Historical Channel Changes on the San Pedro River, Southeastern Arizona

Arizona Geological Survey
Open-File Report 96-15

by Gary Huckleberry

OPEN-FILE REPORT

Published by the
ARIZONA GEOLOGICAL SURVEY
416 W. Congress, Suite 100
Tucson, Arizona 85701
(520) 770-3500

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June 1996

Revised October 1996

MAPS AVAILABLE FOR INSPECTION 2014

Research conducted in cooperation with CH2MHILL as part of the basic data collection for assessment of river navigability in Arizona at the time of Statehood (1912). Funding was provided by the Arizona State Land Department

PREFACE

by Philip A. Pearthree, Research Geologist

This report provides a general summary of the historical geomorphology of the San Pedro River in southeastern Arizona. Abundant information exists regarding changes in channel character on the upper San Pedro River from the vicinity of Benson south to the U.S. - Mexico border. Much less research and documentation is available for the lower San Pedro River. The current version of this report (10/96) includes corrections of several typographical errors relatively minor modifications of the original report based on information provided by Jack Smallhouse, a descendant of the Bayless family and a rancher in the Redington area. Changes are shown in **bold** type. Readers are encouraged to investigate reports and articles referenced in this report for more detailed information.

INTRODUCTION

The San Pedro River in southeast Arizona is by no means a major watercourse in the Southwest, but yet it is probably one of the most-studied rivers in the region. In particular, the upper San Pedro River has been the topic of study by geologists, geographers, hydrologists, and ecologists interested in environmental change (see Bahr, 1991 and Cooke and Reeves, 1976 for an overview). Since 1870, inhabitants of the San Pedro River Valley have witnessed substantial vegetation change (Bahr, 1991; Henderson and Minkley, 1986; Hastings, 1959; Hastings and Turner, 1965; Leopold, 1951) as well as changes in the geometry and hydrologic regime of the river (Cooke and Reeves, 1976; Hereford, 1993; Hereford and Betancourt, 1993). After decades of multidisciplinary research, the chronology of historic channel changes, at least on the upper San Pedro River, is well defined, although the reasons why the channel has changed are still debated (i.e., natural vs. anthropogenic forces).

What the physical characteristics of the San Pedro River were in 1912 is the topic of this report. Because the State of Arizona's claim to ownership of river channels within its boundaries hinges on their navigability at time of statehood, this report is designed to provide baseline information on the historical physical characteristics of the San Pedro River channel and how they have changed through time. It is clear that the San Pedro River was experiencing changes in channel geometry in 1912, but unfortunately there are few descriptions of the channel during that year. The physical characteristics of the river thus must be interpolated from descriptions made before and after 1912. Understanding the geomorphic properties of the river helps to refine the interpolation.

This report is divided into four primary sections. First, in order to place the San Pedro River in its geomorphic context, the physical setting and Cenozoic history of the San Pedro River Valley are presented. Second, an overview of the modern channel morphology is presented. Because of environmental and geomorphological contrasts between the upper and lower reaches of the San Pedro River (Tuan, 1962), the river is divided into two segments separated at a bedrock constriction at "The Narrows" (Figures 1 and 2) following the format of Heindl (1952a,b). This division is arbitrary since in reality environmental and geomorphic variables are transitional downstream. Third, previous archival investigations of historical channel changes on the San Pedro River are reviewed. Fourth, channel conditions in 1912 are extrapolated from descriptions before and after statehood. The changes described herein are viewed from a geomorphic perspective emphasizing natural channel dynamics. However, as is apparent from the historical record, many of the geomorphic changes on the San Pedro River are linked to land-use changes (e.g., grazing, deforestation, mining, etc.) within the valley. This report will avoid the debate over human vs. natural causes of channel changes and instead focus on the river's historical geomorphology.

PHYSICAL SETTING

The San Pedro River is located mostly in southeastern Arizona with a small portion of the upper watershed (ca. 14%) extending into Sonora, Mexico (Figures 1 and 2). Total drainage area of the basin is approximately 12,270 km^2 (4,720 mi^2). Aligned principally north-northeast, river elevation ranges from 1,300 m (4,260 ft) at the Mexican border to 586 m (1,920 ft) at its confluence with the Gila River over a distance of 198 km (123 mi). The San Pedro River is generally bounded by linear, north-trending fault-block mountains of diverse lithologies (Table 1). These mountains include the Mule, Dragoon, Winchester, and Galiuro mountains to the east, and the Huachuca, Whetstone, and Tortilla mountains to the west. Exceptions are the Rincon and Santa Catalina Mountains on the west side of the valley that have a broader and more triangular form. The river flows over basin fill except in a few places where bedrock rises to the surface, e.g., Tombstone Hills, The Narrows, Redington, the mouth of Aravaipa Creek, and Dudleyville (Heindl, 1952a,b; Figures 1 and 2). The Holocene flood plain of the San Pedro River lies in an axial trench near the center of the valley and is 1-3 km (0.5-1.5 mi) in width.

Variations in climate across the San Pedro River valley depend mostly on elevation. Overall, the valley is semiarid. The lower San Pedro River valley receives less than 38 cm (15 in) annually (Bahr, 1991). Some of the higher mountains bounding the valley average greater than 63 cm (25 in) annually. Mean July maximum temperatures range from 42° C (103° F) at Winkelman (633 m (2,075 ft) above sea level) to 32° C (89° F) at Ft. Huachuca (1,423 m (4,664 ft) above sea level) (Sellers and Hill, 1974). Despite its lower elevation, Winkelman has an average January minimum temperature of -2° C (29 ° F) compared to 1° C (34° F) for Ft. Huachuca. The lower winter minimum temperatures at Winkelman probably reflect microenvironmental effects such as cold-air drainage within the middle Gila River Canyon. Throughout the entire San Pedro Valley, the bulk of precipitation comes primarily during the summer when moisture from the south triggers convective thunderstorms. There is also a lesser rainy season in the winter characterized by regionally extensive, frontal storm systems from the north Pacific. Occasionally during September and October, the San Pedro Valley experiences heavy rains associated with dissipating eastern Pacific tropical storms that commonly result in heavy rain and flooding (Hirschboek, 1985; Webb and Betancourt, 1992).

Vegetation is predominantly Sonoran desertscrub in the lower San Pedro River Valley and Chihuahuan desertscrub in the upper San Pedro River Valley (Bahr, 1991; Brown, 1982). Historically, the upper San Pedro Valley was Chihuahuan desert grassland but has since been invaded by woody shrubs (Bahr, 1991; Hastings and Turner, 1965). Along the river is riparian vegetation including cottonwood (*Populus*), willow (*Salix*), mesquite (*Prosopsis*), and tamarisk (*Tamarix*). Oak woodlands dominate the higher elevations of the surrounding mountains with small areas of mixed conifer woodlands above 2,100 m (7,000 ft).

LATE CENOZOIC HISTORY

Most elements of the modern topography in the San Pedro Valley can be traced back to the Basin and Range Disturbance (8-15 Ma[1]) (Damon and others, 1984; Menges and Pearthree, 1989; Shafiqullah and others, 1980). Tensional stresses associated with the change from convergent to transform motion on the west coast plate boundary resulted in a largely north-northwest trending series of alternating basins and mountain blocks separated by steeply dipping normal faults . As the basins dropped, they simultaneously began filling with debris shed from adjacent mountain blocks. Many of the mountain fronts, especially those composed of granite, retreated from the axis of the valley forming broad pediments (Melton, 1965; Morrison, 1985; Tuan, 1962). The upper San Pedro Valley is broader and less dissected with a more gently sloping piedmont than the lower San Pedro Valley (Tuan, 1962). The basin sediments grade from coarse clastics (e.g., boulders, cobbles, and gravels) near the valley margins to finer sediment (sand, silt, and clay) and evaporites in the center (Agenbroad, 1967; Heindl, 1957a,b; Smith, 1963). Also, the upper basin fill stratigraphy is characterized by relatively fine-textured alluvial and lacustrine sediments overlain by coarse-textured fan deposits (Johnson and others, 1975; Melton, 1965; Smith, 1964). The thickness of the basin deposits vary. Geophysical data indicate maximum depths of 1,460-1,950 m (4,800-6,400 ft) in the upper San Pedro River Valley between the Huachuca and Mule mountains and 980-1,460 m (3,200-4,800 ft) in the lower San Pedro River Valley between the Santa Catalina and Galiuro mountains (Oppenheimer and Sumner, 1980).

