Identifying Environmental Flow Requirements for the Pecos River: Background Literature Review and Summary

September 2022

US Army Corps of Engineers®
Albuquerque District

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Acknowledgments

Thank you to the staff and agencies that have worked together to create this document. Each person has dedicated time and energy to make this literature review a useful tool for understanding the environmental flows on the Pecos River. Co-authors, editors, and technical experts include (listed by agency and alphabetical order):

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Pecos River inside of the Pecos National Historic Park.
Source: National Park Service Photo, https://www.nps.gov/peco/planyourvisit/fishing.htm

EXECUTIVE SUMMARY

The Sustainable Rivers Program is a joint venture between The Nature Conservancy and the U.S. Army Corps of Engineers. The Sustainable Rivers Program seeks opportunities to leverage existing river infrastructure operations, particularly dams, to benefit river ecology. Maintaining flood control and water management in the semi-arid southwest remains a top priority for these structures. However, these operations have also impacted downstream river ecosystems by modifying sediment supply and seasonal flow patterns.

The Sustainable Rivers Program aims to identify opportunities for ecosystem uplift while still operating in the constraints of U.S. Army Corps of Engineers and partner agency authorizations and responsibilities. The Sustainable Rivers Program achieves this goal by providing resources for a State of the Science report and delineation of biological needs in an environmental flows (e-flows) workshop. The e-flows workshop is an opportunity for stakeholders to discuss competing water uses that are relevant to their study area, and to work together to develop idealized hydrographs that would meet as many of these water uses as possible. The Pecos River e-flows workshop was held over two days 19-20 July 2022. A separate e-flows workshop summary report was completed October 2022.

The Pecos River was added to the Sustainable Rivers Program in 2020 with the objective to identify flow regimes that support ecosystem function, with components regarding river and floodplain habitat, fish and wildlife species, and water quality. The second objective is to explore whether the flow regimes that support ecosystem function can be achieved within the operational capacities of dams and water allocations of this system.

The U.S. Army Corps of Engineers and U.S. Bureau of Reclamation maintain several dams within the Pecos River Sustainable Rivers Program study area. Of these dams, Santa Rosa, Sumner, and Brantley were used to delineate geomorphic and hydrologic reaches for e-flows evaluation. Operational uses of the Pecos River dams are flood control and water management, particularly for water rights holders in the Carlsbad Irrigation District, the Pecos Valley Artesian Conservation District and Fort Sumner Irrigation District.

The objective of this report is to provide background information necessary to aid in the delineation of e-flows for the Pecos River. This report summarizes the history of water resources in the Pecos, including the impacts of river infrastructure on the natural hydrology. Background data includes ecology and biology flow needs, as well as hydrologic conditions before and after the various dam construction projects.

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1 INTRODUCTION

The Sustainable Rivers Program (SRP) is a joint venture between The Nature Conservancy (TNC) and the U.S. Army Corps of Engineers (USACE). The SRP examines opportunities to optimize reservoir releases and river flows to benefit river ecology while maintaining the federal mandates of the reservoir system in the United States. The Pecos River was added to the SRP in 2020. The aim of the Pecos SRP is to identify preferred flow regimes for ecosystem function, river and floodplain habitat, fish and wildlife species, and water quality, and explore whether it is possible to modify USACE's dam and U.S. Bureau of Reclamation's (USBOR) dam operations to accommodate these flow regimes.

1.1 Sustainable Rivers Program

The SRP was established in 2002 to improve the health and life of rivers by changing dam operations and management to restore and protect ecosystems, while maintaining or enhancing other project benefits. The SRP examines opportunities to optimize reservoir releases and river flows to benefit river ecology while maintaining the federal mandates of the reservoir system in the United States. Maintaining environmental flows (e-flows), or flows that benefit native species and ecological systems, would provide year-round river water levels suitable for the behavioral, reproductive, and habitat needs of river and floodplain flora and fauna (Richter, et al. 2006). The flow regime of the river also impacts nutrient cycling, sediment transport, and bank erosion. Deriving more favorable e-flows (from more favorable reservoir releases within the range of authorized reservoir releases) requires compiling available data and literature of each river system. SRP began in 1998 with an initial collaboration to improve the ecological condition of Green River, Kentucky. When the program was formally started, it involved 8 river systems. Funding was significantly expanded beginning in Fiscal Year 2020 and approximately 10,945 river miles (Figure 1).

Figure 1: Sustainable Rivers Program across the country.

SRP places rivers into the categories of **Advance**, **Implement**, and **Incorporate**. The **Advance** category is the first step– in this stage, stakeholders work with USACE to form e-flow prescriptions for a river basin. The Pecos River is in this category. The **Implement** category is when USACE tests an e-flow prescription to determine the optimum dam operations. The **Incorporate** category is when the e-flow prescription has been tested and becomes a regular operating procedure for USACE.

SRP has a well-established process to think about e-flows for an entire river basin that allows for adaptive implementation (Figure 2). In the first step, basin experts are gathered to discuss the problems in the basin and determine if there are opportunities. Next, TNC and USACE re-engage experts as they draft a review of the basin. This review gathers information about e-flow requirements for multiple organisms (fish, mussels, birds, etc.), habitat conditions (floodplain needs, etc.), and basin characteristics. Within this review, initial analysis is done to assess hydrologic alterations using pre- and post-dam water flow data. In the third step, expert stakeholders review the information and identify incompatibilities between hydrologic alterations and species/habitat flow needs. These experts brainstorm specific recommendations for flows. USACE models these recommendations and assesses how they can maintain their project authorized purposes while making improvements downstream. If a new flow prescription is implemented, research and data continue to refine the knowledge, so USACE is using adaptive management to maximize the downstream benefits.

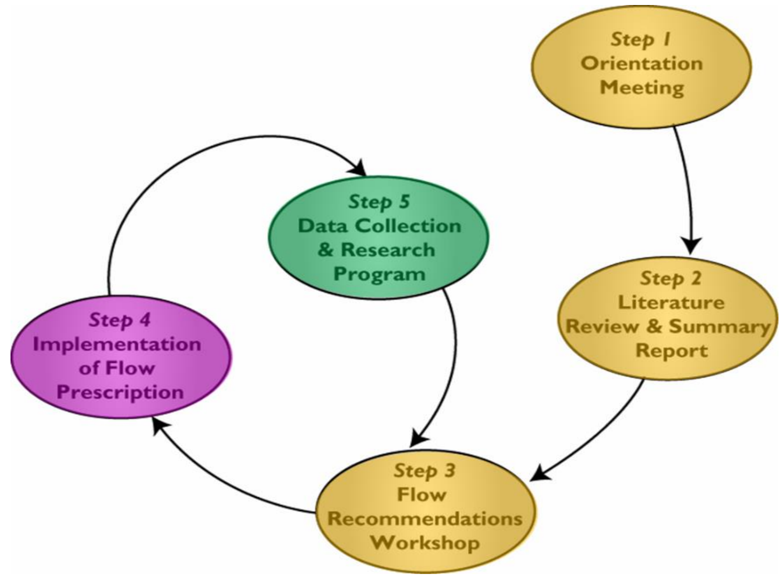

Figure 2: Sustainable Rivers Program process to consider and adopt e-flow prescriptions for a river (Richter, et al. 2006).

The first phase of the Pecos SRP was to gather experts to identify issues of concern and review the basin. The Pecos SRP launch meeting (Figure 2, Step 1) occurred with basin experts in June of 2020. This literature review and summary (Figure 2, Step 2) was designed to support and inform development of flow hypotheses for an e-flows workshop (Figure 2, Step 3) involving expert stakeholders. The review summarizes the natural and current range of variation in low flow, high flow and flood pulses, duration and frequency of each, and the rate of change from one condition to another. Background data includes ecology and biology flow needs, as well as hydrologic conditions before and after various dam construction projects.

1.2 Goals and Objectives

This literature review and report is designed to identify key aspects of flow regimes that are important in sustaining the ecological health of the river-floodplain systems on the Pecos River. The goals of this literature review include:

1. Understand dam operations and constraints.
2. Understand how dam operations have affected Pecos River hydrology by comparing pre-dam to current flow conditions.
3. Understand how flow changes have affected geomorphologic processes.
4. Understand the flow needs of native species and communities, especially the relationship between life stages and seasonal hydrographs, as well as describe how flow changes have affected those species and communities.

This literature review and report is a steppingstone to identifying and integrating the understanding of flow needs into real-time decisions about how and when water is released from the reservoirs to achieve more natural flow regimes, and to adjust operations as needed in response to monitoring and modeled responses throughout the Pecos River Basin.

1.3 Pecos River

The Pecos River watershed is located generally in the eastern part of New Mexico and western part of Texas. It is a large, elongated area extending in a north-south direction originating on the western slope of the Santa Fe mountain range. The Pecos River begins in Mora County, New Mexico, and runs south through San Miguel, Guadalupe, De Baca, Chaves, and Eddy counties in New Mexico before it enters Texas at its confluence with the Rio Grande in the Big Bend area of Texas. The river is approximately 970 miles long, traversing approximately 525 miles through about 25,470 square miles of New Mexico and 400 miles through about 19,070 square miles of Texas. The population in the entire basin is about 250,000 people: about 185,000 in New Mexico and 65,000 in Texas (Figure 3).

The Pecos River is an important water resource with a complex hydrogeology, and a number of different interests compete for water (recreation areas, agriculture irrigation districts, ecological resources (including protected areas), commercial and industrial wells, municipalities, and mining sites). Surface water (the Pecos River and its tributaries) in the study area is derived from three main sources: snowmelt in the Sangre de Cristo and Sacramento Mountains, precipitation from storm events, and groundwater inflows to the river. Annual and seasonal variations in precipitation and snowfall results in highly variable surface water flows. Stream flow in the Pecos River fluctuates between high flow events in the spring, due to snowpack runoff, and lesser events during monsoon season from July to September. Low flow occurs during the fall and winter months, and in the month of June (U.S. Forest Service 2002). From the headwaters high in the northern mountains to savannahs and Chihuahuan Desert grasslands and shrublands in the south, the aquatic and riparian ecosystems within the Pecos Basin are both unique and diverse.

The USBOR summarizes the water supply in the Pecos Basin in their 2021 Basin Study:

"The Pecos River basin's water supply includes surface and groundwater sources. The most recent data for the basin were compiled by the New Mexico Office of State Engineer (NMOSE) for calendar year 2015 (NMOSE 2019), when about 356,000 and 245,000 acre-feet of groundwater and surface water were withdrawn for use, respectively. The total supply was thus roughly 602,000 acre-feet, which was about 20% of the state's total.

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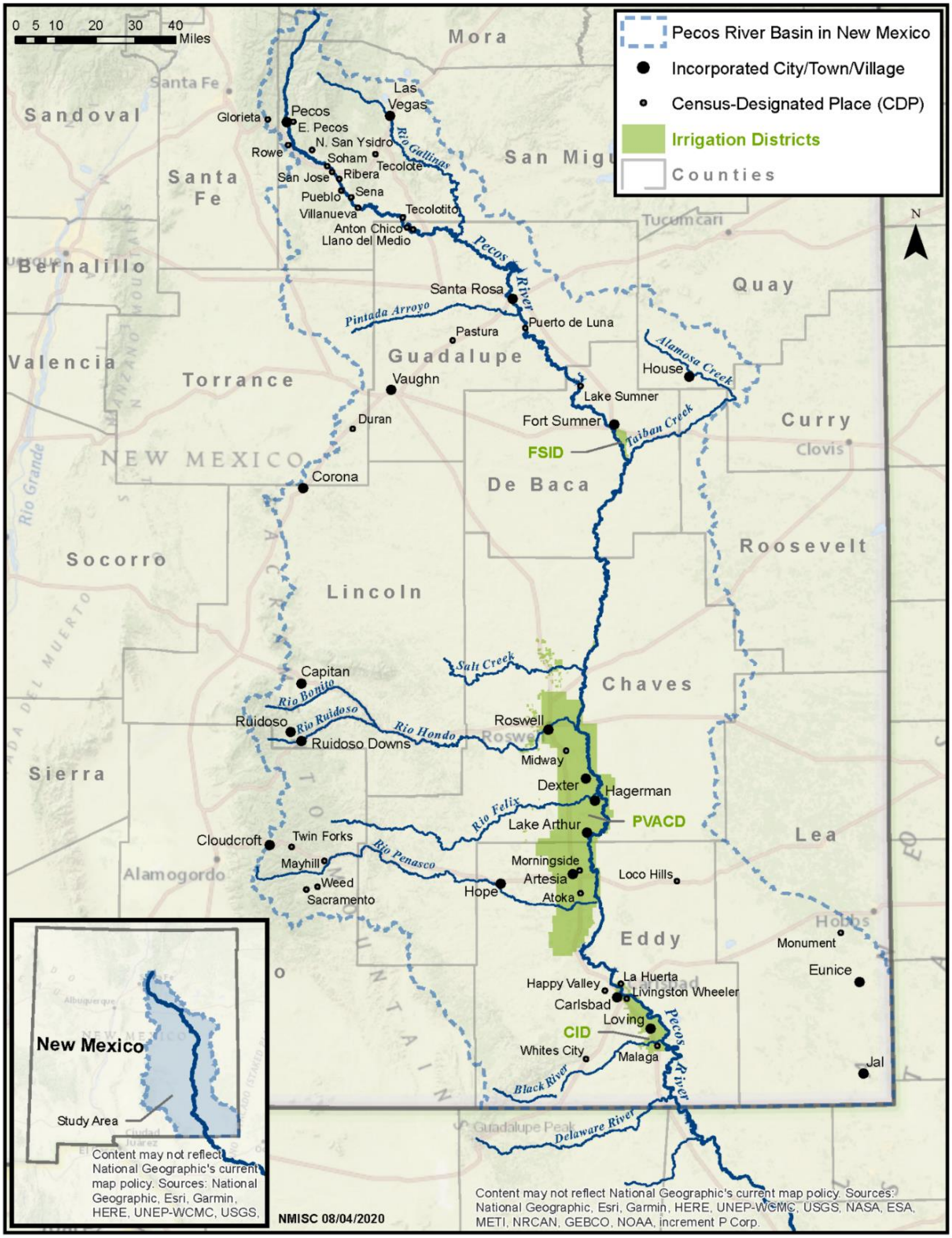

Figure 3: Counties, population centers, tributaries, and irrigation districts within the Pecos River Basin. Source: USBOR 2021, Figure 36.

1.3.1 Climate

The Pecos Basin has an arid continental climate characterized by hot summers and cool winters. Average summer maximum (minimum) July temperature is 85.3°F (52.9°F) at the Pecos, NM cooperative observer station (296676) in the northern portion of the basin and 96.0°F(61.9°F) at Bitter Lakes Wildlife Refuge (209992) in the southern portion of the basin near the Texas border. Average January temperatures are 47.1°F (15.1°F) and 57.1°F (20.8°F) respectively. Average annual precipitation at Pecos is 16.5 inches and at Bitter Lakes it's 12.67 inches, with the majority of it falling in the period May to October when monthly precipitation exceeds 1inch in each month. Higher elevation terrain is generally cooler and wetter than adjacent lower elevation areas. (National Weather Service 2020)

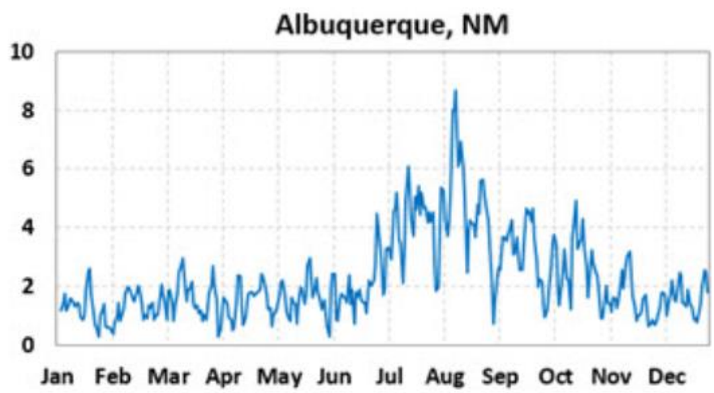

Figure 4: 2006 precipitation for Albuquerque, illustrating monsoon periods followed by dry "break" episodes. Y-axis represents the daily mean precipitation in millimeters. Source: National Weather Service 2020

Except in the mountains, winter precipitation is sparse in the Pecos River Basin because the mountains pull out most of the moisture from winter storms originating to the north and west, and as these air masses move into the Pecos Basin the downslope movement causes the air to warm and therefore dry out (Houghton 1965). In summer months, the region benefits from warm, humid air masses that originate over the Gulf of Mexico bringing in the monsoon rains (Figure 4). Precipitation results when these air masses are lifted over high terrain, over weather fronts, or by surface heating (Houghton 1965).These monsoon rains are separated by drier, less active breaks. The monsoons are supported by a variety of patterns of low-level moisture surges while the breaks often occur with an increase in westerly winds (National Weather Service 2020).

Over the last several decades, annual average temperatures in the Southwest have increased 1.61°F, among the largest increases in the Nation (Figure 5; Vose, et al. 2017). New Mexico has experienced increases in temperature, with increases in the number of extremely hot days over 100°F and summer nights above 70°F and decreases in the number of nights where temperatures drop below 0°F (Frankson, et al. 2017). There has been no trend in the precipitation data (Frankson, et al. 2017). However, the increase in temperature has driven up evapotranspiration rates and pushed the state into moderate to severe drought over most of the period 2000 to present (Williams, et al. 2020).

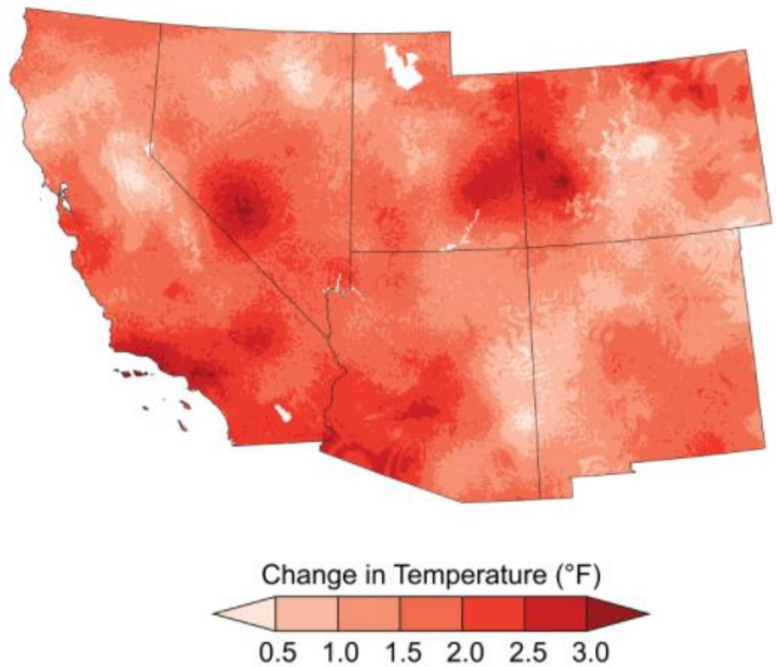

Figure 5: Temperatures increased across almost all of the Southwest region from 1901 to 2016, with the greatest increases in southern California and Western Colorado. This map shows the difference between 1986-2016 average temperature and 1901-1960 average temperature. Source: Adapted from (Vose, et al. 2017)

1.3.2 Climate Change

Climate change is anticipated to impact the basin primarily through increases in temperature (and thus increased evapotranspiration); projected changes to precipitation are small, occur in the context of high inter-annual variability, and model results differ by both magnitude and sign (Frankson, et al. 2017). Average temperatures are projected to increase between 3.72°F to 4.80°F by mid-century (avg. for 2036 - 2065, lower and higher emissions scenarios respectively[1]), and 4.93°F-8.65°F by late-century (2071-2100) compared to the historic era (1976–2005; Vose et al. 2017). Temperature extremes may increase by more than 10°F by century's end (Vose, et al. 2017).

Even under conditions where precipitation increases, the effects of temperature rise is expected to negatively impact water resources, soil moisture, and water budgets in the Pecos River Basin leading to increased aridity (Frankson et al. 2017; Vose et al. 2017):

- Mountain snowpacks and April 1st snow water equivalent will be reduced because warmer temperatures will cause an increasing share of snow to fall as rain and will cause snow to melt or sublimate in winter and spring. The result will be an increase in the share of the runoff occurring in winter and early spring runoff, an increase in loss to

[1] These are emissions scenarios used in the Fourth National Climate Assessment, with lower corresponding to relative concentration pathway (RCP 4.5) and higher to RCP 8.5 (USGCRP 2017).

soil infiltration, and a reduction in water storage in the snowpack. Spring runoff volumes are anticipated to decline, and the supply of water provided by snowmelt runoff is anticipated to decrease. Peak spring runoff is likely to occur earlier in the year by century's end than at present. Spring precipitation is projected to decrease (Easterling, et al. 2017), especially in the southern portion of the basin, exacerbating the effects of temperature on runoff.

- Higher temperatures will expand the potential growing season, allowing for earlier spring green-up and increased plant water demand over a longer growing season.
- Warmer air can hold more moisture, and in water-limited climates may draw more moisture from the soil. Therefore, soil moisture is anticipated to decline. Increased plant transpiration rates, and increased surface water evaporation rates are also projected to result from increased temperatures.
- Droughts are projected to become more frequent and more intense, driven by the effects of temperature increase alone (Breshears, et al. 2005).
- Droughts will increase the occurrence and severity of wildfires, and the frequency of dust storms (Frankson, et al. 2017).

