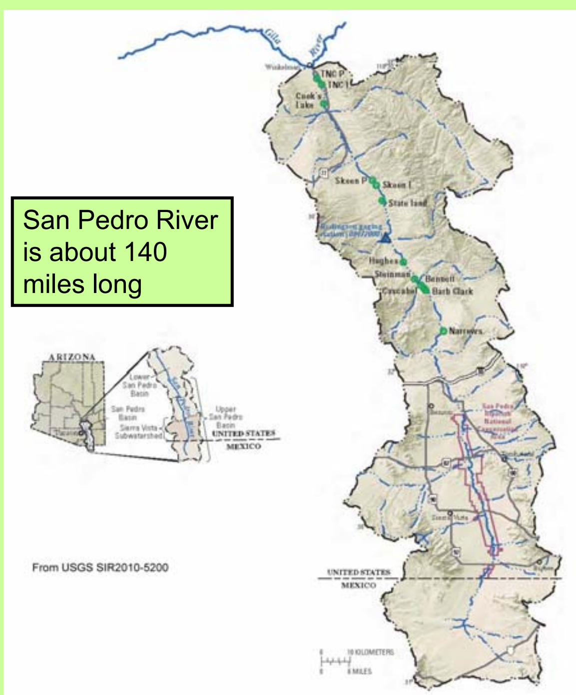
NAVIGABILITY ALONG THE NATURAL CHANNEL OF THE SAN PEDRO RIVER, AZ

From Mexico to mouth at the
Gila River at Winkleman, AZ

ANSAC

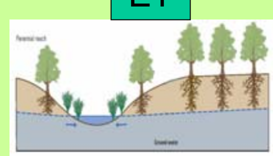
By Win Hjalmarson, PE
May 2013
for
ACLPI



San Pedro River is about 140 miles long

SAN PEDRO RIVER WATERSHED

ET



Was the San Pedro River susceptible to navigation in its natural and ordinary condition at statehood using the Federal Standard?

The standard is:

(1) navigability or non-navigability of the San Pedro River in its "ordinary and natural condition" prior to the State of Arizona's admission to the United States on February 14, 1912, consistent with the Arizona Court of Appeals decision in *State v. Arizona Navigable Stream Adjudication Comm'n,* 224 Ariz. 230, 229 P.3d 242 (App. 2010); and

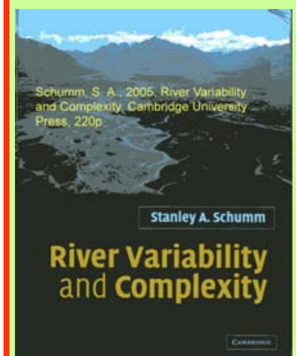
(2) segmentation of the San Pedro River consistent with the United States Supreme Court's decision in *PPL Montana, LLC v. Montana*, 556 U.S. ___, 132 S.Ct. 1215 (2012).

This analysis was prepared at the request of **Joy Herr-Cardillo**, staff attorney, with Arizona Center for Law in the Public Interest. It is a contribution from Win Hjalmarson, PE.

Win is a retired river engineer of the USGS, WRD. Win has 51 years experience with rivers in the southwest US.

As an independent consulting river engineer, Win had the privilege of serving with Stan Schumm for two years on the National Research Council committee studying Alluvial Fan flooding.

This analysis uses data and information of the USGS and applies hydrologic, hydraulic and morphologic methods given in several scientific reports including River Variability and Complexity by Stan Schumm that is shown to the right..



This analysis of navigability uses the present (2013) Federal standard, as interpreted by The Arizona Court of Appeals, of ordinary and natural with potential river segmentation as required by the United States Supreme Court. A previous report—Arizona Stream Navigability Study for the San Pedro River: Gila River Confluence to the Mexican Border" prepared by CH2MHill, revised by JE Fuller/Hydrology & Geomorphology, Inc. June 1997 and January 2004 ("State Report")—that was prepared using a much different interpretation of ordinary and natural has useful information for this analysis.

However, much of the State Report doesn't really lend itself for the present analysis.

River systems like the San Pedro change with time and in space under natural conditions. Human activities like overgrazing, mining, ground water withdrawal and diversion of river flow for irrigation impact river behavior and valley-fill sedimentation. The available information in the State Report tells a story of significant change to the riparian environment and much of the change probably resulted from human activity going back 300 years or more—even to 1697. Understanding the change is important but it doesn't define predevelopment conditions.

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The way we interpret historical accounts of rivers like the San Pedro is important to avoid bias. For example, historical descriptions of the San Pedro River (Chapter 3, History of the San Pedro River: Fuller pp 3-1 to 3-27) depict a wide range of flow conditions. There are accounts of plenty of flow in the river, a few of accounts of no flow, and also several accounts of irrigation ditches. When the hydrology of the San Pedro Valley is considered, the group of varied historic accounts suggest (1) the base flow was diverted to irrigate farmland, (2) ground water was used for mining before it reached the river, and (3) there was arroyo cutting.

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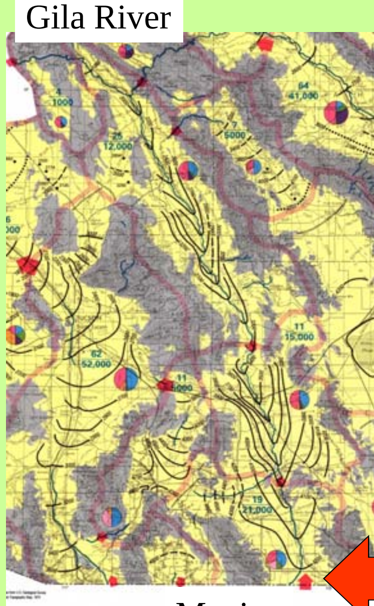
Even in 1697 the San Pedro Valley was "crisscrossed by irrigation ditches, and had irrigated fields in which cotton, squash, watermelon, beans and corn were growing." (Fuller p. 3-13)

So it's important to (1) consider all historical accounts as a group and (2) understand the hydrologic setting when considering historic accounts.

The USGS has defined the San Pedro River as perennial from the Mexican border to the mouth. (USGS HA 664)

There was a narrow riparian corridor sustained by ground water discharge.



Thus, generally accepted hydrologic and geomorphology principles and published data are used for this assessment of navigability for the natural and ordinary condition.

To determine the natural condition of the river, it is necessary to consider the river before it was depleted by all of the diversions.

This analysis is about fundamental hydrologic/morphologic principles keeping in mind the variability and complexity of rivers like the San Pedro. The goal is for an accurate analysis of the San Pedro River's natural condition that recognizes that fine precision is unlikely.

Photo taken July 2008 by Charleston Road Bridge by Marie Goddwin.
Used with permission.

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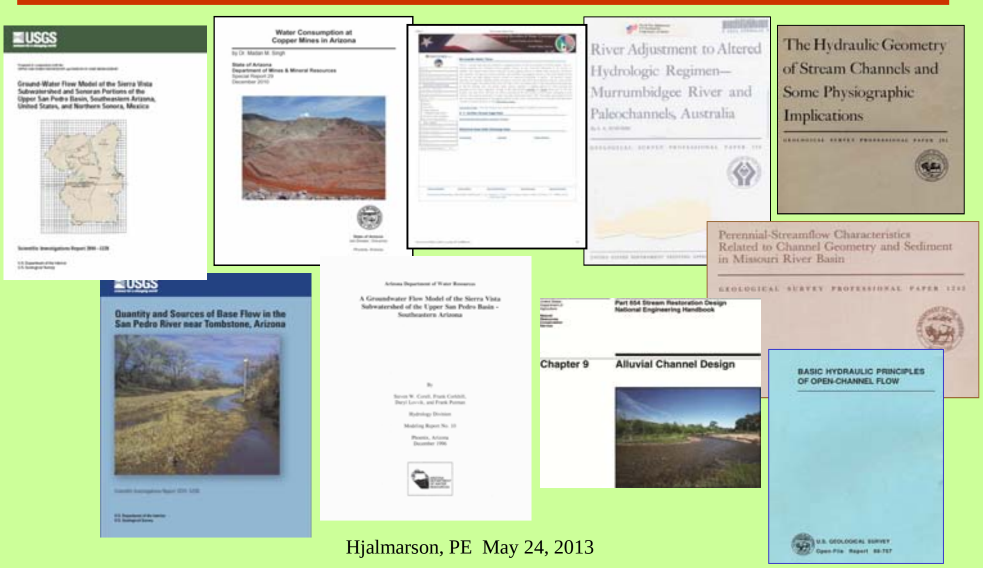
This analysis is based on information from many references including those shown below.



Hjalmarson, PE May 24, 2013

OUTLINE OF TALK

- NATURAL CONDITIONS AND EFFECTS OF HUMANS
- BASIC HYDROLOGY & IMPORTANT TERMS
- HYDROLOGY OF THE SAN PEDRO
- HYDRAULICS & MORPHOLOGY
- NAVIGABILITY

Natural Conditions and Effects of Humans

San Pedro River has an alluvial channel with some restriction by bedrock in a few areas. The many irrigation diversions, stock ponds and depletion of stream flow by groundwater withdrawal has caused an imbalance in the natural hydrology and morphology.

Hydrologic Evolution of The San Pedro River -Present and Emergent Conservation Issues, Ben Lomeli, Hydrologist, US BLM, Gila District,

A predevelopment steady-state or normal period is difficult to define in the Upper San Pedro Basin partly because of documented stream-channel incision, observed variations in stream baseflow, estimated variations in evapo-transpiration rates, and the uncertain transient effects of early withdrawals at mines for dewatering purposes. Stream-channel incision prior to 1900 and subsequent widening of the stream channel through the mid-1950s (Hereford, 1993) likely induced ground-water level decline and increased rates of base flow discharge from the ground-water system for an undetermined period.

Modified from: Pool, D.R., and Dickinson, J.E., 2007, Ground-water flow model of the Sierra Vista Subwatershed and Sonoran portions of the Upper San Pedro Basin, southeastern Arizona, United States, and northern Sonora, Mexico: USGS SIR 2006-5228, 48 p.

Irrigation diversions can substantially deplete the River's flow and thereby influence all downstream accounts of the river condition.

Accounts of irrigation diversion along San Pedro River
(Chapter 3, Fuller, 2004).

1697	Fr. Kino found ten occupied rancherias. All of them practiced irrigation and raised corn, beans, cotton, and squash (Hastings and Turner 1965:26).
1760's	Euroamericans and peaceful Indians from Tucson continued to farm the San Pedro River, though, with protection from the troops of the Presidio.
1800's	During the Spanish and Mexican Periods, "Tucson settlers planted and harvested crops on the San Pedro River at Tres Alamos"."Peaceful Apaches, protected by fifteen or more soldiers" from the Tucson Presidio, farmed the San Pedro floodplain at Tres Alamos, and supplied the Tucson Persidio with farm products (Officer 1987:89).
1830's	People from Tucson farming Tres Alamos, guarded by troops from Tucson Presidio (Officer 1987:148)
Civil War	Joe Felmer's, Israel's, and Kennedy's farms on the San Pedro River supplied the fort (Camp Grant) (Hadley et. al., 1991 :2 17-218).
1868	Irrigation in use on the river (Farish 1915:207).
1877	Hodge (1877:47) wrote that the San Pedro Valley contained 50,000 acres "of good farming land, most of which can be successfully cultivated. At Tres Alamos, in this valley, are some well cultivated farms and one choice dairy farm, that of H.C. Hooker, Esq." GLO maps dated to 1873, 1878, 1880, 1882, 1901 , 1902, and 1903 show acequias and fields along the river in virtually every township.

The difficulty of accurately assessing the post-development impact of Irrigation diversions on base flow of the San Pedro River is exemplified by the following:

"In 1889, 10 canals were used to divert irrigation water from the San Pedro River and by 1899, 41 canals were used to divert water from the river (Newell. 1901. p. 352-354). The St. David ditch has been diverting water for irrigation since 1881 and the Pomerene Canal has been in use since 1912. In 1939, 4000 acres were being irrigated with surface water from diversions. 2,300 acres of those were served by the St. David and Pomerene Irrigation Districts. In 1968 the St. David and Pomerene Irrigation Districts diverted 6,000 acre-feet of water from the San Pedro River for use on 2,400 acres of farmland."*

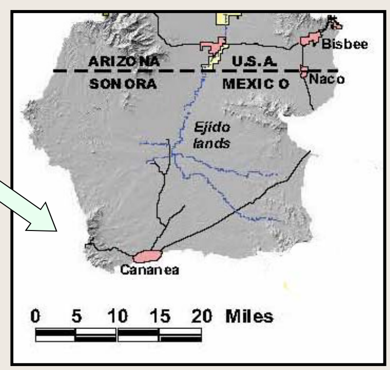
*Roeske, R.H. and W.L. Werrell *1971 Hydrologic Conditions in the San Pedro Valley, Arizona.* U.S. Geological Survey and Arizona Water Commission Bulletin 4, Phoenix, Arizona: Arizona Water Commission, 76 p.

Mining

According to Fuller (2004, Chapter 3) “Mining at the Mammoth Mine and San Manuel began in 1881. San Manuel mine used well water for Milling.” According to Tellman and others (1997), for some time the mine at San Manuel used approximately 22,000 ac-ft annually. This amount of water use was approximately 20% of the pre-development runoff from the San Pedro River watershed.

Mining and farming in Mexico

The first non-native inhabitants of the land where Cananea, Sonora is now located arrived in 1760. Jesuit priests discovered and extracted gold and silver mines.



Operations in the huge open-pit mine began in the late 1800s. Large quantities of water were used by the mine that will be discussed later.

Possible factors that caused the post-development decreasing trends in streamflow of the San Pedro River include fluctuations in precipitation and air temperature, changes in watershed characteristics, human activities, or changes in seasonal distribution of bank storage. A study by Thomas and Pool (2006) found that the variation in streamflow was caused by fluctuations in precipitation. Thus, the remaining variation or trend in streamflow was caused by factors other than precipitation.

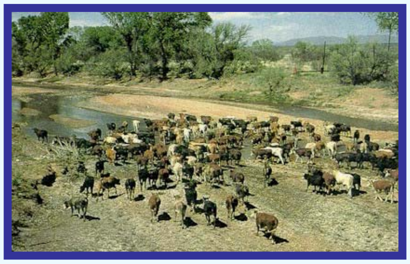
Thomas, B.E., Pool, D.R., 2006, Trends in Streamflow of the San Pedro River, Southeastern Arizona, and Regional Trends in Precipitation and Streamflow in Southeastern Arizona and Southwestern New Mexico: U.S. Geological Survey Professional Paper 1712, 79 p.

Cattle

From about 1750 to the mid 1800s, before Anglo-American activities, there were large livestock herds in the valley and along the river. According to the US Bureau of Land Management (San Pedro RNCA Cultural Resources) over 60,000 cattle of Mexican settlers reportedly were roaming, wild or otherwise, from 1820-1850. Because cattle typically concentrate within 3 miles of natural waters such as along the San Pedro River, there must have been considerable degradation of natural riparian environment as cattle trampled channel banks.

Cattle

Speaking of a large number of cattle that undoubtedly affected the geometry of the river channel by grazing (destroying grassland) and by trampling the river banks. Cattle can drink a lot of water--on the order of 15-25 gallons per hot summer day. If there were 60,000 cows, as has been reported, the cattle could consume nearly 2 cfs.



ARIZONA'S CHANGING RIVERS:

Cattle

"In the early 1800s the Mexican government established land grants for ranching in the upper basin. These ranches were eventually abandoned due to Apache deprivations, but large feral herds remained behind." (Stromberg and Tellman, 2009).

