of California, while a weak cold front trailed across the southern Great Basin. Aloft (at 500 mb) was a long, southwest-to-northeast trough channeling tropical Pacific moisture into northwestern Mexico and southern Arizona. In September, sea surface temperatures had been abnormally high in the tropical Pacific and west coast of North America, favoring tropical storm formation. When tropical storm Octave developed in late September, conditions were ideal for recurvature and persistent advection of large amounts of moisture into southern Arizona. By September 24, when it rained at almost every station in southeastern Arizona, the month had already been unusually wet, this on the heels of normal monsoons in August. The gage at Continental registered a peak discharge of 159 cms on September 22 (78 cms at Cortaro downstream of the Rillito confluence), saturating the river bed through the Tucson Basin.

For a five-day period beginning on September 28, the rains were widespread, persistent, and in some cases quite intense throughout southern Arizona. Of 45 official stations in southeastern Arizona, 20% registered more than 25 mm on September 28, 30% on the 29th, 60% on the 30th, 50% on October 1, and 75% on October 2. In the Santa Cruz watershed, total rainfall for these five days exceeded 150 mm at most stations. In the high mountains, on the west slope of the Santa Rita Mountains, and in the Tucson area, the totals exceeded 200 mm. On September 30, peaks of 159 and 295 cms were measured at the Continental and Cortaro gages, respectively. A mean discharge of 510 cms was recorded at Cortaro on October 1. The Santa Cruz continued to rise in the middle of the night, reaching a peak of 1274 cms just before 3 a.m. at Continental and 1840 cms ca. 6 a.m. at Cortaro. An estimated peak of 1492 cms had passed under the Congress Street bridge sometime between 3 and 6 a.m., October 2. The intense rainfall also triggered record flows elsewhere in the Gila River basin, wrecking havoc throughout southern Arizona (Saarinen et al., 1984; Roeske et al., 1989).

Flood damage along the Santa Cruz River resulted from inundation in the reach from Continental to the southern end of the San Xavier Indian Reservation and downstream of the Cortaro gage to the confluence with the Gila River. Inundation was not a problem through metropolitan Tucson, where channel cross-sections were or became large enough to accomodate the discharge. Instead, most of the damage in the Tucson area was caused by cutbank recession of actively migrating meander bends, similar to that which occurred at Congress Street during the flood of 1915. Soil cement revetments, such as the newly-modified channel upstream of St. Mary's Road and Congress Street performed surprisingly well, except where the revetments joined unprotected banks. Wherever bank protection was minimal or non-existent, lateral erosion resulted in collapse of homes into the river and destruction of bridge approaches. In places, lateral erosion moved the thalweg beyond the boundaries of the 100-year and even outside of the 500-year floodways (Baker, 1984; Slezak-Pearthree and Baker, 1988). Along other reaches, however, the channel contained the discharge of October 2 where overbank flooding had been predicted for a lesser discharge of 850 cms. The discrepancy may be due either to errors in step-backwater modeling, mapping of surface water elevations, or channel enlargement during the flood (Baker, 1984).

One of the more impressive erosional features from the 1983 flood resulted from upstream migration of the headcut at Greene's Canal near the Pinal-Pima County line (Fig. 47, 86). From 1915, when it first formed, to 1983, the Soil Conservation Serivice and local farmers had managed to restrict further erosion of the headcut to a relatively small area north of the county line. However, the 1983 flow, which approached a width of 6 km in the lower Santa Cruz, either overtopped or went around protective measures and cascaded into the headcut, which receded upstream along what was a shallow channel of the Santa Cruz River. The headcut is now located above most of the protective structures intended to restrict its upstream migration.

After the Deluge

The 1983 flood raised concerns about floodplain management in the Tucson area and southern Arizona as a whole. Local authorities reacted almost immediately with amendments to existing floodplain legislation. One such ordinance allowed discretion of local officials to increase both regulatory and design flood values. Pima County commissioned new studies to define these values (e.g., Ponce et al., 1984). By January 1985, both Pima County and the City of Tucson had adopted a regulatory value of 1700 cms and a design value of 1980 cms for the reach between San Xavier and the Rillito confluence. Pleased with its performance during the 1983 flood, Pima County has accelerated channel stabilization with soil cement throughout the Tucson Basin.

There still remain questions about the apparent trend in the annual flood series at Congress Street, which was magnified by the 1983 flood. Is the trend towards increasing peak discharge the consequence of climatic change, improved channel conveyance for critical reaches, or some combination of both factors. Changes in channel topography, such as those that happened as

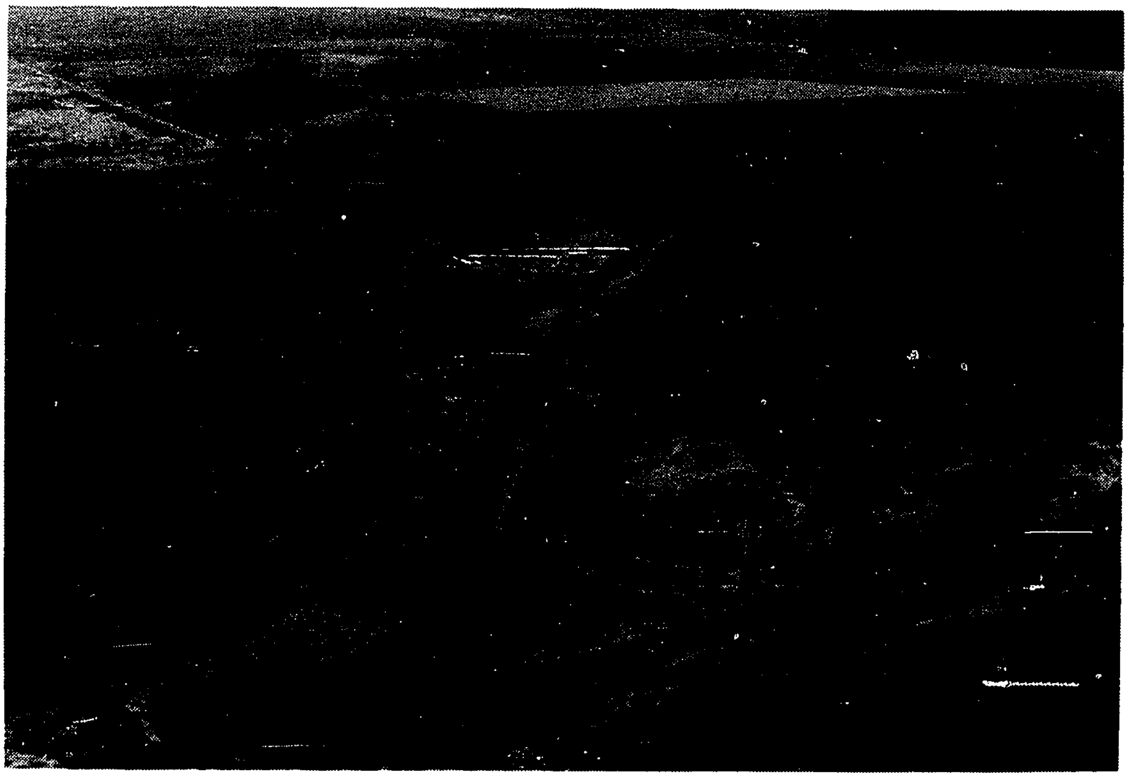


Figure 86. Upstream aerial view of active headcut of the Greene's Canal arroyo, about 4 km upstream of the canal's diversion point from the Santa Cruz River, which runs down photograph. During the October 1983 flood, an overflow 2-5 km wide affected this area. The overflow cascaded into the headcut, promoting headward as well as lateral erosion. With continued upstream migration of this headcut during future floods, sediment eroded from the Santa Cruz arroyo-Tucson Basin reach and deposited in lower reaches between 1890 and 1990, will be tranported farther downstream.

the Santa Cruz arroyo developed into the modern channel, are known to alter conveyance of flow waves (see Burkham, 1981 for the Gila River). The Santa Cruz remained unincised at the southern end of the San Xavier Indian Reservation, at the beginning of the Congress Street gage record. In the Reservation, the channel deepened 3-5 m between 1915 and the late 1930s and another 2-3 m since then. Zero flow elevation at Congress Street dropped 3-5 m since 1946 (Aldridge and Eychaner, 1982), mostly due to encroachment of the channel by landfills and highway construction. Hypothetically, the flood in winter of 1915, which lasted several months and produced a peak of 425 cms at Congress Street, might have produced a much higher peak if routed through the modern channel. Conversely, the 1983 peak of 1492 cms might have been much less if routed through the 1915 channel. There has been little effort to reconcile the effects of channel changes on flood peaks, though some authors maintain that channel changes and not unusual rainfall conditions have produced the increase in annual peaks (Reich, 1984; Zeller, 1984).

The Santa Cruz flood series shows a lack of uniformity in the seasonality of flood peaks (Fig. 85; Betancourt and Turner, 1988; Hirschboeck, 1985), that may partly account for the increase in annual peaks since 1960. In the periods 1915-1930 and 1960-1964, periods characterized by meridional flow and frequent ENSO events, almost half of the annual flood peaks occurred in early fall (September-October) or winter (November-February). In the intervening period of 1931-1959, 93% of the peaks occurred in July or August. Seven of the eight largest peaks in the flood series were produced by fall or winter storms and five of these occurred since 1960. The seasonal pattern is not peculiar to the Santa Cruz, but is repeated in other flood series from southern and central Arizona (e.g., the San Francisco, the Gila, the Rillito and

San Pedro Rivers).

Whether related to climatic or watershed changes, the results of flood-frequency analysis change with the period of measurement or with the type of storm. Figure 87 compares values for 10-year, 50-year and 100-year flood computed from different lengths of record at Congress Street. For the 100-year flood, the last 22 years of record yield a value that is roughly twice that computed for the 67-year series prior to the 1983 flood. Another approach is to examine subpopulations of flood peaks by storm type, test each annual series by storm type for trend, and compute recurrence intervals for each storm type. Hirschboeck's (1985) analysis, using the partial duration series from 1950 to 1980, suggest that 100-year flood for winter frontal storms and fall tropical storm-cutoff lows is double that from the summer monsoonal storms that are the most common source of flood peaks (Fig. 88).

At present, it appears that both watershed and climatic changes may have contributed to larger flood peaks along the Santa Cruz River. Flow conveyance will probably continue to improve with increasing channel stabilization in the Tucson Basin; one result may be greater stream power in downstream reaches and, thus, upstream migration of the headcut at Greene's Canal through the reach between Redrock and Marana. The rate at which this happens will depend on the frequency and intensity of flood-producing storms in coming decades. Should the headcut continue migrating upstream, sediment that originated from arroyo-cutting in the Tucson Basin since 1890 will be transported farther downstream to Santa Cruz Flats and vicinity.