Precipitation changes have high uncertainty but include:

- An increase in the frequency and/or magnitude of the heaviest precipitation events is expected regardless of how precipitation changes. Under the higher scenario the number of extreme events exceeding a 5-year return period increases by a factor of two or three by century's end compared to the historical average (Easterling, et al. 2017); smaller increases are projected under the lower scenario.
- Changes in monsoonal precipitation are highly uncertain, especially outside the core North American Monsoon region.
- Interannual variability in precipitation is determined in part by sea surface temperatures in the Pacific Ocean (El Nino-Southern Oscillation) cycles, and there is little model consensus of how these cycles may change in the future (Perlwitz, et al. 2017). The same applies to other modes of atmospheric variability that may impact precipitation and drought in the Southwest.
- There is little evidence for changes in the frequency of landfalling tropical cyclones in the U.S. (Easterling, et al. 2017), and therefore no information on how these infrequent contributors to precipitation in the region may change in the future.

2 WATER RESOURCE MANAGEMENT

Along the Pecos River, five dams control the flow of the water: Santa Rosa, Sumner, Brantley, Avalon, and Red Bluff (See Figure 3). The first three listed are included in the Pecos SRP (Table 1). There are three major reservoirs in the study area: Santa Rosa, Sumner, and Brantley. Santa

Rosa Dam is owned and operated by USACE, the other dams are owned and operated by USBOR.

Distribution of water resources are primarily controlled by the Pecos River Compact, which was signed in 1948 by New Mexico and Texas and amended by the U.S. Supreme Court in 1988. The Pecos River Compact compels the state of New Mexico to deliver a certain quantity of water to Texas yearly. As a result of the 1988 ruling, a River Master was appointed to oversee the accounting of deliveries. Essentially, New Mexico is required to provide to Texas 45% of the water that flows past Sumner Dam plus a percentage of any flood water between Sumner Dam and the Texas state line (Thorson 2003).

2.1 Dams and Reservoirs

Santa Rosa Reservoir, Sumner Reservoir, and Brantley Reservoir are all authorized for flood control and irrigation water storage. All provide significantly more storage in their flood control pools (the maximum volume of water that can be stored for flood control purposes) than they do for irrigation. Any storage space above the conservation pool is reserved for flood control. Further information regarding Dam and Reservoir Operations is covered in Appendix B.

Table 1: Dams in the study area. All elevations are given in NAVD88

	Santa Rosa Dam	Sumner Dam	Brantley Dam
Owner	USACE	USBOR	USBOR
Authorized	1954	1935	1972
Opening Year	1979	1939	1987
Purpose	Flood control, irrigation storage	Flood control, irrigation storage	Flood control, irrigation storage
Construction Material	Rolled Earth & Rock	Earth & Rockfill	Central concrete gravity section with earth sections on each side
Drainage Area Above Project (sq mi)	2,630	1,483[1]	13,208[2]
Crest Length / Crest Width (ft)	1,950 / 36	3,675 / 30	[3]See Below
Top of Embankment Elevation (ft)	4,826.11	4,302.88	3,308
Conservation Elevation (ft)	4,749.55	4,262.88	3,272.60
Flood Control Storage (acre-ft)	167,000	53,000	189,700
Entitled Storage for Irrigation (acre-ft)	99,763	32,871	40,000
Sediment Reserve (acre-ft)	82,000	64,000	116,000
Minimum Pool (acre-feet)	0	2,500	2,000

[1] Drainage area between Santa Rosa Dam and Sumner Dam

[2] Drainage area between Sumner Dam and Brantley Dam excluding the area upstream of the Two Rivers Project on Rocky Arroyo and the Rio Hondo

[3] Total dam length is approximately 4 miles. The concrete section is 730 ft long and 143.5 ft high with the roadway elevation at 3,308.5 ft. The east wing dam is 12,059 ft long with a crest width of 24 ft and the crest elevation is 3,308 ft. The west wing dam is 8,020 ft long with a crest width of 24 ft and the crest elevation at 3,308 ft.

Reservoir storage varies annually and seasonally. Droughts can drastically reduce storage volumes, but storage levels can recover rapidly following an extreme storm. Figure 6 shows the relative storage amounts and seasonal and drought year variations. Note the immediate recovery after the drought of 2011-2013, due to a large regional storm.

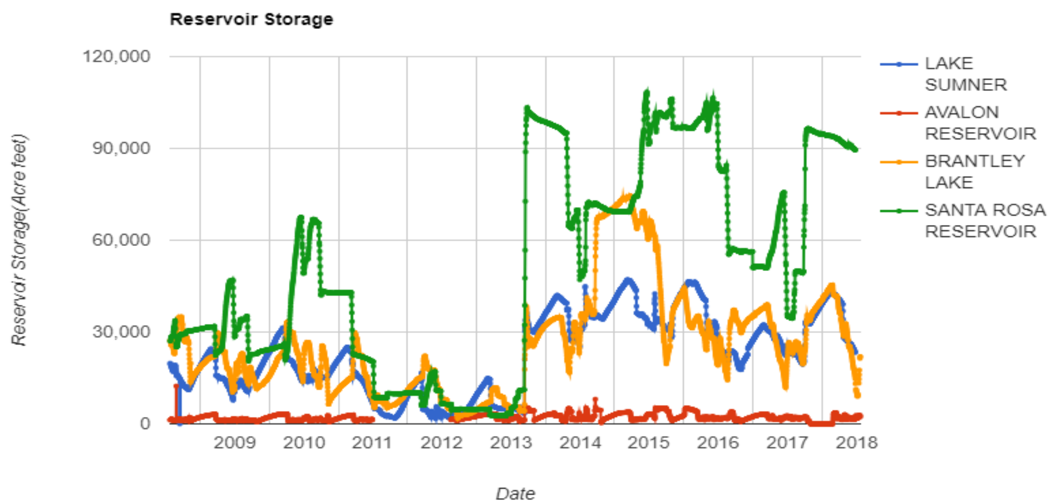

Figure 6: Reservoir storages from 2009-2018 (data derived from USBOR 2019).

2.2 Irrigation Districts

Irrigation districts along the Pecos River also have a large say in how water is transported and used in the basin. The three main irrigation districts are Fort Sumner Irrigation District (FSID), Pecos Valley Artesian Conservancy District (PVACD), and Carlsbad Irrigation District (CID). See Figure 3

2.2.1 Fort Sumner Irrigation District

Fort Sumner Irrigation District, in De Baca County, diverts water directly from the Pecos River about 3 miles northwest of Fort Sumner and about 17 river miles downstream from Sumner Dam. FSID diverts water from the Pecos River's east bank into a large canal to irrigate roughly 6,500 acres of farmland southeast of the village of Fort Sumner (Holdeman 2018). FSID receives a two-week entitlement calculated by the NMOSE office in Roswell. The two-week entitlement is the daily averages of the Above Santa Rosa gage, the below Santa Rosa gage, and with a one day lag the Puerto de Luna gage. This calculation determines what is called the run-of-the-river right. FSID has a run-of-the-river right to the "natural flows" in the Pecos River up to 100 cfs.

A typical rotation cycle in FSID is 21 days, though the cycles can be shorter. This cycle works well for alfalfa, which can handle infrequent but substantial watering. The cycle length can inhibit crop diversification; however, as many other crops are ill-suited for this cycle, requiring more frequent, moderate watering (ARC 2016). As a result, most of the land in FSID is currently used to grow alfalfa.

Actual diversion amounts vary due to maintenance, irrigation requirements, storms, etc. This modeling study used 1950-2009 calculations to determine historical entitlements (Figure 7), and a value of 6,500 acres for the irrigated acreage. Actual FSID entitlements ranged from a low of 38,224 acre-feet in 1956 to the entire entitlement amount from 1992 to 1995 and from 1997 to 1999.

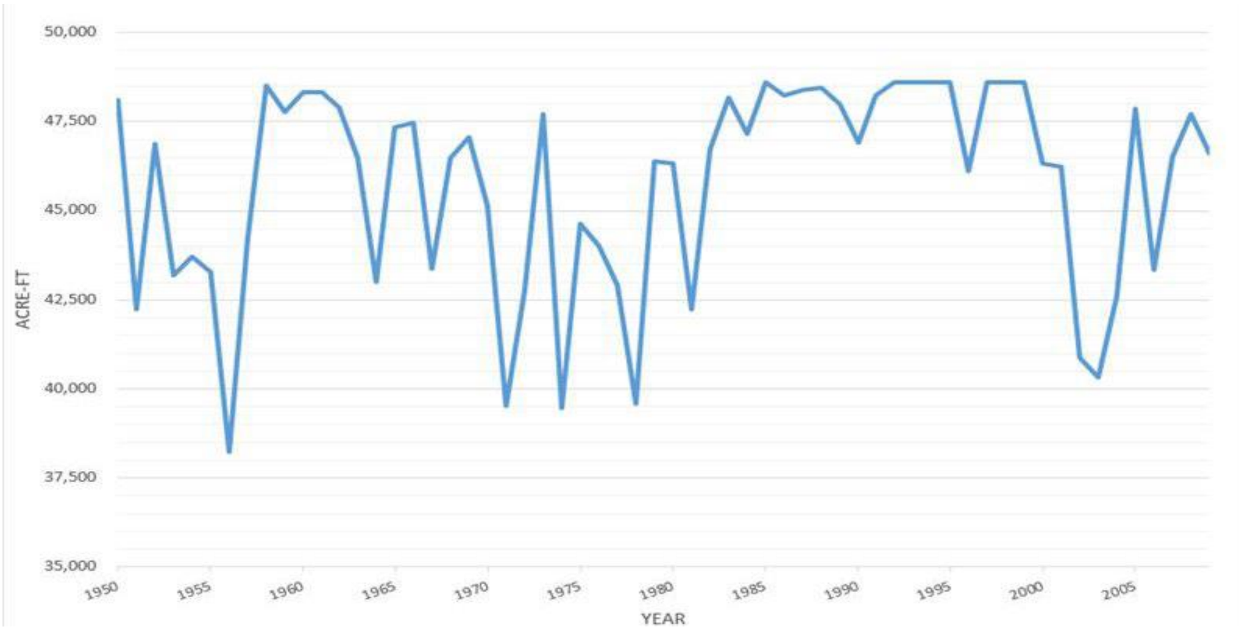

Figure 7: Calculated historical FSID entitlements. Note that entitlements are different from actual use and do not account for additional limited winter diversions. Values range between 35,000 and 50,000 acre-feet (USBOR).

2.2.2 Pecos Valley Artesian Conservancy District

Pecos Valley Artesian Conservancy District lies in Chaves and Eddy Counties, downstream of FSID and upstream of CID. Groundwater from the Roswell Artesian Basin and associated alluvial aquifer is the principal source of water used to irrigate about 110,000 acres of farmland (Balok 2019). PVACD has groundwater rights, with rights to limited surface diversions from the Rio Hondo River.

2.2.3 Carlsbad Irrigation District

Carlsbad Irrigation District is downstream of both FSID and PVACD in Eddy County and lies mostly to the southeast of the City of Carlsbad and west of the Pecos River. CID irrigates primarily using surface water obtained from the Pecos River, and supplements this with groundwater pumping. CID irrigates about 20,000 acres of farmland extending from just below Avalon Dam to south of the Black River (Ballard 2019).

The CID main diversion is located at Avalon Dam downstream of Carlsbad and on the west side of the Pecos River. CID has the sole storage permit on the Pecos River, with storage in four reservoirs on the main stem of the river. CID operates Sumner, Brantley and Avalon Dams, which are maintained jointly by CID and USBOR. CID also holds the rights to conservation storage in Santa Rosa Reservoir (operated by USACE). Currently there is only CID water stored in Santa Rosa. At some point in the future there may be supplemental irrigation water for USBOR use stored in Santa Rosa. In any case, CID can call for their water in Santa Rosa at any time, limited only by dam safety concerns and weather conditions. There are no legal or operational regulations or constraints for release of CID's water to Sumner. CID could call for all the water that is in Santa Rosa Lake and drain the lake.

The volume of water that CID has diverted annually from the river, as measured by USGS Gage 08403500 (Carlsbad Main Canal), has fluctuated over the years, in part due to water availability, averaging 72,588 acre-feet (2.897 acre-feet per acre) from 1950-2009.

The following is an excerpt from Tetra Tech (2000) describing the irrigation demands in a typical year.

"The CID irrigation season typically runs from March 1st through October 31st, at the time of reporting, the allotments range from 100 to 375 cfs (Tetra Tech 2000). The most significant diversion begins in mid-March for the first irrigation of alfalfa and for pre-planting cotton; the next in mid-May for the second irrigation of alfalfa. In June, the diversion increases for the first irrigation of cotton and hay. During July and August, the diversion is continuous for irrigation of all crops. During early September, watering of new hay begins. Diversions gradually decrease as the irrigation season ends October 31st."

CID allotments are measured by on-farm deliveries. The historical records of allotments from CID (1950-2009) show an average CID allotment of 2.47 acre-feet per acre on the farm (Figure 8). In 2016, CID was allotted the maximum amount of 3.697 acre-feet per acre. The volume of surface water that CID diverted in 2016 was 71,409 acre-feet as measured at the Main Canal (USGS Gage 08403500). CID irrigated 17,121 acres of land with this water (Ballard 2020).

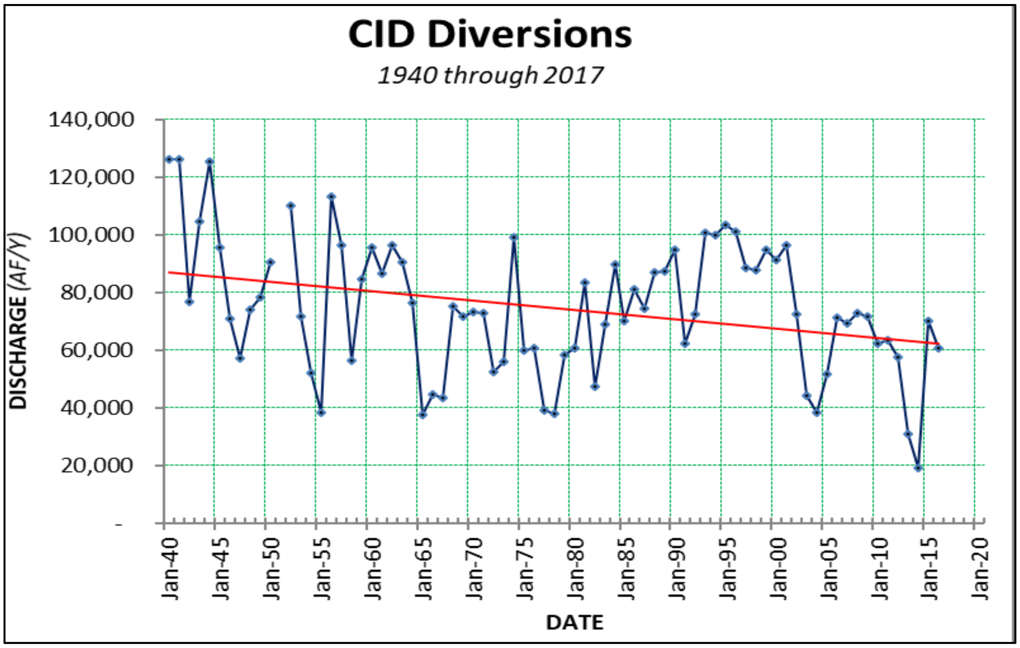

Figure 8. CID Diversions 1940-2017 (USBOR).

Although the four reservoirs can store a maximum of 176,500 acre-feet of irrigation storage, well over double CID's average annual diversions and almost 50% more than their maximum allowed annual use, the system lacks the ability to provide adequate storage during a multi-year drought. Once evaporation from reservoir surfaces and conveyance losses (incurred in moving water from the upper reservoirs to Brantley Reservoir) are accounted for, the effective amount of water stored for CID is substantially lower, and at full capacity the system stores approximately one year's worth of water for the district.

Rainfall patterns in the basin are highly variable. While a single extreme storm event can replenish the entire system and effectively end a drought in a few days, such storms cannot be depended on. Location of storms is also critical—an extreme storm between Sumner Reservoir and Brantley Reservoir could contain enough water to refill the system, but only 40,000 acre-feet could be stored due to Brantley Reservoir's conservation storage limits. Moreover, if the rainstorm is late in the irrigation season, farmers cannot use the water that year. For example, in 2013, CID had a significant rain event in September, and went from 0.8 acre-feet per acre allotment to begin the year, to a much higher allotment of 2.0 acre-feet at the end of the irrigation season. However, due to the timing of the storms, farmers could not make use of the higher allotment. Those with supplemental wells could pump during the drought but preparing for the next year was all that those without supplemental wells could do. Lack of resilience to multi-year droughts is a significant challenge to CID operations, one that will be exacerbated should future conditions become drier and hotter due to climate change.

2.3 Block Releases

Block releases have been determined to be the most efficient, least loss way to deliver water from one reservoir to another in the Pecos Basin (CID, NMOSE, Stockton, TetraTech, etc). A fine scale look at block releases is shown in Figure 9 below.

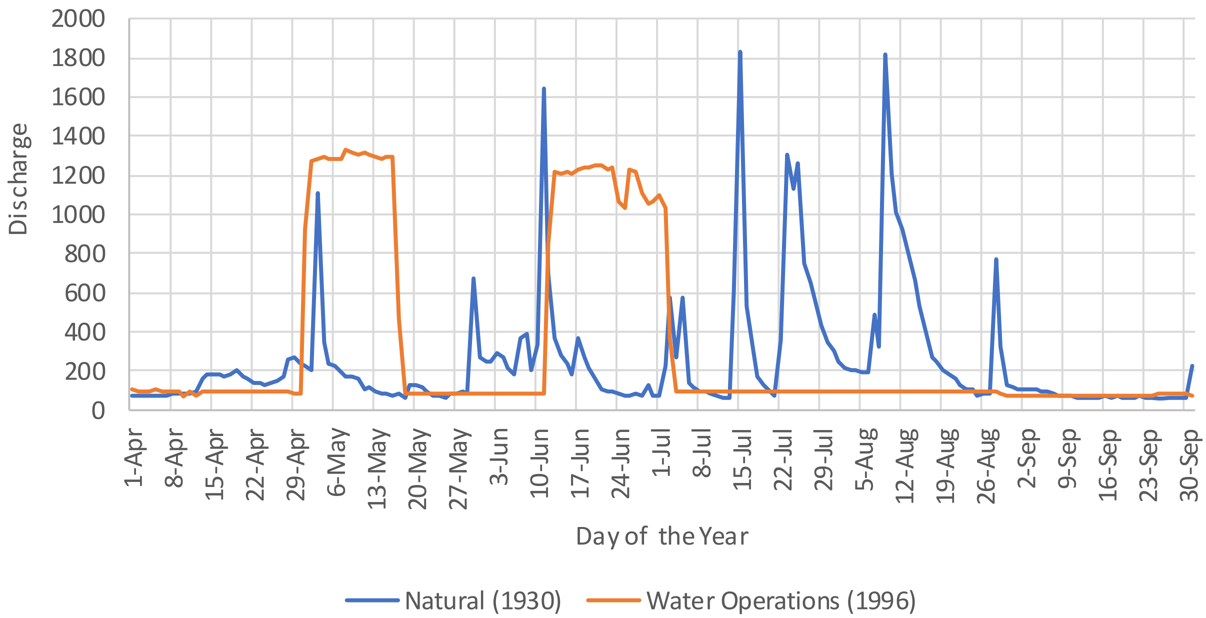

Figure 9: Hydrograph comparison at Pecos River below Sumner Dam for prior to Sumner Dam's closure (Natural, 1930) and after Santa Rosa Dam's closure (Water Operations, 1996). 1930 and 1996 are selected as years representing the flow hydrograph before Sumner Dam was installed and after Santa Rosa Dam, respectively. The selected days are from April 1 to October 1, which would intersect the end of the snowmelt runoff, the entire summer and monsoon season, and one month of the fall/winter season. Both sets of data come from the USGS gage of the Pecos River below Sumner Dam, NM (08384500).

The 1930 hydrograph or the "natural" hydrograph, shows several peak events occurring from the end of April to the end of September (Figure 9). The base flow would be approximately 100 cfs, with peaks ranging from 400 to 1800 cfs. The summer base flows (May to June) and the monsoon season base flows (July to August) would exceed 200 cfs. Notably, the peak events would ramp up rapidly, but would have a more gradual decrease in discharge over time than the Water Operations hydrograph. The number of peaks in the Water Operations hydrograph is less than the Natural hydrograph, and the peaks are sustained for a longer period of time. The baseflows for the Water Operations hydrograph stays consistent throughout all seasons at 100 cfs.

Block flow discharge rates are typically around 1,400 cfs for up to 15 days (mean of 8 days from 2000-2019); these agreed upon limits have been enacted to minimize Pecos bluntnose shiner egg and larval displacement. Being the dominant high-flow hydrology, block releases are responsible for majority of contemporary sediment transport and thus geomorphically most significant. The number of annual block releases varies depending on the available storage in the upper reservoirs and the call for water by downstream irrigators (CID) and can range from 1- 4 block releases/year. At the below Sumner gage, from 2006-2018, block releases average 53% of the total annual volume of the Pecos River, having a range of 25% - 69% (Tetra Tech 2020).