"European ranchers brought in large herds to the upper and lower basins in the late 1800s."

Stromberg, J. C. and Tellman, B., 2009, ECOLOGY AND CONSERVATION OF THE SAN PEDRO RIVER: The University of Arizona Press Tucson, p. 217-267.

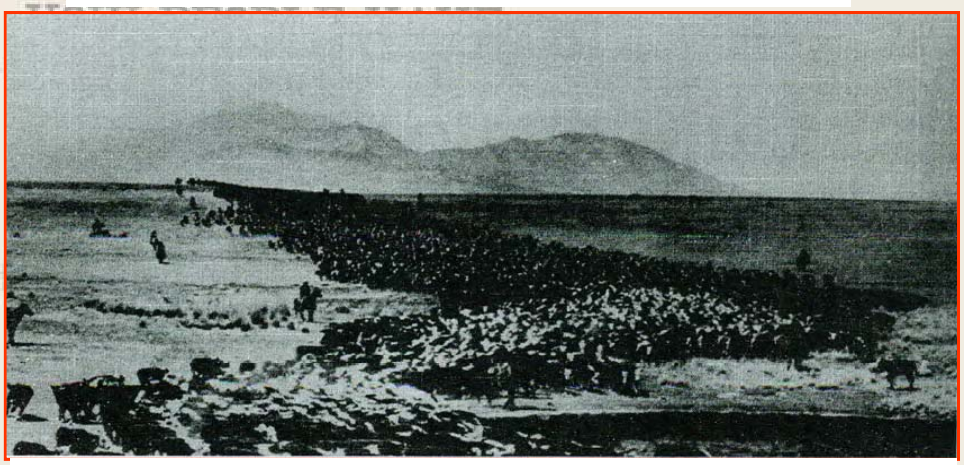
Richard Yarde
Mary G. Wallace

Water Resources Research Center
College of Agriculture
The University of Arizona
March 1997

ARIZONA'S

Cattle

Cattle drive north from Mexico in the vicinity of Hereford (1900-1910).



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Richard Yarde
Mary G. Wallace

College of Agriculture
The University of Arizona
March 1997

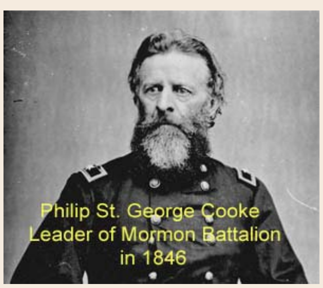
Cattle

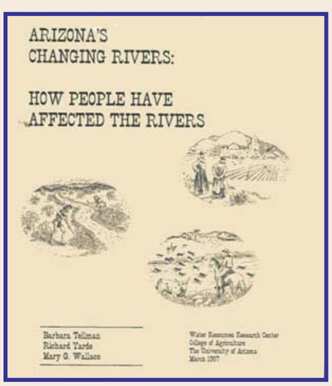
Cattle grazing in the San Pedro on the Boquillas Ranch (20th century) (Stromberg and Tellman, 2009).

Cattle

With severe overgrazing, cienegas and their supporting environments in the San Pedro were destructively trampled, and a well-documented cycle of arroyo cutting began, destroying these aquatic and semi aquatic habitats.

Fish and cattle





Cooke described the San Pedro as a marshy beautiful little river with an abundance of fish with "salmon trout" that by some accounts grew up to 3 ft. long. Others have described the abundance of large fish that is consistent with a perennial river.

"Cooke feared attacks by cattle even more than by Apaches."

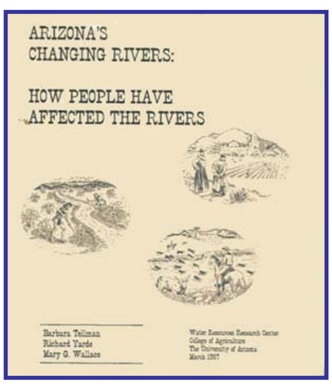
Tellman, p. 29-30

Turned west near Benson

Reached San Pedro at Mexico

Acting Secretary of the Interior, 1975, MORMON BATIALION TRAIL, House Document No. 94-258

Beaver



Tellman, p. 30

The San Pedro was called “Beaver River” by the Patties who trapped the river in 1826.

Pattie described the river: “Its banks are still plentifully timbered with cottonwood and willow.”

“The bottoms on each side afford a fine soil for cultivation.”

ARIZONA'S CHANGING RIVERS:

HOW PEOPLE HAVE AFFECTED THE RIVERS

Sediment

It's common knowledge that activities of Anglo settlers, since about the mid to late 1800s has caused an imbalance of water and sediment discharge and has changed many Arizona rivers.

See, for example, Barbara Tellman, Richard Yarde & Mary G. Wallace, Arizona's Changing Rivers: How People Have Affected the Rivers (Univ. of Ariz. 1997).

Barbara Tellman
Richard Yarde
Mary G. Wallace

General

In regard to navigability along the San Pedro River, it's uncertain precisely when anthropogenic effects became significant. The watershed is rich in history and it's clear the Spanish and Mexican settlers affected the runoff and channel morphology. More significant impacts occurred when many Anglos arrived during the late 1800s. Fortunately, it's not necessary to know precisely when the effects of man were insignificant.

Large cattle herds and the numerous stock tanks and diversions for mining, irrigation, domestic use, etc. have to some degree impacted the stream flow and morphology of the San Pedro River for at least 300 years.

Thus, recent and historic accounts of *natural and ordinary* runoff and morphology during this period may be unreliable.

Its important to consider the hydrologic setting.

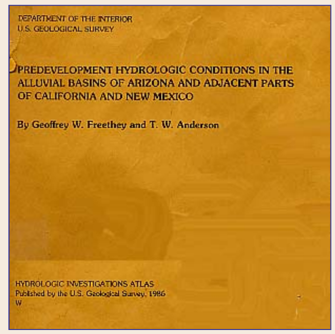
Because of the complexity of both the natural conditions and man-induced instability, a relative simple method based largely in information in two USGS reports is used to assess the hydrology. Fortunately, the use of these reports does not require precise knowledge when anthropogenic effects were insignificant.

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.

William R. Krug, Warren A. Gebert, and David 1. Graczyk, 1987, PREPARATION OF AVERAGE ANNUAL RUNOFF MAP OF THE UNITED STATES, USGS Open File Report 87-535.

According to ADWR: On p. 6 of Subflow Technical Report San Pedro Watershed, March 29, 2002--- U. S. Geological Survey Hydrologic Investigations Atlas HA-664, Predevelopment hydrologic conditions in the alluvial basins of Arizona and adjacent parts of California and New Mexico, should be used to **"identify predevelopment perennial streams."**

This Atlas shows the San Pedro River was perennial from the Mexican border to the mouth at the Gila River. Pre-development water level contours are also shown for the San Pedro River.



BASIC HYDROLOGY & TERMS

Background Info

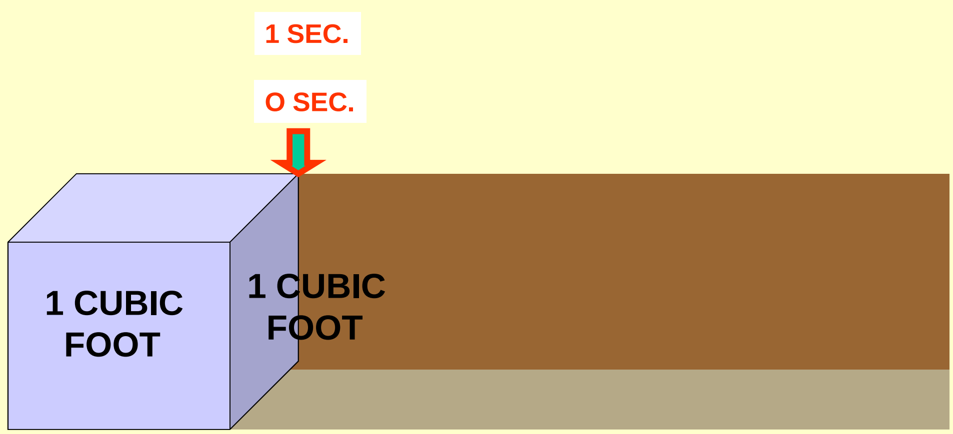
Water Equivalents

1 Cubic Foot = 7.48 Gallons

1 Acre-Foot (AF) = 43,560 Cubic Feet
= 325,851 Gallons

What is a cfs?

Background Info



1 ft^3 moved by in 1 second

1 ft^3/s = 1 cfs

Background Info

What does 50 cfs look like?

Verde River near
Camp Verde

APPROXIMATE

Average width = 80 ft
Average depth = 1.3 ft
Average velocity = 0.48 ft/s

1 cfs= 448.83 Gallons per Minute (gpm)

1 cfs for 24 Hours = 1.9835 Acre-Feet
for 1 Year = 723.97 Acre-Feet

Background Info

Q is the rate of flow of water or the discharge of a canal, stream or river.

Background Info

RUNOFF

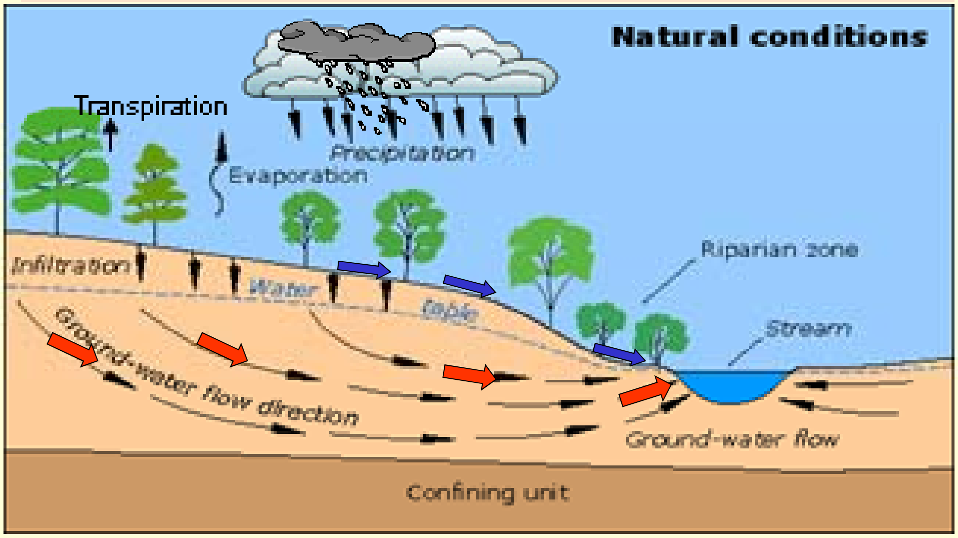
That part of the precipitation that naturally appears in surface streams.

It is the same as **stream flow** unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Runoff is Predevelopment stream flow.

Background Info

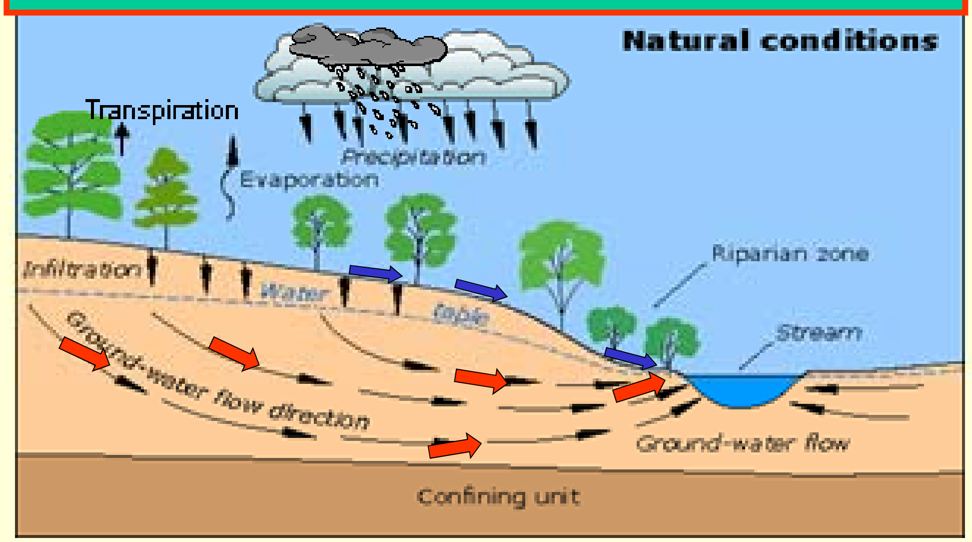
DIRECT AND BASE FLOW



Background Info

From USGS website

Average annual runoff includes both direct and base flow



From USGS website

Background Info

Streams and the relation to ground water

Gaining. A stream or reach of a stream that receives water from ground water.

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

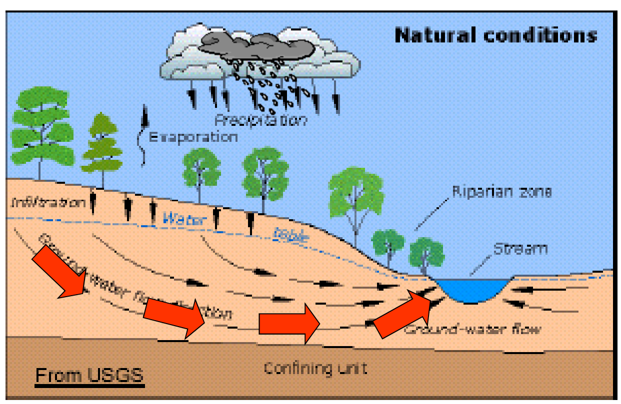
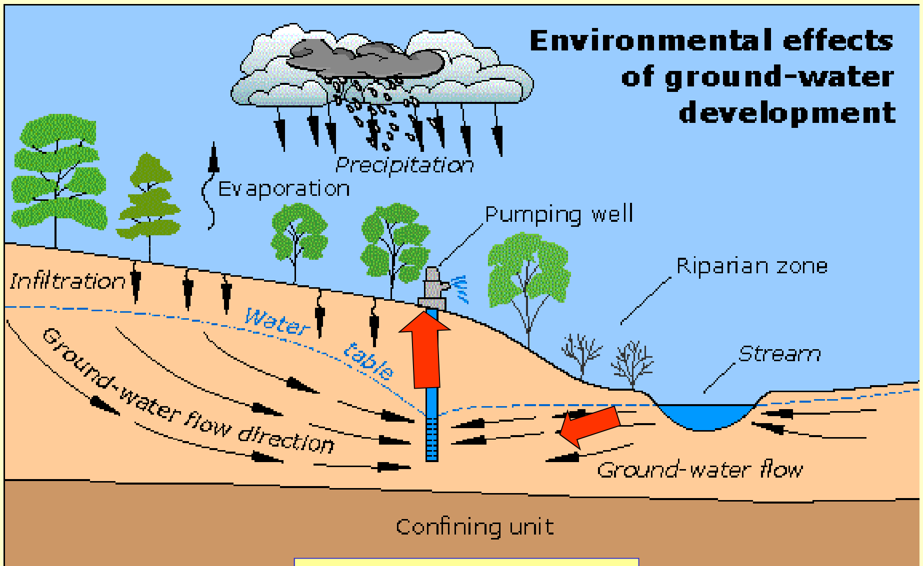


Figure 2.1 Sketch showing ground water under natural conditions.

