Title
Flow Regime, Geomorphology, and Debris Transport of the San Pedro River: An Exploration of Flood History and Monitoring at the Border Wall

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Flow Regime, Geomorphology, and Debris Transport of the San Pedro River: An Exploration of Flood History and Monitoring at the Border Wall

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Abstract

The San Pedro River, which drains from the Sierra Madre, Mexico, into the Sonoran Desert of Arizona, is an arid climate braided river with an episodic flood regime and cottonwood-willow riparian community. In 2020, the US-Mexico border wall was extended across the river and its floodplain with a series of manually operated flood gates that interfere with natural process of episodic flooding, sediment transport, and woody debris recruitment. This project summarizes the flood history of the San Pedro River upstream of the US-Mexico border wall from 1887 to present using historical stream gauge records from Palominas, Arizona, and archival evidence from newspaper accounts prior to establishment of the stream gage in 1930. I reviewed literature on hydrology-sediment-vegetation dynamics specific to the San Pedro River and summarized ongoing monitoring and conservation efforts. I propose a method to track the transport of large woody debris (LWD) downstream on the San Pedro during high flows. Developing a chronology of woody debris and its movement around the US-Mexico border wall will help to assess if debris damming at the floodgate structures will result in increased erosion, scouring, and flooding upstream of the border. I provide methods for LWD monitoring and results from surveying the river downstream of the border in December 2022. Results illustrate an increase in debris accumulation, bed material complexity, bank erosion, and scour pools downstream of the border in the last two years since construction of the floodgates.

Contents

Introduction

The San Pedro River drains an area of 4,720 square miles and flows north from its headwaters in the Sierra Madre Mountains of northern Mexico for 175 miles to Winkelman, Arizona, where it joins the Gila River. The river hosts a range of vegetation types from xeroriparian and saltcedar shrublands to mesquite and cottonwood-willow forests, the latter having increased since the 1850's (Stromberg et al. 2012). In particular, these large cottonwood-willow stands give the river its characteristic appearance as a "ribbon of green" (Webb et al., 2007) that winds through the Sonoran and Chihuahuan Deserts. The river flows through an ecoregion known as the Madrean Archipelago Sky Islands, a series of subtropical and temperate mountain ranges between 3,000 and 10,000 feet in elevation. This ecoregion is recognized one of the most biologically diverse regions in the world, and one of the greatest biodiversity hotspots in North America in terms of bird, ant, reptile, and mammal species (Felger & Wilson 1994; Foreman et al. 2000; Mittermeier et al. 1998, as cited by Spector 2002; Figure *1*). The river's context within the Sky Islands makes it a key corridor for many migrating species, including the near threatened jaguar (*Panthera onca*) and the endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*) (US Fish and Wildlife, 2022).

The geology of the San Pedro River and its floodplain is a complex stratigraphy consisting of approximately 20 feet of Holocene alluvium (sand and gravel) followed by 50 to 100 feet of clay, silt, and fine sand terrace deposits from the late Pleistocene and early Holocene ages, laid atop upper and lower basin fills consisting of clay, silt sand,

and gravel at 150 to 400 feet of depth deposited between the late Miocene and early Pleistocene ages (USGS 1999). The deposits and fills overlay bedrock of siltstone and conglomerate known as the Pantano Formation. The surrounding Huachuca and Mule Mountain Ranges and the Tombstone Hills consist of consolidated rocks, including sedimentary, volcanic, and granitic (USGS 1999). Geomorphic contrasts and a constriction in the San Pedro River Valley structure known as "The Narrows" separate the river into two distinct reaches: an upper reach flowing along relatively low gradients ranging from 50 to 150 feet per mile between the Huachuca and Mule Mountains in Southern Arizona (Figure 3), and a lower reach bordered more closely by the higher-elevation Galiuro, Santa Catalina, and Rincon mountain ranges (Wood, 1997; Tuan, 1962; Figure 4). In the upper watershed, the San Pedro River's floodplains are relatively less developed compared to other rivers in the region, and bank stratigraphy remains relatively intact. This makes the upper reaches of the river appropriate for studying the formation of arroyos, or gullies carved out by strong torrents of water (Stromberg et al. 2012). Geologic relations and geomorphology of the upper reaches of the San Pedro River are typically characterized by an entrenched main channel inset within a main floodplain surrounded by stacked terraces and a wide inner valley (Figure 5), the formation of which depend wholly on the flashy flood regime of the river.

Each year, the months of June through September bring monsoon rains across the Sonoran Desert. These monsoon rains result in periods of rapid discharge along the river (Figure), including 15 peak flows greater than 10,000 cubic feet per second in the last 92 years on the San Pedro River at the US-Mexico border (USGS Gage 09470500, 2022; Figure ; Figure). Such rapidly developing floods have posed a threat to human development in this environment, as evident from historical accounts of the river overbanking, cutting new channels, and destroying ranches, residences, and infrastructure, including bridges and railways. In 2020, the US-Mexico border wall was extended across the San Pedro River and its floodplain. A series of manually operated floodgates were installed with the intention of allowing large floods to pass freely. However, residents documented debris buildup at the floodgates in a flood of 5,640 cubic feet per second (cfs) in August 2021, a year after construction. It is not yet clear to what storm magnitude and debris stage the border wall and floodgates can withstand before failure, but the same storm system in 2021 severely damaged border wall floodgates at Silver Creek in San Bernardino National Wildlife Refuge (Figure 6).

While such floods can be dangerous and destructive, they are also important in creating new alluvial surfaces for riparian vegetation and providing a diversity of age, density, and species composition essential for maintaining habitat complexity (Stromberg et al. 2012). As documented by Stromberg et al. in *Conservation and Ecology of the San Pedro River* (2012), the floods at the turn of the 19th to the 20th century reconfigured the river into a wide, braided channel and “facilitated the establishment of riparian forests of cottonwood and willow” through the processes of channel incision, widening, and arroyo development (Stromberg et al., 2012). Just as floods are necessary to form new surfaces for seedling and propagule establishment, preservation of flow regimes is also essential in maintaining bank stability and sustaining riparian vegetation, as a lowered groundwater table tends to convert cottonwood-willow gallery forests to tamarisk shrublands and eventually sparsely vegetated shrublands (Stromberg et al. 2012). Increased urbanization, excessive groundwater pumping, and livestock grazing in the riparian corridor have led to a decrease in streamflow permanence by reach on the San Pedro River (Stromberg et al. 2009, 6-7; National Audubon Society, 2022). The San Pedro Riparian National Conservation Area (SPRNCA) was established by Congress in 1988 to give special protections to 40 miles of the river and 57,000 acres of public land in the watershed (US Department of the Interior Bureau of Land Management, 2022). Additionally, groups such as the Nature Conservancy continue to purchase acres of land within the watershed to set aside for conservation. These lands are used to conduct research and implement groundwater recharge projects in response to increasing concern due to loss of streamflow at formerly perennial reaches of the river from excessive groundwater pumping. Since 1999, the Nature Conservancy and “citizen scientists” have conducted wet-dry mapping efforts of the San Pedro River and its tributaries to monitor riparian conditions and to use changes to the river’s streamflow permanence as an indicator of groundwater sustainability.

In light of the extension of the US-Mexico border wall over the San Pedro River in 2020, an opportunity for a similar monitoring program for large woody debris presents itself. Documenting debris movement and tracking material that becomes trapped in the floodgates at the border wall following large storm events could allow us to determine at what storm magnitude the wall’s floodgates are a barrier to debris traveling downstream. Such monitoring efforts can be utilized to build a chronology of woody debris and its movement over time, which can inform and further develop hydraulic and mobile bed models. In turn, future modeling efforts will be able to explore how the border wall design affects transport of woody debris, sediments, and propagules downstream, and what the resulting implications for establishing new seedbeds and riparian vegetation may be.

The primary purpose of this study was to catalogue floods on the San Pedro River downstream of the border wall using historical stream gage data from the USGS and accounts from local news sources prior to the establishment of the stream gages. A secondary goal of this study was to assess changes to channel morphology and debris transport regime using GPS tracking of large woody debris (LWD), repeat photo stationing, grain size analyses, and cross-sectional surveys downstream of the US-Mexico border wall. Together, these approaches summarized the river's flood regime and projected possible implications for infrastructure in the San Pedro River channel and floodplain, notably, the newly constructed border wall.

Methods

I reviewed archival evidence using public records available through the Library of Congress (*Chronicling America*) and related literature – namely that of J.C. Stromberg and G.R. Noonan – that have documented and summarized flood events on the San Pedro River and the subsequent geomorphic response, including channel widening, deepening, entrenchment, and arroyo formation. For collecting field data, I used Gaia GPS for tracking LWD that was surveyed in May 2021, and for tagging and tracking new recruitment of LWD during the December 2022 site visit. I used the pebble count method and sieve analysis to measure the river's natural bed material and the riprap placed downstream of the wall following construction. I used a standard auto-level and stadia rod to complete cross-sectional surveys at three sections across the channel downstream of the border wall. I referenced the GPS coordinates and compass bearings for the photo points established in May 2021 for repeat photography in December 2022 (Table 2).

Flood History

Select historical accounts regarding flooding on the San Pedro River from local newspapers are summarized in Table 1. Remarks from the varying sources range from quantifiable measurements (e.g., “half a mile wide and twenty feet deep”) to qualitative impacts (e.g., “several buildings destroyed”). The anecdotes range by location, but the majority are from Benson, Fairbank, and Charleston. Other accounts are from smaller towns of Tres Alamos, Dudleyville, Mammoth, Lewis Springs, Hereford, and St. David (**Error! Reference source not found.**). As early as 1887, local papers, such as the *Arizona Weekly Enterprise*, *Arizona Weekly Citizen, Tombstone Epitaph, Bisbee Daily Review*, and others, document large floods on the San Pedro River that destroyed crops, agricultural fields, and even buildings. Some accounts, such as the 1890 feature from the *Arizona Silverbelt*, document geomorphic changes and arroyo cuttings due to flooding, recounting that “the river in many places changed its channel…rapidly undermining the intervening ground.” Similarly, in 1891, the *Arizona Weekly Citizen* reported a flood that “last August … dug down the channel of the San Pedro River an average of ten feet.” In 1914, the *Tombstone Epitaph* documented a flood near Fairbank that “uprooted trees and left a layer of mud and water over all the land.” The same account noted that this flood on the San Pedro “was the highest it has been for the past 20 years according to reports received from old timers in that section.”

Many of the accounts collected document damage to the Union Pacific Railroad, which was constructed over the San Pedro River in 1880, establishing the city of Benson. The 1896 flood, as reported by the *Arizona Republican*, “tore out three miles of Southern Pacific track … sent the floodwater through the east end of town, destroying several buildings. Twelve persons are believed to be drowned.” The *Tombstone Epitaph* recounted the same flood of 1896, describing that “Benson is again all washed away … about half a mile from town east and west of the bridge which crosses the San Pedro has been … washed away in places to a depth of four feet … rails with ties attached lifted bodily and deposited fifteen to twenty feet to one side.” Beyond railroad infrastructure, damage due to flooding has been reported in other cities along the San Pedro River valley, including Fairbank. The *Bisbee Daily Review* reported floodwaters in 1905 “carrying out a small bridge … likely to close the road for a couple of days. The bridge at Clifton went out for the third time in four months … a repetition of washouts that have kept the road closed almost continuously during the last two months.” Similarly, the *Bisbee Daily Review* reported that the “state highway bridge at Fairbanks was completely under water” due to flooding on the San Pedro in 1914. Notably, the flooding that occurred on the San Pedro in September 1926 is recognized as one of the most damaging storms in the region’s history. The city of Bisbee reported a record monthly rainfall at 10.19 inches (NOAA National Weather Service, 2022). The USGS stream gages at Charleston, Redington, and Winkleman recorded the peak flows on the San Pedro River during this storm as 98,000, 90,000, and 85,000 cubic feet per second, respectively. *The Arizona Star* reported this flood on the San Pedro River as “the most destructive rampage in its entire history”. The State Bureau of Highways reported damage due to this storm valued at $60,000 (NOAA National Weather Service, 2022).