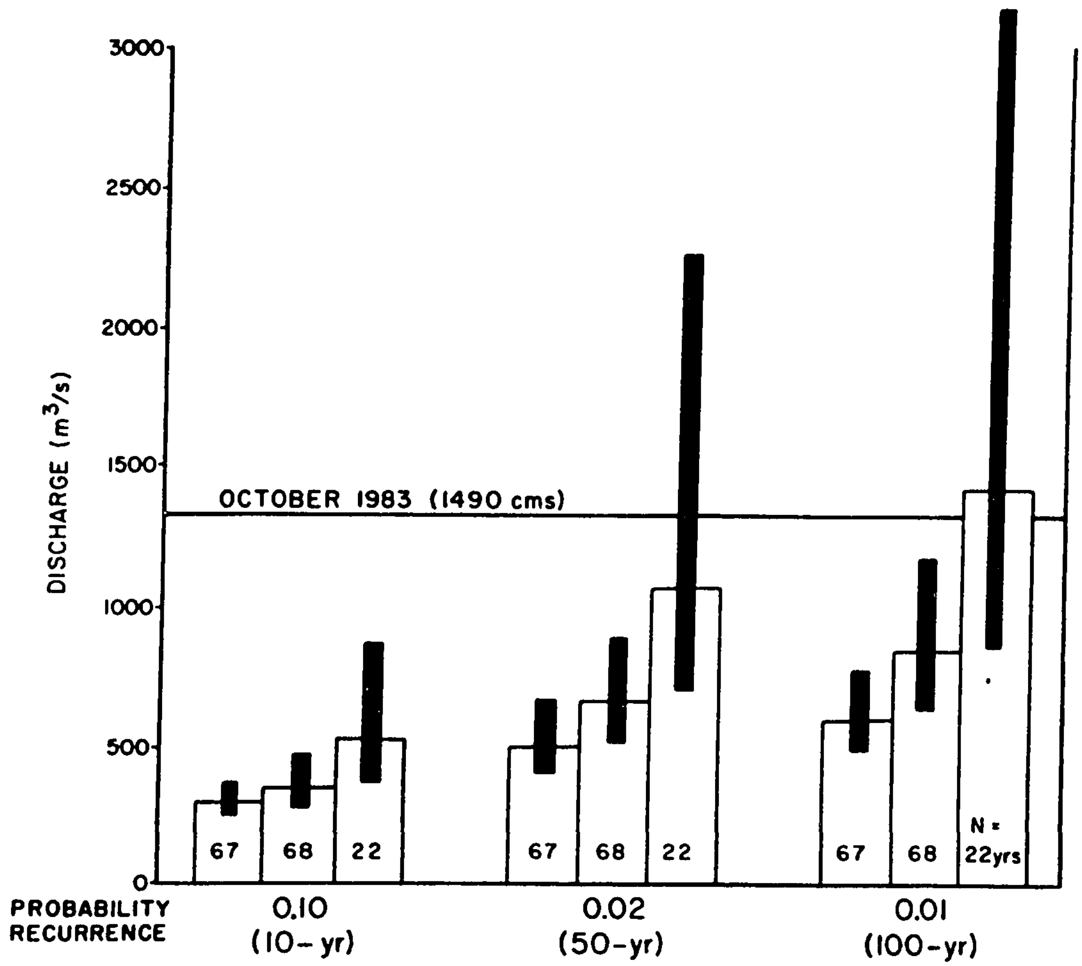


Figure 87. Estimated discharges for 10-year, 50-year and 100-year recurrence intervals on the Santa Cruz River at Tucson, based on annual flood peaks from 1915 to 1981 (67 years), 1915 to 1984 (68 years, including 1983 flood, and 1961 to 1984 (22 years). Solid bars are the confidence limits.

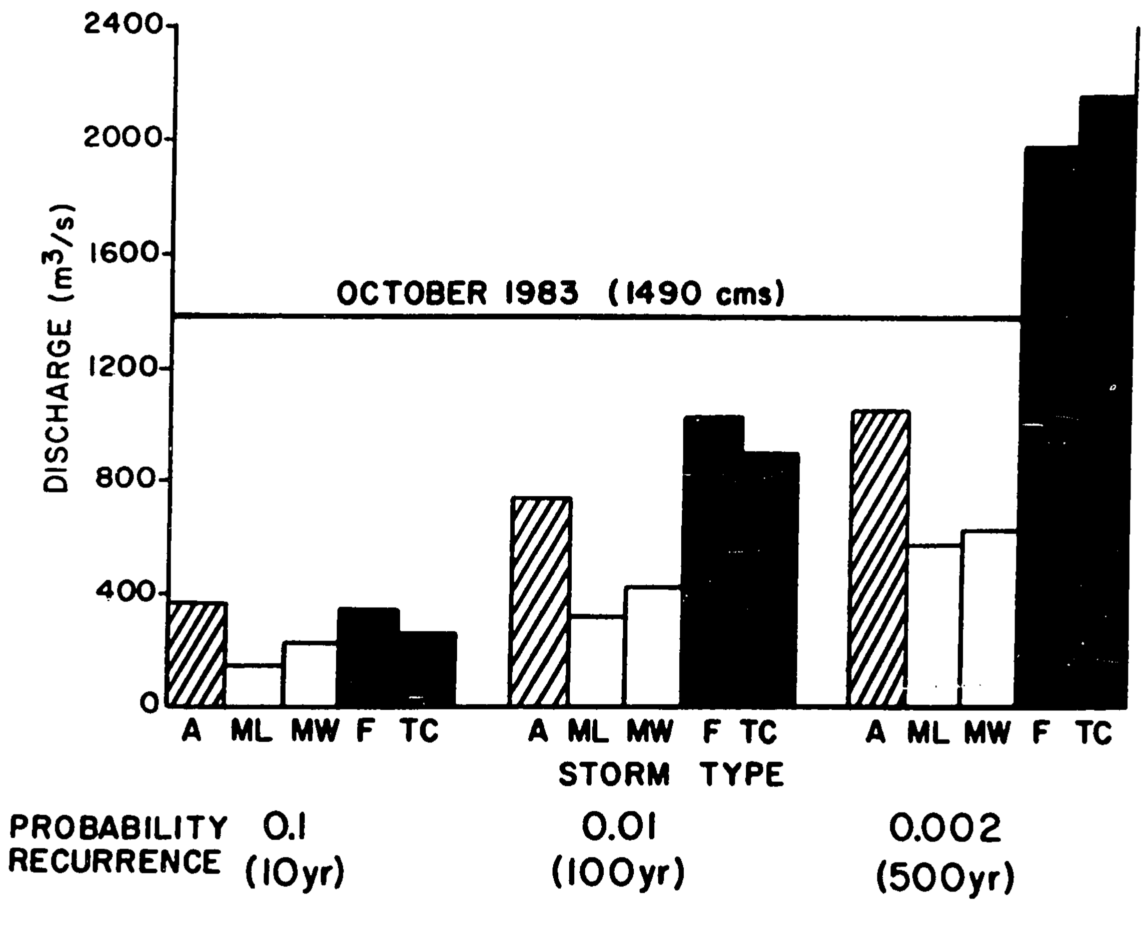


Figure 88. Flow estimates at 10-year, 100-year and 500-year recurrence intervals for different storm types in the partial duration series from 1950 to 1980, Santa Cruz River at Tucson. A= annual, ML= monsoonal local, MW = monsoonal widespread, F = frontal, TC = tropical storm/cutoff low (adapted from Table 9, Hirshboeck, 1985).

CHAPTER 8: CLIMATE AND LAND USE-PROBABLE CAUSES OF ARROYO-CUTTING

This section weighs the effects of climate and land use as explanations for late 19th century arroyo-cutting in the Santa Cruz River Valley. Because many of Arizona's largest floods have occurred during El Niño years (e.g., 1862, 1868, 1891, 1905, 1914-1915, 1926, 1940-1941, 1965-1966, 1972, 1977, 1983), the relationship between the ENSO phenomenom and precipitation in the southern part of the state is examined in detail. An attempt is made to characterize rainfall and flooding during the summer of 1890 and to address whether or not late 19th century climate was unusual. In discussing the effects of land use, greatest emphasis is given to direct manipulation of streamflow and engineering of ditches.

Tucson's Precipitation Record

Tucson boasts one of the longest records (1868-1987) in Arizona, though like other long-lived southwestern stations, it is tarnished by a complicated station history. The early part of the record is spliced together from daily observations by the Post Surgeon stationed at Fort Lowell, first in what is now downtown Tucson (1868-1873), and later on the banks of the Rillito River, 10 km to the northeast (1873-1875). The U.S. Army Signal Service (1878-1883) and the Southern Pacific Railroad (1883-1891) later operated rain gages near the downtown location. The University of Arizona has maintained precipitation records since its opening in 1891, though at 5 separate locations. Overall, there were major station moves in 1873, 1875, 1879, 1883, 1891, 1894, 1956, 1966, and 1968. The effect of these moves on the statistical properties of the time series has not been determined.

Figures 89-91 are three different graphic representations of monthly and seasonal precipitation totals. The seasonal distribution of rainfall is best illustrated by the three-dimensional plot of monthly totals (Fig. 89). Note the biseasonality of rainfall, with maxima in summer and winter, the lower year-to-year variability in summer, the sharpness of the arid foresummer, and the very predictable onset of summer rains in July. Individual years are better discerned in the contour map of monthly totals (Fig. 90), such as the relatively wet summers (densely-packed contours) prior to 1896 and years when the arid foresummer breaks down and there is continuity or near-continuity of contours from winter to summer (e.g., 1905, 1919, 1925-1926, 1931, 1940-1941, 1957-1958, 1965-1966, and the late 1970s). Seasonal totals are summarized and compared with the water year in Fig. 91. Winter is the season best correlated with the water year. Correlations between the monthly totals and the water year are as follows (in order of decreasing correlation): December ($r=0.51$, $p<0.01$), February ($r=0.40$, $p<0.01$), March ($r=0.40$, $p<0.01$), July ($r=0.37$, $p<0.01$), January ($r=0.35$, $p<0.01$), August ($r=0.34$, $p<0.01$), September ($r=-0.30$, $p<0.01$), April ($r=0.22$, $p<0.05$), November ($r=0.21$, $p<0.05$), October ($r=0.18$, $p>0.05$), May ($r=0.12$, $p>0.05$), and June ($r=0.05$, $p>0.05$).

Relationships with ENSO

There is remarkable coincidence between certain features of the Tucson precipitation record and the chronology of ENSO-related phenomena, as defined by the Southern Oscillation Index (the normalized difference in monthly mean pressure anomalies between Tahiti and Darwin), Pacific sea