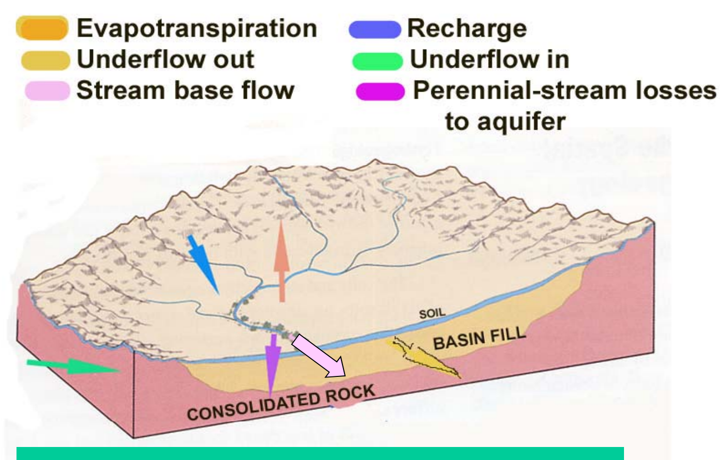
Gaining stream



Losing stream

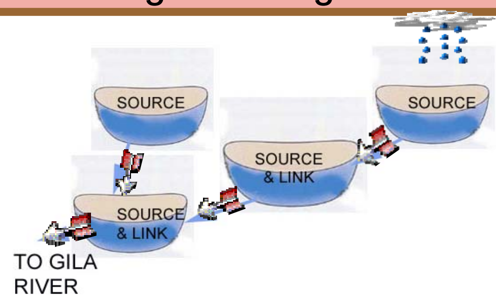
Background Info

PREDEVELOPMENT



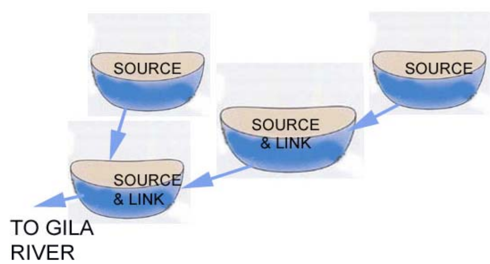
FLOW COMPONENTS
OF
ALLUVIAL BASINS

The San Pedro River was supplied by springs and floodplain and regional aquifers. Much of the regional aquifer recharge is along mountain fronts.



Conceptual Model of Alluvial Basin Flow System

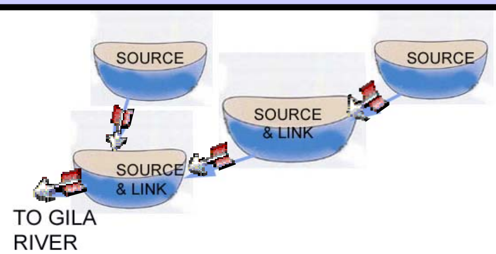
Much of the floodplain aquifer is recharged by runoff from summer storms.



Conceptual Model of Alluvial Basin Flow System

PRE-DEVELOPMENT

Alluvial basins typically were hydraulically connected to the river by upward leakage through the floodplain aquifer. The floodplain aquifer consists of river sediment deposited above the valley fill.



Conceptual Model of Alluvial Basin Flow System

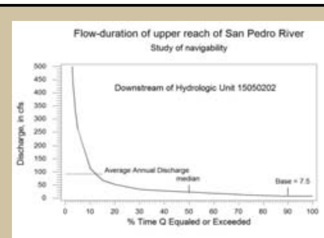
HYDROLOGY

Estimating the amount and temporal distribution of the natural and ordinary runoff of the San Pedro River.

Base runoff in the upper San Pedro River was derived from groundwater discharge to the river from the regional and alluvial aquifer. The regional aquifer is defined as having recharge zones away from the river, primarily at mountain fronts and along ephemeral channels. The alluvial aquifer was recharged from the regional aquifer and from storm flow (direct runoff). Based on recent environmental isotope data, the composition of base flow was mostly from regional groundwater and also from summer storm runoff that may have been stored as alluvial groundwater for several years.

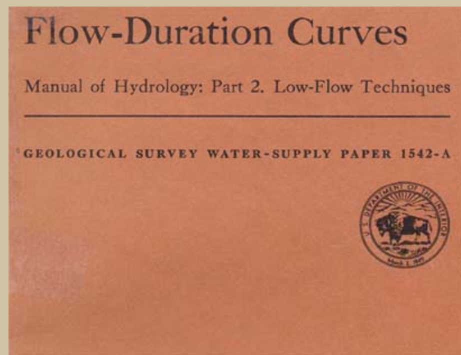
Modified from: Kennedy, J.R., and Gungle, Bruce, 2010, Quantity and Sources of Base Flow in the San Pedro River near Tombstone, Arizona: U.S. Geological Survey Scientific Investigations Report 2010–5200, 43 p.

A great way to display the natural and ordinary flow



The flow-duration curve is a cumulative frequency curve that shows the percent of time specified discharges were equaled or exceeded during a given period.

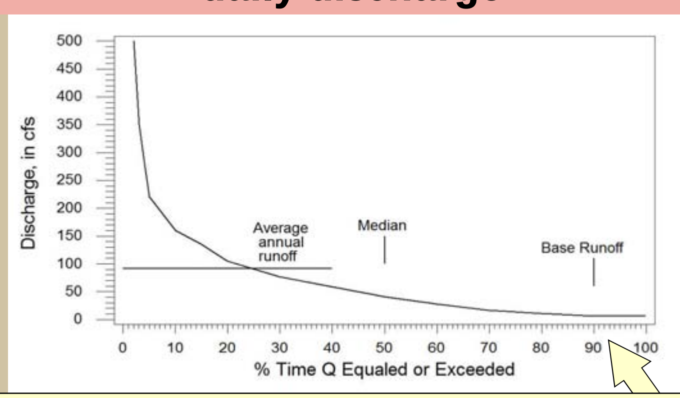
Background Info



Technique used by engineers for more than 100 years to show the amount and distribution of daily discharge throughout a year.

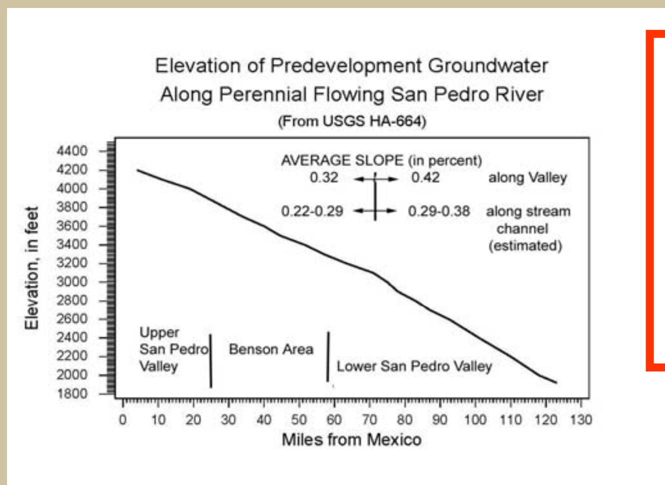
Background Info

Flow-duration relation for average daily discharge



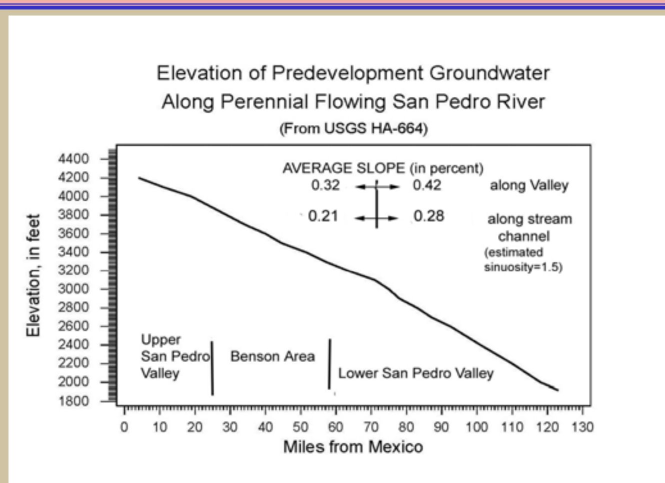
90% of the time during a typical year the discharge of 7 cfs was equaled or exceeded

Before we continue with the hydrology, let's look at profile of the pre-development water along the San Pedro River.

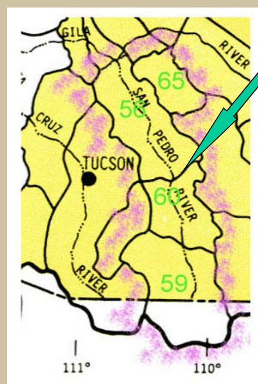


USGS Atlas HA-664 shows the San Pedro River was perennial from the Mexican border to the mouth at the Gila River. Pre-development water level contours are also shown for the San Pedro River.

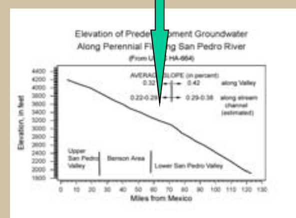
The break in slope near the downstream end of the Benson area where there are a few outcrops of bedrock (including the "narrows" area) suggests two reaches might be considered for this assessment of navigability

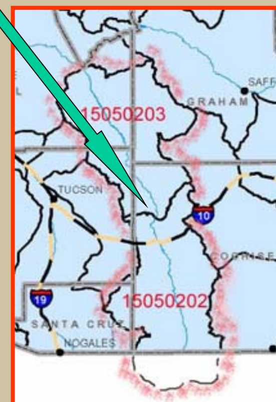


Also, the slope change corresponds to end points of watershed areas used in USGS reports of base runoff and average annual runoff.



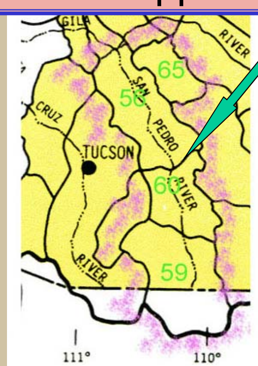
USGS HA-664



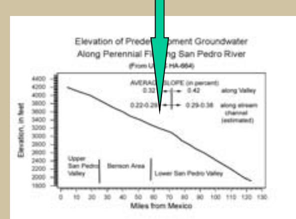


USGS Open File Report 87-535

Thus, the remainder of this analysis will address two segments: the areas above and below this location -- the Upper and Lower watershed or Upper and Lower San Pedro River.

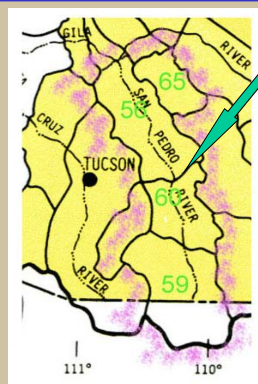


USGS HA-664

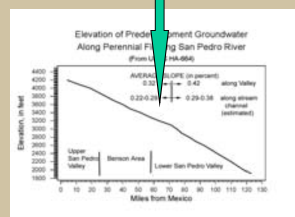


USGS Open File Report 87-535

The area of the Upper watershed is 2456 sq mi and includes 696 sq mi in Mexico. The total area of the watershed at the mouth of the San Pedro River (at the Gila River) is 4460 sq mi.



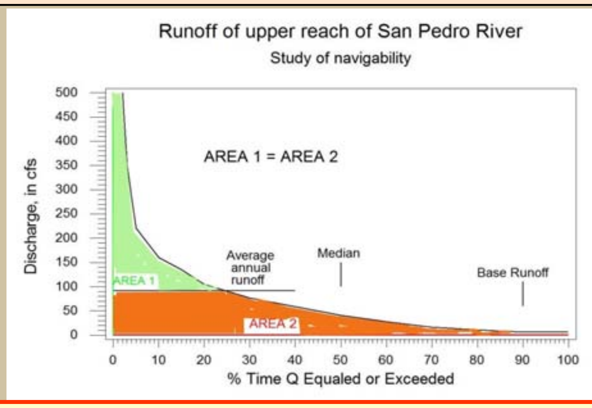
USGS HA-664



USGS Open File Report 87-535

Flow-duration relations of runoff are estimated for reliable assessment of navigability along the San Pedro River. The general shape of the relations is estimated using the flow-duration relation at the USGS stream flow gage near Tombstone. Because there are no large storage reservoirs in the watershed, the relation based on gauged flow reasonably represents direct runoff. With estimates of mean annual and base runoff, predevelopment cumulative frequency relations of daily flow are determined for the ends of the Upper and Lower reaches.

FLOW-DURATION RELATION FOR UPPER REACH



Defined using base runoff, the general shape for direct runoff and adjusting to satisfy the average annual runoff requirement shown above.

Base Runoff of San Pedro River

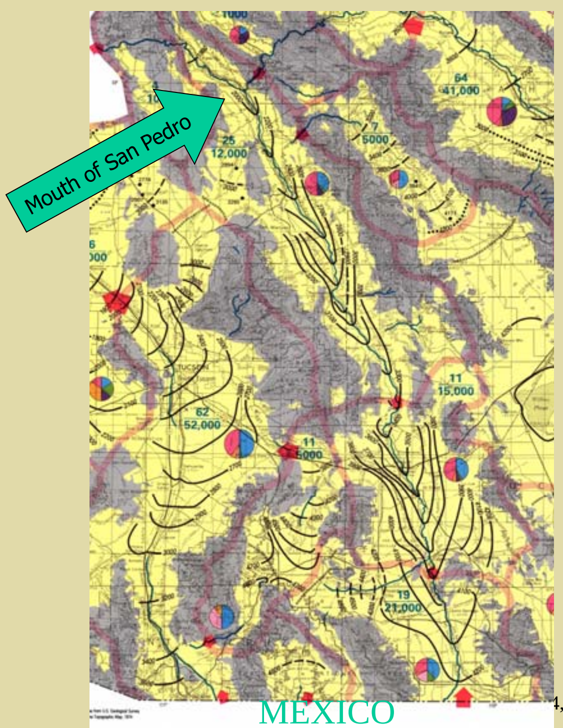
Base (Q_{90}) runoff defined using following reports.

Freethey, G. W. and Anderson, T. W., 1986, Pre-development 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.

Anderson, T.W., Freethey, G.W., and Tucci, P., 1992, Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406−B, 67 p.

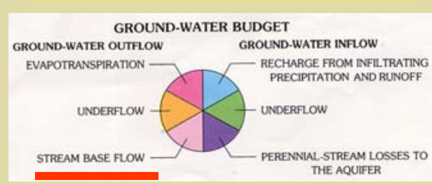
The aerial pattern of ground-water hydraulic heads of the San Pedro Valley shows considerable mountain front recharge all along the perennial San Pedro River. The V-shaped contours are an indication of substantial basin perimeter recharge and a high rate of ground-water discharge along the San Pedro River along the center of the valley*. See next slide.

*Anderson, Freethey, and Tucci, 1992.



San Pedro River (predevelopment)

Sheet 3 of USGS Hydrologic Investigations Atlas HA-664

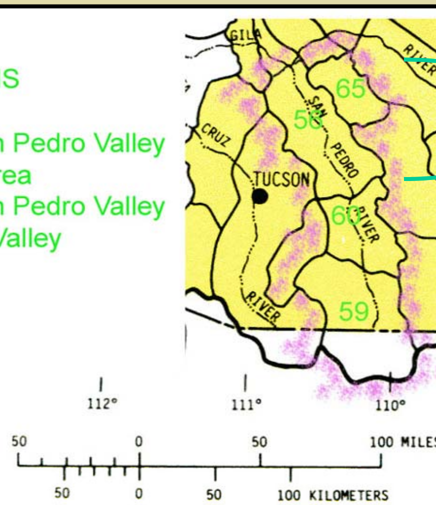


"In the upper San Pedro Valley (previous slide), mountain-front recharge is large compared to other inflow components and the water-level contours are nearly parallel to the mountain fronts. The central drainage (the San Pedro River) represents an almost continuous linear discharge. The San Pedro River is a gaining stream in places, and ground-water discharge occurs throughout the flood-plain area through transpiration by riparian vegetation and evaporation from surface water and soils where water level is shallow. The distance that ground water flows in this type of basin is short".

