NAVIGABILITY ALONG THE NATURAL CHANNEL OF THE SANTA CRUZ RIVER

(From the Mexican border
to the mouth at the Gila River
near Buckeye, Arizona)

An assessment based on history, hydrology, hydraulics and morphology

by

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EXECUTIVE SUMMARY

This Report is an assessment of the navigability of the natural channel of the Santa Cruz River that uses hydraulic geometry methods that project hydrologic information into the past. The assessment is for the 180 mile reach of the Santa Cruz River from the international border to the mouth at the Gila River. The purpose is to determine if this reach of the Santa Cruz River was susceptible to navigation at the time of Arizona statehood (February 14, 1912) in its ordinary and natural condition. This report is being prepared for proceedings before the Arizona Navigable Stream Adjudication Commission (ANSAC).

For purposes of this assessment, I have used the following test for determining navigability

> We hold that, to prove navigability of an Arizona watercourse under the federal standard for title purposes, one must merely demonstrate the following: On February 14,1912, the watercourse, in its natural and ordinary condition, either was used or was susceptible to being used for travel or trade in any customary mode used on water. *See The Daniel Ball,* 77 U.S. (10 Wall.) at 563, 19 L.Ed. 999.

Defenders of Wildlife v. Hull, 199 Ariz. 411,426, 18 P.3d 722 (App. 2001). :Additional legal analysis is provided in a memorandum submitted by the Arizona Center for Law in the Public Interest to ANSAC on Sept. 12, 2013 regarding the navigability of the Santa Cruz River (Case No. 03-002-NAV).

This assessment used a systematic three-step procedure to first determine the natural condition of the Santa Cruz River, and then evaluate its susceptibility to navigation in that condition. This approach is necessary because the long history of human activities that greatly altered the flow and channel morphology greatly challenged this evaluation of the navigability. First, the natural hydrology was defined and expressed in a typical flow-duration curves of daily discharge for the study reach. Channel geometry was then calculated by applying empirical relations that utilize both the flow characteristics from step 1 and sediment characteristics of the Santa Cruz River. Finally, navigability was estimated using two independent methods of federal agencies that use information from steps 1 and 2. Published information and standard engineering hydraulic, hydraulic geometry and hydrologic methods were used to accomplish the three steps.

Important hydrologic characteristics are:

- The Santa Cruz River drained about 533 square miles at the upper end of the study reach and about 8,581 square miles at the lower end. The watershed was hydrologically diverse because of the diversity of climate, geology and topography. The mountainous areas of the south and central parts of the watershed typically received more than 20 inches of precipitation per year. The hot-dry northern areas typically received less than 8 inches of precipitation per year. Precipitation fell during two distinct periods--late summer and midwinter. Some snow accumulated in the higher mountains and typically melted and ran off in the spring.

- When rain fell onto the land in the Santa Cruz River watershed it started moving according to basic principles of hydrology. A portion of the precipitation seeped into the ground to replenish ground water. Some of the water flowed downhill on the land surface as direct runoff and appeared in surface streams that were unaffected by artificial diversions, storage, or other works of man in or on the stream channels. In the Santa Cruz River watershed, most of the runoff from storms reached the river channel directly on the land surface via overland flow, flow in rills, creeks and streams. Direct runoff was seasonal because the storms were seasonal and provided runoff for navigation for part of each year.

- The portion of the water that replenished the ground water was very important for the susceptibility of the Santa Cruz River to navigation. Under natural conditions the water that replenished the ground water was temporarily stored, and later discharged to the rivers at springs and seeps in the watershed. This base runoff was released from storage during dry periods. Because precipitation, and therefore direct runoff, was seasonal and there are a few months each year with little precipitation, the base runoff provided perennial flow for navigation to the Santa Cruz River.

Important hydraulic characteristics under natural conditions at statehood were:

- The Santa Cruz River constructed its own geometry between river mile 78 in the Picacho area to river mile 180 at the Mexican border and this geometry is computed using established runoff and sediment characteristics of rivers and the runoff and sediment characteristics of the Santa Cruz River.

- The natural flow in the Santa Cruz River was both perennial and intermittent with a mean annual flow at the Mexican border, Rillito Creek and the Picacho area of 29, 60 and 54 cubic feet per second, respectively. The corresponding widths and depths of flow were 24, 35 and 33 ft and 2.3, 2.9 and 2.8 ft, respectively. Average velocity of flow was less than about 3 ft/sec.

Important navigability characteristics were:

- The depth and current (velocity) of the Santa Cruz River flow were important: too little depth and too much velocity limited navigability. Most of the time flow depth was sufficiently great and flow velocity was sufficiently small for navigability of small watercraft along the Santa Cruz River.

- Navigability was independent of undesirable conditions such as temporary braiding of the river channel following floods, low flow from severe droughts and flow variability because these characteristics are related to how the river might have been used for navigation rather than the navigability.

Conclusion:

Based on all the hydrologic and hydraulic information, data and analysis contained in this report, it is the author's opinion that the natural channel of the Santa Cruz River, from the Mexican border (river mile 180) to the Picacho-Redrock area (river mile 78), was susceptible to navigation 75 % of the time during a typical year at the time of Arizona statehood in its ordinary and in its natural condition.

INTRODUCTION

This report and analysis were undertaken to assess the navigability of the Santa Cruz River in its natural condition, at the time of Arizona statehood for presentation to ANSAC. This analysis is based on (1) my knowledge and expertise concerning hydrology, hydraulics and fluvial processes, in general, and the application of this knowledge to the Santa Cruz River in central and southern Arizona, in particular, (2) the documents of prior ANSAC studies, (3) published reports by the U. S. Geological Survey and other Federal agencies, and (4) federal definitions of navigable and natural flow. The 180 mile reach of the Santa Cruz River from the international border to the mouth at the Gila River is shown in Figure 1.

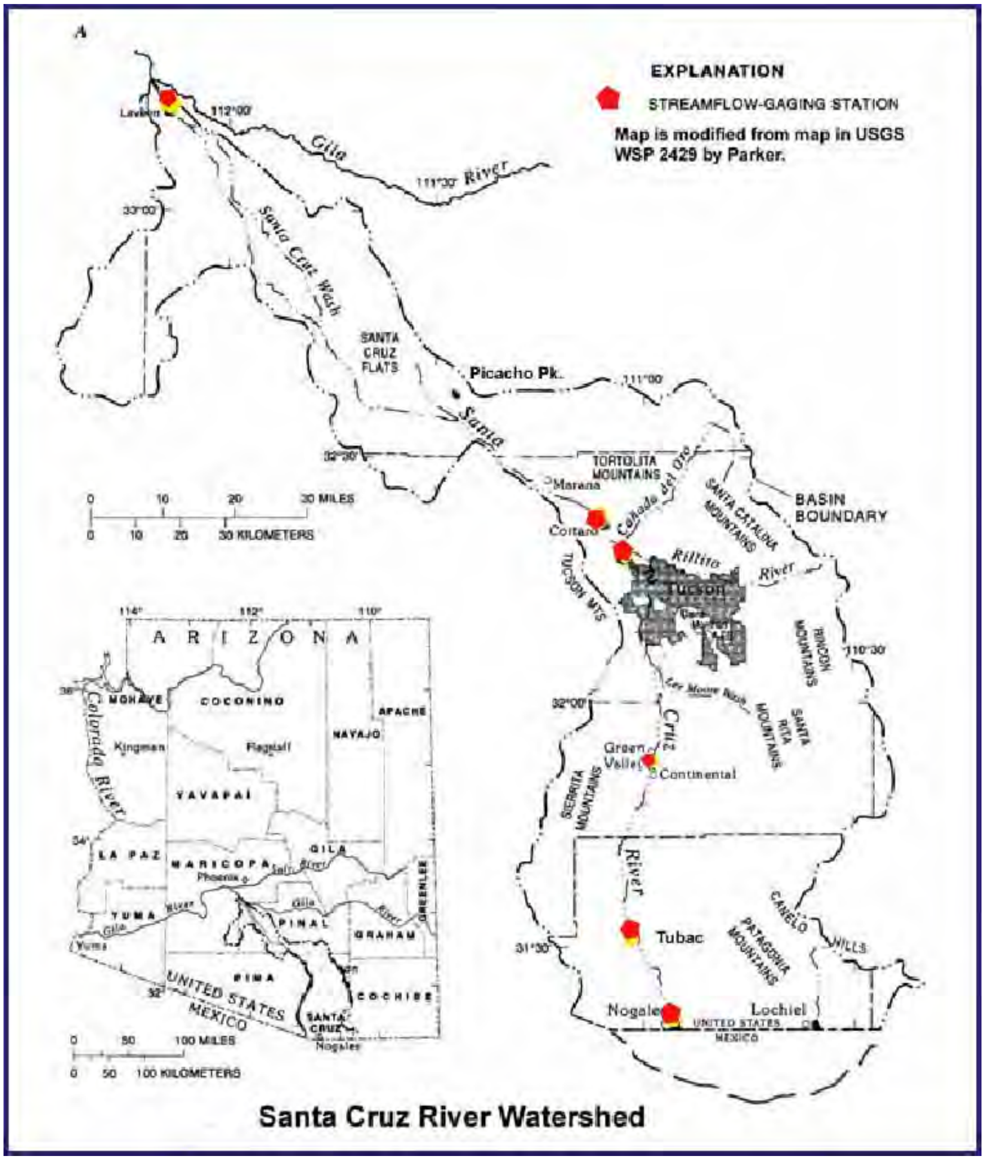


Figure 1.-- Watershed.

The test for determining navigability used in this analysis is from *Defenders of Wildlife v. Hull*, 199 Ariz. 411,426, 18 P.3d 722 (App. 2001):

> We hold that, to prove navigability of an Arizona watercourse under the federal standard for title purposes, one must merely demonstrate the following: On February 14,1912, the watercourse, in its natural and ordinary condition, either was used or was susceptible to being used for travel or trade in any customary mode used on water. *See The Daniel Ball*, 77 U.S. (10 Wall.) at 563, 19 L.Ed. 999.

Additional legal analysis is set forth in a memorandum submitted by ACLPI to ANSAC on Sept. 12, 2013 regarding the navigability of the Santa Cruz River (Case No. 03-002-NAV).

This river engineering report evaluates the ability of the natural channel of the Santa Cruz River to accommodate navigation. The necessary studies are channel widths, velocities, stability and depths at various seasons and locations. The question "*was the natural river channel susceptible to travel?"* is answered.

General approach

The ability to navigate on a river encompasses many factors such as the amount of flow in the river channel, the width and depth of flow in the channel, the type of vessel and the purpose of the travel. Obviously, there must be a minimum depth of water in the channel because even the draft of a canoe will be a few inches. There are other factors of an economic and commercial nature that may be less obvious. These non-hydraulic factors, while important to the actual performance of navigation, are not included in this assessment of navigability.

To make a reliable evaluation of navigability under the federal test, the anthropogenic impacts, such as the many diversions along the Santa Cruz River and its tributaries for irrigation by settlers, should be adjusted for because the diversion of flow may have affected the navigability. Two reports describe the hydrological and geomorphological characteristics of the Santa Cruz River before and at the time of Statehood and compare those characteristics to those of the present day. These two reports document important information regarding the history of the Santa Cruz River, especially the long history of human impacts and associated changes of channel morphology and hydrology of the watershed:

> Fuller, J. E., 2004, Arizona Stream Navigability Study for the Santa Cruz River, Gila River Confluence to Headwaters. Original prepared by SFC Engineering Company in November 1996; revised by Fuller in January 2004.
>
> Wood, M. L, House, P. K., and Peatthree, P. A., 1999, Historical Geomorphology and Hydrology of the Santa Cruz River, Open-File Report 99-13, AZ. Geological

Survey; supported by the Arizona State Land Department as part of their efforts to gather technical information for a stream navigability assessment, 96p.

My analysis in this Report is based on my knowledge of the watershed, Federal Land Surveys (Appendix A), miscellaneous information in Appendices B to D and information in the two aforementioned reports. I only analyzed the segment of river located north of the Mexican border.

Along the upper Santa Cruz River, south of Picacho-Redrock area, the channel generally lies within an inner valley created within broad, dissected pediments and alluvial basin deposits and flanked by mountains. The reach below the present site of Valencia Road was described in 1871 as having a channel with vertical banks 60 feet apart and up to 10 feet high. By the time of statehood in 1912, there was a deep channel, perhaps more than 20 feet deep, well into what is now the San Xavier Indian Reservation.

In 1915 the Federal Land Survey (Appendix A pages 19-20) showed the channel of the Santa Cruz River was incised 12-20 ft and the "trench" was from 154 ft to 317 ft wide. All the base flow seeped into sediments about 3 miles north of the San Xavier Del Bac mission. The same survey showed the river as meandered. According to page 56 of the survey instruction in affect at that time (General Land Office, June 30, 1904, Manual of Surveying Instructions for the Survey of Public Lands of the United States and Private Land Claims; Commissioner of the General Land Office, Washington, 1894.) meandering is as follows:

MEANDERING.

1. Proceeding *down* stream, the bank on the *left* hand is termed the *left bank* and that on the *right* hand the *right bank*. These terms will be universally used to distinguish the two banks of a river or stream.

2. Navigable rivers, as well as all rivers not embraced in the class denominated "navigable," the right-angle width of which is three chains and upwards, will be meandered on both banks, at the ordinary *mean high water mark*, by taking the general courses and distances of their sinuosities, and the same will be entered in the field book. Rivers not classed as navigable will not be meandered above the point where the average right-angle width is less than three chains. Shallow streams, without any well-defined channel or permanent banks, *will not be meandered*; except tide-water streams, whether more or less than three chains wide, which should be meandered at ordinary high-water mark, as far as tide-water extends.

In my analysis, the effects of climate change, if any, are considered insignificant because according to Thomsen and Eychaner (1991), "Tree-ring data do not indicate a significant change in precipitation from 1602 to 1970."

Many diversions of the Santa Cruz began long before statehood. In the late 1880s, the river was diverted to create two lakes, Warner Lake and Silver Lake, near downtown Tucson (Appendix A page 9). Notably, Warner received legal notice that he was interfering with the water in the Santa Cruz and obstructing the "free and continuous passage of the same." (Fuller, 2004). In the early 1900s a third lake called the Santa Cruz Reservoir was created (Appendix B, pages 4 and 5) in the southern part of Santa Cruz Flats (Figure 1). Groundwater pumping also depleted much of the river. Pump technology first became available in 1891 and initiated the extensive groundwater pumping that excluded any reasonable chance of recovery of the entrenchment around Tucson by any natural processes. Groundwater pumping also affected the river's tributaries like the Rillito River.

In this evaluation of the navigability of the Santa Cruz River, the greatest challenge is the fact that by 1912, the river had been so altered by human activities (Appendix D, Item 1 for example and Appendix A pages 26-28) that it is difficult to assess its condition in its "natural and ordinary" state. The evidence shows that the natural river had a substantial natural base flow. The reason that the natural flow did not find its way into the river channel is human interference through diversions, storage, and groundwater pumping. Yet, as the Arizona Court of Appeals made clear, the commission must evaluate the river as though those activities did not occur. When such adjustments are made, it is apparent that several reaches of the Santa Cruz River were sufficiently perennial or intermittent to support a finding that they were susceptible to navigation by small watercraft and, therefore, were capable of being used as a highway for commerce.

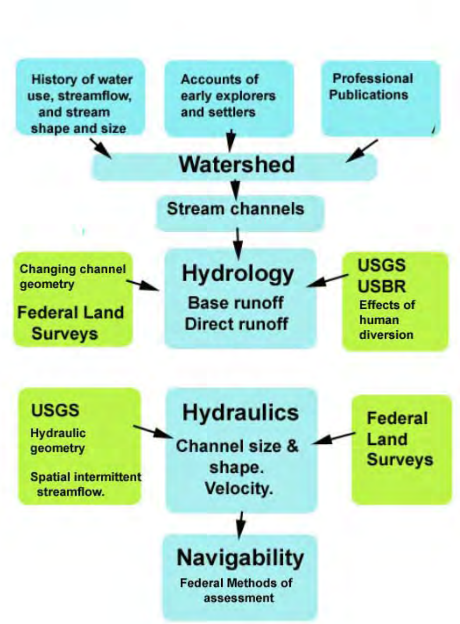
Purpose and scope

The purpose of this report is to assess the navigability along the natural Santa Cruz River at the International border with Mexico to the mouth and the Gila River on February 14, 1912 when Arizona became a state. At statehood, Indians and settlers were diverting large quantities of water from the river. The natural condition of flow that existed before settlers arrived and diverted and stored water for irrigation, livestock and mining was used for this analysis of navigability. This assessment is based on the natural hydrologic, hydraulic and morphologic conditions related to navigability because under the *Defenders of Wildlife* test, navigability is based on natural and ordinary conditions.

The study was performed as outlined in the following diagram. Background information that included historic accounts of water use in the watershed (US and Mexico) and hydrology of the watershed was first examined. Upon learning of the long history (several centuries) of water use in the watershed and the massive changes of the natural channel of the Santa Cruz River before statehood, the river engineering analysis was performed in three basic steps.

Step. 1: Estimate the amount and temporal distribution of natural flow for the Santa Cruz River from the Mexican border to the mouth of the river near Buckeye, Arizona.

The natural hydrology for the Santa Cruz River is based largely on published reports by the U. S. Bureau of Reclamation and by the U. S. Geological Survey.



Step 2: Estimate the natural hydraulic characteristics of the river channel that are related to navigation.

The natural size and shape of the Santa Cruz River channel are based on published hydraulic geometry relations for deformable alluvial channels. Diversion and regulation for several centuries and especially since the 1800s have altered discharge and sediment characteristics in the Santa Cruz River. Observations and measurements of channel size and shape over the past approximately 300 years may be unreliable because the base flow and the morphology of the river changed as a result of this diversion of base flow and sediment from the river. Therefore, it is necessary estimate the size and shape of the river channel when the flow was natural. Sediment-hydraulic geometry (morphology) relations for alluvial channels were used to calculate natural channel size and shape of the Santa Cruz River.

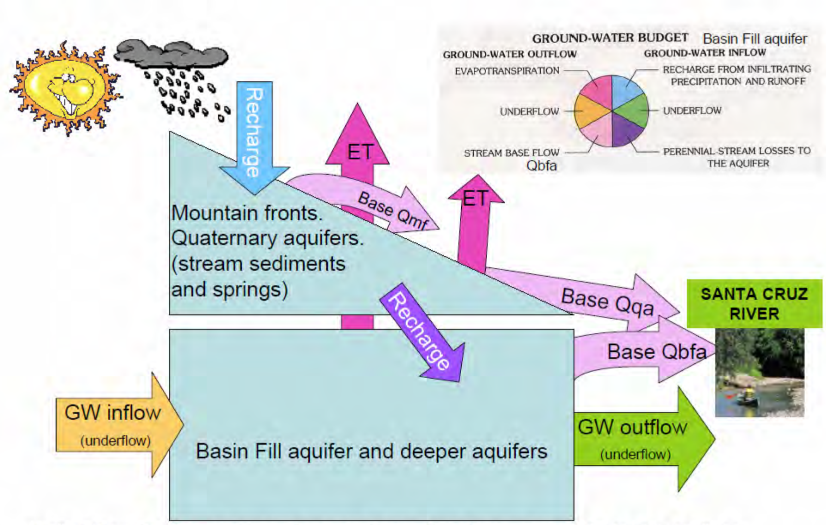
Step 3: Determine whether in its natural condition the Santa Cruz River was susceptible to navigation from the Mexican border to the mouth at the Gila River.

Navigability along the Santa Cruz River is evaluated after the natural hydrology, hydraulics and morphology of the channel determined in steps 1 and 2, are used to estimate the size and shape of the river. Two relatively simple methods developed by the U.S. Department of the Interior were used.

This report presents the results of a quantitative estimate of the navigability of the Santa Cruz River based largely on USGS reports and stream gage records and also a USBR report. Several USGS reports on the flow characteristics of the Santa Cruz River, the use of hydraulic geometry to estimate channel geometry and the assessment of the navigability of rivers formed the basis of the reported analysis. Information in other reports by federal agencies, mostly the USBR report on the natural flow of the Colorado River and tributaries, also was used.

HYDROLOGY

Natural and ordinary perennial/intermittent streamflow is comprised of surface runoff and base runoff. Surface runoff is derived from precipitation, more than 20 inches/yr in the southern/central mountains and less than 8 inches/yr in the northern valley, and some snowmelt. Base runoff is maintained by ground-water discharge to the Santa Cruz River and tributary streams such as Sonota Creek. Base flow is comprised of ground-water discharge from mountain front springs and seeps (Base Qmf on Figure 2) and Quaternary aquifers (Base Qqa) and basin fill and deeper aquifers (Base Qbfa).



Modified from: Freethey, G. W. and Anderson, T. W., 1986, Predevelopment hydrologic conditions in the alluvial basins of Arizona and adjacent parts of California and New Mexico, U. S. Geological Survey Hydrologic Investigations Atlas HA-664, 3 sheets.

Figure 2. Sketch showing ground water under natural conditions.

Under natural conditions the water that replenished the groundwater (recharge) along the mountain fronts all along the upper river valley and in Mexico was temporarily stored, and later discharged (Base Qmf, Qqa and Qbfa) to the river at springs and seeps including cienegas. This base runoff was slowly and steadily released from storage during dry periods. Because precipitation, and therefore direct runoff, was seasonal and there are a few months each year with little precipitation, the base runoff provided perennial and intermittent flow along the upper reaches of the Santa Cruz River.

Mountain front springs typically are springs in bedrock areas at elevations commonly greater than 4,800 ft above sea level. These springs (Base Qmf on Figure 2) are not part of a large aquifer system and generally discharge small volumes relative to springs at lower levels (Base Qqa and Qbfa). Ground water supplying mountain front (higher-altitude) springs is stored in small-volume secondary openings, such as fractures, catchments of colluvium, or pockets of stream alluvium.

Mountain front and Quaternary aquifer springs tend to respond more quickly to temporal changes in precipitation than the lower-altitude springs. For example, summer storm runoff is stored as alluvial groundwater along tributary streams. Despite their relative small volume, the numerous Quaternary aquifers sustain intermittent and/or perennial stream segments of tributary streams and the Santa Cruz River.

The evidence suggests that before development, ground-water discharge was mainly by evapotranspiration, with lesser discharge to streams as base flow. The principal water-bearing sediments consisted of stream-alluvium deposits, where saturated, and upper basin fill. Ground water generally occurred under unconfined conditions, although head differences with depth may have occurred because of the presence of clay lenses in the heterogeneous basin fill.

Before development, water levels ranged from at land surface near perennial streams to as much as a few hundred feet below land surface in places near mountain fronts. Ground water flowed from the perimeter of a basin and from the up gradient end toward the basin center and then down valley to the mouth at the Santa Cruz River. Some ground water probably flowed through the entire length of the basins.

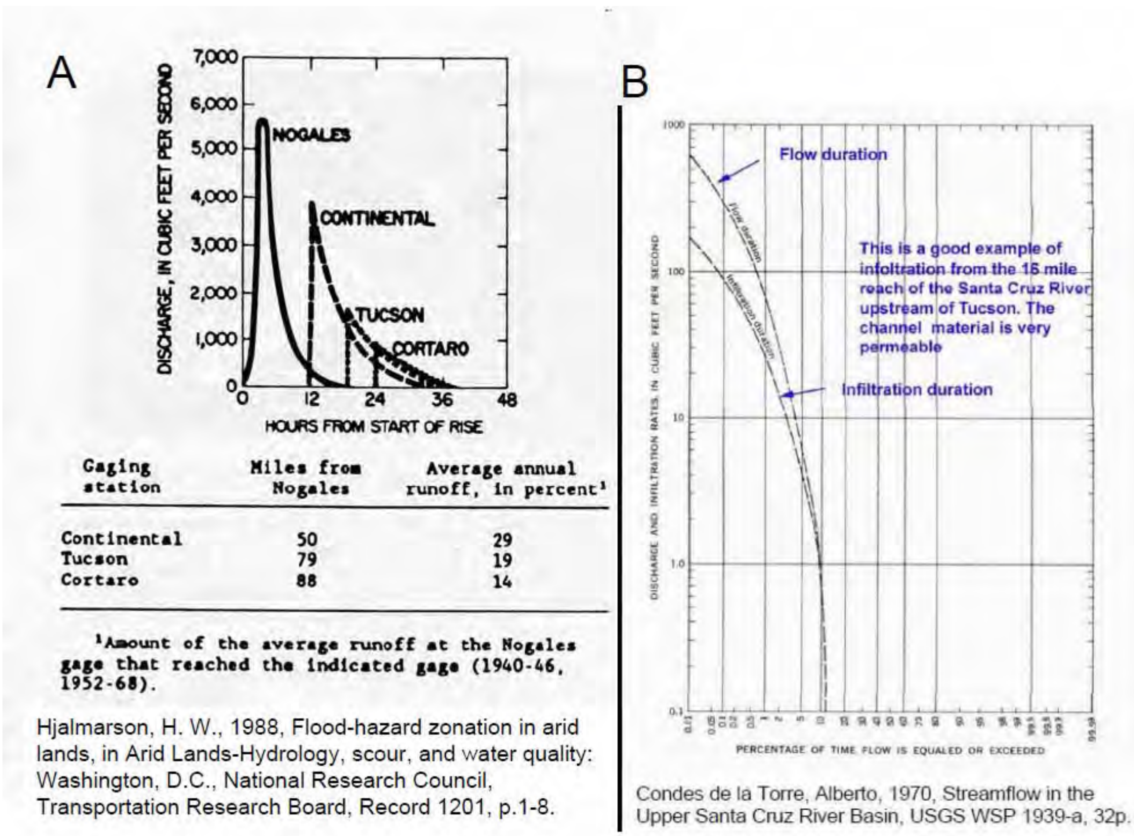
Under natural conditions groundwater flowed toward the Santa Cruz River and encountered geologic constrictions and at these places rose above the river bed and became base runoff. In the Marana area (below Rillito Creek and Canada Del Oro) the groundwater basin became large and any groundwater recharge was offset by evapotranspiration along the river. Below Picacho Peak area the groundwater basin became very large and the relatively little amount of recharge was offset by large amounts of evapotranspiration. The depth to water below Picacho Peak area was shallow and there were large area of mesquite that transpired great quantities of water.
Mowry (1864, p. 186) describes the human affected upper river as a sinuous channel with a width that “varies from 20 to 100 feet, and during very dry seasons portions of it disappear.” Near the mouth of the Santa Cruz groundwater was constricted by bedrock as base runoff was present for a few miles.

Runoff from storms (direct runoff) entered the Santa Cruz River through tributary stream channels all along the watershed. Direct runoff was confined to the Santa Cruz channel and floodplain to the Marana area where high flows would spill onto the floodplain and become separated from the river. Further downstream floodwater entered distributary channels a couple of miles to the south and east of Picacho Peak and spread over a wide area (Santa Cruz Flats) (Figure 1). Thus, direct runoff was not confined to a single channel between the Picacho Peak area and the mouth at the Santa Cruz River (See Appendix B, T8S R7E Santa Cruz Flats and Appendix A).

Based on this river morphology, historic accounts of hydrology and basin fill with constriction of groundwater flow at the boundary between alluvial basins 48 and 49, the reach north of river mile 78 in the Red Rock-Picacho Peak area was initially considered non-navigable for this analysis. Subsequent analysis indicates there may have been a defined channel to the Gila River with intermittent flow but it is more likely neither sufficient flow or a defined channel existed when Spanish explorers were in the area.

Human diversions, both groundwater and surface water, have resulted in lowering of groundwater water levels along the river to far below the river bed. This has induced large amounts of infiltration from the river to the underlying groundwater that is typically far below. Two examples of this “water loss” from the river are shown in Figure 3.

The streambeds of the Santa Cruz River are extremely permeable, and water is lost to the subsurface as the flow moves downstream. In the previous example, flood volumes diminished 86% along the main stem of the Santa Cruz River. Part of the water lost through infiltration reaches the water table, and water levels in wells near the river fluctuate in response to the stream flow. (Condes de la Torre, Alberto, 1970, Streamflow in the Upper Santa Cruz River Basin, USGS WSP 1939-a, 32p).



A.—Typical flow event for incised channel (human induced) showing transmission losses and attenuation of peaks.

B.—Flow duration for tributary inflow and infiltration duration along reach of river above Tucson.

Figure 3. Example of the water loss to infiltration (transmission loses) along the Santa Cruz River

Thus, this base runoff was derived from rather constant (steady) groundwater discharge all along the upper river upstream of Marana (Approximate boundary between T11S R11E and T12 S R11E) from the regional aquifer. This perennial and intermittent flow was sufficient for navigability as discussed later. The regional aquifer is defined as having recharge zones away from the river, primarily at mountain fronts and along ephemeral channels. The aquifer along the river was also recharged from storm flow (direct runoff) as shown by the channel losses to groundwater in Figure 3.

In the absence mostly of evapotranspiration (ET), and to a lesser degree infiltration into the porous stream sediments, along the riparian area of the upper reach the base runoff would have steadily increased along the river throughout an ordinary year. However, the base runoff varied considerably because ET varied seasonally. Large amounts of the rather steady inflowing groundwater to the riparian area were consumed (converted to water vapor) during the summer months. Summer base runoff (roughly represented by Q90, the amount of base runoff equaled or exceeded 90% of the time during a typical year) decreased along the river. Base runoff (Base Qmf, Qqa and Qbfa, Figure 2) also varied considerably throughout the year.

The USGS estimate of predevelopment base runoff (Freethey, G. W. and Anderson, T. W., 1986) that is used for this analysis of navigability focused on groundwater discharge from the basin fill (Qbfa). The USGS method generally ignored ground-water discharge from mountain front springs and seeps (Base Qmf on Figure 2) and Quaternary aquifers (Base Qqa). Thus, because the first human impacts were (1) diversion and storage of springflow and tributary streamflow for mining and livestock, (2) surface diversion made along the river using low earth/rock dams and eventually (3) shallow wells using centrifugal pumps, these rather small but numerous diversions initially had little impact on Qbfa but significantly reduced, or completely consumed, Qmf and Qqa. With the advent of deep wells in the basin fill aquifers, all of the base runoff eventually was partially or totally consumed by human activity.

Estimate of natural flow in the Santa Cruz River

The natural flow in the study reach of the Santa Cruz River was governed largely by the climate of the watershed. The distribution of high flows was governed by the physiography and plant cover of the watershed. The distribution of low flows (base flow) was controlled chiefly by the geology of the watershed. The alluvial basins that were traversed by the river were filled with water, and this ground water drained to the river in many places under natural conditions. Thus, the low-flow end (Q90) of the flow-duration curve (Searcy, 1959) reflects the effect the geology had on the ground-water runoff to the river and its tributaries (Figure 4).

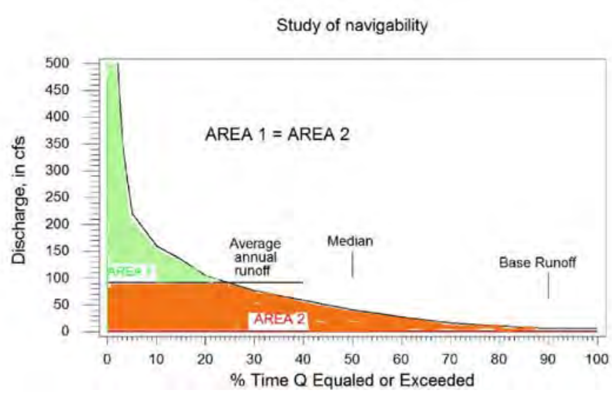


Figure 4: Flow duration relation

Flow-duration curves were used for this study to define the percent of time the natural mean daily discharge was exceeded during a typical or average year. The curve was defined using the basin accounting method for natural stream base flow developed by Freethey and Anderson (1986) to estimate the 90th percentile of daily discharge (Appendix C, Item 1). The average (mean) annual natural streamflow for the Santa Cruz River was estimated by the USBR (USBR, 1952, Report on Water Supply of the Lower Colorado River Basin: US Department of Interior, Bureau of Reclamation Project Planning Report, 444 p.) (Appendix C, Item 2). Finally, the general shape of the relations is estimated using the flow-duration relation at the USGS streamflow gage near Nogales. Many flow-duration curves were defined by Condes (WSP 1939-a, Table 3) (Condes de la Torre, Alberto, 1970, Streamflow in the Upper Santa Cruz River Basin, USGS WSP 1939-a, 32p.) in 1970 where impacts of humans were present but not to the degree more recently (Appendix C, Item 3). Impacts of humans were less at the upper end of the study reach than at downstream gages where groundwater withdrawal and tree removal were more severe. The flow-duration curve at the USGS Nogales gage was used to simply shape the predevelopment FDCs along the river.

The flow duration relations along the river are shown in Figure 5. Generally, smaller amounts of base flow are for non-monsoon summer days because of high evapotranspiration along the riparian area. Also, the estimation of relation at river mile 78 is discussed in Appendix C Item 3.

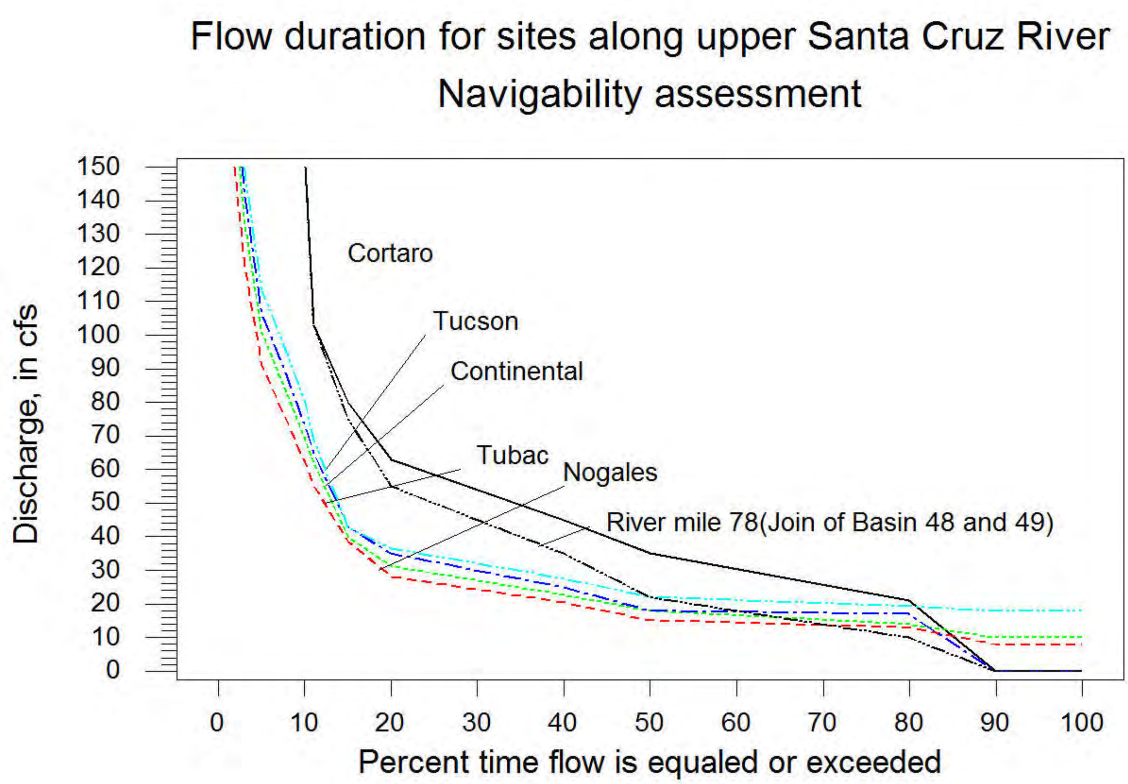


Figure 5. Flow duration relations for middle Santa Cruz River.

Downstream from Basin 48 (Appendix C Item 1 and Figure 6) the flow in the Santa Cruz River became unconfined (See for example Appendix B Item 5 and Appendix C Item 1) and large amounts of streamflow entered the ground. Conversely, the evidence of the Federal Land Surveys, USGS reports, the USBR report and other reports (for example Item 4, Appendix C) shows a defined river channel with perennial/intermittent flow between river mile 78 and 180. Thus, for this analysis, navigability ceased at the north end of Basin 48 and the flow in the single channel of the Santa Cruz River is defined by the flow duration curve at river mile 78 (Figure 5). Therefore, there was no navigability north of river mile 78 (the join of Basin 48 and 49 of Figure 6) of the river there was insignificant base flow and flow was unconfined resulting in nonnavigability (Figure 7).

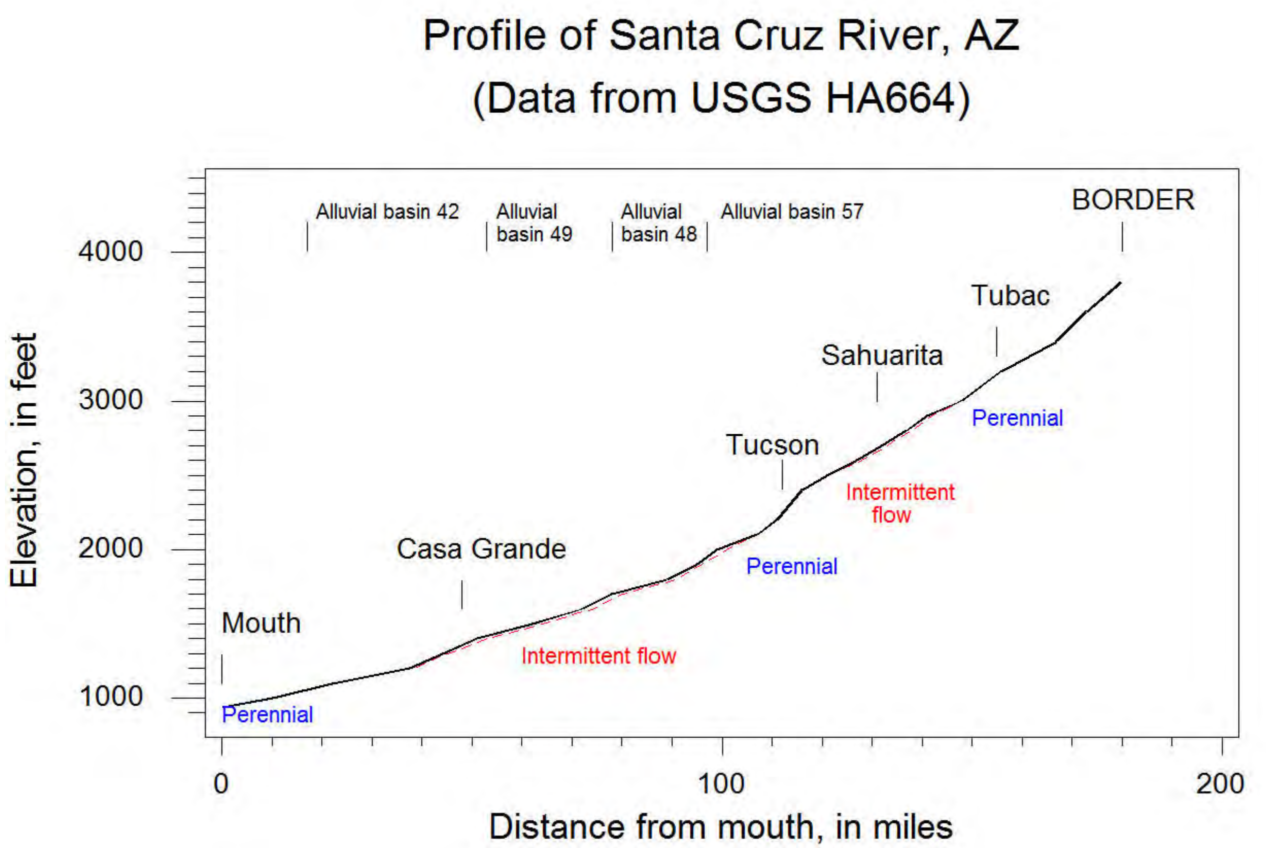


Figure 6. Profile of Santa Cruz River showing alluvial basin boundaries and perennial and intermittent reaches for natural conditions.