Additional news accounts from more recent decades further illustrate the nature of the San Pedro River’s flashy flood regime. In early August of 2006, two men driving a truck towing a trailer attempted to pass the Hot Springs Canyon Wash and were swept downstream by heavy floodwaters; the men fell out of the vehicle and their bodies were later recovered downstream (Death in Hot Springs Canyon, 2022). In August 2022, a man and child were stranded in their car near Hereford, Arizona, due to floodwaters during a monsoon storm on the San Pedro River (KOLD News 13, 2022).

Dating before modern stream gage measurements, numerous accounts from local papers such as the *Arizona Weekly Citizen*, *Tombstone Prospector*, *Arizona Republican*, *Tombstone Epitaph*, and others document massive floods on the San Pedro River that began in the 1880’s, recounting that “the San Pedro River was higher than ever before known, in many places flooding the valley several feet” (Noonan, 2022; Tombstone Epitaph, 1890). Into the 1930s, reports of severe flooding on the San Pedro River include descriptions of bridges, roads, and railways being taken out by the storm(s). As reported by *The Arizona Daily Star*, the floods of September 1926 were the largest floods recorded on the San Pedro River, and this storm event held the record through 2013 (Noonan, 2022; Tellman & Hadley, 2006; USGS, 2015). The flood history documented in this report was limited to the portion of the watershed within the United States and as such is not exhaustive; there are likely other historical accounts of extreme flooding on the San Pedro River. However, the anecdotes and streamflow data included herein demonstrate the nature of the river and the events that contributed to its channel form and lush cottonwood forests that are observed on the river's banks today.

Border Wall Context

Border wall floodgate measurements, photo points, and woody debris surveys at the San Pedro River were first recorded by G.M. Kondolf and graduate students during a site visit in May 2021 (Figure a). The group established 5 photo stations on the downstream side of the border wall and tagged, measured, and recorded GPS coordinates of 9 pieces of LWD (Figure 10b). Coordinates, compass bearings, and notes for repeating the photo station observations in the future are recorded in Table 2. Coordinates, measurements, tag numbers, and notes describing the LWD surveyed in May 2021 are summarized in Table 3. The May 2021 survey conveniently took place before monsoon season, which featured an August storm with a return interval of approximately 2 years (Figure 11). This storm was substantial enough that increased debris accumulation at the border wall floodgates was immediately evident (Figure 12; Figure 13). Of the nine pieces of LWD surveyed in May 2021, only one was found in its initial position during the December 2022 site visit (LWD 105; Table 3). Grain size analysis and comparison between subsequent photos from each station indicate a change in bedform from a flat, sandy channel in May 2021 to a topographically complex channel made up of gravels and small cobbles in December 2022 (Figure 14; Figure 15). In particular, photos from stations 8 and 10 show that riprap which was placed in a clean, straight line following construction of the floodgates was transported as far as 54 feet downstream by December 2022. The repeat photos from station 7 indicate that LWD #110 was moved downstream between May 2021 and December 2022. Changes to the channel's morphology are solidified in cross section 1 (Figure 16), which indicates an approximately 4-foot mound of riprap in the center of the channel (station 90) and that the left bank has incised (station 55). Additionally, cross section 3 (Figure 16) captures a pile of LWD approximately 5 feet in height accumulated upstream of a stand of cottonwoods near the center of the channel (station 87). The December 2022 survey results indicate that what was a flat channel composed primarily of sand has been converted to a more topographically complex channel with scour pools and piles of rip rap transported downstream of the border wall. These changes—along with the transport of 8 of 9 of the LWD tagged in 2021, and an increase in woody debris accumulation—occurred with a peak streamflow of 5,640 cfs having occurred between the May 2021 and December 2022 site visits. Further monitoring following monsoon season that includes the reach upstream of the border will be beneficial to understanding how the floodgate system interacts with the river's flood and debris transport regimes.

During the 2021 site visit, the survey team also recorded flood gate dimensions and quantities, as depicted in Figure 17. The border wall system at the San Pedro River consists of 9 main channel gates that measure 15 feet in width and 20 feet in height. Adjacent to the main channel gates on each bank of the river are low-flow gates that measure 5.5 feet in width and 12 feet in height. 4 low-flow gates are constructed on the right bank, while 52 are installed on the wider, shallower left bank, where the channel was located before migrating to its current position (Figure 18). These gate dimensions can be used in modeling efforts using freely available software such as the USACE's Hydrologic Engineering Center's River Analysis System (HEC-RAS). Using historical hydrographs from the Palominas stream gage (Figure Figure 19; Figure 20), we can then model various scenarios of debris buildup to assess at which storm magnitude and stage of debris accumulation that the border wall's floodgates visibly alter water surface elevation, inundation depth, and flow velocities. Inputs required for such modeling efforts in HEC-RAS are included in Table 4, with reference to their data sources.

Ideally, such surveys can be repeated by local volunteers and watershed stewards following seasonal storm events, similar to the wet-dry mapping and beaver survey efforts that are led annually by the Nature Conservancy (TNC) and Watershed Management Group (WMG), respectively. The surveys conducted in May 2021 were completed using handheld GPS devices, measuring tape, metal tree tags, and orange spray paint. GPS coordinates can be marked and saved in readily accessible software such as Google Maps or Gaia GPS, which are available at no charge. In coordination with Customs and Border Patrol, the Bureau of Land Management (which owns the SPRNCA of which this site is a part), and environmental groups like the Madrean Archipelago Wildlife Center and Sky Island Alliance, such surveying could be repeated on both sides of the border.

Conclusion

As evident by streamflow records and historical anecdotes of flooding, the speed and unpredictability in which storm events develop is common to the San Pedro River.

The river's flow regime naturally fluctuates: nonexistent flow is interrupted by brief periods of intense flash flooding capable of eroding banks, carving new channels, and wiping out human infrastructure in a single storm event. The border wall is the latest iteration in a history of infrastructural projects that bisect the river, and evidence of debris accumulation is already apparent. The watershed has a legacy of community stewardship, action, and cooperation—even spanning political boundaries—to shift the region's water management paradigm from one of "safe yield" to "sustainable yield" for the health of the San Pedro River. In such a setting, initiating a debris monitoring program seems an appropriate and timely opportunity to begin to understand the effects of the border wall on local infrastructure and channel morphology.

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Figures

Figure 1: San Pedro River Watershed: Madrean Archipelago Sky Islands Ecoregion context.

Figure 2: Idealized geologic section of San Pedro River and floodplain, deposits, and stratigraphy.

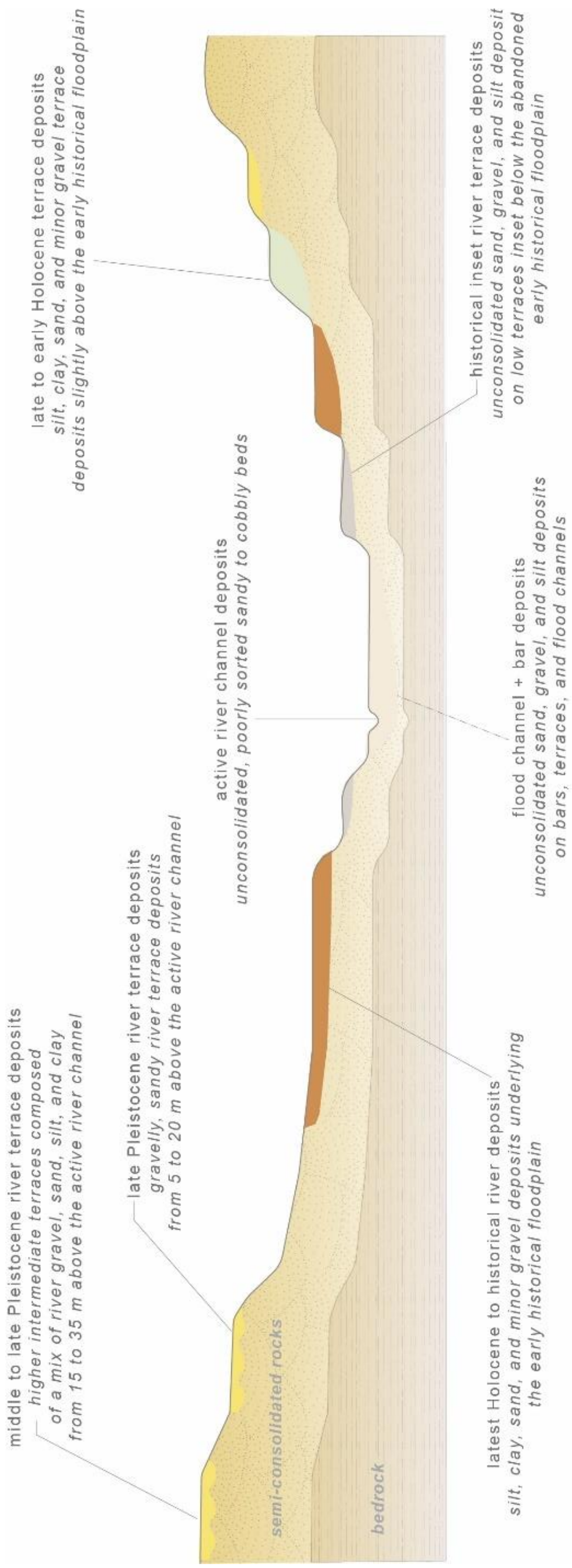


Figure 3: Landforms of the Upper San Pedro River Valley, Southeastern Arizona; Tuan 1962.