Anderson, T.W., Freethey, G.W., and Tucci, P., 1992, Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406−B, 67 p.

BASINS

59 Upper San Pedro Valley
60 Benson Area
56 Lower San Pedro Valley
65 Aravaipa Valley

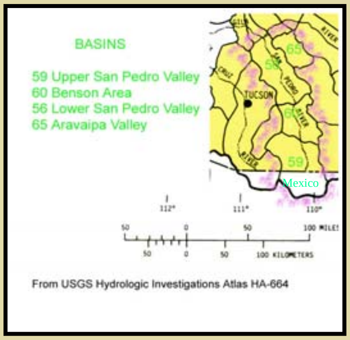


Lower Area

Upper Area

From USGS Hydrologic Investigations Atlas HA-664

Location along San Pedro River	Base Runoff (cfs)
Mexico	4 [1]
Basin 59	10 [2]
Upper reach	7.5
Lower reach (mouth)	4



From USGS Hydrologic Investigations Atlas HA-664

[1] Pool, D.R., and Dickinson, J.E., 2007, Ground-water flow model of the Sierra Vista Subwatershed and Sonoran portions of the Upper San Pedro Basin, southeastern Arizona, United States, and northern Sonora, Mexico: USGS SIR 2006-5228, 48 p. (And oral communication April, 2013)

[2] At Charleston gage--Amount used is lowest of 5 independent estimates as shown in following table.

Base flow estimates at Charleston and Tombstone gages (USGS SIR 2010-5200, Table 2)

Source	Last time period used in analysis	Method of estimating base flow	Charleston gage flow volume (acre-ft) Pre-development	Charleston gage flow volume (acre-ft) Last time period	Tombstone gage flow volume (acre-ft) Pre-development	Tombstone gage flow volume (acre-ft) Last time period
S.G. Brown and B.N. Aldridge (unpublished USGS administrative report, 1973)	1970	estimate of mountain front recharge and underflow	-	4,800	-	-
Freethey (1982)	1977	model	**7,000***	-	7,500	4,500
Vionnet and Maddock (1992)	1988	model	8,300	2,900	-	-
Corell and others (1996)	1985–1991	analysis of streamflow data	9,500	4,800	-	-
Corell and others (1996)	1990	model (final year)	-	-	9,500	5,700
Corell and others (1996)	1941–1990	model (total average)	-	-	9,500	6,290
Rojo and others (unpublished data, 1999)	1990	10-yr flow duration curves in combination with earlier models	-	-	9,500	7,400
Goode and Maddock (2000)	1997	model	9,600	6,400	-	-
Arizona Department of Water Resources (2005a, 2005b)	1997–2003	NA	-	-	-	3,250
USGS/Upper San Pedro Partnership (2005)	1967–1986; 1996–2002	7-day winter low flow and evapotranspiration	-	-	-	4,230
Thomas and Pool (2006)	1991–2002	3-day monthly low flows	7,900	4,300	-	-
Pool and Dickinson (2007)	pre-development	earlier estimates with recent evapotranspiration	-	-	8,500	-
Pool and Dickinson (2007)	03/2002–03/2003	model	-	-	9,150	2,800
Nathan Dieterich, written commun., 2009	1968–85	median total discharge	-	-	-	5,850
Current study (2010)	1968–1986	delta filter	-	-	-	5,830
	1997–2009	delta filter				2,880
	1968–1986 and 1996–2009	delta filter				4,890

* Amount used for this study of navigability (USGS HA 664, sheet 3)

In the late 1800s there was mining at Cananea and in September 1899 the Cananea Consolidated Copper Company was organized along with its parent, the Greene Consolidated Copper Company. Cananea became the leading mining center of Mexico. With 25,000 inhabitants, it was one of the biggest cities of Sonora, enjoyed one of the highest percentages of growth in Mexico.

(Gonzales, M. J., 1994, United States Copper Companies, the State, and Labour Conflict in Mexico, 1900-1910, *J. Lat. Am. Stud.* 26, Cambridge Press, 651-681.)

Estimated annual water use at Cananea Mine, Mexico
(excluding water use of the 25,000 inhabitants)

Year	Copper* (lbs/yr)	Water use (cfs)
1899-1902	32371026	3.84
1903	42310544	5.02
1904	55014339	6.53
1905	62839510	7.46
1906	54833559	6.51
1907	58180856	6.91
1908	18619609	2.21
1909	44547689	5.29
1910	45680145	5.42

Using average water use of 28 gal /lb copper produced at Arizona mines. From: Singh, M. M., 2010, Water Consumption at Copper Mines in Arizona: State of Arizona Department of Mines & Mineral Resources, Special Report 29, 16p.

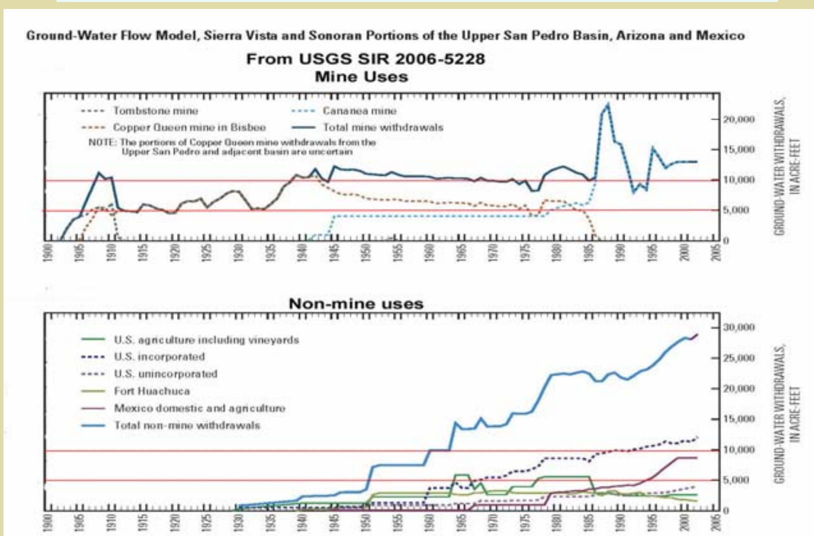
*Gonzales, M. J., 1994, United States Copper Companies, the State, and Labour Conflict in Mexico, 1900-1910, *J. Lat. Am. Stud.* 26, Cambridge Press, 651-681.

Its important to note that since the late 1800s, historic observations of river channel condition and base flow along the San Pedro in the U.S. probably are affected by water use in Mexico.

The water use figures in the previous slide do not include municipal use at Cananea and diversions for a few small farms along the streams in Mexico.

Although unknown, the data suggest that at times there may have been little base flow in the river because of withdrawals in Mexico.

Significant water use in the upper San Pedro



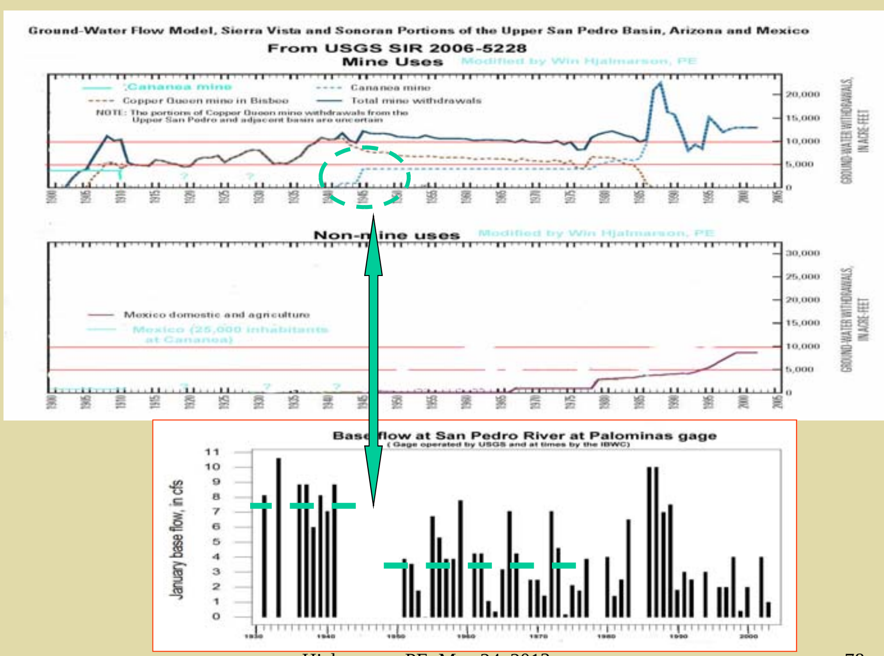
Base runoff at Mexican Border 5 of 6

Base flow at Palominas is compared with water use in Mexico on the following slide. Records for the Palominas gage are from the USGS and IBWC. There are no records for 1934, 1935, and 1940-1950.

The records suggest the base runoff at the Palominas gage may have been greater than 4 cfs used for this study. A predevelopment base flow of about 4.5 cfs was estimated by Corell and others (1996).

Corell, S.W., Putman, F., Lovvik, Daryl, and Corkhill, Frank, 1996, A groundwater flow model of the Upper San Pedro Basin, southeastern Arizona: Phoenix, Arizona Department of Water Resources Modeling Report no. 10, 85 p.

Base runoff at Mexican Border 6 of 6



Average Annual Runoff of San Pedro River

Estimate based on data in:

USGS Open File Report 87-535

PREPARATION OF AVERAGE ANNUAL RUNOFF MAP OF THE UNITED STATES, 1951-80

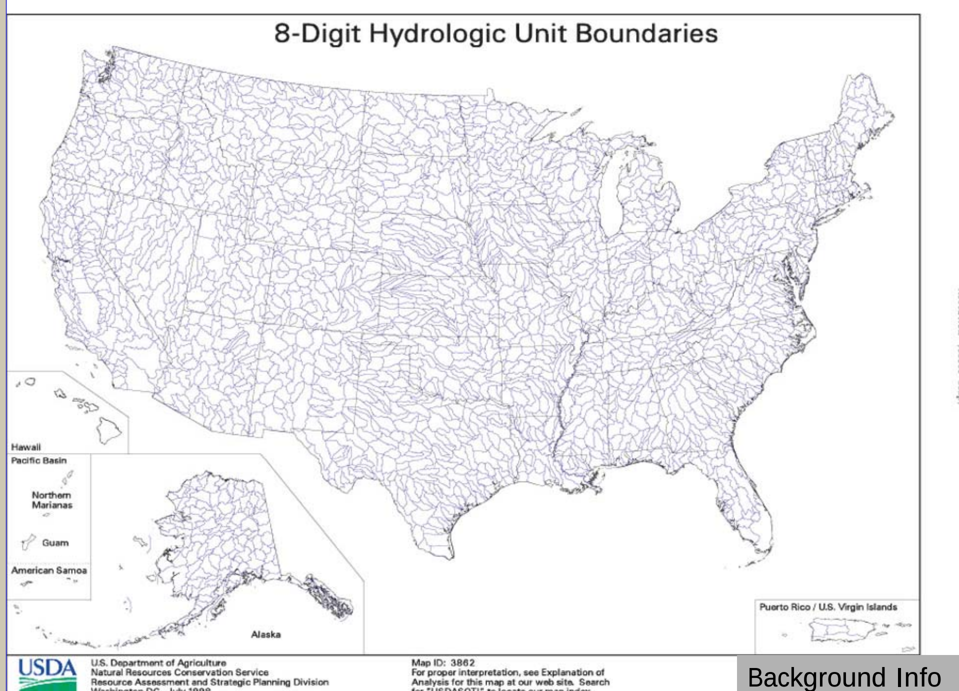
By William R. Krug, Warren A. Gebert, and David 1. Graczyk

RUNOFF

Runoff is Pre-development stream flow.

Background Info

Average annual runoff was computed or estimated by the USGS for each of the 2,148 hydrologic cataloging units in the United States and Puerto Rico, shown on the following slide.

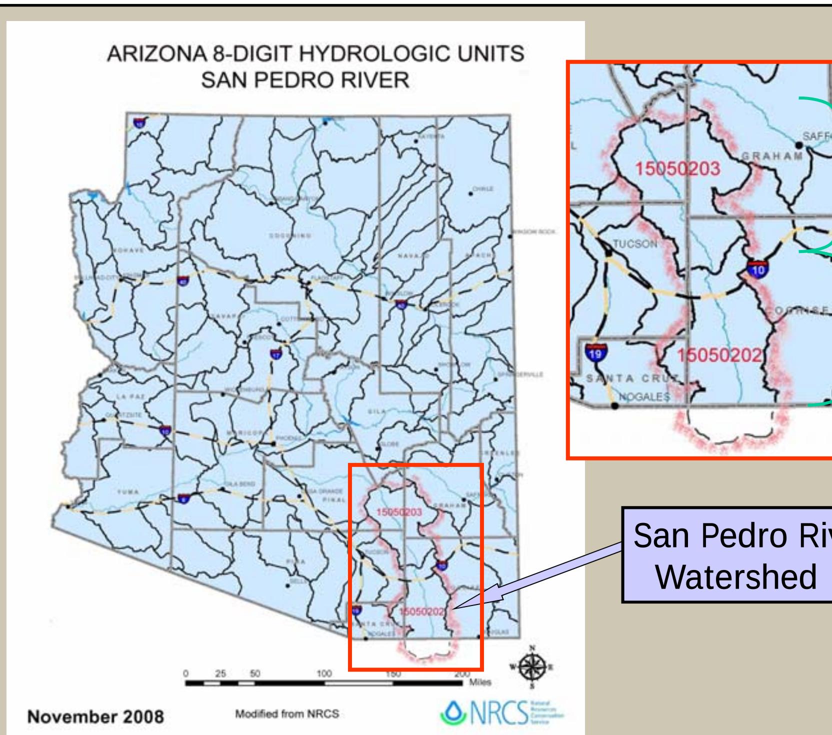


Background Info

The surface-water systems of the United States have been divided into successively smaller hydrologic units called regions, sub regions, accounting units, and cataloging units. A cataloging unit is a geographic area representing part or all of a surface-drainage basin, a combination of drainage basins, or a distinct hydrologic feature.

Background Info

These units for Arizona with highlighted San Pedro Watershed are shown on the next slide.



Lower Area

Upper Area

San Pedro River Watershed

For viewers unfamiliar with USGS records of stream flow, the USGS publishes Hydrologic Unit where each gage resides.

USGS Streamflow gages on San Pedro River

Station Name	No.	Area, mi^2
at Palominas	09470500	737
at Charleston	09471000	1234
at Fairbank	09471500	1672
at Tombstone	09471550	1740
near Benson	09471800	2490
near Redington	09472000	2927
at Redington Bridge	09472050	3096
near Mammoth	09472500	3583
below Aravaipa Ck	09473100	4343
near Winkelman	09473400	4430
at Winkelman	09473500	4453

15050202

15050203

Two adjustments were needed for the San Pedro River

First Adjustment

Because the analysis in USGS Open File Report 87-535 did not include the upper 696 sq. miles of the watershed in Mexico, the average annual runoff was determined as follows: The average annual direct runoff was computed for USGS gage 09470500 at Palominas located about 4 miles from the border and adjusting runoff using the ratio (696/737) of areas drained for the two sites. A base runoff of 4 cfs was added resulting is an annual runoff of 33 cfs.