Initially, drainage in the San Pedro Valley was internal within a series of separate topographic and structural basins, but eventually the basins filled and streams became integrated sometime during the late Pliocene to middle Pleistocene (Johnson and others, 1975; Lindsay and others, 1990). Since then, the San Pedro River and its tributaries have

[1] 1 My = 1,000,000 years; 1 Ma = 1 My before present; 1 ky = 1,000 years; 1 ka = 1 ky before present (North American Commisssion on Stratigraphic Nomenclature, 1983).

episodically downcut into the basin fill forming at least three major erosional surfaces or strath terraces (Bryan, 1926; Bryan and others, 1934; Chronic, 1983; Haynes, 1987; Smith, 1963). Valley degradation within the last 1 My has been due to a combination of slow, regional uplift of the Central Highland Zone in Arizona (Shafiqullah and others, 1980; Menges and Pearthree, 1989) and the San Pedro River's attempt to maintain a graded level or longitudinal profile of equilibrium (Mackin, 1948) as it became connected to the Gila River. During periods of temporary equilibrium the San Pedro River and its tributaries formed erosional strath terraces (Bull, 1991). Since latest Pleistocene and Holocene time, the river has deposited sediments within the axial trench of the basin. (Haynes, 1987; Hereford, 1993; Morrison, 1985). Stratigraphic investigations in the upper San Pedro River Valley by Haynes (1987) indicate that the San Pedro River has repeatedly incised and backfilled its flood plain during the Holocene (approximately 10 ka to present).

MODERN CHANNEL CHARACTERISTICS

Upper San Pedro River. Today the upper San Pedro River has a variably entrenched channel that meanders through a relatively mature gallery of riparian trees (Bahr, 1991). Upstream from Lewis Spring, vegetation within the entrenched channel is predominantly cottonwood and willow, whereas downstream tamarisk and mesquite prevail (Hereford, 1993). The depth of entrenchment generally increases downstream along the reach from the Mexican border to Fairbank (Ben Lomeli, BLM San Pedro Riparian Conservation Area, 1993, oral communication). Within the entrenched channel are coarse-grained point bars that deflect streamflow and play an important role in meandering and channel-widening (Meyer, 1989). The planview form of the channel (see Brice, 1984; Leopold and Wolman, 1957) is both braided and meandering: the low flow channel is braided with several branching channels, but the high flow channel is sinuous. Most of the sediment in the channel is coarser than that exposed in the arroyo walls, especially near the mouths of tributaries. Pre-entrenchment alluvium is composed predominantly of clay, silt, and fine sand with localized deposits of coarse sand, pebbles, and cobbles; commonly intercolated within these sediments are clayey, carbonaceous (cienega) soils (Haynes, 1987; Hereford 1993:5). Based on channel and bank alluvial particle sizes, the upper San Pedro River probably classifies as a mixed-load system (Schumm, 1977) transporting comparable amounts of suspended load and bedload.

Streamflow on the upper San Pedro River is variable spatially and temporally (Brown and others, 1981; Hirschboek, 1985). Like many arid and semiarid streams, the ratio of peak annual flood to mean annual discharge is high. Based on the state surface flow map by Brown and others (1981), the reach between Hereford and 5 km above Fairbank (Figure 1) contains a perennial baseflow less than 0.3 cms (10 cfs). From Fairbank to The Narrows, streamflow is intermittent.

Lower San Pedro River. Below The Narrows, the lower San Pedro River has an entrenched channel that tends to be wider and less sinuous than the upper San Pedro River. Unlike the upper reach, the longitudinal profile of the lower San Pedro River is convex (Heindl, 1952b; Tuan, 1962). The average gradient between the Narrows and Redington is approximately 3.4 m/km (18 ft/mi) whereas between Redington and Winkelman it is 4.2 m/km (22 ft/mi). Like the upper San Pedro River, the baseflow channel is braided and contains coarse-grained (pebbles and cobbles) point bars with the coarsest deposits located near the mouths of tributaries. Because the tributaries entering the lower San Pedro River are steeper and shorter in length than upstream tributaries, overall alluvial particle-sizes in the bank and channel increase downstream, a pattern that contrasts with most humid streams (Knighton, 1984). The lower San Pedro River probably classifies as a bedload system (Schumm, 1977). Vegetation is mostly mesquite and tamarisk along the flood plain, and except for short perennial segments where bedrock is at or near the surface, streamflow is intermittent (Agenbroad, 1967; Brown and others, 1981).

HISTORICAL CHANNEL CHANGES

With the exception of a few short segments confined by bedrock, the San Pedro River is an alluvial river and thus has the capability to adjust its channel shape, planform, and position with changing environmental conditions (Richards, 1982; Ritter, 1986:248). Specifically, alluvial rivers will adjust their depth, width, gradient, and hydraulic roughness to accommodate changing discharge and sediment load (Mackin, 1948; Leopold and Bull, 1979). Changes in channel shape and planform can occur at a variety of timescales ranging from 1 to 10,000 years. Arid and semiarid streams tend to be more susceptible to rapid changes in channel geometry (Graf, 1988) and require a greater amount of time to reform their original geometry following a disturbance (Wolman and Gerson, 1979). Rapid (1-10 years) changes in channel geometry and planform have been documented for the Gila River (Burkham, 1972; Huckleberry, 1993) and several of its tributaries (Betancourt, 1990; Cooke and Reeves, 1976; Pearthree and Baker, 1987) including the San Pedro River (Hereford, 1993). The channel adjustment that has received the most attention in the Southwest is entrenchment or arroyo-cutting (Betancourt, 1990; Cooke and Reeves, 1976; Webb, 1985). Many alluvial streams in the region including the San Pedro River experienced extensive entrenchment in the late 19th and early 20th centuries (Bahr, 1991; Bryan, 1926; Cooke and Reeves, 1976; Hastings, 1959; Hendrickson and Minckley, 1985; Hereford and Betancourt, 1993). Stratigraphic exposures of buried arroyos (Haynes, 1987; Waters, 1988) indicate that these rivers incised prehistorically as well.

Because of strong interest in the arroyo phenomenon, historical channel changes on the San Pedro River are well documented (e.g., Cooke and Reeves, 1976; Hereford and Betancourt, 1993). Most of the historical descriptions of the San Pedro River, however, are from the upper reach, and thus most geological investigations of channel change have focused south of The Narrows (Figure 1). Historical channel changes on the lower San Pedro River are less well defined. Channel changes on the upper reach need not necessarily be in tandem with those of the lower reach since bedrock constrictions present local base level controls and basin morphometry varies between the two reaches. Because of geomorphological contrasts between the upper and lower reaches, historical channel changes are reviewed for both reaches separately.

The chronology is divided into three parts. The first period (1697-1870) includes the earliest descriptions of the river during the Spanish, Mexican, and early part of the American periods. The second period (1871-1933) marks the beginning of permanent

Anglo settlement and the first cadastral surveys. The third period (1934-present) represents the period for which systematic aerial photography exists thus allowing for more objective analysis of channel changes. Maps summarizing channel changes since 1934 for the entire San Pedro River are available for inspection in the library of the Arizona Geological Survey in Tucson.