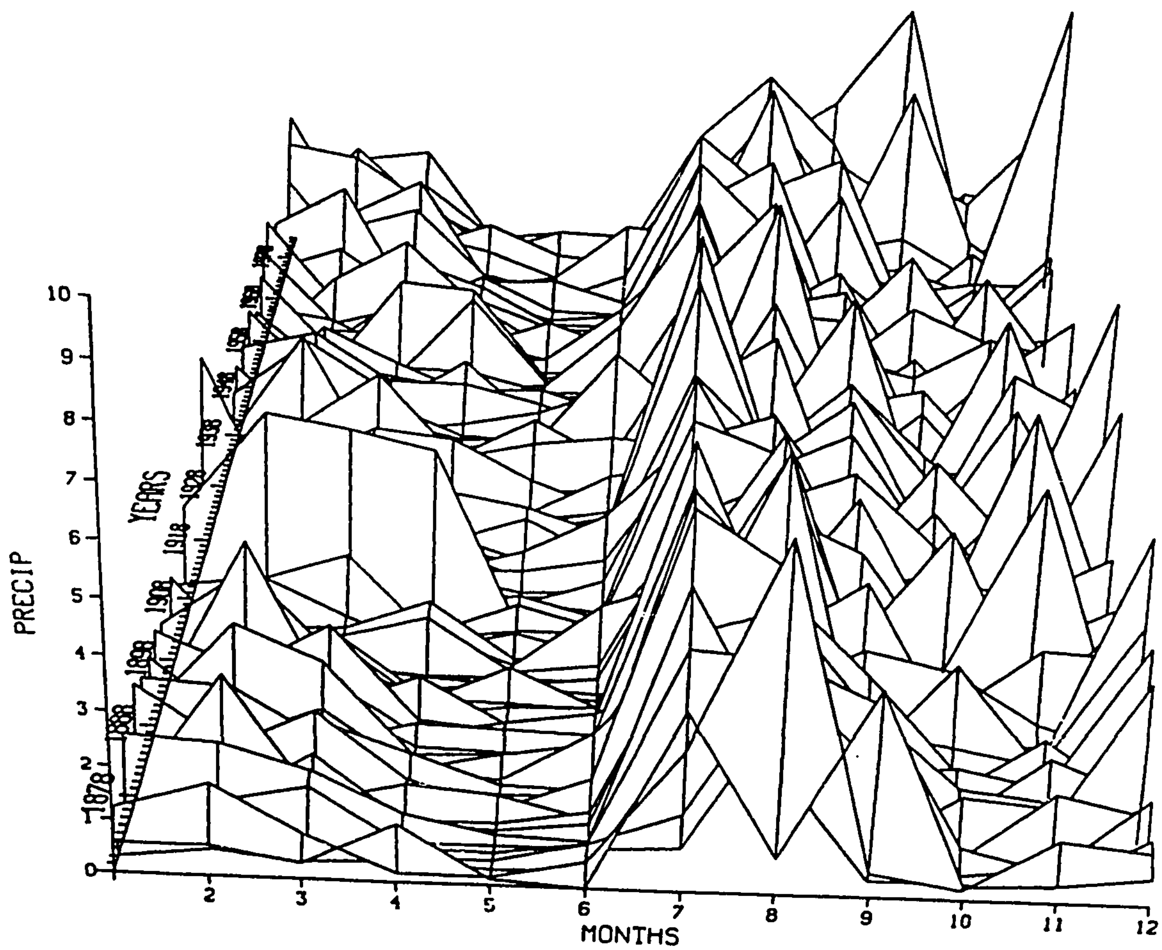


Figure 89. Three-dimensional plot of monthly rainfall totals for Tucson, Arizona, 1868-1987. Note the highly variable totals during the cool half year and the regularity by which the normally arid foresummer is interrupted by the onset of July rains (precipitation in inches, 1 in = 2.54 cm).

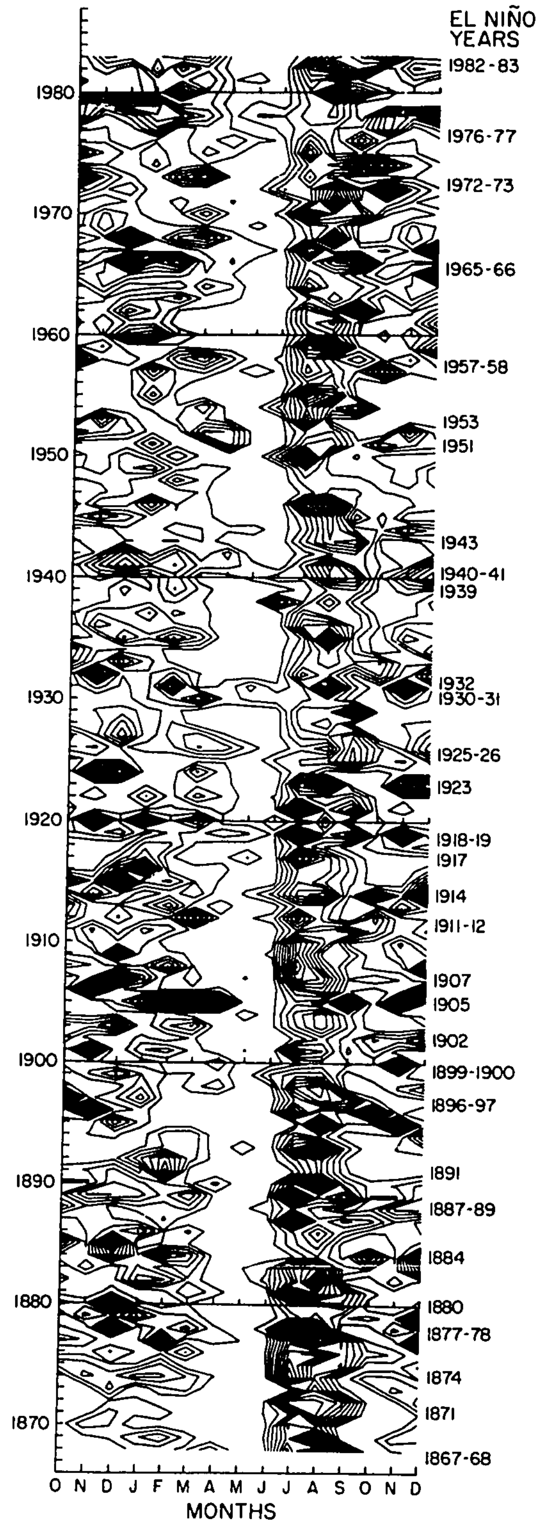


Figure 90. Contour graph of monthly rainfall totals, Tucson, Arizona. The contour interval is 10 mm.

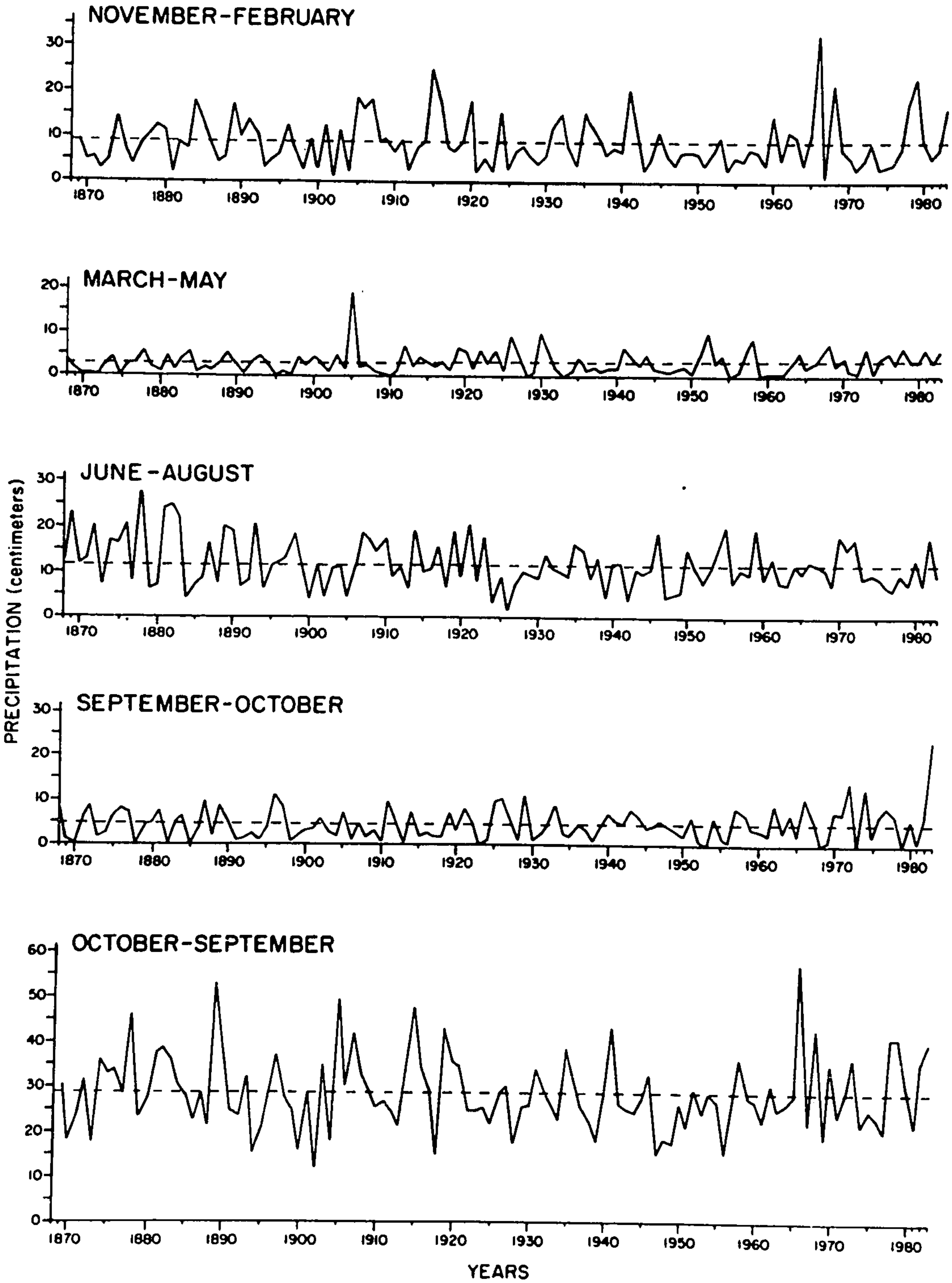


Figure 91. Seasonal and water year precipitation totals in Tucson, Arizona for the period 1868-1983.

surface temperatures, and tropical rainfall in the normally-dry central and eastern Pacific. The suggestion that a teleconnection exists between ENSO and North American weather actually dates back to the pioneering studies of Walker (1924) and Walker and Bliss (1932). The link with seasonal precipitation along the West Coast and in the Southwest has already been investigated by several authors (McEwen, 1925; Namias, 1960; Bjerknes, 1969; Pyke, 1972; Douglas, 1976; Douglas and Englehart, 1984; Ropelewski and Halpert, 1986; Andrade and Sellers, 1988).

Douglas and Englehart (1984) found significant positive correlations between Wright's (1989) Summer Rainfall Index for the Equatorial Pacific and divisional precipitation in the southwestern U.S. during October, November, and the following February and March (Fig. 92). Note that southern Arizona yields the best correlations for each of these months. Also, significant negative correlations coincide for these months in the Pacific Northwest. This regional pattern can now be extended to most of Mexico, which experiences summer drought during ENSO events (Douglas, 1983).

For the southeastern U.S. and northern Mexico, Ropelewski and Halpert (1986) showed that above normal precipitation was associated with ENSO in 80% of the cases studied for the season beginning with October of the ENSO year to March of the following year. In the Great Basin, above normal precipitation was also found in 80% of the cases for the April through October period during ENSO years. Enhanced summer precipitation in Utah and Nevada may be due to local cyclonic circulation (commonly called the Great Basin Low or the southeastern Utah Low), which develops most frequently during ENSO years. Ropelewski and Halpert's (1986) analysis did not include any stations from Arizona.