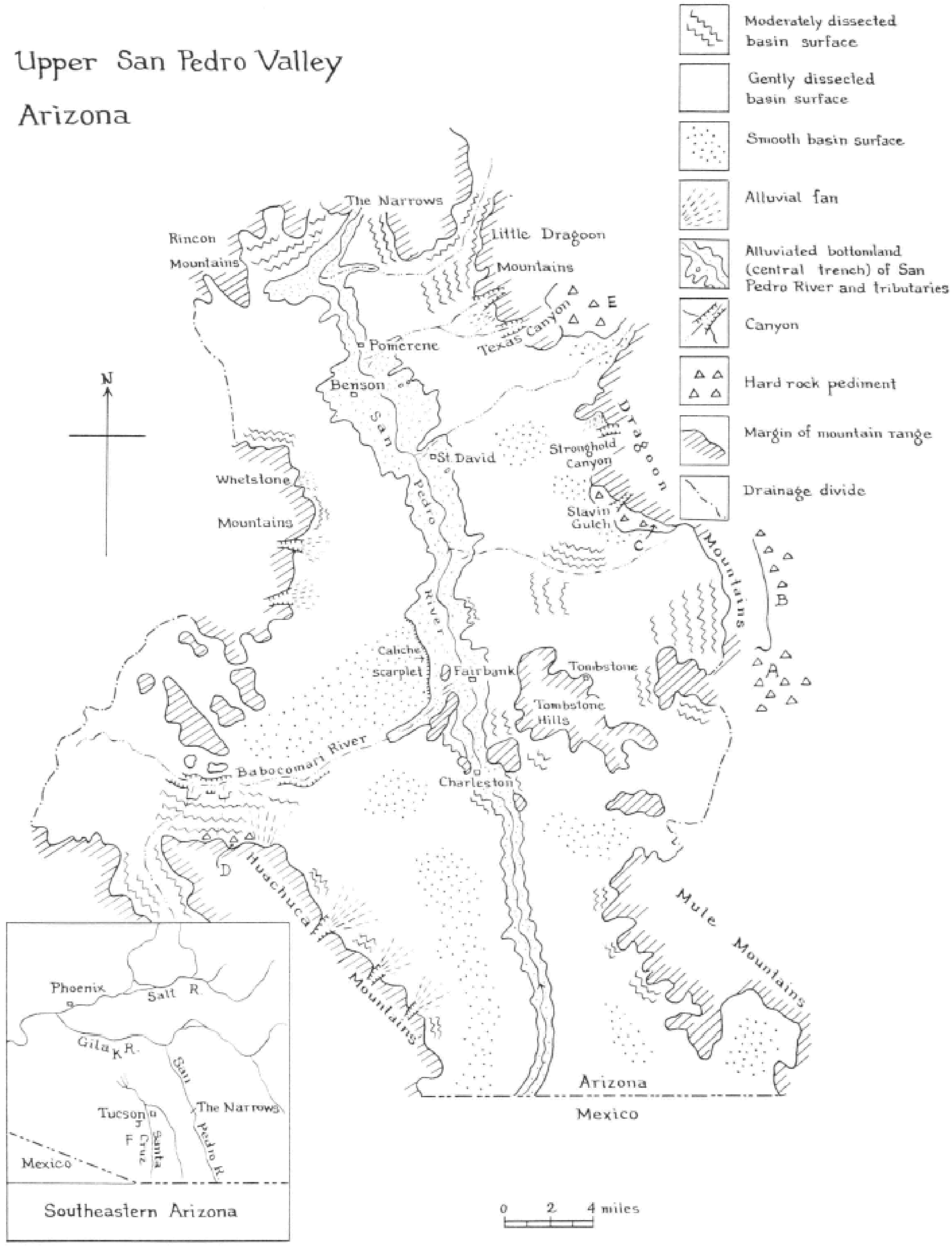


Figure 4: Landforms of the Lower San Pedro River Valley, Southeastern Arizona; Tuan 1962.

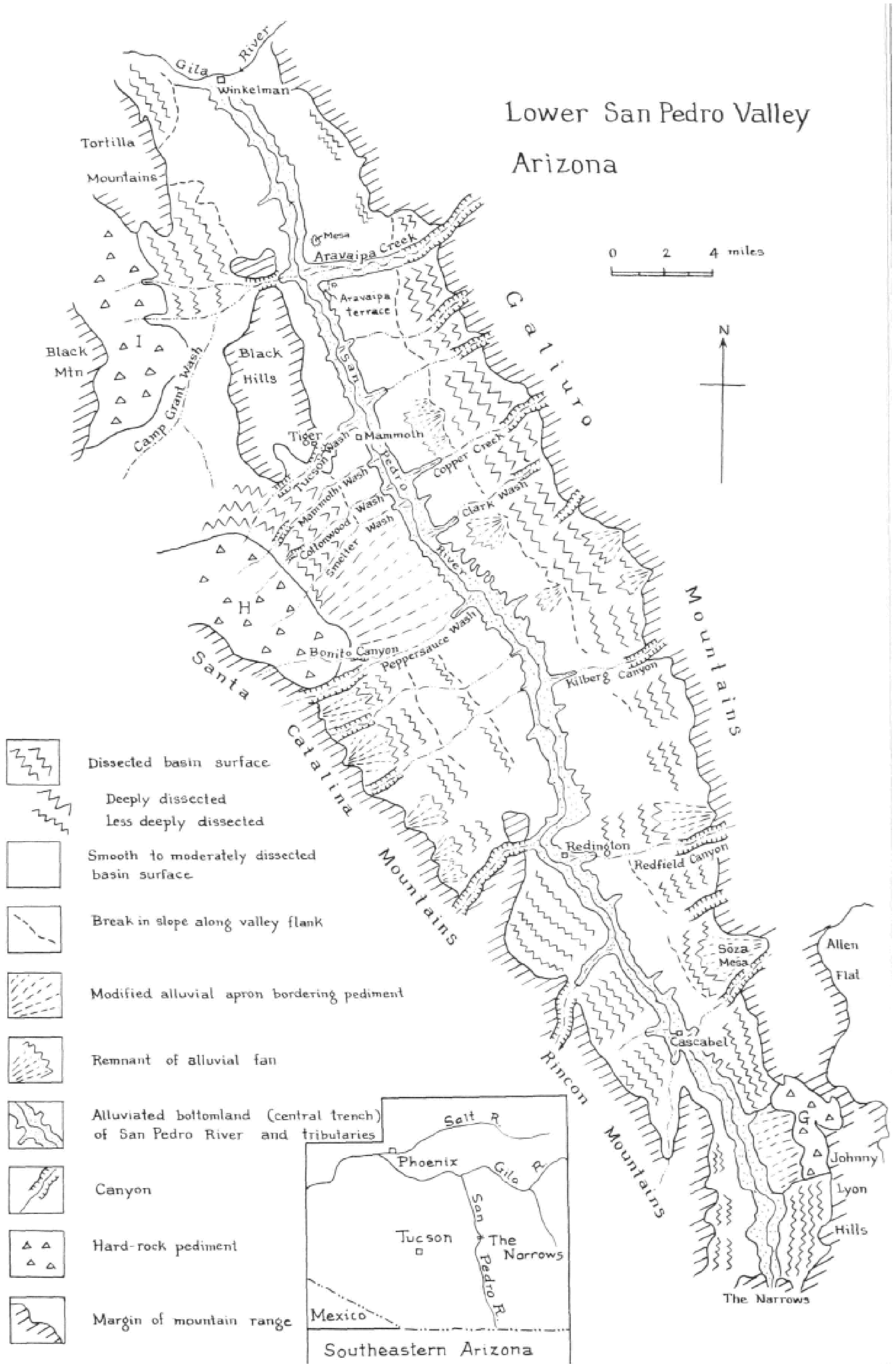


Figure 5: Adapted from Webb and Leake, 2006. Section depicting generalized vegetation response to arroyo cutting and widening of alluvial channels in the Southwest United States since 1880.

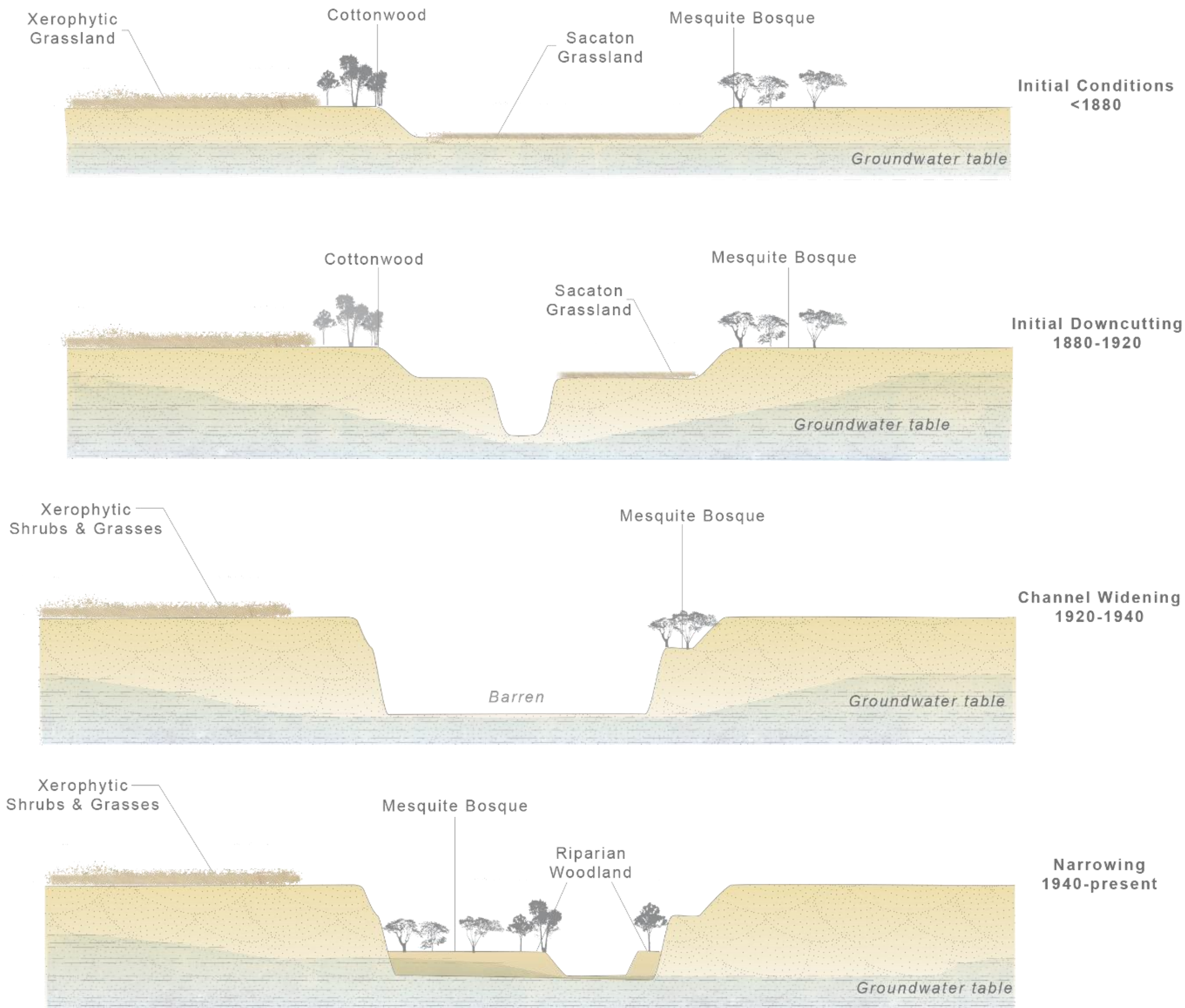


Figure 6: Discharge (cfs) at USGS gage 09470500, San Pedro River at Palominas, AZ, 1996-2022.

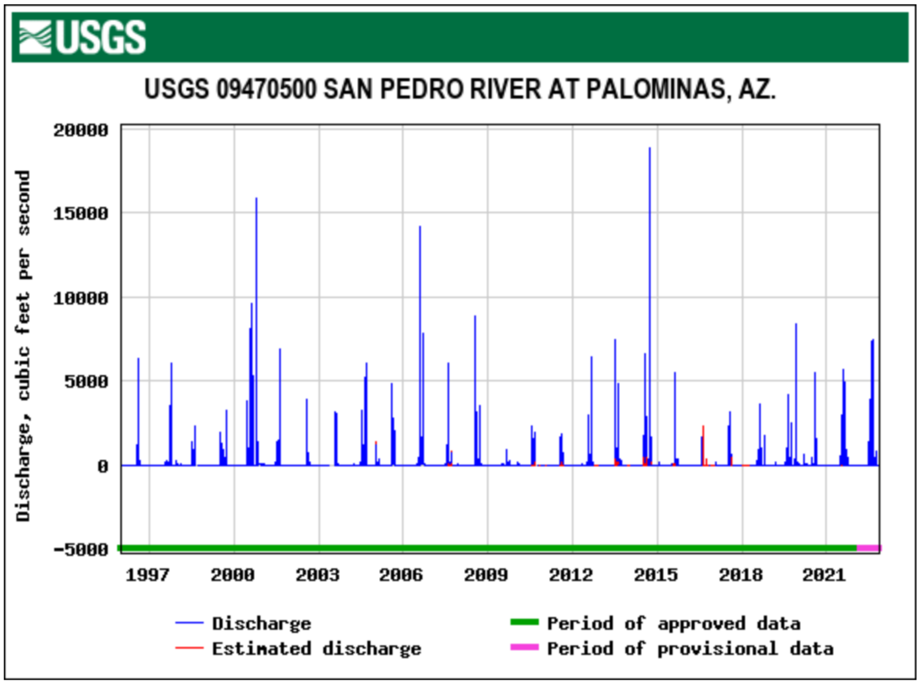


Figure 7: Surface water peak streamflow at USGS gage 09470500, San Pedro River at Palominas. 1930-2022 AZ, 1930-2022.