Upper San Pedro River

1697-1845. Historical descriptions of the San Pedro River begin in 1697 when Padre Eusibio Kino accompanied by Juan Manje made his 4th expedition into the Pimeria Alta (Burrus, 1971). They travelled down the entire length of the San Pedro River to its junction with the Gila River and described in their journals numerous Sobaipuri irrigation ditches and meadows. These descriptions imply the San Pedro River Valley had shallow water tables and was nonentrenched. Subsequent descriptions of the upper San Pedro River Valley during the Spanish and Mexican Periods are scant despite construction of the Presidio of Terrenate in Quiburi (Fairbank) in 1776 (Hereford and Betancourt, 1993; Kessel, 1966) and the presence of ranches on two land grants, the San Juan de las Boquillas y Nogales and the San Rafael de Valle, in 1823 (Bahr, 1991; Figure 1). Trapper James Ohio Patty (1833) visited the San Pedro River during the 1820's which he called "Beaver River" after trapping "200 skins". Although tainted by hyperbole, his accounts imply perennial streamflow throughout most of the San Pedro River.

More direct descriptions of upper San Pedro River begin with the Mexican-American War in 1846. Major Cooke (1938) and his Mormon Batallion marched along the upper San Pedro River from approximately Hereford to Benson (Figure 1) and described it as "a fine, bold, stream" where he and his men caught "fine trout" up to 45 cm (16 in) long (also in Hastings, 1959:62; Rodgers, 1965:16). During the U.S.-Mexico boundary survey if 1851, John Russel Bartlett (1854) also noted continuous streamflow in the upper San Pedro River, but he also noted that the river below St. David (Figure 1) contained steep banks approximately 3 m (9 ft) high (Bartlett, 1854; also in Hastings, 1951, and Hereford and Betancourt, 1993). Bartlett further noted that incision limited the ability to irrigate adjacent terraces. A few years later, Parke (1857:24) noted that the upper San Pedro River was variably incised from a few cm to as much as 5 m (15 ft). Immediately upstream from The Narrows (Figure 1), Hutton (1859) described the upper San Pedro River as having a width of approximately 4 m (12 ft) and a depth of 30 cm (12 in). Although Hereford (1993) cautions that some of these historical descriptions may be of steep banks on older terraces above the active channel, the cumulative archival evidence suggests that the upper San Pedro River was indeed discontinuously entrenched as early as 1850 (Henderson and Minckley, 1984:147), at least thirty years before the estimate of arroyo initiation made by Kirk Bryan (1926).

1871-1933. The first cadastral survey by the U.S. General Land Office (now the BLM) was performed within the upper San Pedro River Valley in 1873 (survey notes on file at the BLM in Phoenix). All of the section lines within townships crossed by the upper San Pedro River had been surveyed by 1901 with the exception of the original Mexican Land Grants (see Cooke and Reeves, 1976: Figure II.6). The survey notes and plat maps provide systematic descriptions of channel dimensions, particularly width and location. However, the survey notes are often cryptic and can be easily misinterpreted (see Bahr, 1991; Betancourt, 1990). For example, measurements of channel width are recorded, but these measurements were made normal to cadastral lines and thus usually do not represent true channel width. Also, whereas the G.L.O. plats are the first scaled maps showing channel location, the position of the channel is only surveyed where it crosses cadastral lines; channel locations between cadastral lines are interpolated. Nonetheless, the G.L.O. survey notes are the first systematic measurements of the San Pedro River and provide a base for analyzing historical channel change.

The first townships in the upper San Pedro River Valley to be surveyed were Townships T. 15, 16, and 17 S., R. 20 E., by Theodore White in 1873 (Figure 1). He later surveyed Township T. 18 S., R. 21 E. in 1881. Very few channel measurements are provided for Townships T. 19, 20, and 21 S., R. 21 E. and Townships T. 21 and 22 S., R. 22 E. due to the private land grants, and Townships T. 23 and 24 S., R. 22 E. were not surveyed until 1901 by Phillip Contzen. Following the procedure of Burkham (1972), measurements of channel width (normal to cadastral lines) were compiled (Appendix A) and averaged for each Township (Table 2). Between St. David and The Narrows (Figure 1), the channel width in 1873 averaged less than 11 m. Between the San Juan de las Boquillas y Nogales land grant and St. David, the channel width in 1881 averaged approximately 18 m. This agrees with historical descriptions of a relatively narrow channel (Hastings, 1959; Hereford and Betancourt, 1993).

Descriptions of the San Pedro River during the 1870's and 1880's increase in step with Anglo settlement (Rodgers, 1965). Streamflow diversions for irrigation and processing ore from the Tombstone Mining District increased during this period. This may have led to reaches on the upper San Pedro River becoming intermittent during periods of heaviest water use (Hereford and Betancourt, 1993). However, overall the area was characterized by shallow water tables. In fact, settlers in St. David destroyed beaver dams and drained local swamps in order to lower water tables and prevent malaria outbreaks (Rodgers, 1965). Descriptions of the river during this period are generally consistent with earlier descriptions, i.e., alternating entrenched and unentrenched reaches and overall perennial flow.

Beginning in the 1880's and continuing into the 1890's were a series of large floods that impacted the geometry of the upper San Pedro River (Hereford and Betancourt, 1993). Large floods occurred in 1886, 1887, 1890, and 1896. The impacts of these floods were variable, but overall they resulted in expanding the entrenched reaches upstream via knick-point retreat (Hastings, 1959; Hereford and Betancourt, 1993) and expanding channel width via bank cutting and collapse (Meyer, 1989). Cadastral survey notes confirm channel widening after 1890 (Cooke and Reeves, 1976; Appendix A). Average channel widths in Township T. 23 S., R. 22 E. and Township T. 24 S., R. 22 E. were 26 and 42 m, respectively (Table 2). The archival record also indicate that more segments of the upper San Pedro River were intermittent after 1890 (Hastings, 1959). This change in streamflow may be related to the large Pitaycachi earthquake that shook the region in 1887 and modified spring activity in the valley (DuBois and Smith, 1980). Drought may also have affected the baseflow. Bahr (1991) notes that one of the worst droughts on record occurred 1891-1893. This drought coincided with a record number of cattle in the

San Pedro Valley, and overgrazing undoubtedly increased the severity of the floods by increasing runoff and gullying (Carpenter and Bransford, 1921; Cooke and Reeves, 1976; Dobyns, 1981).

Almost the entire reach of the upper San Pedro River was entrenched by 1920 (Bryan, 1926; Hereford, 1993). Most of the channel changes in the early 20th century consisted of channel widening, although near Benson the channel may still have been incising (Carpenter and Bransford, 1921). In some reaches, the radii of meanders increased (compare channel positions in 1881 and 1988 in Sec. 22, T. 18 S., R. 21 E., Figure 3). At Contention, the river meandered over part of the old townsite (Bahr, 1991:69). Most of the widening and increased sinuousity occurred during large floods. The largest gaged flood on the upper San Pedro River occurred in September, 1926 and was estimated to have had a peak discharge of 2,800 m^3/s (100,000 ft^3/s). Although this estimate may be exaggerated, this flood nonetheless resulted in tremendous bank erosion and channel widening throughout the San Pedro River system (Hereford and Betancourt, 1993).

1934-1993. The first systematic aerial photographs were flown in 1935 and show a largely continuous streamflow within a sandy, braided channel. Channel widths measured normal to section lines on the 1935 photography are considerably greater than those recorded by the GLO surveyors (Table 2; Appendix A). [Channel changes between 1935 and the 1970's for the entire river were documented for this report; maps are available for inspection at the Arizona Geological Survey Library.] As mentioned above, some meandering reaches show significant changes in channel location during the last 60 years whereas other reaches show very little spatial changes. The frequency of large floods decreased during the 1940's, and 50's, as did the rate of channel widening (Hereford, 1993). Hereford's (1993) photographic analysis of the reach from Hereford to Contention (Figure 1) indicates that the entrenched channel reached its maximum width in the 1950's. Since then, alluvium has been accumulating within the entrenched channel. Removal of cattle from this reach in 1986 has resulted in increased vegetation within the channel which in turn has facilitated aggradation (Ben Lomeli, BLM, 1993, oral communication).