Second Adjustment

(Slide 1 of 5)

An adjustment for loss to ET of runoff along the river associated with the combining of runoff from hydrologic units 15050202 and 15050203 was made. This loss is associated with the rising of water levels along the river and adjacent sediments. As water level rises the area of open water increases with more evaporation, plants transpire more water and there is more evaporation from bare ground. The rather steep groundwater gradient toward the river, on the order of 1% or more, associated with the V-shaped ground water contours all along the river (USGS HA 664) was considered when estimating this additional loss to ET.

(Slide 2 of 5)

Densely vegetated riparian land changed during the 19th-20th centuries. Total dense riparian land along the upper San Pedro River in the United States increased and the amount of mesquite land cover increased significantly.

Changes in extent of riparian vegetation suggest variations in rates of evapotranspiration. Estimates of changes in rates of riparian evapotranspiration, however, require information on changes in the extent and density of several vegetation types that use ground water from different depths and at different rates. Such information for pre-development is not available.

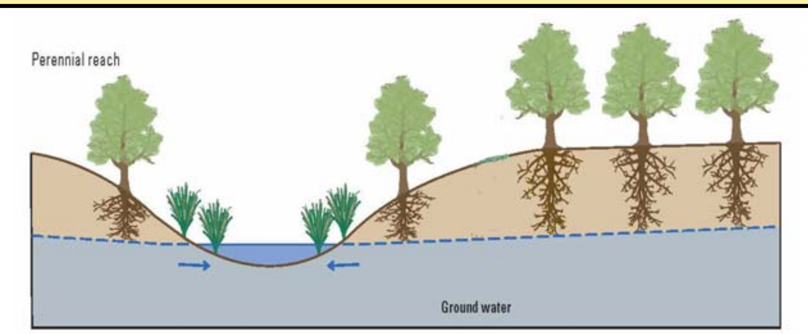
Modified from: Pool, D.R., and Dickinson, J.E., 2007, Ground-water flow model of the Sierra Vista Subwatershed and Sonoran portions of the Upper San Pedro Basin, southeastern Arizona, United States, and northern Sonora, Mexico: USGS SIR 2006-5228, 48 p.

(Slide 3 of 5)

An objective of USGS Open File Report 87-535 was to determine the "average runoff near its source, rather than the cumulative runoff after several sources have contributed runoff to large rivers" (Krug and others, 1987). Thus, it is necessary to account for additional losses to evapotranspiration (ET) of the runoff from the upper watershed (15050202) as it passes along the San Pedro River across the lower watershed (15050203). This additional estimated loss to ET from the water, bare earth and plants such as cottonwood, willow, mesquite, etc. along the river is 4,500 ac-ft.

(Slide 4 of 5)

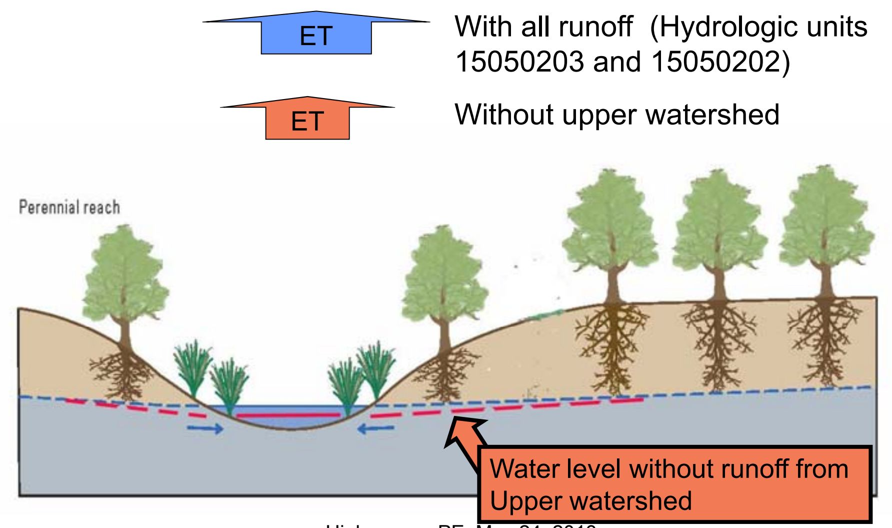
Schematic cross section of lower reach of San Pedro River (Predevelopment)



Modified from Figure 41 of: Leenhouts, J. M., Stromberg, J.C., and Scott, R.L., eds., 2006, Hydrologic requirements of and consumptive ground-water use by riparian vegetation along the San Pedro River, Arizona: U.S. Geological Survey Scientific Investigations Report 2005–5163, 154 p.

(Slide 5 of 5)

General effect of "added" runoff from upper watershed on ET (Explanation of computational adjustment)



Adjusted Average Annual Runoff (direct + base runoff) along the San Pedro River

Downstream end of area / unit shown below	Average annual runoff (cfs)	Area drained (sq. miles)
Mexico	33	696
15050202 (UPPER)	92	2476
15050203 (LOWER)	113	4456

Modified From: USGS Open File Report 87-535, PREPARATION OF AVERAGE ANNUAL RUNOFF MAP OF THE UNITED STATES, 1951-80, By William R. Krug, Warren A. Gebert, and David 1. Graczyk

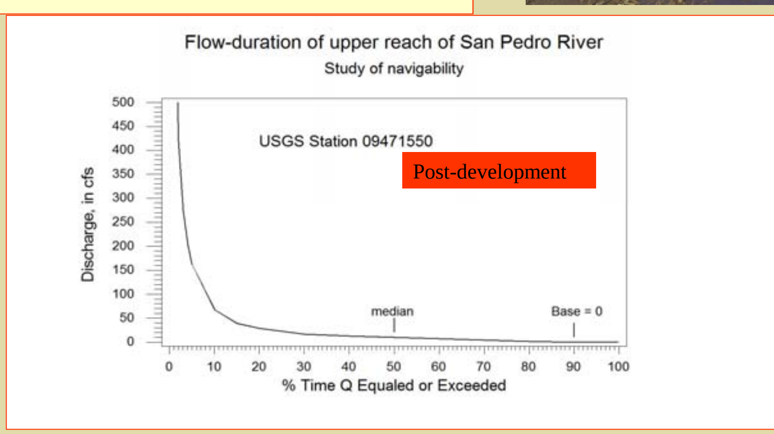
It's interesting that the unit runoff for the San Pedro is considerably less than the unit runoff for the Gila River below the confluence with the Salt River.

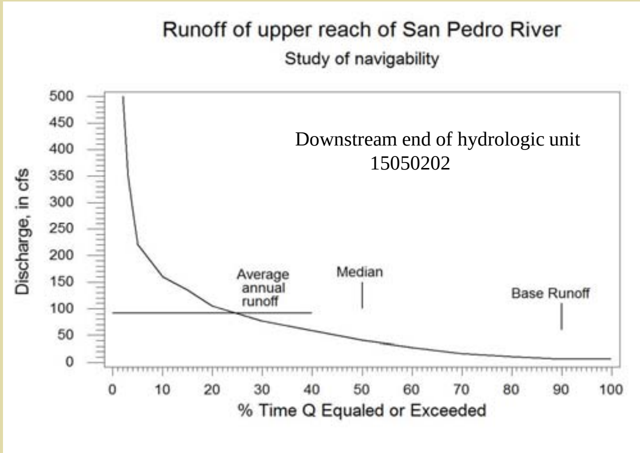
Site	Area (mi^2)	Runoff (cfs)	Unit Runoff (cfs/mi^2)
San Pedro at mouth	4456	113	0.0254
Gila below Salt **	43000	2330	0.0542

** Thomsen, B.W., and Eychaner, J.H., 1991, Predevelopment hydrology of the Gila River Indian Reservation, south-central Arizona: U.S. Geological Survey Water-Resources Investigations Report 89-4174, 44 p., 2 sheets.

**Thomsen, B.W., and Porcello, J.J., 1991, Predevelopment hydrology of the Salt River Indian Reservation, East Salt River Valley, Arizona: U.S. Geological Survey Water-Resources Investigations Report 91-4132, 37 p.

The typical duration of daily runoff is determined at the end points of the Upper and Lower reaches using base runoff, average annual runoff and the relation shown below.

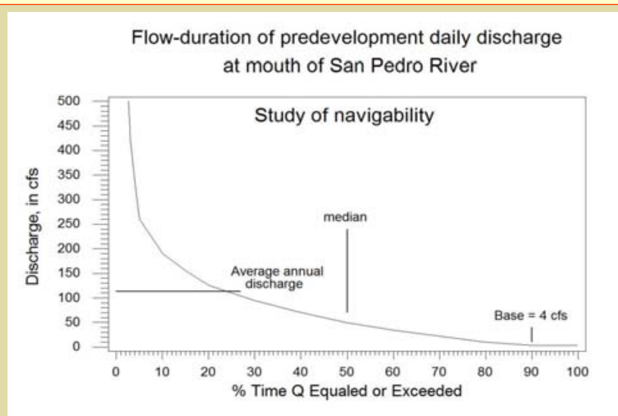




Average Annual Runoff was adjusted for unequal drainage areas and base runoff.

Average annual runoff = 92 cfs at the end of HU 15050202 (shown previously based on USGS Open File Report 87-535).

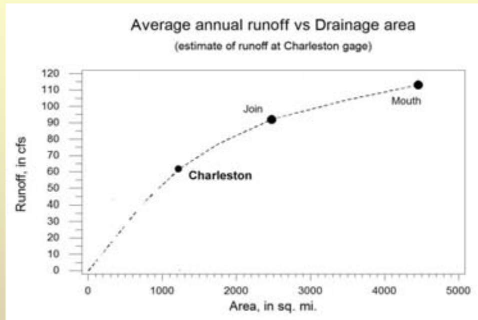
A similar procedure was used at the lower end of the lower reach using the base runoff of 4 cfs.



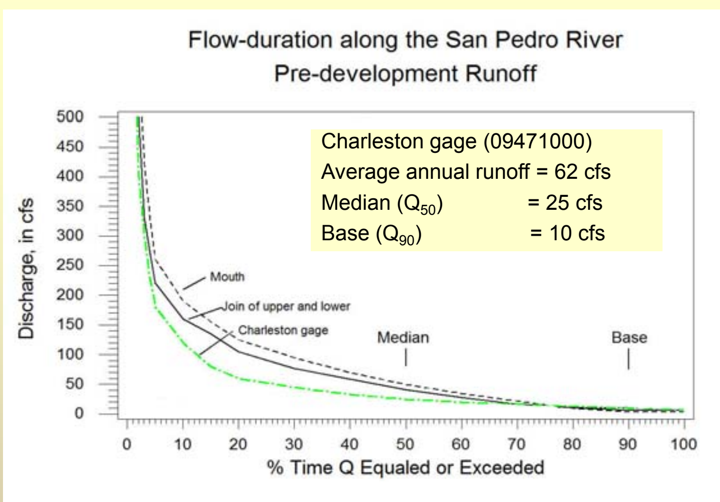
Computed average annual runoff = 113 cfs

It's interesting to examine the average annual runoff (predevelopment) at the USGS Charleston gage (09471000)

The average annual runoff corresponding to the drainage area of 1,234 mi² is about 62 cfs using the relation to the right.

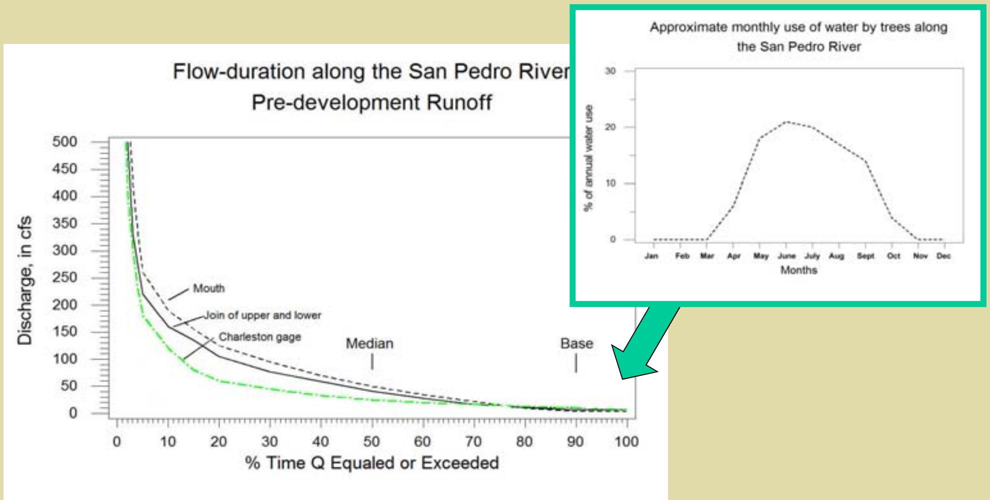


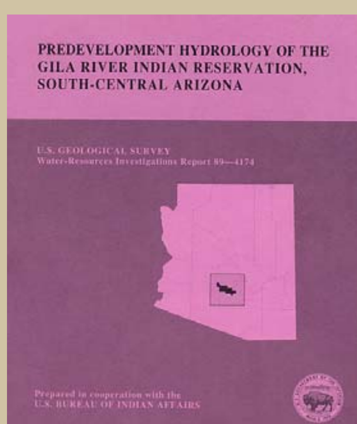
The runoff is 10 cfs greater than the annual mean streamflow of 52.1 cfs for water years 1904-2012



The latest USGS statistics for 09471000 show Q_{90} =3.2 cfs and there have been periods of no flow. This suggests the base flow is at least 7 to 10 cfs less than the base runoff.

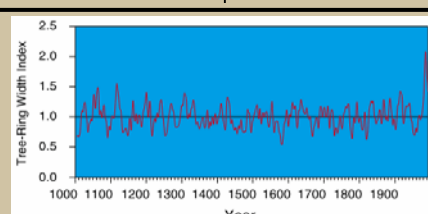
Generally, smaller amounts of base flow are for non-monsoon summer days because of high evapotranspiration along the riparian area.





According to Thomsen and Eychaner (1991), "Tree-ring data do not indicate a significant change in precipitation from 1602 to 1970."

DENDROCHRONOLOGY
Example

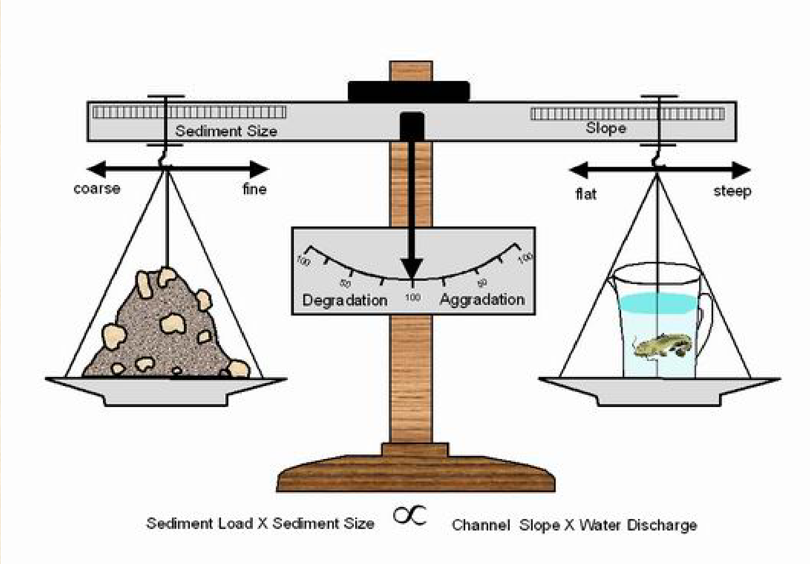


The rather recent post-development trend of precipitation (Thomas and Pool, 2006) mentioned previously complicated this analysis but had little effect on the hydrology used for this study of navigability.