CORRELATIONS BETWEEN
SUMMER TROPICAL RAINFALL INDEX
AND
DIVISIONAL PRECIPITATION

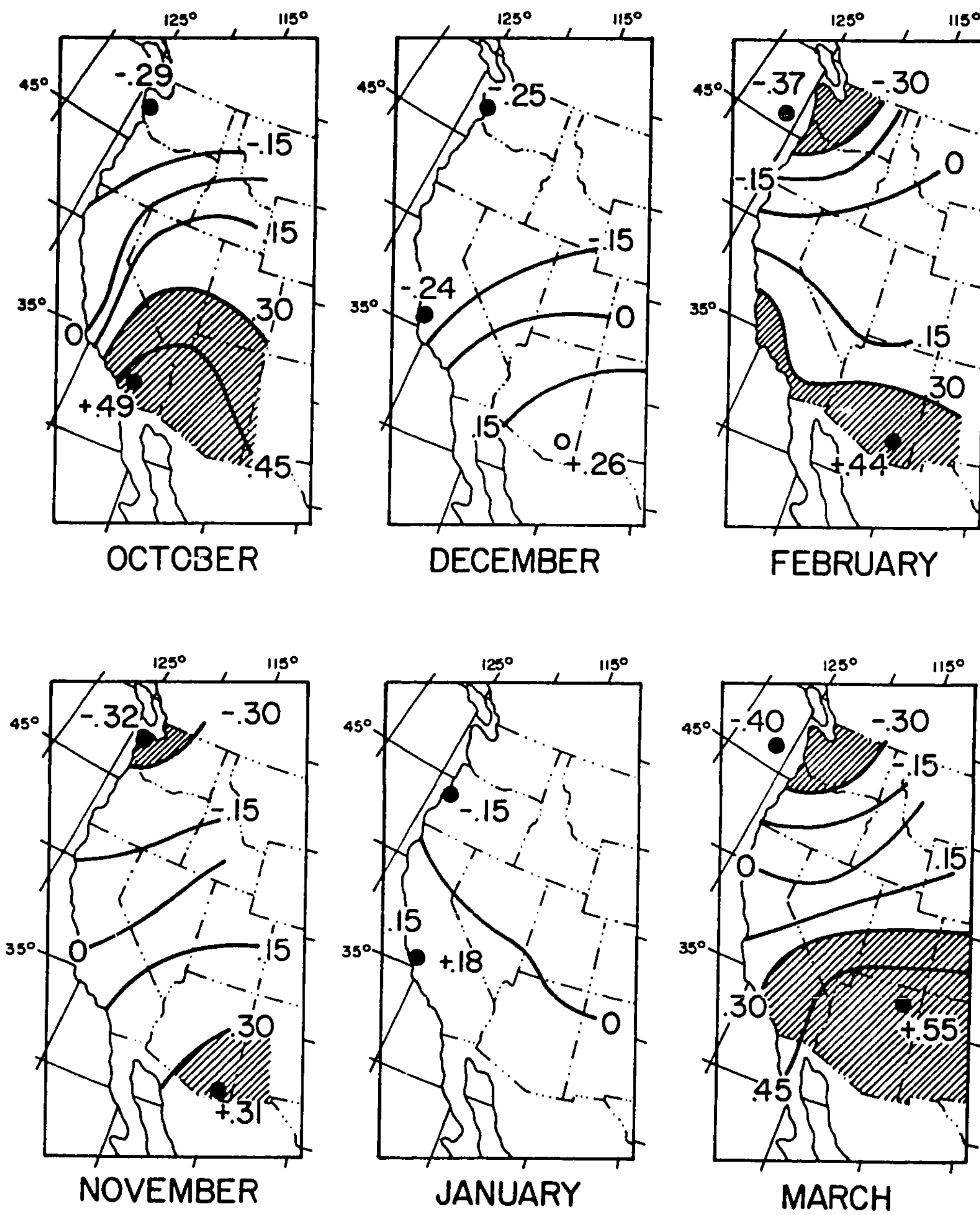


Figure 92. Correlations between summer rainfall index for the Line Islands in the central equatorial Pacific and divisional precipitation in the western United States during the cool half-year. Shaded areas indicate significance at the 0.05 level (after Douglas and Englehart, 1984).

Andrade and Sellers (1988) recently examined the relationship between ENSO events and precipitation in Arizona and western New Mexico, noting that precipitation is enhanced during the normally-dry spring and fall. They suggest that warm water off the west coasts of Mexico and California provides the necessary energy for the development of strong west-coast troughs; weakens the tradewind inversion, and thus allows moist air to penetrate into the Southwest; and spawns stronger more numerous Pacific tropical storms than usual. Andrade and Sellers (1988) also found no significant correlation between ENSO and winter or summer precipitation. However, this may be due in part to integration of stations across a gradient where the ENSO effects change sign and cancel each other. For example, summer precipitation is probably enhanced in northern Arizona with development of the Great Basin Low, while significantly reduced in the southern part of the state (positive height anomalies over the southwestern U.S. and Mexico).

One of the problems in analyses of ENSO-related phenomena is the use of different criteria for identifying ENSO events (e.g., SST temperatures at Puerto Chicama, Peru, several versions of the Southern Oscillation Index, or rainfall in the Line Islands). The strong events (e.g., 1982-83) are recognized as such by most investigators, but differences arise when classifying the weaker anomalies. Below, the effect of ENSO on Tucson precipitation patterns is investigated using Line Island rainfall (Wright, 1989) and Quinn et al.'s (1987) catalogue of ENSO occurrences of strong and moderate intensity (listed in Fig. 90). ENSO events of weak intensity are lumped with non-ENSO years.

The teleconnection between the tropical Pacific and southern Arizona is evident in comparisons between monthly precipitation in the Line Islands

(Wright, 1989) and Tucson for the period 1900 to 1982 (Table 1). The most consistent positive correlations occur between previous summer through current spring rainfall in the Line Islands and late winter-spring precipitation in Tucson. Line Island rainfall during the current summer and fall also is positively correlated with October and November precipitation in Tucson. Note that correlations for July and August tend to be negative, though not statistically significant.

Figure 90 shows the tendency for continuous or near-continuous contours from winter to summer in most El Niño years, and the association of sparse contouring (dry years) during periods of infrequent ENSO events (e.g., 1892-96, 1926-29, 1933-39, 1944-56). The marked aridity of periods dominated by non-ENSO years is evident in the water year totals (Fig. 91).

A similar pattern is evident in mean monthly differences in Tucson precipitation between ENSO and non-ENSO years for a 36-month period centered in June (Fig. 93). Positive differences indicate enhanced precipitation during ENSO years, negative differences denote greater rainfall during non-ENSO years. Precipitation during ENSO years is enhanced in both the normal (calendar) year during and after, but not in the year before. For the year during, every month is wetter during ENSO than non-ENSO years except January and August. The same is generally true for the year after. Precipitation amounts for at least some months have a quasi-normal distribution, but the transition months (spring and fall) have skewed distributions. The paired monthly means were compared using the Mann-Whitney U-Wilcoxon Rank Sum W-Test (Siegel, 1956). Significant differences at the 0.05 level were found for March of the year before, April, May, June, August, and October of the year during and April of the year after

(Table 2).

The differences in March of the year before and August of the year during are negative -in other words, both months tend to be dry during ENSO years when compared to non-ENSO years. The situation in August of the year during is reversed dramatically in September. Some years ago, Sellers (1960) noted a slight negative correlation between September precipitation and that in July and August for the period 1898-1959 in Arizona and western New Mexico. At the time, he suggested that atmospheric conditions conducive to heavy midsummer rains were not favorable for late season tropical storms and vice-versa. Figure 93 suggests that conditions favorable for midsummer rains predominate during non-ENSO years. The exception may be those years when tropical Pacific storms affect southern Arizona during July or August. The influence of the Pacific certainly heightens during the fall with a greater occurrence of recurving tropical storms and hurricanes.

The late winter and springs in both "during" and "after" years tend to be wetter for ENSO than non-ENSO events, even though only the the spring after is usually thought to be wetter (Douglas and Englehart, 1984). This may be due in part to the fact that one-third of ENSO years occur in pairs (e.g., 1940-41, 1957-58, 1982-83), and that unusually wet late winters and springs are essentially factored into the means twice (note that even the spring before tends to be wetter). However, Ropelewski and Halpert (1986) noted wet springs in the year during for the Great Basin, a pattern that may extend as far south as Tucson.

Namias (1986) suggests that periods of high persistence seem to precede the Northern Hemisphere mature stage of ENSO by as much as one year. He also implies that abnormal flow patterns due to an expanded circumpolar vortex in the cool season prior to the ENSO summer may actually induce air-sea interactions responsible for the generation of ENSO. Other authors suggest that circulation anomalies in the North Pacific and North America (i.e. an intensified Aleutian Low) are the typical response of the northern hemisphere winter atmosphere to ENSO forcing (Yarnal and Diaz, 1986). However, not all ENSO events are associated with an intensified Aleutian Low; neither is an intensified Aleutian Low restricted to ENSO events (Emery and Hamilton, 1985).

Even if they are not always in phase, El Niño conditions happen most frequently during decades typified by an expanded circumpolar vortex (a higher incidence of meridional flow in the upper air westerlies). This prompted Namias and others (1988) to suggest that low-frequency climatic variability in western North America is driven by long-term increases in the subtropical westelies and in the frequency of ENSO. The resulting decadal trends may be reflected in low-frequency variations of Line Island rainfall. Figure 94 is the time series of the mean rainfall for the period August through February in the Line Islands, the period of maximum sea surface pressure and temperature anomalies in the central Pacific. Note that precipitation surges in the Line Islands occur frequently before 1930 and after 1960, which parallels apparent shifts in flood seasonality on the Santa Cruz River. A greater mix of storm types contributed to the annual flood series during the first and last third of this century, periods dominated by meridional flow, frequent El Niños, and above normal rainfall in the Line Islands; this connection probably stems from increased interaction of temperate and tropical weather systems during fall and winter.

Table 1. Correlation matrix comparing Line Island monthly rainfall, beginning with June prior to calendar year, with Tucson monthly precipitation for the period 1900 to 1982. Pearson correlation coefficients with $p<0.05$ ($r>0.22$) are italicized and underlined. Note that for $r>0.28$, $p<0.01$.

	INDEX OF LINE ISLAND PRECIPITATION																		
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	-.11	-.15	-.13	0.03	-.09	-.08	-.02	0.01	-.03	0.07	0.01	-.05	0.04	0.02	-.14	-.03	0.02	-.06	-.02
Feb	*0.22*	*0.27*	*0.26*	*0.37*	*0.34*	*0.43*	*0.33*	*0.36*	*0.27*	0.19	0.21	0.08	0.12	-.01	0.05	0.08	0.05	0.03	0.16
Mar	*0.25*	*0.28*	*0.47*	*0.42*	*0.45*	*0.47*	*0.51*	*0.38*	*0.41*	*0.31*	*0.24*	0.19	0.15	0.04	-.07	0.05	0.00	0.01	-.01
Apr	0.14	0.16	*0.27*	*0.27*	*0.26*	0.20	*0.31*	*0.33*	*0.25*	*0.24*	*0.28*	0.21	*0.28*	0.14	*0.26*	0.19	0.12	-.08	0.10
May	-.02	0.11	0.17	0.14	0.16	*0.22*	*0.25*	0.17	0.19	*0.22*	*0.24*	0.11	*0.23*	0.06	0.13	*0.29*	*0.25*	0.18	*0.23*
Jun	0.02	0.12	0.12	0.19	0.14	0.06	0.09	0.05	0.06	0.07	0.00	-.01	0.06	0.06	0.12	0.11	0.16	0.14	0.14
Jul	-.05	-.06	-.15	-.16	-.17	-.19	-.10	-.10	-.09	-.14	-.12	*-.26*	*-.28*	-.17	-.19	-.10	-.16	-.19	-.22
Aug	-.01	0.00	-.10	-.15	-.11	-.15	-.14	-.08	-.10	-.13	0.10	-.15	0.08	0.05	-.07	-.06	0.05	0.05	0.09
Sep	0.06	-.13	0.08	0.12	0.14	0.05	0.04	0.02	0.03	0.05	0.14	0.09	0.12	*0.23*	0.18	0.01	0.06	0.10	0.16
Oct	0.00	-.17	0.03	-.06	0.06	-.13	0.06	0.03	0.04	0.14	*0.23*	*0.30*	*0.22*	*0.34*	0.21	0.21	*0.30*	*0.29*	*0.29*
Nov	-.01	0.20	*0.22*	0.16	0.17	0.13	0.19	0.17	0.20	0.17	0.17	0.13	*0.33*	*0.25*	*0.37*	*0.29*	*0.34*	*0.27*	*0.24*
Dec	-.02	0.04	0.06	-.06	0.10	0.04	0.08	0.09	0.11	0.15	0.15	0.08	0.16	0.11	0.15	0.19	0.20	*0.24*	0.07

Table 2. Mann-Whitney U-Wilcoxon Rank Sum W-test of significance between the mean monthly rainfall of El Niño vs. non-El Niño years in Tucson. Comparisons are for the 36-month period centered in June of the target year (year before, year during, and year after). Negative z-values reflect greater precipitation during non-El Niño than non-El Niño years. Values significant at $p<0.05$ are italicized and underlined.