Lower San Pedro River

1697-1870. Descriptions of the lower San Pedro River during the Spanish, Mexican, and early American periods are less abundant than those for the upper reach since most of the ranching and agricultural activity took place upstream from The Narrows. In general, descriptions of the lower reach during this period are consistent: a small unentrenched stream with low but generally consistent streamflow. The numerous Sobaipuri irrigation ditches described by Kino and Manje (Burrus, 1971) imply that the river in 1697 was unentrenched, at least at the Sobaipuri villages. They also described marshy conditions indicating shallow water tables (Henderson and Minckley, 1985). The river also contained numerous beaver ponds and edible fish (Patty, 1833).

Like the upper reach, descriptions of the lower San Pedro River begin in earnest with the Mexican-American War in 1846. The archival record suggests that water tables were generally shallow, but there may have been some reaches below Mammoth that were seasonally dry. In November, 1846, Steven Watts Kearny expedition passed down the Gila River and camped on the lower San Pedro River approximately 2 km from its mouth. Several men kept journals describing the terrain including William Emory and Abraham Johnston. Emory (1848:75) noted that the San Pedro River was a "few yards wide and one foot deep", and Johnston (1848:592) commented that an active man could jump across the water. Six years later, Parke (1857:24-26) noted that at this reach (within a few km of the Gila River) "water sinks below the surface and rarely runs above it". This is the earliest reference to intermittent streamflow on the San Pedro River. Leach (1858; referenced in Brown and others, 1981) also noted no flow in reaches of the lower San Pedro River. Other indications are that water tables were still relatively high in the lower San Pedro Valley. Conditions were certainly marshy at Camp Grant located at the mouth of Aravaipa Canyon. Constructed in 1859, it was plagued by malaria and soon abandoned and moved to the base of the Pinaleno Mountains (Bahr, 1991; Henderson and Minckley, 1985).

1870-1933. Channel conditions changed little between 1870 and 1890 (Hastings, 1959). The first cadastral surveys were performed in the lower San Pedro Valley in 1877 and 1879 by John L. Harris. His survey notes indicate that the channel was generally less than 13 m wide (Appendix A; Table 3). Moreover, plat maps show several "acequias" or irrigation ditches implying nonentrenchment.

Beginning in 1890, the lower San Pedro River started to change. A series of large floods in 1890, 1893, 1894, and 1896 resulted in channel and widening and cutting **along some portions of the lower San Pedro** (Hereford and Betancourt, 1993). Newspaper accounts indicate considerable farm property was lost along the river during this decade, especially near Dudleyville. Channel changes during this period are perhaps best summarized by rancher C.H. Bayless (Bahr, 1991:111) who in 1900 noted:

> About 12 years ago the [lower] San Pedro Valley consisted of a narrow strip of subirrigated and very fertile lands. Beaver dams checked the flow of water and prevented the cutting of a channel. Trappers exterminated the beavers, and less grass on the hillsides permitted greater erosion, so that within four or five years a channel varying in depth from 3 to 20 feet was cut almost the whole length of the river. Every year freshets are carrying away new portions of the bottom lands.

By 1926, well defined channels existed along the lower San Pedro River and the dominant process was channel widening. The first cadastral survey of Township T. 14 S., R. 20 E. was in 1902 (Appendix A; Table 3) and records wider channel dimensions than those in adjacent townships that were surveyed 25 years earlier. **The main channel of the San Pedro did not become incised into the floodplain in the Redington area, however, until the large flood of September, 1926 (Jack Smallhouse, oral communication, 1996).**

1934-1993. The first systematic aerial photography of the lower San Pedro Valley was performed by the Soil Conservation Service in 1934. The photography reveals a shallow, braided channel within an incised flood plain. The channel is dramatically wider than in the

19th century (Appendix A; Table 3), especially downstream from Redington. The magnitude of widening during this period is greater on the lower reach, perhaps because the bank materials are coarser and more susceptible to erosion (Knighton, 1984:63; Schumm, 1977). Because of the wider, entrenched reach below Redington, changes in channel position through time are greater along this segment than any other part of the river (Figure 4). Channel widening has probably slowed if not stopped, and reaches below Mammoth are presently aggrading (Hereford and Betancourt, 1993).

CHANNEL CONDITIONS IN 1912

At the time of statehood, Arizona was experiencing one of the wettest periods in several centuries (Stockton, 1975). The period 1905-1917 was a time of above average winter and spring precipitation throughout the region. Some of the largest historical peak discharges within the Gila River system occurred during this period (Burkham, 1970; Ely, 1992, Huckleberry, 1993; Olmstead, 1919). The frequency of large floods on the San Pedro River increased as early as 1890, although Hereford (1993) notes that on the upper San Pedro River it was greatest between 1915 and 1940. This period of increased large flood frequency during the early part of the 20th century undoubtedly affected channel geometry and position. There is, however, no evidence that the baseflow of the river changed during this period.

Channel entrenchment had begun on the San Pedro River several decades before statehood, and most of the San Pedro River was already entrenched by 1912 (Bahr, 1991; Cooke and Reeves, 1976; Haynes, 1987; Hereford, 1993; Hereford and Betancourt, 1993). Exceptions were along short bedrock reaches (e.g., The Narrows) and a reach near Hereford that was only 0.5-1.0 m deep between 1910 and 1914 (Haury and others, 1959). In 1912, streamflow in the upper San Pedro River was largely perennial and shallow with less than 0.3 cms (10 cfs) baseflow, and the braided channel meandered within the confines of the arroyo banks. On the lower San Pedro River, streamflow was largely intermittent with short reaches of perennial flow (less than 0.3 cms (10 cfs)).

Because much of the river was already entrenched, flood flows during the wet period of the early part of this century were largely confined within the walls of the channel. This undoubtedly increased the velocity and magnitude of floods along the river since less water was retained as storage on the vegetated flood plain (Burkham, 1976). The incised channel also effectively concentrated flow and accentuated the erosive capacity of the river. Gravel bars within the channel deflected flow into the arroyo walls resulting in bank collapse and channel widening (Meyer, 1989). Thus the dominant channel process in 1912 was channel widening.

Although not as wide as shown in 1934 and 1935 photography, the entrenched channel of the San Pedro River in 1912 was considerably wider than what was recorded in the original cadastral survey notes of the 1870's and 1880's (Tables 2 and 3). On the upper San Pedro River, the width of the entrenched channel probably averaged between 40 and 80 m. On the lower San Pedro River channel widths were greater and more variable. Between The Narrows and Redington, the width of the entrenched channel probably averaged 40 to 80 m; downstream from Redington, channel width probably averaged 100-200 m. The depth of the modern entrenched channel varies **1 to 6 m (5 to 20 ft)** throughout the San Pedro River (Kottlowski and others, 1965:Figure 1) and probably does not differ substantially from channel depths in 1912.

SUMMARY

The San Pedro River is perhaps archetypal of alluvial streams in the Southwest that have experienced significant geomorphic and hydrological changes in response to climatic and/or human perturbations. Both the upper and lower reaches experienced channel entrenchment and widening during the last half of the 19th century and the first half of the 20th century (Bahr, 1991; Henderson and Minckley, 1985; Hereford, 1993; Hereford and Betancourt, 1993). By 1912, most of the San Pedro River had already experienced entrenchment. In the upper San Pedro Valley, the river generally consisted of a small braided stream with a baseflow of less than 0.3 cms (10 cfs) flowed between vertical banks 40-80 m wide. In the lower San Pedro Valley, the river also had a small braided channel that flowed between vertical banks, but intermittent reaches were common below Redington, and the channel banks were commonly wider than 100 m.