This completes the hydrology

The natural San Pedro River was a single meandering channel.

A SIMPLE WAY OF UNDERSTANDING ALLUVIAL CHANNELS



From USGS website

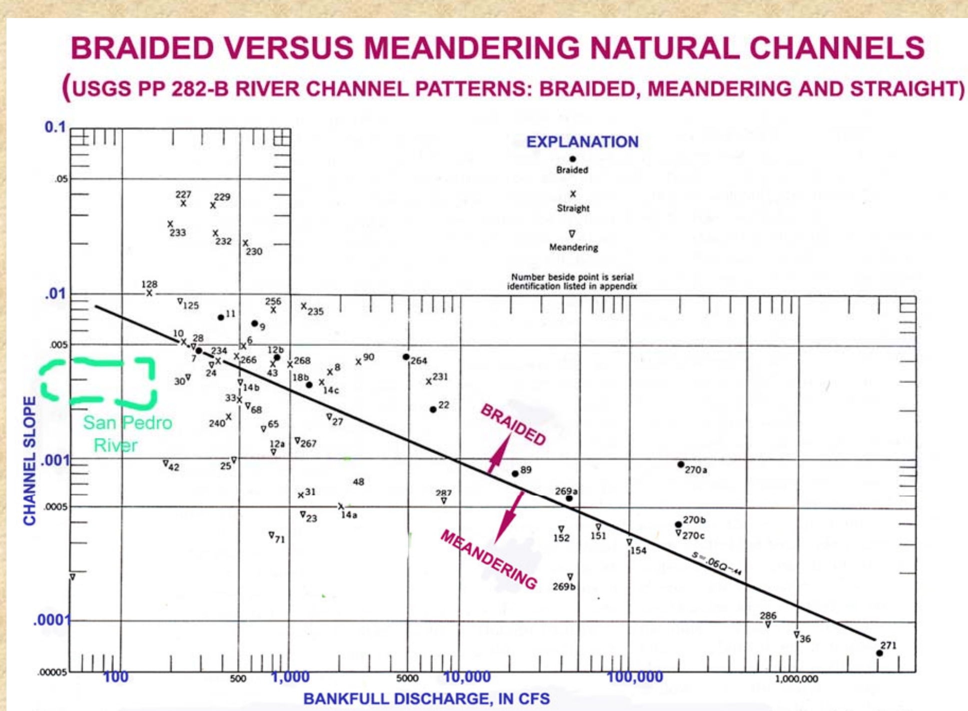
The morphology was self-formed with few hard rock controls that appear have had little effect on channel shape. The natural channel was formed in material that was entrained, transported, and deposited by the river and tributary streams.

Leopold-Wolman Association

Association distinguishing between meanders and braided channels on the basis of channel slope and discharge (Leopold and Wolman, 1957)

Relation between bank full discharge and channel slope shows the San Pedro River was meandering.
See following figure.

Leopold, L.B., Wolman, M.G., and Miller, J.P, 1964, Fluvial processes in geomorphology: New York, Dover Books on Earth Sciences, 503 p.



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 wide valley and somewhat marshy environment. Marshy cienegas reportedly were along the river from Mexico to the Mouth at the Gila River*. 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.

* Fogg, J., Elmore, J., Gonzale, M., 2012, RIPARIAN CONDITIONS ALONG THE SAN PEDRO RIVER: POTENTIAL NATURAL COMMUNITIES AND FACTORS LIMITING THEIR OCCURRENCE, For BLM by Lowclouds Hydrology, Inc.

Hydraulics and Morphology

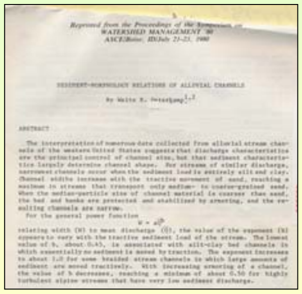
What did the natural channel look like?

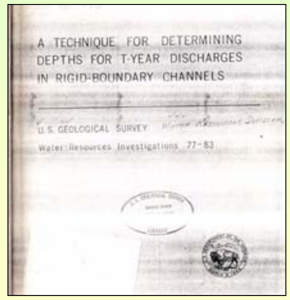
What were the widths, depths and velocities for the natural and ordinary runoff?

Primary references used for channel hydraulics

Osterkamp, W. R., 1980, Sediment-morphology relations of alluvial channels: Proceedings of the symposium on watershed management, American Society of Civil Engineers, Boise Idaho, p. 188-199.

Burkham, D. E., 1977, A technique for determining depths for T-year discharges in rigid-boundary channels: U. S. Geological Water- Resources Investigations 77-83, 38 p.



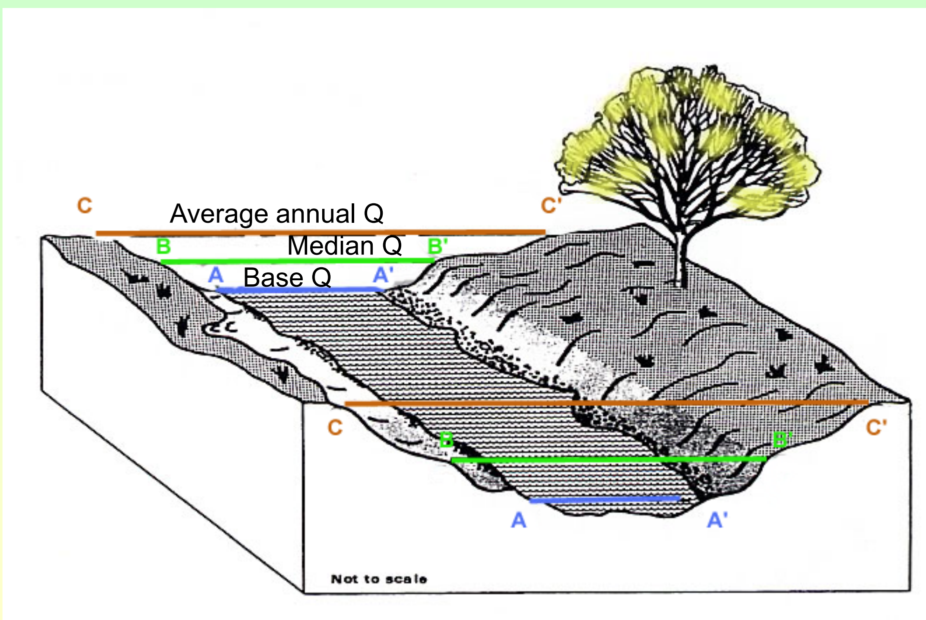


A TECHNIQUE FOR DETERMINING
DEPTHS FOR T-YEAR DISCHARGES
IN RIGID-BOUNDARY CHANNELS

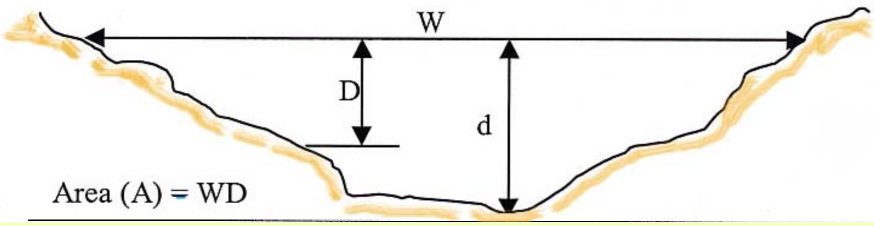
U.S. GEOLOGICAL SURVEY

Water Resources Investigations 77-83

SKETCH OF RIVER CHANNEL



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



Rivers with natural alluvial channels like most of the San Pedro River construct their own geometries. This *hydraulic geometry* of the San Pedro 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.

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 the relation between width and discharge has been reliably defined for rivers like the San Pedro.

Power function to determine width along self-forming rivers like most of the San Pedro

$$W = aQ^{b}$$

Coefficient a and exponent b are related to sediment characteristics (Osterkamp, 1980).

For this assessment of predevelopment navigability only a general description of the sediments at and near the natural channel are needed to define the coefficient and exponent of the previous equation.

There are several theories on precisely how and when the river channel changed from meandering and slightly incised with extensive marshy reaches with fine sediments of pebbles, sand, silt, clay, and evaporite deposits (Cook and others, 2009).

Cook, Joseph P., 2009, and others, Mapping of Holocene River Alluvium along the San Pedro River, Aravaipa Creek, and Babocomari River, Southeastern Arizona, Arizona Geological Survey, 76 p and 6 maps.

Of importance for this analysis is that the present channel has down cut with significant bank cutting and with sand-gravel bed and banks. The natural channel and floodplain were composed of finer material that commonly consisted of fine sand, silt, and clay with interspersed pebble to gravel beds.

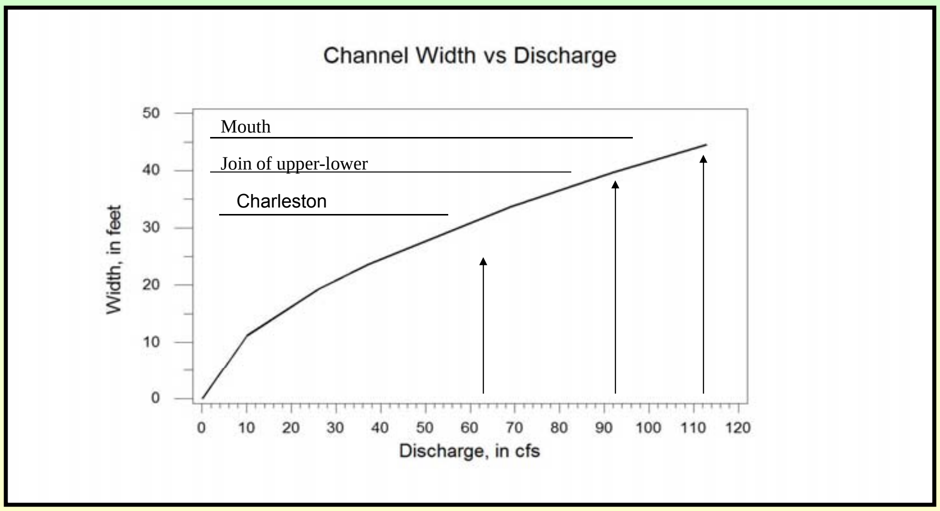
Thus, for practical considerations, a typical channel mostly of medium silt-clay and some sand was used. The corresponding coefficient ‘a’ = (3.01) and the exponent ‘b’= 0.57.

Equation 1

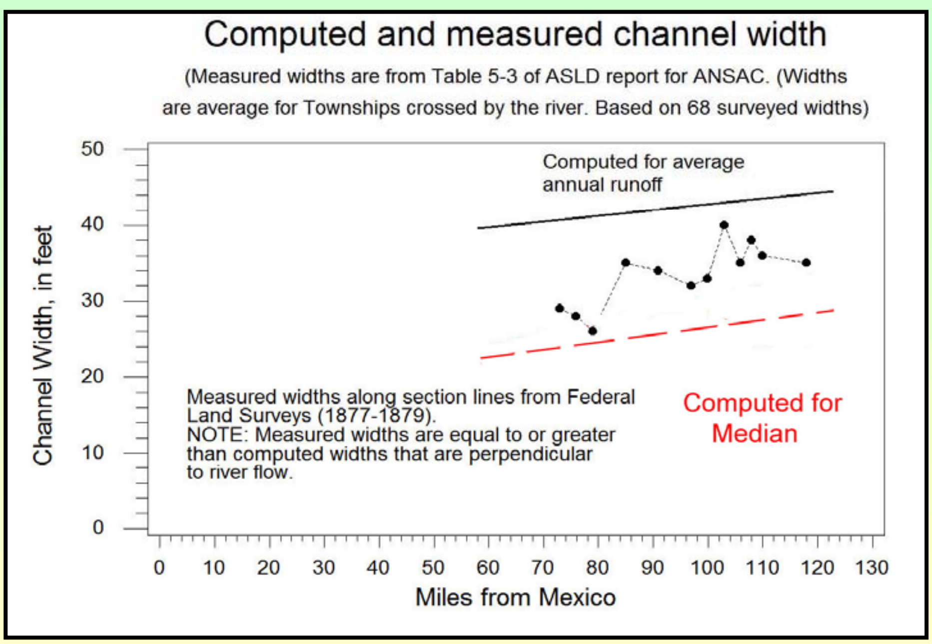
$$W = 3.01\ Q^{0.57}$$

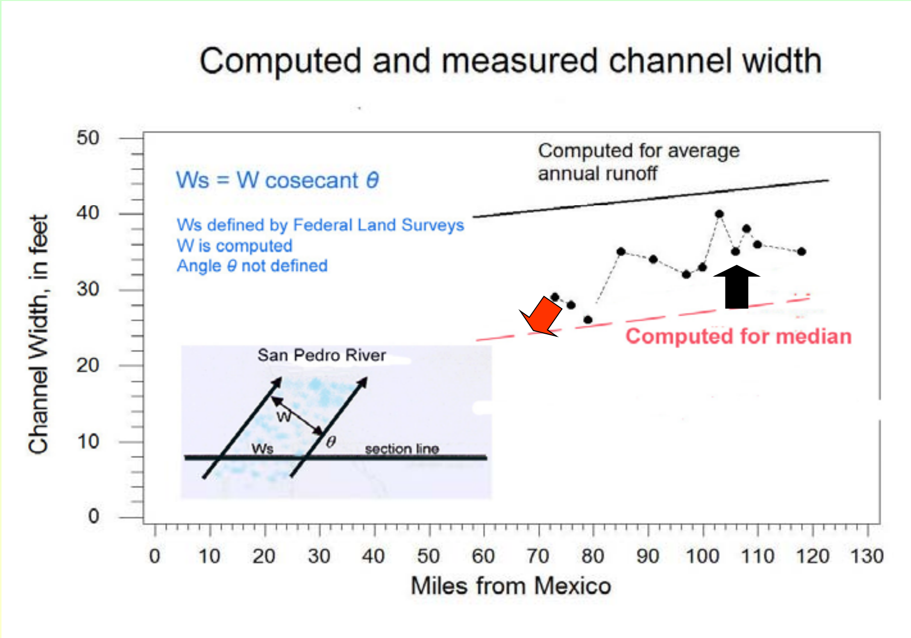
Equation from: Osterkamp, W. R., 1980, Sediment-morphology relations of alluvial channels: Proceedings of the symposium on watershed management, American Society of Civil Engineers, Boise Idaho, p. 188-199.

$$W = 3.01\ Q^{0.57}$$



There are no known documented observations of the predevelopment (natural) river morphology (width, depth, sinuosity, etc.). A few measurements of channel width along section lines of Federal land surveys between 1877 and 1879 were available for this analysis--the significance of any anthropogenic effects on the surveyed widths is unknown. The following widths were measured using Federal standards.





Manning's discharge equation, which is widely used for channels like the San Pedro River, was used to estimate the depth and velocity of flow. Techniques of Burkham (1977) were used to account for the approximate parabolic shape of the natural channel.