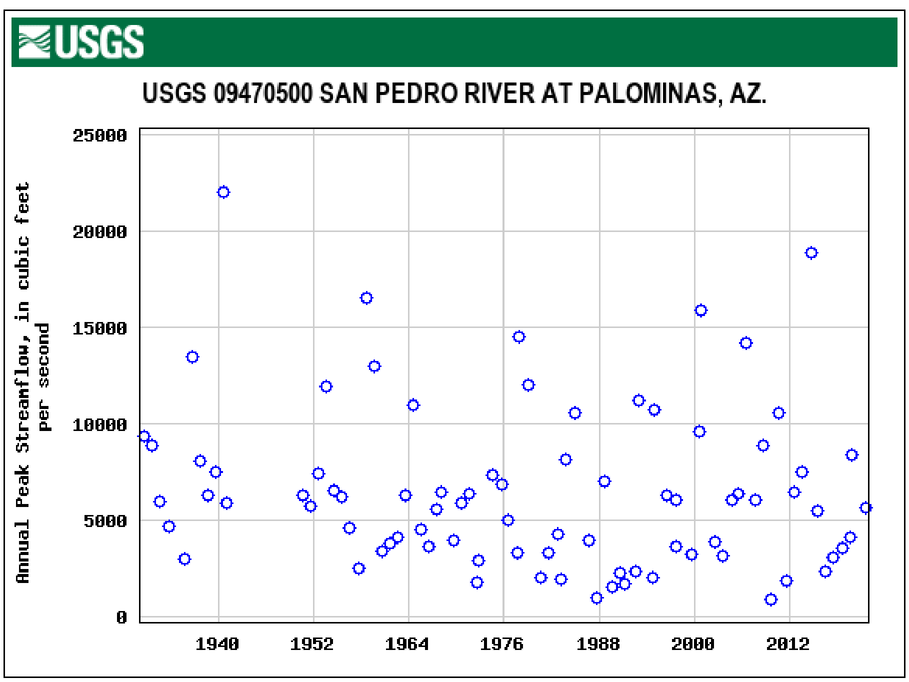


Figure 6: Flood gates torn from their hinges after the August 2021 monsoon on Silver Creek at the US-Mexico border wall. Photos by Fernando Sobrazo / Cuenca Los Ojos.

Figure 9: The San Pedro River watershed and cities/towns affected in historical accounts of flooding.

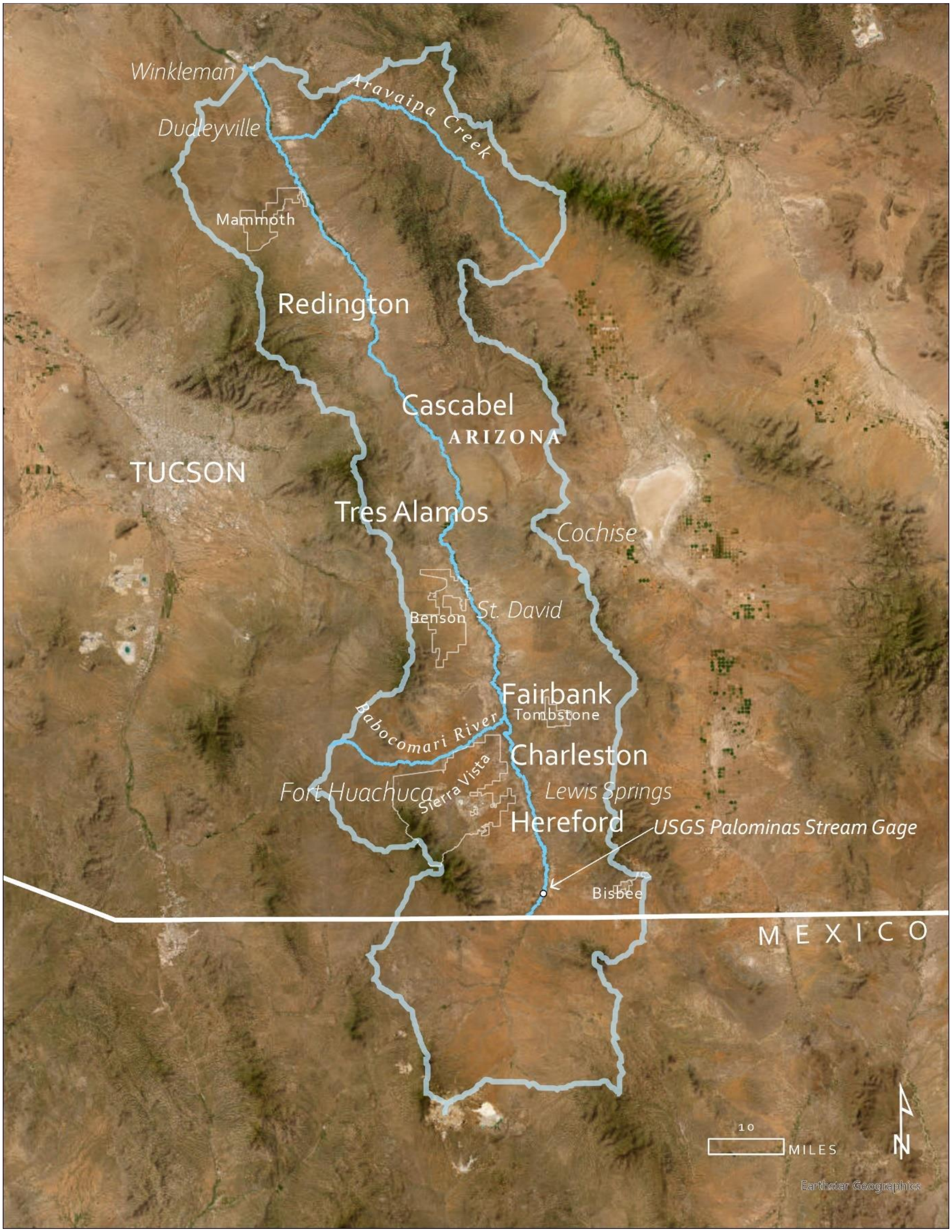


Figure 10a: Context within the San Pedro River Watershed and detail of study site (2 kilometers up- and downstream of the US-Mexico border wall).

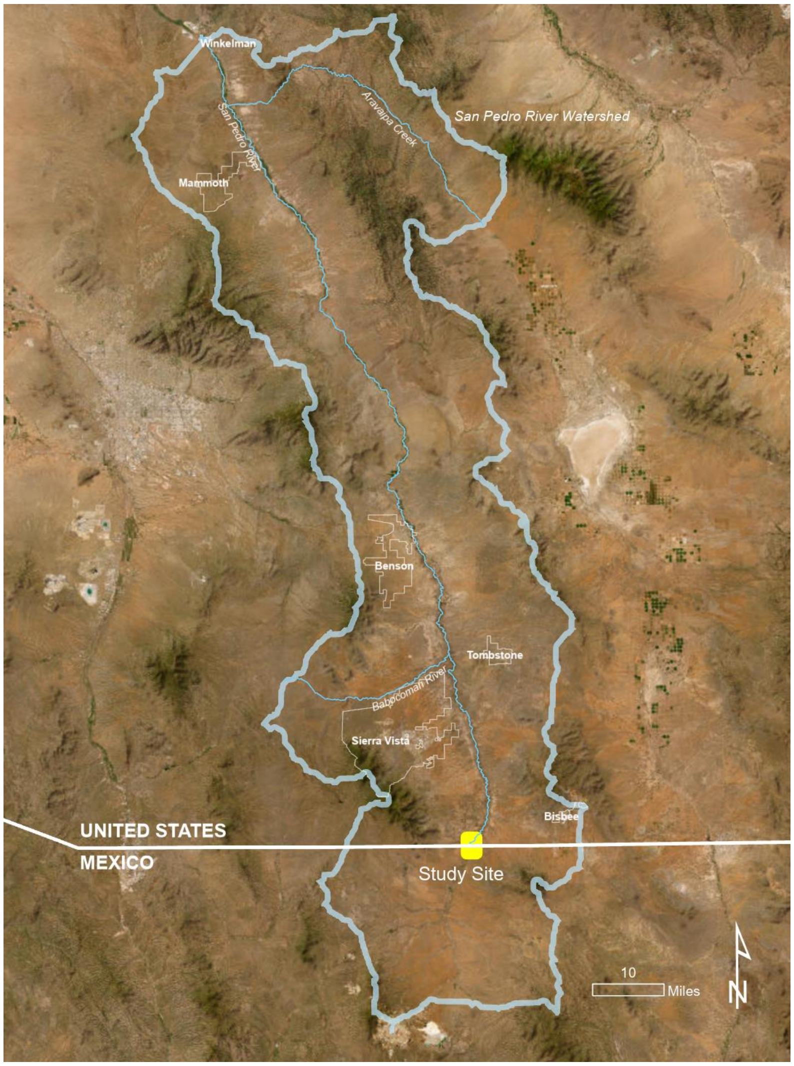


Figure 7b: Locations of photo stations (marked in teal), LWD surveyed in May 2021 (marked in yellow), and LWD surveyed in December 2022 (marked in blue) within the San Pedro River border wall study site (highlighted in green).