Based on Holocene stratigraphy (e.g., Haynes, 1987; Hereford, 1993), entrenchment and widening have occured in the past and appear to be a natural cycle within the fluvial system. This may simply be a fluvial adjustment to changes in the discharge:sediment load ratio. There is no denying that human disturbances have affected the magnitude and rate of channel change on the San Pedro River (Bahr, 1991; Dobyns, 1981), but the driving force in these changes are probably not anthropogenic. That some reaches are presently aggrading (Hereford, 1993) suggests that these fluvial adjustments are cyclical, and one can expect the entrenched channel to fill in the future.

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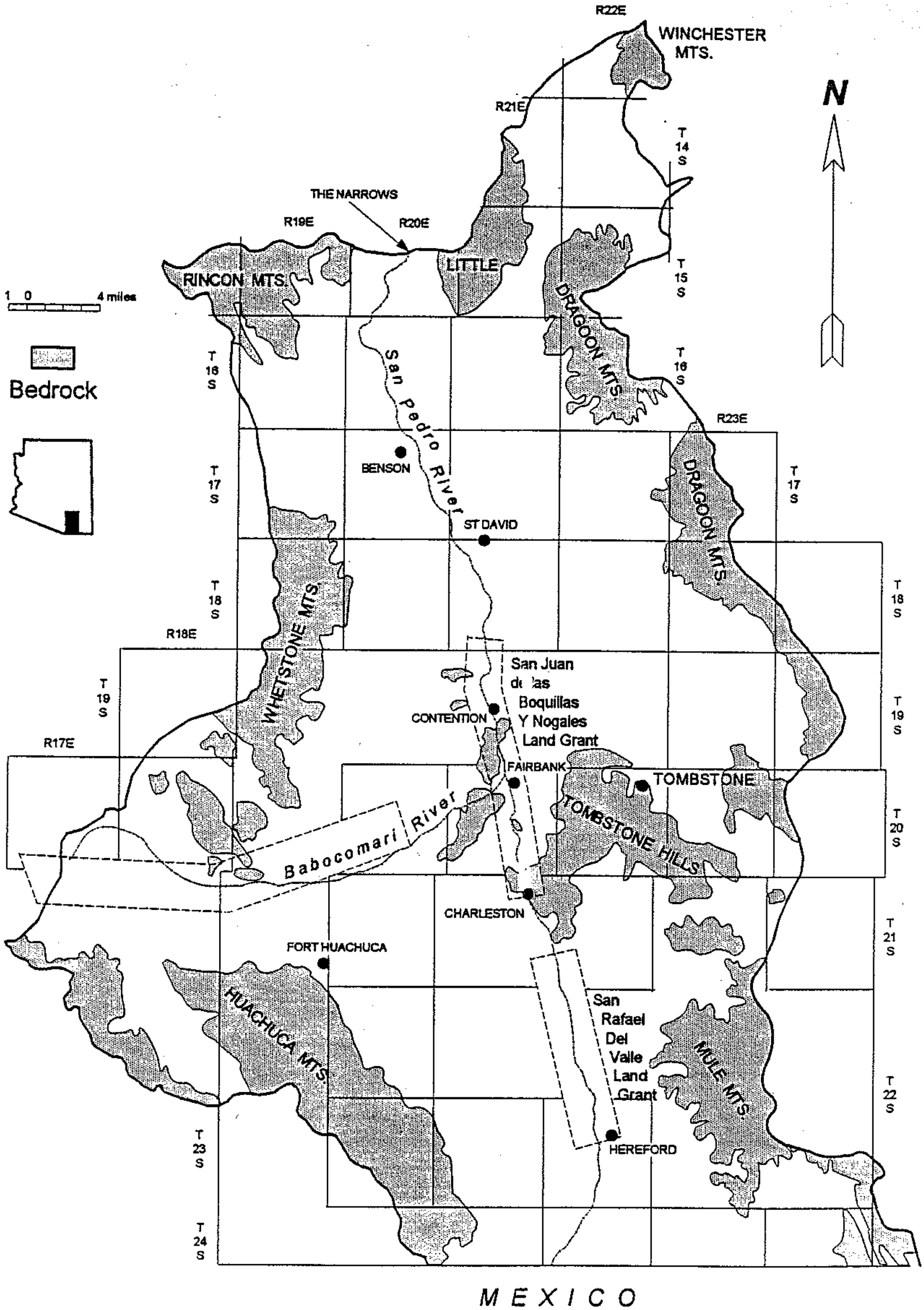

Figure 1. Upper San Pedro River (adapted from Heindl 1952a: Plate 9).

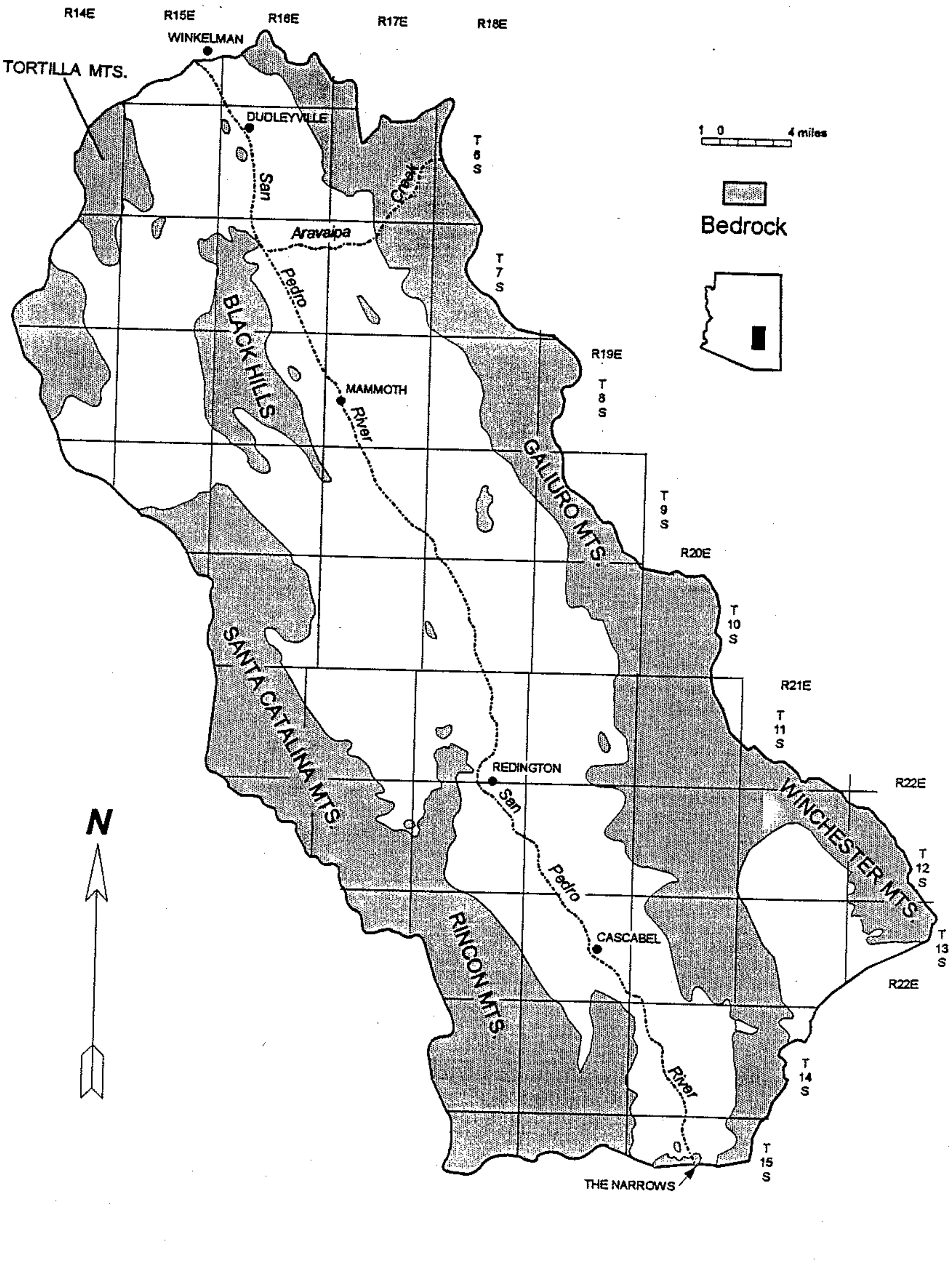

Figure 2. Lower San Pedro River (adapted from Heindl 1952b: Plate 10).