	YEAR BEFORE		YEAR DURING		YEAR AFTER	
Month	z	p	z	p	z	p
January	0.31	0.76	-0.31	0.75	-0.26	0.79
February	-1.38	0.17	0.95	0.34	1.72	0.08
March	*-1.93*	*0.05*	-0.01	0.99	1.64	0.10
April	1.78	0.07	*2.37*	*0.02*	*2.33*	*0.02*
May	-0.03	0.97	*2.77*	*0.01*	0.46	0.64
June	0.61	0.54	*2.20*	*0.03*	1.47	0.14
July	-0.67	0.50	0.08	0.94	-0.85	0.40
August	-1.01	0.31	*-1.94*	*0.05*	-1.13	0.89
September	-0.69	0.49	1.64	0.10	-0.35	0.72
October	-0.36	0.72	*2.06*	*0.04*	1.22	0.22
November	0.98	0.33	0.92	0.36	0.53	0.60
December	-0.43	0.67	0.05	0.96	1.41	0.16

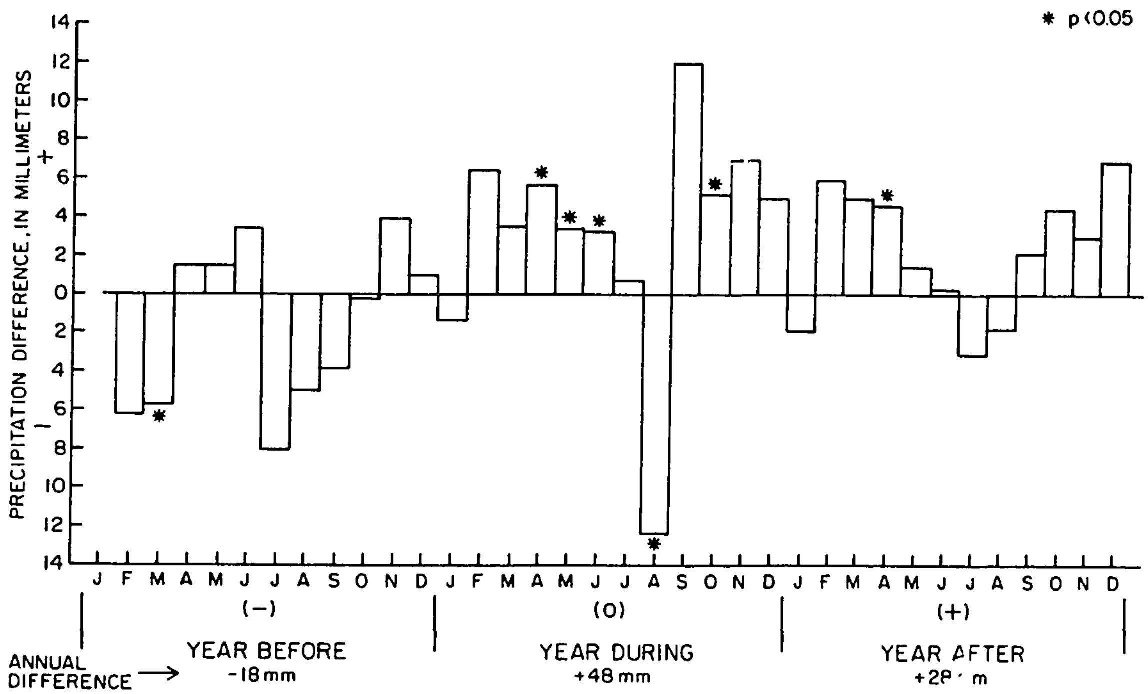


Figure 93. Difference between mean monthly precipitation during ENSO vs. non-ENSO years in Tucson, Arizona (1868-1983). A 36-month sequence is centered in June of the target year. Positive differences denote enhanced rainfall during ENSO events. Negative differences indicate greater rainfall during non-ENSO years. Asterisks denote significantly different means at the 0.05 level (Mann-Whitney U-Test; see Table 2).

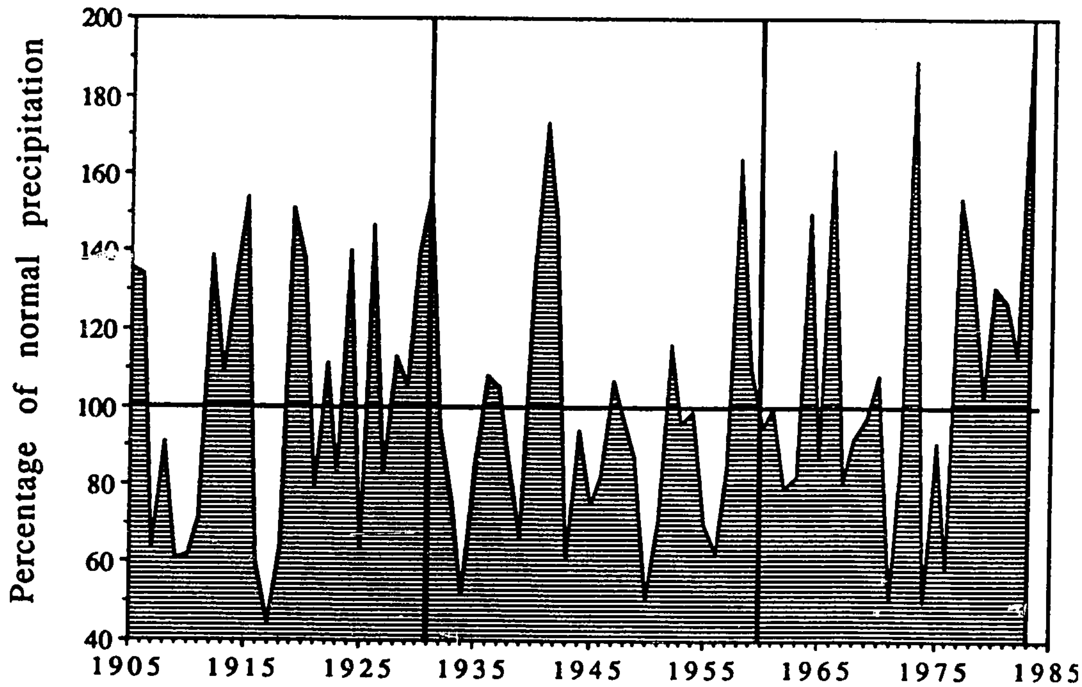


Figure 94. Time series of percentage of normal Line Island rainfall for the months of August through February.

Heavy vs. Light Rains: Summers of the late 1880s

One of the more popular explanations for synchronous arroyo-cutting in the Southwest is a shift to a climatic regime favoring heavy rains at the expense of light ones. Though such shifts have been documented in the northern Rio Grande Valley (Leopold, 1951; Leopold et al., 1966), the Colorado Plateau (Webb, 1985), southern Arizona (Cooke and Reeves, 1976), and California (Bull, 1964; Cooke and Reeves, 1976), they are generally asynchronous. In the Santa Fe record, the average annual intensity of rainfall was highest in the period 1850-1880, lowest between 1880 and 1925 (Leopold et al., 1966). On the Colorado Plateau, rainfall intensities in summer were highest between 1909 and 1932, when many arroyos developed in the region (Webb, 1985). However, late 19th century precipitation was not examined. In southern Arizona, summer rainfall was unusually heavy in the period 1868-1890 and the contrast between heavy and light rain appears most dramatic (Cooke and Reeves, 1976). California exhibits the same trends in heavy rainfalls as southern Arizona, with 1884-1890 being the wettest period of record (Bull, 1964; Cooke and Reeves, 1976).

Figure 95 illustrates the anomalous July-August rainfall that occurred in Tucson between 1868 and 1890. Seven years exceeding 200 mm for July and August were registered during the period, compared to only three in the 97 years since. Comparisons of the seasonal (June-September) frequency of heavy (>2.54 cm) vs. light rains (<1.27 cm) rains yield show a startling contrast (Fig. 96). A high frequency of heavy rains and low frequency of light rains characterize the period 1868-1890. A return to a high frequency of heavy rains occurred after the 1950s without a concomittant decrease in light rains.

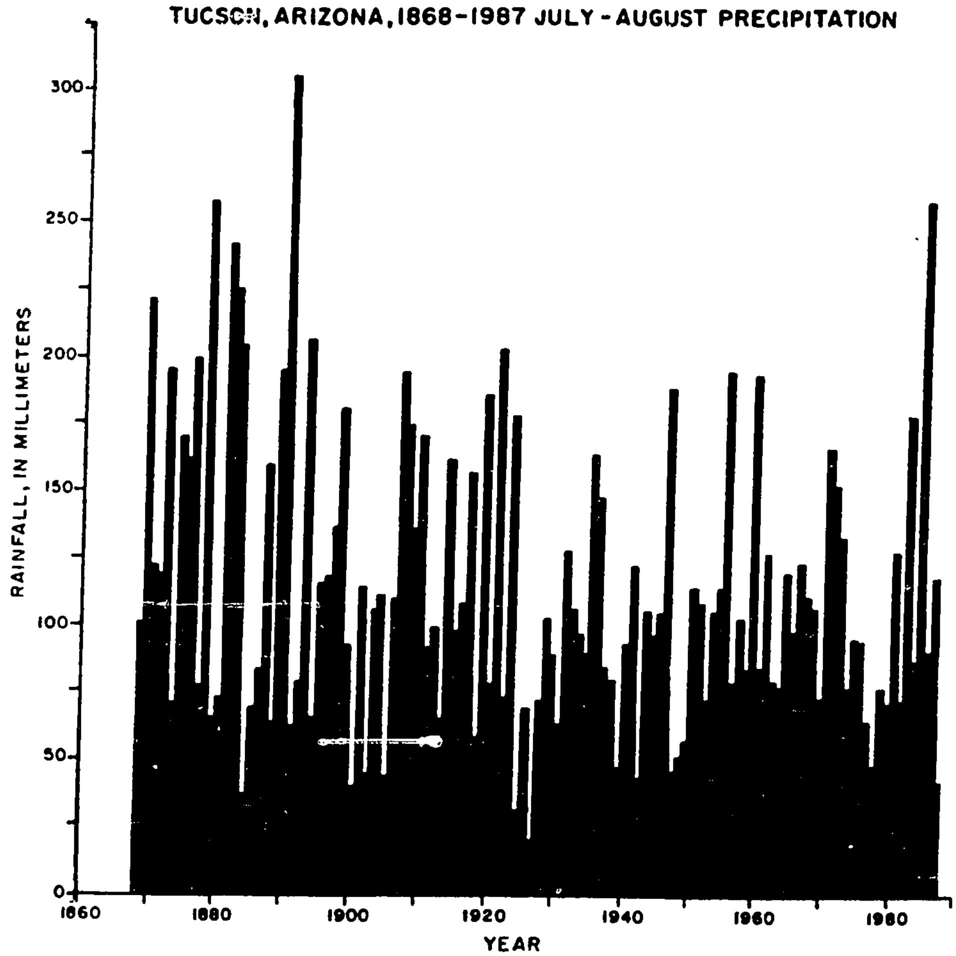


Figure 95. July through August rainfall totals for Tucson from 1868 to 1897.