Typically, Lake Sumner is permitted to store up to 20,000 ac-ft of water in the joint use pool from November 1st to April 30th, this winter storage is required to be vacated by May 1st, usually as a block release a few days before the 30th. However, this permit is in abeyance until the radial gates are repaired, which is expected to occur in 2025 or 2026 (Young, 2022).

Block releases from Sumner are regulated and best described in the 2016 Biological Opinion (note, the 2016 BO was published in 2017):

Carlsbad Project Water Delivery

"USBOR delivers Project water from storage in the Upper Reservoirs, consistent with applicable Federal and State laws, pursuant to contractual obligations to downstream irrigators. A block release is a high magnitude release of Project water from Sumner Reservoir, typically around 39.6 m3/s (1,400 cfs), which is used to most efficiently deliver water to Brantley Reservoir (USBOR 2017a: 19). It is a release of a relatively short duration (approximately 1-2 weeks; USBOR 2017a: 75) designed to minimize evaporative and seepage losses. Block releases will be used for Project water delivery. Mussetter (2004) presents the typical block release hydrograph for 2002-2003 year in the following figure:

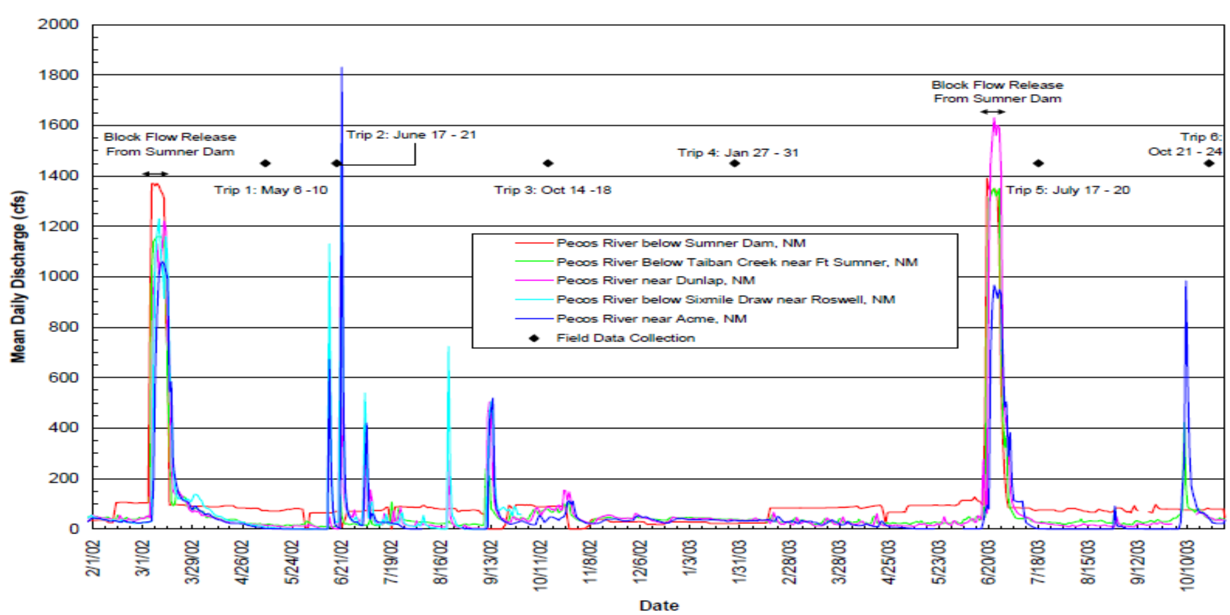

Figure 10, Mean daily discharges at 5 USGS stream gages between Sumner Dam and Acme (1 Feb 2002 – 30 Oct 2003). Also shown are the times of the field data collection efforts for this study. Source: Mussetter 2004, Figure 4.8

Much of the motivation for high releases comes from Tetra Tech 2000, where dam releases underwent a conveyance efficiency analysis. The low flows of 20 cfs from Sumner had loss rates of 50% at Acme and 40% to Kaiser; while 1000 cfs in summer had loss rates of 82% at Acme to 74% at Kaiser. These efficiencies were seasonally and discharge dependent (Figure 11; Tetra Tech 2000).

Sumner Release Begins 2/15/94		Time	Discharge (cfs)
	Begins:	6:00	0.12
	Shoulder:	7:00	344

Inflection: hour that flow begins to increase
Median: approximate mid-point of wave
Shoulder: hour that flow increase ends

	Hours toTaiban	Discharge at Taiban (cfs)	Hours to above Acme	Discharge at above Acme (cfs)	Hours to near Acme	Discharge at near Acme (cfs)	Hours to Lake Arthur	Discharge at Lake Arthur (cfs)	Hours to Artesia	Discharge at Artesia (cfs)	Hours to Kaiser	Discharge at Kaiser (cfs)
Inflection	21	13	80	6.3	92	22	138	36	150	64	158	50
Median	23	140	81	76	-	-	139	98	153	159	159	101
Shoulder	28	207	86	140	93	174	152	190	156	228	160	205

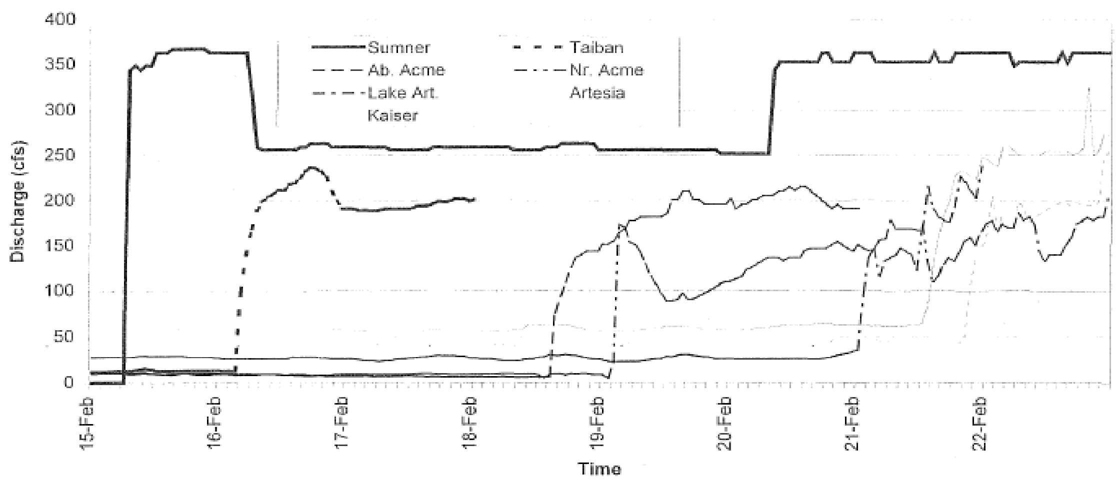

Figure 11. Wave travel times and discharge attenuation from Taiban to Kaiser (15 Dec 1994 – 22 Dec 1994) Stop Releases. Source, Tetra Tech 2000, Figure P-5

The Proposed Action will continue to release stored water, consistent with 2016 Biological Opinion, as follows (USBOR 2017a: 19-20):

- *Release stored water for the beneficial use of irrigation in a manner that does not constitute a wasteful use due to excessive losses through seepage and evaporation from the Upper Reservoirs to Brantley Reservoir (i.e., block releases);*
- *Manage the block release schedule from Sumner Reservoir, if possible, to alleviate any intermittency;*
- *Restrict the duration of block releases from Sumner Reservoir to a maximum of 15 days;*
- *Restrict the cumulative duration of block releases from Sumner Reservoir in a calendar year to a maximum of 65 days; and*
- *The number of days between block releases from Sumner Reservoir shall be no less than 14. (Note: maximum release from Sumner is ± 1,600 cfs at full winter storage)*

USBOR also proposes that any remaining attributes of block releases (e.g., flow rates, irrigation demand) should be considered part of the Environmental Baseline (USBOR 2017a: 20).

As to the timing of the block releases CID can call for water whenever they feel that water is needed in a downstream reservoir throughout the year, following the rules above. However, the usual timing is just prior to May 1st, late June or early July, and late August or early September."

The citation (USBOR 2017a) is the 2016 Biological Assessment provided to the USFWS for their 2016 Biological Opinion on the Pecos Bluntnose Shiner and Interior Least Tern. Carlsbad Project Water Operations, Consultation Number 02ENNM00-2016-F-0506. As of 12 February 2021, the Interior Least Tern has been removed from the Endangered Species list and is considered to be at viable population levels.

2.4 Flexibility in Water Resource Operations

USBOR only has flexibility in the use of supplemental water. That flexibility is in the volume of water used to maintain a continuous river as indicated by 5 cfs at the Acme gage. This flexibility only lasts until the supplemental water runs out or if there is not enough water in storage to provide supplemental water.

Currently the supplemental water is stored in Lake Sumner on a calendar year schedule, Bypass and FCP water acquired is available on January 1st, Forbearance water is acquired as FSID forgoes the water and is available once the water begins to accumulate in storage. All supplemental water in storage on December 31st reverts to CID. However, if storage of supplemental water becomes available in Santa Rosa Lake (USACE) the water on December 31st will be transferred from Sumner and increase USBOR's flexibility.

The only other way to increase flexibility is to work with the irrigation districts, mainly CID, to develop changes in water movement in the basin.

3 CHANGES IN PHYSICAL PROCESS AND FLOWS RESULTING FROM DAMS AND OPERATIONS

Hydrology is a driver for geomorphic and biologic trends in arid river reaches: 1) arid rivers are most often sand bed dominated and 2) sand bed systems are quite dynamic. Large-scale factors, such as climatic wet and dry seasons, affect snowpack and precipitation patterns throughout watersheds. When engineered structures such as dams, levees, and bank stabilization methods are introduced, the underlying hydrology (mean discharge of water and sediment) is influenced. Cumulatively, over time, this generally results in a homogenization of the river (Poff et al. 2007) and a progressive decline in the diversity of structure and functions of both the aquatic and riparian ecosystems. This is owed to the decrease in ranges of water and sediment discharges, which are shown to drive diversity of river morphological features that are found there. Historically, the Pecos fits the arid river definition. It is largely a sand bed system that historically was braided and had the characteristic transverse bars.

3.1 River Reaches

For the purposes of this document, the Pecos River was divided into three river reaches (Table 2; Figure 12). Reach A includes the headwaters to Santa Rosa Dam. Reach B is everything downstream of Santa Rosa Dam to Sumner Dam. Reach C, the longest reach, includes everything downstream of Sumner Dam to Brantley Dam. In some sections of this report, Reach C is further divided into three sub-reaches (C-1, C-2, C-3). These sub-reaches relate to how the U.S. Fish and Wildlife Service (USFWS) has traditionally divided up the river based on habitat quality (Horner 2020).

Table 2: River reach information for the Pecos SRP.

	Location	Length	Elevation Drop	Overall Slope
Reach A	Headwaters – Santa Rosa Dam	232 km 144 mi	1,200 m 3,937 ft	0.5%
Reach B	Santa Rosa Dam to – Sumner Dam	87.7 km 54.5 mi	122 m 400 ft	0.1%
Reach C	Sumner Dam – Brantley Dam	354 km 220 mi	305 m 1,000 ft	0.08%

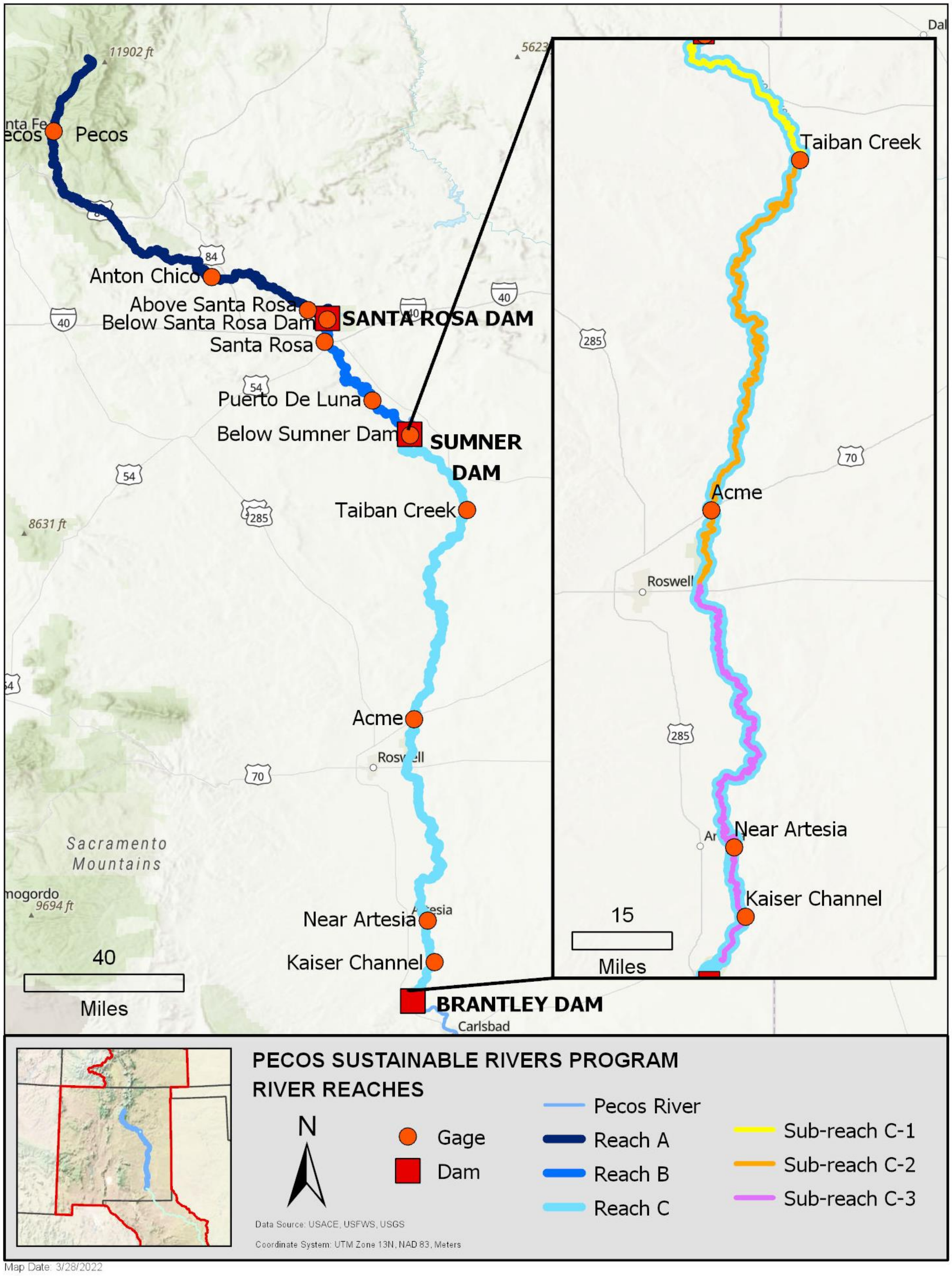

Figure 12: The reaches and sub-reaches for the Pecos SRP Literature Review.

As discussed above, the construction of dams has a significant impact on a river's natural hydrology and the watershed landscape. The dam acts as a physical barrier that stores inflows and manages outflowing discharges for specific purposes. The dam construction also affects the transport of sediment in the reach, again by acting as a physical barrier that stores sediment, but also by effecting riverine hydraulics that transport or stores sediment. Since 1880, the Pecos River has become increasingly fragmented due to sediment capture and flood control by dams, and base inflows being affected by groundwater withdrawal (Mussetter Engineering, Inc. 2001). The surface hydrology for the system is evaluated by two foci relevant to an environmental flows workshop: pre-dam versus post-dam hydrology changes and daily averaged seasonal representation.

The paired influence of sediment and hydrology may change a river's geometry and affect ecosystems that are sensitive to hydraulic shear forces, sediment transport regimes, or other geomorphologic patterns that affect water conveyance on land. This hydrologic analysis uses percent exceedance and annual peak discharge to analyze pre- and post-dam eras. Percent Exceedance describes the magnitude and duration of flows through a basin. The high-flow, less frequent events, can be used to characterize the flood regime of the basin. Certain ecological processes, such as vegetation development, are dependent on flood freque ncies. Flood events may mobilize larger sediment and bed loads, affect the stability of vegetation, and influence the topography of the terrain that directs flows of less magnitude. The low-flow, more frequent events, demonstrate the base- and low- flows for a reach, demonstrating the frequency of dry periods.

While the Percent Exceedance can be used to demonstrate durations and magnitudes of discharge over several years or decades, the annual peak discharge is helpful in demonstrating trends over an annual basis. U.S. Geological Survey (USGS) gages were used as primary data sources to evaluate the system, the gages utilized are listed in Table 3 and shown in Figure 12.

Table 3: USGS gages used for the Pecos SRP hydrology analysis.

Pecos River Gages	*USGS Number*	*Period of Record*	*Analysis Reach*
Near Pecos, NM	*08378500*	*10/1/1919*	*A*
Near Anton Chico, NM	*08379500*	*10/1/1910*	*A*
Above Santa Rosa Lake	*08382650*	*2/28/1976*	*A*
Below Santa Rosa Dam	*08382830*	*1/17/1980*	*B*
Santa Rosa, NM	*08383000*	*10/1/1912*	*B*
Near Puerto de Luna, NM	*08383500*	*5/1/1938*	*B*
Below Sumner Dam, NM	*08384500*	*10/1/1912*	*C*
Below Taiban Creek	*08385522*	*8/12/1992*	*C*
Near Acme, NM	*08386000*	*7/1/1937*	*C*
Near Artesia, NM	*08396500*	*10/1/1905*	*C*
Kaiser Channel Near Lakewood, NM	*08399500*	*5/16/1950*	*C*

Lastly, the seasonal hydrology is evaluated based on hydrologic seasons that impact the ecology surrounding the Pecos Basin (Table 4). These hydrologic seasons coincide with changes in temperature and historic precipitation patterns that affected which species inhabit the areas surrounding and within the Pecos River.

Table 4: Seasons used to evaluate seasonal hydrology for the Pecos SRP Literature Review.	
Season	**Starting Date**
Snowmelt runoff	January 27 – May 27
Summer low flow	May 28 – July 25
Monsoon	July 26 – September 4
Fall-winter base flow	September 5 – January 26

The hydrologic data from USGS gages were synthesized into daily averaged data into three "eras". The eras are punctuated by dam construction:

- Pre-Sumner Dam (period of record to October 1937);
- Pre-Santa Rosa (October 1937 to 1979); and
- Modern (October 1979 to present).

USACE starts the water year in October and uses this date for Compact accounting. Reclamation begins the water year on November 1st. Water years do not necessarily coincide with the dam closure dates.

Following the surface hydrology analysis for each reach, there is a discussion on the changes in channel geometry and sediment transport in order to identify sub-reach trends that are occurring in each study reach. The channel geometry and sediment transport discussion uses historical aerial photography from 1997, 2011, 2016, and 2018 was used to measure and compare active channel width, active channel area, sinuosity, and assess channel plan view (e.g. channel migration, etc.). The objective is to link these trends with changes in morphological drivers: sediment and water supply; as a means to both characterize these reaches and to prepare for analyses of geomorphic trends that may be affected by environmental flows recommendations and analysis. More information regarding channel geometry and sediment transport can be found in Appendix A.

3.2 Reach A

Reach A extends from the headwaters to the Santa Rosa Reservoir Dam and is approximately 144 miles long. With an elevation drop of over 1,200 meters (3,937 ft), the overall slope of the reach is 0.5%. Reach A flows are not influenced by a dam and a 20.5 mile section of the river, from the headwaters to Terrerro townsite, has been designated a *Wild and Scenic River* by the National Wild and Scenic Rivers System. Reach A has been included in this report to understand the natural flow changes occurring in the headwaters.

The 2021 USBOR Basin Study summarizes Reach A –

"From its headwaters in the Sangre de Cristo Mountains, the Pecos River flows generally southeast, dropping in elevation from 11,700 ft [Watershed Elevation] *at its source to about 4,800 ft upstream of Santa Rosa Reservoir (USFS 2002). The Pecos River above Santa Rosa Reservoir is perennial except for short reaches of intermittent flow between Anton Chico and Colonias. In these reaches, the river loses the entirety of its flow unless flows are very high (e.g., during snowmelt runoff season and after major storms). Much of this water ultimately rejoins the river further downstream. Average annual snowmelt runoff over the past 30 years has been approximately 50,000 to 60,000 acre-feet. Major tributaries to this reach include the Rio Mora, Willow Creek, Glorieta Creek, Cow Creek, Tecolote Creek, and the Rio Gallinas."*

Specific, year-by-year peak discharge data are presented in the following Figure 13. Reach A has three USGS gages that were used for its peak annual discharge evaluation. The Pecos, NM gage is the most upstream gage in the system. Though in some years the downstream gage at Anton Chico, NM experiences similar magnitudes of peak discharge, Anton Chico gage regularly exceeds the daily averaged data from the gage at Pecos, NM peak by approximately 3,000 cfs. The gage above Santa Rosa Lake generally follows the order of magnitude of the Anton Chico, however there are several years in the 2010s that greatly exceed the Anton Chico peaks, by as much as 9,000 cfs. The magnitude of the peak event has generally decreased over the period of record. The frequency of daily average discharge events exceeding 2000 cfs occurred approximately every 4 years, but from 1997 to 2019, 2000 cfs has only been exceeded twice.