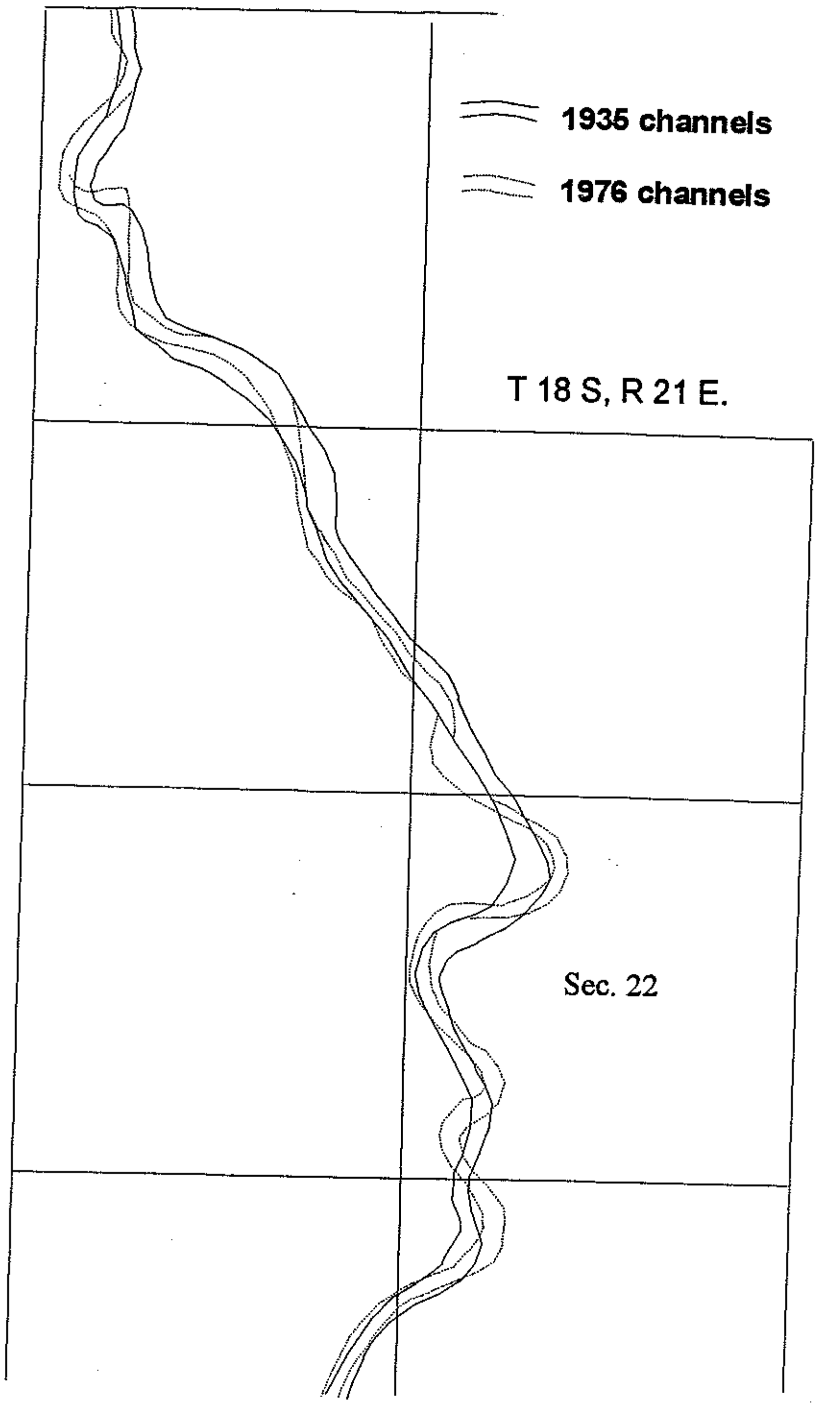

Figure 3. Channel changes in upstream from St. David, upper San Pedro River. Channel postions were documented using aerial photographs from 1935 and 1972. Channels in 1972 are shown only where they are different from those of 1935. Note the increased meander development in the southern portion of the map area. Section boundaries are shown by fine vertical and horizontal lines.

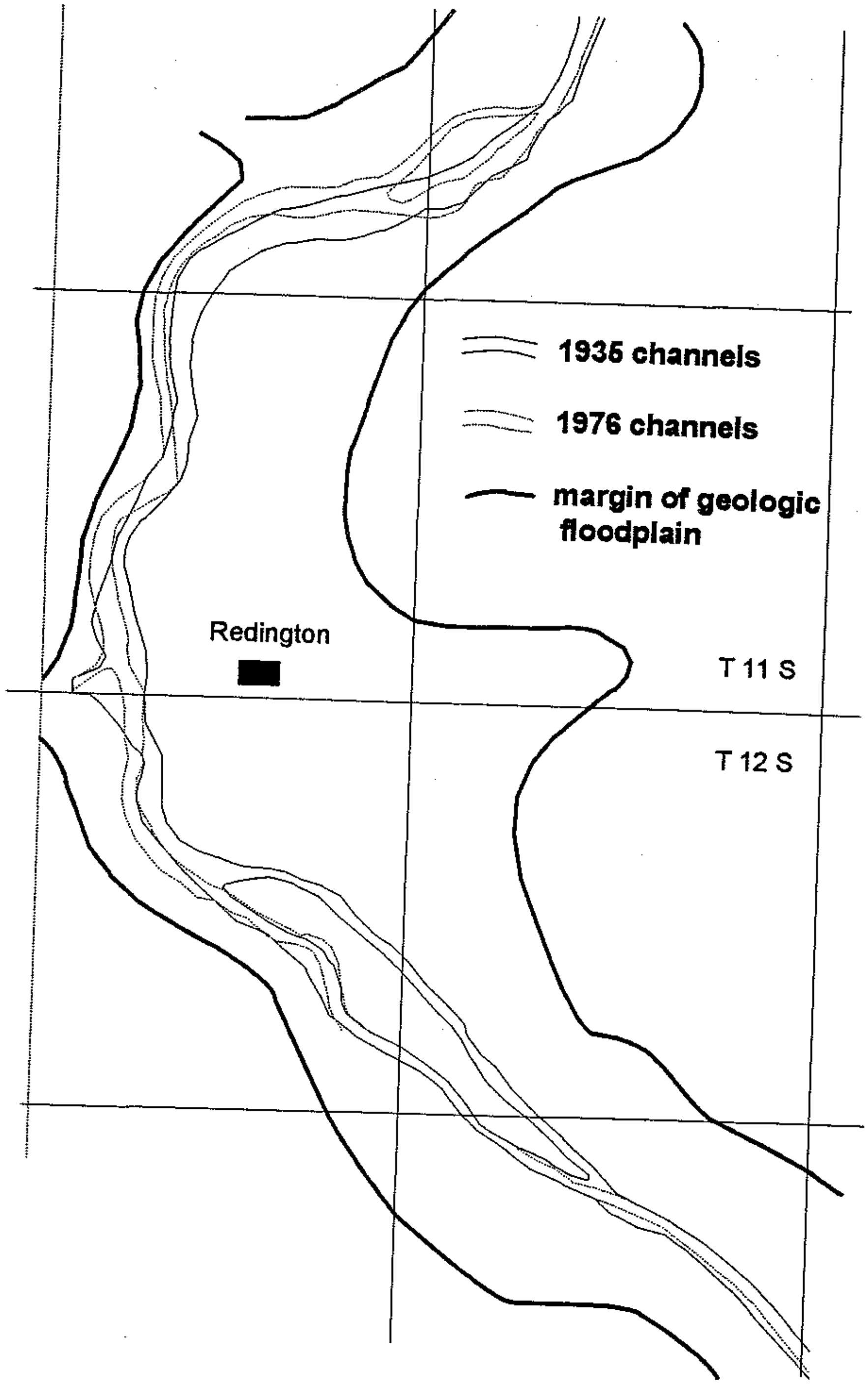

Figure 4. Channel changes in the Redington area, lower San Pedro River. Channel postions were documented using aerial photographs from 1935 and 1976. Channels in 1976 are shown only where they are different from those of 1935. The geologic floodplain is the extent of Holocene deposits associated with the San Pedro. Section boundaries are shown by fine vertical and horizontal lines.