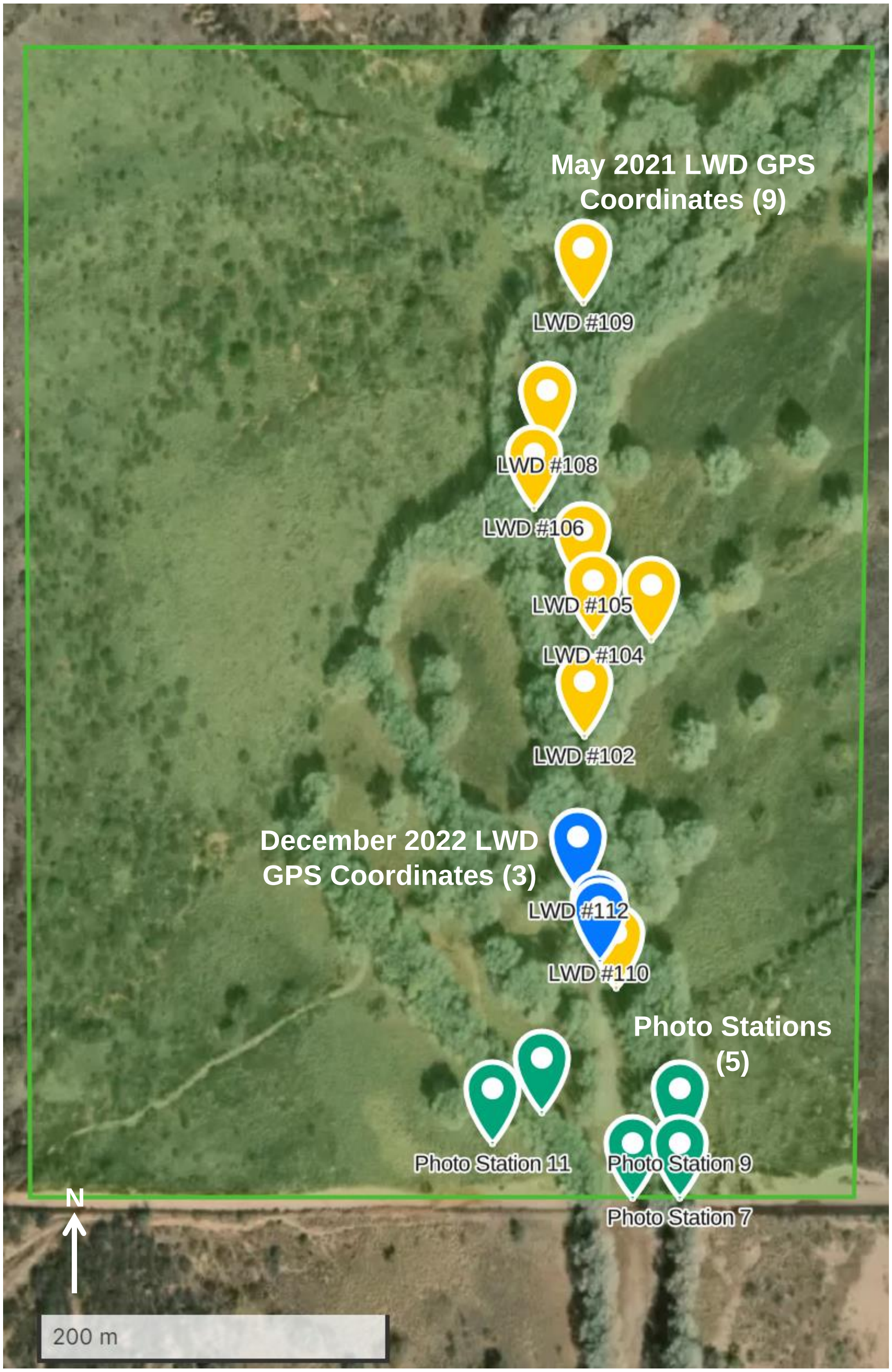


Figure 8: Generalized Flood Frequency Curve for the USGS Stream Gage San Pedro at Palominas.

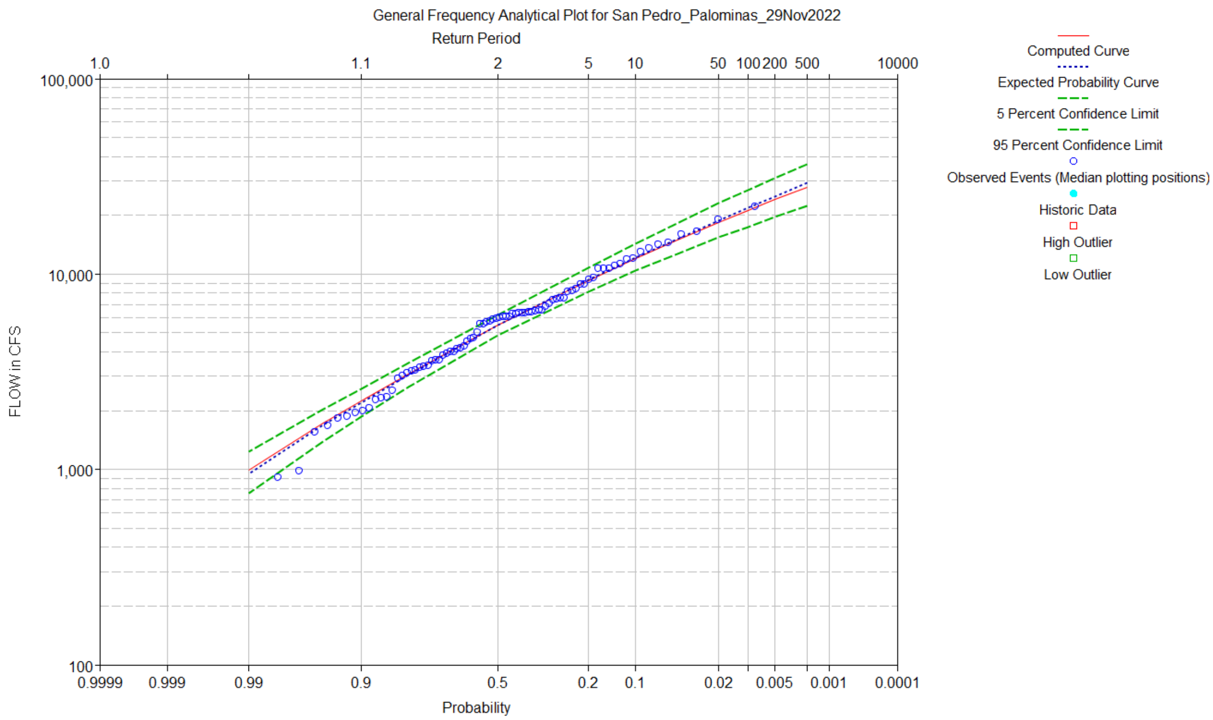
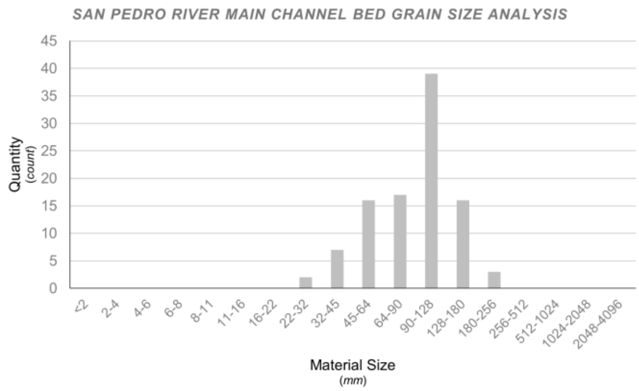


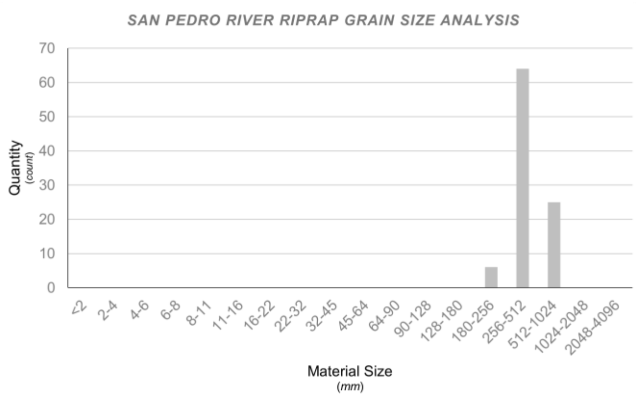
Figure 12: Looking upstream into the San Pedro River channel at the border wall floodgates following the August 2021 storms. Photo by Tony Heath.

Figure13: Woody debris accumulation following the August 2021 floods at the San Pedro River border wall. Photo by Tony Heath.

Figure 14: Results from pebble counts of riverbed material (top left), riprap (middle left), photos of riverbed material (top right) and riprap (middle right), and sketch of facies map (bottom center).

Grain Size Analysis





Grain Sizes Observed

Natural riverbed material(s): small gravels and fine sand.

Riprap placed during floodgate construction: large cobbles and small boulders.

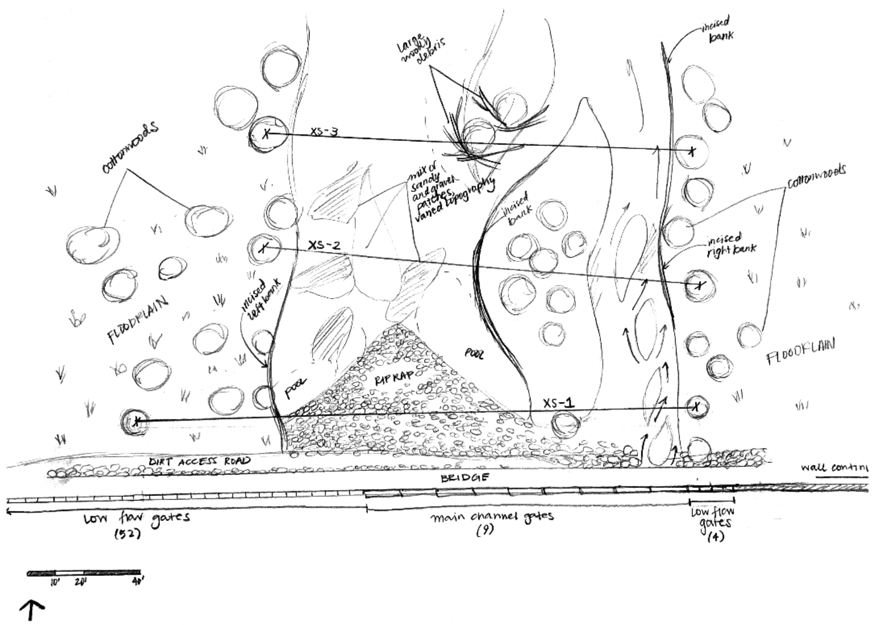


Figure 15: Select photo station results (May 2021 and December 2022 site visits).

<u>May 2021</u> **<u>December 2022</u>**

Photo Station 7

Photo Station 8

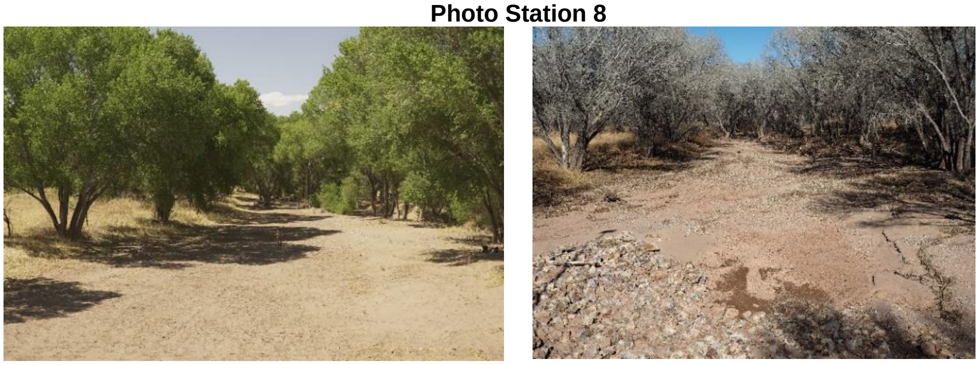
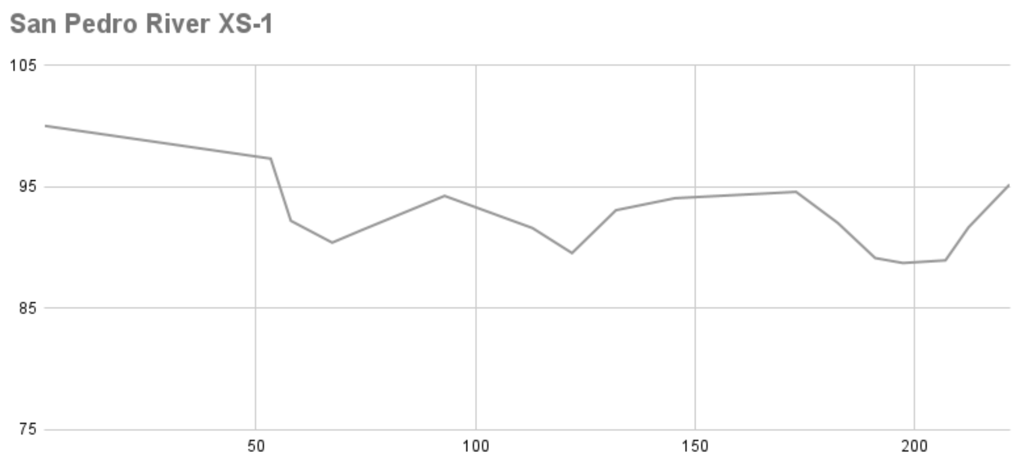
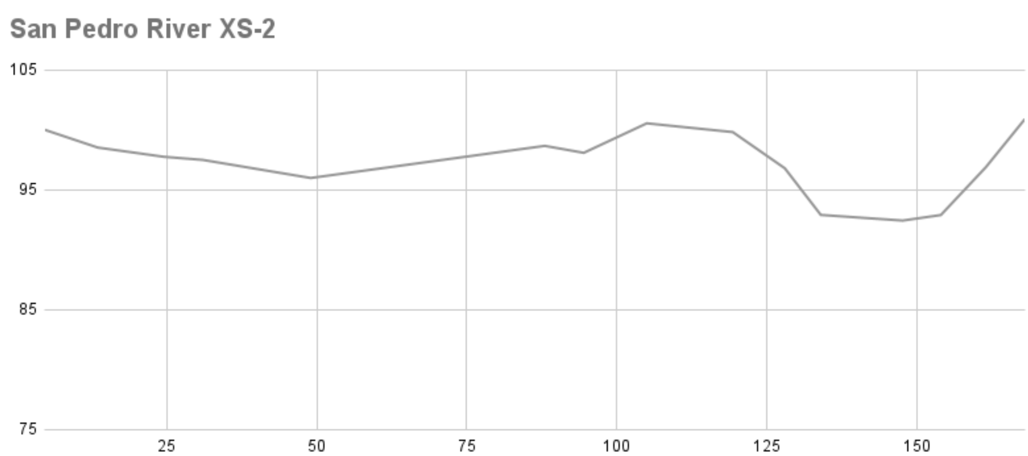