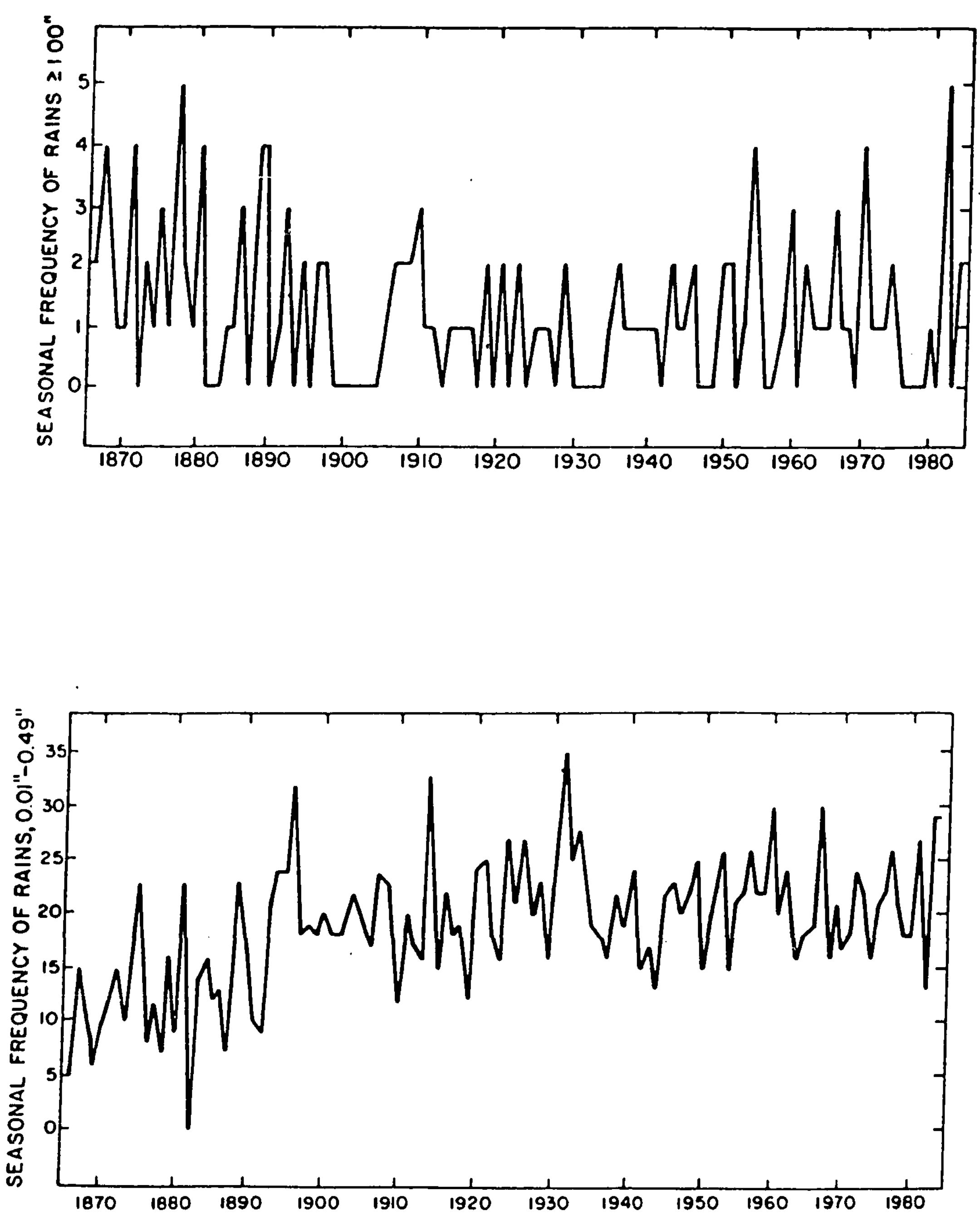


Figure 96. Frequency of rains greater than one inch (>2.54 cm, top) and less than 0.5 inches (1.27 cm, bottom) in Tucson between 1868 and 1984.

Perhaps only coincidentally, Quinn et al. (1987) note that ENSO activity was unusually strong and frequent during the period 1864-1891. Between 1868 and 1890, all but one of the years registering more than 3 days with >2.54 cm of rain were ENSO events (1868, 1871, 1874, 1878, 1880, 1884, 1887, 1889), as classified by Quinn et al. (1987). The one exception was the summer of 1890. This relationship does not persist into the 20th century, when ENSO events are associated with significantly lower totals of August rainfall than for non-ENSO events.

Unless there is a grave error in early rainfall records from southern Arizona, the period 1868-1890 appears to have few analogs in 20th century climate. But is it also anomalous when compared to periods prior? Quinn et al. (1987) suggest that intensified ENSO activity during the period 1864-1891 may be symptomatic of long-term climatic change, perhaps associated with global warming at the end of the Little Ice Age. In northern Peru, heavy rains during the period transformed the Desert of Sechura into thick woodlands, certainly a rare phenomenon in the past few centuries (Quinn et al., 1987).

Ice cores from the Quelccaya ice cap in the central Peruvian Andes provide an interannual, 1500-year proxy record for the strength of the easterlies and possibly ENSO activity in the tropics (Thompson et al., 1986). The end of the Little Ice Age (1530-1880) in the late 1800s is recorded in the cores by a systematic shift in microparticle concentration, oxygen-isotope ratios and electrical conductivities. The shift is recorded in other interannual proxy records along the west coast of the Americas. In the Gulf of California, an abrupt oceanographic change since 1880 is recorded in a 3000-year chronology of marine varved sediments (Juillet-Le Clerc and Shrader, 1987). The last 100 years are characterized by warm Gulf waters, low upwelling activity, and weak northwesterly tradewinds, conditions typical of ENSO events. These conditions apparently were not representative of the previous 3000 years. Similar shifts in the oceanographic regime also are evident in marine varved sediments of the Santa Barbara Basin in the California Bight Zone (Soutar and Isaacs, 1974; Soutar and Crill, 1977; Dunbar, 1983). Thus, there is ample indication that southwestern arroyos happened contemporaneously with changes in Pacific oceanographic regimes, if not climate worldwide. These changes apparently favored more frequent and intense ENSO activity.

The Floods of 1890

The floods of 1890, which initiated the arroyo from Sam Hughes' intercept ditch, were preceded by notable floods in 1886 and 1887. On August 3 and 13, 1886, two separate events washed away the dams at Silver and Warner's Lake, but initiation of headcuts was not reported. The 1887 floods followed closely on the heels of the Bavispe earthquake and its considerable hydrological effects throughout southeastern Arizona. On July 11, the dam at Silver Lake was swept away; on September 9 and 15, the combined flows of the Rillito and Santa Cruz River inundated the floodplain north of Tucson. On the Rillito the most recent flood with a higher flood stage had been in September 1868 (*Tucson Citizen*, September 12, 1887). The floods of 1887 may have produced headcutting in the marshy area fed by the Spring Branch, south of Martinez Hill. Sam Hughes' ditch, which was constructed in 1888, became an active headcut during minor flooding in October 1889.

Floods in summer of 1890 received a great deal of attention in the newspapers, comparable perhaps to coverage of the floods in 1915, 1977, and 1983. The season was unusual in the character and amount of precipitation for

July and August, anomalously cool summer temperatures, the repetitiveness of flooding. The first flood swept through the valley during the five-day period of July 27-August 1, producing overflows more than 600 m wide and up to 3.7 m deep in the Tucson area. Resumed flooding between August 4 and 7 resulted in the catastrophic erosion of Sam Hughes' ditch and migration of the enlarged headcut to a point upstream of Congress Street. Flooding on the Rillito River also resulted in arroyo-cutting. One astute observer noted that the deepened channel of the Rillito could now carry a third more water without reaching the flood stage of a few days before. The Santa Cruz began to rise again on August 13, washing out the dam at Silver Lake. Flooding resumed on August 23-25, reportedly reaching the highest flood stage of the summer. Arroyo initiation, then, was produced by four major floods spaced 3 to 10 days apart in summer of 1890.

With the exception of August 1955, the summer of 1890 has few analogs in the last century in respect to duration or repetition of flooding along the Santa Cruz River. There is presently no way of determining the magnitude of any of the 1890 floodflows. Rainfall conditions in summer of 1890 were unusual. Low surface pressure and low-level winds from the south-southwest prevailed over most of July, intensifying in August (U.S. Signal Service, 1890). The distribution of monthly rainfall over southern Arizona (Fig. 97, compare with other years between 1883 and 1894) suggests that the primary source of moisture was the Pacific Ocean rather than the Gulf of Mexico. In Lochiel, where the Santa Cruz first crosses the International Border, Alice F. Cameron, Rainfall Observer for the U.S. Signal Service, made the following notes:

> July 31st was very damp and cloudy ranging low all day-- very damp and chilly [in fact, E.L. Wetmore, the Rainfall Observer at Tucson, remarked that July rains resembled winter and spring rains, cooling off the atmosphere]....The rains of August 1, 4, 5, 6, 11, 15, 22, and 24

> came from the southwest, as in fact have most of our heaviest rains this year. Heretofore, in other years, since my first coming to this country in 1884, the heaviest rains come from the south and east....Many heavy rains this year have fallen (particularly this month of August-- also in July) five miles northeast of here, when not one drop fell here. The rainfall there must have been tremendous for the San Rafael Valley has been flooded very many times this summer, by that fall of water (Cameron, 1890).

Figure 98 depicts daily precipitation and maximum temperature in July and August 1890. A total of 300 mm of rainfall was recorded for the two months at Camp Lowell (Tucson) and other stations throughout the upper Santa Cruz and San Pedro Valleys. Note the association of cool maximum temperatures over several days associated with individual rainfall events. During July and August at Tucson, the probability of observing maximum daily temperatures equal to or less than 29°C, which occurred on 4 separate days in 1890, is about one percent (Green, 1962). This radical drop in temperatures may be explained by advection of cold air with southward penetration of a trough in the westerlies (i.e., a cold front), though the same effect could also result when the tropical air mass is abnormally cool. Regardless of the mechanism, it appears that precipitation and temperature patterns in summer of 1890 were unique.

Unlike most 20th century floods on the Santa Cruz River, the 1890 floods were associated with positive seasonal values of the Southern Oscillation Index (SOI; Figure 99) and cold sea surface temperatures in the central equatorial Pacific (Wright, 1989). Large winter floods did occur throughout central Arizona with a return to negative SOI conditions in 1891. With the exception of August 1961, all of the annual peaks at Congress Street above 425 cms have been associated with negative SOI values and winter frontal storms or tropical storms-cutoff lows. Perhaps it is significant that 1961 experienced strong North Pacific atmospheric circulation (an intensified