Table 1. Major Mountain Ranges Bordering the San Pedro River, Arizona.

Mountain Range	Highest Elevation m (ft)	Prinicpal Lithologies*
Dragoon Mts.	2,293 (7,519)	Jurassic and Tertiary granite
Galiuro Mts.	2,300 (7,540)	Tertiary volcanics
Huachuca Mts.	2,887 (9,466)	Precambrian granite; Jurassic volcanics
Mule Mts.	2,012 (6,597)	Paleozoic limestone
Rincon Mts.	2,643 (8,666)	Tertiary-Cretaceous granite and gneiss
Santa Catalina Mts.	2,793 (9,157)	Tertiary-Cretaceous granite and gneiss
Tortilla Mts.	1,387 (4,547)	Tertiary-Cretaceous granite
Whetstone Mts.	2,022 (6,628)	Paleozoic limestone; Precambrian granite
Winchester Mts.	2,327 (7,631)	Cretaceous-Jurassic sedimentary and volcanic rocks; Precambrian granite

* Reynolds (1988)

Table 2. Mean Channel Widths for the Upper San Pedro River (Data from Appendix A).

Township	Year	mean	standard deviation	sample number
T. 15 S., R. 20 E.	1873*1	10.7	5.0	10
	1935*9	81.1	42.3	9
T. 16 S.; R. 20 E.	1873*2	8.2	2.1	9
	1935*9	72.5	24.3	8
T. 17 S., R. 20 E.	1873*3	8.6	1.4	8
	1935*9	87.1	30.4	7
T. 18 S., R. 21 E.	1881*4	17.8	3.8	8
	1935*9	112.0	57.2	5
T. 19 S., R. 21 E.	-			
T. 20 S., R. 21 E.	-			
T. 21 S., R. 21 E.	1901*5	22.3	3.9	3
	1935*9	150.0	50.0	3
T. 21 S., R. 22 E.	1909*6	79.6	72.4	2
	1935*9	75.0	7.1	2
T. 22 S., R. 22 E.	-			
T. 23 S., R. 22 E.	1901*7	25.8	11.5	6
	1935*9	92.5	31.0	4
T. 24 S., R. 22 E.	1901*8	41.9	8.0	5
	1935*9	98.0	29.5	5

*1: White; Book 811
*2: White; Book 804
*3: White; Book 845
*4: White; Book 889
*5: Contzen: Book 935
*6: Wright: Book 2167
*7: Contzen: Book 983
*8: Contzen: Book 989
*9: Measured from 1:62,500 scale aerial photography

Table 3. Average channel widths (m) within townships along the lower San Pedro River. Measurements made along section lines.

	Years		
Township	1877*1	1879*1	1934*2
T5S, R15E	9		291
T6S, R16E	14		373
T7S, R16E	11		225
T8S, R16E	11		
T8S, R17E	12		265
T9S, R17E	10		454
T9S, R18E		10	371
T10S, R18E		10	364
T11S, R18E		11	228
T12S, R18E		8	88
T12S, R19E		9	118
T13S, R19E		9	119

Note: *1 Compiled from survey notes (Harris, 1879, 1877).

*2 Measured from 1:62,500 scale aerial photography

Appendix A. Channel Width (m) for the San Pedro River Measured Along Cadastral Survey Lines.

Township and Range	Cadastral Line		Channel Width (1877)*1	Channel Width (1934)*22
T 5 S; R 15 E	S. boundary of Sec. 23		7.0	400
	E. boundary of Sec. 36		10.1	560
		average	8.6	480
		std. dev.	2.2	113
Township and Range	Cadastral Line		Channel Width (1877)*2	Channel Width (1934)*22
T 6 S; R 16 E	E. boundary of Sec. 6		10.1	400
	S. boundary of Sec. 5		13.1	280
	S. bounary of Sec. 8		12.1	300
	S. boundary of Sec. 17		10.1	265
	S. boundary of Sec 28		10.1	600
	S. boundary of Sec 32		10.1	500
		average	10.9	391
		std. dev.	1.3	136
Township and Range	Cadastral Line		Channel Width (1877)*3	Channel Width (1934)*22
T 7 S; R 16 E	E. boundary of Sec. 5		12.1	290
	S. boundary of Sec. 4		10.1	320
	S. boundary of Sec. 9		10.1	170
	E. boundary of Sec. 16		10.1	160
	S. boundary of Sec. 15		10.1	110
	E. boundary of Sec. 22		10.1	530
	S. boundary of Sec. 26		20.1	290
	S. boundary of Sec. 35		11.1	400
		average	11.7	284
		std. dev.	3.5	138
Township and Range	Cadastral Line		Channel Width (1877)*4	Channel Width (1934)*22
T 8 S; R 16 E	E. boundary of Sec. 2		10.1	560
	S. boundary of Sec. 1		12.1	120
	E. boundary of Sec. 12		10.1	channel parallel to boundary
		average	10.8	340
		std. dev.	1.2	311
Township and Range	Cadastral Line		Channel Width (1877)*5	Channel Width (1934)*22
T 8 S; R 17 E	S. boundary of Sec. 7		20.1	270
	S. bundary of Sec. 18		10.1	230
	E. boundary of Sec. 19		10.1	340
	S. boundary of Sec. 20		10.1	230
	S. boundary of Sec. 29		11.1	340
		average	12.3	282
		std. dev.	4.4	55

Appendix A. Channel Width (m) for the San Pedro River Measured Along Cadastral Survey Lines.

Township and Range	Cadastral Line		Channel Width (1877)*6	Channel Width (1934)*22
T 9 S; R 17 E	S. boundary of Sec. 4		10.1	330
	E. boundary of Sec. 9		10.1	190
	S. boundary of Sec. 10		10.1	340
	E. boundary of Sec. 15		10.1	400
	E. boundary of Sec. 23		10.1	560
	S. boundary of Sec. 24		10.1	340
	E. boundary of Sec. 25		10.1	640
		average	10.1	400
		std. dev.	0.0	152
Township and Range	Cadastral Line		Channel Width (1879)*7	Channel Width (1934)*22
T 9 S; R 18 E	S. boundary of Sec. 30		9.7	320
	S. boundary of Sec. 31		10.1	420
		average	9.9	370
		std. dev.	0.3	71
Township and Range	Cadastral Line		Channel Width (1879)*8	Channel Width (1934)*22
T 10 S; R 18 E	E. boundary of Sec. 6		10.5	190
	S. boundary of Sec. 5		10.1	530
	E. boundary of Sec. 8		10.1	660
	S. boundary of Sec 9		5.0	480
	S. boundary of Sec. 16		10.5	210
	E. boundary of Sec. 21		14.1	240
	S. boundary of Sec. 22		12.1	260
	E. boundary of Sec. 28		10.1	790
	S. boundary of Sec. 29		10.1	240
		average	10.3	400
		std. dev.	2.4	222
Township and Range	Cadastral Line		Channel Width (1879)*9	Channel Width (1935)*22
T 11 S; R 18 E	S. boundary of Sec. 3		10.2	270
	E. boundary of Sec. 10		16.8	channel parallel to boundary
	S. boundary of Sec. 10		9.3	190
	E. boundary of Sec. 15		10.2	340
	S. boundary of Sec. 14		9.0	100
	E. boundary of Sec. 27		9.9	320
	S. boundary of Sec. 27		9.9	310
		average	10.8	255
		std. dev.	2.7	93

Appendix A. Channel Width (m) for the San Pedro River Measured Along Cadastral Survey Lines.