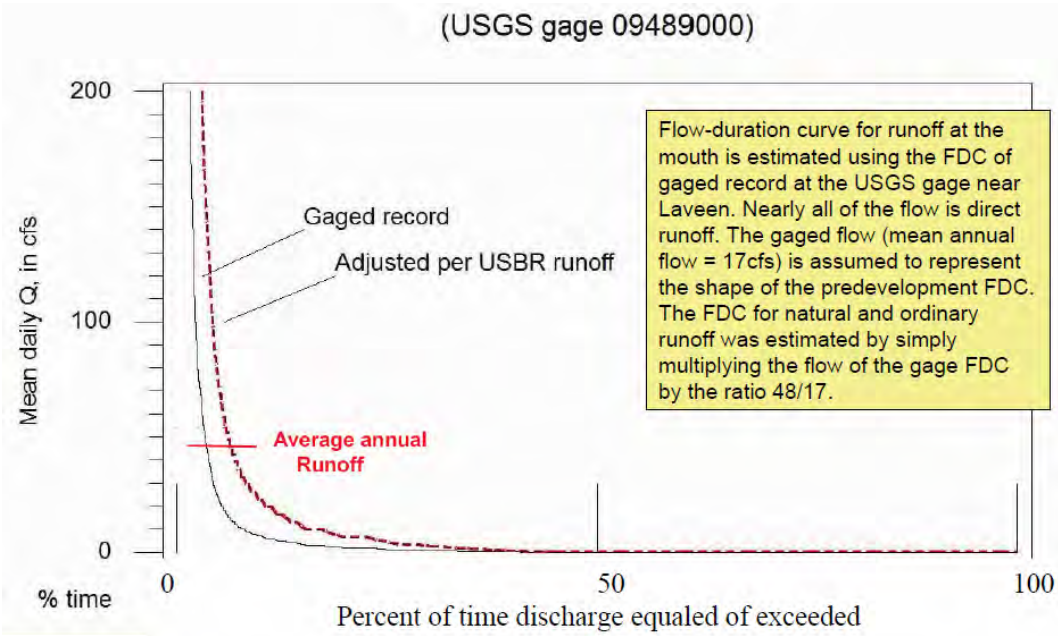


Figure 7. Flow duration relation for mouth of the Santa Cruz River.

The flow-duration relations (Figure 5) for the Santa Cruz River are cumulative frequency curves that show the percent of time specified discharges were equaled or exceeded during a given period. The flow-duration curve does not show the chronological sequence of flows. Rather, it combines in one curve the flow characteristics of the Santa Cruz River throughout the range of discharge, without regard to the sequence of occurrence. It represents the distribution of average natural flow of the Santa Cruz River for the year and is useful for the assessment of navigability. The duration graph represents mean daily rates of discharge that are arranged in order of magnitude. This display simplifies general assessment of navigability because it represents long-term average flow conditions.

Discussion and summary of the natural hydrology

The hydrology for natural (pre-settler) conditions of the Santa Cruz River below the Mexican border was defined using published USGS information (Freethey and Anderson, 1986) and (Condes de la Torre, Alberto, 1970) and USBR information (USBR, 1952). The information in the USBR report is well suited for this analysis of navigability as evidenced in the purpose and scope of the USBR report as follows:

> This report has been prepared to fill an urgent need for a comprehensive analysis of the water supply of the Lower Colorado River Basin. There has been a definite need for a determination, in more detail than presented in the Department of Interior report "The Colorado River" (March 1946), of the average natural or virgin flows of streams and the rates of use of water to serve as the basis for planning future developments for the maximum utilization of water supplies presently and ultimately available.

> The report presents detailed analyses and estimates of historic stream flow at selected gaging stations and other key points; an estimate of average natural or virgin flow at the same stations and points; rates of consumptive use of crops, natural vegetation, and other water consuming items; estimates of channel and evaporation losses and considerable other information on water supply and
> use in the Lower Colorado River Basin.
>
> A similar report covering the Upper Colorado Biver Basin was prepared in November 1948 by the Engineering Advisory Committee to the Upper Colorado River Basin Compact Commission. Together, these reports provide a basis for a comprehensive analysis of the water supply of the entire Colorado River Basin.

(USBR 1952). Flow-duration relations for natural flow were computed using the published information. The flow-duration relations are used to assess the amount of time a particular amount of mean daily discharge can be expected in the study reach of the Santa Cruz River.

The Santa Cruz River was a single natural channel with continuous flow 75% of the time during normal years. Even with many diversions of base flow for the past few hundred years crops were raised in 1905 at a cienega at the end of the study reach (Appendix A page 4). The study reach is from the Mexican border (river mile 180) to river mile 78 at the join of sections 9 and 10, T10S R9E.

It is my opinion, based on this analysis, the natural flow of the Santa Cruz River was as defined by the flow duration curves in Figure 5. The evidence shows that the river had a substantial natural base flow. The average annual runoff along the Santa Cruz River typically was from 29 cfs to 60 cfs. Flow between river mile 78 and river mile 180 typically was at least 17 cfs for 50% of each year.

HYDRAULIC GEOMETRY AND HYDRAULICS

Rivers with natural alluvial channels like the Santa Cruz River along the study reach construct their own geometries. This hydraulic geometry of the Santa Cruz River is related to the water flow and sediment characteristics. The amount of flow, computed in the previous section of this report, is the principal control of channel size and the sediment characteristics largely determine channel shape (Osterkamp (1980), Hey (1978), Schumm (1960) and Osterkamp and Hedman (1982)).

Along the study reach the channel morphology was self-formed. The natural channel was formed in material that was entrained, transported, and deposited by the river and tributary streams. Based on the association distinguishing between meanders and braided channels on the basis of channel slope and discharge (Leopold and Wolman, 1957), the relation between bank full discharge and channel slope shows the upper Santa Cruz River was meandering (Figure 8).

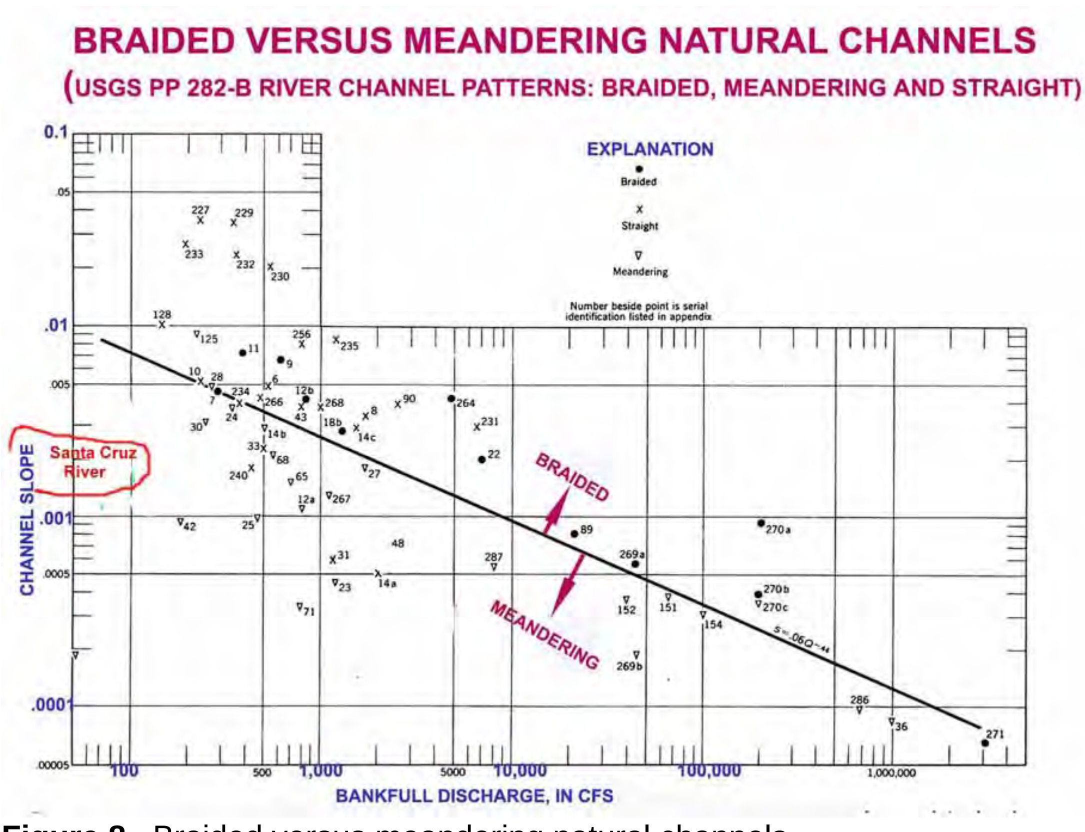


Figure 8. Braided versus meandering natural channels.

The Leopold-Wolman Association shows the river was a meandering stream and this agrees with the generally accepted characterization that the natural river was a shallow meandering stream in a rather wide valley and somewhat marshy environment. Cienegas reportedly were along the river in the San Xavier Mission and a few other places. The floodplain was several feet above the present down cut channel and was composed of river sediments with dark-rich soil. The following analysis is based on this natural riverine condition.

Two important natural parameters of the main channel are depth and velocity because too little depth and too much velocity limits navigability. Width is also an important parameter partly because width was commonly measured. For example, the original federal land surveyors of the General Land Office (Appendix A) identified, measured and recorded channel width of the Santa Cruz River along the study reach. Also, channel width of main channels can be reliably estimated from flow characteristics (Leopold and Maddock (1953), U. S. Corps of Engineers (1990), Schumm (1968) and Osterkamp (1980)). The depth and velocity of the natural alluvial channel of the Santa Cruz River are related to channel width.

Channel characteristics for the more common flows of the Santa Cruz River are important for the assessment of navigability. For example, about 75% of the time the flow is less than the mean annual flow (Figure 5). In terms of using a vessel on the Santa Cruz River, the reaches with intermittent (no flow for short periods) and little base runoff, obviously limit navigability for at least part of a typical year. While base runoff is a rather small portion of the mean annual runoff, base runoff is all or a large amount of the total runoff at least 50 percent of the time. Therefore, the low, medium and average flow conditions of the river are examined.

Channel size and shape along the study reach of the Santa Cruz River are estimated using the mean annual flow as the formative or dominant discharge (independent variable) of the channel property (dependent variable) width. This permits estimates of the channel dimensions to be made along the Santa Cruz River on the basis of the discharge characteristic. The approach infers that the discharge characteristic to be estimated is related directly to the formative discharge of the Santa Cruz River but does not require precise identification of that formative discharge.

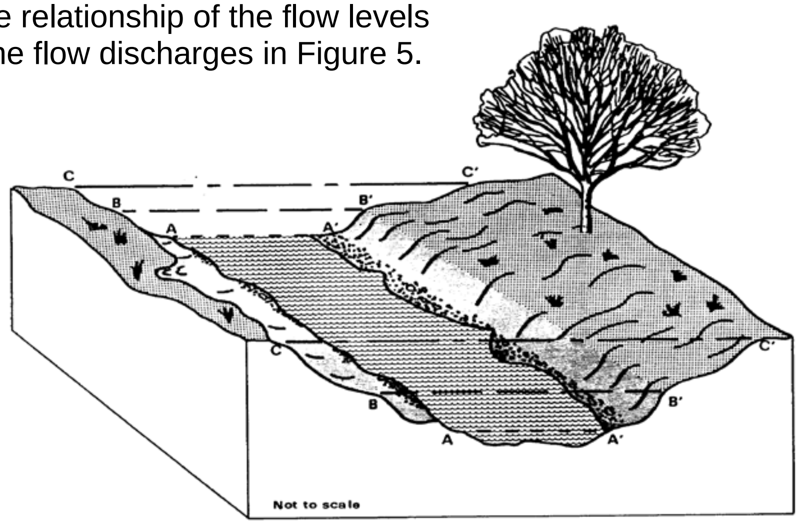
Along rivers like the Santa Cruz, functions for width and mean annual discharge are:

$$W = aQ^{b} \qquad \text{Equation 1}$$

where width (W) (Figure 9), the dependent variable, is related to mean discharge (Q), the independent variable, the value of the exponent (b) varies with the tractive sediment load of the stream and (a) is a constant.

A. Main channel showing width of average annual flow(C-C'), width of median daily flow(B-B'), and width of base flow(A-A').

Note the relationship of the flow levels and the flow discharges in Figure 5.



B. Cross section of channel showing width of flow (W), depth of flow(d) and mean depth of flow(D).

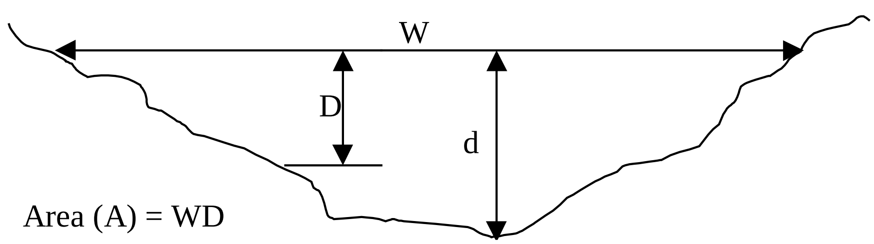


Figure 9: Sketches showing general characteristics of river channel

The study reach typically is coarse sand with some silt, clay and gravel. Thus, for practical considerations, a typical channel mostly of sand, gravel and some silt and clay was used. The corresponding coefficient ‘a’ = (3.70) and the exponent ‘b’= 0.55. The equation (Osterkamp, 1979b and 1980) for the natural Santa Cruz channel is:

$$W = 3.70\, Q^{0.55} \qquad \text{Equation 2}$$

There are no known documented observations of the predevelopment (natural) river morphology (width, depth, sinuosity, etc.). All of the original Federal land survey maps and most of the survey notes were examined for this study. There were several diversions and the upper river channel was dry in places. Where there was flow the widths generally agreed with computed widths for this study. No precise measurements of flow depth were found. Small arroyos were noted by the early surveyors in a few places. (See Appendix B).

Depths of water for the main channel along the Santa Cruz River are related to flow characteristics and channel roughness, slope and width. The corresponding depth of flow for natural conditions is estimated using channel conveyance-slope characteristics and rating curve characteristics (Rantz and others, 1982).

Manning's discharge equation is widely used for conditions of channel control to compute flow ratings (Rantz and others, 1982). The typical natural channel, like the natural channel of the Santa Cruz River, is approximately parabolic in shape. Using techniques of Burkham (1977) the following equation results:

$$Q = (1.49/n)\,(0.67d)^{5/3}\, W\, S_o^{1/2} \qquad \text{Equation 3}$$

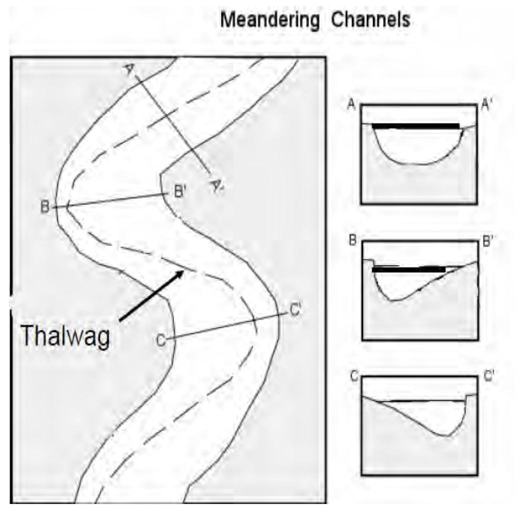
Where d = depth of water above channel invert,
S_o = energy gradient, and
n = roughness coefficient.

Channel size and shape along the study reach of the Santa Cruz River are estimated using the average annual flow of 29 cfs to 60 cfs of the study reach respectively as the formative or dominant discharge (independent variable) of the channel property (dependent variable) width.

This permits estimates of the channel dimensions to be made along the river on the basis of the discharge characteristic. The approach infers that the discharge characteristic to be estimated is related directly to the formative discharge of the Santa Cruz River but does not require precise identification of that formative discharge

It’s important to realize that the hydraulic geometry method yields representative cross section characteristics of width, depth and velocity. Cross section shape for meandering rivers like the predevelopment Santa Cruz appears to have been varies along the river. A sketch of how shape typically varies is shown in Figure 10. A common misconception about rivers like the Santa Cruz is presence of large riffles that would impede navigability. The fact is there are riffles but the riffles are small partly because of energy processes associated with meandering. The beds of meandering segments of rivers have a more uniform gradient (smoother appearance and fewer and/or smaller riffles) than the beds of straight segments (Langbein, W. B., and Leopold, Luna, 1966, River Meanders-theory of minimum variance; USGS Professional Paper 422-H, 15p.).

Figure 10. Sketch of typical meandering channel showing how channel shape changes.



Cross section A-A represents the regime section computed in this analysis. Channels of alluvial rivers scour on the outside of bends and fill on the inside of bends.

Computed estimates of predevelopment width-duration and depth-duration curves, are shown in figures 11 and 12. Computed velocities typically were between about 0.5 and 2.5 ft/sec except for flood flows.

Figure 11. Width duration relations along the study reach.

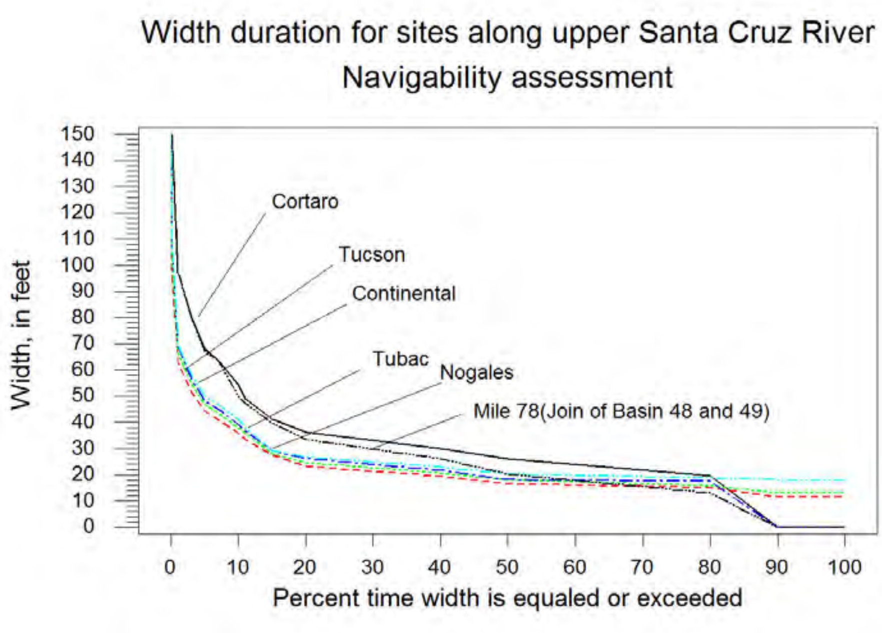
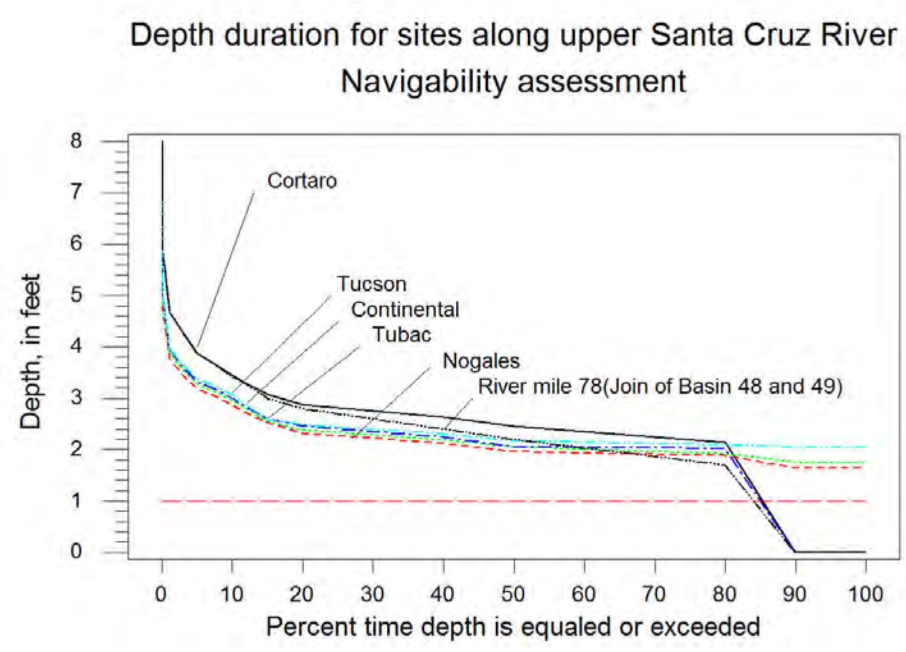


Figure 12. Depth duration relations along the study reach.



The significance of this analysis at this point, in regard to navigability, is that the natural channel was meandering. Such a channel is relatively stable.

Discussion and summary of the shape and size of the natural channel

Along the study reach the channel morphology of the Santa Cruz River was self-formed. In other words, the natural channel was formed in material that was entrained, transported, and deposited by the river and tributary streams. For such a river channel, simple power functions of width, sediment partical size and mean annual discharge can be used to estimate single channel geometry for the perennial and intermittent flow. Discharge, channel depth and channel width were estimated using established methods for rivers like the Santa Cruz River.

Because the natural hydrology and natural channel morphology were significantly altered by human activities many (hundreds) years before Statehood in 1912, the science-based method used here is considered the best way to assess the river condition in its "natural and ordinary" state.

The depth of water above the channel invert (maximum depth of Equation 3) closely approximates the depth for optimum navigability for channel widths of several feet using channel shape of the regime equations. Average channel depth, computed using total discharge and overall channel width was not used because it represents the minimum depth for navigability as explained in Item 3 of Appendix D.

NAVIGABILITY

Navigability along the Santa Cruz River is evaluated using the natural hydrology and hydraulic geometry of the natural channel in the study reach. The river is evaluated as a single segment from the Mexican border south to river mile 78. Two convenient methods of assessing instream flows are used. The two relatively simple methods were developed by the U.S. Department of the Interior mostly for modern recreational boating (Figure 13).

Figure 13. Boating along the river.

The following assessment of navigability is unaffected by channel sinuosity that is mild such that curvature at meander bends does not adversely affect channel width and alignment along potential navigable lanes. The channel widths of 24-35 ft at the average annual flow along the river easily accommodate navigable lanes where depths are at or near maximum.

Bureau of Outdoor Recreation Method

The first method is a rule of thumb rating of navigation difficulty by Jason M. Cortell and Associates Inc. of Waltham Mass (U. S. Bureau of Outdoor Recreation, 1977). This method is easy to use and was developed for the Bureau of Outdoor Recreation of the U. S. Dept. of the Interior in July 1977.

The use of small watercraft, that includes canoes, kayaks drift boats and rafts, is rated in terms of flow criteria based on an International River Classification scale. A minimum stream flow condition is used to rate the difficulty of using these watercraft in rivers. Six classes of white water are used and Class I is the easiest for navigability. The discharge and gradient of the study reach is well within Class I and the use of watercraft is considered very easy (Figure 14).

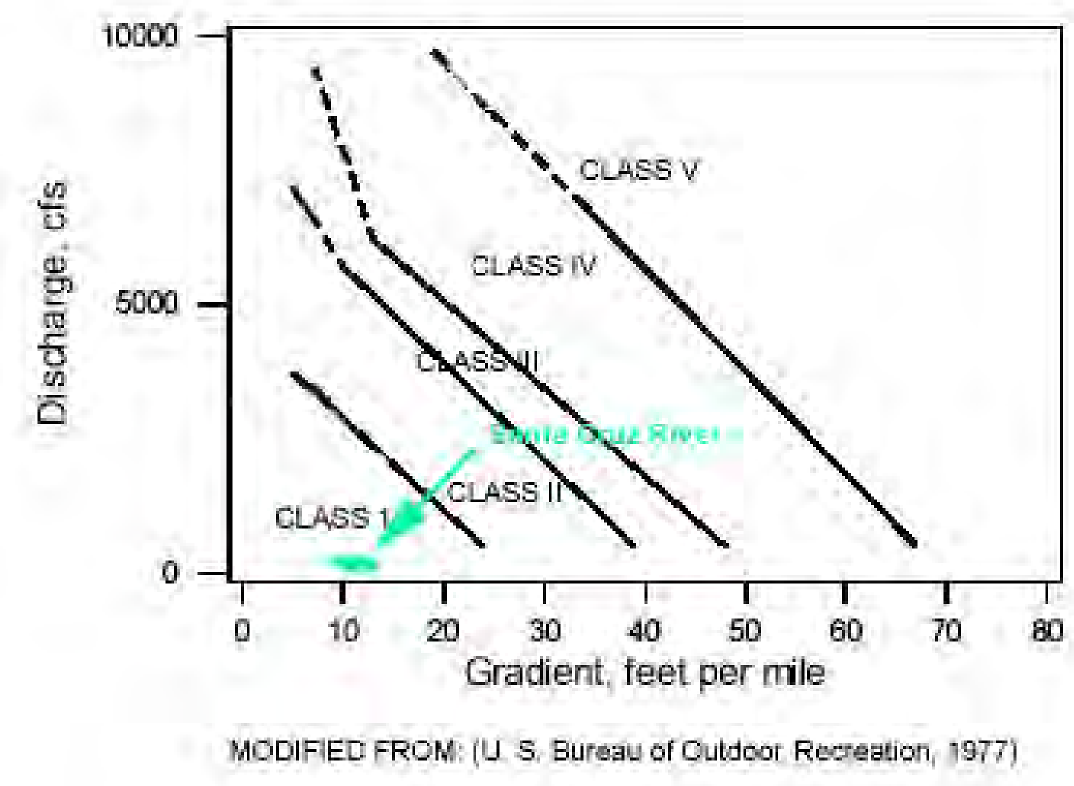


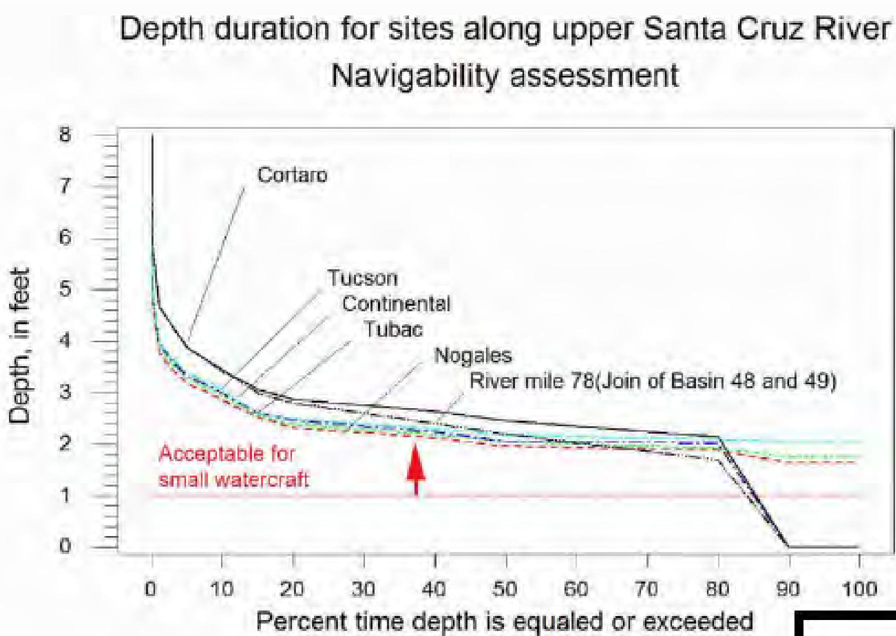
Figure 14. River discharge and gradient showing navigation difficulty.

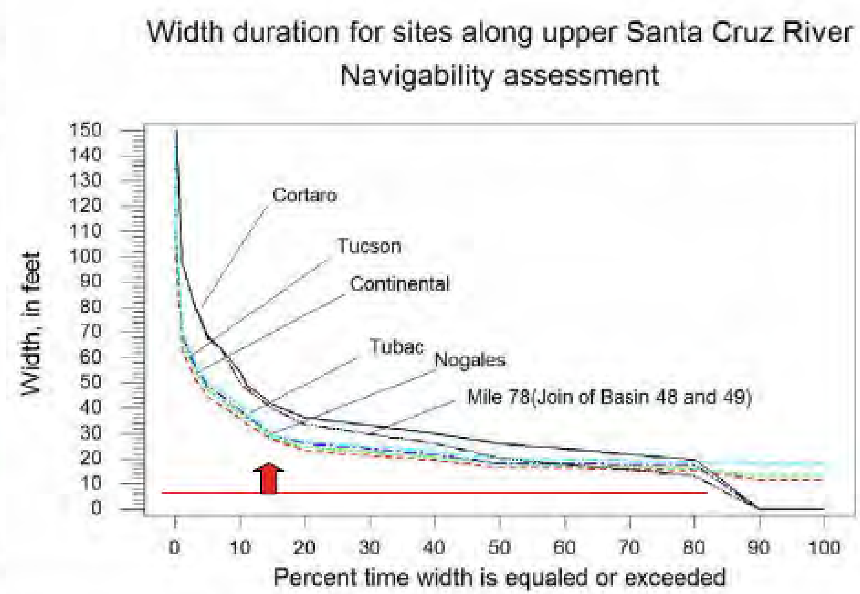
Fish and Wildlife Service Method

The second method is also easy to use and is based on hydraulics of a single channel cross section that is representative of channel conditions. These navigation requirements (*Instream Flow Information No. 6*) were developed by R. Hyra (1978) for the Fish and Wildlife Service of the Dept. of the Interior. Channel depth and width requirements are defined for types of watercraft such as rafts and rowboats.

The U.S. Fish and Wildlife Service (Hyra, 1978) developed a method of assessing streamflow suitability for recreation that is applied to the Santa Cruz River. The single cross section technique is very simple to use and results in an assessment of the minimum flow recommended for a particular watercraft activity. The characteristics of the hydraulic geometry sections for the upper and lower parts of the study reach are used. Hyra (1978) presents minimum depth and width requirements for canoes, kayaks and other small watercraft. Minimum width and depth requirements are met for canoes, kayaks, drift and row boats along the Santa Cruz from mile 78 to 180 at the Mexican border as shown in Figures 15 and 16.

Figure 15. Acceptable depths and width for small watercraft.





(Hyra, R., 1978, Methods of assessing instream flows for recreation: Instream Flow Information Paper No. 6, U. S. Fish and Wildlife Service and others, 14p.)

Table 1. Required stream width and depth for various recreation craft as determined by single cross section method.

Recreation Craft	Required depth (ft)	Required width (ft)
Canoe-kayak	0.5	4
Drift boat, row boat-raft	1.0	6
Tube	1.0	4
Power boat	3.0	6
Sail boat	3.0	25

Figure 16. Acceptable and optimal depths and velocities for small watercraft.

BOATING CANOEING-KAYAKING

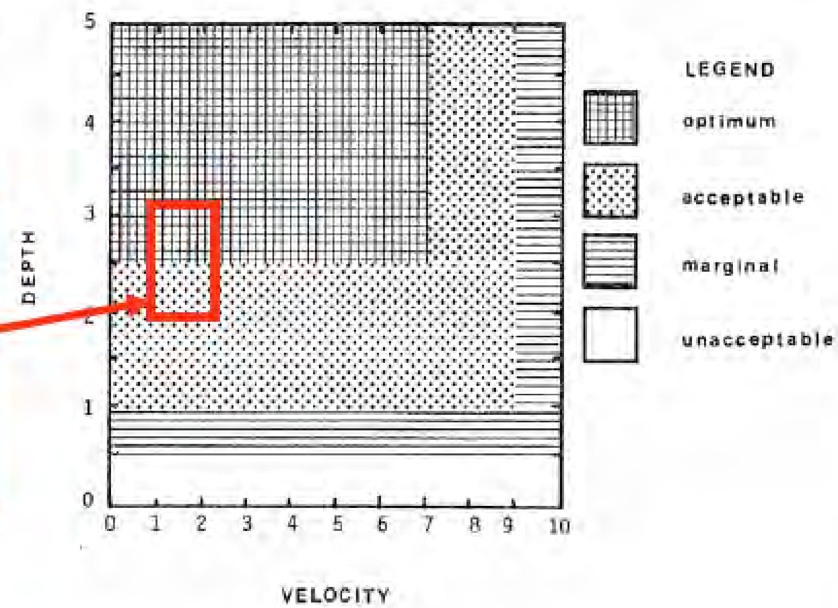
CRITERIA

.	PHYSICAL	SAFETY	OPTIMUM
DEPTH			2.5 ft +
minimum	0.5 ft	1.0 ft	
maximum	NA	NA	
VELOCITY			0.5-7.0 fps
minimum	0 fps	0 fps	
maximum	10.0 fps	9.0 fps	

COMMENTS: Higher velocities exclude open canoes. Higher velocities safe only under certain conditions.

(Hyra, R., 1978, Methods of assessing instream flows for recreation: Instream Flow Information Paper No. 6, U. S. Fish and Wildlife Service and others, 14p.)

The depth and velocity for natural and common runoff of the Santa Cruz is acceptable or optimum for canoeing and kayaking.



SUMMARY AND CONCLUSION

The two Federal methods show the Santa Cruz River along the study reach was navigable (Figure 17).

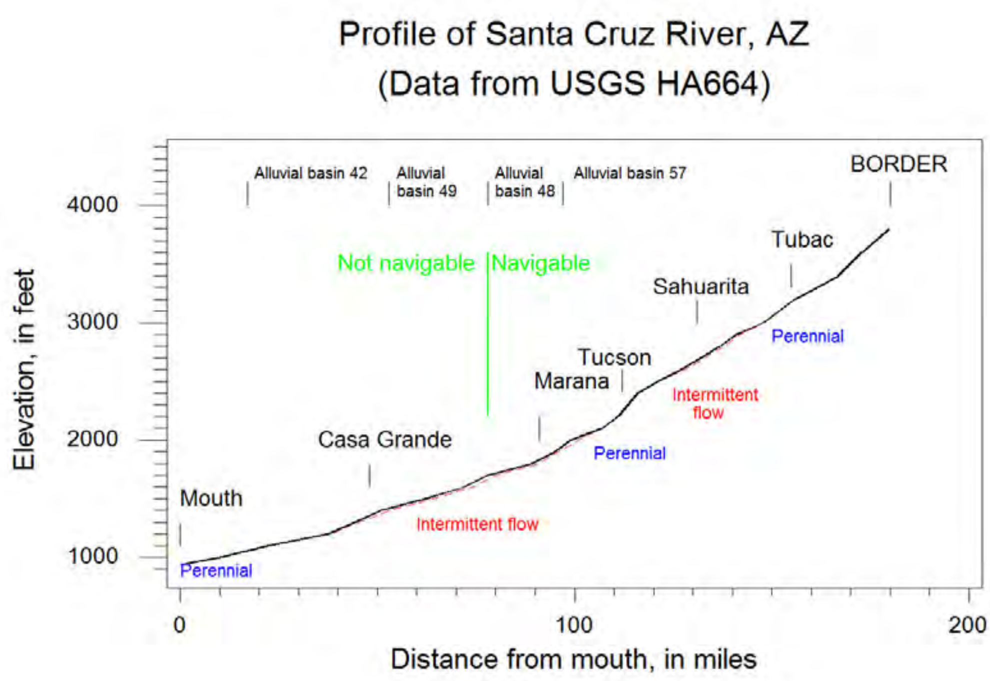


Figure 17. Profile of Santa Cruz River showing the navigable and non-navigable reaches.

Assessment of whether the natural channel of the Santa Cruz River was navigable involves taking known hydrologic and geomorphic information and relationships from the present and projecting this information into the past. The three-step method is based of the fact that rivers construct their own geometry and this geometry can be estimated using hydrologic and hydraulic principles.

The assessment used published information and data and was performed in three steps using standard engineering/hydrologic methods. The first step was the definition of the runoff for the Santa Cruz River using hydrologic techniques. A flow-duration relation for the river was estimated using the base, general shape and the mean annual runoff. The second step utilized hydraulic geometry techniques to estimate the width, depth and velocity for the natural flow in the study reach. There is a predictable relation between the channel geometry, type of sediment and the mean annual amount of natural flow. Finally, navigability was assessed using the physical characteristics of the natural channel of the Santa Cruz River such as discharge, gradient, depth, sediment and velocity. The two methods of Federal agencies showed the Santa Cruz River was navigable from river mile 78 to the Mexican border (mile 180).

At the time of statehood the runoff in the study reach was impacted by many upstream diversions and storage for irrigation, livestock and mining. Diversions for irrigation, livestock and irrigation along the Santa Cruz River and tributary streams reduced the amount of downstream water and sediment flow and thus influenced many downstream river functions in the study reach at and long before Statehood in 1912. This method takes into account the anthropogenic impacts.

There is reasonably good agreement between the surveyed channel widths by the federal surveyors and the estimated widths of this assessment.

It is my opinion the Santa Cruz River, from river mile 78 (boundary of sections 9 and 10, T10S R9E in the Red Rock-Picacho Peak area at boundary of alluvial basins 48 and 49) to the Mexican border (mile 180), was susceptible to navigation at the time of statehood (February 14, 1912) in its natural condition. During ordinary years the river was susceptible to navigation 75% of the time. Evidence relied upon to form this opinion is in this report and in the references for this report.

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GLOSSARY
(Mostly from Langbein and Iseri, HTML Version 1995)

HYDROLOGIC DEFINITIONS FOR THIS STUDY OF NAVIGABILITY

Acre-foot. A unit for measuring the volume of water, is equal to the quantity of water required to cover 1 acre to a depth of 1 foot and is equal to 43,560 cubic feet or 325,851 gallons. The term is commonly used in measuring volumes of water used or stored.

Average discharge. In the annual series of the Geological Survey's reports on surface-water supply—the arithmetic average of all complete water years of record whether or not they are consecutive. Average discharge is not published for less than 5 years of record. The term "average" is generally reserved for average of record and "mean" is used for averages of shorter periods, namely, daily mean discharge.

Bank. The margins of a channel. Banks are called right or left as viewed facing in the direction of flow.

Base flow. See Base runoff.

Base runoff. Sustained or fair weather runoff. In most streams, base runoff is composed largely of groundwater effluent. (Langbein and others, 1947, p. 6.) The term base flow is often used in the same sense as base runoff. However, the distinction is the same as that between streamflow and runoff. When the concept in the terms base flow and base runoff is that of the natural flow in a stream, base runoff is the logical term. (See also Ground-water runoff and Direct runoff.)

Braiding of river channels. Successive division and rejoining (of river flow) with accompanying islands is the important characteristic denoted by the synonymous terms, braided or anatomizing stream. A braided stream is composed of anabranches.

Channel (watercourse). An open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. River, creek, run, branch, anabranch, and tributary are some of the terms used to describe natural channels. Natural channels may be single or braided (see Braiding of river channels) Canal and floodway are some of the terms used to describe artificial channels.

Direct runoff. The runoff entering stream channels promptly after rainfall or snowmelt. Superposed on base runoff, it forms the bulk of the hydrograph of a flood.

Discharge. In its simplest concept discharge means outflow; therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream, or an ocean. (See also Streamflow and Runoff.)

Drainage basin. A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drainage divide. The rim of a drainage basin. (See Watershed.)

Evaporation. The process by which water is changed from the liquid or the solid state into the vapor state. In hydrology, evaporation is vaporization that takes place at a temperature below the boiling point.