Photo Station 9

Photo Station 10

Figure 16: Cross sections surveyed in December 2022. Elevation is indicated on vertical axis in feet from arbitrary benchmark at each cross section. Horizontal axis represents horizontal distance from benchmark on left bank in each cross section.





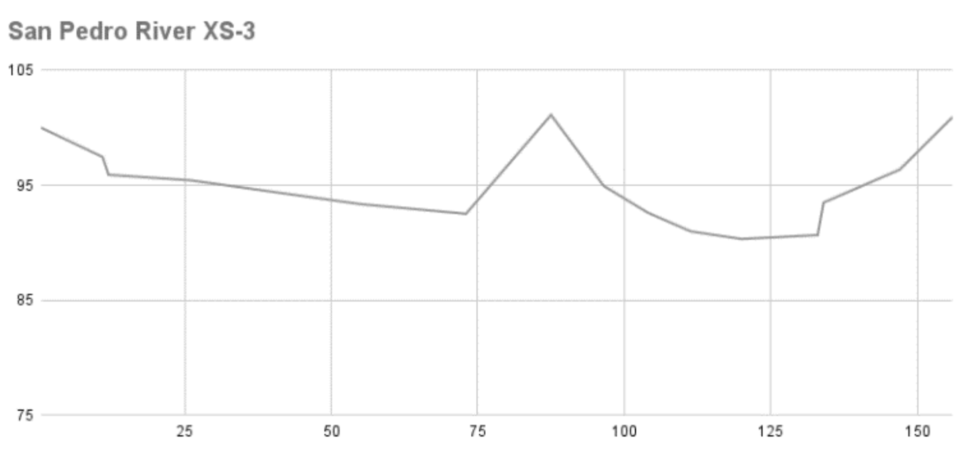


Figure 17: Section of the San Pedro River and floodplain at the US-Mexico border wall.

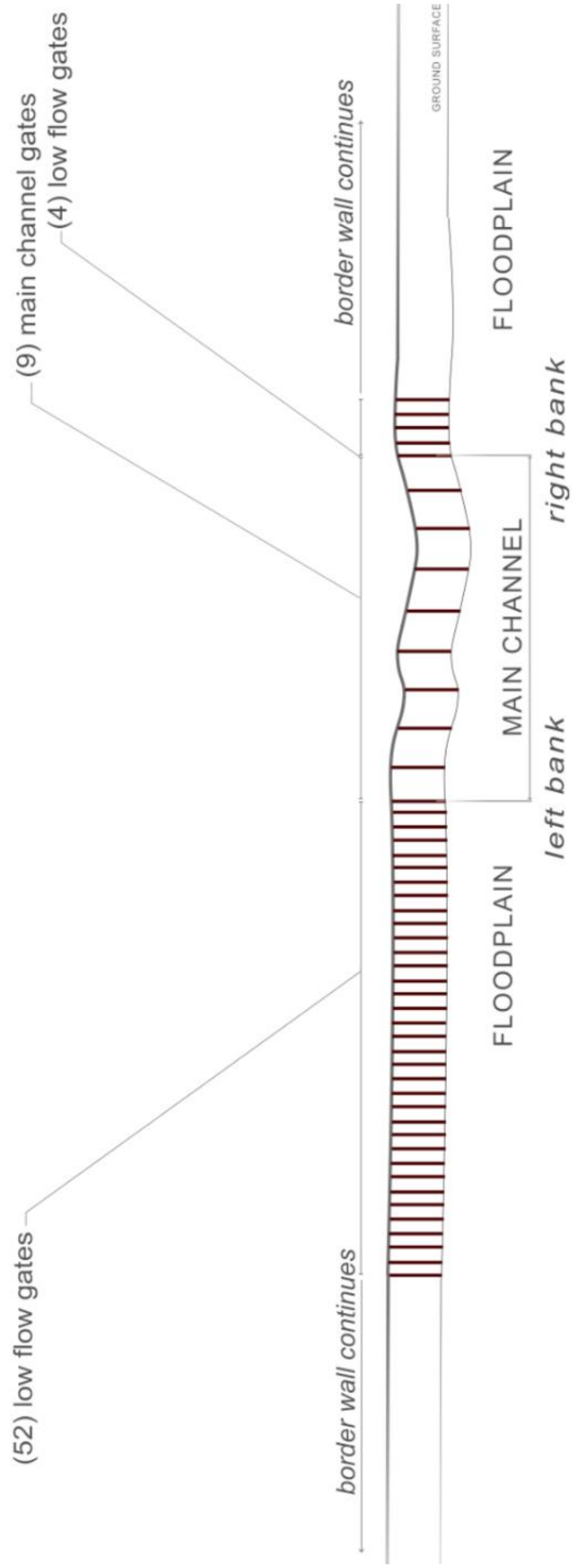


Figure 18: Aerial imagery (left) and digital elevation model (DEM; right) of the San Pedro River's topography approximately 0.5 kilometers upstream and 5 kilometers downstream of the border wall.

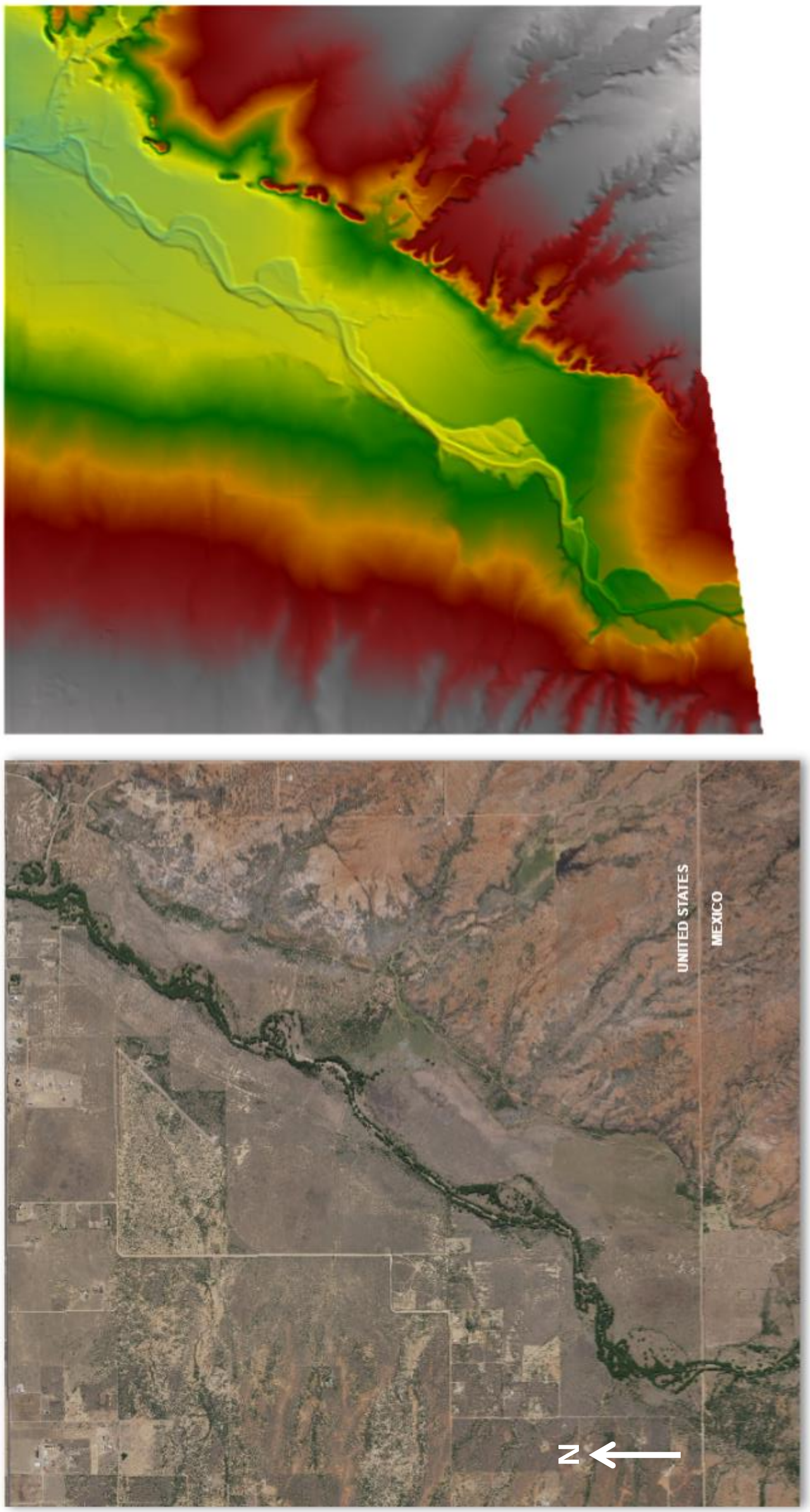


Figure 19: Hydrograph from August 13, 2021, event.