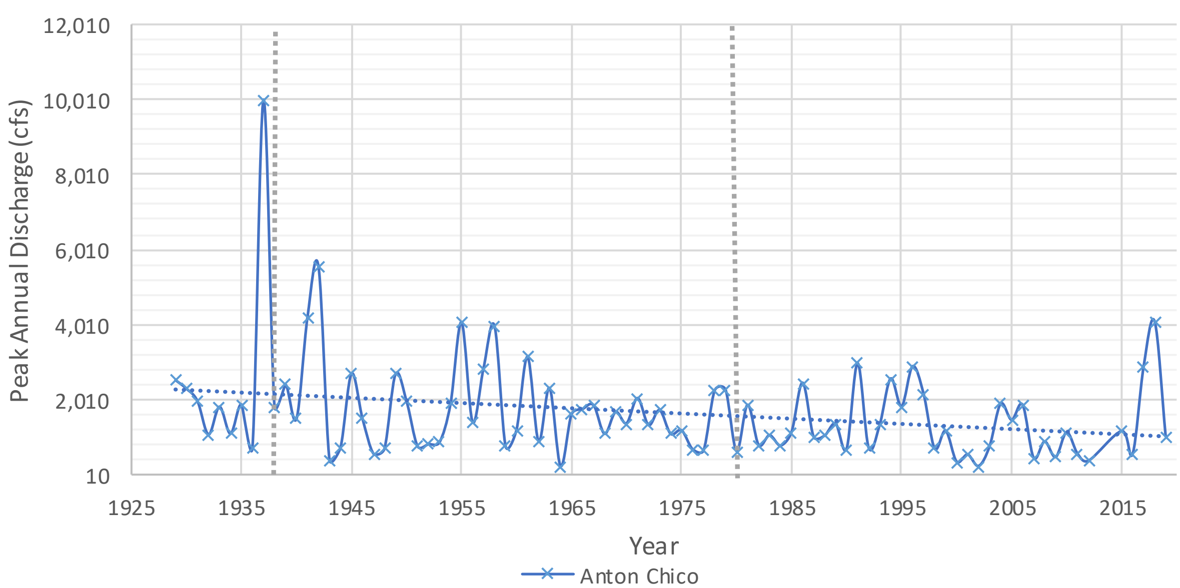

Figure 13: Annual maximum daily averaged discharges for USGS gage Pecos River Near Anton Chico, NM.

USGS also presents the maximum instantaneous discharge for each of its gaged sites. Often, these present a longer period of record than the daily-averaged data. Differences between the maximum daily averaged and the peak instantaneous data occur because flood frequency events can be “flashy” and rapidly attenuated over a few hours. The daily average usually shows an attenuated record of the peak discharge. The Pecos River near Anton Chico (USGS 08379500) has a demonstrable decrease in magnitude of peak events over time (Figure 14), with the last event exceeding 30,000 cfs occurring in the 1930s, and the last event exceeding 20,000 cfs occurring in the 1990s.

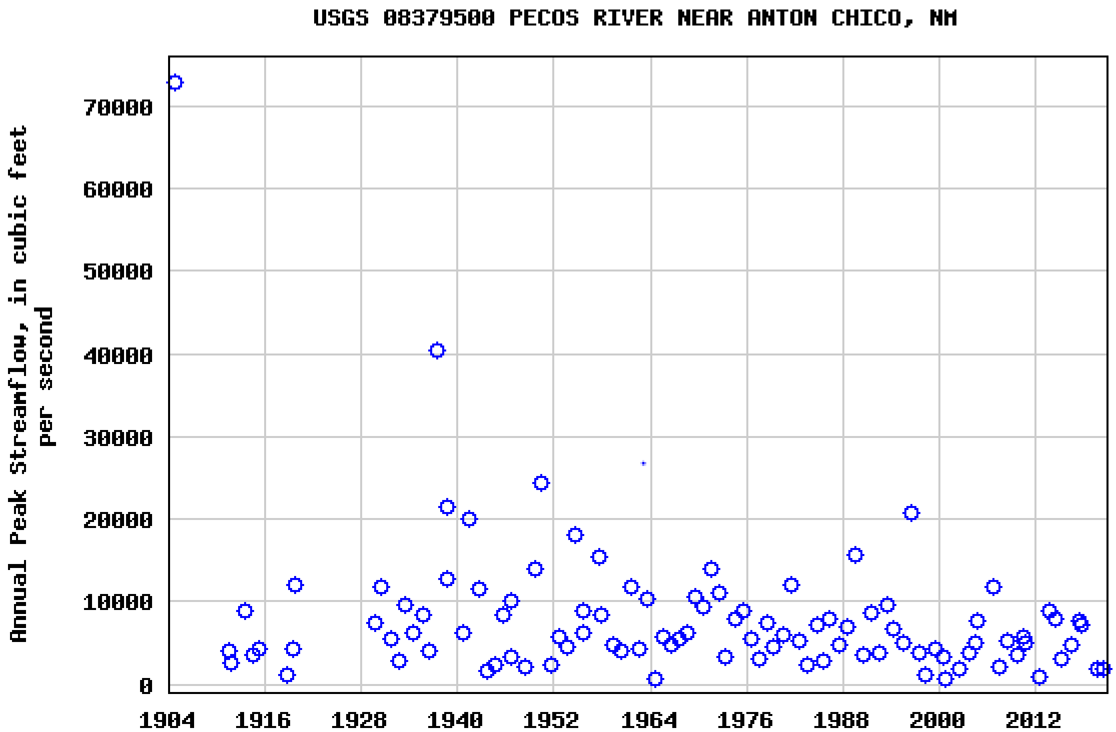

Figure 14. Peak annual stream flow for Pecos River near Anton Chico, NM.

3.3 Reach B

Reach B is below Santa Rosa Dam and just upstream of Sumner Dam. Flows are affected by Santa Rosa Dam. Reach B was evaluated using the USGS gage of the Pecos River at Santa Rosa, NM (08383000) and Below Santa Rosa Dam (08382830) for the pre- and post-dam conditions, respectively. It is a relatively short reach of only 54.5 miles with an elevation drop of roughly 400 ft and an overall slope of 0.1%.

The USBOR summarizes water resources in this reach in the 2021 Pecos Basin Study –

“From Santa Rosa Dam, the Pecos River flows about 60 miles southwards to Sumner Reservoir, at an elevation of just under 4,300 ft, near the Village of Fort Sumner. The springs near the town of Santa Rosa provide about 36,000 to 60,000 acre-feet of water annually to the river. Major tributaries to this stretch include numerous short, spring-fed creeks in the Santa Rosa area,

Agua Negra, and Alamogordo Creek. The springs around Santa Rosa Reservoir provide a fairly consistent flow in this reach of the river."

The following percent exceedance curves show the pre-dam conditions sustaining lower flows for a greater percentage of the time (Figure 15). Prior to the construction of Santa Rosa Dam, 75% of daily averaged flows throughout the years were less than 100 cfs. In the post-Santa Rosa era (since 1980) a daily averaged discharge of less than 100 cfs occurs 85% of the time.

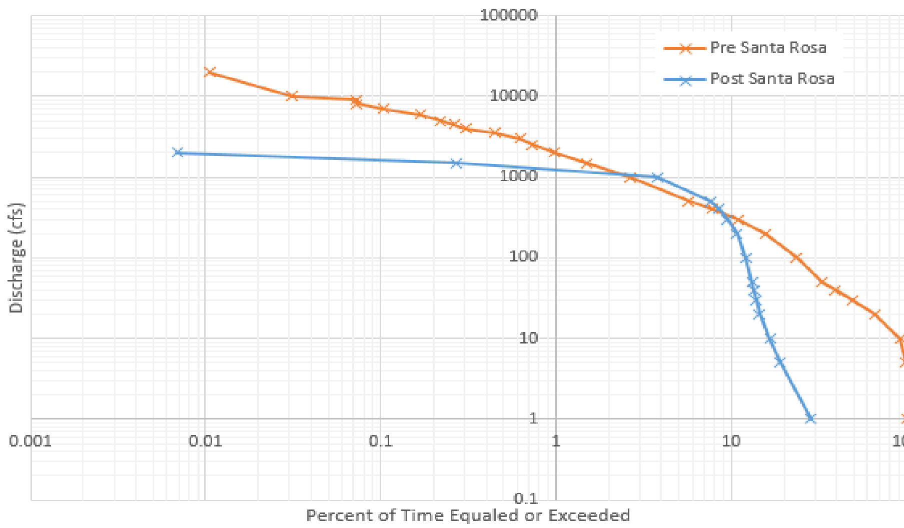

Figure 15: Reach B daily average percent exceedance prior to and following installation of Santa Rosa Dam.

More dramatically affected for Reach B are the high flow events. Prior to the construction of Santa Rosa, there were occurrences of daily averaged discharges exceeding 10,000 cfs. Though these events were infrequent over the recorded time period, with the period of record beginning in 1912, such events would be influential of vegetative and sediment distribution in the reach. Post-Santa Rosa conditions of a similar frequency, albeit over half an accumulated time period, 40 years, has a maximum event of 2,000 cfs. The 1% event after dam construction was found to be 1,200 cfs. Prior to the construction of Santa Rosa Dam, the 2,000 cfs discharge would be exceeded 1% of the time. This indicates that the 1% peak event has been reduced by a magnitude of 40% in Reach B.

For Reach B, the discharge related to the Santa Rosa Dam location is reflected by two USGS gages: Pecos River at Santa Rosa, NM (08383000) and Below Santa Rosa Dam (08382830; shown in Appendix A). These are effectively near the same location, however using the Santa Rosa, NM allows for the period of record to extend back to 1928. The USGS gage at Puerto de Luna, NM is downstream of the Santa Rosa gage (Figure 16). Prior to the construction of Santa Rosa Dam, the magnitude of the peak events for Puerto de Luna, NM gage and the Santa Rosa gage were very similar. The maximum daily averaged discharge exceeded 10,000 cfs on three occasions throughout the period of record. Following the construction of Santa Rosa Dam, Puerta de Luna annual peak discharges continued to have greater magnitude than those upstream. Maximum averaged daily discharges generally continued a low-magnitude trend, with the maximum discharges from Santa Rosa not exceeding 2,000 cfs (Figure 16). Prior to the construction of the dam, 2,000 cfs would be the maximum daily averaged annual discharge about 20% of the time.

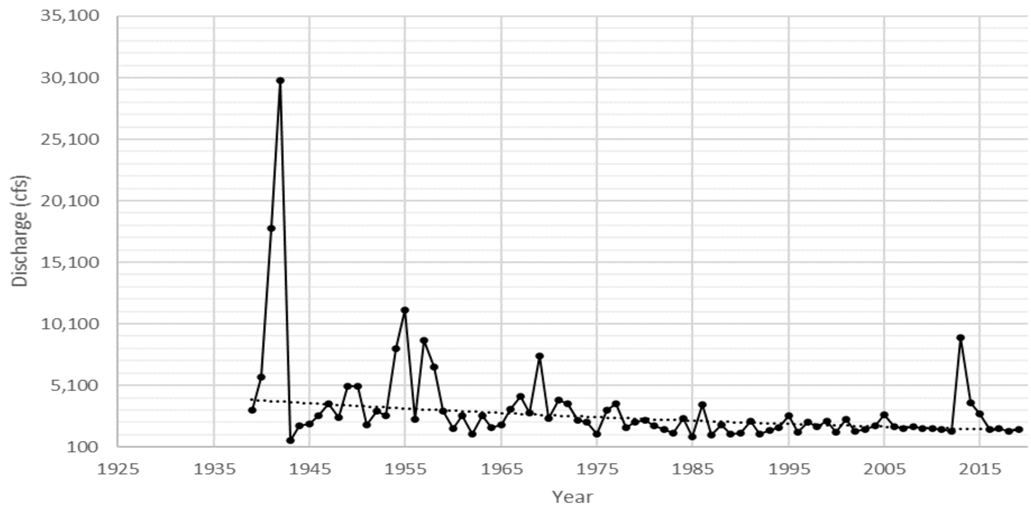

Figure 16: Annual maximum daily average discharges for USGS gage Pecos River near Puerto de Luna, NM in Reach B.

According to instantaneous peak data from USGS, the magnitude of peak discharges has decreased over the period of record (Figure 17). Prior to closure of Santa Rosa Dam, instantaneous peak events would exceed 10,000 cfs nearly 40% of the period of record with some events including 6 events ranging from 20,000 to 50,000 cfs. After closure the 10,000 cfs magnitude instantaneous events occurred 10% of the years.

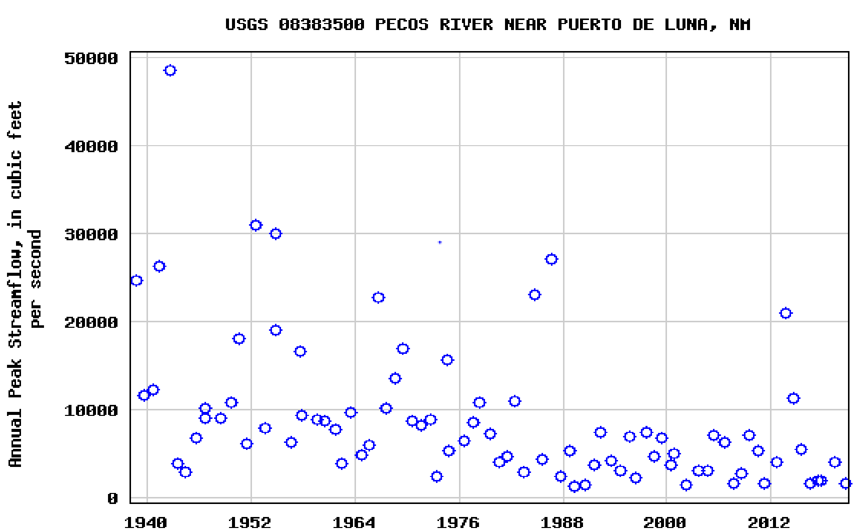

Figure 17. Peak annual stream flow for Pecos River near Anton Chico, NM.

Following the closure of Santa Rosa Dam, there is much more variation in the Fall-Winter baseflows, with discharges dropping from an average of 20-30 cfs, to 1 to 10 cfs. Generally, the Snowmelt season starts off with much higher discharges at the beginning of the season, with the average being 100 cfs in the Modern era, relative to a 20-30 cfs continuation of the baseflow. The summer and Monsoon seasons are constant at approximately 100-200 cfs, whereas prior to Santa Rosa Dam's closure, there would be peaks that increased the average to 400 cfs or more. (Figure 18)

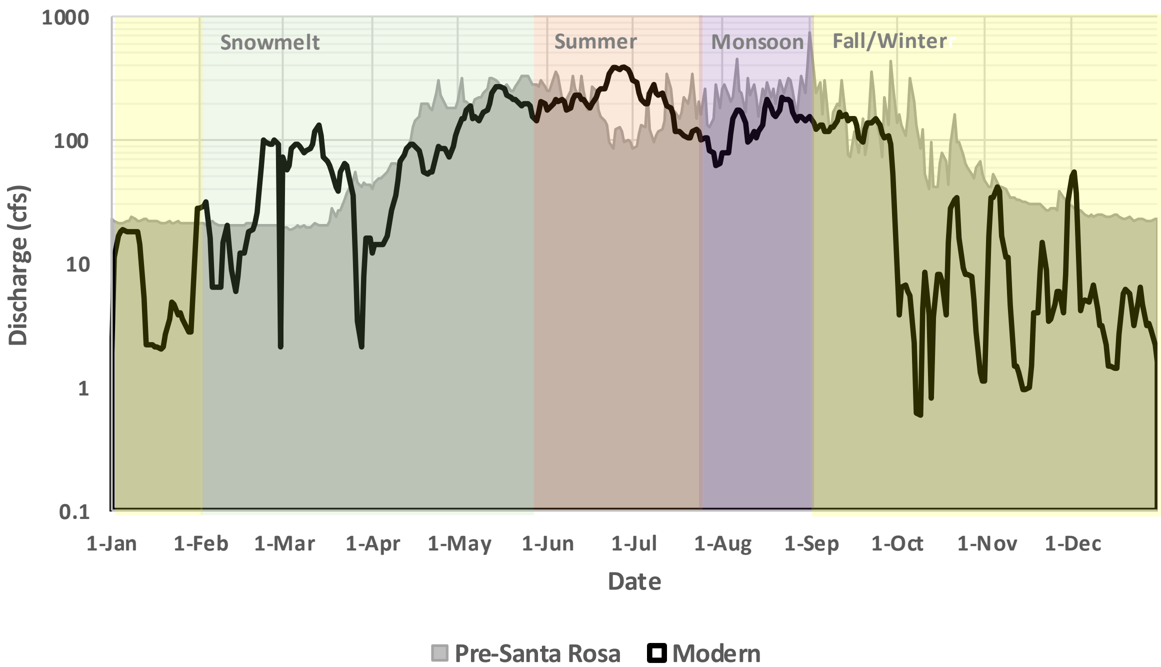

Figure 18: Daily averaged data representing Reach B, from Pecos River near Santa Rosa, NM (USGS 08383000) and Below Santa Rosa Dam (USGS 08382830)

Sediment supply to the Pecos has declined in the post-dam period (Tetra Tech 2020). Bathymetric surveys of Sumner Reservoir (USBOR 2014) estimated the annual sedimentation rate between 1936 and 1989 (pre-Santa Rosa Dam) was approximately 1,170 acre-feet/year; however, in the post-Santa Rosa dam period (1989-2013) the sedimentation rate has progressively declined from approximately 76 acre-feet/year (1989-2001) to around 32 acre-feet/year (2001-2013). These measurements are only a relative estimate of changes in upstream sediment supply, as operations at the dam may affect sediment passing through the reservoir and compaction may affect total sediment estimates.

The decline in sediment supply downstream of the dam has been documented in the 2016 Biological Opinion for the Carlsbad Project Water Operations, where USFWS associated habitat degradation with scour and sediment-poor releases from Sumner (USFWS, 2017). Sediment supply to the Pecos has shifted to storm-driven inputs from tributaries (MEI 2003).

3.4 Reach C

Reach C is affected by both Santa Rosa Dam and Sumner Dam. Reach length is approximately 220 miles with an elevation drop of roughly 1,000 ft and an overall slope of 0.08%.

The USBOR 2021 Pecos Basin Study describes Reach C as –

"The Pecos River flows generally southward for approximately 120 miles through the broad plains of eastern New Mexico. In this reach, the river is typically fairly shallow and meanders across a relatively wide channel at low flows, featuring numerous sand bars and frequent sections of braided channels (Figure 3). At moderate flows, the river extends across the channel. In this reach, the Pecos River only overtops its banks and spills onto the surrounding floodplain in extreme floods. These characteristics continue to the downstream end of the reach near the USGS Acme Gage 08386000 north of the city of Roswell (Acme Gage) at U.S. Highway 70 just north of the city of Roswell. Major tributaries to this stretch of the river include Taiban Creek, Yeso Creek, and Salt Creek. This stretch of the river is perennial but prone to occasional drying during drought conditions.

Below the Acme Gage, the Pecos River flows through the Bitter Lake National Wildlife Refuge between U. S. Highway 70 and U.S. Highway 380. Within the refuge, the river retains a moderately active channel. From the refuge downstream to USGS Artesia Gage 08396500 near the city of Artesia (Artesia Gage), the river channel narrows and deepens, becoming more incised and confined to a single channel, but with a broad floodplain. A sometimes-significant source of water in this area is base inflow from the adjacent aquifer that has been as high as 120,000 acre-feet and as low as 15,000 acre-feet per year over the period of record (1905-1998). The Rio Hondo and Rio Felix are the largest tributaries to this reach.

Downstream of the Artesia Gage, the Pecos River flows about 25 miles through a broad floodplain to Brantley Reservoir. Rio Peñasco is the only significant tributary in this reach, though it and numerous small arroyos in the reach only flow after heavy rains. Several miles upstream of the Brantley Reservoir, the river enters the Kaiser Channel, a man-made canal that traverses the lakebed of the former McMillan Reservoir."

Prior to the construction of Sumner Dam, the 2-year return flood at Artesia NM was 10,200 cfs; following the closure of Sumner Dam (1938-1996), the 2-year return flood is 2,900 cfs (Tetra Tech 2000). The water management of Sumner Dam has also increased the number of days per year where flows are less than 50 cfs. The 100-year peak flow event was reduced from 43,100 cfs prior to Sumner Dam, 22,800 cfs prior to construction of Santa Rosa Dam, and now to 1,620 cfs under current conditions (Mussetter Engineering, Inc. 2001).

Percent Exceedance figures for Reach C were recorded by Mussetter, 2002 (Figure 19). For Reach C, the duration of flows below 100 cfs were attenuated by the construction of Sumner

Dam in 1937. Prior to Sumner Dam, 50% of the time, discharges in the Pecos would fall below 100 cfs, and about 60% of the time post Sumner dam. This indicates that water operations in the Pecos Reach have curtailed the duration of flows less than 100 cfs. Increased durations of these flows may support vegetation encroachment and stabilization of islands and bars. This change may also affect what vegetative species dominate the riparian zone.

It is important to note that until 1999 all the water released from Sumner, except storm flow, was for FSID entitlements ranging from approximately 60 cfs to 100 cfs. This means that the flows below Sumner Dam prior to 1999 were all regulated to FSID's entitlement and block releases. Beginning in 1999 supplemental water was added, increasing the steady release of water out of Sumner Dam.

The water operations following the installation of Sumner Dam did not appreciably affect the high-flow events for Reach C. However, following the construction of Santa Rosa Dam upstream, the magnitude of high-flow, low- frequency events were reduced similar to what was demonstrated in Figure 15. Though Santa Rosa Dam is not within this reach, the regulation of water affects downstream hydrology.