Evapotranspiration. Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Flow-duration curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. (See Searcy, 1959.)

Gaging station. A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained. (See also Stream-gaging station.)

Ground water. Water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied. (After Meinzer, 1949, p. 385.)

Groundwater runoff. That part of the runoff which has passed into the ground, has become ground water, and has been discharged into a stream channel as spring or seepage water. See also Base runoff and Direct runoff.

Hydrologic budget. An accounting of the inflow to, outflow from, and storage in, a hydrologic unit, such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project.

Hydrologic cycle. A convenient term to denote the circulation of water from the sea, through the atmosphere, to the land; and thence, with many delays, back to the sea by overland and subterranean routes, and in part by way of the atmosphere; also the many short circuits of the water that is returned to the atmosphere without reaching the sea.

Hydrology. The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground. The science that relates to the water of the earth.

Infiltration. The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.

Irrigation. The controlled application of water to arable lands to supply water requirements.

Meander. The winding of a stream channel.

Overland flow. The flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a stream, it becomes runoff.

Percolation. The movement, under hydrostatic pressure, of water through the interstices of a rock or soil, except the movement through large openings such as caves

Precipitation. As used in hydrology, precipitation is the discharge of water, in liquid or solid state, out of the atmosphere, generally upon a land or water surface.

Reservoir. A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

Return flow. That part of irrigation water that is not consumed by evapotranspiration and that returns to its source or another body of water. The term is also applied to the water that is discharged from industrial plants. Also called return water.

Riparian. Pertaining to the banks of a stream.

Runoff. That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Stream. A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal. More generally as in the term stream gaging, it is applied to the water flowing in any channel, natural or artificial. Streams in natural channels may be classified as follows:

Relation to time.

Perennial. One which flows continuously.

Intermittent or seasonal. One which flows only at certain times of the year when it receives water from springs or from some surface source such as melting snow in mountainous areas.

Ephemeral. One that flows only in direct response to precipitation, and whose channel is at all times above the water table.

Relation to space.

Continuous. One that does not have interruptions in space.

Interrupted. One which contains alternating reaches, that are either perennial, intermittent, or ephemeral.

Relation to ground water.

Gaining. A stream or reach of a stream that receives water from the zone of saturation.

Losing. A stream or reach of a stream that contributes water to the zone of saturation.

Insulated. A stream or reach of a stream that neither contributes water to the zone of saturation nor receives water from it. It is separated from the zones of saturation an impermeable bed.

Perched. A perched stream is either a losing stream or an insulated stream that is separated from the underlying ground water by a zone of aeration.

Streamflow. The discharge that occurs in a natural channel. Although the term discharge can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course. The term “streamflow” is more general than runoff, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Transpiration. The quantity of water absorbed and transpired and used directly in the building of plant tissue, in a specified time. It does not include soil evaporation.

Underflow. The downstream flow of water through the permeable deposits that underlie a stream and that are more or less limited by rocks of low permeability.

Watershed. The divide separating one drainage basin from another and in the past has been generally used to convey this meaning. Drainage divide, or just divide, is used to denote the boundary between one drainage area and another. Used alone, the term “watershed” is ambiguous and should not be used unless the intended meaning is made clear. As used in this report, watershed refers to the entire drainage of the Santa Cruz River and basins refers to internal areas of the “watershed”.

Water table. The upper surface of a zone of saturation. No water table exists where that surface is formed by an impermeable body.

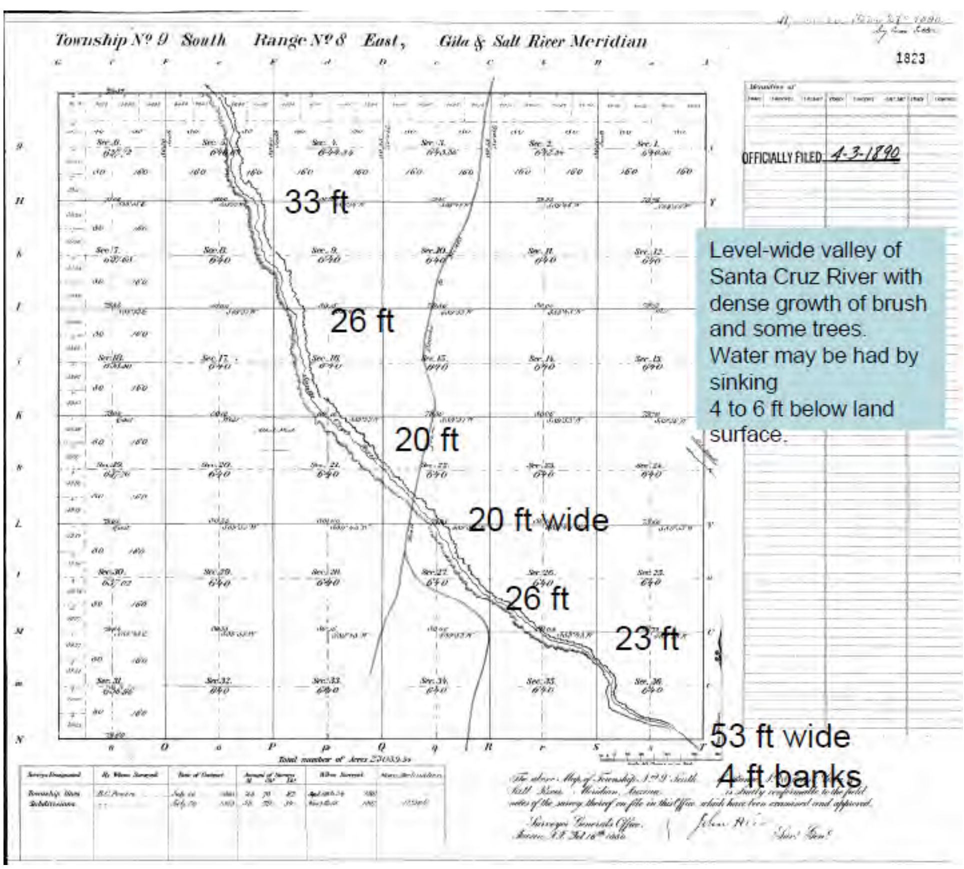
Appendix A. Original and early land surveys with a few photographs and maps.

This appendix presents the original Federal Land Survey maps (plats) with information, such as channel widths, from selected associated survey field notes for the reach of Santa Cruz River near Picacho to the Mexican border. The maps and survey notes, when used together, provide valuable morphology, hydrology and hydraulic information for the assessment of navigability for ANSAC. These maps and field notes were obtained from the Bureau of Land Management (BLM) in 2013.

The Department of the Interior, that included the General Land Office (GLO), was created in March 3, 1849. In 1946, the GLO was merged with U.S. Grazing Service to form the Bureau of Land Management (BLM) in the Department of the Interior. In the process, BLM became the custodian of the official land records of the United States.

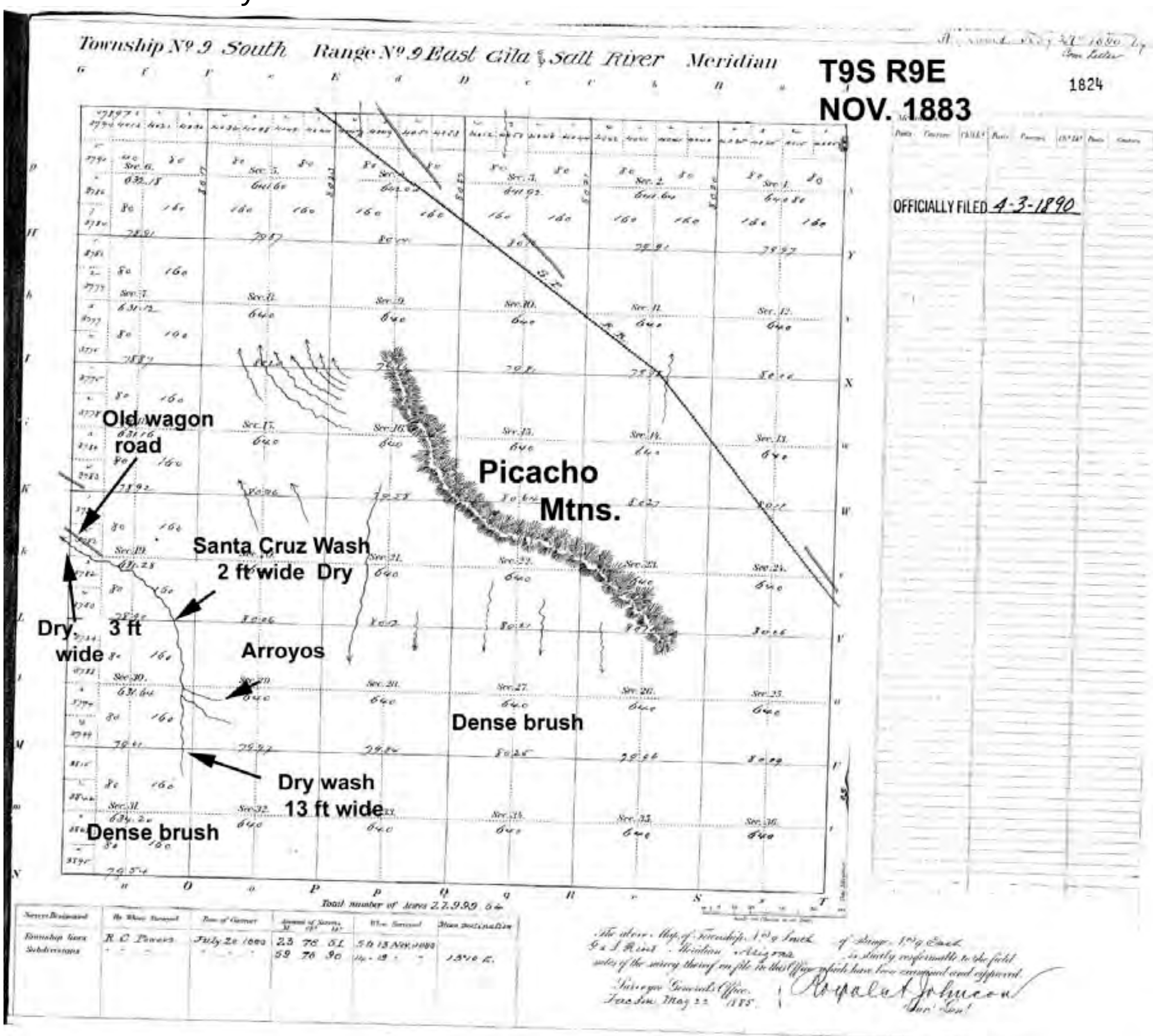
Its important to keep in mind that this group of maps is very useful for assessing natural morphology/hydrology of the Santa Cruz River but significant diversions and other affects of humans were present when these surveys were made.

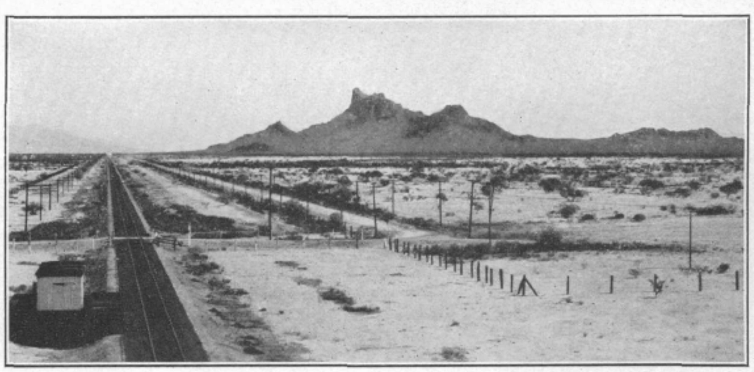
T9S R8E



T9S R9E

The arroyos suggest some channel incision but this eastern channel of the Santa Cruz River is very small.





B. PICACHO, A NOTABLE LANDMARK NEAR WYMOLA, ARIZ.
A mass of volcanic rock of Tertiary age. Looking southeast.

Photo taken from near section 2 of T9S R9E. (About 1930).

From Tucson the railroad follows the wide flat adjoining the Santa Cruz River, which has a sandy bed of many braided channels, usually dry. At times of rain the Santa Cruz carries considerable water. According to records of the United States Geological Survey the flow at Tucson aggregated 57,200 acre-feet in 1914 and 24,700 acre-feet in 1915. The Santa Cruz is an affluent of the Gila, which its channel reaches in the neighborhood of Phoenix, but even in *Garcés' time it sank into the sands near Picacho Peak, and at present it rarely flows even that far. However, there is considerable underflow in the sand and gravel of the valley fill, especially below the mouths of Rillito Creek and Cañada del Oro, and this water is pumped for irrigation. The irrigated area is entered near Jaynes, a short distance out of Tucson, where there is a State experimental farm; it continues with some interruptions nearly to Naviska.

Cortaro.
Elevation 2,156 feet.
Population 80.*
New Orleans 1,511 miles.

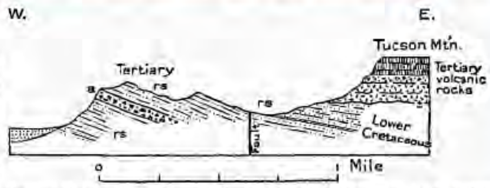


FIGURE 49.—Section of the west side of the Tucson Mountains, Ariz., about 3 miles south of the Ajo road, or 2 miles south of Amole Peak. a, Agglomerate; rs, red sandy shale

Bulletin 845

GUIDEBOOK
OF THE
WESTERN UNITED STATES

PART F. THE SOUTHERN PACIFIC LINES
NEW ORLEANS TO LOS ANGELES

BY
N. H. DARTON

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

*1776 304 p

Figure 4.7: Father Kino's map of the Papagueria. The Gila is identified as the "R. de Hila."

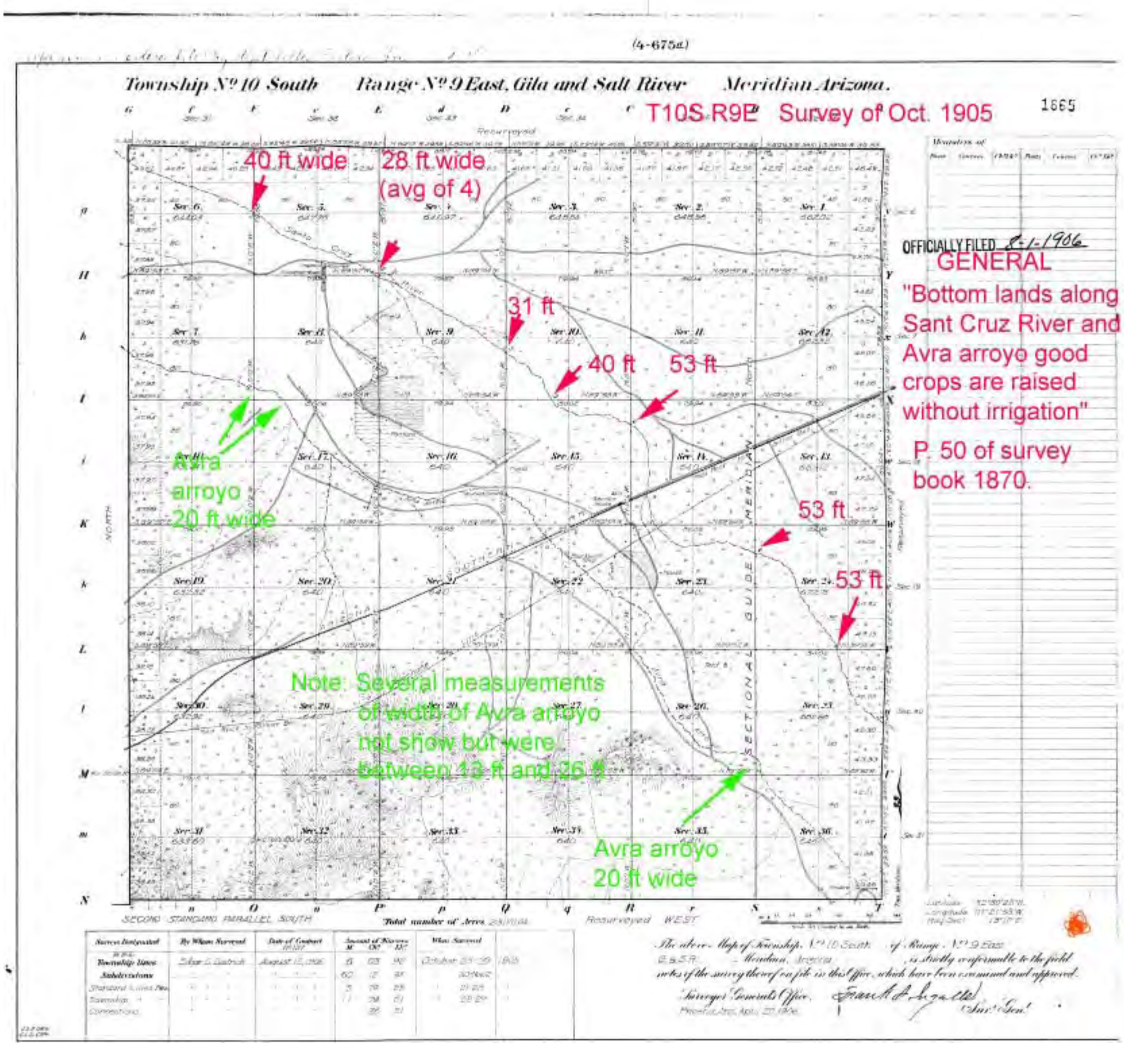
McNamee, Gregory, 1998, Gila: the life and death of an American River, updated and expanded edition, University of New Mexico Press, 232p.

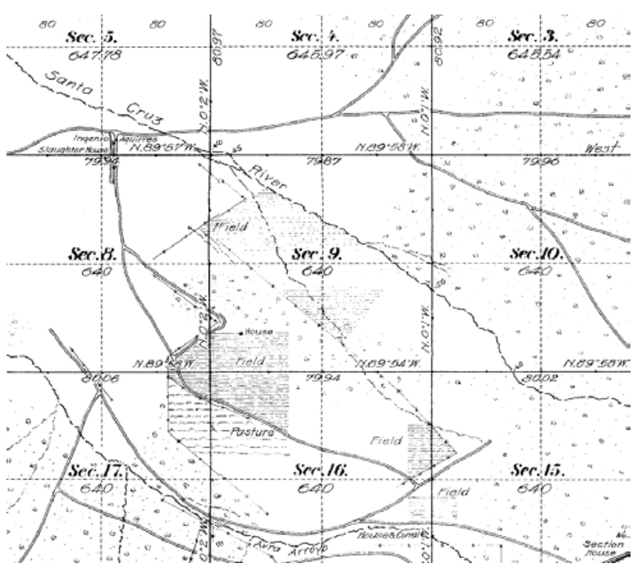
69

Perennial runoff, or nearly so, as far north as Picacho is also suggested by Bryan, 1923, p. 78, where he says that Kino found 1000 persons with considerable farming at the San Xavier del Bac area in 1699 and also 300 men representing 300 families at a rancheria near the present Picacho. This large population in the Picacho area (at Santa Catarina del Cuytoabagum) suggests there was base flow in the Santa Cruz River most of the time in the Picacho Peak area in 1699.

Bryan, Kirk, 1923, Erosion and sedimentation in the Papago country, Ariz., with a sketch of the geology: U. S. Geol. Survey Bull. 730-B, pp.19-90.

T10S R9E

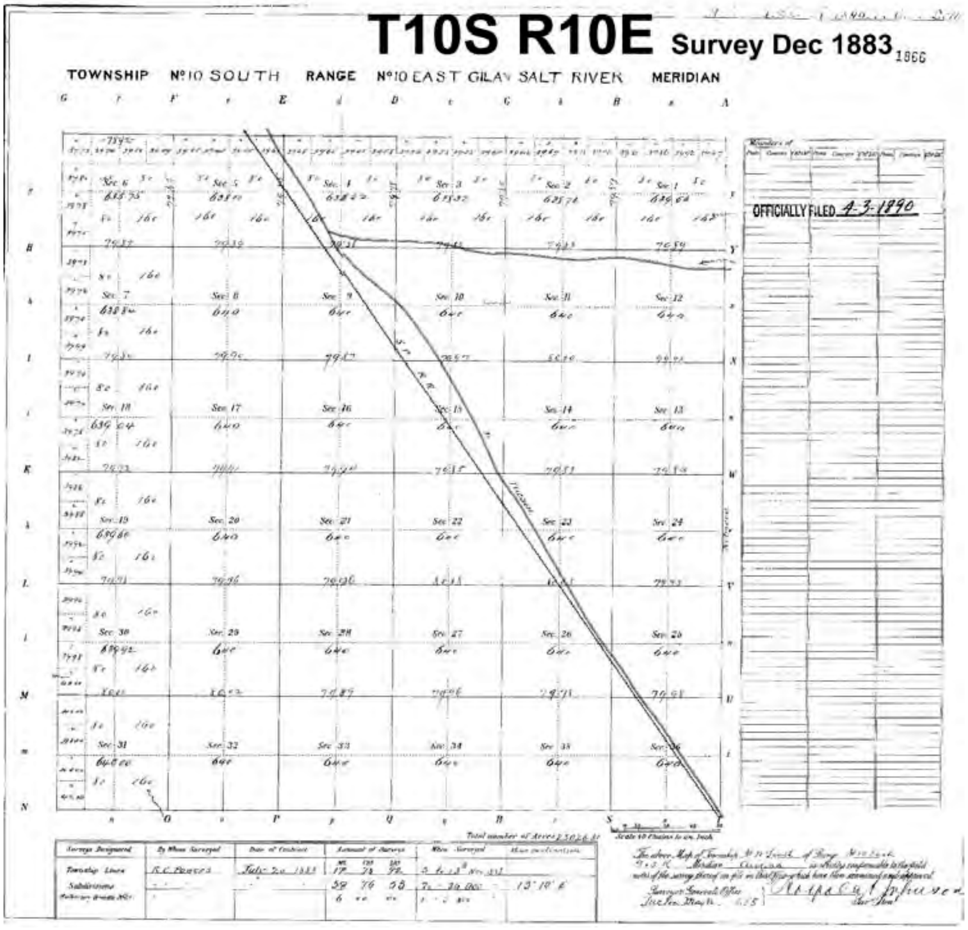


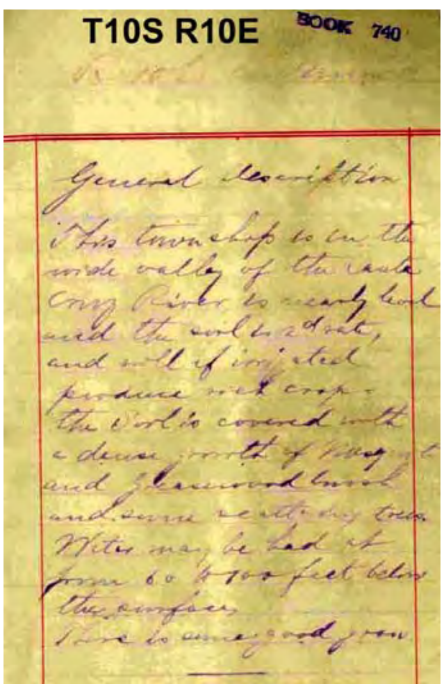


A portion of the above plat depicting un-irrigated fields where crops were grown is shown to the left. It's amazing this cienaga condition was present in 1905 considering the many diversions of base flow for irrigation along the Santa Cruz River upstream of this location.

Also noted on the land survey notes was dense mesquite and grass along the lowlands adjacent to the Santa Cruz River and Avra Arroyo.

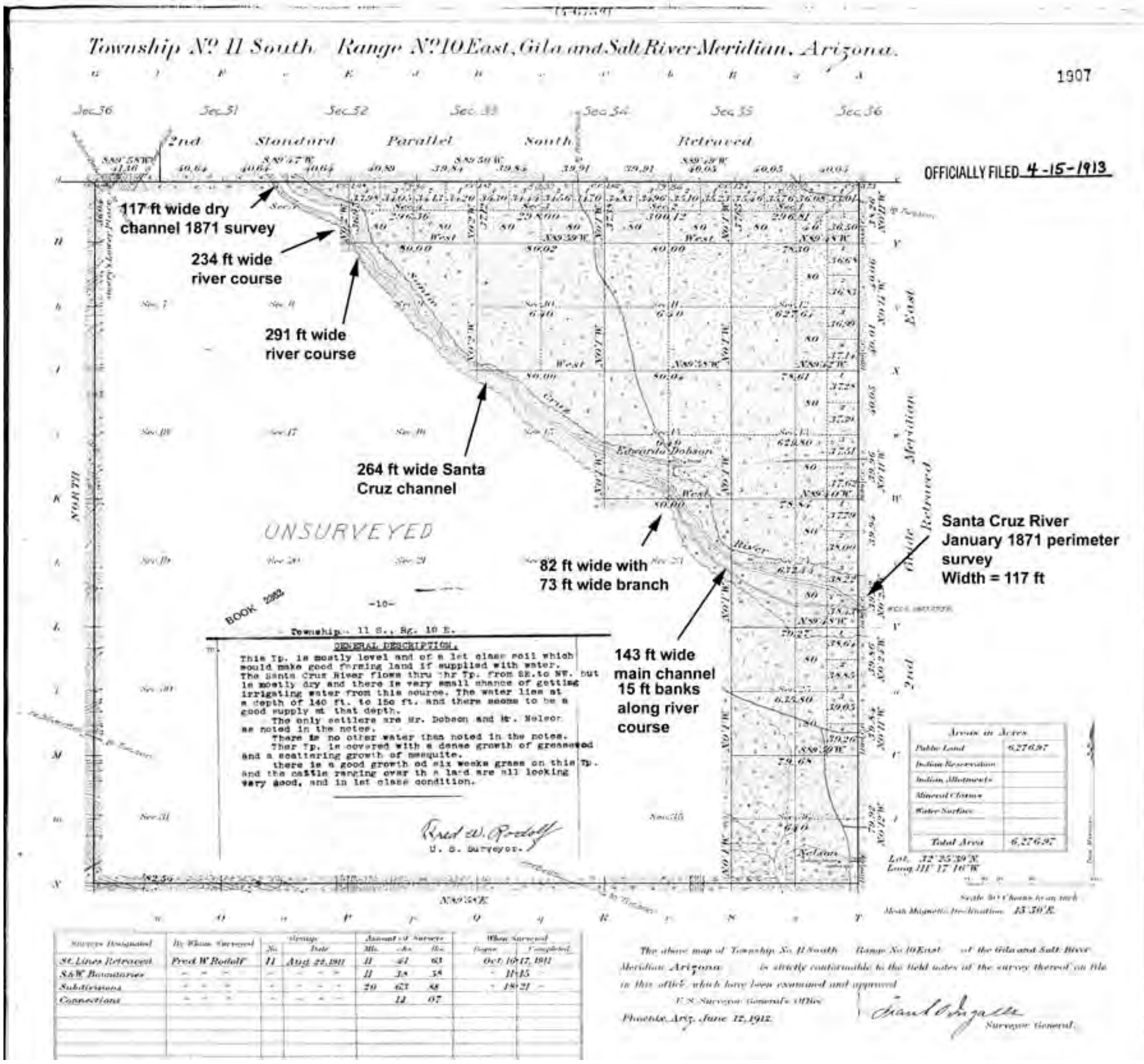
T10S R10E





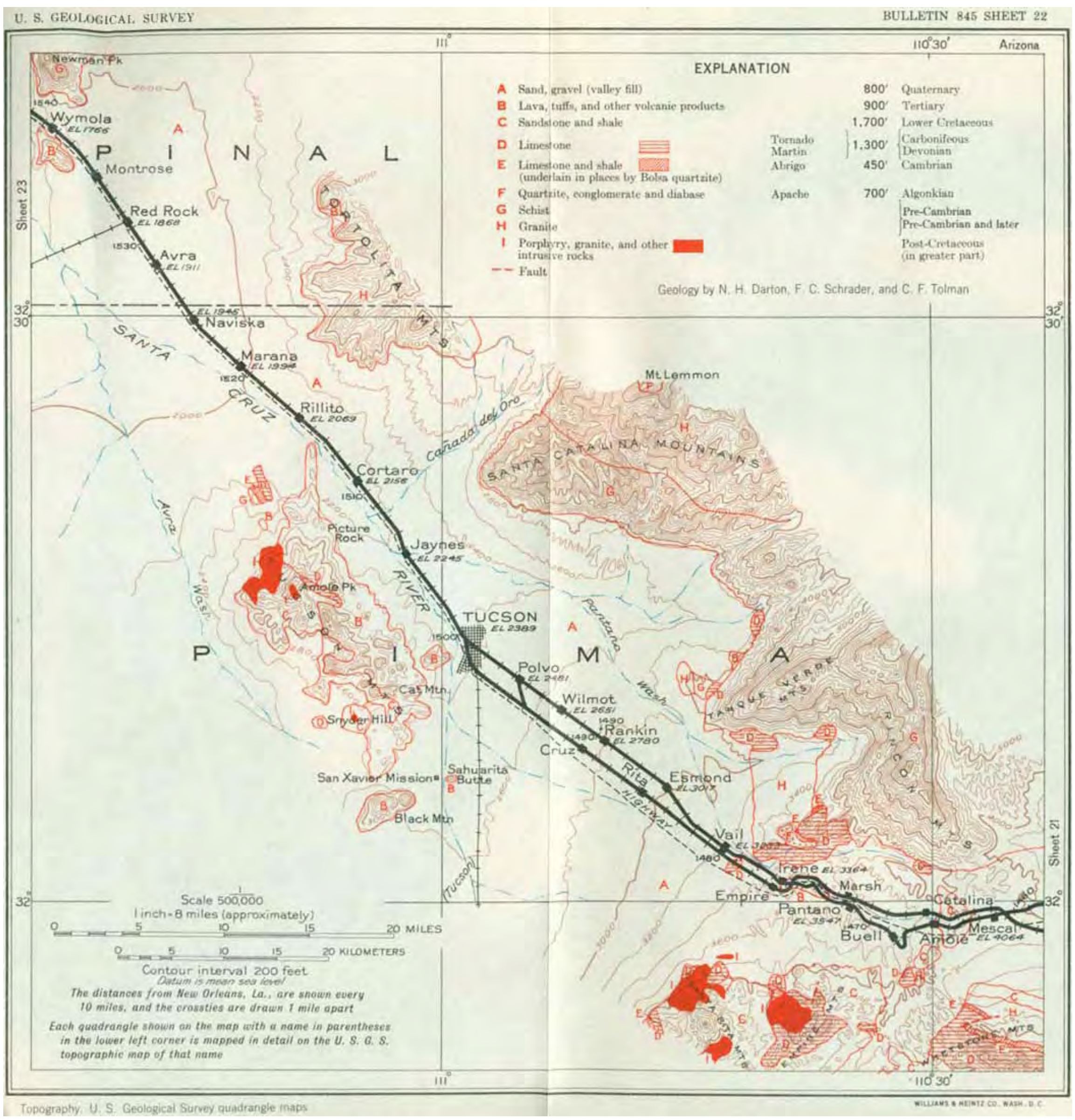
Wide-flat Santa Cruz valley.. Covered with dense growth of mesquite, grass and scattered trees

T11S R10E

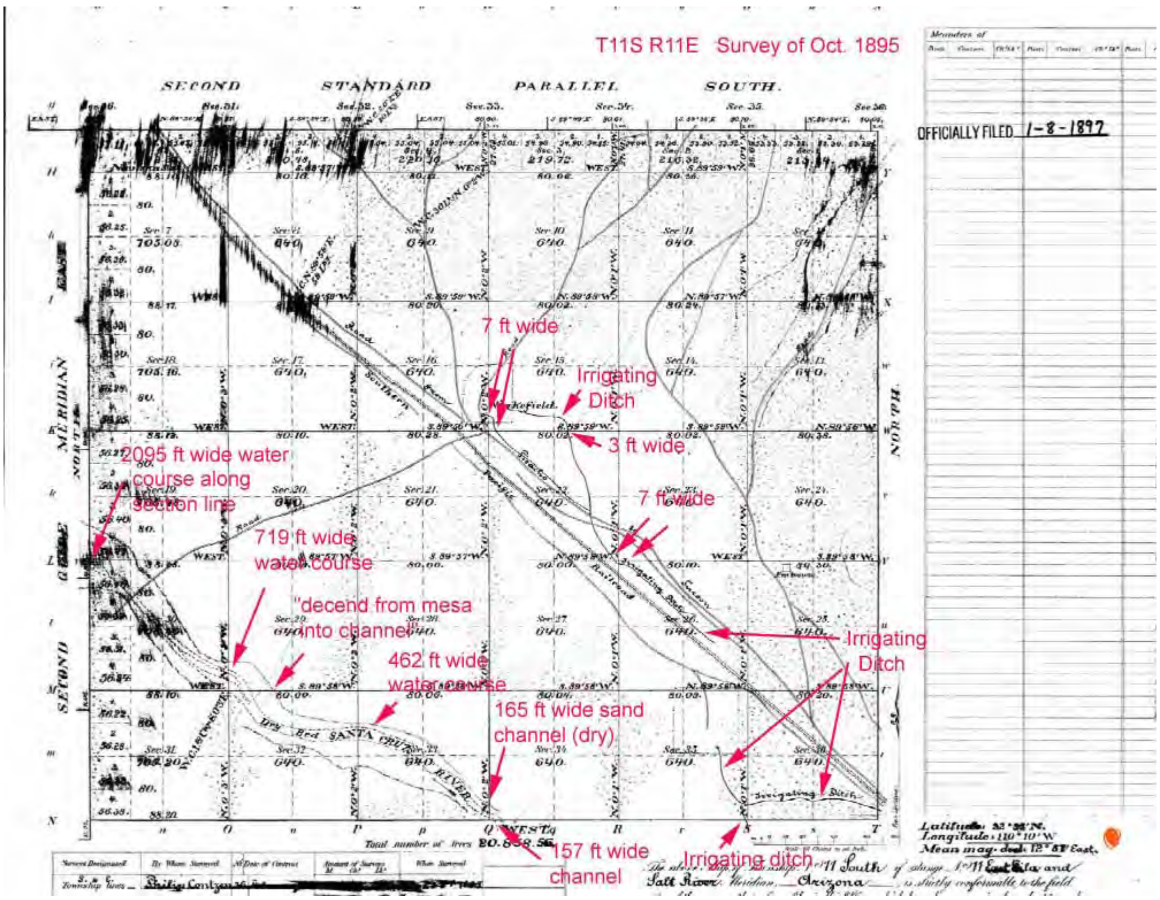

Township Nº 11 South. Range Nº 10 East, Gila and Salt River Meridian, Arizona.
1907
OFFICIALLY FILED 4-15-1913
2nd Standard Parallel South Retraced
117 ft wide dry channel 1871 survey
234 ft wide river course
291 ft wide river course
264 ft wide Santa Cruz channel
Santa Cruz River January 1871 perimeter survey Width = 117 ft
82 ft wide with 73 ft wide branch
143 ft wide main channel 15 ft banks along river course
UNSURVEYED
Edwardo Dobson
Nelson
BOOK 2082
-10-
Township 11 S., Rg. 10 E.
GENERAL DESCRIPTION.
This Tp. is mostly level and of a 1st class soil which would make good farming land if supplied with water.
The Santa Cruz River flows thru the Tp. from SE. to NW. but is mostly dry and there is very small chance of getting irrigating water from this source. The water lies at a depth of 140 ft. to 150 ft. and there seems to be a good supply at that depth.
The only settlers are Mr. Dobson and Mr. Nelson as noted in the notes.
There is no other water than noted in the notes.
Ther Tp. is covered with a dense growth of greasewood and a scattering growth of mesquite.
there is a good growth od six weeks grass on this Tp. and the cattle ranging over th a land are all looking very good, and in 1st class condition.
Fred W. Rodolf
U. S. Surveyor.
Areas in Acres
Public Land 6,276.97
Total Area 6,276.97
Fred W Rodolf
Phoenix, Ariz. June 12, 1912.
Surveyor General

A different perspective to help orient the reader.

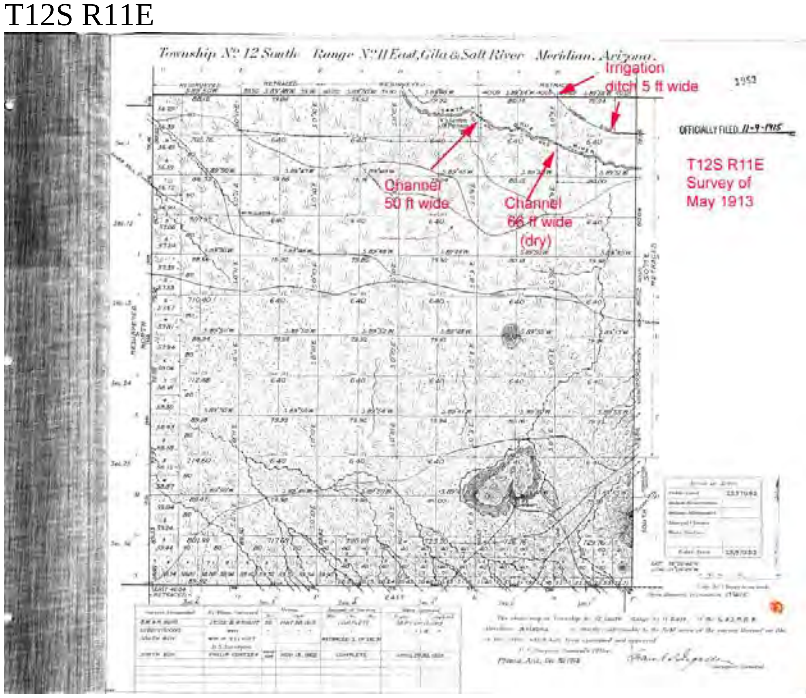
Darton, N. H., 1933, Guidebook of the Western United States: Part F, the southern Pacific Lines New Orleans to Los Angeles; USGS Bulletin 845, 304 p.