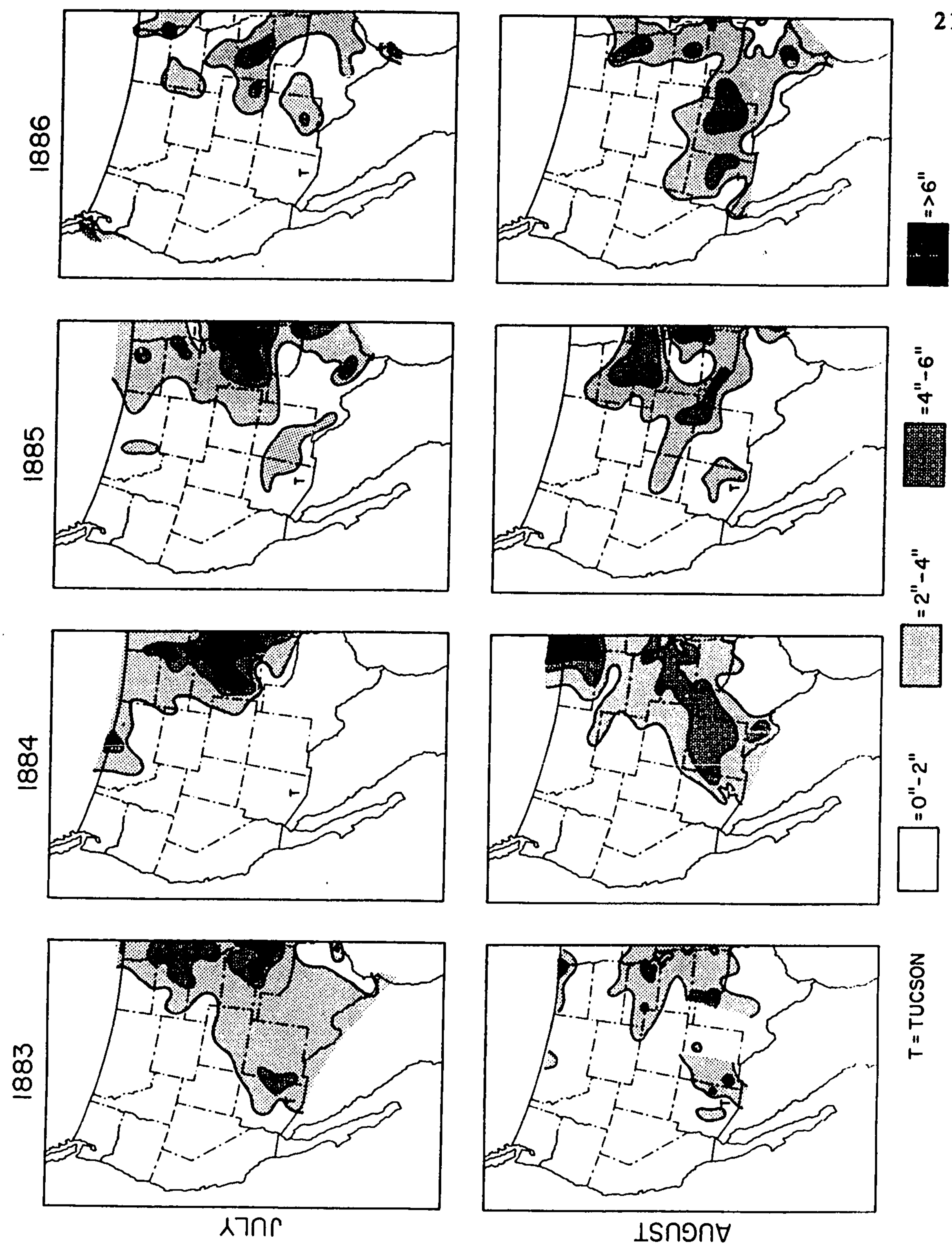


Figure 97A. Mapped summaries of July and August rainfall in the western United States from 1883 to 1886. Contours are < 2 in (<5.1 cm), 2-4 in (5.1-10.2 cm), 4-6 in (10.2-15.2 cm) > 6 in (>15.2 cm). Adapted from monthly summaries in Monthly Weather Reviews for each year.

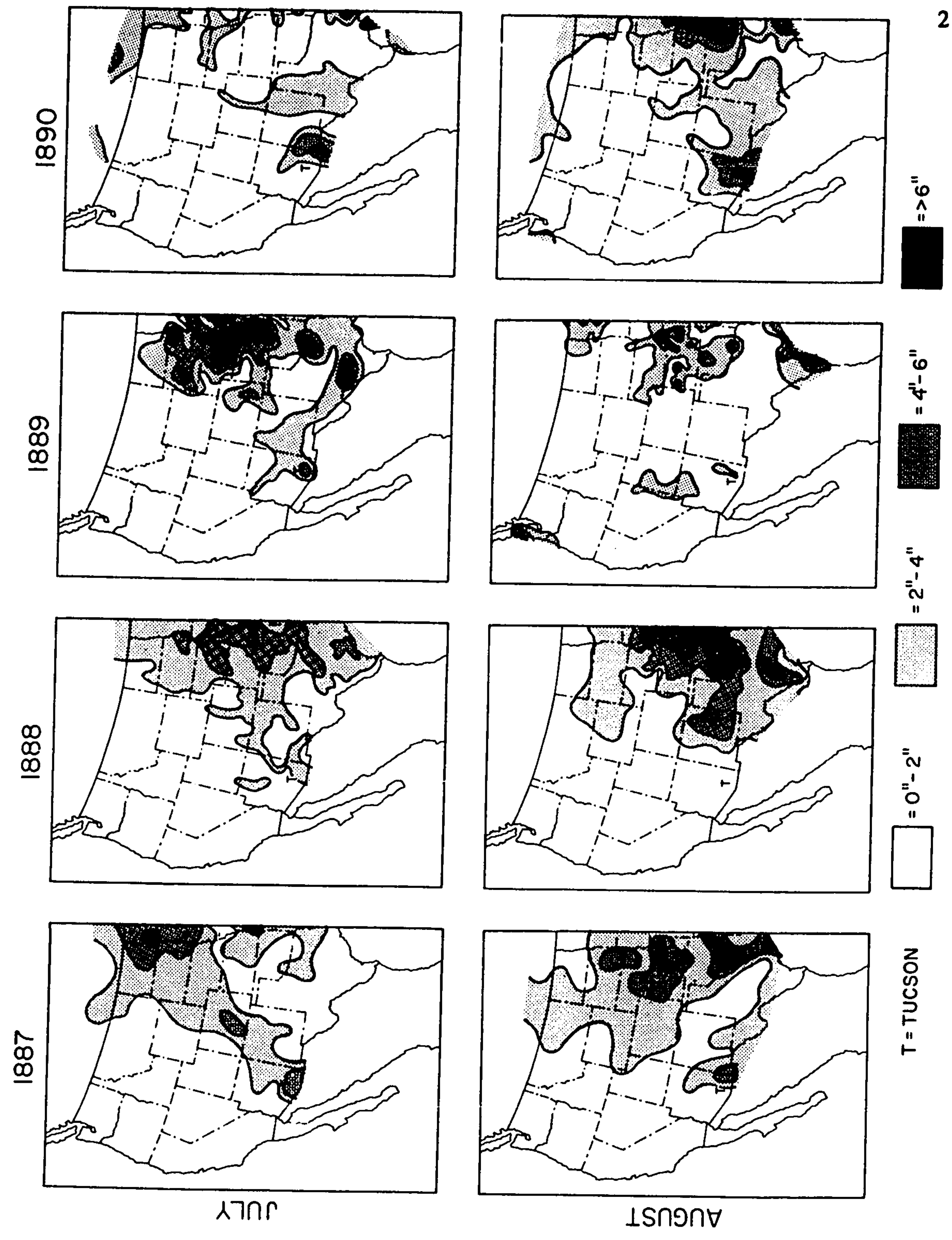


Figure 97B. Mapped summaries of July and August rainfall in the western United States from 1887 to 1890. Contours are < 2 in (<5.1 cm), 2-4 in (5.1-10.2 cm), 4-6 in (10.2-15.2 cm) > 6 in (>15.2 cm). Adapted from monthly summaries in Monthly Weather Reviews for each year.

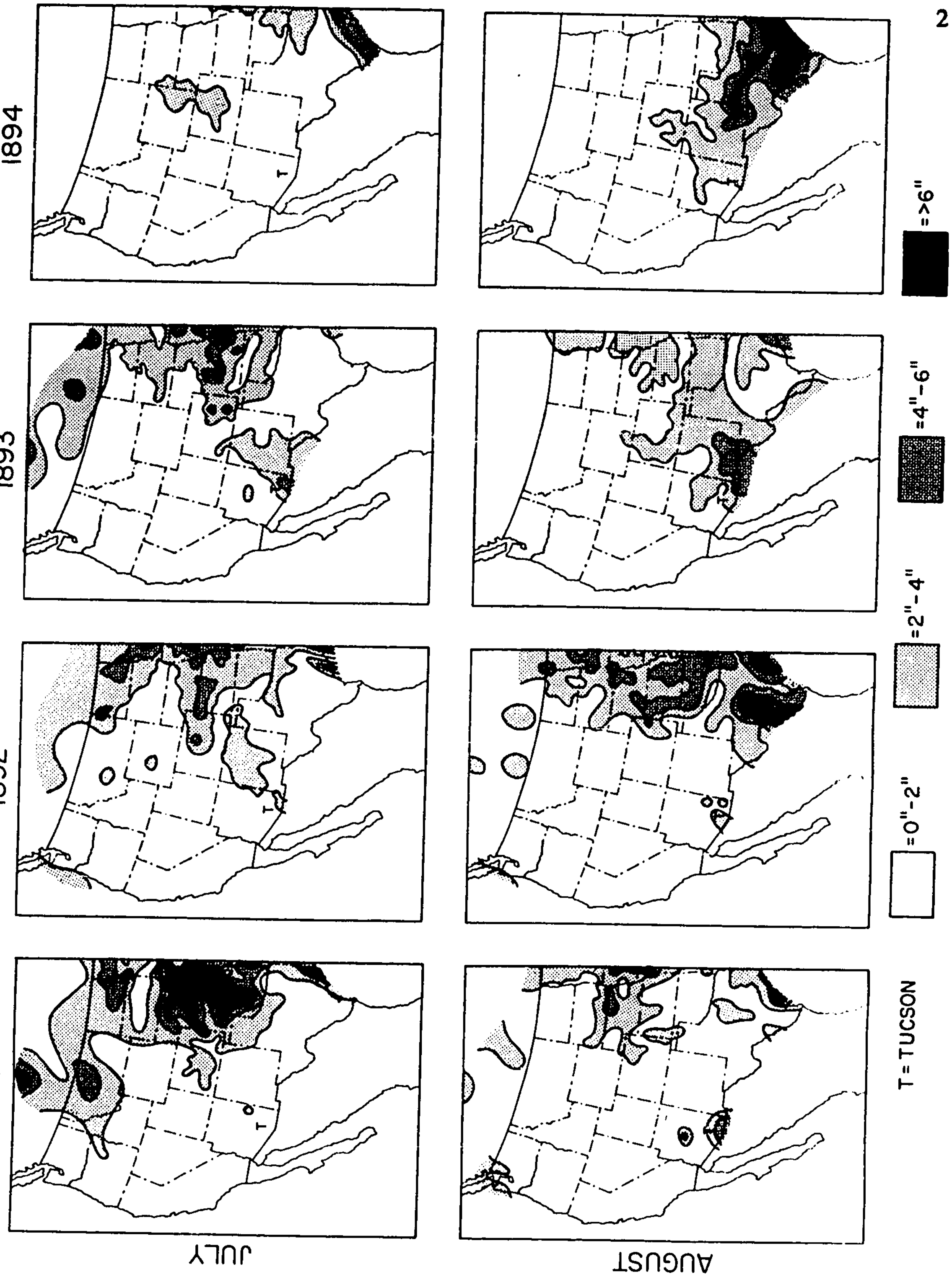


Figure 97C. Mapped summaries of July and August precipitation in the western United States from 1891 to 1894. Contours are < 2 in (<5.1 cm), 2-4 in (5.1-10.2 cm), 4-6 in (10.2-15.2 cm) > 6 in (>15.2 cm). Adapted from monthly summaries in Monthly Weather Reviews for each year.