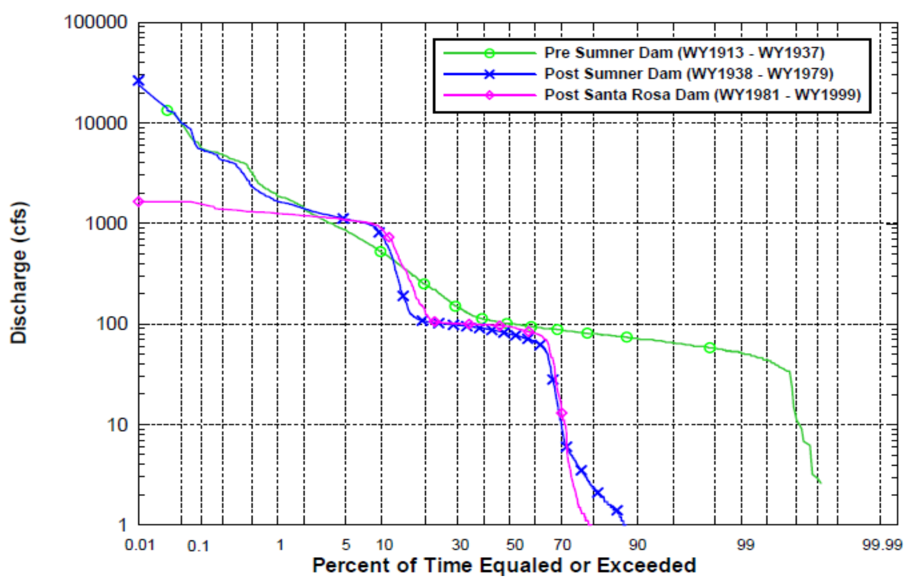

Figure 19: Reach C percent exceedance following the installation of Sumner Dam and Santa Rosa Dam. Source: Mussetter Engineering, Inc. 2001, Figure 2.1

For the modern era (Post-Santa Rosa), the longitudinal attenuation of water is represented in Figure 20. It is shown that downstream USGS gages generally have the same percent chance exceedance when discharges are averaged on a daily basis. Acme, NM shows higher discharges than downstream and upstream gages, 30% of the time. For all four gages, the average daily discharge is less than 100 cfs for 70% of the time.

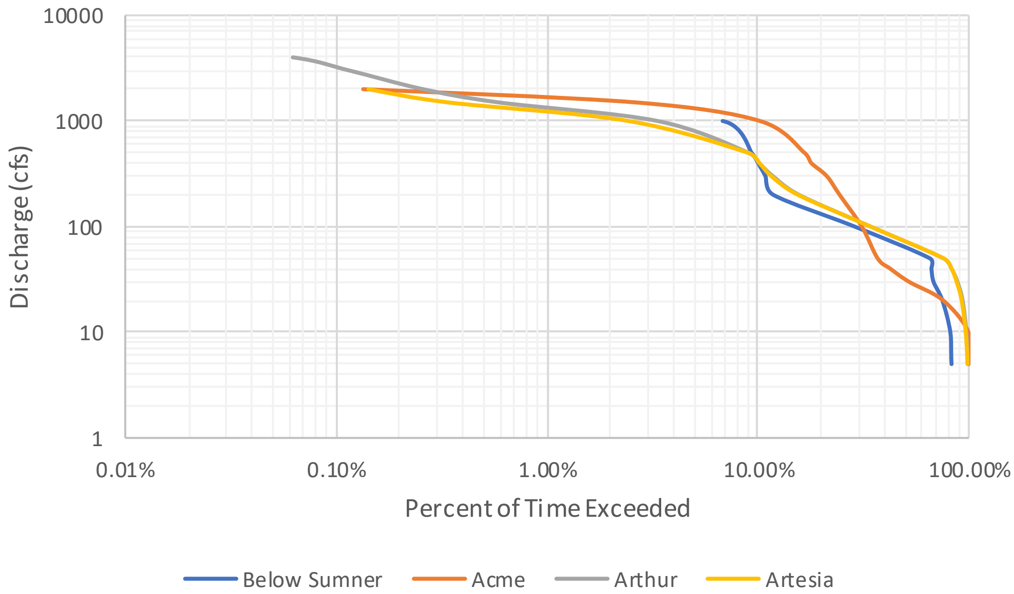

Figure 20: Reach C profile of daily average discharges from Sumner to Brantley Dams from 1981 to 2019.

Reach C, from Sumner Dam to Brantley Dam, is a much longer reach than the preceding two. Following the installation of Sumner Dam in 1937, annual discharge peaks continue to exceed 10,000 cfs on five occasions at Acme, NM. The peak events from the outflow of Sumner Dam were greatly reduced, especially after 1946. Acme, Artesia, and Kaiser gages showed relatively consistent peak annual discharges to those at Artesia before Sumner Dam's closure (shown in Appendix A). Following the closure of Santa Rosa Dam in 1979, there has been one instantaneous peak discharge event exceeding 10,000 cfs throughout the reach – 12,300 cfs in Artesia in 1986. The maximum instantaneous discharge from Acme, NM is 8,140 cfs, in 1991. Annual daily averaged maximums from Sumner, post- Santa Rosa, have been a steady 1,000 to 1,600 cfs for the time period (Figure 21). The decrease in all gages below Sumner may reflect a climatic trend of drying throughout the watershed.

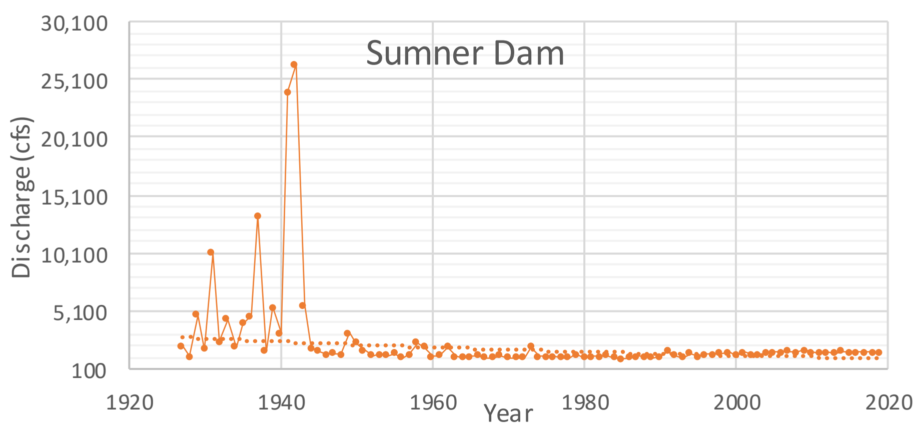

Figure 21: Annual maximum daily averaged discharges for USGS gage Pecos River below Sumner Dam in Reach C.

Mussetter (2001) observed that Sumner Dam operations mostly affect low-flow periods, and the Santa Rosa Dam has significant effects at high flows. The data presented here does not dispute that assessment, though following the construction of Santa Rosa Dam, low flows during the fall and winter season have been affected by extending the duration of low flow. It is important to remember that low flows in the river below Sumner are the result of storing all inflow and only releasing the minimum to keep the river continuous.

In observing the instantaneous peak discharge data from USGS, all gages have reduced magnitude in peak discharge events (Figure 22). The gage below Sumner was strongly affected by the closure of Sumner Dam. Acme and Artesia, NM have the highest instantaneous peak events after 1980. Generally, these instantaneous peaks are less than 10,000 cfs.

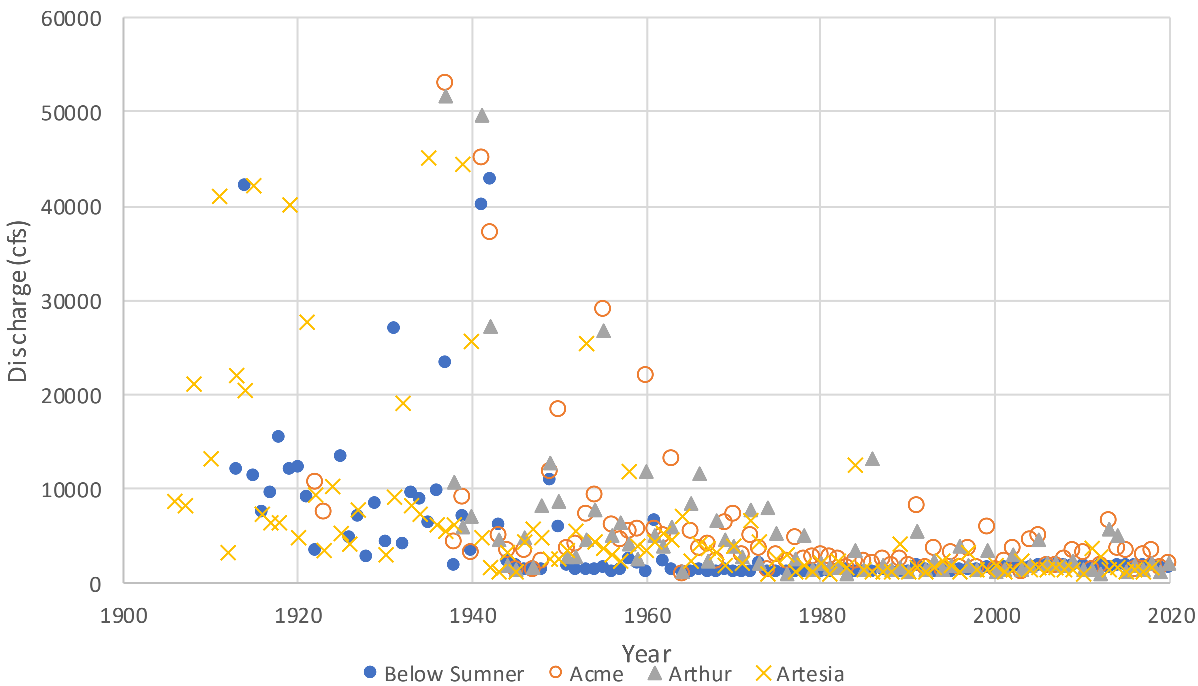

Figure 22: Maximum annual instantaneous discharge events for USGS gages in Reach C.

For Reach C, Prior to Sumner's construction, average daily flows for the "Summer Low-Flow" season would be the highest, exceeding 1,000 cfs for much of the duration and at times exceeding 10,000 cfs. Prior to regulation at Sumner, the end of Monsoon season and the beginning of the Fall-Winter season flows would consistently fall below 100 cfs, whereas in more recent eras, the average was consistent at 200-300 cfs. Regulation following the construction of Sumner attenuates the winter flows to approximately 20-30 cfs, where before discharges during the Winter season was close to 100 cfs (Figure 23).

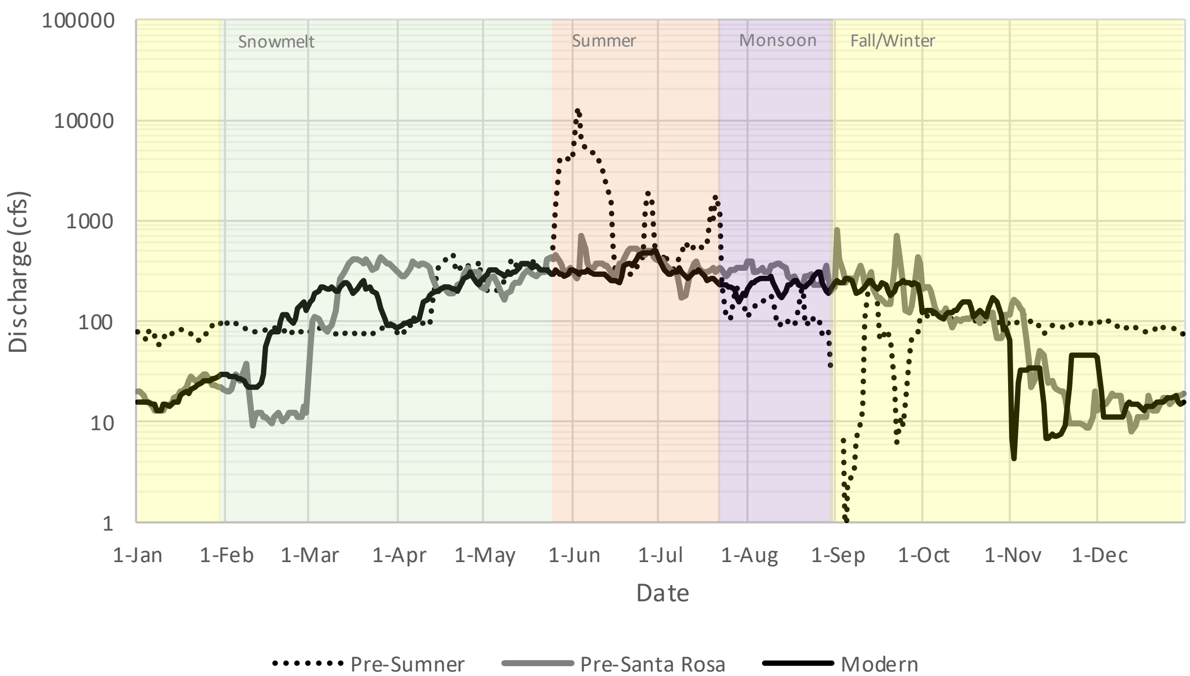

Figure 23: Daily averaged data representing Reach C, from Pecos River below Sumner Dam (USGS 08384500)

Reach C has been further divided into three subreaches that reflect how the USFWS classifies habitat suitability for the threatened Pecos bluntnose shiner (*Notropis simus pecocensis*; shiner). Reach C subreaches defined by the Service are: Tailwater, Rangelands, and Farmlands. For the SRP, these are referred to as subreaches C-1, C-2, and C-3, respectively (Figure 12).

- Sub-reach C-1 (Tailwater) extends from Sumner Dam to the Taiban Creek confluence and is approximately 34 miles long.
- Sub-reach C-2 (Rangelands) begins at the Taiban Creek confluence and ends near the southern boundary of Bitter Lake National Wildlife Refuge (BLNWR), just east of Roswell, New Mexico.
- Sub-reach C-3 (Farmlands) begins near the southern boundary of BLNWR and ends at the Brantley Reservoir delta.

3.4.1 Sub-reach C-1

The Taiban gage site has a broad valley floor bordered by two six-foot high terraces. As the river flows downstream beyond the gaging station, it meanders across the floodplain until it runs up against a bluff on the right (west) side of the valley. The site lacks significant formations of rock or bedrock and the riverbanks are composed of mildly cohesive sand, silt, clay mixtures characteristic of eastern New Mexico soils. In certain locations, lenses of thick, erosion resistant clay material were found in and along the riverbanks.

Due to sediment sequestration by upstream dams and relatively clear water releases below Sumner Dam, the riverbed in this reach is incised and armored consisting of gravel and cobble substrate. In terms of historical conditions, it is generally degraded aquatic habitat that is not suitable for native, pelagic spawning fishes such as the Pecos bluntnose shiner.

3.4.2 Sub-reach C-2

The Near Acme gage site is located in a broad and open valley where the Pecos River meanders from the right (west) side of the valley across to the left (east) side of the valley. The gaging station is located on the right side of the valley on a bluff with bank materials composed of mildly cohesive sand, silt, clay mixtures characteristic of eastern New Mexico soils. The river turns across the valley toward the east bluff, which is formed from a geologic fault. Bank materials of the eastern bluff are composed of sand/silt/clay mixtures and large boulders. River flows have continually cut into the toe of the bluff and recently dislodged a large boulder, approximately five feet in diameter, which now rests at the toe of the slope. Vegetation includes seep willows and grasses along the banks and thin stands of mature tamarisk. Vegetation transitions into upland prairie and rye grasses and the occasional mesquite bush beyond the tamarisk stands.

Sub-reach C-2 represents the best overall aquatic habitat within Reach C, and within the Upper Pecos as a whole. It is a key stronghold for the shiner and is more indicative of the historical, mobile sand-bed river system; there are numerous unregulated tributaries which provide sediment during monsoon events. Although sediment in the Pecos River is limited by upstream dams, tributary sediment loads in sub-reach C-2 have reached a quasi-equilibrium with block release hydrology and thus a dynamic but generally stable channel planform.

3.4.3 Sub-reach C-3

Sub-reach C-3 is generally more channelized than Sub-reach C-2. The river is bordered by several farms and has been channelized for infrastructure protection of the highway bridge throughout leaving a homogenous U shape as the cross-section geometry and a straight planform. Bank soil structure is composed of cohesive sand/silt/clay materials. The banks are heavily vegetated on both sides of the river, with tamarisk and Russian thistle. Beyond the tamarisk and the outer banks, the vegetation transitions into upland grasses, mesquite and more Russian thistle. Dense vegetation on the riverbanks has greatly increased soil strengths and reduced local bank erosion through establishment of dense root systems.

With respect to Sub-reach C-3, Mussetter Engineering (2001) contends that the channel was likely always relatively narrow and deep due to the silt and clay content of the stream banks. This is in contrast to Hoagstrom (2000) which posited that channel incision in Sub-reach C-3 was due to upstream impoundments and sediment sequestration by dams. Regardless of the cause, poorer habitat conditions in this sub-reach currently dominate.

4 BIOLOGICAL & ECOLOGICAL CONDITIONS

4.1 Water Quality

Impoundments, water operations, and natural sources in the Pecos Basin influence riverine water quality and in-stream ecosystem processes temporally and longitudinally. Strategic water storage and flow regime restoration using the existing reservoir network could be used to reduce salinization, possibly reducing the dominance of euryhaline fishes and promoting the native fish assemblage. However, Santa Rosa, Sumner, and Brantley reservoirs also function as mercury sinks, providing an ecosystem service downstream and should be taken into consideration if flow regime restoration is implemented. A detailed description of water quality in the Pecos River Basin is given in Appendix D.

4.2 Ecological Resources Water Requirements

A number of ecologically protected areas are scattered throughout the study area, including five major wilderness areas, two national parks, two national wildlife refuges, and the Wild and Scenic stretch of the river's headwaters. Except for riparian vegetation and wetland evapotranspiration, none of these protected reaches have direct consumptive use of water. Figure 24 shows IUCN protected areas.

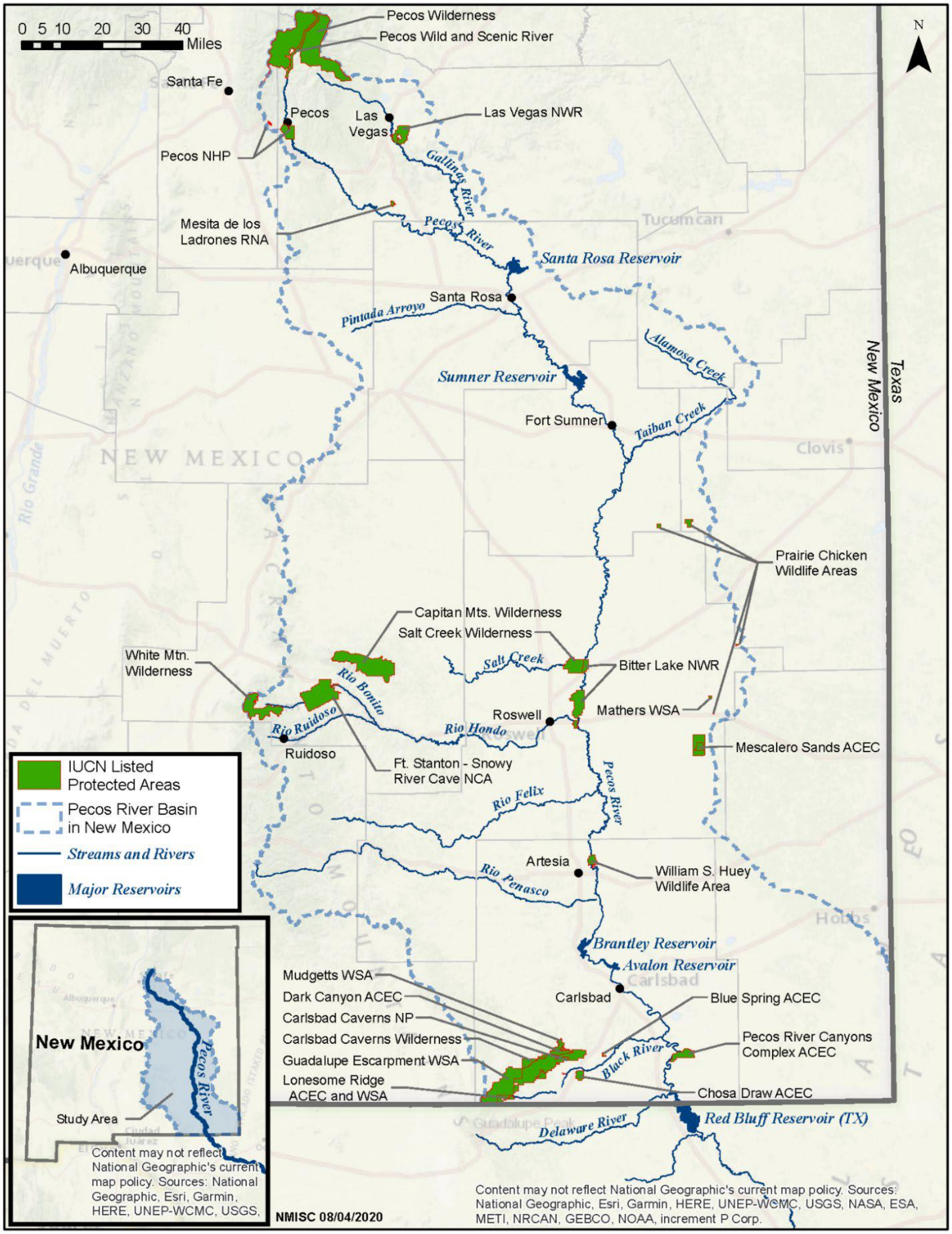

Figure 24: IUCN listed protected areas in the Pecos River Basin in New Mexico (USBOR 2021, Figure 18).