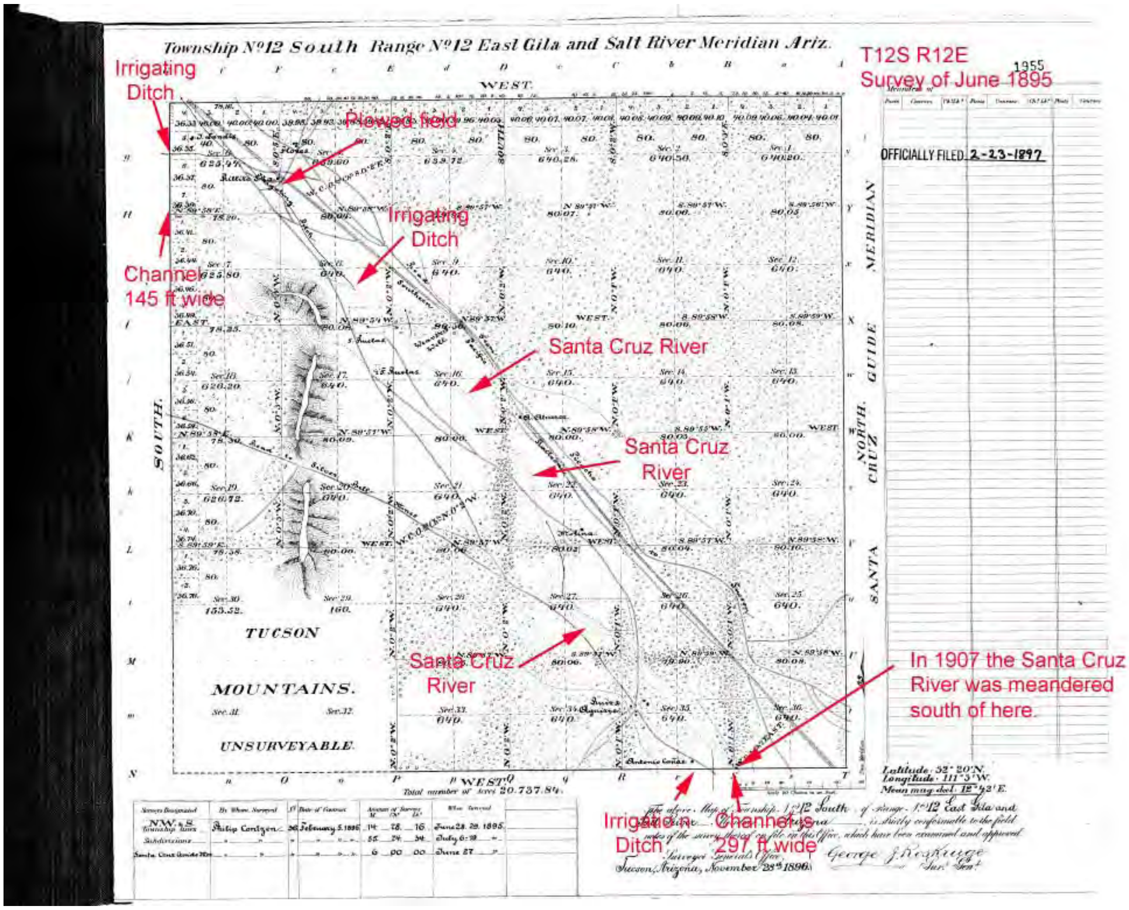
T11S R11E

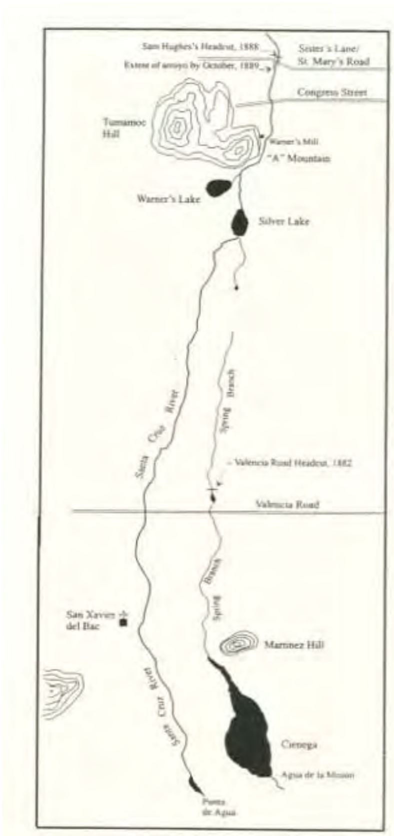


T12S R11E



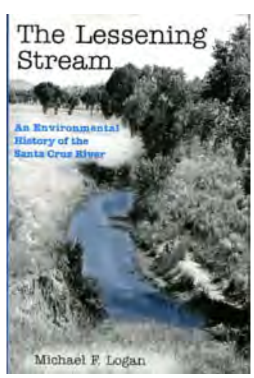
T12S R12E



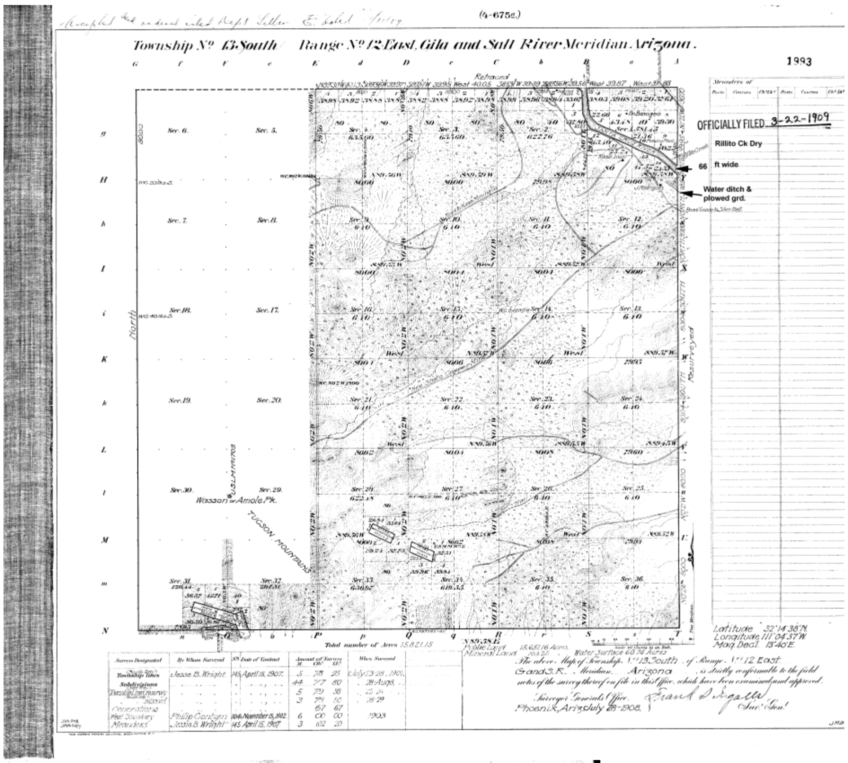


Historic (1880) landmarks shown on map to left.

Logan, M. F., 2002, The Lessening Stream, University of Arizona Press; 311 p.



T13S R12E



Meanders of the Santa Cruz River through T.13 S. R. 12 E.

BOOK 2072

Survey begun May 27,1908 and executed with a Young & Sons light mountain transit No. 6492, with Smith Patent solar attachment on side, the arcs and plates reading by verniers to 1' of arc. This instrument I tested by a true meridian established by polaris and found it to be correct.
I begin at the closing Cor. of Secs. 1&2 on N. b'dy of T. 13 S. R. 12 E. as established by me at point 12 lks W. of the witness corner of Secs. 35 & 36 of T 12 S R 12 E. This closing corner I also mark M.C. on S. Face for a meander Cor. and at this point at 8h 30m l.m.t. I set off 21° 19' N. on the declination arc and 32°20 N. on the lat. arc and determine a true meridian with the solar, thence I run Var. 14°40'E.
West, along N. b'dy of Sec. 2. T 13 S R 12 E.
.20 Enter Santa Cruz River bed.
5.00 West bank of Santa Cruz River 2 ft. high.
Set a sandstone 20" X 12" X 6" 15" in the ground for a meander corner marked M.C. on S.E. face and raise a mound of stone 2 ft. base 1 1/2 ft. high W. of Cor. from which,
a mes. tree 10" diam. brs. S.84°W.70 lks. dist. mkd. T13SR12ES2MCBT
a mes. tree 3" diam. brs. S.66°E.61 lks. dist. mkd. " " "
No other trees available.
Thence I run, through dense mesquite, Var. 14°40'E. along West bank of Santa Cruz River.

S.45°E.------ 3.00 chs. River bank 2 ft. high.
South ------20.00 chs. " " 3 " "
S.18°E.------ 6.60 " " " 4 " "
S.10°E.------ 4.90 " " " 4-10 ft. high

At this point I intersect the Sec. line bet. Secs. 1 & 2 6.20 chs. N. of 1/4 Sec. Cor. At pt. of intersection, I set limestone 20"X10"X8" 15" in the ground for Meander Cor. Marked M.C. on N. face and I groove on E. face and raise a mound of stone 2 ft. base 1 1/2 ft. high S. of Cor. from which,
a mesquite tree 6" diam. brs. N.7° E. 65 lks dist. marked T. 13 S. R. 12 E. S. 1 M.C.B.T.
A mesquite tree 14" diam. brs. S. 71 1/2° E. 75 lks. dist. marked T. 13 S. R. 12 E. S. 1 M.C.B.T. No other bearings available.
Bank at this point is 10 ft. high, being against edge of mesa.
Thence I run,

S.47° E.---- 3.60 chs. desc. to low bottom subject to overflow,
S. 80° E. -- 6.90 " bank 1 ft. high
S. 60E E.---10.00 " " 2 " "
S. 68° E. --10.20 " " 2 " "
S. 63° E.--- 9.90 " " 2 " "
S. 61° E.--- 9.00 " " 3 " "
S. 75° E.--- 5.00 " " 2 " "
S. 78° E.--- 6.30 " " 3 " "
S. 62° E.---10.40 " " 3 " "
S. 45° E. ---8.00 " " 3 " "
S. 50° E.---12.60 " " 3 " "

At this point intersect the East b'dy of Tp. 3.70 chs. N. of the Cor. of Secs. 1, 6, 7 and 12, at which point of int. set a granite stone 24" X 10"X 8" 18" in the ground for meander Cor. marked M.C. on N. face and raise a mound of stone 2 ft. base 1 1/2 ft. high S. of Cor. from which,
a mesquite tree 6" diam. brs. S.42° E. 63 lks marked T. 13 S. R. 13 E. S.6 M.C.B.T.
a mes. tree 12" diam. brs. S.89°W.88 lks. dist. mkd. T.13 S.R.12E S. 1 M.C.B.T. No other bearings available.

Meanders of Santa Cruz River through T.13 S. R. 12 E.

Chains

From the corner of secs. 1 & 12 on E. b'dy of Tp. I run, North, Var. 14° 40' E.
3.70 meander Cor. on S. bank of Santa Cruz River as heretofore described and enter Santa Cruz River.
10.85 North bank of Santa Cruz River 10 ft. high, on top of bank Set a granite stone 20" X 10" X 8" 15" in the ground for a meander Cor. marked M.C. on S. face, from which,
Mesquite tree 8" diam. brs. S. 9° W.19 lks. dist. mkd. T.13 S. R. 12. E. S. 1 M.C.B.T.
a mes. tree 6" diam. brs. N.85° E. 24 lks. dist. mkd. T.13 S. R. 13 E. S.6 M.C.B.T.
No other trees available,
thence I run, through dense mesquite, along N. bank of River

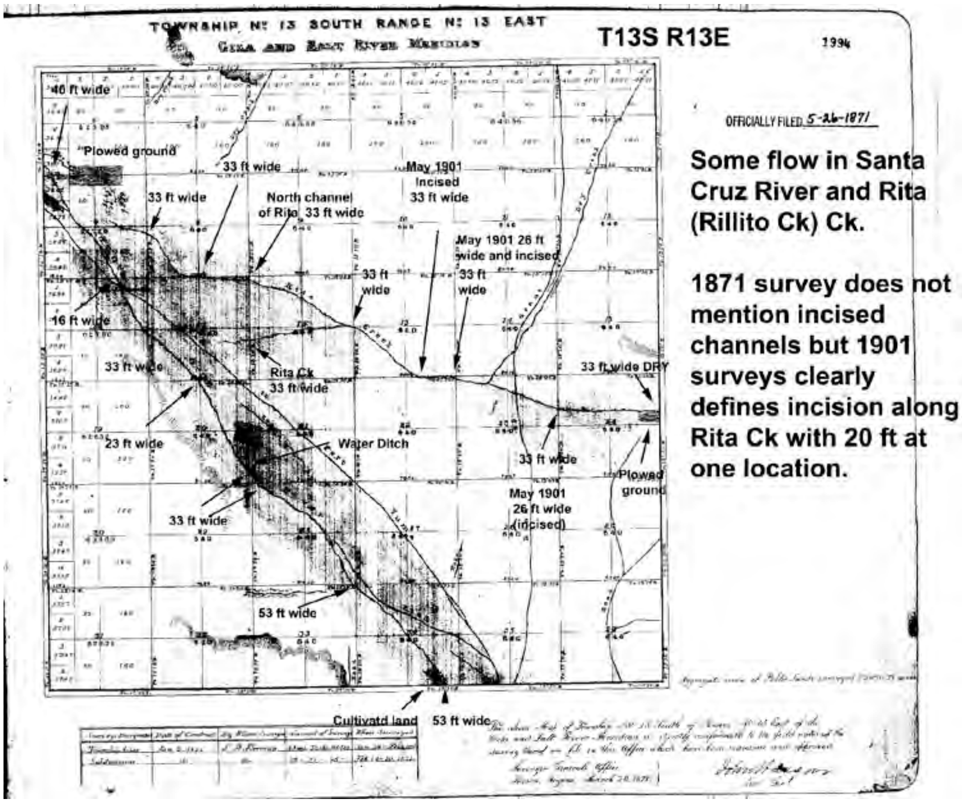
N.42°02'W.--10.10 chs. bank 10 ft. high.
4.20 on this line S. bank of Rillito Creek, dry.
8.10 " " " N. " " " "
N.58°40'W.--15.60 chs. bank 2 ft. high.
N.75° W. -- 8.00 " " 4 " "
N.85° W. --- 3.00 " " 4 " "
N.74° W. --- 3.00 " " 4 " "
N.66° W.---- 5.00 " " 4 " "
N.60° W.---- 9.00 " " 4 " "
N.63° W. ---14.00 " " 4 " "
N.79° W.---- 5.20 " " 4 " "
N.68° W. --- 3.60 " " 4 " "
N.53°15'W.-- 6.10 " " 4 " "
N.44° W.---- 3.60 " " 4 " "
N.32° W.---- 8.60 " " 3 " "
N. 1°15'W.--12.10 " " 3 " "
N. 7° W. --- 5.00 " " 3 " "
N.6°1 W.---- 4.00 chs. to meander Cor. on N. b'dy of Tp. being point of beginning and identical with closing Cor. of secs. 1 & 2 on N. b'dy of T.13 S. R. 12 E.

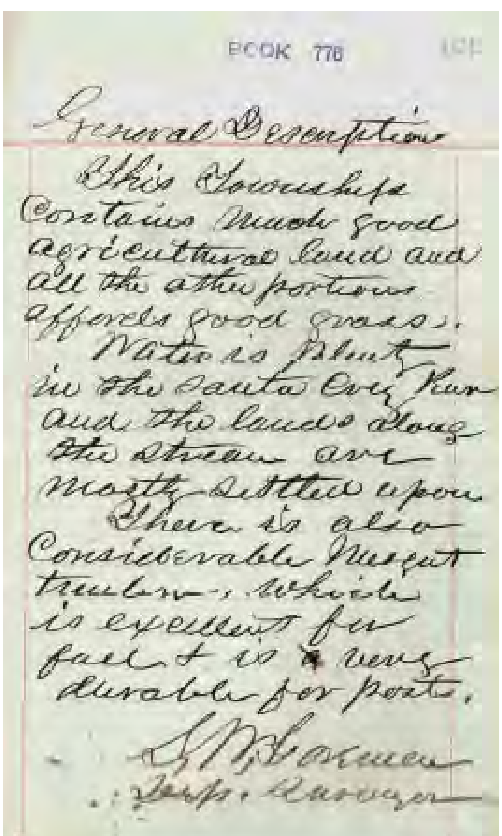
Land gently rolling, soil 1st & 2nd rate loamy, sandy, gravelly; timber, mesquite and cottonwood, undergrowth, dense mesquite and tesota.
Distance- 242.20 chs. of land covered with dense undergrowth and exceptionally difficult to survey.

Survey completed May 27,1908

Jesse B. Wright
U.S. Deputy Surveyor.

T13S R13E




BOOK 778

General Description
This Township
Contains much good
agricultural land and
all the other portions
affords good grass.
Water is plenty
in the Santa Cruz Run
and the lands along
the stream are
mostly settled upon.
There is also
Considerable Mesquit
timber, which
is excellent for
fuel & is very
durable for posts.
S. W. Foreman
Dep. Surveyor

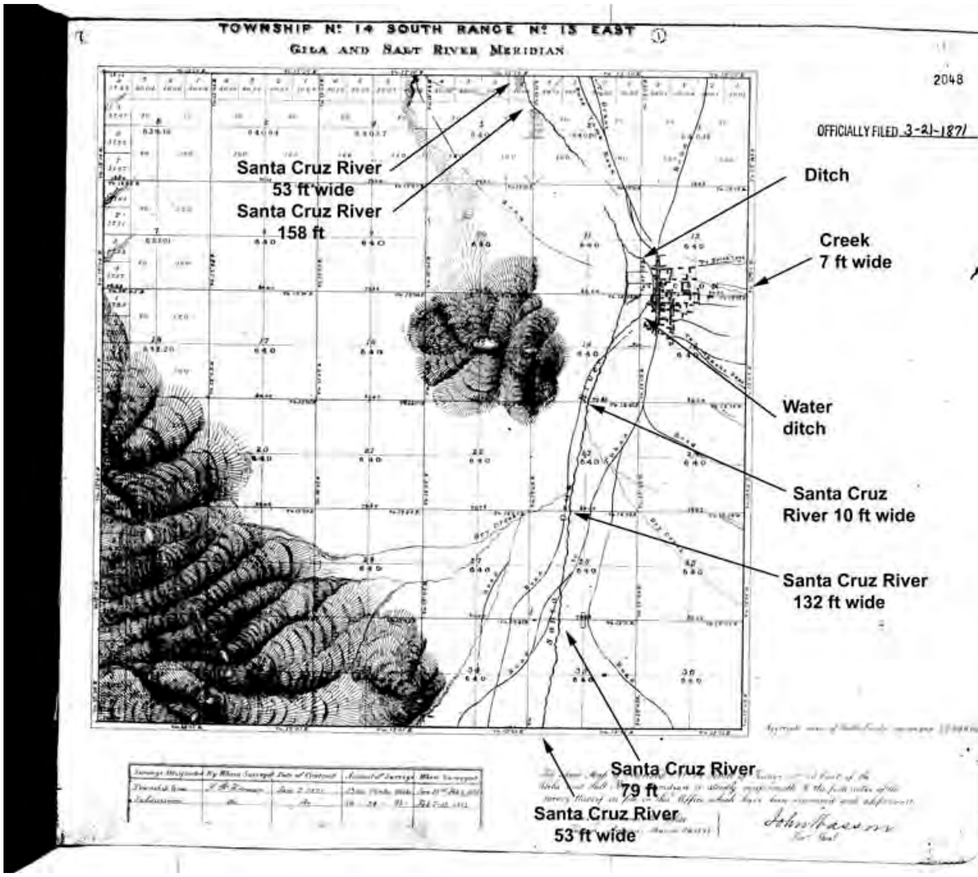
1871

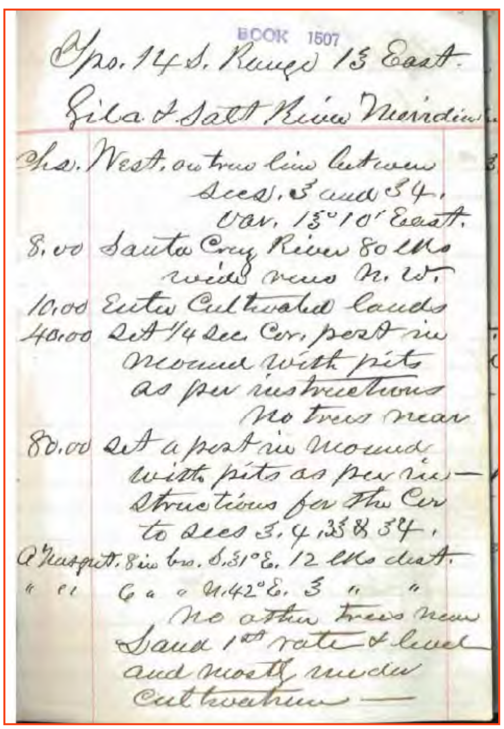
Plenty of water in the Santa Cruz River.

".. the lands along stream are mostly settled upon."

Considerable mesquite. (See lightly shaded areas of above map)

T14S R13E



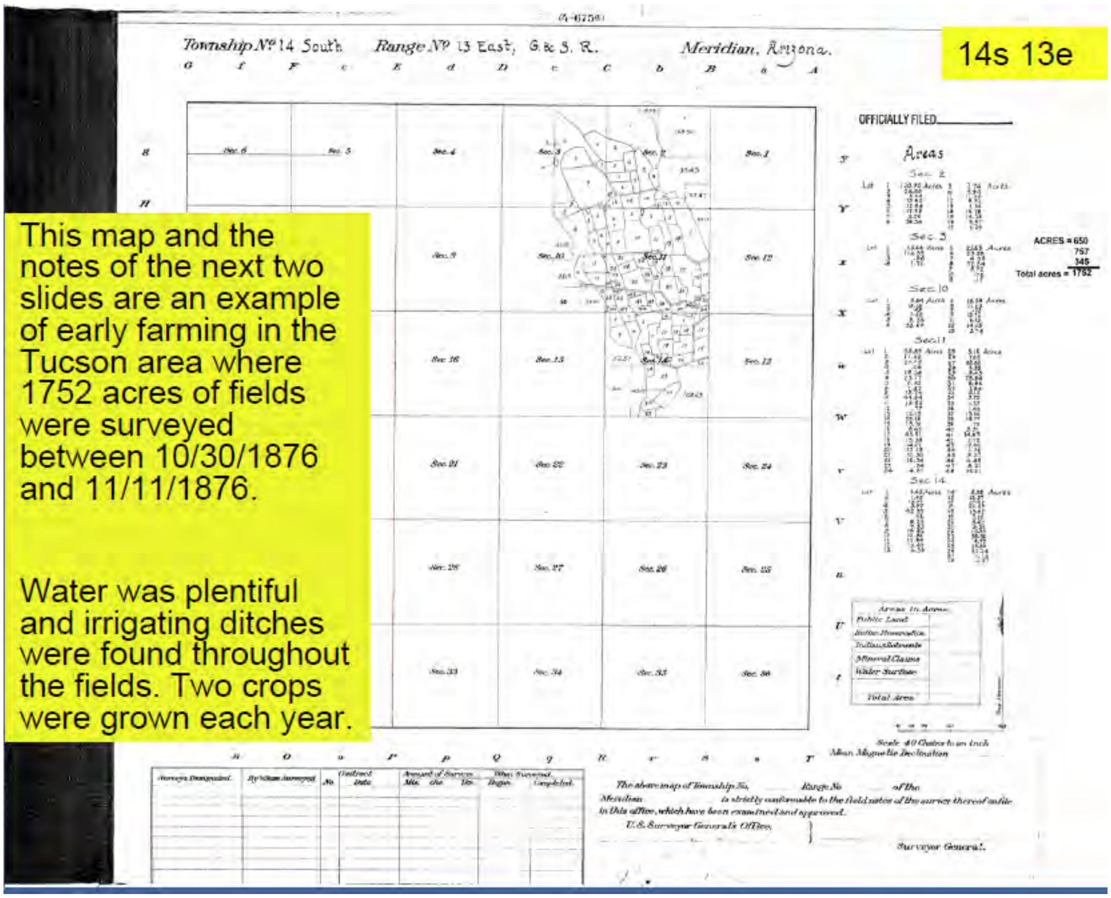

BOOK 1507

Tps. 14 S. Range 13 East.
Gila & Salt River Meridian
Chs. West, on true line between
Secs. 3 and 34.
Var. 13°10' East.
8.00 Santa Cruz River 80 lks
wide runs N. W.
10.00 Enter Cultivated lands
40.00 Set 1/4 Sec. Cor. post in
mound with pits
as per instructions
No trees near
80.00 Set a post in mound
with pits as per in-
structions for the Cor
to Secs 3, 4, 33 & 34.
A Mesquit. 8 in dia. bears S.31°E. 12 lks dist.
" " 6 " " N.42°E. 3 " "
No other trees near
Land 1st rate & level
and mostly under
Cultivation —

Surveyor indicated that Santa Cruz channel became 2 water ditches

Most of land under cultivation

T14S R13E



822

FIELD NOTES

OF THE SURVEY OF

Lands in Secs. 2, 3 10, 11, & 14 of T. 14 S., R. 13 E., granted to Settlers therein by Act of Congress approved Feb. 8, 1875.

Gila and Salt River Base and Meridian,

ARIZONA.

By Theodore F. White, D. S.
Contract dated Sept. 18, 1876.
Survey commenced Oct. 30, 1876.
Survey completed Nov. 11, 1876.

BOOK 822

111

General Description.

The foregoing are the field notes of the survey of fields in Secs. 2, 11, and   and the E. 1/2 of secs. 3, 10 and 15 of Tp. 14 S. Range 13 E. Gila and Salt River Meridian, Arizona granted to settlers by an act of Congress entitled an "Act to grant title to certain lands in Arizona" approved February 8, 1875.

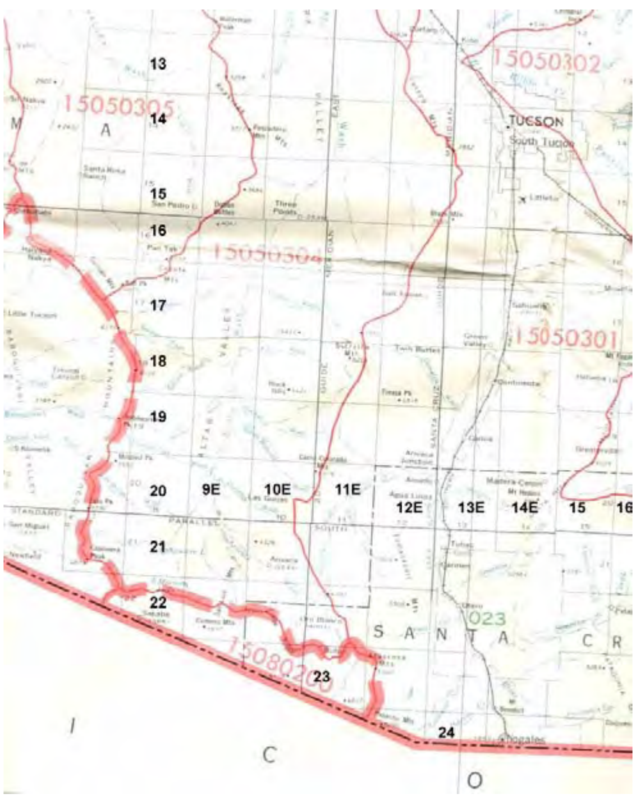
Acting under contract made by me with parties in interest, in conformity to instructions issued by the Hon. Commissioner to the Register at Florence of date April 8, 1875, I made a preliminary survey of these fields or lots in Oct. 1875 and verified the same under oath. This preliminary survey furnished the Register the necessary information concerning the various fields and the present survey is identical with the preliminary one with such slight alterations as were rendered necessary by the decisions of the Register.

The posts mentioned in the notes, which were set in the preliminary survey, are all about 3 ft. in length, 2 ins. diameter and driven 2 ft. in the ground. They are all plainly marked

and will be lasting. No instructions were given concerning posts the fence bounding and marking the fields perfectly well.

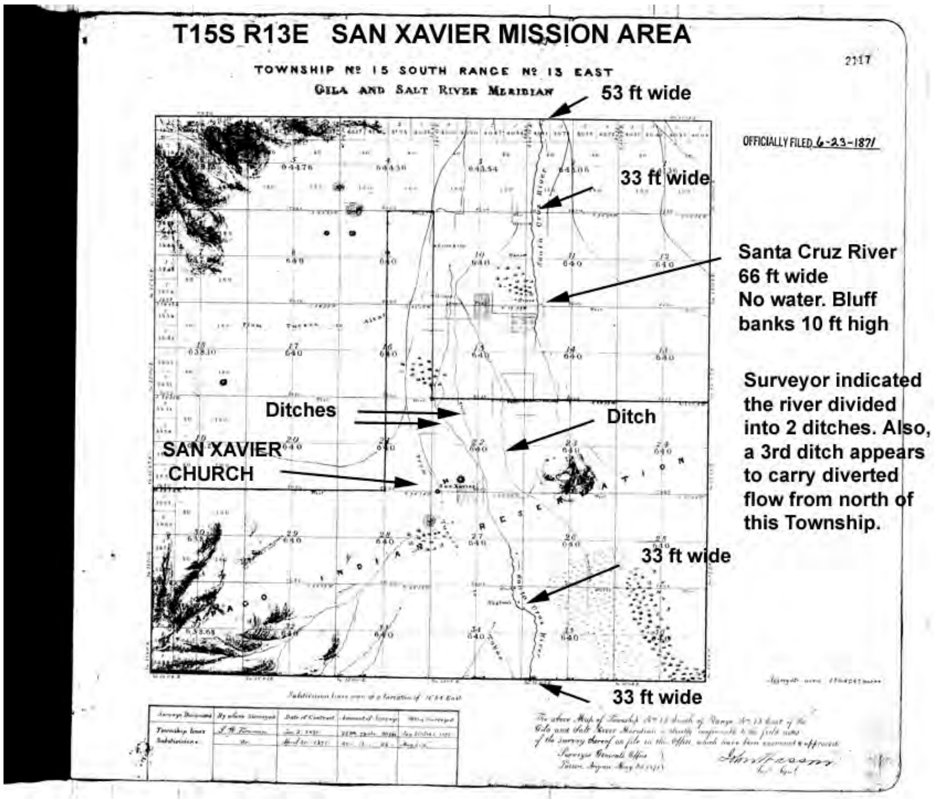
These fields lie in the valley of the Santa Cruz river directly in front and to the west of the Town of Tucson. The soil is exceedingly fertile yielding now as it has done for years two full crops each year. Water is plentiful and irrigating ditches are found throughout the fields.

Theodore F. White,
U. S. Deputy Surveyor.



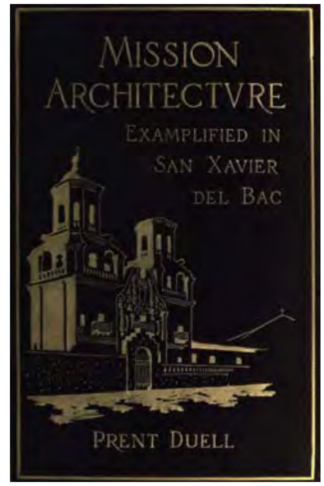
index map to left.

T15S R13E


T15S R13E SAN XAVIER MISSION AREA
2117
TOWNSHIP Nº 15 SOUTH RANGE Nº 13 EAST
GILA AND SALT RIVER MERIDIAN
53 ft wide
OFFICIALLY FILED 6-23-1871
33 ft wide
Santa Cruz River
66 ft wide
No water. Bluff
banks 10 ft high
Surveyor indicated
the river divided
into 2 ditches. Also,
a 3rd ditch appears
to carry diverted
flow from north of
this Township.
Ditches
Ditch
SAN XAVIER
CHURCH
33 ft wide
33 ft wide

T15S R13E (Cont.)

SAN XAVIER DEL BAC about 1868, just as the Franciscans left it.

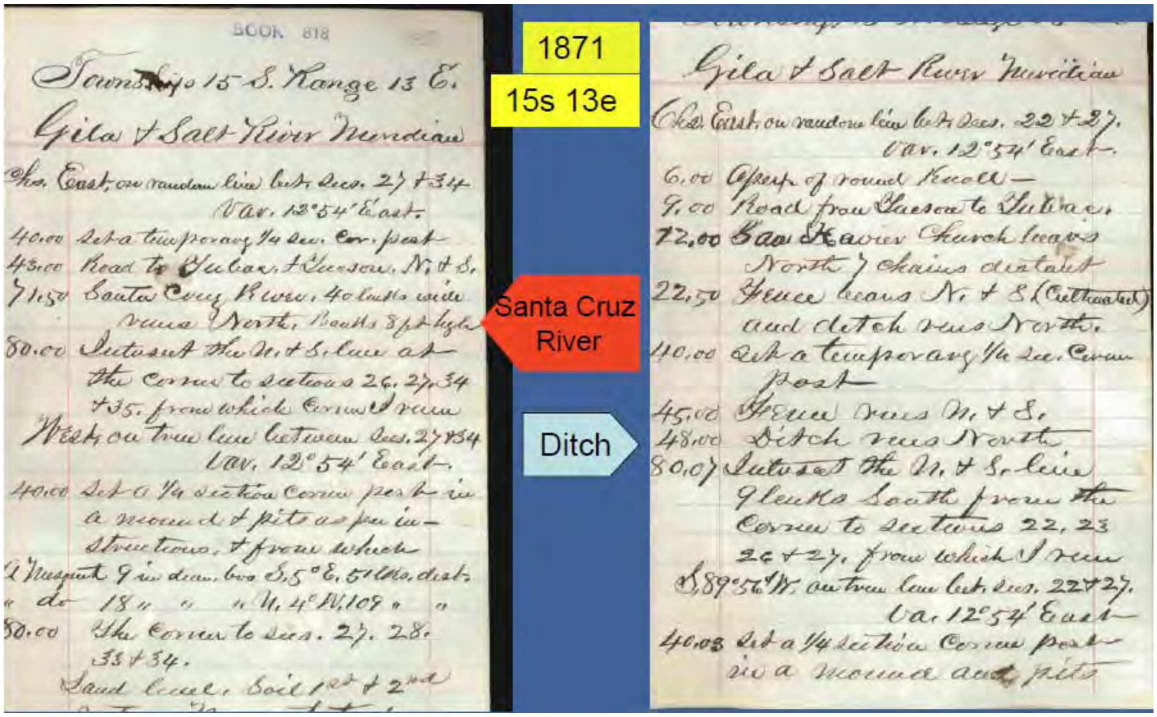


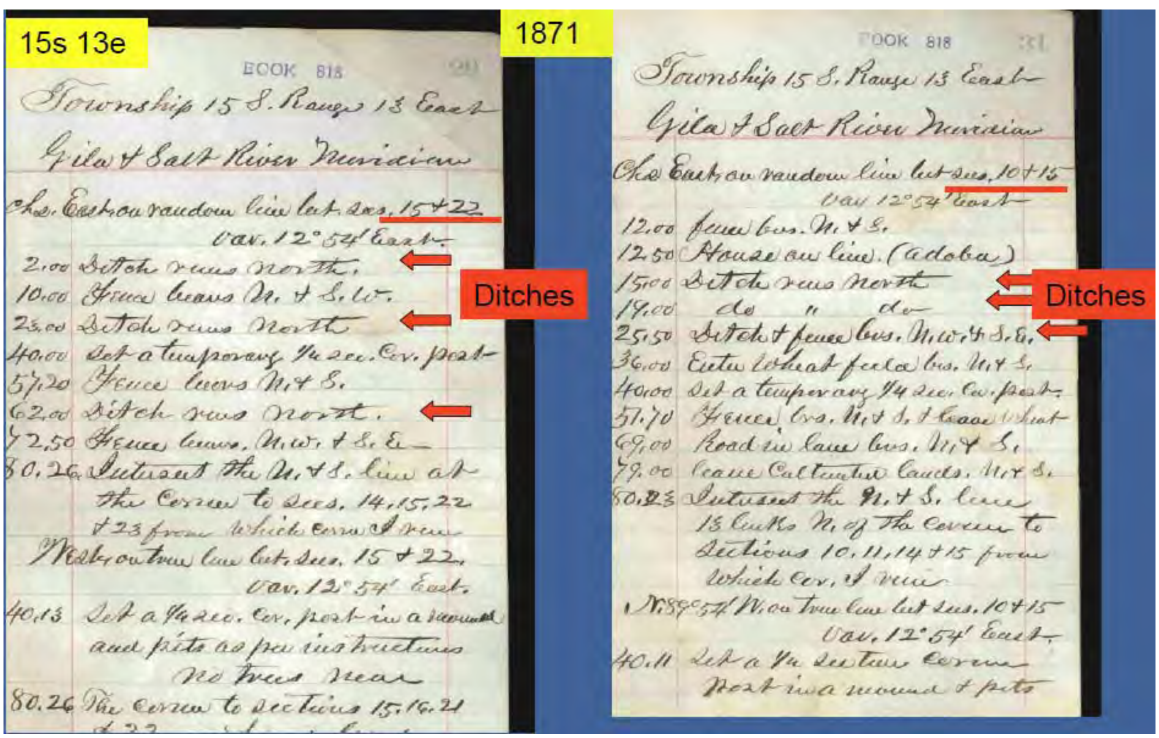
Duell, Prent, 1919, Mission Architecture, as exemplified in San Xavier Del Bac, PUBLISHED BY THE ARIZONA ARCHAEOLOGICAL AND HISTORICAL SOCIETY, TUCSON, ARIZONA, 135p.

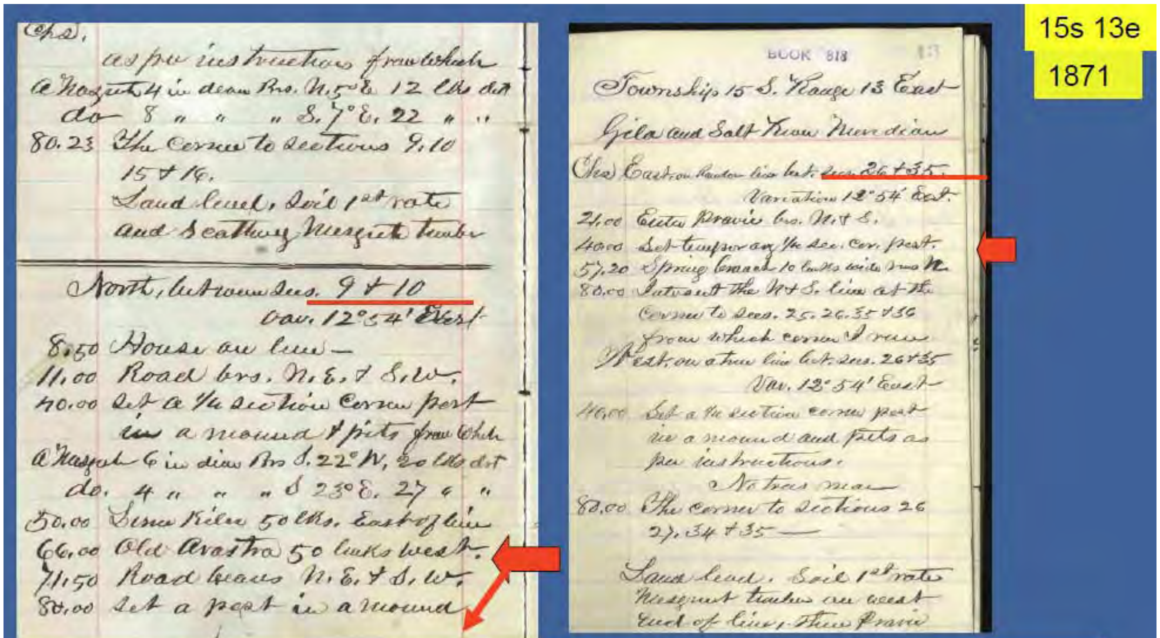
In the year 1692, as has been said, Kino made the first of many visits to Bac. He often dwells upon the excellence of its location for a mission. In a letter to King Philip V. of Spain, he describes Bac in the following words: "There are already very rich and abundant fields, plantings and crops of wheat, maize, frijoles, chick-peas, beans, lentils, bastard chick-peas, etc. There are good gardens, and in them vineyards for wine for masses, with reed-brakes of sweet cane for syrup and panocha, and, with the favor of Heaven, before long for sugar. There are many Castilian fruit trees, as fig-trees, quinces, oranges, pomegranates, peaches, apricots, pear-trees, apples, mulberries, pecans, prickly pears, etc., with all sorts of garden stuff, such as cabbages, melons, watermelons, white cabbage, lettuce, onions, leeks, garlic, anise, pepper, mustard, mint, Castilian roses, white lilies, etc., with very good timber for all kinds of building, such as pine, ash, cypress, walnut, china-trees, mesquite, alders, poplar, willow, tamarind, etc."