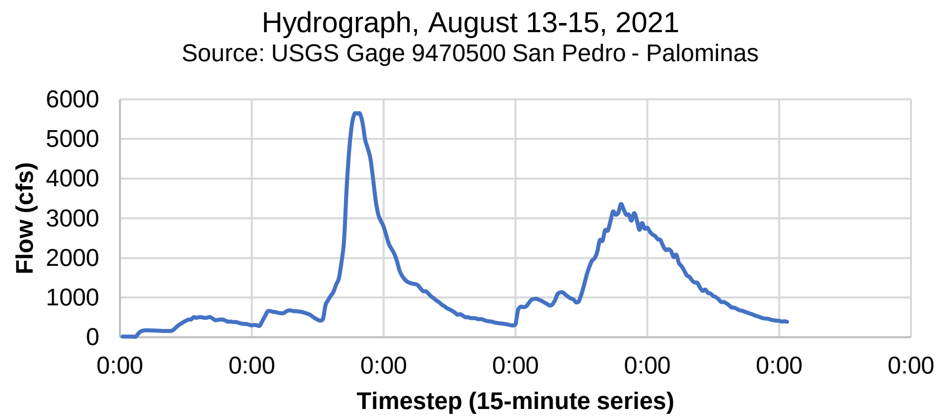
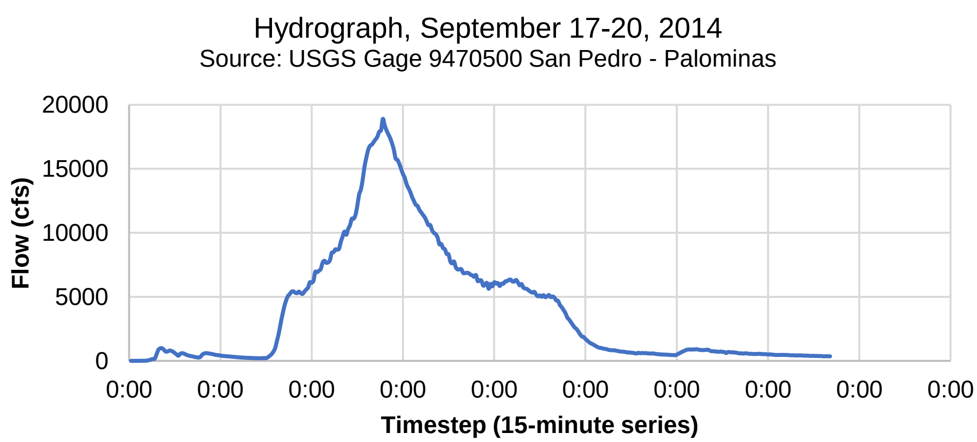


Figure 20: Hydrograph from September 17, 2014, event.



Tables

Table 1: Accounts of Flooding on the San Pedro River prior to 1930.

Date	Location	Publishing Source	Account
1887	Benson	*Arizona Weekly Enterprise*	"…for nearly the entire length of the river from Benson down to the Gila, the crops with the exception of hay have been destroyed by the recent floods. The oldest resident pronounces the river higher this season than it has been for years."
1889	Tres Alamos	*Arizona Weekly Citizen*	"The [San Pedro] river was on a boom last week – over half a mile wide and from five to twenty feet deep. The bridge was knocked down … repair will entail quite an expense."
1890	Dudleyville, Mammoth	*The Arizona Silver Belt*	"…great damage to farms and settlements along the San Pedro from Benson to its mouth … the river in many places changed its channel, cutting through farms and washing away houses in Mammoth and Dudleyville … the river … was rapidly undermining the intervening ground..."
1891	Tres Alamos	*Arizona Weekly Citizen*	"The flood did some damage … washed out crops and fences – but took no houses or livestock. This was mostly due to the freshet of last August, which dug down the channel of the San Pedro river an average of ten feet … the water of the present flood, greater in volume, did less damage."
1893	San Pedro River Valley	*The Arizona Silver Belt*	"Reports from the San Pedro valley are that water is running high in the river and that much of the country is flooded"
1896	Benson	*The Arizona Republican*	"…flood from the western end … tore out three miles of Southern Pacific track … a wall of water at least twelve miles long was poured into the San Pedro … cloudburst in the Whetstone mountains sent the floodwater through the east end of town, destroying several buildings. Twelve persons are believed to be drowned."
1896	Benson	*Tombstone Epitaph*	"…the last flood which proved so disastrous to Benson is again all washed away … about half a mile from town east and west of the bridge which crosses the San Pedro has been … washed away in places to a depth of four feet … rails with ties attached lifted bodily and deposited fifteen to twenty feet to one side."
1896	Boquillas	*Ecology and Conservation of the San Pedro River; Chapter Twelve* (Stromberg et al. 2012)	Development of a channel almost 244 meters wide and 6 meters deep
1899	*Not specified*	*The Arizona Republican*	"The San Pedro river has been a raging torrent during the past few days … banks have been overflowed."
1904	Fairbank, Lewis Springs	*Bisbee Daily Review*	"The heaviest flood known in this section swept down the San Pedro … the bridge across the San Pedro below Fairbank … was swept away … a mile of track between Fairbank and Lewis Springs was under water … the S.P. Bridge on the Nogales branch is also gone…"
1905	Fairbank	*The Bisbee Daily Review*	"…trouble occurred yesterday morning about a mile beyond Fairbank, the San Pedro, which is in high flood, carrying out a small bridge … the damage done … is said to be considerable, and is likely to close the road for a couple of days. The bridge at Clifton went out for the third time in four months … a repetition of washouts that have kept the road closed almost continuously during the last two months."
1914	Fairbank	*Tombstone Epitaph*	"…severe rain … in the southern part of the state on Monday … a mile from Fairbank suffered heavy losses from the flood … the waters, which uprooted trees and left a layer of mud and water over all the land. The San Pedro, which most of the year is only a small stream of water was the highest it has been for the past 20 years according to reports received from old timers in that section."
1914	Hereford, Benson, St. David, Fairbank	*The Bisbee Daily Review*	"…Nogales, Fort Huachuca, Florence and Ray are isolated … water damage on the San Pedro … have been the heaviest in history … raging torrent pouring down the valley was at all points in the neighborhood of one mile wide, and was showing no signs of lowering … water in their farms and residences was from three to ten feet deep … state highway bridge at Fairbanks was completely under water."
1926	Charleston	*Arizona Daily Star* (Tellman and Hadley, 2006; Noonan, 2015)	"The flood of 1926 was the greatest flood ever. Most of the water came down in the river over a 3-day period, knocking down bridges throughout the area. Every highway and railroad bridge on the San Pedro river from the International boundary line to where it flows into the Gila River below Mammoth were either destroyed or rendered useless last Monday evening and Tuesday morning when the San Pedro River, swollen by a three day rain, went on the most destructive rampage in its entire history."

Table 2: Photo stations IDs, GPS locations, compass bearings, and notes from May 2021 site visit.

Photo ID	Photo Station	Date, Time	GPS Location	Compass Bearing	Notes
PS7_Photo31_DSC00044	7	5/31/2021, 14:15	31°20'3"N 110°8'52"W	307°NW	Approx. 20' west of easternmost light on bridge
PS7_Photo32_DSC00046	7	5/31/2021, 14:16	31°20'3"N 110°8'52"W	270°W	Approx. 20' west of easternmost light on bridge
PS7_Photo33_DSC00048	7	5/31/2021, 14:17	31°20'3"N 110°8'52"W	238°SW	Approx. 20' west of easternmost light on bridge
PS8_Photo34_DSC00050	8	5/31/2021, 14:33	31°20'3"N 110°8'53"W	36°NE	Approx. 100' west of easternmost light on bridge
PS8_Photo35_DSC00052	8	5/31/2021, 14:34	31°20'3"N 110°8'53"W	2°N	Approx. 100' west of easternmost light on bridge
PS8_Photo36_DSC00054	8	5/31/2021, 14:35	31°20'3"N 110°8'53"W	320°NW	Approx. 100' west of easternmost light on bridge
PS8_Photo37_DSC00056	8	5/31/2021, 14:36	31°20'3"N 110°8'53"W	288°W	Approx. 100' west of easternmost light on bridge
PS9_Photo38_DSC00058	9	5/31/2021, 14:45	31°20'4"N 110°8'52"W	134°SE	Approx. 20' west of cottonwood on the right bank of secondary channel marked with nail and orange paint
PS9_Photo39_DSC00060	9	5/31/2021, 14:46	31°20'4"N 110°8'52"W	165°S	Approx. 20' west of cottonwood on the right bank of secondary channel marked with nail and orange paint
PS9_Photo40_DSC00062	9	5/31/2021, 14:47	31°20'4"N 110°8'52"W	101°S	Approx. 20' west of cottonwood on the right bank of secondary channel marked with nail and orange paint
PS10_Photo41_DSC00064	10	5/31/2021, 15:05	31°20'4"N 110°8'53"W	117°SE	Approx. 50' east of cottonwood on the left bank of main channel marked with nail and orange paint. Approx. mid-channel
PS10_Photo42_DSC00066	10	5/31/2021, 15:06	31°20'4"N 110°8'53"W	157°S	Approx. 50' east of cottonwood on the left bank of main channel marked with nail and orange paint. Approx. mid-channel
PS10_Photo43_DSC00068	10	5/31/2021, 15:07	31°20'4"N 110°8'53"W	196°S	Approx. 50' east of cottonwood on the left bank of main channel marked with nail and orange paint. Approx. mid-channel
PS10_Photo44_DSC00070	10	5/31/2021, 15:08	31°20'4"N 110°8'53"W	231°SW	Approx. 50' east of cottonwood on the left bank of main channel marked with nail and orange paint. Approx. mid-channel
PS11_Photo45_DSC00072	11	5/31/2021, 15:13	31°20'4"N 110°8'56"W	232°SW	Approx. 100' west of cottonwood on the left edge of floodplain marked with nail and orange paint
PS11_Photo46_DSC00074	11	5/31/2021, 15:14	31°20'4"N 110°8'56"W	189°S	Approx. 100' west of cottonwood on the left edge of floodplain marked with nail and orange paint
PS11_Photo47_DSC00076	11	5/31/2021, 15:15	31°20'4"N 110°8'56"W	149°SE	Approx. 100' west of cottonwood on the left edge of floodplain marked with nail and orange paint
PS11_Photo48_DSC00078	11	5/31/2021, 15:16	31°20'4"N 110°8'56"W	112°E	Approx. 100' west of cottonwood on the left edge of floodplain marked with nail and orange paint

Table 3: Large woody debris inventory including LWD tag numbers, length and width measurements, GPS coordinates, and notes from May 2021 site visit at the San Pedro River near the border wall.

Tag	Date Surveyed	Length (ft)	Width (ft)	CBH/DBM	GPS Coordinates		Notes	Observed at 2nd Site Visit?
101	May 2021	54	6	1.8	31.335241	-110.148148	Mid channel, back edge of high flow channel	No
102	May 2021	34	22	2.5	31.336525	-110.148343	Mid channel, right bank top of high flow channel	No
103	May 2021	19.5	1	1.6	31.337018	-110.147939	Right edge of major channel	No
104	May 2021	16	4.5	1.1	31.337006	-110.14829	Right edge of major channel	No
105	May 2021	18.5	3	1.6	31.337294	-110.148354	Right edge of major channel	Yes, remained in place
106	May 2021	46	4	1.4	31.337688	-110.148646	Right edge of minor, top of bank, min major	No
107	May 2021	19.5	1.1	11	31.338008	-110.148565	Right major, gnawed by beaver	No
108	May 2021	14	1	1	31.338008	-110.148565	Right side of major / mid major right of minor	No
109	May 2021	21	20	1.2	31.338734	-110.148348	Mid major, right of minor	No
110	Dec. 2022	26	0.75	-	31.33541	-110.14826	Part of debris buildup pile at cottonwoods between main and active channels; marked w/ 1 tag and orange spray paint in line pattern.	N/A
111	Dec. 2022	35	1.1	-	31.33537	-110.14825	Part of debris buildup pile at cottonwoods between main and active channels; marked w/ 2 tags and orange spray paint in dot pattern.	N/A
112	Dec. 2022	43.5	1.33	-	31.33573	-110.14838	Lodged between cottonwoods, LB active channel. Marked w/ 3 tags and orange spray paint in one line.	N/A