The 2016 Biological Opinion established flow requirements at the Acme and Taiban gages to support specific species in the Pecos River system.

- ***Target flows at Acme Gage (5 cfs) -*** According to the 2016 Biological Opinion, flows above 5 cfs at Acme are an indicator of continuous flow in the river (Figure 25 and Figure 26 show the conditions at Acme at various flow levels). The primary goal of ESA operations for the bluntnose shiner is to maintain a constant flow of 5 cfs at Acme.
- ***Target flows at Taiban Gage (35 cfs) -*** The 2016 Biological Opinion also requires 35 cfs at the Taiban gage. The Taiban gage flow requirements for each year are determined in January based on the US Drought Monitor determination of drought in New Mexico. In critically dry years, this requirement does not have to be met so that flows at Acme can be met. If the drought classification in the Upper Pecos River New Mexico Basin is greater than or equal to 50% of the basin in extreme drought or exceptional drought, then the basin is determined to be critically dry. When in critically dry conditions, the 2016 Biological Opinion requires a continuous river determined by 5 cfs at the Acme gage. Supplemental water supplies will not be used to meet target flows at the Taiban gage but will be used for augmenting flows for the Acme gage.

Figure 25. Typical flow conditions at Acme (34.3 cfs) on April 18, 2011 (USBOR).

Figure 26. Low flow conditions at Acme (1.9 cfs) on August 11, 2011 (USBOR).

From the 2016 Biological Opinion is the following criteria for determining environmental releases from Sumner:

"Carlsbad Project Water to Storage Diversions

The Project is currently permitted to store water in four federally owned reservoirs on the Pecos River: Santa Rosa (Corps); Sumner (USBOR); Brantley (USBOR); and Avalon (USBOR). The maximum combined storage is 217.71 million cubic meters (million m^3) (176,500 acre-feet), which is governed by the Pecos River Compact and the New Mexico Office of the State Engineer (NMOSE) storage permit, Filing Number 6 (USBOR 2017a: 16). Storage entitlements in Santa Rosa and Sumner (Upper Reservoirs) are expected to change over the period of this Proposed Action (USBOR 2017a: 17). The Proposed Action integrates senior water rights and USBOR's nondiscretionary actions (see USBOR 2017a: 26 for a discussion of the discretionary and nondiscretionary actions).

USBOR will divert available water to storage when flows at the Acme gage (USGS Gage 08386000) are greater than 0.14 meters^3 per second (m^3/s)(5 cfs), and flows at the Taiban gage (USGS 08385522) are greater than 1 m^3/s (35 cfs). Storage of water will occur under all hydrologic conditions except those characterized as Critically Dry (USBOR 2017a: 18).

During Critically Dry hydrologic conditions, USBOR proposes to remove the target flow of 1 m^3/s (35 cfs) at the Taiban gage and focus Carlsbad Project Water Operations solely on the Acme target flow (for a detailed discussion of the rational herein, see USBOR 2017a: 18). USBOR will coordinate with the U.S. Fish and Wildlife Service (Service) each year for the duration of the Biological Opinion to determine if a designation of Critically Dry is appropriate for the current and forecasted water storage and availability, and will work with the Service to utilize the *bypass, block releases, and supplemental water to minimize river intermittency. (Consultation Number 02ENNM00-2016-F-0506 pages 7 & 8).*

USBOR defines Pecos intermittency as non-continuous flows from Sumner Reservoir to the Brantley Reservoir inlet. USBOR further contends that the Proposed Action does not cause intermittency in these areas of the Pecos River; however, USBOR will fully utilize its authorities and discretion over the Project to prevent or minimize intermittency to the greatest extent possible.

Bypassing water means allowing Pecos water to flow downstream, unchecked by the Upper Reservoirs. Bypass may occur if Pecos discharge recorded at Taiban and Acme gages are not high enough to ensure river connectivity. If water is available for Project storage, USBOR will only divert to storage inflow to the Upper Reservoirs not needed to support the downstream flow targets (USBOR 2017a: 17; see also this reference for bypass flow calculations and additional explanation).

A designation of a Critically Dry year does not guarantee intermittency will occur but is an indicator that the hydrologic conditions in the Pecos Basin are such that USBOR may not be able to cover the deficit in the system with its available resources (see USBOR 2017a: 16 and Supplemental Water Conservation Measures below).

The Critically Dry year designation, collaboratively defined by the USBOR and the Service, is an adaptive process whereby USBOR will continually assess basin forecasts to determine the prevailing hydrologic conditions. A normal water year (Normal year) is defined here as favorable river conditions within the Taiban to Acme reach from June 1 through October 31 not defined as Critically Dry (see below)."

The schedule and methods for determining Critically Dry conditions are further defined in Figure 27 (USBOR 2017a: entire).

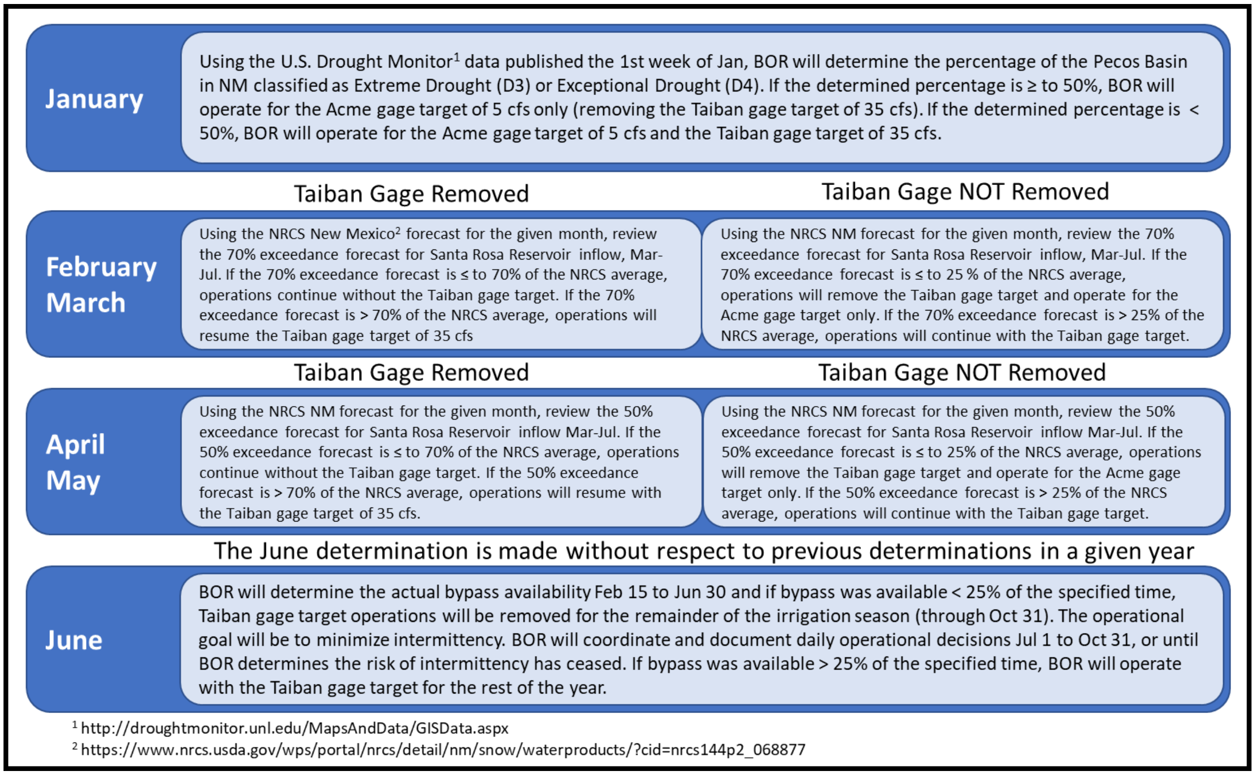

Figure 27: Schedule and methods for determining Critically Dry conditions.

Methods that USBOR and partners use to meet the flow targets include:

- **Pumping supplemental water from the Vaughan Wellfield.** Located near Fort Sumner, these groundwater wells are operated by NMISC to provide additional water to meet ESA flow requirements. The wellfield can produce approximately 8.5 cfs, depending on the groundwater levels. NMISC supplies the water and USBOR provides funds for the operation and maintenance (O&M) of the wells, plus payment for water used. The Vaughan Wellfield is often referred to as the Vaughan Conservation Pipeline ("Vaughan Pumps" in the model.)
- **Using water from the USBOR's Seven Rivers Wellfield in Brantley Reservoir.** The Seven Rivers wells pump water from USBOR wells directly into Brantley Reservoir. Using a 25% loss rate of water traveling from Sumner Dam to Brantley Reservoir, USBOR pumps an annual average of 750 acre-feet of water into Brantley Reservoir in exchange for 1,000 acre-feet in Sumner. The 1,000-acre-foot pool in Sumner is called the Fish Conservation Pool. This water is used to supplement CID irrigation demands and instream flow requirements ("Seven Rivers Exchange" in the model.)
- **Storing water in Sumner Reservoir.** An agreement between USBOR and FSID resulted in USBOR acquiring 2,500 acre-feet of water annually from FSID and storing this water in Sumner Reservoir for releases needed for the river to maintain ESA-required flows. Sumner Reservoir Bypass water is available before and after irrigation season and during irrigation season when FSID's two-week allotment is 100 cfs. This water is purchased by

contractual agreement with downstream water right holders that used to pump water from the river or from surface water users that do not use their surface water. The bypassed water is the water not used by these river pumpers. ("Sumner Lake Bypass" in the model.) 500 acre-feet of water is held in Sumner Reservoir to release water to meet instream flow requirements. ("Sumner Lake Fish Conservation Pool" in the model.)

4.3 Flow-Biota Relationships

The following categories will be used during the ecosystem flow workshop to help structure discussions related to flow requirements of different parts of the river system. Flows are discussed in terms of seasonality and flow magnitude which includes flood flows and baseflows (Table 5 and Table 6). Discussions of flow-biota connections are presented both in terms of broad relationships and also in the context of key taxa or guilds about which there was a relatively substantial base of information available.

4.3.1 Flow Categories

Flow Timing -- We have defined already defined flow seasonality in Table 3. Snowmelt runoff (Jan 27 – May 27), Summer low flow (May 28 – Jul 25), Monsoon (Jul 26 – Sep 4), Fall-winter base flow (Sep 5 – Jan 26).

Flow Magnitude -- We distinguish two flow magnitude groups: flood flows and baseflows. Flood flows include flood magnitude, frequency, duration, and rates of flow recession or drawdown following the flood. Flow recessions or drawdowns extend from the flood peak down to baseflow levels, which we define here as less than or equal to 100 cfs. Within both the flood flow and baseflow groups, we have identified three magnitude classes and estimated various associated physical effects (Table 5 and Table 6). Direct and indirect effects on different biota are discussed in more detail within each section below.

Table 5: Flood flow impacts to channel geomorphology, sediment, vegetation, the floodplain, organic matter and groundwater. These flood flows are representative for Reach B and Reach C. Flow impacts are approximate and may not reflect the conditions throughout the river reaches. Table adapted from Shafroth and Beauchamp (2006).

	Large Flood	Moderate Flood	Small Flood
Channel Geomorphology	• Channel avulsion • Channel geometry change and formation of new channels • Channel widening and deepening	• Some channel migration, widening, local deepening (magnitude and duration dependent)	• No significant changes to channel geomorphology
Sediment	• Extensive sediment erosion and deposition, including channel bed sediment, tributary fans, and channel banks in incised reaches • Complete turnover of instream sediments	• Some bare substrate generated via sediment mobilization (erosion and deposition)	• Turnover of some sediments
Vegetation	• Removal of mature trees in some floodplain locations • Removal of most herbaceous vegetation	• Mechanical damage or removal of smaller woody plants in broad floodplain reaches • Large woody plants damaged or removed in narrow reaches • Some herbaceous vegetation scoured	• Some mechanical damage to near-channel riparian vegetation
Floodplain	• Creation of new off-channel aquatic habitats such as pools, destruction or filling of old off-channel habitats • Wetting of entire floodplain	• Refresh and/or rescour existing off-channel aquatic habitats • Some creation of new off-channel aquatic habitats such as pools, and some destruction or filling of old off-channel habitats (magnitude dependent) • Most of floodplain wetted	• Refilling of some (lower lying) existing off-channel habitats without major scouring • Some of floodplain wetted
Organic Matter*	• CPOM and FPOM removed	• Some CPOM and FPOM removed	• Little CPOM and FPOM removed
Groundwater	• Alluvial groundwater and soil moisture recharge	• Alluvial groundwater and soil moisture recharge	• Partial recharge of alluvial groundwater and soil moisture

*CPOM = Coarse particulate organic matter; FPOM = fine particulate organic matter]

Table 6: Baseflows from low to high on the Pecos basin. These baseflows are representative for Reach B and Reach C. Flow range and surface flow conditions are approximate and may not reflect the conditions throughout the river reaches.			
	High Baseflow	**Moderate Baseflow**	**Low Baseflow**
Flow Range	50-100 cfs	10-50 cfs	1-10 cfs
Surface flow	Surface flows maintained in all reaches.	Surface flow maintained in most river reaches. Some river reaches by have little to no flow.	Surface flow may be absent in several of the river reaches.

4.4 Plant Communities

The flow regime strongly affects all aspects of the riverine environment such as channel widening, channel meandering, interaction with wetlands, and groundwater recharge. These factors, overlaid on the geologic and climatic setting, form the physical "stage" on which riparian vegetation location and success play out (Friedman and Auble, 2000; Stromberg, 2001).

River flow impacts on riparian vegetation are best summarized by Shafroth and Beauchamp (2006):

*" **Large floods** may have sufficient energy to remove or damage woody vegetation from significant portions of the flood plain, whereas small floods may only remove or damage vegetation within the highest energy flow paths. Floodflows entrain and transport sediment, leading to erosion, deposition (and perhaps associated burial of vegetation), and consequent changes to fluvial surfaces. Floods often drive dominant fluvial processes (e.g., channel meandering, widening, sediment deposition), which in turn determine the nature of substrates upon which riparian vegetation becomes established and grows (Scott and others, 1996). Infrequent, large-magnitude flood events can result in the establishment of new cohorts of woody vegetation throughout a river system ("general replenishment model" sensu Hughes, 1994).*

***Smaller magnitude floods** can result in more spatially limited establishment of new cohorts ("incremental replenishment model" sensu Hughes, 1994). Sediment deposition associated with floods can also elevate flood plains, making plants there less susceptible to future flooding and leading to an increased importance of autogenic (successional) processes in determining vegetation change on the highest surfaces. Changes in elevation above the stream channel or water table can alter water availability, perhaps affecting plant growth.*

***All floods** can also play a role in dispersing the seeds of riparian species ("hydrochory"; see Merritt and Wohl, 2002). Flood regimes include flows that differ in their timing (e.g., winter versus summer or fall), magnitude, frequency, and duration, contributing to the high dynamism associated with riparian plant communities on unregulated rivers. Over decades, floods of different magnitudes,* *timing, etc., create a mosaic of sites and vegetation patches along rivers (Stromberg, 1998; Lytle and Merritt, 2004).*

***Low flows** are typically important for maintaining the relatively high water availability on which riparian plants depend for growth and survival. Low flows replenish ground water through infiltration and percolation. On southwestern U.S. flood plains, differences among species in tolerance of low or high soil moisture result in somewhat predictable variation in the abundance of dominant species along gradients of water availability (Stromberg and others, 1996). Saltcedar or tamarisk (Tamarix spp.) is more drought tolerant than is cottonwood or willow (Salix spp.) (Busch and Smith, 1995; Horton and others, 2001a, b; Rood and others, 2003) and thus can dominate river reaches where flows are typically lower and ground water is deeper (Stromberg, 1998; Shafroth and others, 2000; Lite and Stromberg, 2005)."*

4.4.1 Riparian and Wetland Vegetation

Riparian and wetland vegetation types are rare in New Mexico; comprising less than one percent (0.7%) of New Mexico's land cover (Abrahamson 2020). Many riparian plant species are adapted to, and depend on, flood dynamics for recruitment and persistence. *Populus* (cottonwood) species, for example, disperse short-lived seeds in synchronization with spring flooding events (flood subsidence), when suitable moist, bare mineral substrates become available for seed germination and plant establishment (Abrahamson 2020). Knowledge of plant species responses to flood dynamics empowers strategic management of river systems for maintenance of these rare ecosystems and conservation of the species that compose them. Flood dynamics by vegetation type and dominant species are presented below in Section 4.4.2 and Section 4.4.3, respectively. This information can be enhanced over time as additional research and literature reviews are conducted. Federally at-risk, threatened, and endangered plant species that are affected by flood dynamics are presented in Section 4.4.4.

Vegetation within the study area is mapped to Land Cover Type within the Southwest Regional Gap Analysis Project's (SWReGAP) landcover dataset (Lowery, et al. 2005) and to custom New Mexico riparian vegetation Level 3 map units (approximating the U.S. National Vegetation Classification System [NVCS] Group level) within the New Mexico Riparian Habitat Map (NMRipMap) dataset (Muldavin, et al. 2020). Level 3 riparian vegetation map units are currently available for Reach A of the study area. Pecos River riparian vegetation mapping is in progress, and the entire study area should be mapped to NMRipMap Level 3 map units within with the NMRipMap dataset by December 2021 (E. Muldavin 2020). This analysis references SWReGAP land cover concepts for vegetation types and would benefit from revision once NMRipMap map units are available for the entire study area.

SWReGAP vegetation types within the study area are identified by reach in Table 7, and dominant species within each vegetation type are identified in Table 8. Table 9 identifies the responses of these dominant species to flood dynamic where relevant information was available within the USFS's Fire Effects Information System (FEIS; Abrahamson 2020).

All riparian and wetland plant species have higher soil moisture requirements than upland plant species. The abundance and distribution of plant species within riparian and wetland habitats is driven by nuances in individual's needs and tolerance thresholds. Flood dynamics analyzed here include snowmelt, seasonal flooding, flash or episodic flooding, seasonal drying, and up- and down-stream effects of natural and anthropogenic damming (artificial drought and inundation). Snowmelt refers to areas seasonally saturated by direct release of water from snowpack while seasonal flooding refers to the rise in surface water flows caused by system-wide natural seasonal climatic cycles (snowmelt within this study area) that temporarily inundate areas. Flash or episodic flooding refers to rises in surface water flows caused by more intense or localized precipitation events that temporarily inundate and may scour areas. Seasonal drying refers to drops in the water table caused by natural seasonal climatic cycles, and artificial drought refers to drops in the water table caused by up-reach obstacles to or use of natural water flows. Inundation refers to areas that retain and are submerged by surface water.

4.4.2 Vegetation Types by Reach

Riparian and wetland vegetation types within one kilometer of the study area include (estimated land cover area, percent of riparian and wetland vegetation land cover within the analysis area) Western Great Plains Mesquite Woodland and Shrubland (441,166 ac, 34.43%), Rocky Mountain Aspen Forest and Woodland (366,380 ac, 28.60%), Western Great Plains Riparian Woodland and Shrubland (212,872 ac, 16.61%), Rocky Mountain Lower Montane Riparian Woodland and Shrubland (194,539 ac, 15.18%), Rocky Mountain Alpine-Montane Wet Meadow (33,618 ac, 2.62%), Rocky Mountain Subalpine-Montane Riparian Shrubland (25,355 ac, 1.98%), North American Warm Desert Wash (3,340 ac, 0.26%), North American Warm Desert Lower Montane Riparian Woodland and Shrubland (1,685 ac, 0.13%), North American Warm Desert Riparian Woodland and Shrubland (1,341 ac, 0.10%), and North American Arid West Emergent Marsh (975 ac, 0.08%). Reach A, immediately down-stream from the Pecos River headwaters, contains the highest diversity of riparian and wetland vegetation types because this reach has the steepest elevation gradient and passes through more life zones than Reach B and Reach C. It also contains 99.29% of the riparian and wetland vegetation land cover within the study area. Reach C contains the next most riparian and wetland vegetation land cover within the study area (0.66%), followed by Reach B, which has the lowest riparian and wetland vegetation land cover (0.04%). Reach A is above the first major anthropogenic dam on the Pecos River, and Rocky Mountain Subalpine-Montane Riparian Shrubland needs within this reach include beaver damming.