The condition today is entirely different and small sagebrush and dwarfed mesquite-trees mark the spot of this former paradise. That his letter is probably true is borne

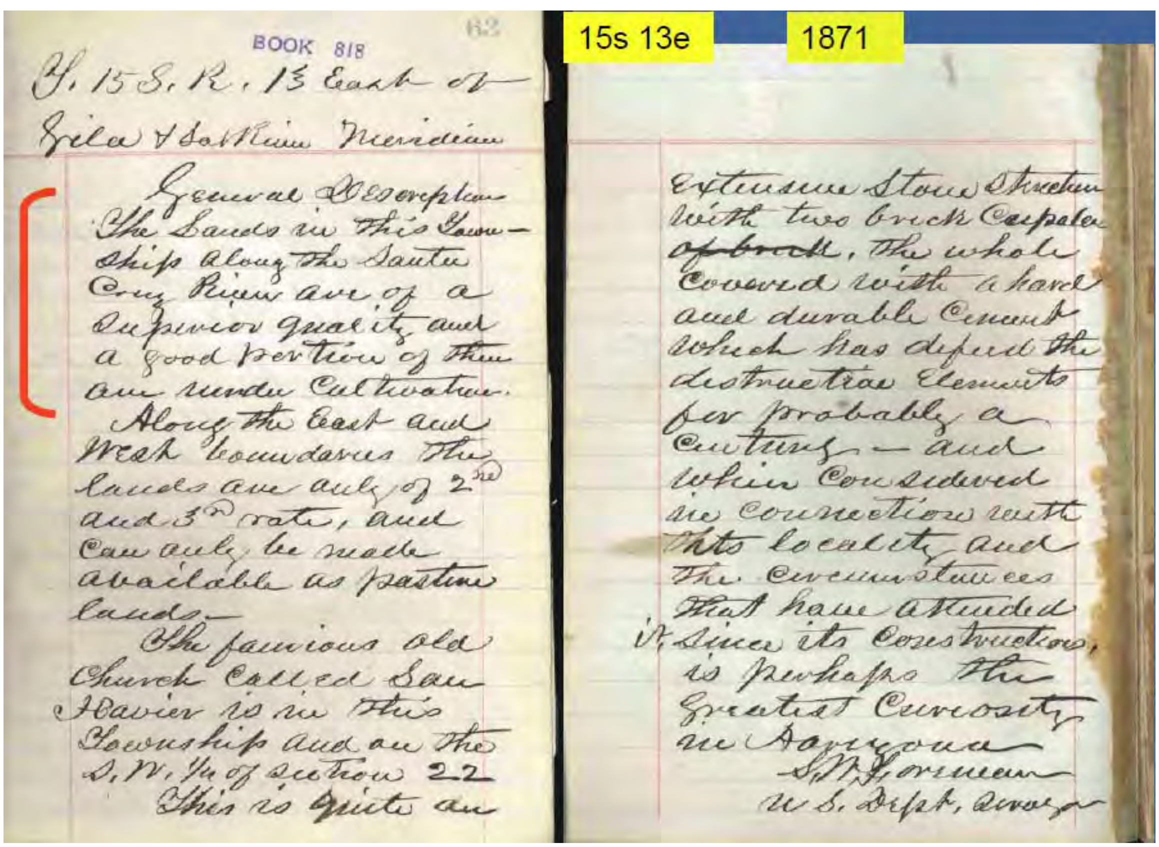
T15S R13E (cont.)



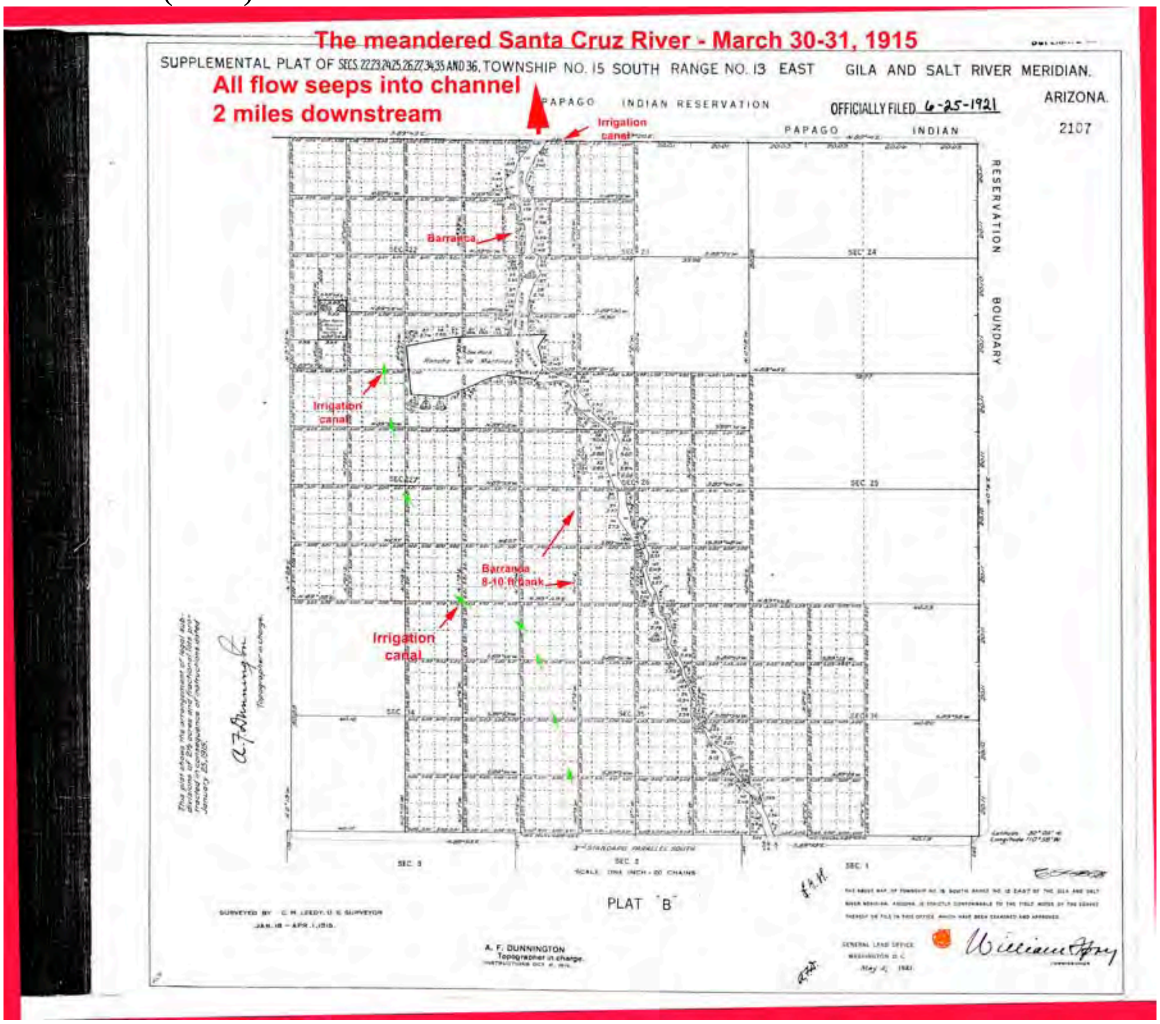




An **Arrastra** is a primitive mill for grinding and pulverizing (typically) gold or silver ore driven by a water wheel. A steady flow of water is implied for an Arrastra to be successful.



T15S R13E (Cont.)



Note: All canals identified by Fed. Land Survey are not shown.

T. 15 S., R. 13 E.

T15S R13E (Cont.)

GENERAL DESCRIPTION.

This fractional township contains three general varieties of land, level bottom, nearly level mesa, and mountainous land.

"Black Mountain" covers the western third of the township and the soil is rocky, 4th rate. "Berger Butte" lies in the S½ of sec. 23, and is of same character.

The Santa Cruz River flows northerly through secs. 22, 23, 26, 35 and 36, and from one-half to one mile on each side is level bottom land; soil 1st rate. The river in this township is from 2.20 to 4.80 chs. wide. The banks at present are well defined - cut banks from 12 to 20 feet high. About a mile south of the Standard Parallel in T. 16 S., R. 13 E. the stream disappears entirely, the flow being underground. The remainder of the fractional township is nearly level mesa land. It is practically covered with scattered mesquite and some palo verde timber, mesquite brush, greasewood, and numerous species of cacti.

Road from Tucson to Nogales enters in sec. 9, running through sec. 16, and dividing in sec. 21, the western branch being known as the hill road, and the other, the valley road. There are numerous cross roads from one part of the valley land to another.

The old San Xavier Mission is located in the NE¼ of the SW¼ of sec. 22.

The Berger Ranch (or Rancho de Martinez) lies in the NE¼ of sec. 27, and SE¼ of sec. 22, and is occupied as Agency Headquarters for the employees of the Indian Service. The main village of the Papagos on this reservation is located near San Xavier Mission. There is a smaller village near the center ¼ sec. cor. of sec. 23.

By March 30-31, 1915 the channel of the Santa Cruz River was incised 12-20 ft and the "trench" was from 154 ft to 317 ft wide. All of the base flow seeped into sediments about 3 miles north of the San Xavier Del Bac mission.

There are numerous scattered Indian houses along the road to Tucson in secs. 9, 16, and 21.

There are about 1500 acres under cultivation producing abundant crops. Probably 1500 acres more would be equally as productive if sufficient water for irrigation was available.

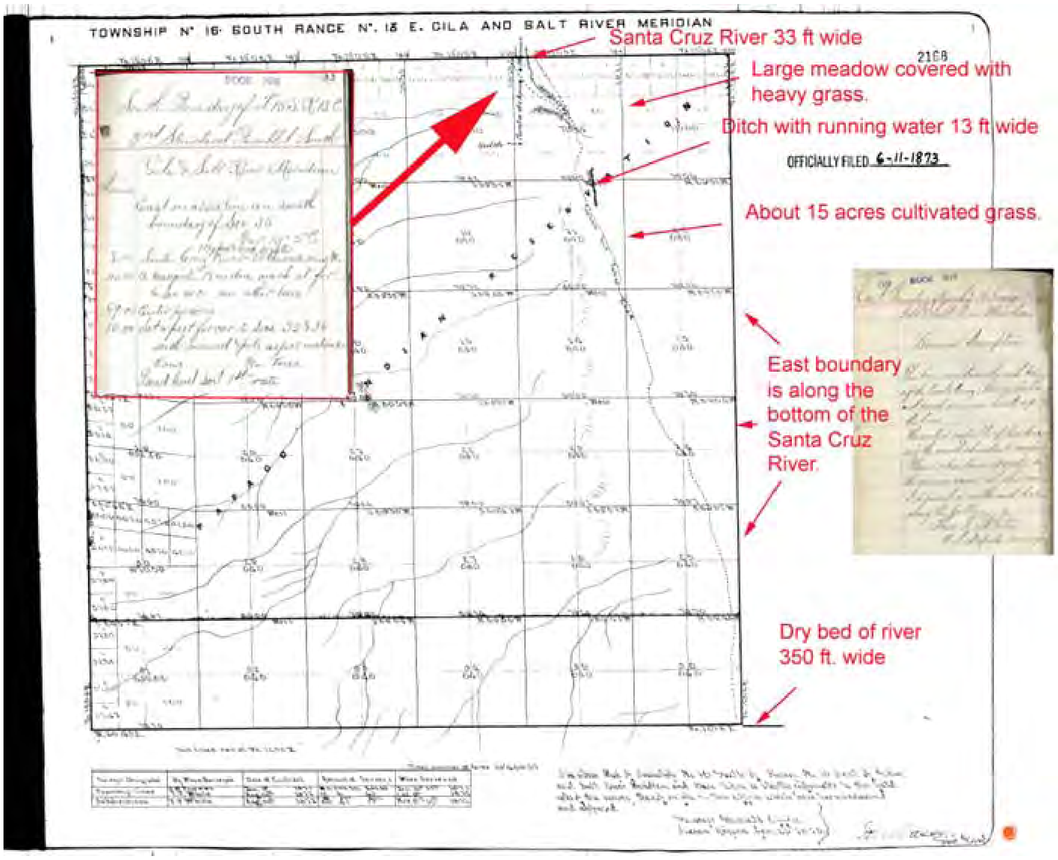
irrigation

The fractional township as a whole is very well improved.

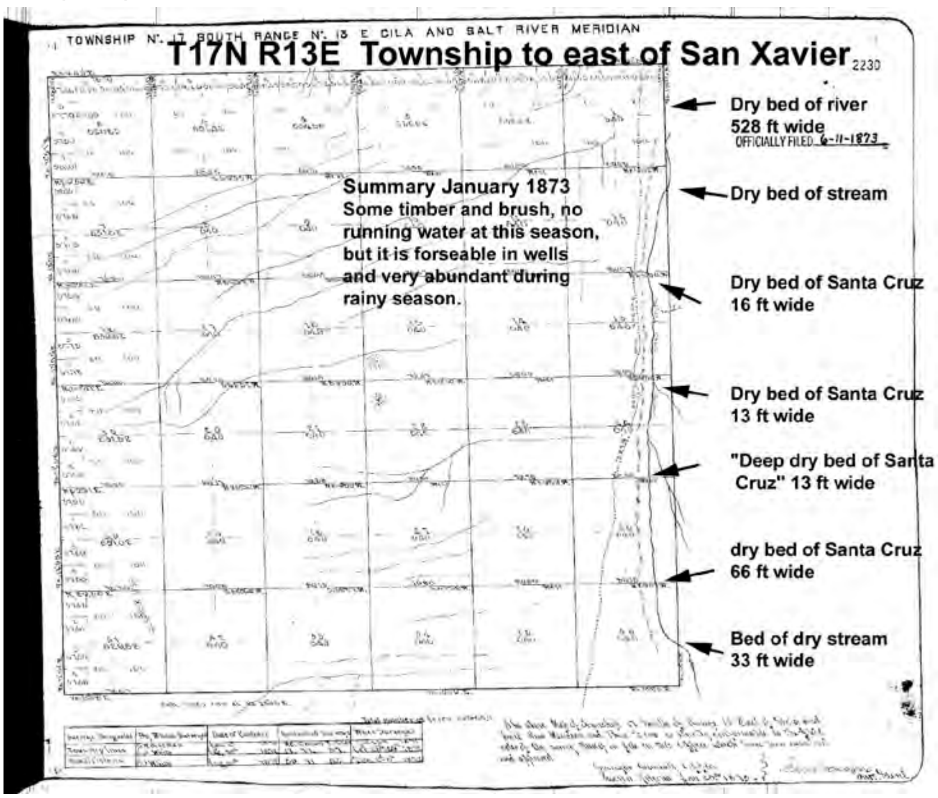
Charles M. Leady

U. S. Surveyor.

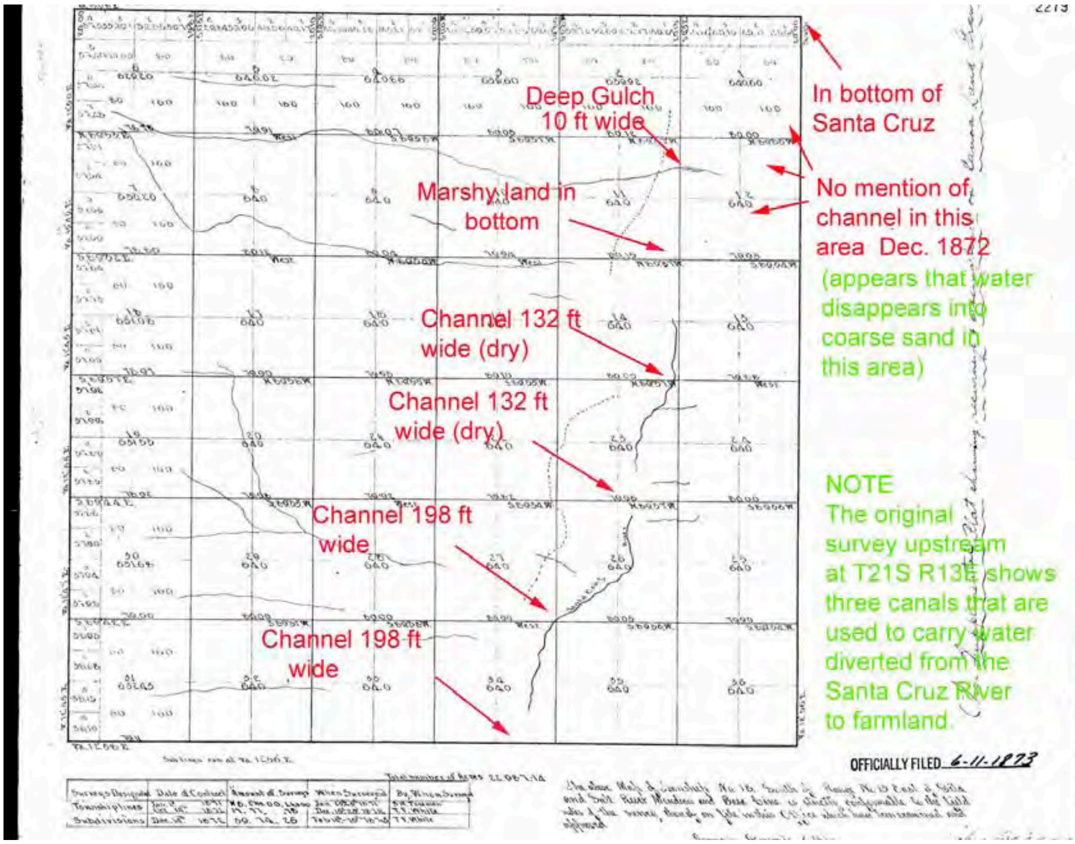
T16S R13E

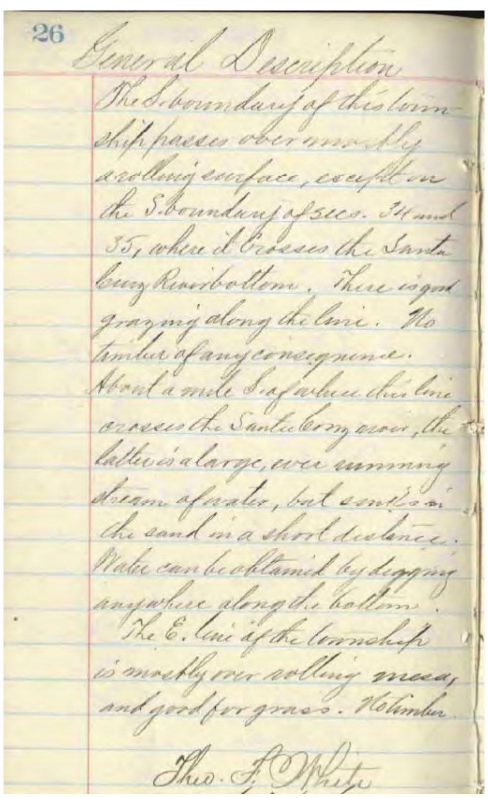


T17S R13E



T18S R13E




26

General Description

The S. boundary of this township passes over mostly a rolling surface, except on the S. boundary of secs. 34 and 35, where it crosses the Santa Cruz River bottom. There is good grazing along the line. No timber of any consequence.

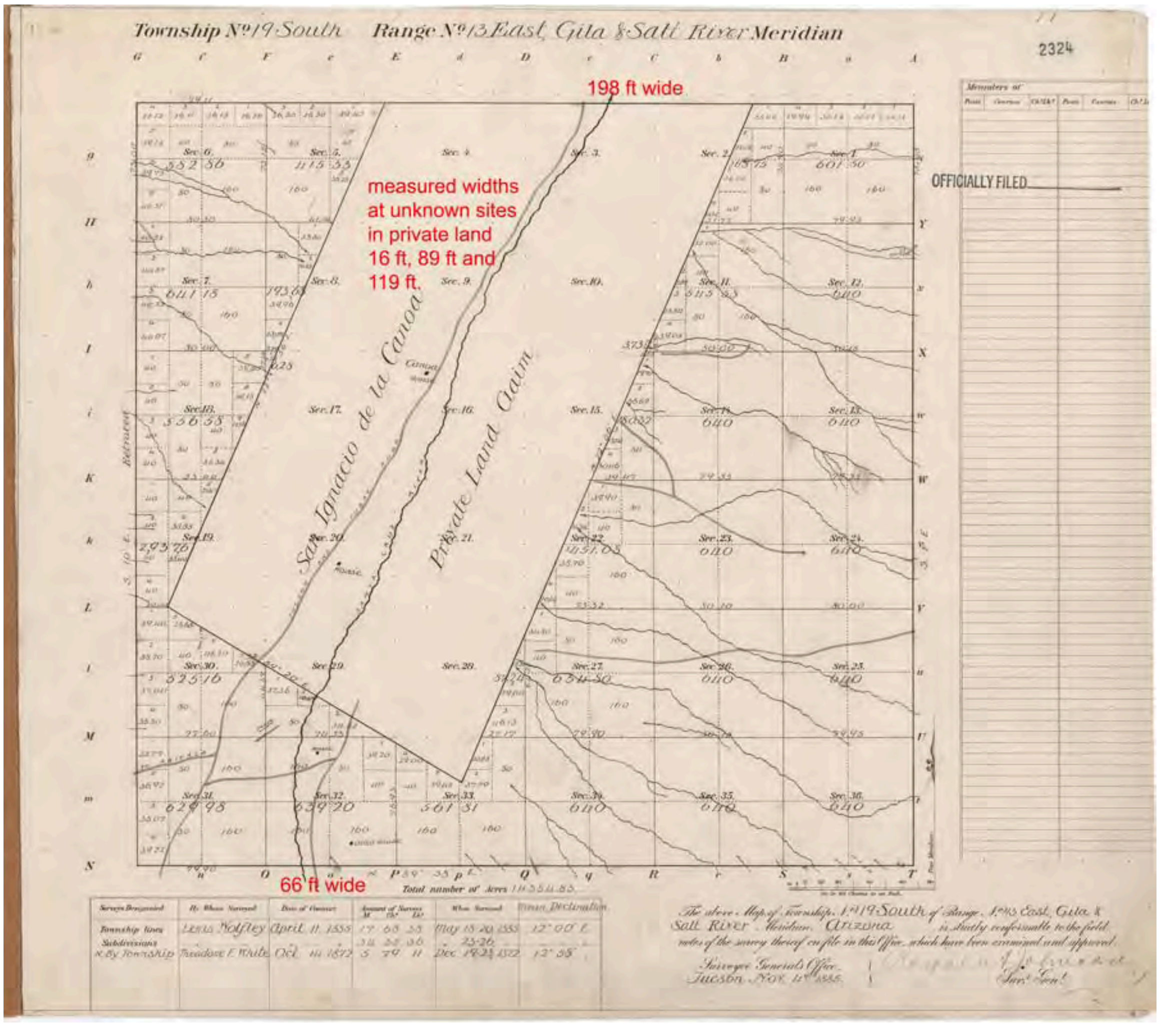
About a mile S. of where this line crosses the Santa Cruz river, the latter is a large, ever running stream of water, but sinks in the sand in a short distance. Water can be obtained by digging anywhere along the bottom.

The E. line of the township is mostly over rolling mesa, and good for grass. No timber.

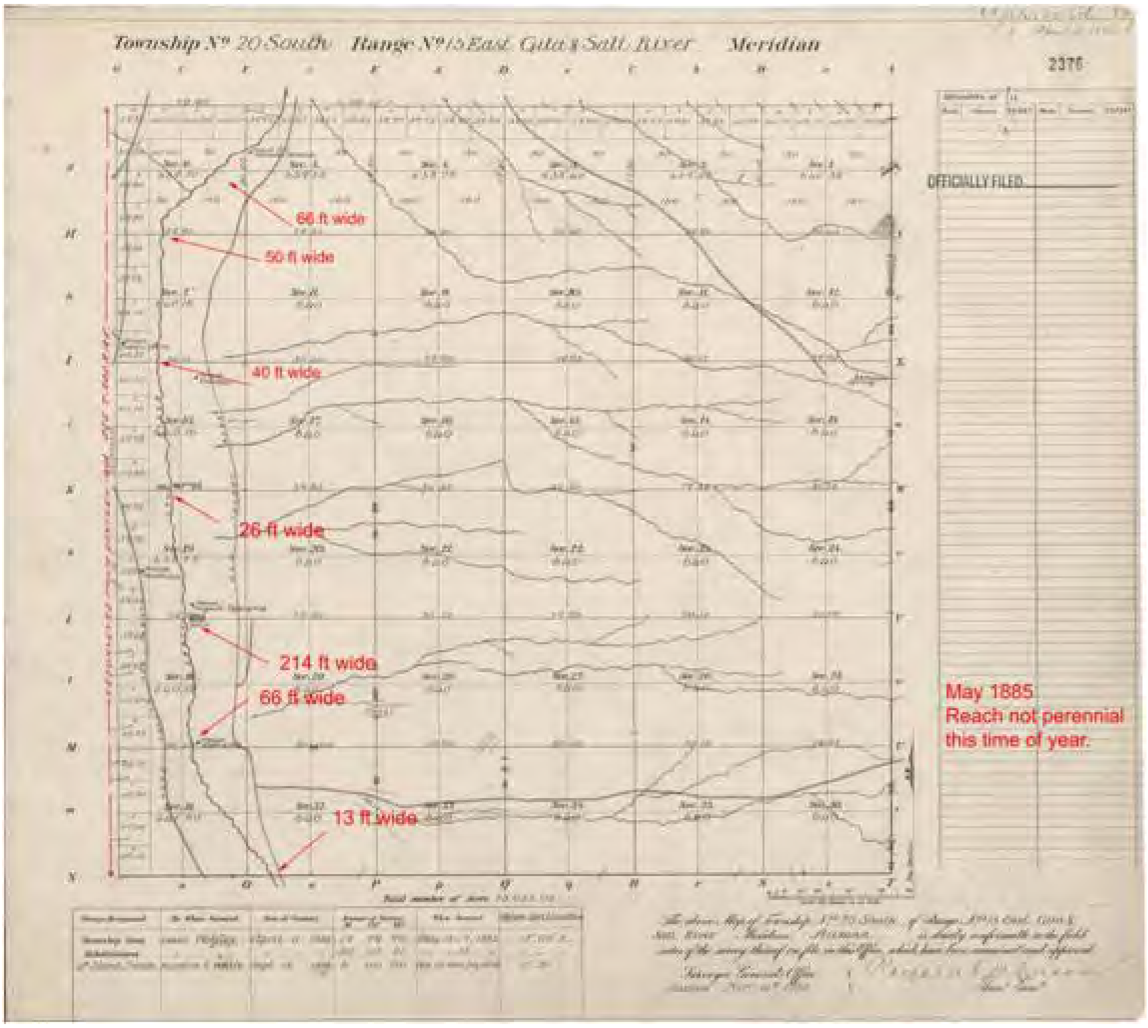
Theo. F. White

At the southern boundary of this township the Santa Cruz "is a large, ever running stream of water, but sinks in the sand in a short distance. Water can be obtained by digging anywhere along the bottom."

R19S R13E

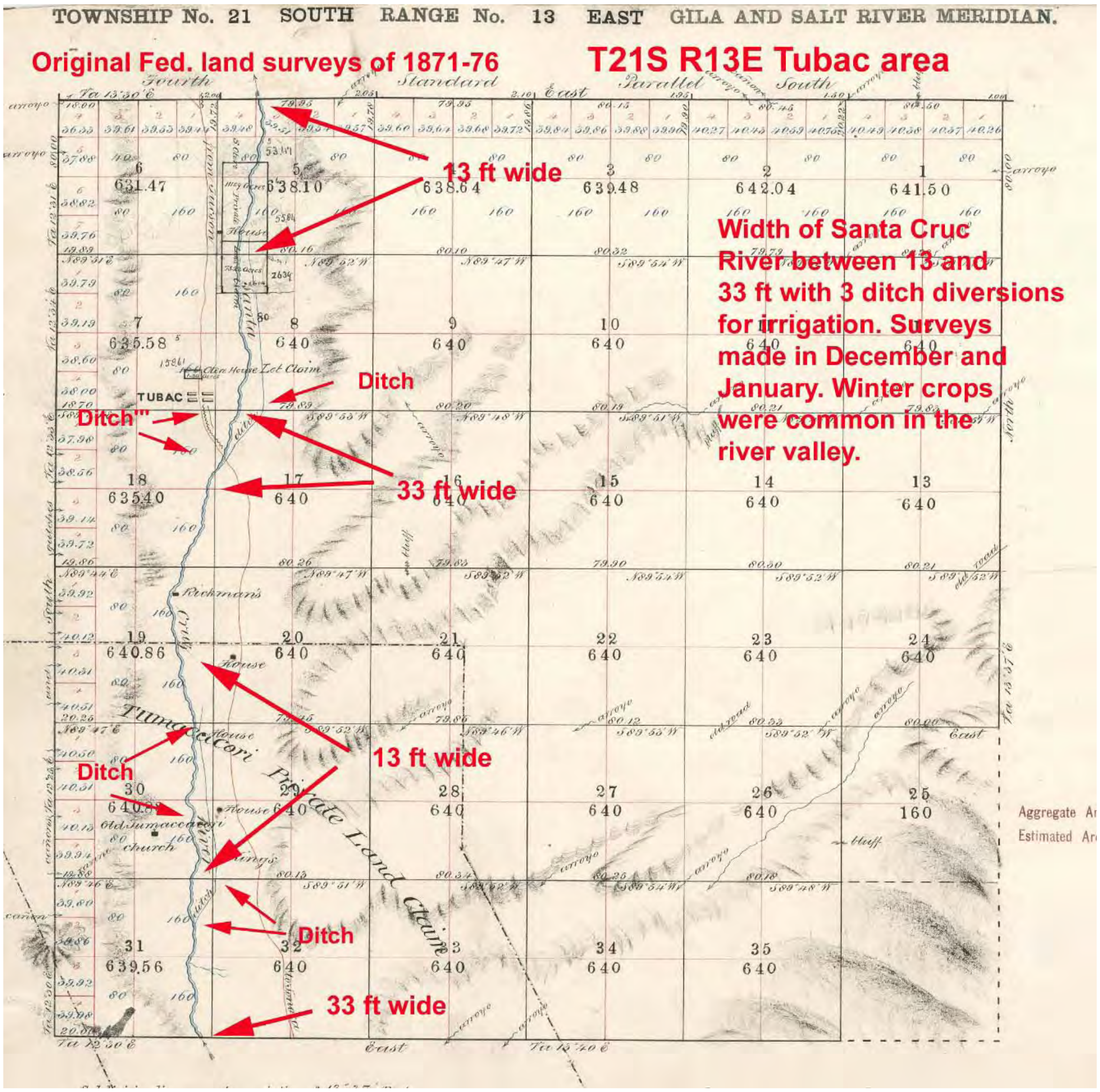

Township Nº 19 South Range Nº 13 East Gila & Salt River Meridian
2324
198 ft wide
measured widths
at unknown sites
in private land
16 ft, 89 ft and
119 ft.
San Ignacio de la Canoa
Private Land Claim
66 ft wide
OFFICIALLY FILED
Total number of Acres

T20S R13E

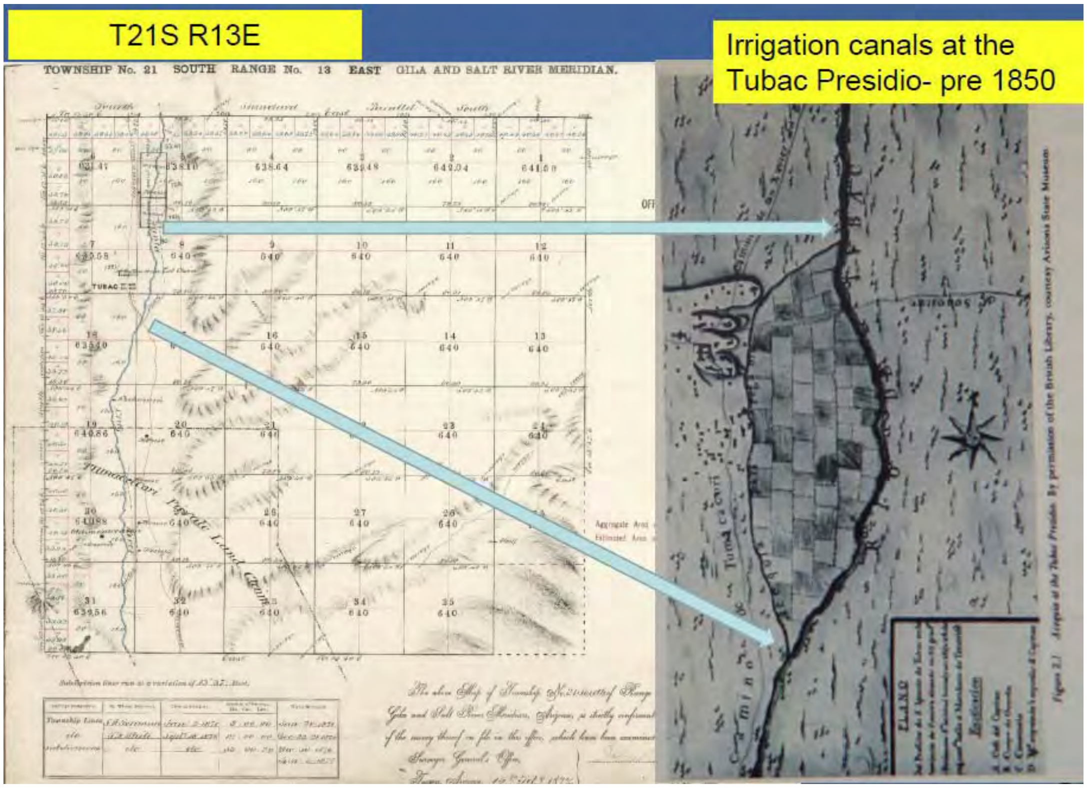


66 ft wide
50 ft wide
40 ft wide
26 ft wide
214 ft wide
66 ft wide
13 ft wide
May 1885
Reach not perennial
this time of year.
OFFICIALLY FILED

T21S R13E

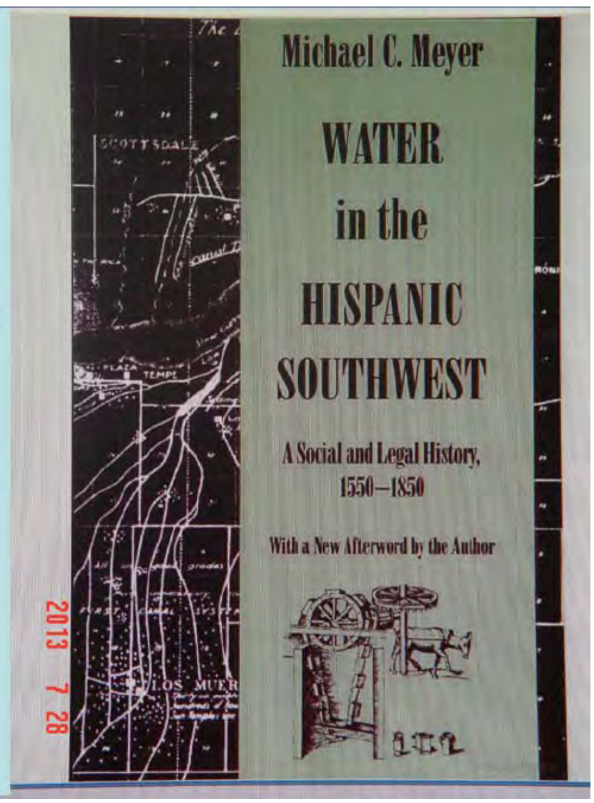

TOWNSHIP No. 21 SOUTH RANGE No. 13 EAST GILA AND SALT RIVER MERIDIAN.
Original Fed. land surveys of 1871-76
T21S R13E Tubac area
13 ft wide
Width of Santa Cruc River between 13 and 33 ft with 3 ditch diversions for irrigation. Surveys made in December and January. Winter crops were common in the river valley.
Ditch
TUBAC
Ditch
33 ft wide
13 ft wide
Ditch
Ditch
33 ft wide
Aggregate
Estimated

T21S R13E (Cont.)



Early accounts of base runoff in the Santa Cruz suggest that flow was not continuous. In addition to the source on the right is the boundary survey of 1857. However, the Spanish established farming communities (Spanish tradition) where irrigation diversions from upstream farms impacted the flow in the river. Downstream users often did not have water. Also, these historic diversions at Tubac and further upstream obviously affected the base flow downstream and may have influenced the selection of reaches with intermittent flow in USGS HA664.

A tradition was to return unused diverted water back to the river as shown on the following slide.



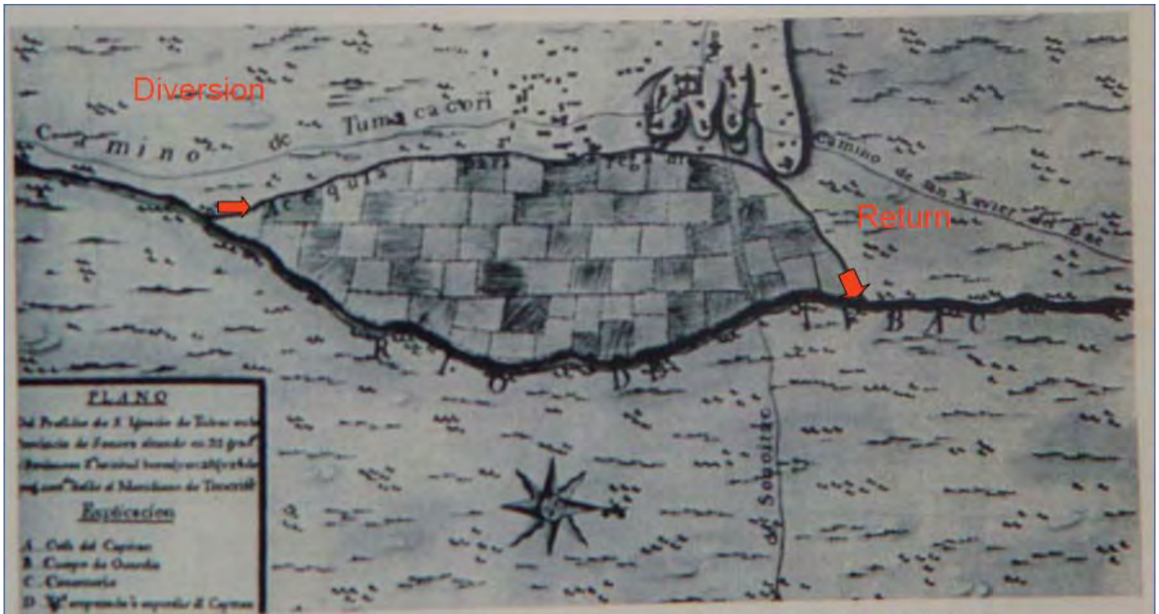


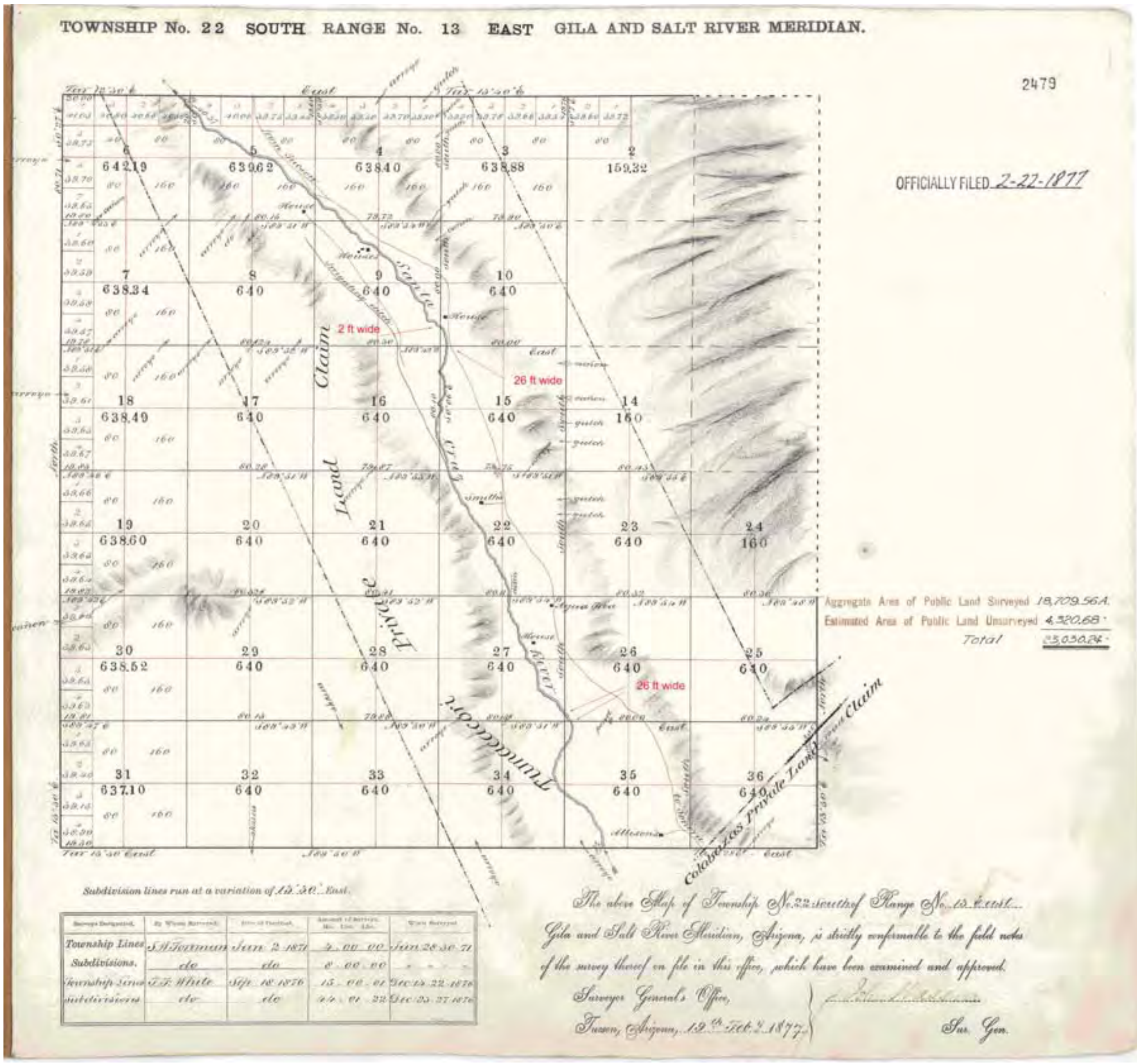
Figure 2.1 *Acequia at the Tubac Presidio.* By permission of the British Library, courtesy Arizona State Museum

Meyer, M. C., 1996, Water in the Hispanic Southwest, a social and legal history, 1550-1850; University of Arizona Press, 209p.