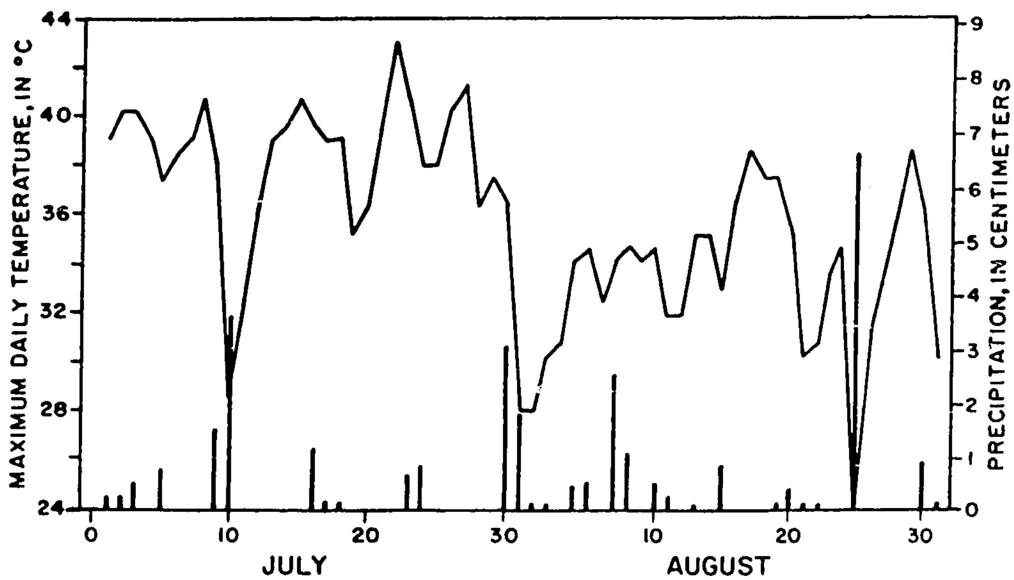


Figure 98. Daily rainfall totals (bars) and maximum daily temperatures at Camp Lowell, Tucson, Arizona in July and August 1890.

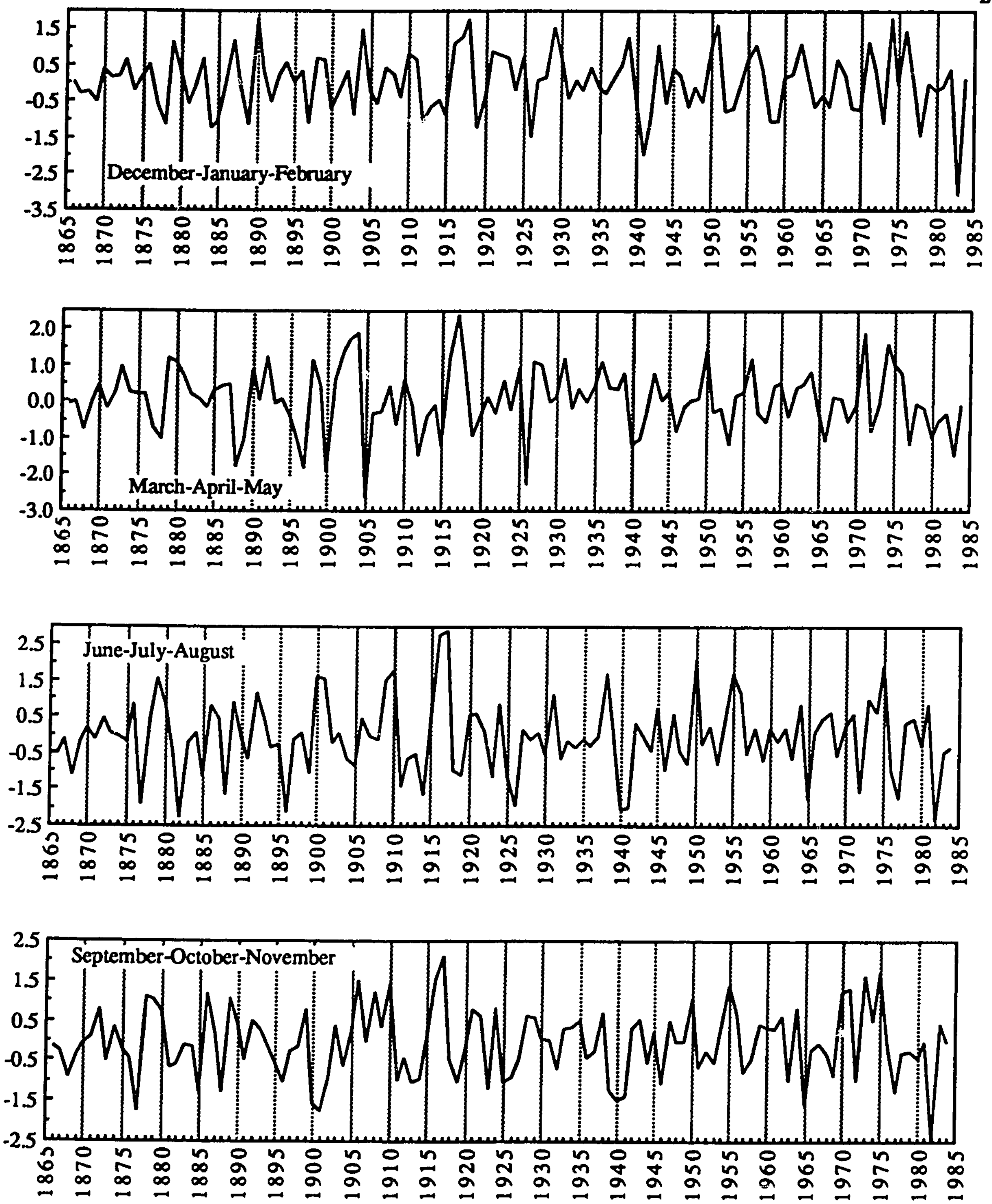


Figure 99. Seasonal values of the Southern Oscillation Index from 1866 to 1984 (from data in Ropelewski and Jones, 1987).

Aleutian Low), which is more characteristic of ENSO events (Emery and Hamilton, 1985). It bears repeating that the 1890 floods that initiated the Santa Cruz arroyo in the Tucson reach happened during a year of anti-ENSO conditions in the tropical Pacific, but during a summer when an enhanced trough in the westerlies apparently intruded into southern Arizona and northern Mexico, drawing moisture from the Pacific. The arroyo was extended upstream through the San Xavier Indian Reservation by winter floods in 1905 and 1915 and was modified greatly by floods from tropical storms in the fall of 1977 and 1983; all four years were ENSO events.

Human Impacts on a Desert Floodplain

Given that land use surely modified flow conditions along the Santa Cruz, particularly in the decade prior to 1890, it would have been much more surprising if arroyo-cutting had not happened than that it did. The question is when. The general pattern of land use, though intensifying around the time of arroyo-cutting, had actually been in place for a couple of centuries. Discontinuous arroyos existed in the Martinez Hill-San Xavier area as early as 1849, at least one of these blamed on early irrigation practices. However, even though the Santa Cruz must have carried large flows in the mid-nineteenth century (e.g., the late 1850s and 1860s), the reach near Tucson remained unentrenched until erosion of Sam Hughes' ditch in summer of 1890. Several developments in the 1880s deserve mention.

First, floods in the Santa Cruz Valley traveled as broad sheets of water which would coalesce wherever the floodplain narrowed, such as it does at the base of Sentinel Peak. In the 1880s, the resulting flow emptied into Silver and Warner's Lake. Pandemonium would strike while workers struggled to raise the floodgates. The dams were not engineered to control large flood peaks, but to store water for operation of mills and irrigation downstream. Should the dams wash out, as happened during floods in 1886 and 1887, the floodwaters would gather into a constricted channel and gain flow velocity and erosive power as they poured into the main acequias opposite Tucson. Yet, an arroyo still failed to develop in the reach below the dam.

Second, the irrigation technology of the day included intercept ditches (referred to as infiltration galleries in Cooke and Reeves, 1976). Starting some distance downstream, depending on the fall of the river, a ditch would be excavated at a lesser gradient than the dry river bed in order to intercept the near-surface underflow at the ditch heading. Thus, gravity flow could be carried to agricultural fields where the bottom of the ditch became level with the surface of the floodplain.

After a ruling denied water rights to downstream users where the perennial flow of the Santa Cruz became subterranean, Sam Hughes decided to build an intercept ditch in 1888. It was a homespun affair and Hughes was short of cash, so he failed to protect the heading properly. In fact, he expected the next season of flooding to further excavate the heading, saving him the expense of labor. In effect, Hughes had produced an artificial headcut, a fact widely acknowledged by Tucsonans during and after the 1890 floods. Had the intercept ditch never come about, it is difficult to say whether or not an arroyo still would have developed. But once it was started on August 4, 1890, subsequent floods that same summer extended the headcut upstream to Silver Lake. The headcut continued to migrate upstream during floods in the 1890s, 1900s, and 1910s, eventually forming a continuous arroyo well into the San Xavier Indian Reservation. What if several decades of low flow conditions, such as those between 1930 and 1960, had prevailed in the years after Sam Hughes had completed his intercept ditch? Would the arroyo still have developed?

The arroyo at Greene's Canal presents a similar dilemma. A diversion canal had been constructed in 1910 to channel floodwaters to a reservoir several kilometers west of the Santa Cruz River. The project engineer, P.E. Fuller, recognized that the capacity (17 cms) of the canal would be increased by erosion during future floodflows. To carry the then existing maximum flow of record (ca. 190 cms), the canal would have to be widened from 4.6 m in its present form to 61 m wide. Given the experiences upstream, near Tucson, Fuller understood that this could be accomplished during a single flood. And so, the arroyo at Greene's Canal developed during the 1915 flood. Again, had Greene's Canal not been constructed, it is doubtful that the arroyo would have developed during the 1915 flood. It is perhaps important to note that no other arroyos have developed in the lower Santa Cruz since the cutting of Greene's Canal in 1915.

In summary, catastrophic erosion failed to occur for at least 200 years prior to 1890, even though the floodplain in the area of San Xavier and Tucson had been heavily cultivated and grazed. On the Santa Cruz River, poorly-engineered dams and ditches concentrated floodflows, which were apparently of large magnitude and certainly of long duration, to initiate arroyos.

CHAPTER 9: CONCLUSIONS

The cutting of the Santa Cruz arroyo, however spectacular, was not a unique phenomenon. Arroyos were also initiated in various southwestern watersheds throughout the late 19th and early 20th centuries. The 1890 floods produced channel erosion on other streams in southern Arizona (specifically, the Rillito, San Simon, and San Pedro Rivers), but apparently not elsewhere in the Southwest. The dates of channel-cutting for many of these streams is uncertain due to sketchy historical information. Where historic data is adequate, however, it suggests the 1880s and 1890s as the time when the greatest number of streams became entrenched. Some arroyos, particularly those on the Colorado Plateau (Webb, 1985) and California (Cooke and Reeves, 1976) were not initiated until the 1900s and 1910s, at a time when arroyos that were inititiated earlier in southern Arizona were being extended by large floods.

Arroyo initiation and extension occurred, not during a dry period as some geologists would have it, but during relatively wet decades. These decades were characterized by strong and frequent ENSO activity in the tropical Pacific and high rainfall intensities in the Southwest. These high rainfall intensities occurred primarily during ENSO years, at least in southern Arizona and California. However, heavy July and August rains during a non-ENSO year produced the runoff that cut the arroyo along the Santa Cruz River. Most of this moisture apparently originated in the Pacific; advection into southern Arizona was apparently directed by an enhanced trough in the westerlies. Millennia-long proxy records on the Pacific Coast of the Americas indicate a major shift in oceanographic regime at ca. 1880, perhaps signalling the ocean's response to the end of the Little Ice Age. Late 19th century climate was different than that of the 20th century and, given the oceanographic record, may have differed from climatic regimes in previous centuries.

Changing flood probabilities with low-frequency (decadal) climatic fluctuations may partly explain both arroyo intitiation in the late 19th-early 20th centuries and non- or weak stationarity in annual flood series since then. Traditionally, both phenomena have been attributed to accelerated land use -- e. g., introduction of cattle and artificial concentrations of streamflows caused gullies and urbanization of floodplains and hillslopes increased flood magnitudes.

In summary, the arroyo of the Santa Cruz River formed when climatic conditions heightened the probabilities for occurrence of large floods in southern Arizona. Intensified floodplain use with the coming of the railroad, especially inadequate engineering of ditches and other water-control features, further augmented probabilities that any one of these floods would initiate an arroyo.

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