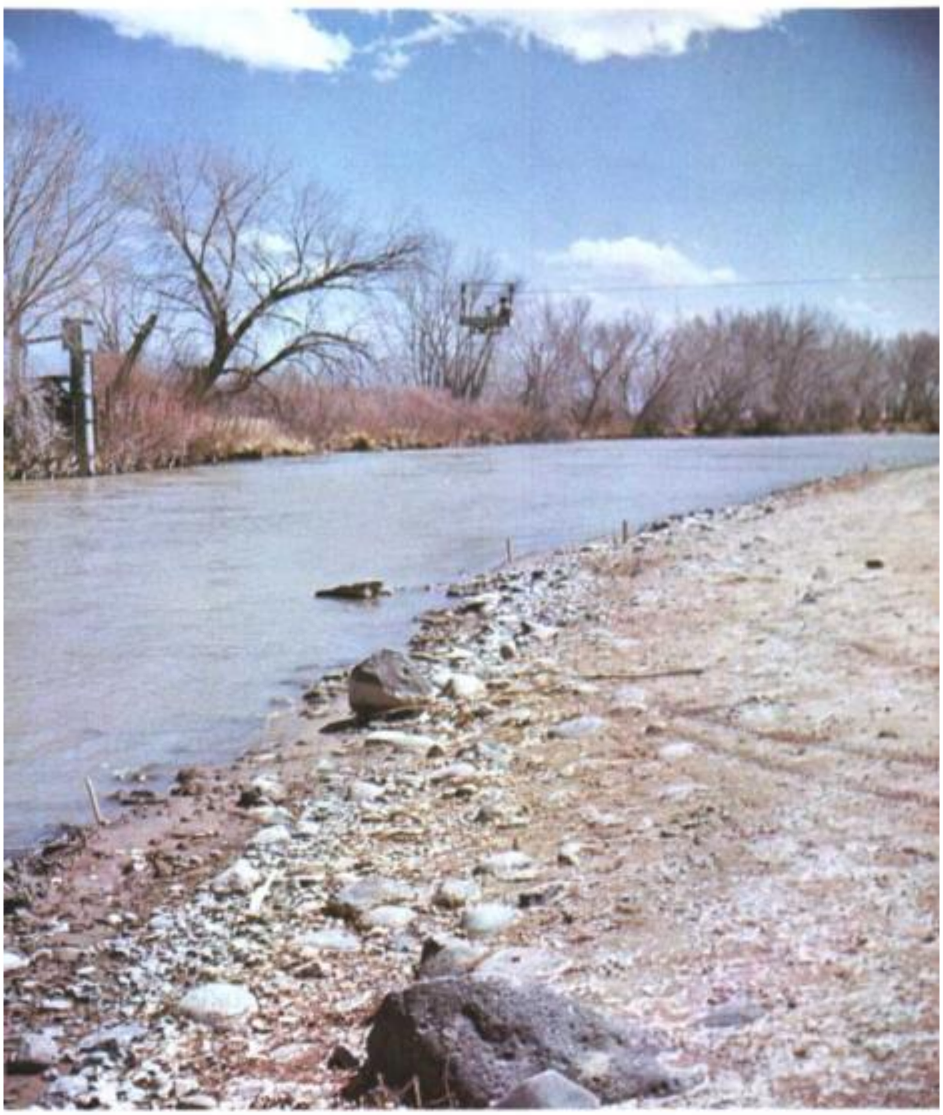
Table 4: Data and Sources for Modeling in HEC-RAS.

Input Requirement	**Data**	**Data Source**
Terrain and channel geometry	1-meter digital elevation model (DEM)	USGS
Floodgate locations and dimensions	Field measurements	May 2021 site visit (G.M. Kondolf)
Roughness coefficient	0.05	Field observation from May 2021 site visit and comparison to roughness estimates of other rivers on a visual basis (Barnes, 1967; Appendix A)
Upstream boundary condition	Stage time series (streamflow data, historical hydrographs)	USGS gage 09470500 (San Pedro River at Palominas)
Existing grade slope for distributing flow at up- and downstream boundaries	Held constant at 0.01 and 0.003 (average slope at upstream and downstream boundaries of the study site, respectively)	Google Earth Pro. NASA Shuttle Radar Topography Mission (SRTM) DEM
Downstream boundary condition	Normal depth	N/A
Debris stage(s)	0’ of debris accumulation 3’ of debris accumulation 6’ of debris accumulation	Site observations of debris conditions on the San Pedro River following 2021 monsoon season

Appendices

Appendix A**:** Color photographs with roughness coefficients determined by Barnes (1967) referenced to estimate channel roughness for the San Pedro River at the US-Mexico border wall.

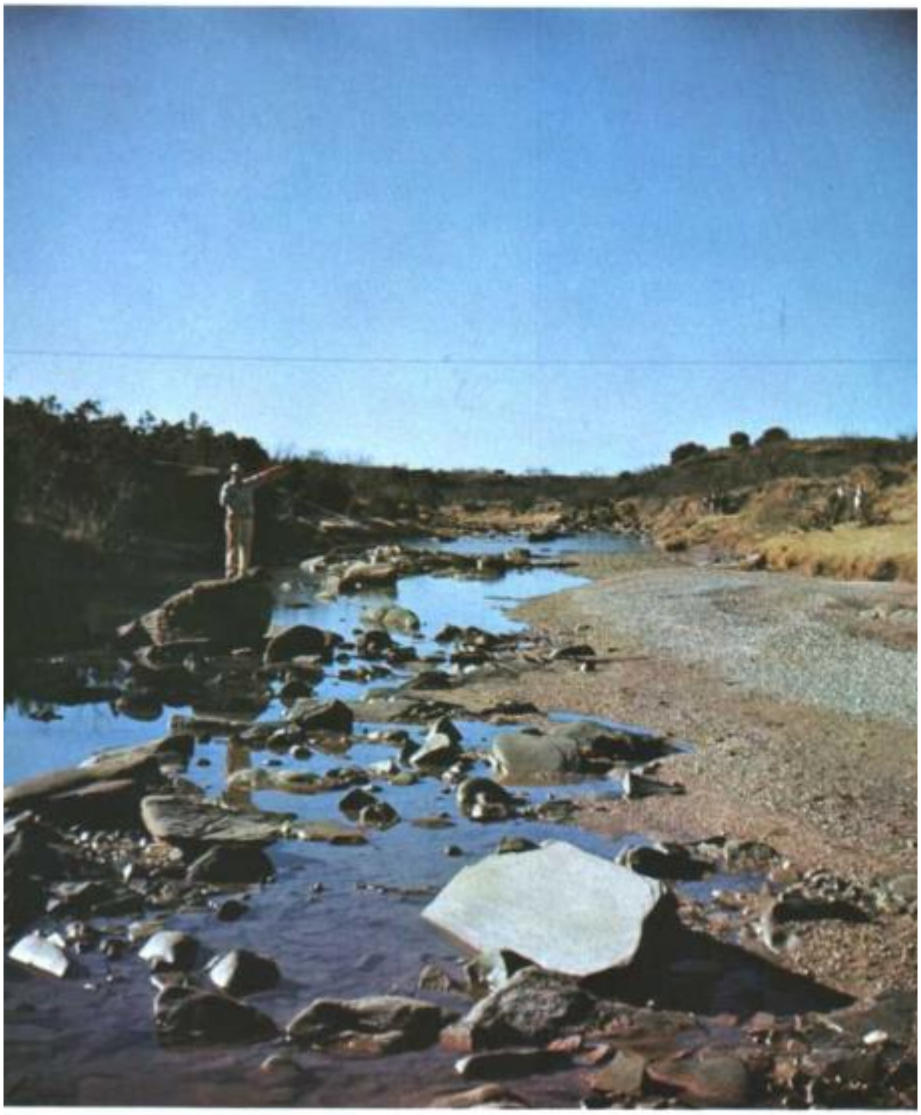
$n = 0.032; 0.036$



No. 550 downstream from right bank at section 1, Rio Chama near Chamita, N. Mex.

Roughness Characteristics of Natural Channels (Barnes, 1937), page 53.

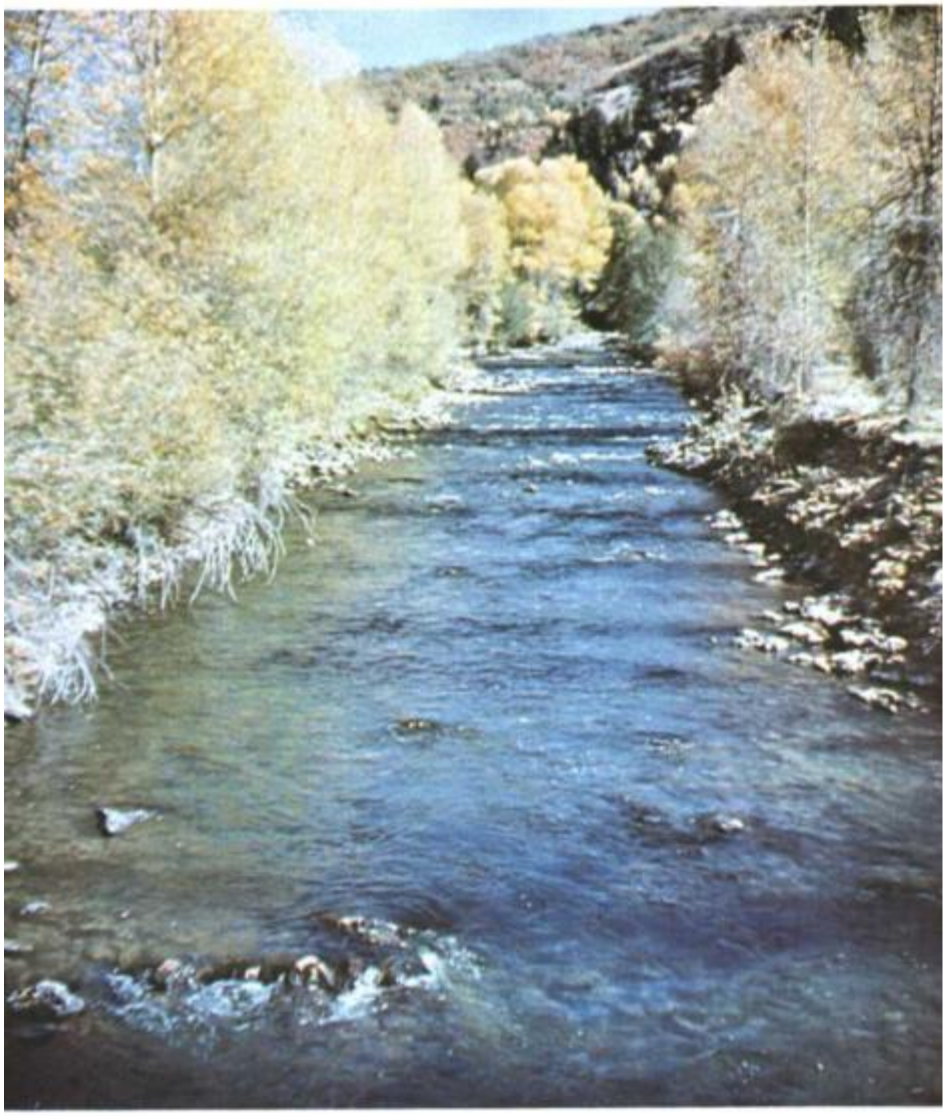
n = 0.041



No. 345 upstream from below section 2, Bull Creek near Ira, Tex.

Roughness Characteristics of Natural Channels (Barnes, 1937), page 101.

$n = 0.045; 0.073$



No. 770 upstream from section 3, Provo River near Hailstone, Utah.

Roughness Characteristics of Natural Channels (Barnes, 1937), page 137.

The San Pedro River looking downstream into the channel from the border wall (May 2021).