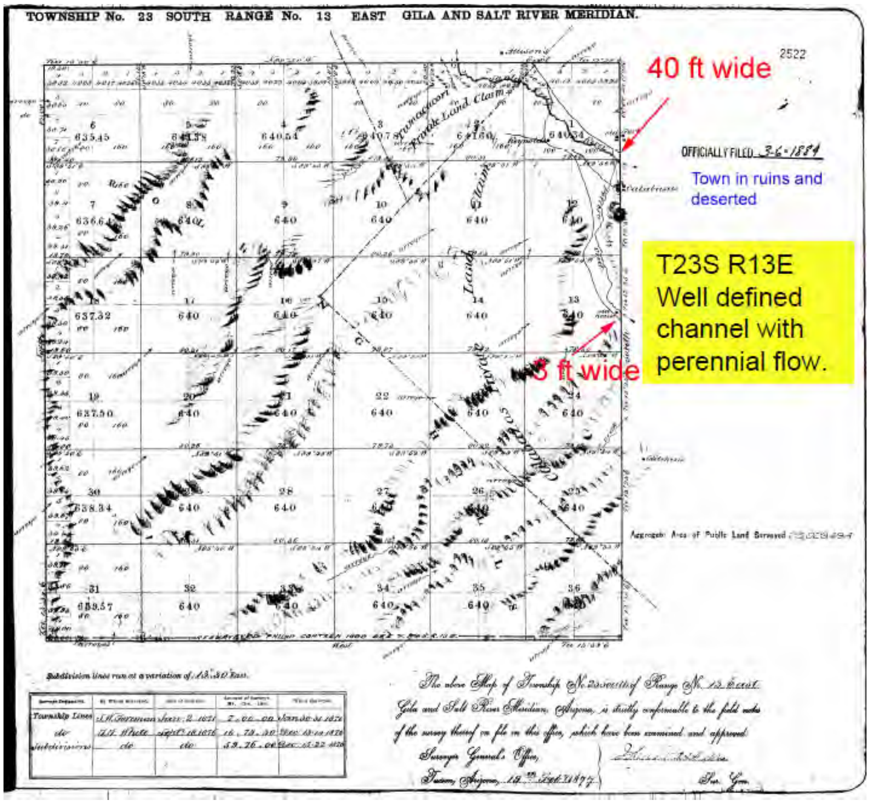
SAN JOSE DE TUMACACORI, two miles south of Tubac, Ariz.

Photo of 1919.

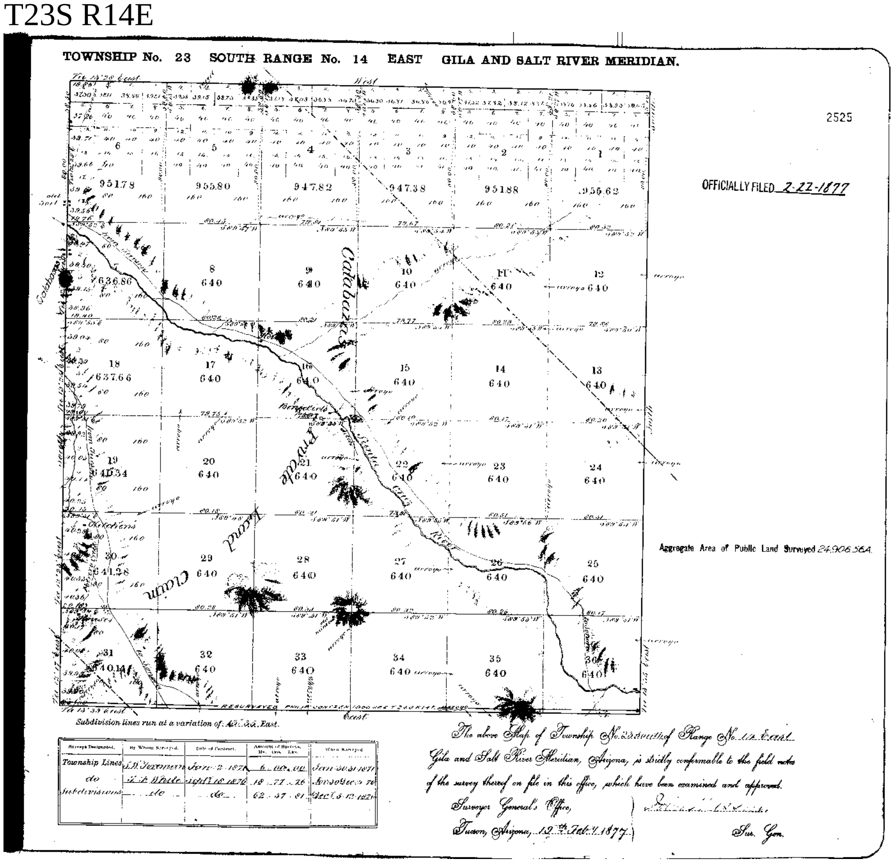
T22S R13E


TOWNSHIP No. 22 SOUTH RANGE No. 13 EAST GILA AND SALT RIVER MERIDIAN.
2479
OFFICIALLY FILED 2-22-1877
2 ft wide
26 ft wide
26 ft wide
Claim
Land
Private
Santa Cruz
Tumacacori
Calabazas Private Land Claim
Aggregate Area of Public Land Surveyed 18,709.56A.
Estimated Area of Public Land Unsurveyed 4,320.68
Total 23,030.24
Subdivision lines run at a variation of 12° 30' East.
The above Map of Township No. 22 South of Range No. 13 East Gila and Salt River Meridian, Arizona, is strictly conformable to the field notes of the survey thereof on file in this office, which have been examined and approved.
Surveyor General's Office,
Tucson, Arizona, 19th Feb. 1877.
Sur. Gen.

T23S R13E



T23S R14E



T24S R15E USGS Kino Springs map

Appendix B.-- Miscellaneous Supplemental information

Item 1. The following account of the "immense artificial lake" for Warner's grist mill near Tucson captures the effects of human diversions along the Santa Cruz River. Upstream diversions depleted the quantity of flow and the natural uniformity of flow needed for the mill to be successful, particularly in the summer time. The past success of the mill implies a good-steady base runoff in the Santa Cruz River at nearly all times. However, because of upstream diversions, mostly for irrigation, the building of a large lake was needed for an adequate supply of water for the grist mill as described below.

Arizona weekly citizen. (Tucson, Ariz) 1880-1901, November 17, 1883, Image 3

WARNER'S WORK.

An Immense Artificial Lake Created Near Tucson.

It is to be Filled With Carp, and its Waters Will Insure a Continually Full Race For the Mill.

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 their mill, and also to afford a place for the breeding and rearing of carp.

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 along side 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 that one by the mill race.

At the hill is a bulk-head ten feet 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 putting on the finishing touches to the dam.

The result of this big dam has al-

When the dam is completed and the waters have occupied all their space, about fifty acres will be covered. It is the intention to build a miniature Cliff house, as a popular summer resort for boat riding, pleasure, drives, hunting, etc. None of the water of this big pond comes from the Santa Cruz river. It is all from the land owned by Mr. Warner, and the economical measures he has taken to save this water for his own use first, and after that for the farmers below him is to be commended. It will cause more land than ever below the mill to be cultivated because more water can be procured. The waters of the Santa Cruz river still flow in the old ditches undisturbed by this new and great improvement by Mr. Warner.

Santa Cruz Wheat.

Robert Miller, of Warner's mill, has presented the CITIZEN office with a bottle of Santa Cruz wheat. It is of the variety that has been sown and reaped by the Mexican farmers upon the bottoms of the Santa Cruz river for the past three hundred years. Subsoil plowing is something these Mexican farmers never knew or practiced. For over two centuries the soil was scraped with a stick and sown with the same seed every year. Irrigation is also imperfectly practiced by them. Yet the wheat thus grown for nearly thirty decades is a fair sample of the staff of life, and makes fine flour.

It is true that the grain is not so large and long and full, and as golden hued as the California grain, but it is a good grain if it is small, and shows the wonderful vitality and richness of the soil of the Santa Cruz bottoms.

The wheat is perfectly free from rust and smut.

Item 2. This newspaper account is an example of the many accounts of upstream diversions depleting the base flow of the Santa Cruz.

Arizona weekly citizen. (Tucson, Ariz) 1880-1901, March 15, 1884, Image 1

The year 1733 marks an important epoch in the agricultural history of Tucson. Previous to that date the Santa Cruz river was allowed to pursue its natural course. That year, however, irrigating ditches were constructed and the entire waters of the river turned into them. Since then the old river bed in the vicinity of Tucson has been plowed so many times that it has been entirely obliterated.

Rev. Father Jacob Keller, in 1743, started to Cibola, and got as far as Tucson. He could get no further on account of the Apaches.

In 1739 the mission of St. Augustine was established at Tucson, and yet remains. It was done by the order of the Marquis of Croix, then viceroy of Mexico.

Item 3. The Santa Cruz and Tucson ditch were built south of Tucson where diversion will be about 2 miles north of Tubac. Land at this location had been farmed for about a century where flow was perennial. The river was about 60 ft wide with a stony bottom and firm banks where head gate was located.

Arizona weekly citizen. (Tucson, Ariz) 1880-1901, December 03, 1887, Image 1

Santa Cruz and Tucson Ditch.

Work was commenced this week on the Santa Cruz and Tucson Ditch owned by the Santa Cruz Land & Water Company, incorporated under the laws of Arizona,

The head of the ditch or canal is two miles north of the town of Tubac, on land owned and cultivated by the Otero family for upwards of a century, and at a point where the waters of the Santa Cruz river, even in the driest seasons, never fail, for this reason the location was selected, it also being at a point where the river is about sixty feet in width, with a stony bottom and firm banks, and no better place could have been chosen for the head gate.

The Santa Cruz is an underground river, sinking and running for several miles, then again coming to the surface, as at Tubac, San Xavier and Tucson, where thousands of acres are brought under a high state of cultivation, the land producing annually two crops.

The Santa Cruz drains a large scope of country, both in Arizona and Sonora, and has tributary to it several streams having a never failing supply of water. The ditch will be taken out on the west side of the river and follow along the mesa line down the valley for a distance of about ten miles, when it will be taken across the Santa Cruz bottom to the mesa lands on the east side of the valley and thence to Tucson. By this means at least 100,000 acres of first-class bottom and mesa land will be made to produce both agricultural and fruit crops, and hundreds of families will be enabled to make themselves good homes.

All the land to be covered by this ditch has been subdivided by the government. A railroad has been surveyed through the valley from Calabasas to Tucson, which, when built, will furnish transportation for the different kinds of produce that can be raised to perfection in this valley, such as corn, wheat, barley, alfalfa, grapes, peaches, plums, figs, apples, pears, vegetables, etc.

Item 4. An engineering report by P. E. Fuller on June 11, 1913 is a great example of the use of water along the Santa Cruz River. Fuller's report shows 10 cfs of Santa Cruz River base flow was diverted into the Manning and Farmer ditches above Tucson in the early 1900s.

P. E. FULLER
CONSULTING ELECTRICAL, MECHANICAL AND HYDRAULIC ENGINEER

SUBJECT

REPORT UPON THE SANTA CRUZ RESERVOIR PROJECT

During 1909, 1910, and 1911 the Rillito River gaugings at the Oracle Road showed a total annual flow of 22,252, 4,610, and 11,300 acre-feet respectively. The point where these gaugings were made is about 5 miles east of the confluence of the Rillito and the Santa Cruz rivers; hence takes account of practically all of the losess in this stream from its heading. In other words, it is the net flow that may be considered as water for storage at this point.

During this period, the total precipitation at Tucson (elevation 2390′) was from the U. S. Weather Bureau records, 11.58 inches for 1909, 9.8″ for 1910, and 11.25″ for 1911. The total catchment area for the Rillito River is 947 square miles, part of which is above the 6,000′ elevation. Assuming that the mean elevation of the entire Rillito catchment area is 4,000′, the precipitation over that area, using the same increase per 100′ rise, as heretofore computed; that is .21″, would be $\frac{(4000-2390)}{100}$ x .21″) + 11.57 = 14.96″ for 1909, 13.18″ for 1910. and 14.63″ for 1911, or a total of 757,600 acre-feet for 1909, 660,600 for 1910 and 739,400 for 1911.

The measured flow of the Rillito River is 2.94% of this precipitation for 1909, closely 7% for 1910, and 1.52% for 1911. Considering this run-off with that computed from the Newell Curve for Relation of Run-off to Rainfall—which shows a run-off, from gentle slopes, of 40,300 acre-feet in 1909, 25,200 in 1910, and 39,500 in 1911, it will be seen that it represents a higher percentage of run-off, but deducting from these quantities the loss in stream channels, which was found from measurement, to average 12.9% per mile of main channel, the results compare quite closely to those found actually to abtain.

The Santa Cruz catchment area, south of Tucson, is computed to be 2,100 square miles, while the gaugings at the Congress street bridge shows the stream to flow a total of the following:

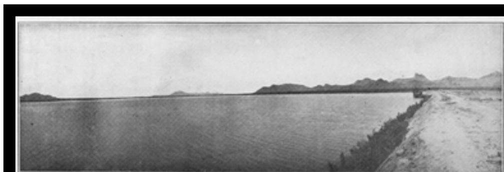
The Santa Cruz catchment area, south of Tucson, is computed to be 2,100 square miles, while the gaugings at the Congress street bridge shows the stream to flow a total of the following:

YEAR	Discharge in Sec-feet			Volume in Acre-feet			Total
	Maxi-mum.	Mini-mum.	Mean	River	Manning Ditch	Farmer Ditch	
1905 (Partial)	3200	....	....	.....	....	....	.....
1906	1575	0	20.3	14670	4900	2800	22370
1907	5000	0	41.1	29780	5610	1810	37200
1908	6780	0	20.8	15130	5000	2400	22530
1909	1740	0	....	15820	4220	2235	22275
1910	....	....	....	5710	4920*	**	10600
1911	....	....	....	6250	**	**	
							36694

*Now owned by the Tucson Farms Company. **Incomplete.

Item 5. P. E. Fuller's report of June 11, 1913 also shows interesting photographs of the Santa Cruz Reservoir Project, that had failed by 1915, and the influence of Greene's Canal where flow (mostly floodwater) was diverted from the Santa Cruz River for irriation use. This is a great example of early human impact on the natural hydrology of the river.

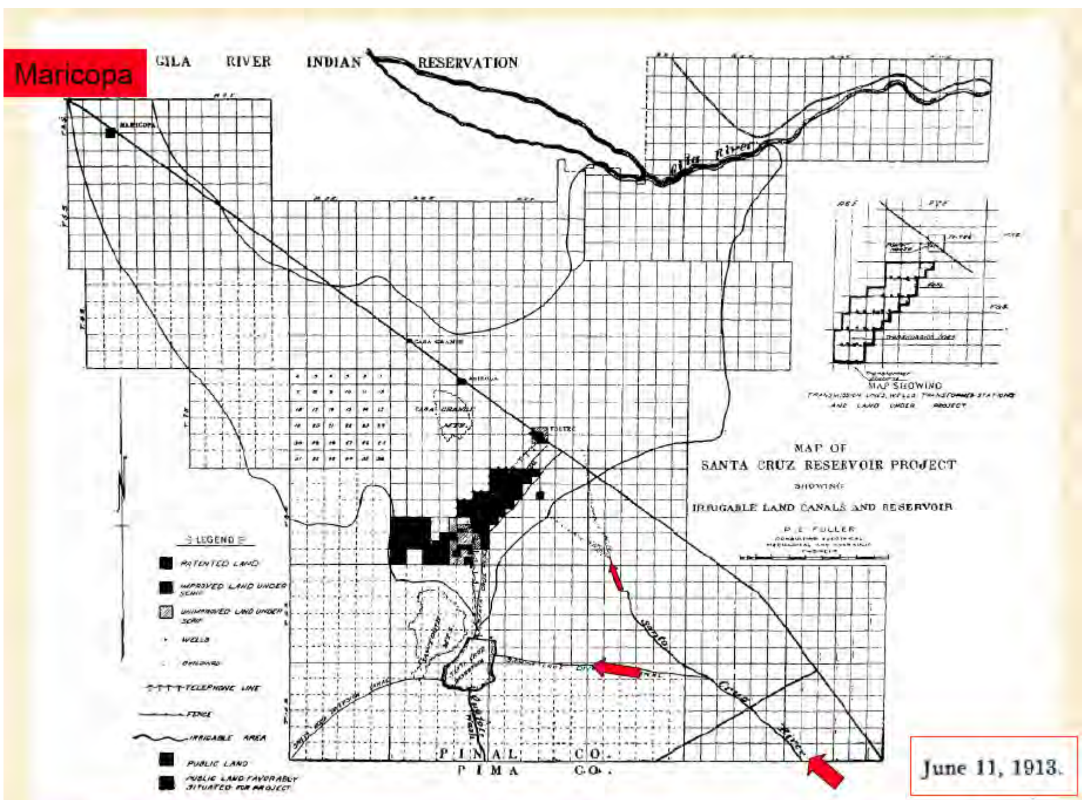
At the point of the interception of the Santa Cruz River by the diversion canal, an earth-fill diversion dam, some 2,000′ long and 10′ high, has been constructed across the Santa Cruz River channel. Also, there is constructed a diversion canal, from this point to the reservoir, which has an average width of 20′, an average depth of 5′, and a gradient of 14′ 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 closely 100 square feet. The water discharged through these waste gates flows into the old channel of the Santa Cruz River below the point of diversion.


View of Santa Cruz Reservoir with approximately 10,000 acre-feet in storage.

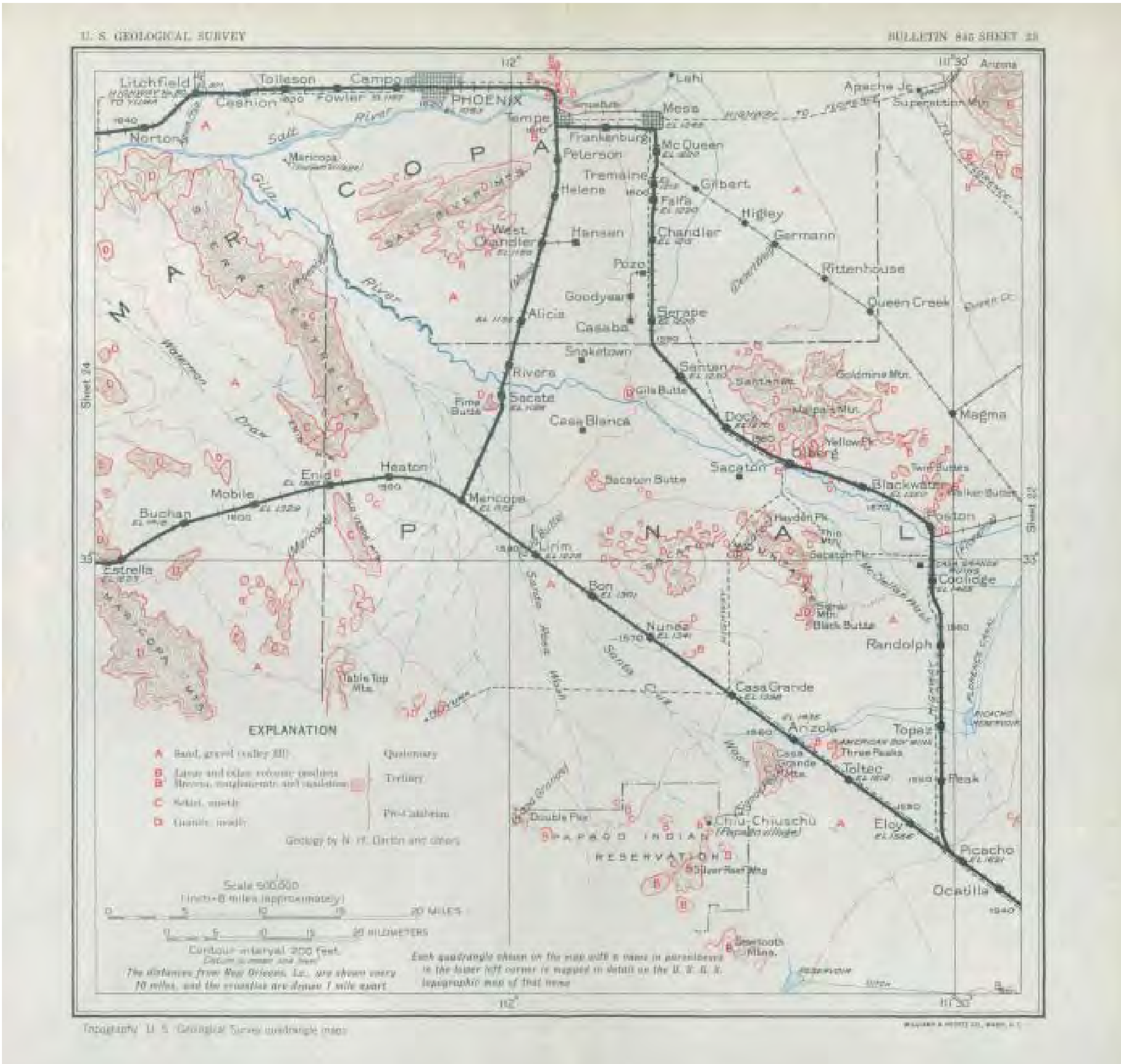

View of Santa Cruz Diversion Canal near Dam.


Outlet gates from reservoir open and discharging.


Head of Santa Cruz Canal.



The following map shows the reservoir (lower right hand corner) and the lower Santa Cruz watershed.



Darton, N. H., 1933, guidebook of the Western United States: Part F, the Southern Pacific Lines of New Orleans to Los Angeles; USGS Bulletin 845, 304p.

The original Fed. Land Surveys north of Picacho Peak mention groundwater depths of 4-6 feet below land surface for many of the Townships of the wide-flat basin shared with the Gila River. At the time of the earliest surveys (1870-1880) the river in this northern part of the watershed was poorly defined with numerous small distributary and braided channels. There was a general swale like water course with limited flow capacity. This was before the Santa Cruz Reservoir and Greene's canal that significantly changed the course of the river.

Item 6. Father Kino was known for his precision of mapping. Thus, why would Kino show a presently dry-dusty ill defined ephemeral river channel as a single line? Consider Kino's map of 1698-1701. Is it possible the Santa Cruz River was perennial/intermittent as Kino seems to suggest with his map?

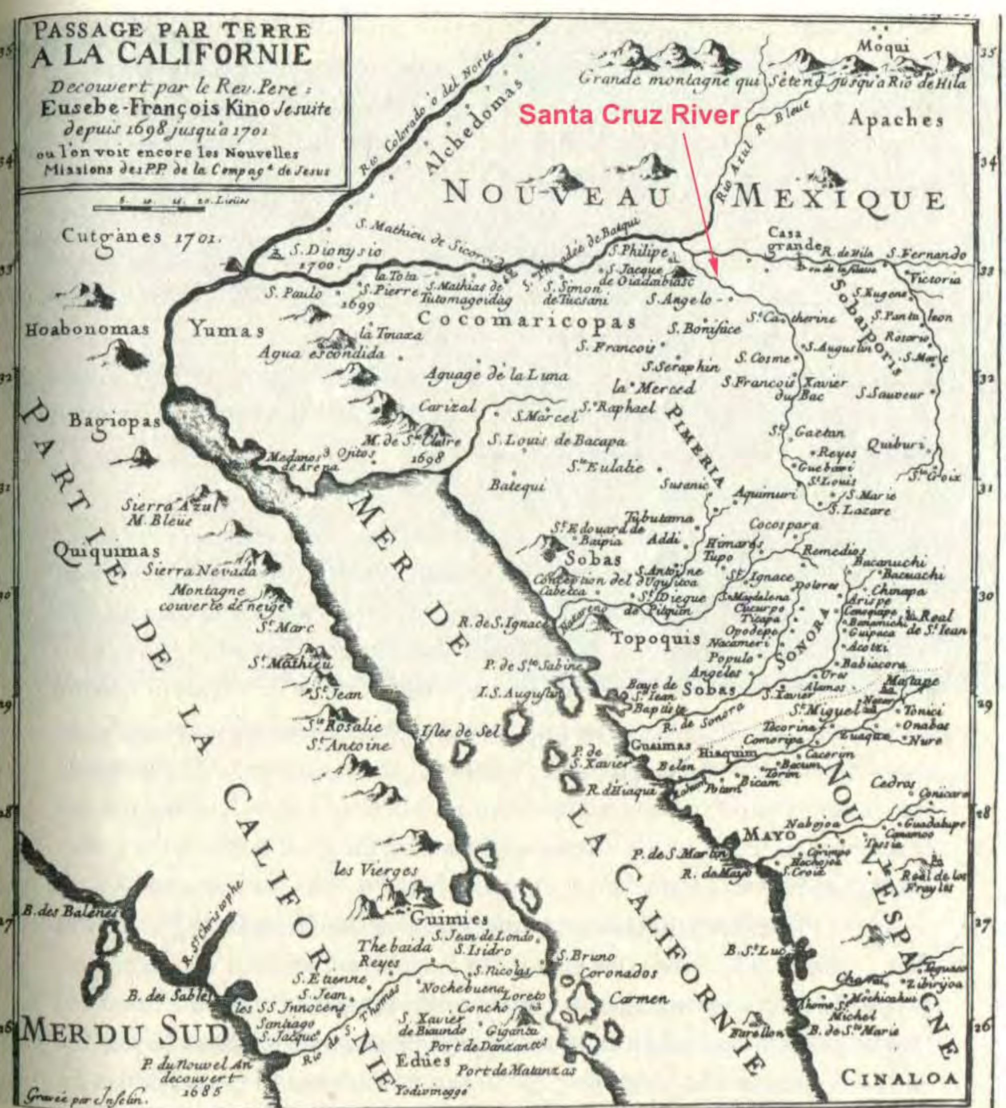


Figure 4.7: Father Kino's map of the Papaguería. The Gila is identified as the "R. de Hila."

McNamee, Gregory, 1998, Gila: the life and death of an American River, updated and expanded edition, University of New Mexico Press, 232p.

69

This account of an irrigation diversion from the Santa Cruz River supports Kino's account of a single channel.

About two miles south of the Hollen Canal, but diverting water from the Santa Cruz River, is a small ditch known as the Breckenridge. This ditch serves a small acreage adjacent to the upper end of the area irrigated by the Hollen. This ditch was constructed about 13 years ago - that is 1902. It has a bottom width of 2½ feet, top width of 3 feet, water depth 1 foot, grade of 1 in 2000. At the time of this survey, only 5.0 acres were in cultivation, while 30.8 acres had been cultivated at some previous period.

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

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

Y4. In 2/1: In 2/2/v.2

APPENDIXES A, B, AND C

INDIANS OF THE UNITED STATES

HEARINGS

BEFORE THE

COMMITTEE ON INDIAN AFFAIRS

HOUSE OF REPRESENTATIVES

SIXTY-SIXTH CONGRESS

FIRST SESSION

ON

THE CONDITION OF VARIOUS TRIBES OF INDIANS

ACT OF JUNE 30, 1919

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

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

(IN TWO VOLUMES)

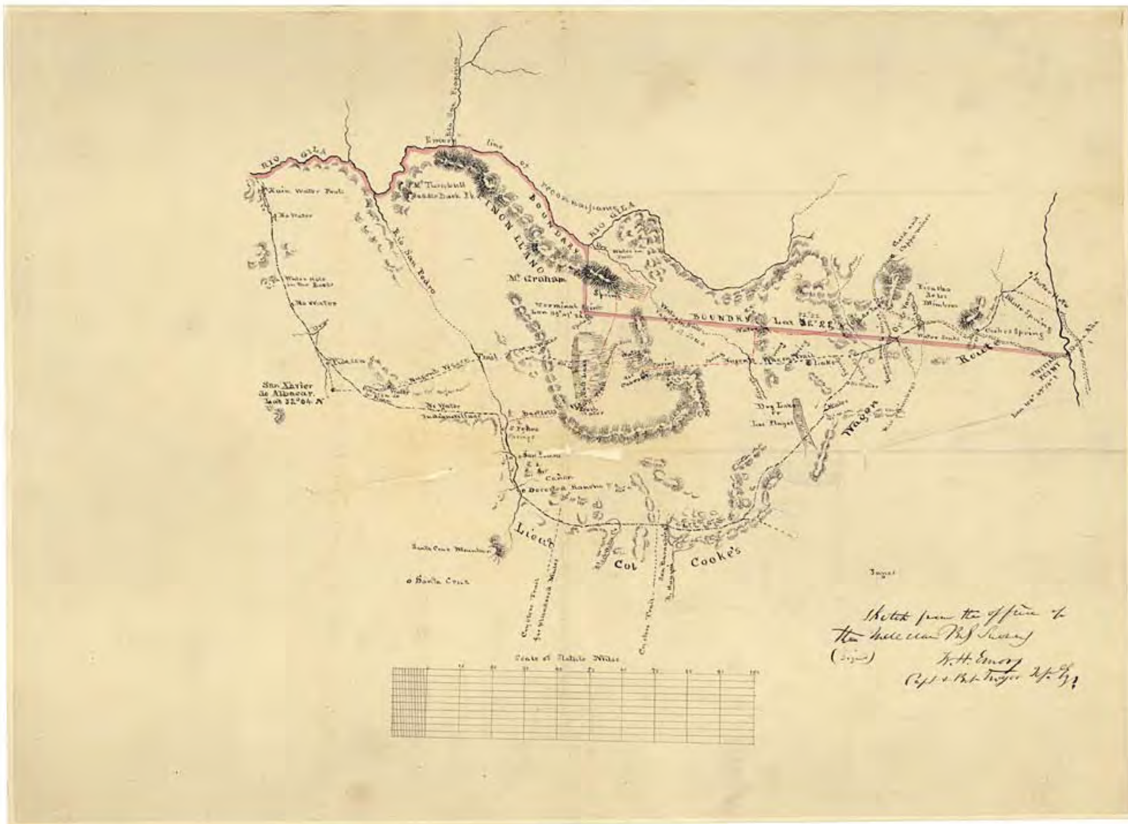
VOL. 2—APPENDIXES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

Digitized by Google

700 pages.

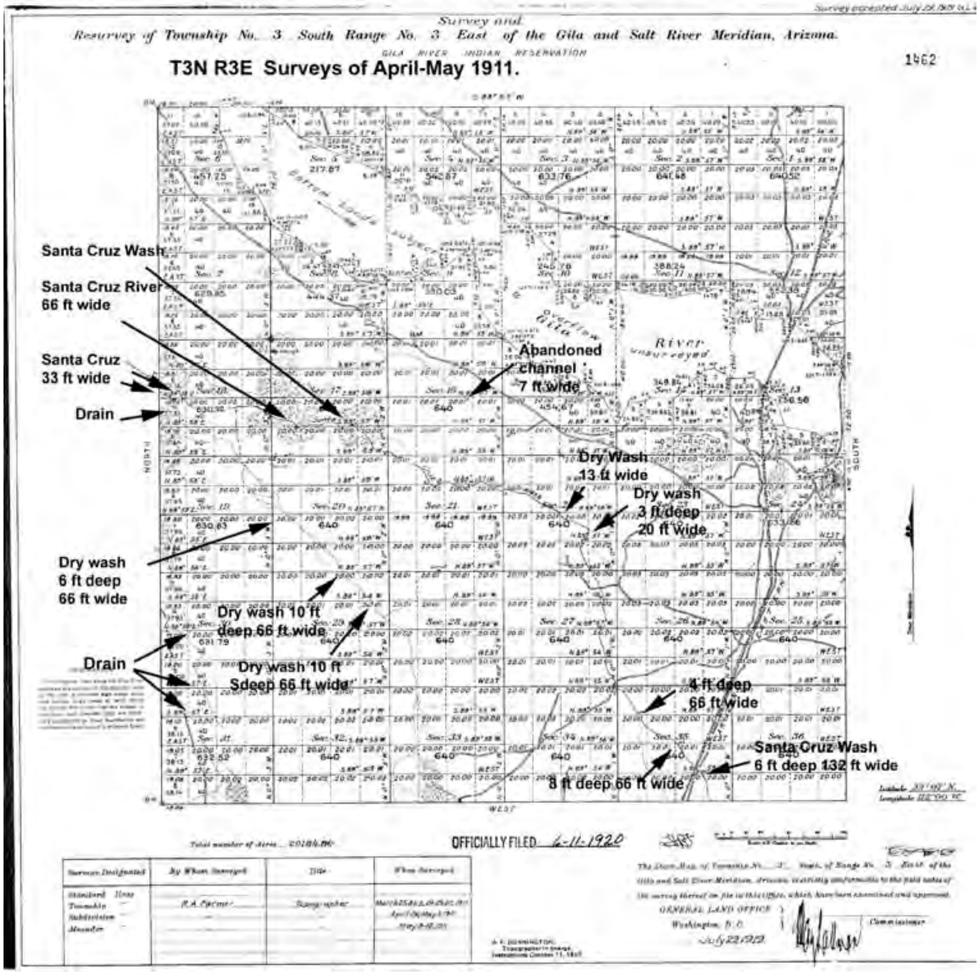
Item 7. Another example of a single channel along the lower Santa Cruz River in a sketch from the Office of the Mexican Boundary Survey, 1853



The Treaty of Guadalupe Hidalgo mandated that a boundary commission survey and mark the border between the U.S. and Mexico. The Army Corps of Topographical Engineers, under the direction of William H. Emory, conducted the actual surveying from 1848 – 1855. This sketch is from that survey. It shows the area south of the Gila River—part of present-day Arizona.

RG 233, Records of the U.S. House of Representatives

Item 8. An example of the channels of the lower Santa Cruz River near the Gila River is shown below.



G E N E R A L D E S C R I P T I O N

This township is, as a whole, level; excepting a butte in Secs. 23 and 26.

The land in the southwest portion of this township is alkali, and cut by washes (dry) and old channels of the Santa Cruz River. While there is no running water in this river, good water is within six or eight feet of the surface.

The Gila River runs through the northern part of the township.

There is a little timber of value, except cottonwood along the Gila River.

The greater part of this township is covered with low mesquite, which in many places is very dense.

R. A. F A R M E R

Topographer.

Maricopa Wells today (above) and in 1870 (below). Notice the southeastern tip of the Estrella Mountains in the background of both photographs.

Pima-Maricopa Irrigation Project
Education Initiative
2005-2006

Restoring water to ensure the continuity of the Akimel O'otham and Pee Posh tradition of agriculture

Item 9. Meandering of the Santa Cruz River

3422 Book "K"

Duplicate

FIELD NOTES

OF THE

RESURVEY OF

Subdivision and Meander Lines

in

TOWNSHIP 15 SOUTH RANGE 13 EAST
and Rancho de Martinez

Within the Papago Indian Reservation

Of the Gila & Salt River Base and Meridian

In the State of Arizona

EXECUTED BY

Charles M. Leedy

In the capacity of U. S. Surveyor, under instructions dated Oct. 6, 1914,

issued by the Commissioner of the General Land Office to J. F. Dunnington, Topographer in Charge of Indian Surveys

~~Group No. , which were approved by the Commissioner of the General Land Office, 191 , pursuant to authority contained in the Act of Congress dated , 191~~

Survey commenced January 18, 1915

Survey completed April 1, 1915

1894 survey instructions where in effect. Unclear why channel was meandered but 1894 instructions suggest basis was because river was considered navigable. However, channel width, that is more that 3 chains wide (1 chain = 66 ft), may have had something to do with the survey.

Meandering Santa Cruz River

242.

BOOK 3422

Resurvey of meanders of T. 15 S., R. 13 E.

Meanders of Right bank of Santa Cruz River, up stream.

March 30, 1915. At 8h 0m a.m., l.m.t., I set off 32° 07½' on the lat. arc, 3° 31' E. on the decl. arc, and determine a meridian with the solar, at the M.C. bet. secs. 14 and 23, on right bank of Santa Cruz River.

Thence I run with meanders in sec. 23, along right bank, up stream.

Over open land; cut bank 12 ft. high.

S. 20¾° W.,	2.10 chs.	
S. 40½° W.,	4.20 "	Thence across mouth of barranca, course NW., 2.00 chs. wide, 8 ft. deep.
S. 29° W.,	6.10 "	Thence across mouth of barranca, 8 ft. deep, course NW.
S. 16° W.,	2.40 "	
S. 17¼° E.,	4.20 "	
S. 25°7'E.,	3.60 "	At 3.00 - Fence brs. E. and W. At 3.20 - Road, brs. E. and W. At 3.40 - Fence brs. E. and W. At 3.60 - N. 1/16 M.C., which is also 1/256 sec. cor.
S. 15½° E.,	1.90 "	
S. 5¾° W.,	3.30 "	Indian house 50 lks. E. of this point. Thence across barranca, 8 ft. deep, course NW.
S. 1½° E.,	5.50 "	
S. 21½° E.,	1.70 "	
S. 18¾° W.,	2.10 "	
S. 9½° W.,	3.40 "	
S. 14° E.,	1.50 "	
S.63°33'E.,	2.14 "	To M.C. on ¼ sec. line.
S. 16½° W.,	3.40 "	
S. 33¾° E.,	3.50 "	At 2.50 chs. - Canal 50 lks. wide, course N. 30° E.
S. 32° W.,	4.30 "	
S. 16¾° W.,	5.90 "	
S. 6° W.,	3.00 "	
S. 9°52'E.,	1.69 "	To 1/16 M.C.
S. 18° W.,	2.80 "	
S. 1½° W.,	3.60 "	
S. 14° E.,	1.75 "	To M.C. on N. bdy. of Rancho de Martinez. Thence with meanders across Rancho de Martinez.
S. 2° E.,	.80 "	
S. 19¼° E.,	5.00 "	
S. 25¼° E.,	2.20 "	
S.41°04'E.,	3.17 "	To M.C. on S. bdy. of Rancho de Martinez.
S. 50¾° E.,	2.20 "	
S.60°55'E.,	1.47 "	To M.C. bet. secs. 23 and 26.