Table 7: Analysis unit and flood dynamic requirements for riparian and wetland vegetation types within the Pecos SRP study area.									
Vegetation Type	**In Reach**			**Flood Dynamic**					
	A	**B**	**C**	**Snowmelt**	**Seasonal Flooding**	**Flash or Episodic Flooding**	**Seasonal Drying**	**Damming, Inundation**
Rocky Mountain Alpine-Montane Wet Meadow (AMWM)	X			X				
Rocky Mountain Subalpine-Montane Riparian Shrubland (SMRS)	X							X
Rocky Mountain Aspen Forest and Woodland (AFW)	X							
Rocky Mountain Lower Montane Riparian Woodland and Shrubland (RM-LMRWS)	X	X			X	X		
Western Great Plains Mesquite Woodland and Shrubland (MWS)	X							
Western Great Plains Riparian Woodland and Shrubland (GP-RWS)	X	X	X			X	X	
North American Warm Desert Wash (WDW)		X	X			X	X	
North American Arid West Emergent Marsh (AWEM)		X	X					X
North American Warm Desert Riparian Woodland and Shrubland (WD-RWS)			X		X	X		
North American Warm Desert Lower Montane Riparian Woodland and Shrubland (WD-LMRWS)			X		X	X		

4.4.3 Dominant Species

Vegetation types are determined by their relative composition and cover of dominant plant species. Dominant plant species (or genera) within each riparian or wetland vegetation type are identified in Table 8. The distribution and abundance of these species are mediated by species' and individuals' responses to environmental factors. Table 9 identifies dominant species' general needs and tolerances in relation to flood dynamic factors. Species without relevant information available in the FEIS are excluded from Table 9. Nuances in species' and individual's needs and tolerance thresholds also influence vegetation dynamics within riparian and wetland vegetation types, but these nuances are not analyzed here. Table 9 is intended to serve as a quick reference to the potential species responses to alternate flow, flood and inundation scenarios and as a guide for additional research. Table 8 can be used as a quick reference to potential vegetation changes resulting from species' responses to alternate flow, flood and inundation scenarios. Many data gaps remain to be filled, and managers are encouraged to monitor dominant and rare plant species' responses to standard and experimental flood dynamic management strategies.

Table 8: Dominant plant species within each riparian or wetland vegetation type with the Pecos SRP study area. * = introduced species or genera, ^ = species or genera that may be native or introduced to the study area.

Dominant Plant Species			Vegetation Type									
Species Name	**Common Name**	**Growth Habit**	**AMWM**	**SMRS**	**RM-LMRWS**	**AFW**	**MWS**	**GP-RWS**	**WDW**	**AWEM**	**WD-RWS**	**WD-LMRW.S**
Acer negundo	boxelder	Tree				X					X	
Fraxinus velutina	velvet ash	Tree									X	X
Juglans major	Arizona walnut	Tree									X	X
Picea pungens	blue spruce	Tree				X						
Populus angustifolia	narrowleaf cottonwood	Tree				X						X
Populus deltoides	eastern cottonwood	Tree				X		X				X
Populus deltoides ssp. *wislizeni*	Rio Grande cottonwood	Tree										X
Populus fremontii	Fremont cottonwood	Tree				X					X	X
Populus tremuloides	quaking aspen	Tree			X							
Pseudotsuga menziesii	Douglas-fir	Tree				X						
Salix gooddingii	Goodding's willow	Tree									X	
Acer glabrum	Rocky Mountain maple	Shrub/Tree				X						
Alnus incana	gray alder	Shrub/Tree		X		X						
Betula occidentalis	water birch	Shrub/Tree		X		X						
Celtis laevigata var. reticulata	netleaf hackberry	Shrub/Tree									X	
Chilopsis linearis	desert willow	Shrub/Tree							X			
Cornus sericea	redosier dogwood	Shrub/Tree		X		X						
*Elaeagnus angustifolia**	Russian olive	Shrub/Tree				X						
Juglans microcarpa	little walnut	Shrub/Tree							X			
Juniperus scopulorum	Rocky Mountain juniper	Shrub/Tree				X						
Prosopis glandulosa	honey mesquite	Shrub/Tree					X		X			
Prosopis velutina	velvet mesquite	Shrub/Tree							X			
Prunus virginiana	chokecherry	Shrub/Tree				X						
Rhus microphylla	littleleaf sumac	Shrub/Tree							X			

Salix amygdaloides	peachleaf willow	Shrub/Tree				X						
Salix bebbiana	Bebb willow	Shrub/Tree		X								
Salix eriocephala	Missouri River willow	Shrub/Tree		X								
Salix exigua	narrowleaf willow	Shrub/Tree				X					X	X
Salix lasiolepis	arroyo willow	Shrub/Tree									X	
Salix lucida	shining willow	Shrub/Tree				X						
Salix monticola	park willow	Shrub/Tree		X		X						
*Salix^*	willow	Shrub/Tree						X				
Sapindus saponaria	wingleaf soapberry	Shrub/Tree										X
Tamarix	tamarisk	Shrub/Tree				X						
Salix planifolia	diamondleaf willow	Shrub/ Subshrub/Tree		X								
Fallugia paradoxa	Apache plume	Shrub							X			
Forestiera pubescens	stretchberry	Shrub				X						
Rhus trilobata	skunkbush sumac	Shrub				X						
Salix boothii	Booth's willow	Shrub		X								
Salix brachycarpa	shortfruit willow	Shrub		X								
Salix drummondiana	Drummond's willow	Shrub		X		X						
Salix irrorata	dewystem willow	Shrub				X						
Symphoricarpos occidentalis	western snowberry	Shrub				X						
Symphoricarpos albus	common snowberry	Shrub/Subshrub				X						
Caltha leptosepala	white marsh marigold	Forb/herb	X									
Cardamine cordifolia	heartleaf bittercress	Forb/herb	X									
Nuphar	pond-lily	Forb/herb								X		
*Polygonum aviculare**	prostrate knotweed	Forb/herb								X		
*Potamogeton^*	pondweed	Forb/herb								X		
*Typha angustifolia^*	narrowleaf cattail	Forb/herb								X		
Typha latifolia	broadleaf cattail	Forb/herb								X		
Calamagrostis stricta	slimstem reedgrass	Graminoid	X									
Carex illota	sheep sedge	Graminoid	X									
Carex microptera	smallwing sedge	Graminoid	X									
Carex utriculata	Northwest Territory sedge	Graminoid	X									
Deschampsia caespitosa	tufted hairgrass	Graminoid	X									
Eleocharis palustris	common spikerush	Graminoid	X									
Eleocharis rostellata	beaked spikerush	Graminoid	X									
Juncus	rush	Graminoid								X		

Pascopyrum smithii	western wheatgrass	Graminoid						X				
Phalaris arundinacea	reed canarygrass	Graminoid								X		
Schizachyrium scoparium	little bluestem	Graminoid						X				
Schoenoplectus acutus	hardstem bulrush	Graminoid								X		
Schoenoplectus tabernaemontani	softstem bulrush	Graminoid								X		
Scirpus	bulrush	Graminoid								X		
Sporobolus cryptandrus	sand dropseed	Graminoid						X				

Table 9: Dominant plant species' (or genera's) needs, tolerances, and intolerances in relation to flood dynamics. X = species overall need; D = species dispersal need; E = species establishment need; T = overall tolerance, and I = overall intolerance, * = introduced species or genera, ^ = species or genera that may be native or introduced to the study area

Dominant Plant Species			Flood Dynamic					
Species Name	**Common Name**	**Growth Habit**	**Snowmelt**	**Seasonal Flooding**	**Flash or Episodic Flooding**	**Seasonal Drying**	**Damming, Artificial Drought**	**Damming, Inundation**
Acer negundo	boxelder	Tree		T	T			
Fraxinus velutina	velvet ash	Tree						
Juglans major	Arizona walnut	Tree		T	T			
Picea pungens	blue spruce	Tree		X, E	X, E			T
Populus angustifolia	narrowleaf cottonwood	Tree		X, E			I	T
Populus deltoides	eastern cottonwood	Tree		X, E				T
Populus deltoides ssp. *wislizeni*	Rio Grande cottonwood	Tree						
Populus fremontii	Fremont cottonwood	Tree		X, E	I		I	T
Populus tremuloides	quaking aspen	Tree						
Pseudotsuga menziesii	Douglas-fir	Tree						
Salix gooddingii	Goodding's willow	Tree		X, E	T	T		
Acer glabrum	Rocky Mountain maple	Shrub Tree		T	T			
Alnus incana	gray alder	Shrub Tree		T, E				I
Betula occidentalis	water birch	Shrub Tree		T				

Celtis laevigata var. reticulata	netleaf hackberry	Shrub Tree		I	I			
Chilopsis linearis	desert willow	Shrub Tree		T				
Cornus sericea	redosier dogwood	Shrub Tree		T, E	T, E			T
*Elaeagnus angustifolia**	Russian olive	Shrub Tree		I, E	I, E		X	
Juglans microcarpa	little walnut	Shrub Tree		T	T			I
Juniperus scopulorum	Rocky Mountain juniper	Shrub Tree						
Prosopis glandulosa	honey mesquite	Shrub Tree		I, D	I, D			
Prosopis velutina	velvet mesquite	Shrub Tree		E	I, E			
Prunus virginiana	chokecherry	Shrub Tree						I
Rhus microphylla	littleleaf sumac	Shrub Tree						
Salix amygdaloides	peachleaf willow	Shrub Tree		X, E	X			T
Salix bebbiana	Bebb willow	Shrub Tree		X	X, E			
Salix eriocephala	Missouri River willow	Shrub Tree						
Salix exigua	narrowleaf willow	Shrub Tree		T	I	T	T	T
Salix lasiolepis	arroyo willow	Shrub Tree						
Salix lucida	shining willow	Shrub Tree		D	E, D			
Salix monticola	park willow	Shrub Tree			E			
*Salix^*	willow	Shrub Tree						
Sapindus saponaria	wingleaf soapberry	Shrub Tree						
Tamarix	tamarisk	Shrub Tree		T, E	T, D, E	T	T	T
Salix planifolia	diamondleaf willow	Shrub Subshrub Tree		X, D	D			
Fallugia paradoxa	Apache plume	Shrub			D, E			
Forestiera pubescens	stretchberry	Shrub						
Rhus trilobata	skunkbush sumac	Shrub		I	I			I
Salix boothii	Booth's willow	Shrub						
Salix brachycarpa	shortfruit willow	Shrub						

Salix drummondiana	Drummond's willow	Shrub		X	X, D		I	I
Salix irrorata	dewystem willow	Shrub						
Symphoricarpos occidentalis	western snowberry	Shrub		T	T			I
Symphoricarpos albus	common snowberry	Shrub Subshrub						
Caltha leptosepala	white marsh marigold	Forb/herb						
Cardamine cordifolia	heartleaf bittercress	Forb/herb						
Nuphar	pond-lily	Forb/herb						
*Polygonum aviculare**	prostrate knotweed	Forb/herb						
*Potamogeton^*	pondweed	Forb/herb						
*Typha angustifolia^*	narrowleaf cattail	Forb/herb				X		X
Typha latifolia	broadleaf cattail	Forb/herb		T	T	X		
Calamagrostis stricta	slimstem reedgrass	Graminoid						
Carex illota	sheep sedge	Graminoid						
Carex microptera	smallwing sedge	Graminoid						
Carex utriculata	Northwest Territory sedge	Graminoid		X, D	D			
Deschampsia caespitosa	tufted hairgrass	Graminoid						
Eleocharis palustris	common spikerush	Graminoid		X, E	E			X
Eleocharis rostellata	beaked spikerush	Graminoid						
Juncus	rush	Graminoid						
Pascopyrum smithii	western wheatgrass	Graminoid		X				
Phalaris arundinacea	reed canarygrass	Graminoid		T	T		I	I
Schizachyrium scoparium	little bluestem	Graminoid						
Schoenoplectus acutus	hardstem bulrush	Graminoid				I		X
Schoenoplectus tabernaemontani	softstem bulrush	Graminoid				I, E		
Scirpus	bulrush	Graminoid						
Sporobolus cryptandrus	sand dropseed	Graminoid		X				

4.4.4 Threatened and Endangered Species

Three federally at-risk, candidate or threatened plant species are known to occur in wetlands within the study area: Leoncita false foxglove (*Agalinis calycina*), Wright's marsh thistle (*Cirsium* *wrightii*), and Pecos sunflower (*Helianthus paradoxus*). Leoncita false foxglove is federally under review for listing under the Endangered Species Act (ESA), there's a proposed rule to list Wright's marsh thistle as threatened with critical habitat under the ESA, and Pecos sunflower is listed as threatened with critical habitat under the ESA. Water management is a documented threat to all three of these species (Lowery, et al. 2005). These species require perennially moist soils. Drought and wetland drying adversely affect these species.

4.4.5 Invasive Saltcedar

Although there are several invasive species along the Pecos River, this section will focus on saltcedar as it is the most abundant and threatening to this river system (Figure 28). Saltcedar (*Tamarix* spp.) is an invasive plant common to southwestern states and has been listed as a noxious weed in New Mexico. Saltcedar is an extremely successful nonnative facultative phreatophyte shrub that has spread extensively and presently occupies hundreds of thousands of acres in the southwest, including the Pecos River. Saltcedar has become a dominant plant of banks of rivers, streams, springs, and ponds throughout its range; decreasing habitat quality for many wildlife species. Saltcedar has been a problematic species in southwestern riparian systems for decades (Animal and Plant Health Inspection Service 2005).

Figure 28: Tamarisk Photo (Washington Invasive Species Council)

Saltcedar was introduced into the United States as an ornamental in the early 1800's. In the early 1900's, government agencies as well as private landowners began planting saltcedar for stream bank erosion control along such rivers as the Pecos. Saltcedar rapidly became the dominant species in the Pecos River floodplain, occupying 28,000 acres of the 41,000-acre floodplain in 1958 (Mower, et al. 1964).

The Pecos River's vegetation changes drastically moving north to south. The presence and impact of saltcedar increases from north to south as well. In the upper reach of the watershed (Reach A), vegetation is the most diverse with saltcedar being a minor component. In the middle reach (Reach B), saltcedar increases, however, there are other dominant species present. Starting in this reach, there are live and dead saltcedar. The dead saltcedar is due to management efforts by federal, state, and local conservation agencies trying to eradicate this invasive species. The lower reach (Reach C) is nearly a monoculture of saltcedar. Studies, investigations, and projects to control saltcedar have been occurring since the 1960's.

Saltcedar has a deep, extensive root system that extends to the water table, and is capable of extracting water from unsaturated soil layers. Saltcedar has a primary root that grows with little branching until it reaches the water table, at which point secondary root branching is profuse (Brotherson and Winkel 1986).

Mature tamarisk plants reproduce vegetatively by adventitious roots, or by seed. Saltcedar plants may flower in their first year of growth, but most begin to reproduce in their third year or later. Because saltcedar reproduces sexually throughout most of the growing season, a small plant can produce a substantial seed crop. Saltcedar seeds have small hairs on the apex of the seed coat and are readily dispersed by wind, and also can be dispersed by water (L. E. Stevens 1989).

Saltcedar seeds are short-lived and do not form a persistent seed bank (L. E. Stevens 2002). Saltcedar seeds produced during the summer remain viable for up to 45 days under ideal field conditions (ambient humidity and full shade), or for as few as 24 days when exposed to full sunlight and dry conditions. Seed mortality is generally due to desiccation (L. E. Stevens 1989).

Saltcedar seeds have no dormancy or after-ripening requirements (L. E. Stevens 1989). Germination requires direct contact with water or extremely high humidity and is very rapid (<24 hours). Seeds require a moist, fine-grained (silt or small particle size) substrate for germination, such as found in southwestern riparian habitats after flood waters subside. Seed produced in August had the highest germination percentage (51.4%) and in those produced in June had the lowest (19.0%; L.E. Stevens 2002).

The timing of seed dispersal, relative to the pattern of annual flow, is a critical component to the establishment of riparian vegetation (Figure 29). Compared to cottonwood, saltcedar has a longer seed dispersal window. Cottonwood has a short seed-viability period that occurs during spring flooding, while saltcedar produces seeds over a much longer period and can establish throughout the summer during low flow regimes when seeds of other species are not present. Therefore, timing flood flows later in the season and subjecting saltcedar to the scouring effects of the floods and prolonged inundation may increase saltcedar mortality, although buried root crowns or aboveground portions of branches and smaller stills will of sprout (Briggs 1996). Saltcedar seedlings (around 5 weeks old) are more susceptible to summer flooding than are older plants (Sprenger, Smith and Taylor, Restoration of riparian habitat in the Middle Rio Grande Valley 1998). Prolonged inundation (1 to 3 years) can kill most saltcedar (Hoddenback 1989). Because of the high mortality of cottonwood in response to complete submergence, flooding saltcedar seedlings may not be desirable when submergence of cottonwood seedlings would occur (Sprenger, Smith and Taylor 2001). Cottonwood and willow are favored if germination sites are moistened only during spring but become dry during summer when tamarisk continue to disperse seeds (Stromberg, et al. 1993). Therefore, it is recommended to release winter or spring regeneration floods and limit duration of summer flooding (Levine and Stromberg 2001). Later, summer floods of long duration may increase inundation-related mortality of saltcedar seedlings, and those of large magnitude but short duration can scour or bury saltcedar seedlings (Levine and Stromberg 2001).

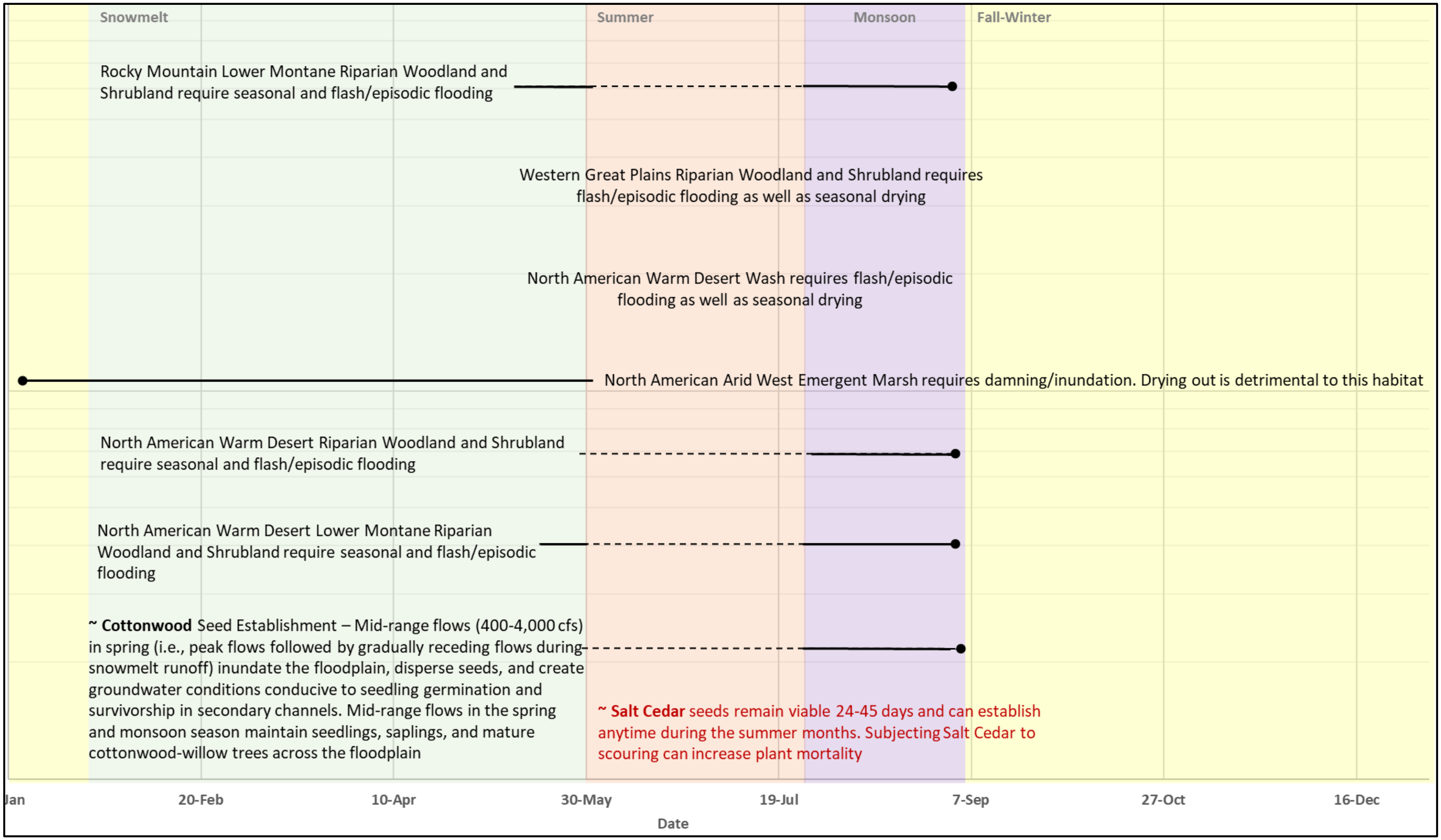

Figure 29: Major vegetation types' seasonal water needs. Cottonwood and the invasive Salt Cedar are included due to their overall ecosystem importance. Species shown in red are considered invasive in New Mexico.

4.5 Fish Communities

In terms of organisms discussed in this e-flows analysis, fish are the most immediately affected by flood, drought, and other flow events. Worthington et al. (2016) provides an overview of conservation concerns for pelagic-broadcast spawning (PBS) fish, including several species found in the Pecos River. Propst et al (2008) divides the hydrologic regime needs of native Gila River fish species into pre-spawn, spawn, and post-spawn periods (Table 10). Brewer et al. (2016, 2018) review how altered landscapes affect environmental flow for aquatic communities and provide a foundation for evaluating the effects on flow on fish populations. Reach length as an important factor for understanding the life history of many PBS species (Chase et al. 2014; Wilde and Urbancyzk 2013; Worthington et al. 2017). Egg drift of several Pecos fish species that respond to environmental flows have been the topic of several studies (Alleman 2008; Medley et al. 2007). Appropriate methods for representative sampling of Pecos fish communities to support population models is an ongoing topic of discussion (Widmer et al. 2010, 2013).