Equation 2

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

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

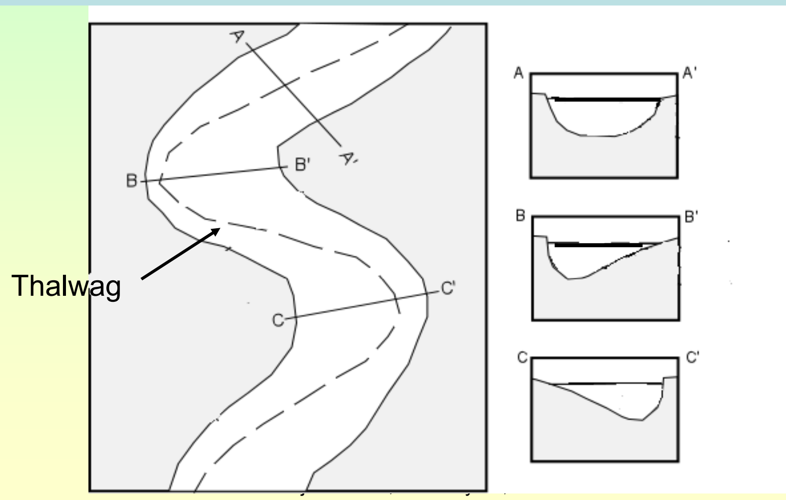
For the San Pedro,
Q is from about 10 to 113 ft^3/s,
W is from about 11 to 45 ft,
S_o = about 0.0028 upper channel &
about 0.0021 lower channel
using sinuosity of 1.5,
n = 0.035

Channel size and shape along the study reach of the San Pedro River are estimated using the average annual flow of 33 cfs to 113 cfs, upper and lower ends of the study reach respectively, as the formative or dominant discharge (independent variable) of the channel property (dependent variable) width.

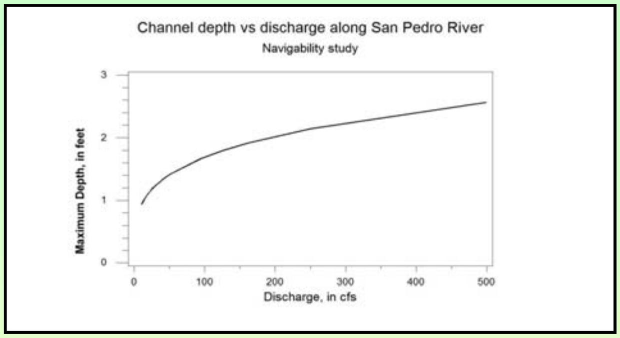
This permits estimates of the channel dimensions to be made along the river on the basis of the discharge characteristic. The approach infers that the discharge characteristic to be estimated is related directly to the formative discharge of the San Pedro River but does not require precise identification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

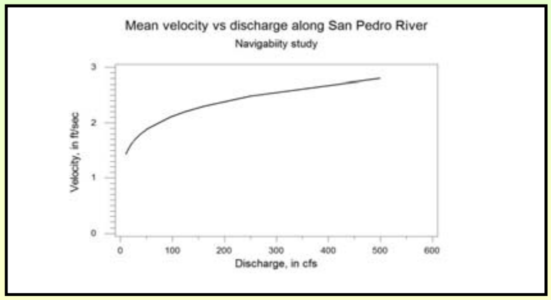
It's important to realize that the hydraulic geometry method yields representative cross section characteristics of width, depth and velocity. Cross section shape for meandering rivers like the predevelopment San Pedro appears to have varied along the river. A sketch of how shape typically varies is shown on the next page.

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.

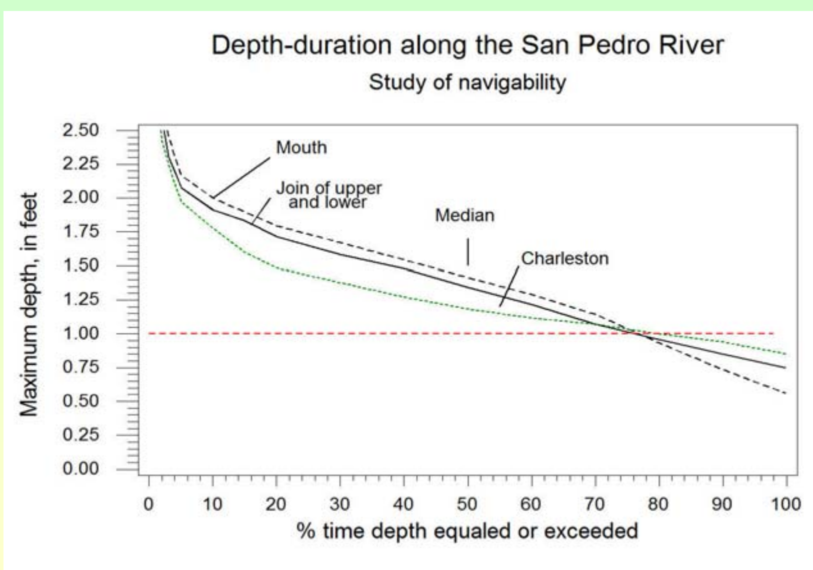


Computed estimates of predevelopment depth vs. discharge and velocity vs. discharge, using equation 2, are shown on the following page.

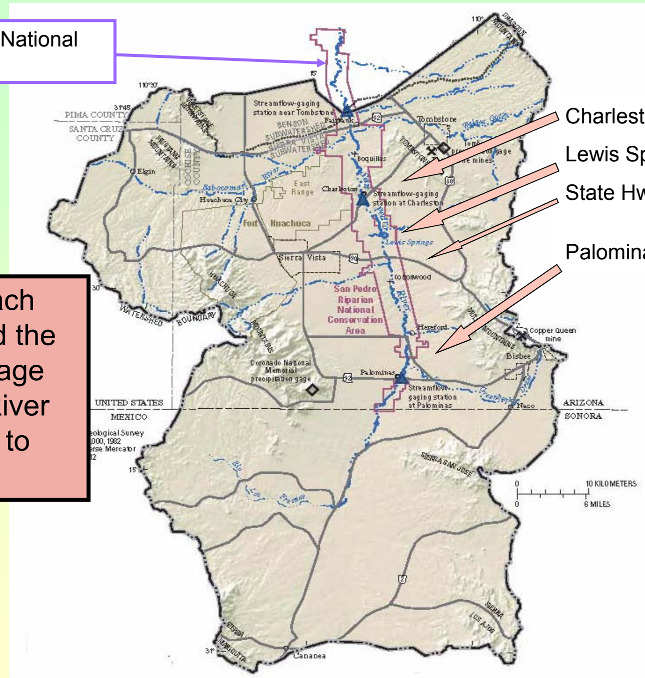




Depth-duration relations for San Pedro River



San Pedro Riparian National Conservation Area



Charleston gage

Lewis Springs

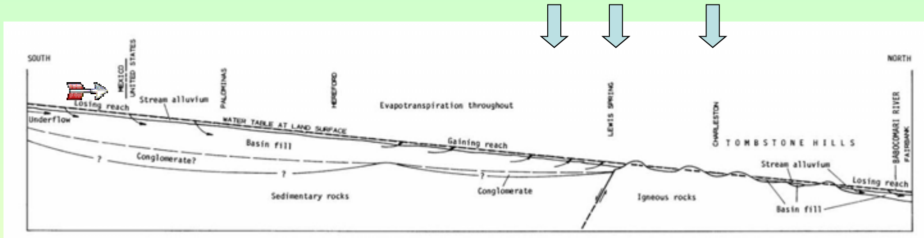
State Hwy 90

Palominas gage

Where along the reach between Mexico and the USGS Charleston gage did the San Pedro River become susceptible to navigation?

Mexico | Arizona

State Hwy 92 | Lewis Springs | USGS gage Charleston

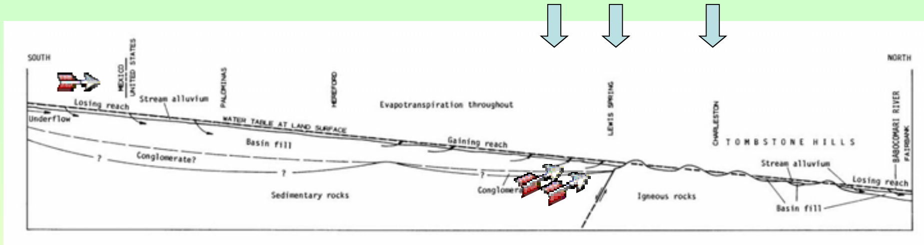


Profile beneath the San Pedro River from 2 miles south of International boundary to Fairbanks, AZ (Freethey, 1982)

Considering the reach above Lewis Springs is gaining for post-development shown here, and the 5 estimates of base runoff at the Charleston gage are from 10-13 cfs, the base runoff at Lewis Springs is assumed to be 10 cfs (same as the conservative amount used at Charleston for this study).

Mexico | Arizona

State Hwy 90 | Lewis Springs | USGS gage Charleston



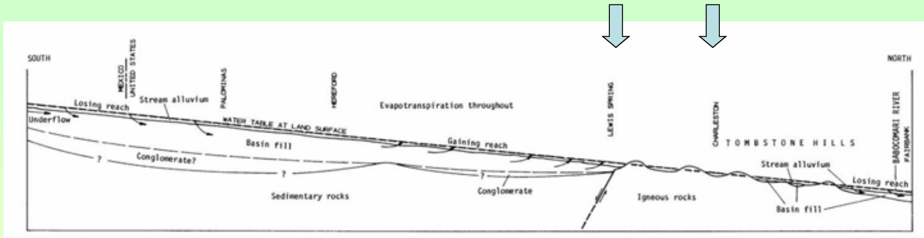
Profile beneath the San Pedro River from 2 miles south of International boundary to Fairbanks, AZ (Freethey, 1982)

Also, inflow to the stream channel in this area is derived from storage in both the alluvial and regional aquifers (Pool and Coes, 1999).

Pool, D.R., and Coes, A.L., 1999, Hydrogeologic investigations of the Sierra Vista sub watershed of the Upper San Pedro Basin, Cochise County, Southeast Arizona: U.S. Geological Survey Water-Resources Investigations Report 99−4197, 41 p.

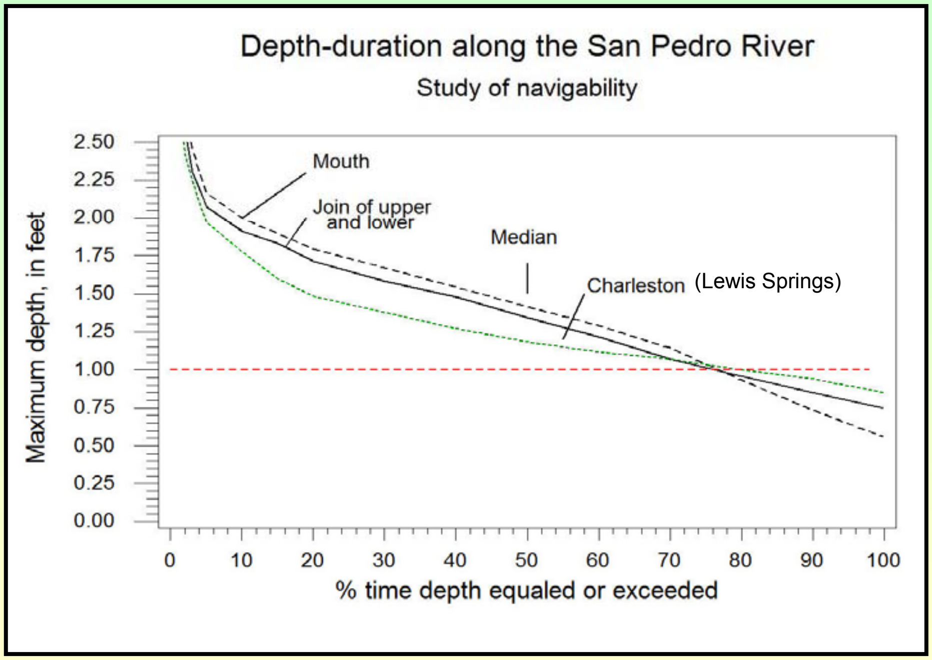
Mexico | Arizona

Lewis Springs | USGS gage Charleston



Profile beneath the San Pedro River from 2 miles south of International boundary to Fairbanks, AZ (Freethey, 1982)

Navigability is considered to start at Lewis Springs (about 18 miles below the Mexican border). Runoff at Lewis Springs and the Charleston gage are considered the same for this study.



The natural channel was meandering and such a channel is relatively stable.

Simple power functions of width, sediment particle size and mean annual discharge were used to estimate single channel geometry for the perennial flow.

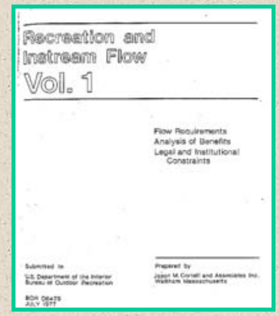
The discharge and depth of runoff from the Lewis Springs to the mouth was sufficient for navigability.

NAVIGABILITY

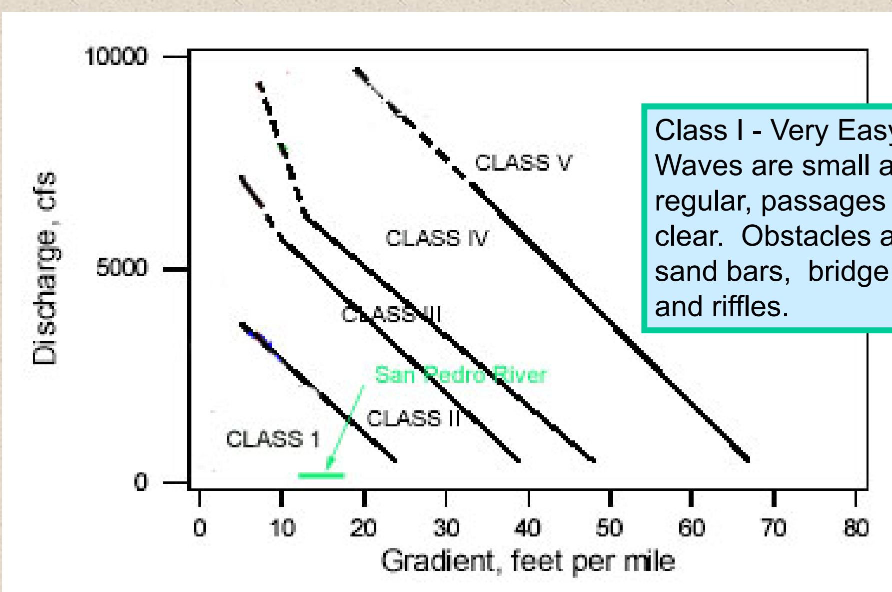
Navigability along the San Pedro River is evaluated using the natural hydrology and hydraulic geometry of the natural channel in the study reach. The river is evaluated as a single segment. Two convenient methods of assessing instream flows are used. The two relatively simple methods were developed by the U.S. Department of the Interior mostly for modern recreational boating. These assessments are followed by a discussion of Beaver dams

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.



MODIFIED FROM: (U. S. Bureau of Outdoor Recreation, 1977)

Class I - Very Easy. Waves are small and regular, passages are clear. Obstacles are sand bars, bridge piers, and riffles.

Fish and Wildlife Service Method

The U.S. Fish and Wildlife Service (Hyra, 1978) developed a method of assessing stream flow suitability for recreation that is applied to the San Pedro 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.