Land, open bottom.
Soil, 1st rate.

March 30, 1915. At this M.C. I set off 3° 35' E. on the decl. arc, and at apparent noon observe the sun on the meridian; the resulting lat. is 32° 07', which is the proper lat.

244

BOOK 3422

Resurvey of meanders in T. 15 S., R. 13 E.

Chains

S. 15½° E.,	3.60 chs.	
S. 8¾° W.,	4.00 "	
S. 36° E.,	5.20 "	
S.15°15'E.,	3.68 "	To M.C.on 1/16 sec.line of sec.35.
S. 25° E.,	3.50 "	
S. 16½° E.,	3.00 "	
S. 30½° E.,	2.60 "	
S.8°12' E.,	1.76 "	To M.C.on 1/16 sec.line of sec.35.
S.22½° E.,	3.10 "	
S. 4¾° W.,	5.00 "	
S.32°11'E.,	2.56 "	To M.C. on ¼ sec. line of sec. 35.
S. 44¾° E.,	4.20 "	
S. 49½° E.,	3.80 "	
S. 6¾° W.,	1.90 "	
S. 40¾° E.,	1.00 "	
S. 59½° E.,	1.60 "	
N. 82½° E.,	1.70 "	
S. 35¾° E.,	2.90 "	
S. 14¾° E.,	3.50 "	
S. 27½° E.,	3.50 "	
S. 36°21'E.,	3.18 "	To M.C. on 1/16 sec. line of sec.35.
S. 27¾° E.,	1.30 "	
S.59°04'E.,	2.26 "	To M.C. bet. frac. secs. 35 and 36.

Land, level bottom.
Soil, 1st rate.
Scattered timber, dense mesquite brush and cactus.

Thence with meanders in Sec. 36, along cut bank 10 ft. high, on right bank of Santa Cruz River, up stream.

Through scattered timber, dense mesquite brush and cactus.

S. 43½° E.,	1.30 chs.	
S. 57¾° E.,	1.90 "	
S. 23° E.,	3.10 "	
S. 8° E.,	2.10 "	
S. 14¾° E.,	1.40 "	
S. 25½° E.,	4.30 "	
S. 17° E.,	5.30 "	
S.61°30'E.,	1.29 "	To standard M.C. of sec. 36, on right bank of Santa Cruz River.

Land, level bottom.
Soil, 1st rate.
Scattered timber, dense mesquite brush and cactus.

March 31, 1915. At this cor. I set off 3° 59' E. on the decl. arc, and at apparent noon observe the sun on the meridian; the resulting lat. is 32° 08', which is the proper lat.

Meanders of Left bank of Santa Cruz River, down stream.

From the Standard Meander Cor., on left bank of Santa Cruz River in Sec. 36, I run with meanders in sec. 36, along cut bank 10 ft. high, on left bank of Santa Cruz River, down stream.

Through scattered timber, dense mesquite brush and cactus.

N. 56° W., 3.50 chs.

Meandering Santa Cruz River

245

BOOK 3422

Resurvey of meanders in T. 15 S., R. 13 E.

Chains

N. 7½° W.,	1.90 chs.	
N. 50½° E.,	.50 "	
N. 15½° W.,	1.90 "	
N. 45½° W.,	1.10 "	
N. 37° W.,	3.40 "	
N. 15° W.,	3.90 "	
N. 40° W.,	.88 "	To M.C. of frac. secs. 35 and 36.

Land, level bottom.
Soil, 1st rate.
Scattered timber, dense brush and cactus.

Thence with meanders in sec. 35, along left bank of Santa Cruz River, cut bank 10 ft. high, downstream.

Through scattered timber, dense mesquite brush and cactus.

N. 37½° W.,	.70 chs.	
N. 36¾° W.,	2.70 "	
N. 24° W.,	3.20 "	
N. 40½° W.,	1.30 "	To 1/16 W.C. of sec. 35.
N. 41¾° W.,	2.00 "	
N. 28° W.,	1.86 "	
N. 32½° W.,	3.00 "	
N. 8½° E.,	1.30 "	
N. 85½° W.,	2.20 "	
N. 52½° W.,	4.70 "	
N. 18½° W.,	1.60 "	
N. 26½° W.,	2.30 "	
N. 53° W.,	4.80 "	
N.45°39'W.,	2.87 "	To M.C. on ¼ sec. line of sec. 35 (also E. 1/16 sec. cor.)
N. 13½° W.,	3.00 "	
N. 7° E.,	3.10 "	
N. 3½° W.,	2.80 "	
N. 14¾° W.,	4.40 "	
N. 32¾° W.,	4.10 "	
N. 3½° E.,	1.50 "	
N.28°55'W.,	3.41 "	To M.C.on 1/16 sec.line of sec.35
N. 29½° W.,	2.90 "	
N. 35¾° W.,	5.30 "	
N. 14¾° W.,	2.10 "	
N. 28½° E.,	1.84 "	
N. 5° W.,	2.10 "	
N. 20½° W.,	1.80 "	
N. 65½° W.,	3.20 "	
N. 27½° W.,	2.60 "	
N.9°45'E.,	1.96 "	To M.C. of frac. secs. 26 and 35.

Land, level bottom.
Soil, 1st rate.
Scattered timber, dense brush and cactus.

March 31,1915.

April 1, 1915. At 8h 0m a.m., l.m.t., I set off 32°06' on the lat. arc, 4° 18' E. on the decl. arc, and determine a meridian with the solar, at the M.C. of frac. secs. 26 and 35, on left bank of Santa Cruz River.

Thence I run with meanders in sec. 26, along left bank of Santa Cruz River, down stream; cut bank 12 ft.high.

Through scattered timber, dense mesquite brush and cactus.

Meandering Santa Cruz River

247
BOOK 2422

Resurvey of meanders in T. 15 S., R. 13 E.

Thence with meanders in sec. 22, along left bank of Santa Cruz River, down stream; cut bank 10 ft. high.

Over level open land.

N. 84½° W.,	2.50 chs.	
N. 24½° W.,	5.00 "	
N. 18° W.,	2.26 "	To M.C. on N. bdy. of Rancho de Martinez.
N. 1¾° E.,	4.00 "	
N. 8½° E.,	4.06 "	To M.C. on 1/16 sec. line of sec. 22.
North	1.90 "	
N. 14°41' E.,	8.68 "	To M.C. of frac. secs. 22 and 23.

Land, level bottom.
Soil, 1st rate.
No timber or brush.

Thence with meanders in sec. 23, along left bank of Santa Cruz River, down stream; cut bank 12 ft. high.

N. 65¼° E.,	1.20 chs.	
N. 15° E.,	3.50 "	
N. 46¼° W.,	1.50 "	
N. 7¾° W.,	3.10 "	
N. 11°25' E.,	2.75 "	To M.C. on ¼ sec. line of sec. 23.
N. 36¾° E.,	1.40 "	
N. 3¼° E.,	3.00 "	
N. 3° W.,	4.50 "	
N. 21° W.,	2.80 "	
N. 7°51' W.,	5.61 "	To M.C. of frac. secs. 22 and 23. At 1.30 chs. - Barranca, 2.00 chs. wide, 10 ft. deep, course N. 15° E.

Land, level bottom.
Soil, 1st rate.
No timber or brush.

Thence with meanders in sec. 22, left bank Santa Cruz River, down stream; cut bank 10 ft. high.

Over open level land.

N. 44° W.,	4.39 chs.	To M.C. on 1/16 sec. line of sec. 22.
N. 2¾° E.,	1.70 "	At .40 chs. - Road brs. E. and W.
N. 36¼° W.,	3.40 "	
N. 4¼° W.,	3.30 "	
N. 58° E.,	4.10 "	
N. 27°13' E.,	4.06 "	To M.C. bet. secs. 22 and 23.

Land, open, level bottom.
Soil, 1st rate.
No timber or brush.

Thence with meanders in sec. 23, left bank of Santa Cruz River, down stream; cut bank 12 ft. high.

Over open level land.

N. 40¾° E., 5.90 chs.

Meandering Santa Cruz River

T. 15 S., R. 13 E.

G E N E R A L D E S C R I P T I O N.

This fractional township contains three general varieties of land, level bottom, nearly level mesa, and mountainous land.

"Black Mountain" covers the western third of the township and the soil is rocky, 4th rate. "Berger Butte" lies in the N½ of sec. 33, and is of same character.

The Santa Cruz River flows northerly through secs. 22, 23, 26, 35 and 36, and from one-half to one mile on each side is level bottom land; soil 1st rate. The river in this township is from 2.20 to 4.80 chs. wide. The banks at present are well defined - cut banks from 12 to 20 feet high. About a mile south of the Standard Parallel in T. 16 S., R. 13 E. the stream disappears entirely, the flow being underground. The remainder of the fractional township is nearly level mesa land. It is practically covered with scattered mesquite and some palo verde timber, mesquite brush, greasewood, and numerous species of cacti.

Road from Tucson to Nogales enters in sec. 9, running through sec. 16, and dividing in sec. 21, the western branch being known as the hill road, and the other, the valley road. There are numerous cross roads from one part of the valley land to another.

The old San Xavier Mission is located in the NE¼ of the SW¼ of sec. 22.

The Berger Ranch (or Rancho de Martinez) lies in the NE¼ of sec. 27, and SE¼ of sec. 22, and is occupied as Agency Headquarters for the employees of the Indian Service. The main village of the Papagos on this reservation is located near San Xavier Mission. There is a smaller village near the center ¼ sec. cor. of sec. 23.

257.
BOOK 2422

T. 15 S., R. 13 E.

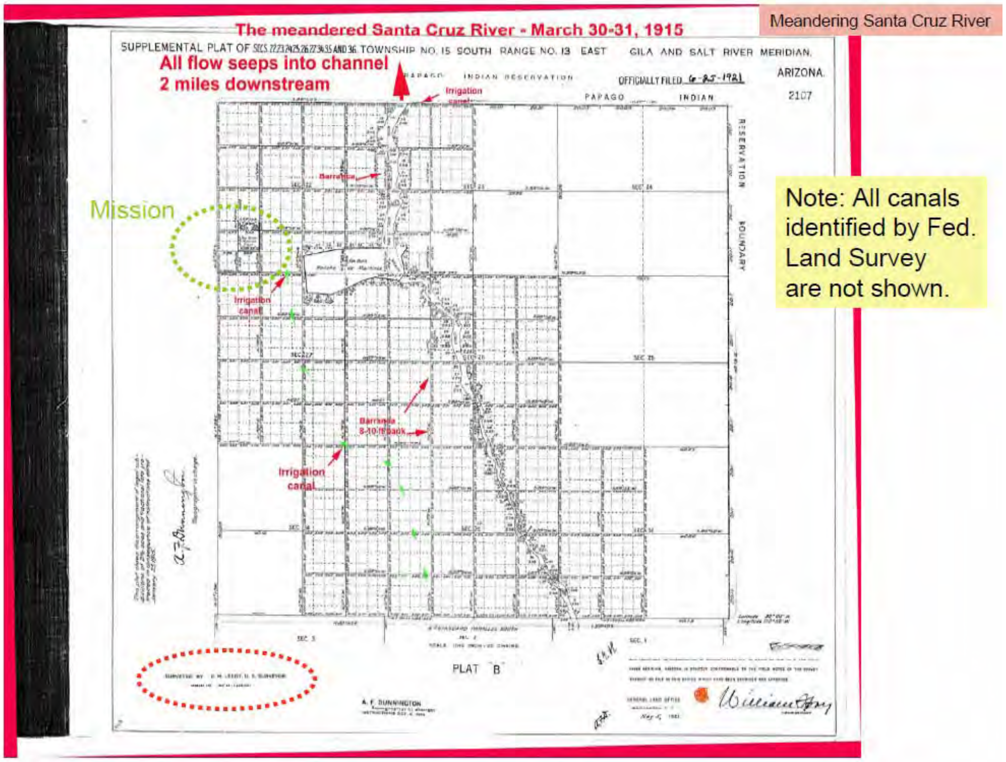
There are numerous scattered Indian houses along the road to Tucson in secs. 9, 16, and 21.

There are about 1500 acres under cultivation producing abundant crops. Probably 1500 acres more would be equally as productive if sufficient water for irrigation was available.

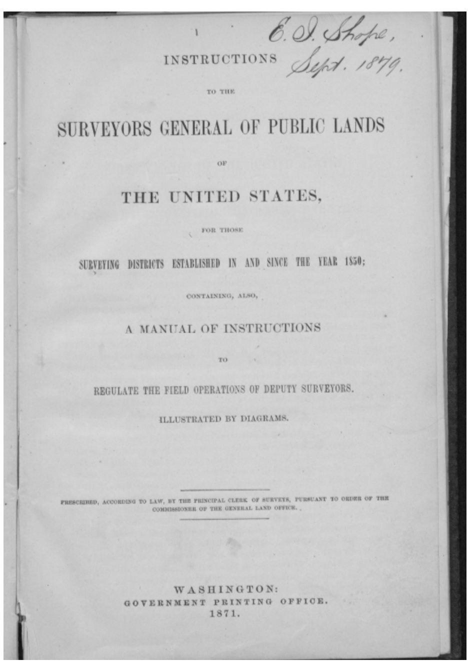
irrigation

The fractional township as a whole is very well improved.

Charles M. Leedy
U. S. Surveyor.



Following are some survey instructions for meandering.



E. D. Shope,
Sept. 1879.

INSTRUCTIONS

TO THE

SURVEYORS GENERAL OF PUBLIC LANDS

OF

THE UNITED STATES,

FOR THOSE

SURVEYING DISTRICTS ESTABLISHED IN AND SINCE THE YEAR 1850;

CONTAINING, ALSO,

A MANUAL OF INSTRUCTIONS

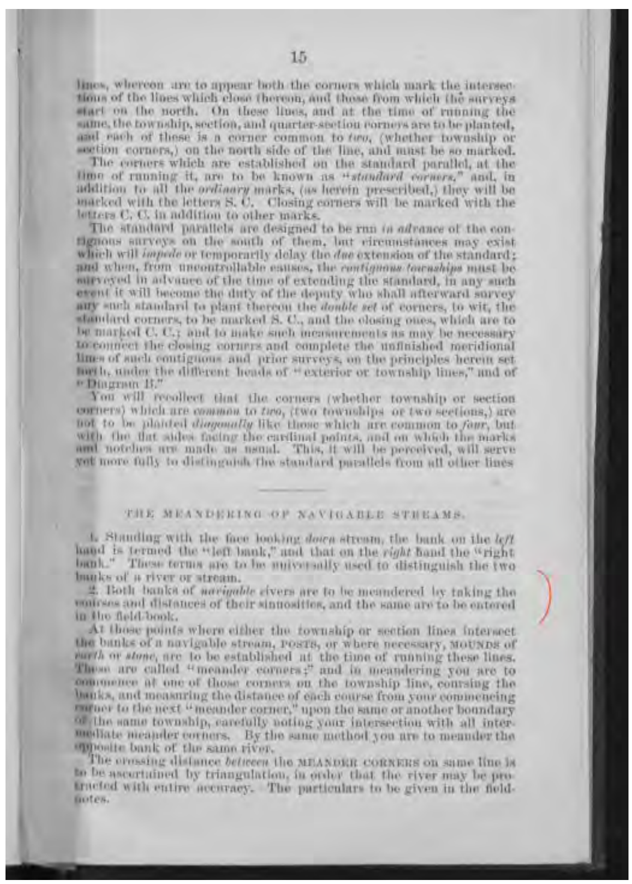
TO

REGULATE THE FIELD OPERATIONS OF DEPUTY SURVEYORS.

ILLUSTRATED BY DIAGRAMS.

PRESCRIBED, ACCORDING TO LAW, BY THE PRINCIPAL CLERK OF SURVEYS, PURSUANT TO ORDER OF THE COMMISSIONER OF THE GENERAL LAND OFFICE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1871.



15

lines, whereon are to appear both the corners which mark the intersections of the lines which close thereon, and those from which the surveys start on the north. On these lines, and at the time of running the same, the township, section, and quarter-section corners are to be planted, and each of these is a corner common to *two*, (whether township or section corners,) on the north side of the line, and must be so marked.

The corners which are established on the standard parallel, at the time of running it, are to be known as "*standard corners*," and, in addition to all the *ordinary* marks, (as herein prescribed,) they will be marked with the letters S. C. Closing corners will be marked with the letters C. C. in addition to other marks.

The standard parallels are designed to be run *in advance* of the contiguous surveys on the south of them, but circumstances may exist which will *impede* or temporarily delay the *due* extension of the standard; and when, from uncontrollable causes, the *contiguous townships* must be surveyed in advance of the time of extending the standard, in any such event it will become the duty of the deputy who shall afterward survey any such standard to plant thereon the *double set* of corners, to wit, the standard corners, to be marked S. C., and the closing ones, which are to be marked C. C.; and to make such measurements as may be necessary to connect the closing corners and complete the unfinished meridional lines of such contiguous and prior surveys, on the principles herein set forth, under the different heads of "exterior or township lines," and of "Diagram B."

You will recollect that the corners (whether township or section corners) which are *common to two*, (two townships or two sections,) are not to be planted *diagonally* like those which are common to *four*, but with the flat sides facing the cardinal points, and on which the marks and notches are made as usual. This, it will be perceived, will serve yet more fully to distinguish the standard parallels from all other lines

THE MEANDERING OF NAVIGABLE STREAMS.

1. Standing with the face looking *down* stream, the bank on the *left* hand is termed the "left bank," and that on the *right* hand the "right bank." These terms are to be universally used to distinguish the two banks of a river or stream.

2. Both banks of *navigable* rivers are to be meandered by taking the courses and distances of their sinuosities, and the same are to be entered in the field-book.

At those points where either the township or section lines intersect the banks of a navigable stream, POSTS, or where necessary, MOUNDS of *earth* or *stone*, are to be established at the time of running these lines. These are called "meander corners;" and in meandering you are to commence at one of those corners on the township line, coursing the banks, and measuring the distance of each course from your commencing corner to the next "meander corner," upon the same or another boundary of the same township, carefully noting your intersection with all intermediate meander corners. By the same method you are to meander the opposite bank of the same river.

The crossing distance *between* the MEANDER CORNERS on same line is to be ascertained by triangulation, in order that the river may be protracted with entire accuracy. The particulars to be given in the field-notes.

MANUAL

OF

SURVEYING INSTRUCTIONS

FOR THE

SURVEY OF THE PUBLIC LANDS

OF THE

UNITED STATES

AND

PRIVATE LAND CLAIMS.

Prepared in conformity with law under the direction of
THE COMMISSIONER OF THE GENERAL LAND OFFICE.

JUNE 30, 1894.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1894.

excess or deficiency in the measurements will be thrown, according to law, on the extreme tier or range of quarter sections, as the case may be.

10. Where by reason of impassable objects only a portion of the south boundary of a township can be established, an auxiliary base line (or lines,* as the case may require) will be run through the portion which has no linear south boundary, first random, then corrected, connecting properly-established corresponding section corners (either interior or exterior) and as far south as possible, and from such line or lines, the section lines will be extended northwardly in the usual manner, and any fraction *south* of said line will be surveyed in the opposite direction from the section corners on the auxiliary base thus established. (See Plate I, figs. 3, 4, and 5.)

11. Where by reason of impassable objects *no portion of the south boundary* of a township can be regularly established, the subdivision thereof will proceed from *north to south* and from east to west, thereby throwing all fractional measurements and areas against the west boundary, and the meanderable stream or other boundary limiting the township on the south.

If the *east* boundary is without regular section corners and the north boundary has been run eastwardly as a true line, with section corners at regular intervals of 80.00 chains, the subdivision of the township will be made from *west to east*, and fractional measurements and areas will be thrown against the irregular east boundary.

12. When the proper point for the establishment of a township or section corner is inaccessible, and a witness corner can be erected upon each of the two lines which approach the same, at distances not exceeding twenty chains therefrom, said witness corners† will be properly established, and the half miles upon which they stand will be recognized as *surveyed lines.*

The witness corner will be marked as conspicuously as a section corner, and bearing trees will be used wherever possible.

The deputy will be required to furnish good evidence that the section corner is actually inaccessible.

MEANDERING.

1. Proceeding *down* stream, the bank on the *left* hand is termed the *left bank* and that on the *right* hand the *right bank.* These terms will be universally used to distinguish the two banks of a river or stream.

2. Navigable rivers, as well as all rivers not embraced in the class denominated "navigable," the right-angle width of which is three chains and upwards, will be meandered on both banks, at the ordinary *mean high water mark*, by taking the general courses and distances of their sinuosities, and the same will be entered in the field book. Rivers not classed as navigable will not be meandered above the point where the average right-angle width is less than three chains. Shallow streams, without any well-defined channel or permanent banks, *will not be meandered*; except tide-water streams, whether more or less than three chains wide, which should be meandered at ordinary high-water mark, as far as tide-water extends.

At every point where either standard, township, or section lines intersect the bank of a navigable stream, or any meanderable line, corners will be established at the time of running these lines. Such corners

*Section corners will be established by correct alinement and measurement of *meridional* sectional lines whenever practicable.

†See "Witness Corners," page 47.

DEPARTMENT OF THE INTERIOR
U.S. GENERAL LAND OFFICE

ADVANCE SHEETS
of Chapters I to VI, inclusive, of a revision of the

MANUAL OF INSTRUCTIONS FOR THE SURVEY OF THE PUBLIC LANDS OF THE UNITED STATES

Prepared and published under the direction of the Commissioner of the General Land Office

WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

be measured; the original lines forming the boundary of the lands to be surveyed will be retraced, as already provided, and the marks upon the original corners will be appropriately modified as necessary; new quarter-section corners marked to control the subdivision of the new sections will be established on the original lines at mid-points between the closing section corners, or at 40 chains from one direction, according to the manner in which a new section is to be subdivided.

There are generally two or more ways in which a fragmentary subdivision may be executed, but a careful study of a sketch plat representing existing conditions will generally reveal the superiority of one method over another, and objectionable results should be avoided as far as existing conditions relating to the original surveys will permit.

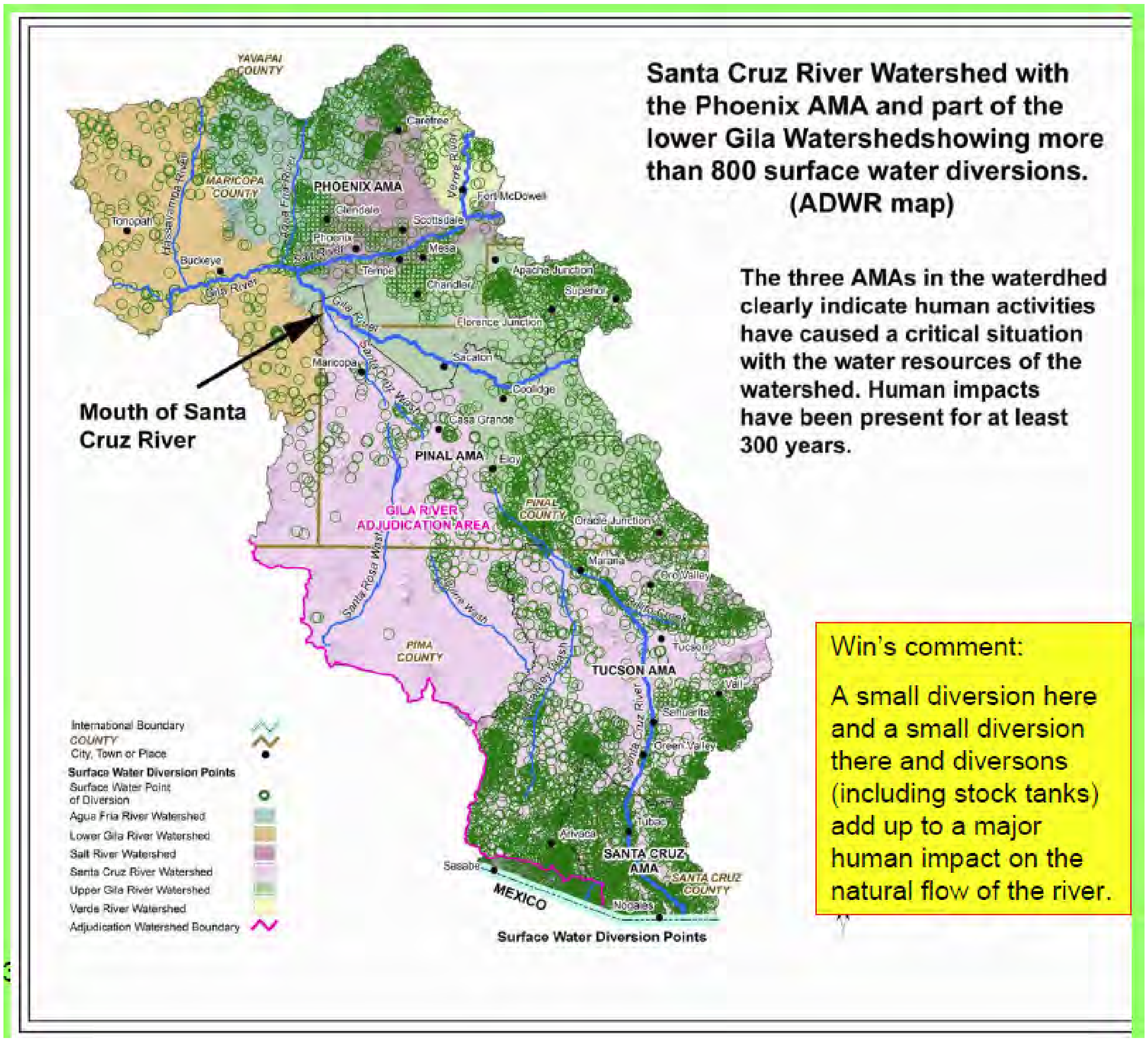
MEANDERING.

226. All navigable bodies of water and other important rivers and lakes (as hereinafter described) are to be segregated from the public lands at mean high-water elevation. The traverse of the margin of a permanent natural body of water is termed a meander line.

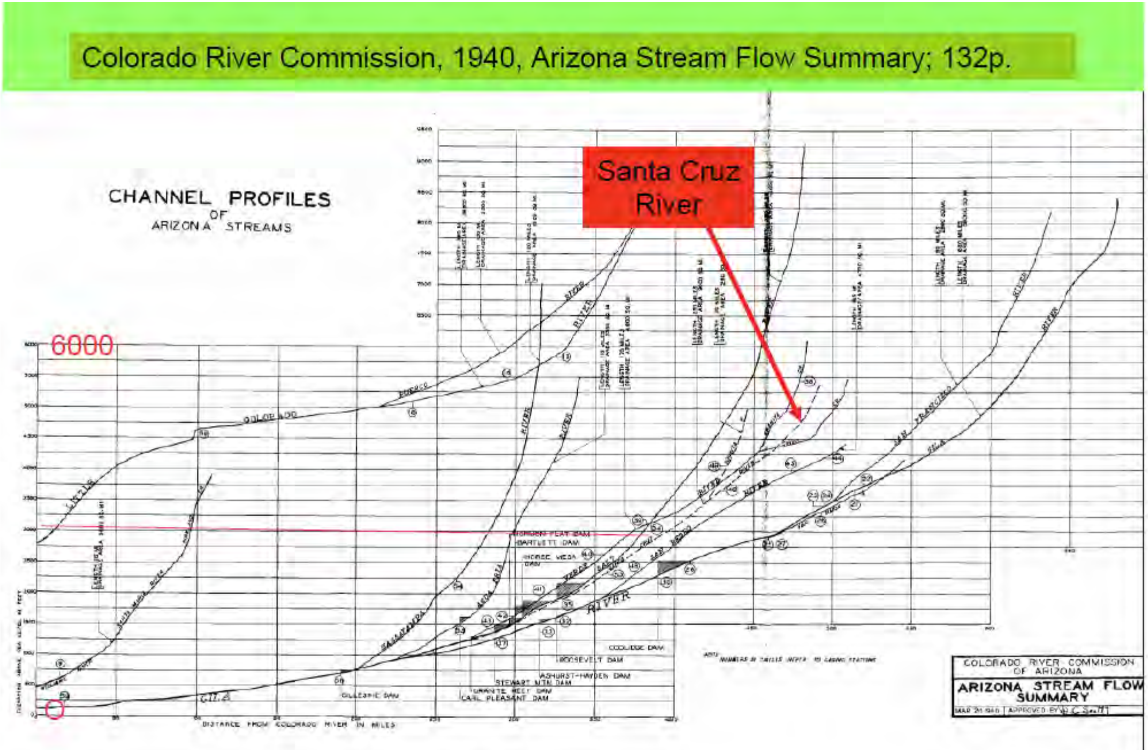
The running of meander lines has always been authorized in the survey of public lands fronting on large streams and other bodies of water, but the mere fact that an irregular or sinuous line must be run, as in case of a reservation boundary, does not entitle it to be called a meander line except where it closely follows the bank of a stream or lake. The legal riparian rights connected with meander lines do not apply in case of other irregular lines, as the latter are strict boundaries.

Mean high-water mark has been defined in a State decision (47 Iowa, 370) in substance as follows: High-water mark in the Mississippi River is to be determined from the river bed; and that only is river bed which the river occupies long enough to wrest it from vegetation. In another case (14 Penn. St., 59) a bank is defined as the continuous margin where vegetation ceases, and the shore is the sandy space between it and low-water mark.

Numerous decisions in the United States Supreme Court and many of the State courts assert the principle that meander lines are not boundaries defining the area of ownership of tracts adjacent to waters. The general rule is well set forth (10 Iowa, 549) by saying that in a navigable stream, as the Des Moines River in Iowa, Item 10. Many diversions in watershed.

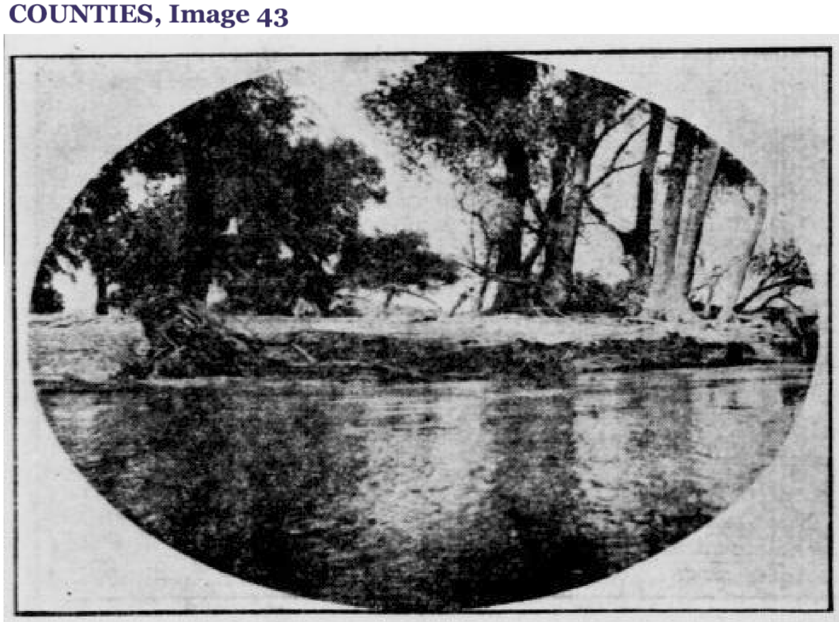


Item 11. Channel profiles of Arizona streams



Item 12. Santa Cruz River in Nogales area in 1911

Arizona republican. (Phoenix, Ariz.) 1890-1930, November 06, 1911, RESOURCE EDITION, YUMA, SANTA CRUZ, GRAHAM, COCHISE, APACHE, PIMA COUNTIES, Image 43

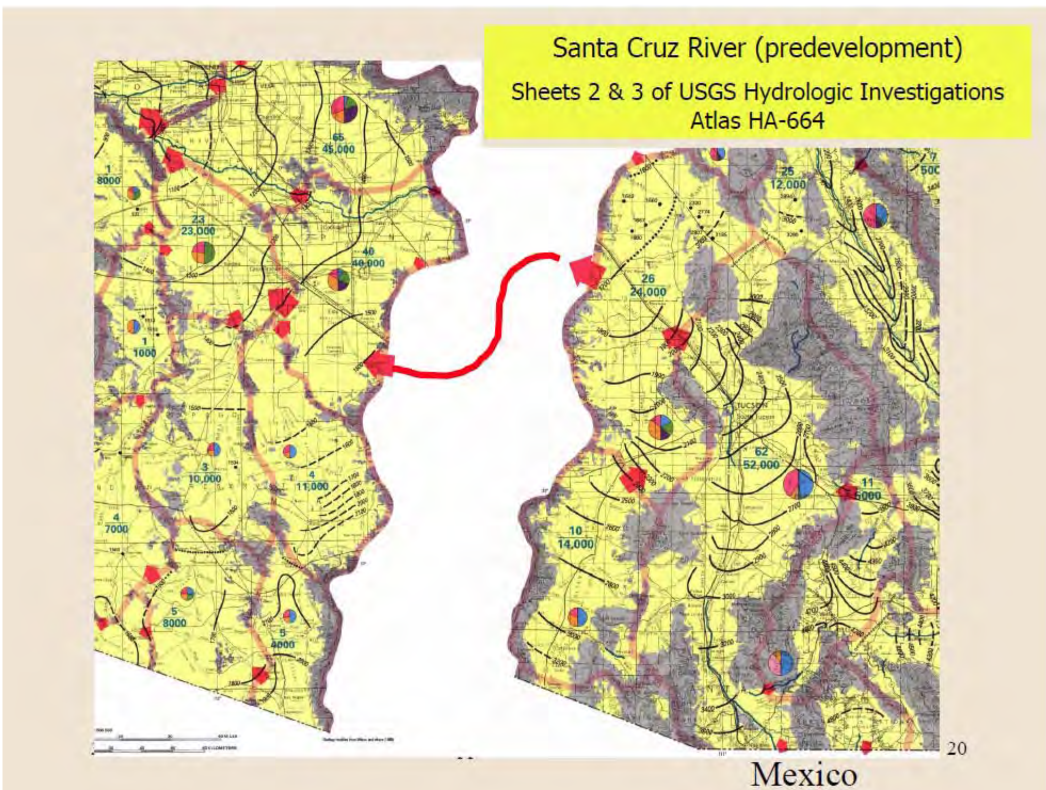


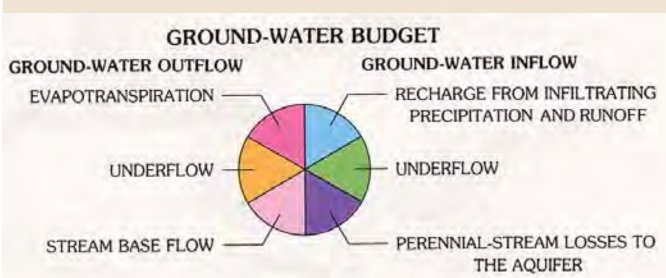
Handsome Spots Abound Near Nogales

Appendix C. River engineering methods

Item 1. Predevelopment base runoff (Q90) for hydrologic units

The generalized U-shaped contours of head distribution of the following map (Freethey, G. W. and Anderson, T. W., 1986) indicate various combinations of groundwater recharge and discharge. The water-level contours for the Tucson basin area illustrate a composite flow condition in which multiple sources of inflow and outflow exist. The shape of the water-level contours indicates that mountain-front recharge occurs along the basin perimeter and underflow occurs at the upstream end. Surface-water infiltration represents an additional inflow source.





In contrast, the generalized head distribution in the lower Santa Cruz watershed is a series of rather parallel contour lines normal to the axis of the basin. Water enters the basin mainly at the upstream end, and any mountain-front recharge is relatively minimal.

Under natural conditions the Santa Cruz River watershed was a few multiple source-sink basins, where surface water may have been fully appropriated or consumed in places, and other sources of water, such as capture of natural discharges from evapotranspiration or ground-water underflow, was available.

Historically, as the pumping rate from wells has increased, a proportionally greater part of the pumpage has been supplied by decreases in evapo-transpiration (ET) and reductions in aquifer storage. As a result the predevelopment ET has been estimated to be less than post development ET (USBR 1952).

Before the use of wells there was minimal depletion of aquifer storage and demands for water were almost completely met by down valley flow. In other words, the surface diversions for irrigation depleted the base flow all along the river. In the lower Santa Cruz watershed where groundwater contours are straight indicating little mountain-front recharge there was no inflowing base runoff from mountain-front recharge. Under these conditions, the basin is classified as a multiple source-sink basin.

Generally speaking, upper basin fill consists of less than 1,000 ft of sediments and includes basin-center deposits of more than 60-percent fine-grained material (Anderson, T.W., Freethey, G.W., and Tucci, P., 1992). The fine-grained material of the upper basin fill grades laterally to coarse-grained material near mountain fronts. The sediments also grade vertically from fine grained at depth to coarse grained at land surface. Stream-alluvium deposits consist of as much as 300 ft of coarse material along major streams.

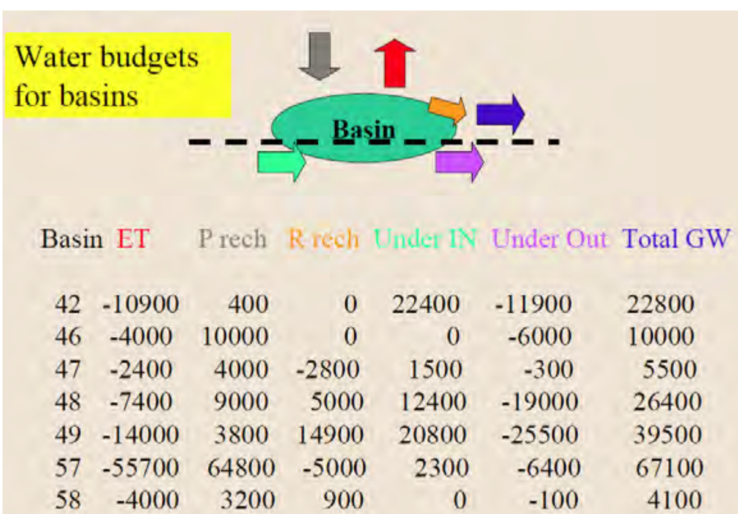
Before development, ground-water discharge was mainly by evapotranspiration, with minor discharge to streams as base flow (Anderson, T.W., Freethey, G.W., and Tucci, P., 1992). The principal water-bearing sediments consist of stream-alluvium deposits, where saturated, and upper basin fill. Ground water generally occurs under unconfined conditions, although head differences with depth may occur because of the presence of clay lenses in the heterogeneous basin fill. Before development, water levels ranged from at land surface near perennial streams to as much as a few hundred feet below land surface in places near mountain fronts. Ground water flows from the perimeter of a basin and from the up-gradient end toward the basin center and then down-valley to the mouth at the Gila River. Some ground water probably flowed through the entire length of the basins.

As development increased, the main source of ground water to meet the increasing demand was from aquifer storage. This is especially true in the lower basin. Therefore, the lower basin is classified as a storage-depletion basin.