Township and Range	Cadastral Line		Channel Width (1879)*10	Channel Width (1935)*22
T 12 S; R 18 E	E. boundary of Sec. 3		8.1	split channel
	S. boundary of Sec. 2		8.1	150
	E. boundary of Sec. 11		9.9	40
	E. boundary of Sec. 12		8.1	60
	E. boundary of Sec. 13		6.8	70
	E. boundary of Sec. 24		7.0	40
		average	8.0	72
		std. dev.	1.1	45
Township and Range	Cadastral Line		Channel Width (1879)*11	Channel Width (1935)*22
T 12 S; R 19 E	S. boundary of Sec. 19		8.1	130
	E. boundary of Sec. 30		8.1	channel parallel to boundary
	S. boundary of Sec. 29		9.9	60
	S. boundary of Sec. 32		8.1	120
		average	8.6	103
		std. dev.	0.9	38
Township and Range	Cadastral Line		Channel Width (1879)*12	Channel Width (1935)*22
T 13 S; R 19 E	E. boundary of Sec. 5		9.9	110
	S. boundary of Sec. 4		6.9	160
	E. boundary of Sec. 9		8.1	240
	S. boundary of Sec. 10		7.5	210
	S. boundary of Sec. 15		10.8	80
	E. boundary of Sec. 22		8.1	320
	S. boundary of Sec. 23		9.0	110
	E. boundary of Sec. 26		8.1	210
	S. boundary of Sec. 25		9.0	80
	E. boundary of Sec. 36		9.1	40
		average	8.7	156
		std. dev.	1.2	88
Township and Range	Cadastral Line		Channel Width (1902)*13	Channel Width (1935)*22
T 14 S; R 20 E	S. boundary of Sec. 6		69.3	100
	E. boundary of Sec. 7		19.8	40
	S. boundary of Sec. 8		29.7	50
	S. boundary of Sec. 17		15.0	45
	E. boundary of Sec. 20		33.9	80
	S. boundary of Sec. 21		33.9	80
	S. boundary of Sec. 28		15.6	80
	E. boundary of Sec. 33		23.7	channel parallel to boundary
		average	30.1	68
		std. dev.	17.5	23

Appendix A. Channel Width (m) for the San Pedro River Measured Along Cadastral Survey Lines.

Township and Range	Cadastral Line		Channel Width (1873)*14	Channel Width (1935)*22
T 15 S; R 20 E	S. boundary of Sec. 4		19.8	80
	E. boundary of Sec. 9		19.8	70
	S. boundary of Sec. 10		6.0	50
	S. boundary of Sec. 15		6.0	50
	E. boundary of Sec. 21		9.9	150
	E. boundary of Sec. 20		9.9	90
	S. boundary of Sec. 20		7.8	50
	E. boundary of Sec. 29		7.8	channel parallel to boundary
	S. boundary of Sec. 28		9.9	40
	E. boundary of Sec. 32		9.9	150
		average	10.7	81
		std. dev.	5.0	42

Township and Range	Cadastral Line		Channel Width (1873)*15	Channel Width (1935)*22
T 16 S; R 20 E	E. boundary of Sec. 6		8.1	120
	S. boundary of Sec. 6		9.9	40
	E. boundary of Sec. 7		12.0	50
	E. boundary of Sec. 8		6.0	80
	S. boundary of Sec. 9		6.0	60
	S. boundary of Sec. 16		6.0	70
	S. boundary of Sec. 21		8.1	80
	S. boundary of Sec. 28		8.1	80
	E. boundary of Sec. 33		9.9	channel parallel to boundary
		average	8.2	73
		std. dev.	2.1	24

Township and Range	Cadastral Line		Channel Width (1873)*16	Channel Width (1935)*22
T 17 S; R 20 E	E. boundary of Sec. 3		6.0	130
	S. boundary of Sec. 2		8.1	70
	S. boundary of Sec. 11		9.9	50
	S. boundary of Sec. 14		9.9	100
	E. boundary of Sec. 23		8.1	80
	S. boundary of Sec. 24		8.1	120
	S. boundary of Sec. 25		9.9	60
		average	8.6	87
		std. dev.	1.4	30

Appendix A. Channel Width (m) for the San Pedro River Measured Along Cadastral Survey Lines.

Township and Range	cadastral line		Channel Width (1881)*17	Channel Width (1935)*22
T 18 S; R 21 E	E. boundary of Sec. 6		19.8	channel parallel to boundary
	S. boundary of Sec. 5		13.8	60
	S. boundary of Sec. 8		9.9	190
	E. bundary of Sec. 17		19.8	channel parallel to boundary
	S. boundary of Sec. 16		19.8	100
	S. boundary of Sec. 21		19.8	60
	E. boundary of Sec. 29		19.8	channel parallel to boundary
	S. boundary of Sec. 29		19.8	150
		average	17.8	112
		std. dev.	3.8	57
Township and Range	Cadastral Line		Channel Width (1901)*18	Channel Width (1935)*22
T 21 S; R 21 E	E. boundary of Sec. 11		20.1	150
	S. boundary of Sec. 12		20.1	100
	E. boundary of Sec. 13		26.8	200
		average	22.3	150
		std. dev.	3.9	50
Township and Range	Cadastral Line		Channel Width (1909)*19	Channel Width (1935)*22
T 21 S; R 22 E	S. boundary of Sec. 18		28.4	70
	S. boundary of Sec. 19		130.8	80
		average	79.6	75
		std. dev.	72.4	7
Township and Range	Cadastral Line		Channel Width (1901)*20	Channel Width (1935)*22
T 23 S; R 22 E	S. boundary of Sec. 15		20.1	50
	E. boundary of Sec. 21		20.1	channel parallel to boundary
	E. boundary of Sec. 21		14.0	channel parallel to boundary
	S. boundary of Sec. 22		40.3	90
	E. boundary of Sec. 28		20.1	120
	S. boundary of Sec. 18		40.3	110
		average	25.8	93
		std. dev.	11.5	31
Township and Range	Cadastral Line		Channel Width (1901)*21	Channel Width (1935)*22
T 24 S; R 22 E	S. boundary of Sec. 4		50.3	150
	E. boundary of Sec. 8		40.3	80
	S. boundary of Sec. 8		48.3	80
	E. boundary of Sec. 18		30.2	90
	S. boundary of Sec. 18		40.3	90
		average	41.9	98
		std. dev.	8.0	29

Appendix A. Channel Width (m) for the San Pedro River Measured Along Cadastral Survey Lines.

*1 Harris; Books 633, 1477		*12 Harris; Books 780 and 1474	
*2 Harris; Books 672; 1477		*13 Jacobs; Book 879	
*3 Harris; Books 686, 1477		*14 White; Book 811	
*4 Harris, Books 698, 1477		*15 White; Book 804	
*5 Harris; Book 699		*16 White; Book 845	
*6 Harris; Books 733, 1477		*17 White; Book 889	
*7 Harris; Books 734, 1474		*18 Contzen; Book 935	
*8 Harris; Book 752		*19 Wright; Book 2167	
*9 Harris; Book 721		*20 Contzen; Book 983	
*10 Harris; Books 762, 1474		*21 Contzen; Book 989	
*11 Harris; Books 763 and 1474		*22 Measured from 1:62:500 scale aerial photography	