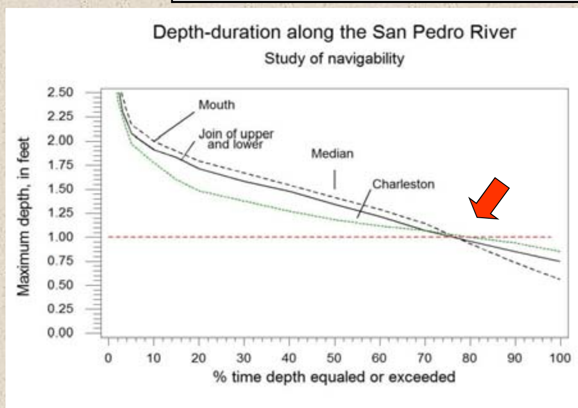
Hyra(1978) presents minimum depth and width requirements for canoes, kayaks, drift boats and row boats and power boats (See table on next page). The minimum width and depth requirements are met for canoes, kayaks, drift and row boats along nearly all of the San Pedro.

(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.)

(Hyra, 1978)

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



The depth of flow in the San Pedro River exceeds the depths required for canoes, kayaks, drift boats, row boats and rafts nearly 80% of time during an ordinary year.

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(Hyra, 1978)

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

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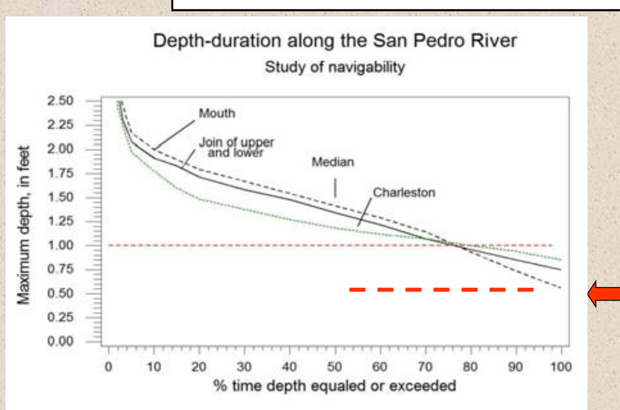

The depth of flow exceeds the minimal depth required for canoes- kayaks.

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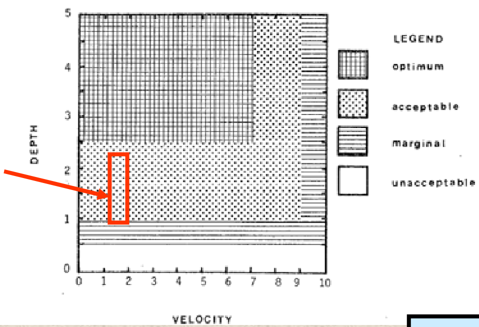
BOATING CANOEING-KAYAKING

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.



The depth and velocity for common and natural runoff of the San Pedro is acceptable for canoeing and kayaking about 80% of time.

(Hyra, 1978)

SUMMARY

Study based on:

•Published information
•Standard engineering methods
•fundamental hydrologic/morphologic principles
•Systematic three-step method
(hydrology, hydraulics-morphology, navigability)

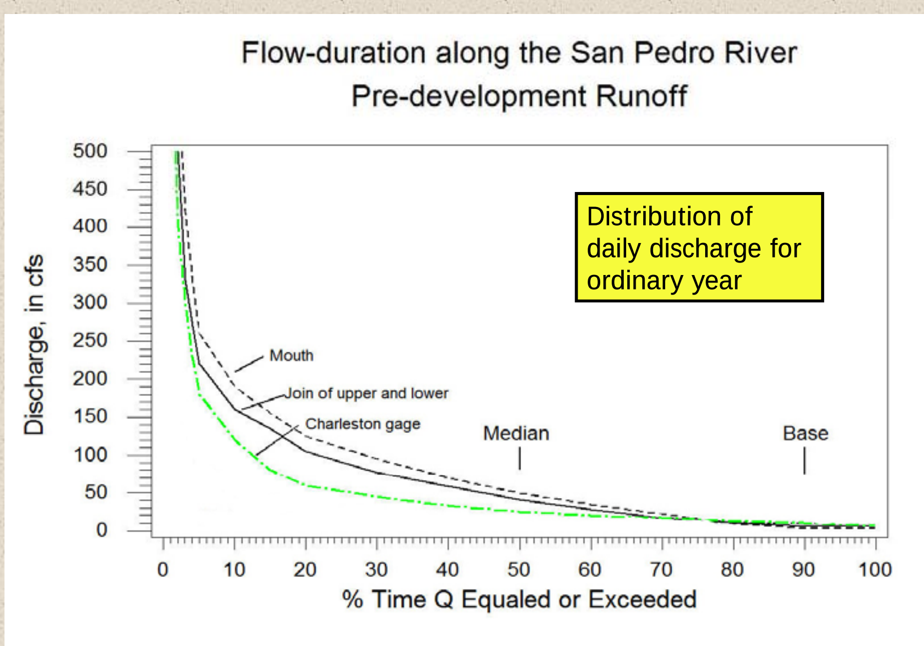
ALLUVIAL CHANNELS
(like the natural San Pedro)

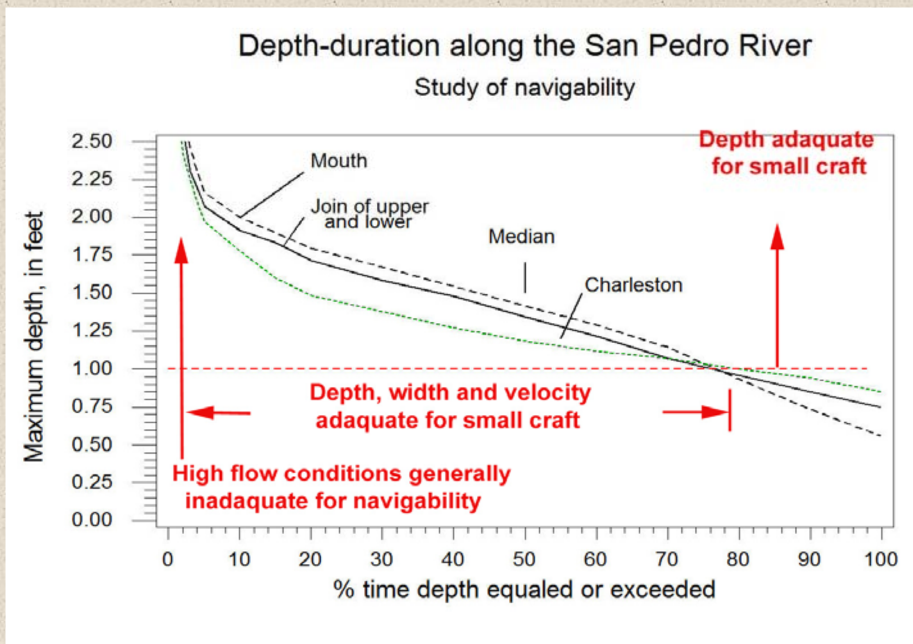
Big floods can suddenly disrupt channel form and increase width. Over time the channel will gradually recover (heal) as smaller flow reworks the mobile bed and banks, deposits sediment where the channel is too wide and shallow, and vegetation is again established.

Based on the natural conditions *(e.g.,* slope, channel bed material, etc.) the San Pedro River would return to a single meandering channel after any braiding had occurred as the result of an extraordinary flow.

Evidence suggests the following natural channel

Relatively low gradient and well defined alluvial channel slightly entrenched in defined floodplains covered with brush and trees. Meandering channel developed in generally fine sediment with some riffles and pools.





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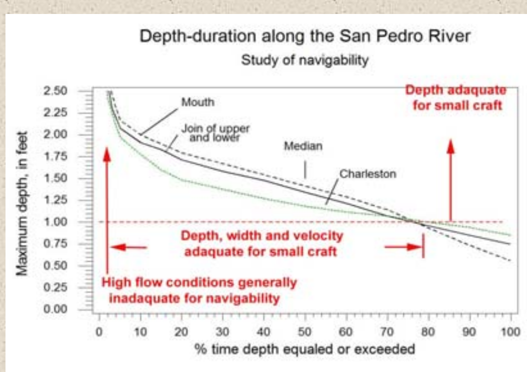

The analysis at this point suggests the San Pedro River from the the Lewis Springs area to the mouth was susceptible to navigation because for about 80% of the time during a typical year, the width, depth and velocity were acceptable for use of small craft such as canoes, kayaks, row boats and rafts.

The river is not segmented because susceptibility to navigation from Lewis Springs to the mouth at the Gila River is similar.

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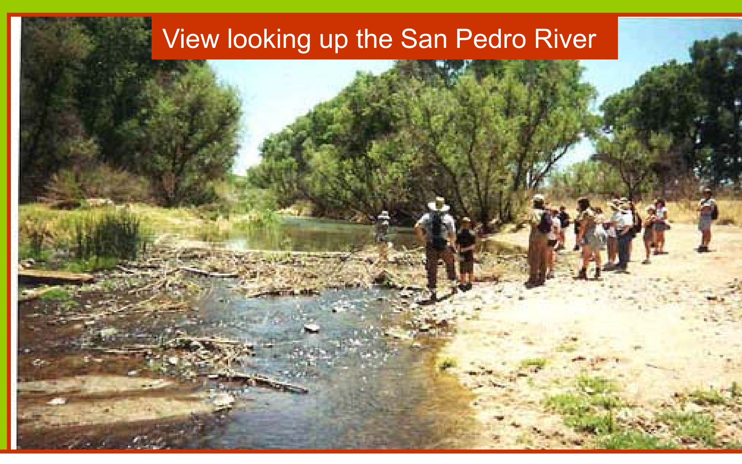

By all accounts, Beaver's were building dams and modifying the river environment before humans influenced the San Pedro River. The influence of Beaver dams and pools on navigability is a subject for some speculation.

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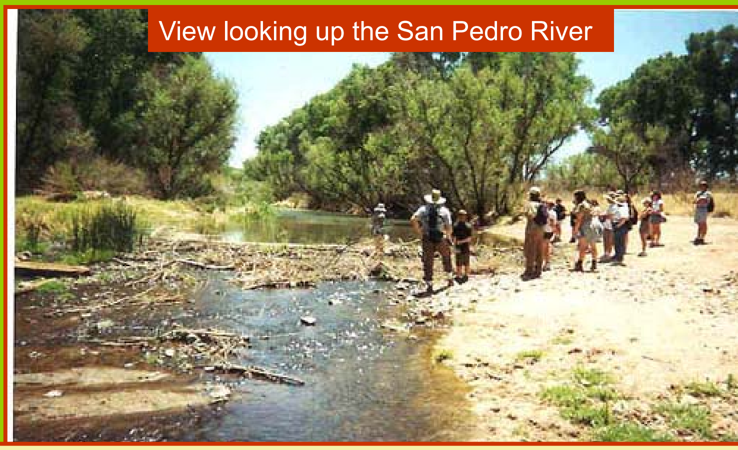

The base discharge shown in this recent scene is less than the predevelopment base discharge at this location.

No reports of comprehensive studies of the affect of beaver dams on navigability were found for this study.

The following cartoons show beaver dams from the perspective of a beaver and recreational humans.

4 feet deep pond

1 foot deep backwater from downstream pond

Hmm. Channel slope = 0.0025,
Pond = 4 ft deep,
Minimum depth = 1 ft
Drop at dam = 4-1 = 3 ft
3/.0025 = 1,200 ft
Must build my dam 1200 ft above Eager's

Easy going upstream except for Eager's dam

Yeah, plenty of depth for a small river

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There's the Gila dead ahead

Nearly 500 dams in the last 123 miles from Mexico

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Reintroduced beaver are doing well in the San Pedro Riparian National Conservation Area according to BLM wildlife biologist Marcia Radke's observations. That's a big change since just a few beavers were reintroduced into the river beginning in 1999 - about a century after trappers wiped out the last native beavers there.

Fifteen beaver were released on the San Pedro Riparian National Conservation Area from 1999 to 2002 - and the population quickly expanded.

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Most of the dams are located along a reach of the river between the Mexican border and an area south of St. David. In 2008 the beavers had 46 dams, Radke said. "But that year we had a good monsoon, and it took out all the dams."

Many new dams have been built since the 2008 flood.

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The historic abundance of beaver dams along the San Pedro is unknown but seems to be related to the stability of the channel bed and banks and the erosive capacity of the river as "characterized by stream power"*. Stream power is a function of river discharge and river slope. There may be some threshold of channel stability and stream power "above which the dams will fail (e.g., during floods)."*

The river sediment along much of the natural channel of the river provided an unstable footing for beaver dams.

*Pollock, M. M., Pess, G. R,. Beech, T. J., and Montgomery, D. R., 2004, **The Importance of Beaver Ponds to Coho Salmon Production in the Stillaguamish River Basin, Washington, USA,** *North American Journal of Fisheries Management* 24:749–760.

Beavers build dams to impound base flow-- snowmelt and storm runoff easily overtops dams.

Andersen, D. C and others, 2011, Managed Flood Effects on Beaver Pond Habitat in a Desert Riverine Ecosystem, Bill Williams River, Arizona
Received: 9 August 2010 / Accepted: 19 January 2011 / Published online (doi:10.1007/s13157-011-0154-y) US Government.

"Historically, beaver dams created stream systems with slow, deep water and floodplain Wetlands."**

**Pollock, M. M., Heim, M., Werner, 2003, Hydrologic and Geomorphic Effects of Beaver Dams and Their Influence on Fishes, *National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington*

The natural San Pedro River was susceptible to navigation above and below beaver dams using small craft such as canoes and kayaks - even if boaters get out, walk around a dam, then re-enter the river.

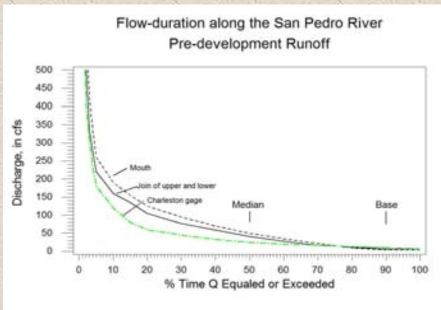
Beaver dams are not permanent structures - often being washed away by heavy monsoon flows.

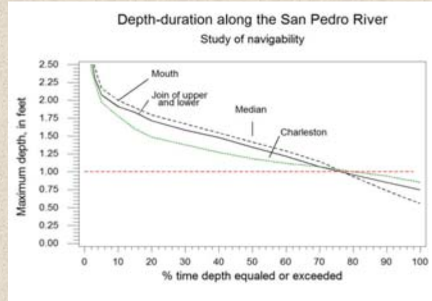
Under natural conditions, without beaver dams, navigability is limited to small craft mostly because of the depth of base runoff. Beaver dams create ponds that increase water depth.

Context is Important.

For example, “on December 9, 1846, Cooke first saw the San Pedro Valley from the mountains to the east, but saw "no other appearance of a stream than a few ash trees in the midst.. .. On we pushed, and finally, when twenty paces off, saw a fine bold stream! There was the San Pedro we had so long and anxiously pursued.“ (Fuller, p. 3-15)

With hydrology/morphology we can see the San Pedro River for what it was.





The low runoff end of the flow- and depth-duration relations clearly shows the effect of summer evapotranspiration along the river. The decreasing base runoff and associated depth along the river suggests navigability during some of the summer was limited.

Navigability was independent of any potential undesirable conditions such as beaver dams, low flow from severe droughts, sediment deposits at tributaries and flow variability because such characteristics are related to how the river might have been used for navigation rather than the navigability.

Opinion

It is my opinion the San Pedro River, from Lewis Springs area to the mouth at the Gila River, was susceptible to navigation at the time of statehood (February 14, 1912) in its ordinary and natural condition using the Federal Standard (2013).

For about 80% of the time during a typical year, the width, depth and velocity were acceptable for use of small water craft such as canoes, kayaks, drift boats, row boats and rafts.

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