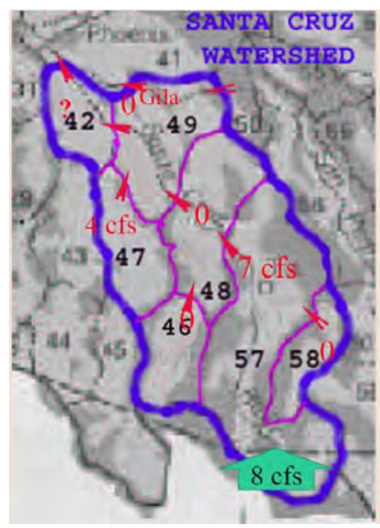
Because 1) the depletion of base flow in the upper basins has removed base flow from the lower basins and 2) the depletion of aquifer storage in the lower basins, there is no base flow in the lower Santa Cruz River.

In summary, basins that were initially a multiple source-sink type have at least partially evolved toward a storage-depletion type as human development increased. Pumping has captured evapotranspiration and stream base flow. Surface water infiltration has increased locally because a larger volume of sediments is available for storage. Mountain-front recharge has been affected to some degree by development such as stock tanks and lakes. Most ground water is derived from storage within the aquifer, and water levels have declined below the river bed. Base flow is discharge from groundwater. Because groundwater levels have dropped below stream channels along valley floors, there is no base flow in many places.

The following is the estimate of natural annual base flow (Q90) along the Santa Cruz River using USGS data for HA664 (Freethey, G. W. and Anderson, T. W., 1986). The 8 cfs at the Mexican border is the difference between the average annual streamflow of 21 cfs from Table 2 (p A10) of USGS WSP 1939-A by Condes de la Torre (1970) and the Virgin flow of 29 cfs determined by the USBR (Krug, 1946). The Virgin flow determined by the USBR is shown in the following section of this Appendix (Item 2).



Basin	ET	P rech	R rech	Under IN	Under Out	Total GW
42	-10900	400	0	22400	-11900	22800
46	-4000	10000	0	0	-6000	10000
47	-2400	4000	-2800	1500	-300	5500
48	-7400	9000	5000	12400	-19000	26400
49	-14000	3800	14900	20800	-25500	39500
57	-55700	64800	-5000	2300	-6400	67100
58	-4000	3200	900	0	-100	4100



Item 2. Computation of Average Annual Runoff of Santa Cruz River

To understand why I used average annual runoff for my analysis, it is important to first understand what runoff is. Runoff is that part of the precipitation that naturally appears in surface streams. Therefore, it is the same thing as “stream flow” unaffected by artificial diversions, storage, or other works of man in or on the stream channels. In other words, runoff is the same as predevelopment stream flow or Virgin flow. Runoff includes both direct flow and base flow.

For the average annual runoff data, I started by using the USBR report shown below, which shows runoff (Virgin flow) for two USGS stream gages on the upper Santa Cruz River.

Gaging station	Area (mi²)	Runoff	
		(Ac-ft)	(cfs)
near Nogales	533 (348 in Mex.)	21 2 00	29
At Rillito (Cortaro)	3503	44,200	60

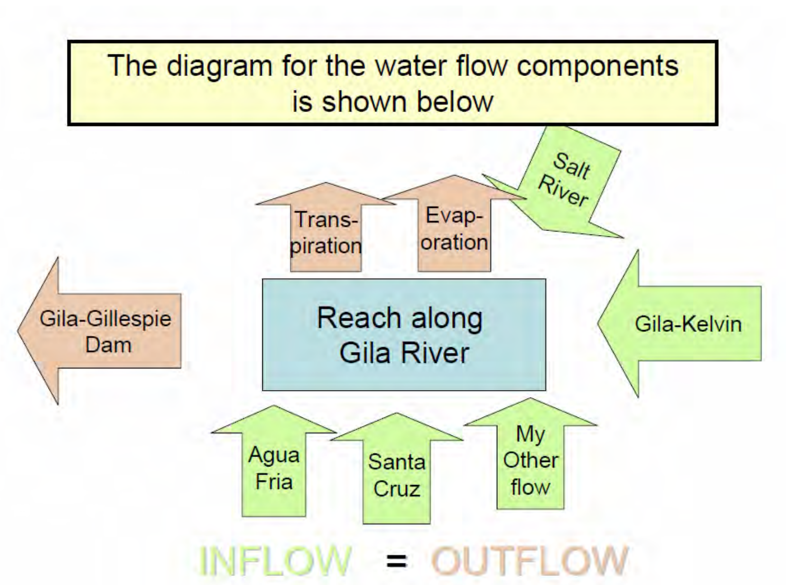
USBR, 1952, Report on Water Supply of the Lower Colorado River Basin: US Department of Interior, Bureau of Reclamation Project Planning Report, (p. 152), 444 p.

Because the report by the USBR did not include the runoff at the mouth of the Santa Cruz River, I had to independently compute the average annual runoff using runoff data for other river sites given in the USBR report. I also used transpiration and evaporation published in the same USBR report. The published data I used are shown in the following table:

Gaging station	Area (mi²)	Runoff (cfs)
Gila River at Kelvin	18031	754
Salt River at Granite at Granite Reef Dam	12907	1964
Agua Fria River at Lake Pleasant	1459	179
Gila River at Gillespie Dam	49626	-2473
Santa Cruz River at Rillito	3523	60
For area between the sites shown above		
Transpiration		- 554
Evaporation		- 60
My computed runoff for area defined by the above USBR data		
Area (lower Santa Cruz and other streams)	13716	131

NOTE: Negative sign indicates water leaving the area.

To determine the average annual runoff at the mouth of the Santa Cruz River it was necessary to calculate the portion of the "my computed runoff" shown in the previous water budget for the reach of Gila River that includes the Santa Cruz River and other streams (Centennial Wash, Hassayampa River, Caver Creek, etc..).



A simple ratio of drainage areas was used to estimate runoff as shown on the right.

$$\text{Runoff}_{\text{SC mouth}} = \frac{(\text{Area}_{\text{SC mouth}})}{\text{Area}_{\text{other}}} \times \text{Runoff}_{\text{other}}$$

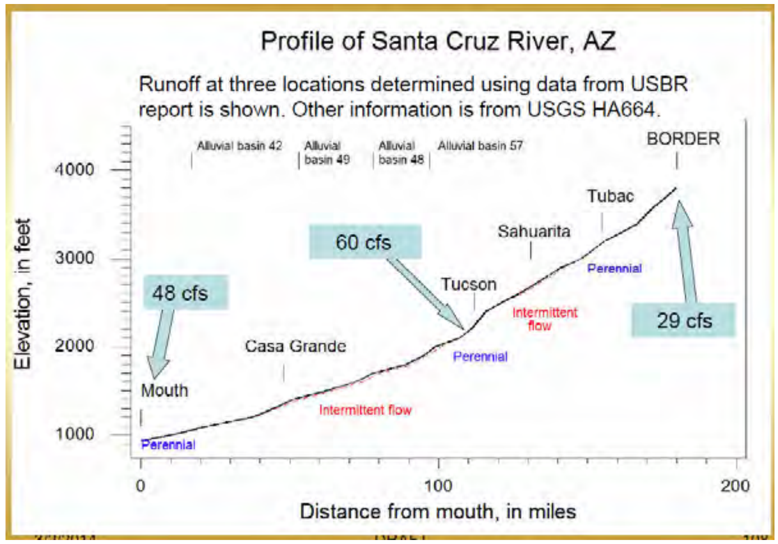
Where, $\text{Runoff}_{\text{SC mouth}}$ is the runoff from the Santa Cruz River
$\text{Runoff}_{\text{other}}$ = 131 cfs (see prior table)
Area SC_{mouth} = 5058 mi^2
$\text{Area}_{\text{other}}$ = 13716 mi^2

$\text{Runoff}_{\text{SC mouth}}$ = 48 cfs

The resulting amounts of runoff at three locations along the 180 mile reach from the Mexican border to the mouth of the Santa Cruz River are shown to the right.

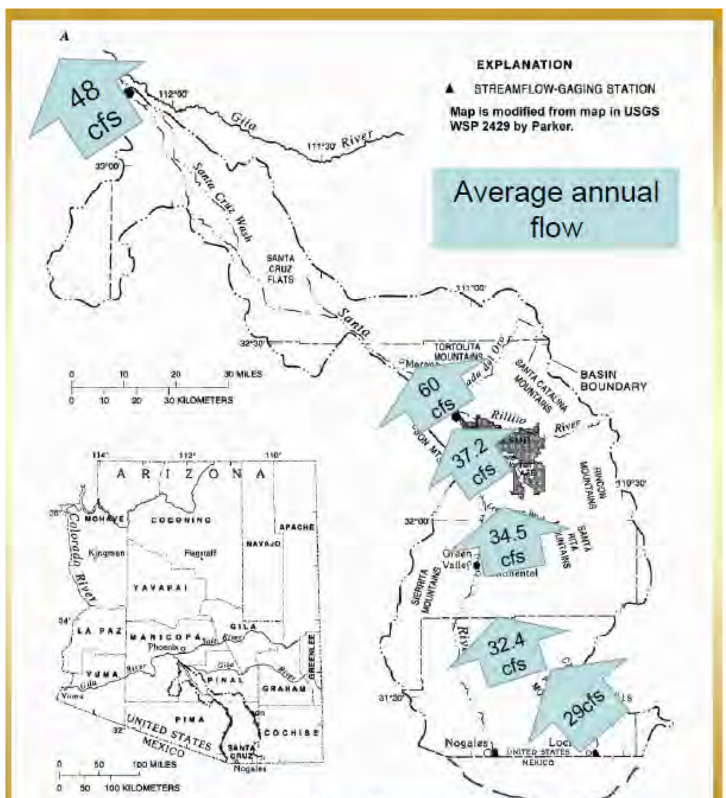
Site	Area (mi^2)	Runoff (cfs)
Mexican border	533 (348 in Mex.)	29
At Rillito (Cortaro)	3503	60
At Mouth (Laveen)	8581	48

These amounts of runoff (predevelopment streamflow) were used for this assessment of navigability.



Runoff for five reaches in the upper Santa Cruz River watershed that have either perennial or ephemeral flow are shown below (Minitab output). These reaches are defined on Sheet 3 of 3 of USGS HA 664. Runoff for the Tubac, Continental and Tucson was estimated using data for historic mean annual runoff in USBR (1952) report and ratios of drainage areas for the gage sites.

SITE	DA sq. mi.	State of Flow	Base flow (Q90) cfs	Annual Runoff cfs
Nogales	533	Perennial	8	29
Tubac	1209	Perennial	10	32.4
Continental	1662	Intermittent	0	34.5
Tucson	2222	Perennial	13	37.2
Cortaro	3503	Intermittent	0	60



Santa Cruz River Watershed

Item 3. Flow duration relations:

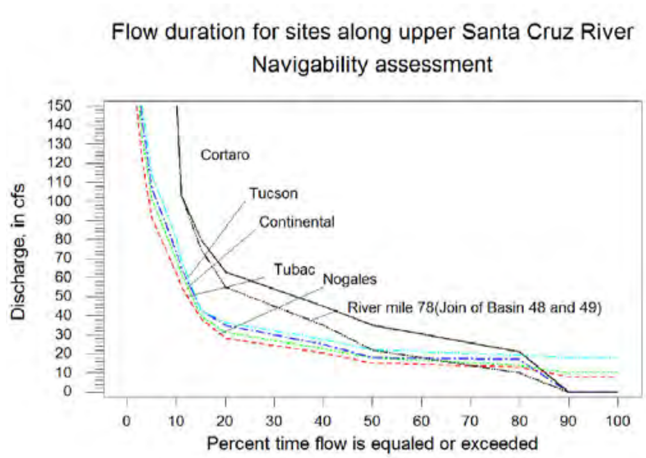
The general shape of the flow duration relations along the river is estimated using the flow-duration relation at the USGS streamflow gage near Nogales. Sample flow-duration relations, that were defined by Condes (WSP 1939-a, Table 3 shown below) in 1970 where significant impacts of humans were present but not to degree more recently, are shown below. Impacts of humans were less at the upper end of the study reach than at downstream gages where groundwater withdrawal and tree removal was more severe. Post development flow duration curves, especially at the USGS Nogales gage, were used to simply shape the predevelopment FDCs along the river while keeping in mind the perennial/intermittent flow along the river as defined by the USGS (HA664).

TABLE 3.—*Percentage of time in a 28-year period that streamflow would equal or exceed selected discharge rates between 1 and 100 cfs at gaging stations*

Station	Discharge (cfs)				
	1	5	10	50	100
Santa Cruz River near Lochiel	12	5	3	1	0. 5
Santa Cruz River near Nogales	67	34	19	6	4
Sonoita Creek near Patagonia	79	20	7	2	1
Santa Cruz River at Continental	9	7	6	4	3
Santa Cruz River at Tucson	11	8	7	4	3
Tucson Arroyo at Vine Avenue, Tucson	5	2	1	. 3	. 1
Tanque Verde Creek near Tucson	27	16	10	3	1
Sabino Creek near Mount Lemmon	24	5	2	. 2	. 1
Sabino Creek near Tucson	43	25	17	4	2
Bear Creek near Tucson	21	11	7	1	. 5
Tanque Verde Creek at Tucson	19	15	12	5	2
Pantano Wash near Vail	90	7	5	2	1
Rincon Creek near Tucson	17	11	7	2	. 5
Rillito Creek near Tucson	8	6	5	3	2
Santa Cruz River at Cortaro	13	11	9	6	4

Condes de la Torre, Alberto, 1970, Streamflow in the Upper Santa Cruz River Basin, USGS WSP 1939-a, 32p

The flow duration relation at river mile 78 (downstream end of Basin 48) was estimated by subtracting the runoff (R rech = 5000 ac-ft/yr in table on p. 3 of Appendix C Item 1) for basin 48 from the flow at Cortaro. The resulting difference between average annual runoff for Cortaro and at river mile 78 is about 7 cfs as shown on the relations to the right.



Item 4. Early settlement along the Santa Cruz River and associated water is discussed by the USGS (Bryan, Kirk, 1923, Erosion and sedimentation in the Papago country, Ariz., with a sketch of the geology: U. S. Geol. Survey Bulletin 730-B, pp.19-90.).

Father Kino's account of the valley near Tucson is of course colored by his enthusiasm and missionary zeal, but his statements imply conditions very unlike those of the present. In 1692 he found 800 persons at San Xavier del Bac, 12 miles south of Tucson. In January, 1697, there were at the same place " beginnings of good sowings and harvests of wheat," and in November of the same year he counted in the rancheria and environs 6,000 persons and " found even bread, fresh and very good." In October, 1699, he counted 1,000 persons in the rancheria of San Xavier del Bac and states:" The fields and lands for sowing were so extensive and supplied with so many irrigation ditches running along the ground that the father visitor [Antonio Leal] said they were sufficient for another city like Mexico."

“Of San Cosme del Tucson, probably located just west of the present city of Tucson, he says that it had "splendid fields.“ Similarly he states that he counted 200 men representing 200 families at San Agustin del Oyaut (Oiaur), probably between Jaynes and Rillito. At Santa Catarina del Cuytoabagum he found 300 men representing 300 families. (See map below) This rancheria was probably near the present Picacho. In April, 1700, after erecting the foundation of a church and beginning a mission at San Xavier del Bac, Kino states that the mission " will be able to have throughout the year all the water it may need, running to any place or workroom one may please, and one of the greatest and best fields in all Nueva Biscaya." “

Bryan continues: The purport of these statements is that at the beginning of the eighteenth century….the flood plain of Santa Cruz River was without a deep channel and had a permanent stream, else the Indians with their primitive wooden tools would not have been able to divert the water into ditches, nor would the water have lasted all the year. It should be remembered also that the cutting of the channel trench has facilitated the flow of ground water at the present time. There must, then, have been much more water available in 1700 to cause the river to flow the year round.

The extensive settlements down the river from Tucson are also significant, for, unless the floods were stronger and more frequent than now, 200 families could not live by primitive agriculture between Jaynes and Rillito, nor could 300 families live near Picacho.

Figure 4.7: Father Kino's map of the Papagueria. The Gila is identified as the "R. de Hila."

McNamee, Gregory, 1998, Gila: the life and death of an American River, updated and expanded edition, University of New Mexico Press, 232p.

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At Santa Catarina del Cuytoabagum he found 300 men representing 300 families. This rancheria was probably near the present Picacho.

Bryans argument clearly is supported by the original Federal Land surveys (See Appendix A). Cienaga-like conditions north of Tucson were present as late as 1905 as shown on the original Federal Land Survey for T10S R9E (Cienegas are wetlands characterized by permanent, scarcely fluctuating water sources and semi-arid surroundings.). Based largely on the original land surveys there was a single channel from the Mexican border through this Township. Also, the boundary between alluvial basins 48 and 49 (Appendix C Item 1), where groundwater flow is constricted, is near the center of this Township. Several small farms are shown on the survey plat of 1905 and the field notes identify corn, grain and sunflowers were in cultivated fields. Its most interesting that on pages 50-51 of the survey notes (book 1870) the surveyor says there was a good growth of grass on the bottom lands along the Santa Cruz River and Avra arroya where good crops are raised without irrigation.

Item 5. A description of the Santa Cruz River by Mowry (1864) is especially informative.

Mowry, S., 1864, Arizona and Sonora, The Geography, History and Resources, Silver Region of North America; Harpee Brothers Pub., 251p.

We now approach the Santa Cruz River and its valley, unquestionably the finest agricultural district in the whole of the Gadsden Purchase, after leaving the bottom lands of the Rio Grande. It is also the best wooded of any portion of the Territory, and in other respects presents many advantages for settlers; indeed, this valley, with its adjacent districts, where there are several rich and highly cultivated haciendas and missions, must become the granary for the future State of Arizona.

The Santa Cruz River rises in a broad valley, or rather plain, north of the town of the same name. We struck it at the base of a mountain range, where an open country, studded with oaks, lay before us. Passing these was an open plain covered with luxuriant grass, without a tree or shrub; crossing which, after being contracted between low ranges of hills, we reached Santa Cruz. This is an old town and presidio, and falls about ten miles south of our line. Flowing south nine miles to San Lorenzo, a deserted rancho, it soon after takes a northerly course, winding its way through a beautiful valley, until it is lost in the desert plain or sands, some ten or fifteen miles north of Tucson. Its entire length in a direct line, without reckoning its sinuosities, is about a hundred miles. Its width varies from 20 to 100 feet, and during very dry seasons portions of it disappear.

This valley was traversed by the earliest Spanish explorers in 1535, seduced by the flattering accounts of Cabeça de Vaca. Marco de Niza and Coronado led their adventurers through it in search of the famed cities of Cibola, north of the Gila; and before the year 1600, its richness having been made known, it was soon after occupied as missionary ground. Remains of several of these missions still exist. The mission church of San Xavier del Bac, erected during the last century, is the finest edifice of the kind in Sonora. Tumacacori, a few miles south of Tubac, was the most extensive mission in this part of the country. The extensive buildings, irrigating canals, and broad cultivated domain here at once attest its advantages.

The towns and settlements in the Santa Cruz valley are Santa Cruz and San Lorenzo (south of our line), Calabazas, Tumacacori, Tubac, Sopori, the mission of San Xavier, and Tucson. Santa Cruz, Tubac, and Tucson were presidios. With the exception of Santa Cruz and Tucson, this entire valley was abandoned to the savage Apaches at the time of my first visit in 1851, and the population of these was greatly diminished; indeed, but for the military the Indians would have had entire possession of it. At Calabazas a small stream enters, upon which are fine bottom lands. At Sopori is another extensive hacienda, with a broad domain and fine bottom lands. Between Tubac and San Xavier is the finest timbered district in the country; it extends from the river to the base of the mountains, and is apparently several miles in width. The timber is wholly mesquit, of a larger size than I noticed any where in the Territory, except in the valley of the Colorado. This timber must be of incalculable value both for railroad and mining purposes. For building purposes it is too hard and crooked. Besides, the cottonwood is found on the margin of all

streams; it is of rapid growth, and well adapted for building.

Appendix D. A Few Additional Facts and Observations by a Professional River Engineer

Item 1. Bull (Bull, W D., 1997, Discontinuous ephemeral streams: Geomorphology, Volume 19, Issues 3-4, p227-276) discusses arroyo development in the Santa Cruz River in the Tucson area where he points out The Santa Cruz River already had discontinuous channels before the 1890 floods. Humans concentrated streamflow and caused arroyo cutting by construction of infiltration galleries in streambeds with intermittent and perennial flow. These consisted of open ditches excavated below the shallow ground-water table that were well situated to become sites of initial stream-channel entrenchment. Downstream from Tucson, Arizona certain old settlers undertook to ‘develop water’ at a point about 2 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 to do the rest. Their expectations were fully realized, for the river scoured out the cut and carried on its work. In the next year the infamous floods of 1890 created an arroyo at Tucson 6-20 ft deep and ½ mile long, largely along an irrigation ditch dug by Sam Hughes. Headcuts were an early phase of the arroyo cutting; now the Santa Cruz River arroyo has alternating narrow and wide reaches that may be a function of bank materials and the transport and deposition of gravel (Parker, John. T.C, 1995, Channel change on the Santa Cruz River, Pima County, Arizona, 1936-86; U.S. Geological Survey water-supply paper; 2429, 58p.).

According to Bull (1997) the Desert Land Act encouraged settlers to divert water from the streams of semiarid regions in order to claim homestead rights to farmland. Diversion dams were constructed that diverted streamflow into rather straight ditches. Such reductions in channel sinuosity served to increase unit stream power by increasing gradient, thereby causing a reach close to equilibrium to become strongly degradational with resulting arroyo formation.

Item 2. Diversion dam along Gila River in basin shared by the Gila and Santa Cruz Rivers. This is presented to show ANSAC one type of diversion used to divert river flow before the channel of the Santa Cruz River became deeply incised.

PIMA IRRIGATION DAM

This diversion was in Hydrologic Unit basin 49 that is shown in Item 1 of Appendix C. This is presented to give the reader an idea of early diversions used by settlers and Indians.

Judson, K. B., 1912, Myths and Legends of California and the Old Southwest: A. C. McClurg and Co., Chicago, 193p.

In regard to ditches in the Middle Gila Valley, according to Davis (Davis, A. P., 1897, IIRRIGATION NEAR PHCENIX, ARIZONA , USGS Water Supply Paper 2, 98p.), “Water is diverted by means of a " burro" dam, which consists of a forked stick driven into the river bed, inclined slightly up stream, supporting in its forks another stick with its end driven diagonally into the sand 6 or 8 feet above. *A* series of these so-called " burros" are constructed across the stream and support a mass of sticks and brush, which is finally weighted down with rocks and sand. This character of dam is quite common for small ditches in the West, and of course usually requires renewal after the season of high water.

Item 3. Burtell Analysis and rating curves and mean depths

See: Burtell, R., 2013, DECLARATION OF RICH BURTELL ON THE NON-NAVIGABILITY OF THE SANTA CRUZ RIVER AT AND PRIOR TO STATEHOOD, *In re Determination of Navigability of the Santa Cruz River (Case No. 03-002-NAV),* October 2013, *Prepared for:* Freeport-McMoRan Corporation, 333 North Central Avenue, Phoenix, AZ 85004, 17 p. and tables, etc., Pages 6-7 including Table 4 and Figure 4. (Burtell Declaration)

Having carefully reviewed the Burtell Declaration, I provide the following observations and critique. It appears from the Declaration, that Mr. Burtell downloaded from the internet about 253 measurements of discharge for the USGS gage near Nogales, Az (09480500). The downloaded measurement information included the discharge and channel width for each of the measurement sites. Mr. Burtell then estimated the mean depth of these measurements (and estimates) by dividing the discharge measured by the corresponding width across the river at the site. Mr. Burtell then generated a plot of mean depth versus discharge and a regression line through the data. This plot and line are shown on the next page. Mr. Burtell made the following statements on pages 6 and 7 of his report.

B. Streamflow Records

32. **Table 4** lists median monthly streamflows measured at a USGS gage on the Santa Cruz River near Nogales from 1913 to 1920 and from 1930 through 1939. The gage was located about 6 to 7 miles downstream of the International Border during the earlier period of record and about 1 mile downstream of the border since that time. **(Figure 2)**

33. **Table 4** also notes average stream depths during the period that were estimated using the median monthly streamflows and a rating curve developed by Plateau. The rating curve is shown in **Figure 4** and was based on 200 field measurements taken by the USGS at the upstream gage site between 1975 and 2011.

34. Stream depths estimated at the gages near Nogales were typically less than 1 foot in 165 of the 169 months with record. Such shallow water would have precluded

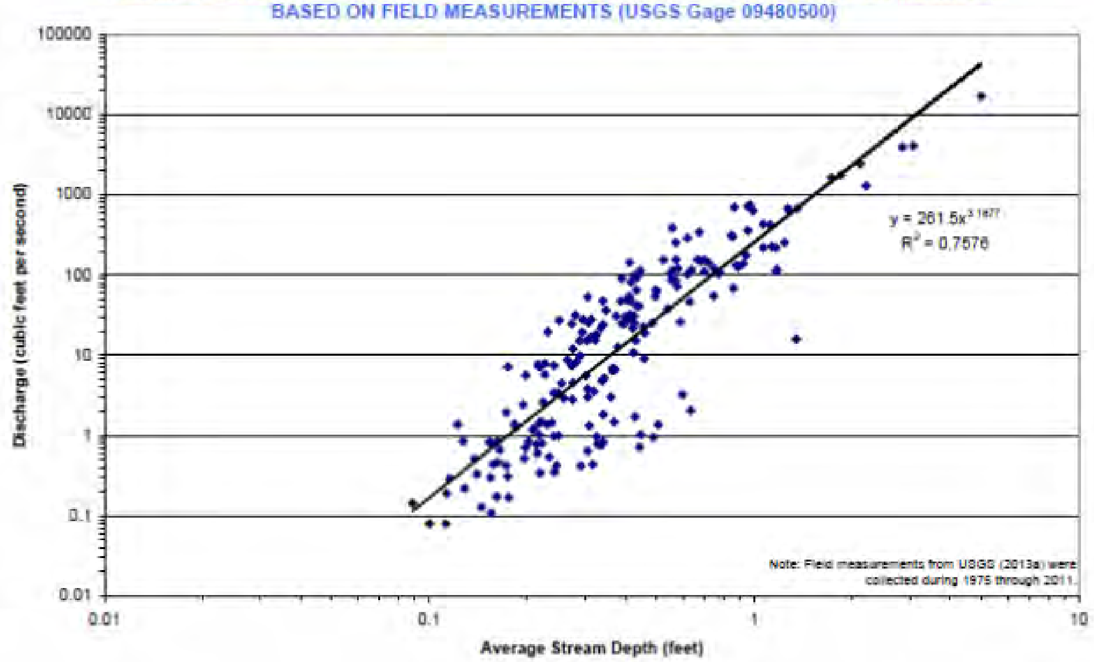
San Cruz River Navigability Determination

commercial boat travel along this portion of the Santa Cruz River. Four months had median flows greater than 100 cfs, two during the monsoon in August and two during the winter months of January and February. However, based on the rating curve in **Figure 4**, even during these months of higher flows, average stream depths would typically have been less than 2 feet.

35. Like the gage near Lochiel, the streamflow data presented in **Table 4** were collected after statehood. However, because there were only relatively minor diversions above the gage, these data are useful in evaluating ordinary and natural streamflow conditions. In 1913 and 1920, the USGS reported that about 140 acres of land were irrigated above the station plus a "small irrigation ditch" located a short distance above the gage was said to divert water. USGS reported "minor diversions for irrigation above station" in 1931 and in 1939 "several small diversions above station for irrigation" were noted. It was also noted in 1939 that "no water (had been) diverted around station by Buena Vista canal since April 1939." Diversions by this ditch were measured during 1937 through 1939 and ranged from 0.11 to 1.6 cfs (USGS, 1977).

36. During the height of the growing season, irrigation of a few hundred acres upstream and diversion of a few cfs immediately above the gages would not, on average, deplete more than 5 cfs from the stream. If these potential diversions are added to the median streamflows presented in **Table 4** and compared again to the rating curve in **Figure 4**, typical stream depths still remain below 1 foot.

FIGURE 4 - AVERAGE DEPTH VS. DISCHARGE OF THE SANTA CRUZ RIVER NEAR NOGALES BASED ON FIELD MEASUREMENTS (USGS Gage 09480500)

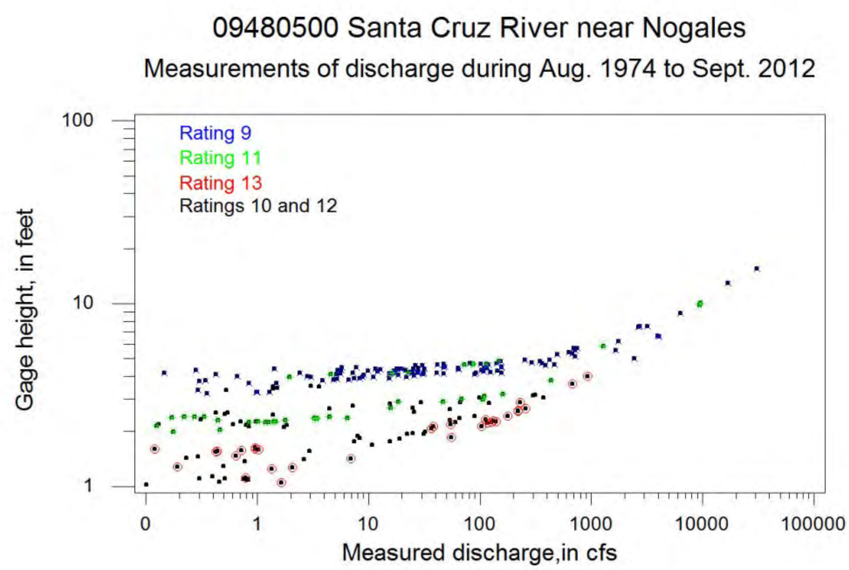


Based upon my 53 years of professional experience with river engineering, I concluded that Mr. Burtell's assessment is flawed and misleading for the following reasons:

A. Setting aside for the moment, Mr. Burtell's comments in paragraph 32 regarding median and monthly depths from 1913 to 1920 and 1930 to 1939, it is important to first note that the 200+ stream measurements that were used to compute stream depths shown in Figure 4 above were different measurements. As paragraph 33 of the Burtell Declaration explains, Mr. Burtell computed the average stream depth shown in Figure 4 from the measured discharges and widths of flow on the USGS web site that were measured between 1975 and 2011.

B. Because the computed stream depths in Figure 4 are based on measurements made between 1975 and 2011, the streamflow of the river and the corresponding measured discharge and computed mean depth reflect a river that has been significantly affected by human activity. Based on the USBR (1952) the natural flow in the river was considerably more than the flow during 1975-2011. Therefore, any conclusions drawn by Mr. Burtell about the flow depths shown in Figure 4 refer to human-altered flow that is only a fraction of the river's natural base flow.

C. It is also important to recognize that the USGS measurements were made over a period (1975-2011) of changing channel geometry that is typical for a sand channel stream like the Santa Cruz River. The USGS used 5 rating curves (Nos. 9-13) in order to define the stage-discharge relation that was used for the computation of streamflow. Each rating was applied to a relatively stable period as shown on the next figure. Thus, the average depths computed by Mr. Burtell are for a channel experiencing changing geometry and slope.



Note: The channel of the Santa Cruz River is not what is known as a fixed channel (Rantz, 1982, p. 376) where well-defined stage-discharge relations can usually be developed that show only minor shifting at low flow. Because of the coarse sand channel, the stage-discharge relation is continually changing with time because of scour and fill and also because of changes in the configuration of the channel bed, possibly associated with upper and lower regime flow, during large floods. These changes cause the shape and position of the stage-discharge relation to vary from time to time especially from flood to flood. Plots of depth and discharge like Mr. Burtell's Figure 4 have an apparent haphazard scatter when these channel changes are not properly considered. Familiarity with sand bed channels and even bedforms, that Mr. Burtell fails to account for, is useful when examining data at gages like the USGS gage 09480500.

D. The USGS measurements were also made at various locations upstream and downstream of the gage depending on where a satisfactory site was found for the making of a measurement. Some measurements were made a few hundred feet from the gage. Thus, the average depths computed by Mr. Burtell are actually for different locations along the channel.

E. Mean depth has limited value for assessment of navigability as the following comparison of channel cross-sections demonstrates:

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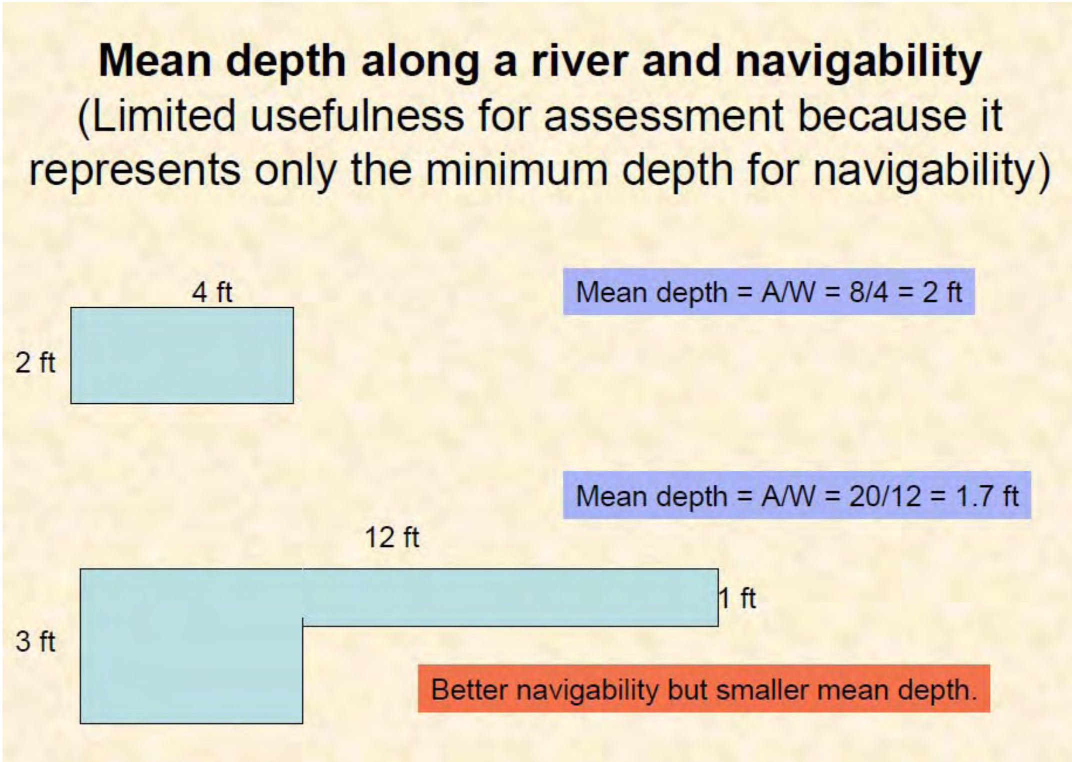
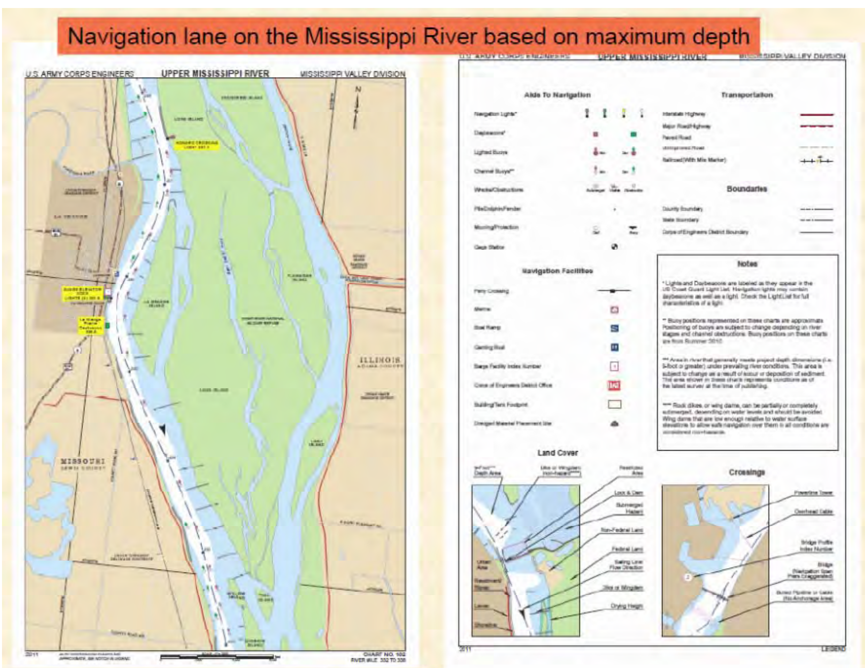


See also:



F. Mr. Burtell's regression (Figure 4) where discharge (y) is the "dependent variable" and average channel depth (x) is the "independent variable" is also grossly illogical. Although a relation depicted by a regression relation does not necessarily imply causation, the average channel depth is the result of the discharge and the channel hydraulics (shape, roughness, gradient, etc.). Obviously the discharge is not the result of average channel depth. Thus, Mr. Burtell apparently failed to grasp the fundamental logic of why when using a simple regression, discharge is necessarialy the "independent variable" and average channel depth is the "dependent variable". Also, the basic concept of regression, in the simplest form, mathematically describes an unchanging relationship between two phenomena. However, as the five ratings used by the USGS demonstrate, the relationship between mean channel depth and discharge was obviously changing. Thus, a "regression" analysis under these circumstances, is both inappropriate and meaningless.

G. The rating curve in figure 4 (Burtell Declaration, paragraph 34) is inaccurate for the following reasons. It is a crude uneducated fit of a line through data for changing channel geometry.

For channel controls, the flowing parabolic relation is applicable (Rantz, S, E, and others, 1982, Measurement and Computation of Streamflow: Volume 2. Computation of Discharge, USGS Water-Supply Paper 2175, 388p. (following equation on p. 330):

$$Q = C\,(G-e)^{N}$$

where N will commonly vary between 1.3 and 1.8 and practically never reach a value as high as 2.0.

where Q is discharge (cfs), G is gage height (ft), e is effective point of zero flow (ft), C is a constant and N is an exponent or slope of rating.

This USGS equation is like Mr. Burtell's rating where his average depth (X) = (G-e) and Y = Q. Mr. Burtell's equation from his Figure 4 is:

$$Y = 261.5\,X^{3.1877}$$

Mr. Burtell's slope (N = 3.1877) is considerably greater that the limiting value of 2 (USGS WSP 2175) and is, therefore, impossible.

I realize that this level of mathematics (differential equations) is extraordinarily complex and may be beyond the expertise of ANSAC, but

> the limiting slope for all natural channel controls is 3. A slope greater than 3 (Mr. Burtell used 3.1877) implies the incremental amount of increasing discharge (Y) for an incremental increase of depth (X) is increasing. In other words the exponent for the second derivative of X with respect to Y is greater than 1 (1.1877 to be exact) and this is an impossible hydraulic condition for a natural channel like the Santa Cruz River near Nogales.

In sum, Mr. Burtell's analysis is both grossly erroneous and outside his area of expertise. Even without evaluating the erroneous calculations, his analysis should be rejected because he failed to account for human affects that greatly reduced streamflow and the natural depth of flow in the channel of the Santa Cruz River. In other words, Mr. Burtell neglected to consider a US Bureau of Reclamation report (USBR, 1952) that defined the natural flow at the Nogales gage. Also, the idea that average depth along a channel represents the navigation lane (or corridor) is contrary to navigation practices along rivers throughout the world. At best average depth simply represents the minimum depth and is computed using the total width of the channel that typically includes wide areas of shallow flow or secondary channels. Mr. Burtell's analysis demonstrates an acute lack of knowledge of fundamental hydraulic methods and navigation principles and a lack of understanding and ability to apply those methods and principles to data.