Table 10: Environmental attributes and their ecological relevance for arid stream native fish. Adapted from Propst et al. (2008) Table 2

Period	Flow	Ecological Relevance
Pre-spawning hydrology (Nov – Feb)	Median Discharge	Amount of habitat
	Maximum Daily	Inter-day variation
	High Flood Pulses	Faunal displacing and channel forming
Spawning hydrology (Mar – Apr)	Medium Discharge	Amount of habitat
	Minimum Daily	Spawning habitat reduction or loss
	Maximum Daily	Modify stream morphology; eggs and larvae displacement
	Baseflow Index	Current conditions vs. record norm
	High Flood Pulses	Disrupt spawning
	Reversals	Spawning disruption; egg exposure
Post-spawning hydrology (May – Oct)	Medium Discharge	Amount of habitat
	Minimum Daily	Increased competition or predation
	Maximum Daily	Modify stream morphology
	Baseflow Index	Current conditions vs. record norm
	High Flood Pulses	Disrupt non-native spawning; displace non-native eggs or larvae
	Low Flood Pulses	Disrupt non-native spawning

The following fish species are listed under the ESA and the New Mexico Wildlife Conservation Act and are endemic to the Pecos River Basin (Table 11).

Table 11: Listed fish species in the Pecos River Basin. Table adapted from USBOR 2021, Table 1

Species	Listed Status	Threats	Spawning Cues	Location
Gray Redhorse (*Moxostoma congestum*) 	NMDGF listed endangered in 2008	Dams, modification of stream flow patterns, and outbreaks of golden algae have degraded habitat. This has drastically diminished its population in the Pecos River.	Spring spawner over riffles, photoperiod and water temperature likely cues.	Reach C
Pecos Gambusia (*Gambusia nobilis*) 	NMDGF listed endangered in 1975	Depletion of groundwater causes water quality and quantity impacts. Habitat modification by livestock grazing and predation by non-native species are further threats.		Springs in the Basin
Pecos bluntnose shiner (shiner) (*Notropis simus pecosensis*) 	USFWS listed threatened in 1987 NMDGF listed endangered in 2006	Block releases from reservoirs during summer spawning season carry eggs and larvae into unsuitable habitat. Fish are also impacted by reduced river flow at other times, habitat degradation and fragmentation, and pollution from agricultural	Late spring through summer, associated with increased flow. Eggs and larvae transported downstream.	Reach C
Pecos pupfish (*Cyprinodon pecosensis*) 	NMDGF listed threatened in 1988	The non-native sheephead minnow displaces this species. Golden algae blooms threaten habitat.	Spawn in backwater habitat, peak in May and June. Spring spawner, photoperiod likely cue.	Lakes/ Reach C
Greenthroat darter (*Etheostoma lepidum*) 	NMDGF listed threatened in 1975	Pumping groundwater and diverting spring surface flows threaten habitat.	Spawning throughout the year, varies with water temperature.	Reach C
Bigscale logperch (*Percina macrolepida*) 	NMDGF listed threatened in 1975	Reduced river flow and diversions reduce flow velocity, and water quality degradation threaten habitat.	Spring spawner, photoperiod likely cue.	Reach B and C

More information for each fish listed above can be found with the document *Threatened and Endangered Fishes of New Mexico* (Propst 1999; Sublette et al. 1990). The bluntnose shiner will be covered in detail below because this fish is federally listed, and the 2016 Biological Opinion for the Pecos River established flow requirements at the Acme and Taiban gages to support specific species (including the bluntnose shiner) in the Pecos River system.

4.5.1 Flow Targets for the Pecos Bluntnose Shiner

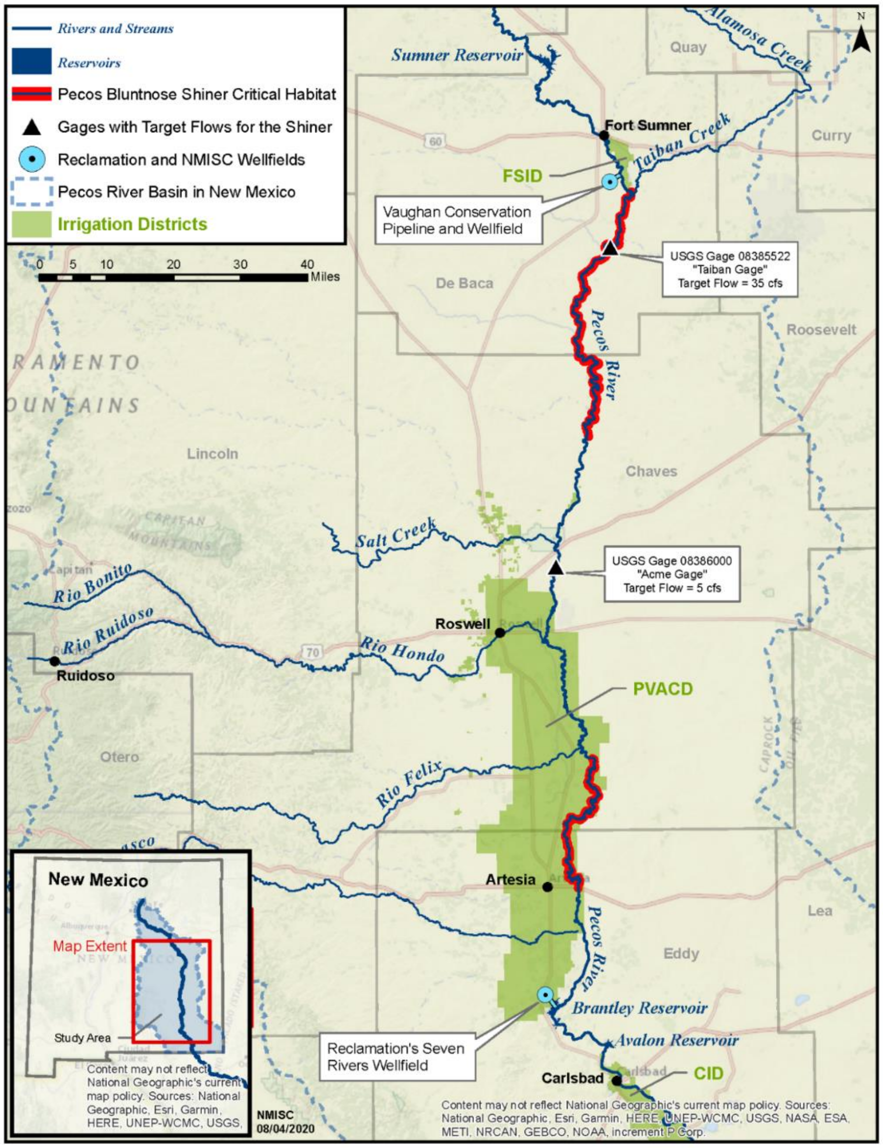

Figure 30: Gages and critical habitat for flow targets (NMISC).

The Pecos bluntnose shiner (shiner) is the primary species of concern in mainstem of the Pecos River as it is nationally listed. The shiner benefits from multiple years of perennial stream flow. Populations can be negatively impacted by extended periods of stream intermittency ("drying"). Critical habitat for the shiner is shown in Figure 30. All the shiner critical habitat is found within Reach C.

The three sub-reaches in Reach C come from the USFWS classification of habitat suitability for the threatened Pecos bluntnose shiner. Reach C sub-reaches defined by the USFWS are: Tailwater (C-1), Rangelands (C-2), and Farmlands (C-3). Table 12 details the shiner habitat quality for each sub-reach.

Table 12: USFWS's detailed description of each sub-reach in Reach C.	
Sub-reach C-1	A result of sediment sequestration by upstream dams and scour by block release hydrology, the riverbed in this reach is armored consisting largely of a gravel substrate. Relative to historical conditions, it is generally degraded aquatic habitat that is not suitable for native, pelagic spawning fishes such as the Pecos bluntnose shiner.
Sub-reach C-2	This sub-reach represents the best overall aquatic habitat within the Upper Pecos as a whole. It is a key stronghold for the shiner and is more indicative of the historical, mobile sand-bed river system; there are numerous unregulated tributaries which provide sediment during sizable precipitation events. Although sediment in the Pecos River is limited by upstream dams, tributary sediment loads in C-2 have reached a quasi-equilibrium with block release hydrology and thus a dynamic but generally stable channel planform.
Sub-reach C-3	Sub-reach is generally more channelized then reaches to the north with smaller shiner populations than C-2.

To reduce stress to the shiner populations, flow targets in the critical habitat reaches are prescribed by the 2016 Biological Opinion. The criteria for these flow targets are:

1. USBOR will divert water to storage, when water is available and flows at Acme are greater than 5 cfs under all hydrologic conditions, and flows at Taiban are greater than 35 cfs, except under critically dry hydrologic conditions. During critically dry hydrologic conditions (covered in Section 4.2), USBOR will focus only on the Acme target flow. This action integrates senior water rights and non-discretionary actions.
2. USBOR will deliver Project water from storage as contracted for irrigation, consistent with applicable Federal and state laws, and as per the block release constraints from Sumner Dam.
3. USBOR will continue to use additional water from the bypass or the conservation pool to augment flows and avoid Pecos intermittency.
4. USBOR will apply conservation measures to facilitate ESA compliance and acquire water to offset depletions to the Project.

The spring snowmelt runoff would historically signal the spring spawning season for Shiner. Shiner will also spawn into the summer months when monsoon storms would hit the region and signal spawning conditions (Figure 31). Typically, block releases occur in the late spring and summer months which generally coincides with shiner spawning season. In fact, the increased discharge from a block release is a cue for spawning and tends to mimic the spring snowmelt runoff and monsoon events; however, there are significant differences between a block release hydrograph and a more natural flow regime. A snow melt hydrograph has a vastly more protracted ascending and descending limb than a block release which is virtually an instantaneous increase to peak flow levels followed by a rapid decrease back to base flow. The spring spawn is central to the shiner's annual recruitment success (S. Davenport pers. comm.) and it is thought that the abrupt block release hydrology diminishes that success by promptly flushing eggs and larvae downstream at a far greater rate than would be expected under natural snow melt runoff conditions.

Tetra Tech (2019) provided some important information and context on past geomorphic studies of the Pecos and their relationships to shiner habitat as well as the basis for an analysis of current trends within the study reach. Phase II of the USFWS effort (Tetra Tech 2020) therefore focused on the following:

- An assessment of main stem and tributary hydrology;
- An in-depth synthesis of geomorphic changes over time withing the study area; and
- Evaluation of a number of sites for potential habitat restoration projects.

Again, the overarching purpose for this work were concerns over declining habitat trends (e.g., channel narrowing and degradation) resulting from a non-natural, high-flow hydrologic regime (i.e., block releases) and potential reductions in tributary sediment inputs due to both short- and long-term drought cycles. Central to this focus is egg and larval retention in upstream reaches with suitable slack-water nursery habitat (Chase et al. 2015). Detrimental planform changes can greatly influence the rate of downstream egg and larval transport into areas of poor habitat (Sub-reach C-3) and drastically increased predation (Brantley Reservoir). Over time, the downstream displacement of eggs and larvae has a significant impact on recruitment and threatens shiner survival.

Block flow discharge rates are typically around 1,400 cfs for up to 15 days (mean of 8 days from 2000-2019); these agreed upon limits have been enacted to minimize Pecos bluntnose shiner egg and larval displacement. Nonetheless, spring block releases are the contemporary analog, in the highly regulated Pecos, to a natural spring runoff spawning pulse and thus, in addition to being the most geomorphically significant, an ecologically important attribute of the annual hydrograph. Conversely, summer block releases are typically smaller and of shorter duration. These are more similar to monsoon spates which can supplement annual recruitment by stimulating smaller spawning events.

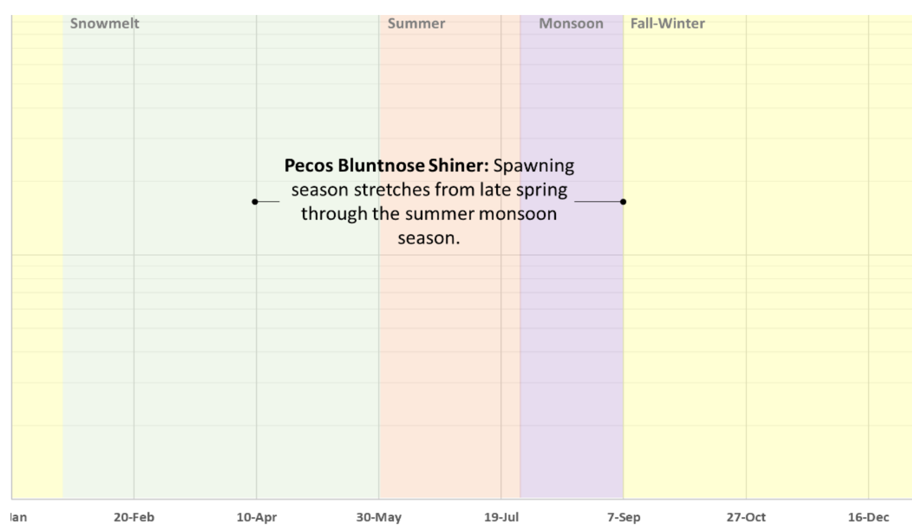

Figure 31: Spawning season for the Pecos bluntnose shiner. Spawning is signaled by the late spring snowmelt runoff and summer monsoon storms.

4.6 Reptile and Amphibian Communities

The Pecos River supports a rich community of amphibians and reptiles, including at least 8 frog and toad species and 10 snake and turtle species that depend primarily on the river for their habitat (Table 13). As might be expected for a river that changes as it flows from mountain headwaters to low desert, the species are not evenly distributed. One, the Terrestrial Gartersnake, is known only from the upper river, above Santa Rosa Dam, while the Rio Grande Leopard Frog is only known below Brantley Dam. Five species are recognized on the New Mexico list of Species of Greatest Conservation Need, and four are listed as Sensitive by the U.S. Forest Service. Two of the gartersnakes (*Thamnophis marcianus* and *T. proximus*) have not been documented in the river in more than 20 years, and it's been at least 10 years for another gartersnake (*T. elegans*) and a leopard frog (*Rana blairi*), which might be due to lack of surveys in recent years.

Table 13: Distribution, status, and flow needs for amphibian and reptile species of the Pecos River. Species highlighted in yellow are on the New Mexico list of Species of Greatest Conservation Need[1]. Species highlighted in green are on both the New Mexico list of Species of Greatest Conservation Need and listed as Sensitive by the U.S. Forest Service[1].

Scientific Name[2]	Common Name[2]	Last Record[3]	Found in Reach[4]			Flow Needs[5]
			A	B	C	
AMPHIBIANS						
Acris blanchardi	Blanchard's Cricket Frog	2017			X	Abundant vegetation along rivers and streams.
Anaxyrus debilis	Chihuahuan Green Toad	2013	?	X	X	Temporary and permanent waters. Breeds in temporary waters.
Anaxyrus punctatus	Red-spotted Toad	2018	X	X	X	Temporary and permanent waters.
Anaxyrus speciosus	Texas Toad	2018			X	Temporary and permanent waters.
Anaxyrus woodhousii	Woodhouse's Toad	2020	X	X	X	Permanent water, with overbank flooding, March to September, to create temporary off-channel pools for breeding.
Rana berlandieri	Rio Grande Leopard Frog	2018				Permanent water, emergent vegetation. In NM, generally found in clear, flowing streams or permanent poos in streams that originate from springs.
Rana blairi	Plains Leopard Frog	2010	X	X	X	Temporary and permanent waters. Somewhat terrestrial during part of the year.
Rana catesbeiana	American Bullfrog	2018	X	X	X	Permanent water. Absence of high velocity flows.
REPTILES						
Nerodia erythrogaster	Plain-bellied Watersnake	2020				Permanent water with slow-moving currents.

Thamnophis elegans	Terrestrial Gartersnake	2009	X			Widespread, most abundant near surface water.
Thamnophis marcianus	Checkered Gartersnake	1999	X	X	X	Wet habitats but uses uplands extensively.
Thamnophis proximus	Western Ribbonsnake	1998			X	Permanent water, with streamside vegetation.
Apalone spinifera	Spiny Softshell	2020	X	X	X	Permanent water.
Chelydra serpentina	Snapping Turtle	2019	X	X	X	Quiet permanent water with aquatic vegetation
Chrysemys picta	Painted Turtle	2019		X	X	Quiet permanent water
Kinosternon flavescens	Yellow Mud Turtle	2020		X	X	Prefers shallow, quiet waters with muddy or sandy bottoms.
Pseudemys gorzugi	Rio Grande Cooter	2020			X	Permanent water, with substantial vegetation. Needs riparian vegetation dominated by Fremont cottonwood, willow, or netleaf hackberry.
Trachemys scripta	Pond Slider	2020		X	X	Inhabits permanent wetlands. Aquatic vegetation, soft bottom, still or slow-moving water, depths 1-2m.

[1]Conservation status shows presence on New Mexico or Texas list of Species of Greatest Conservation Need, and U.S. Forest Service list of Sensitive species.

[2]Scientific and common names follow Crother (2017).

[3]Last record represents the most recent documented observation, taken from museum records (www.VertNet.org; accessed on 8/31/2020), and records at New Mexico Department of Game and Fish as analyzed by Leland Pierce.

[4]Distribution relative to dams was determined from georeferenced museum records, maps in Degenhardt et al. (1996) and Christman and Kamees (2007). Distributions may not be current.

[5]Flow needs were identified from Degenhardt et al. 1996 and species-specific literature.

The body of knowledge about ecological relationships and habitat needs for amphibians and reptiles in the Southwest is limited, especially for aquatic species and particularly in the realm of flow patterns needed to sustain healthy populations. The following summarizes the available literature, recognizing that additional knowledge may be available in the personal experience of local researchers and land managers.

Most of the amphibian and reptile species in the Pecos River depend on permanent water bodies and aquatic or riparian vegetation. Many are commonly found in quiet, slow-moving streams or in ponds (Degenhardt et al. 1996), though their distribution suggests they can also tolerate the seasonal peaks and lows of the natural hydrologic regime.

More detailed flow needs have been described for a few species (Figure 32):

Woodhouse's Toad: The Woodhouse's toad is associated with rivers and streams but requires mid-range flows to inundate secondary channels during the spring and summer monsoons and create temporary ponds and wetlands that the toads use for mating, egg development, and tadpole rearing and metamorphosis. The species benefits because reproduction occurs away from permanent water and high densities of invertebrate and vertebrate predators. These temporary ponds must be of sufficient duration to complete the reproductive cycle from breeding through metamorphosis (Gori 2014, Woodward 1987).

Plains Leopard Frog: The plains leopard frog typically have two breeding peaks; one in early spring, usually in March, and the other in late summer, usually in September, although they may breed after heavy rains in most months (Vitt 2021). They inhabit ponds and marshy areas and thus require mid-range flows to inundate secondary channels to create temporary ponds and wetlands.

Rio Grande Cooter: The Rio Grande cooter requires permanent water, with substantial vegetation. The pattern of flows on the Pecos have supported expansion and dominance of *Tamarix* sp. along the riparian corridor at the expense of native trees and shrubs. Primary food items for the Rio Grande cooter are leaves of Fremont cottonwood and netleaf hackberry (Letter et al. 2019), which are displaced by nonnative tamarisk.

Flow patterns that would encourage cottonwood and hackberry while discouraging saltcedar would improve habitat for the cooter. For the upper Gila River, that was described as "Large floods scour away competing vegetation and deposit fine sediments that create germination beds for cottonwood-willow seedlings. Mid-range flows (400-4,000 cfs) in spring (i.e., peak flows followed by gradually receding flows during snowmelt runoff) inundate the floodplain, disperse seeds, and create groundwater conditions conducive to seedling germination and survivorship in secondary channels. Mid-range flows in the spring and monsoon season maintain seedlings, saplings, and mature cottonwood-willow trees across the floodplain" (Gori 2014).

Natural movement of some aquatic reptiles may be blocked by dams on the Pecos, which would prevent genetic mixing and repopulation after local extirpations. The Pecos River between Sumner and Brantley dams is the northwestern edge of the Rio Grande cooter distribution. The species is known to travel at least 35 km in natural dispersal, and a related species has been documented traveling 130 km before returning to its original capture site (Johnston et al. 2017, MacLaren et al. 2017). Thus dams may be isolating the Pecos River populations in New Mexico from those further downstream.

Plain-bellied Watersnake: The Plain-bellied watersnake requires permanent water with generally slow-moving currents (Werler and Dixon 2010). In New Mexico it is "confined to rivers, main irrigation diversion drains, or rocky intermittent streams where large deep pools with abundant fish and frogs remain." The water snake eats primarily fish and frogs, so a flow regime that supports those species is important to the snake (Degenhardt et al. 1996).

Dewatering of rivers by large dams has caused the loss of this species in parts of its former range in Mexico (Conant 1969).

Bullfrog: Bullfrogs are considered non-native in the Pecos River, and may be responsible for displacing other aquatic species through predation (Painter et al. 2017). Bullfrogs are typically found in lentic or low-velocity habitats such as backwaters, pools, off-channel emergent wetlands, and sloughs with dense vegetation (Gori 2014).

Frequent floods reduce bullfrog abundances as the tadpole stage is long (> 4 months to 12+ months) and vulnerable to flood scour (Sartorius and Rosen 2000). Because of their broad diet, reductions in bullfrog populations should benefit aquatic and terrestrial species including frogs and juvenile turtles (Bury and Whelan 1984).

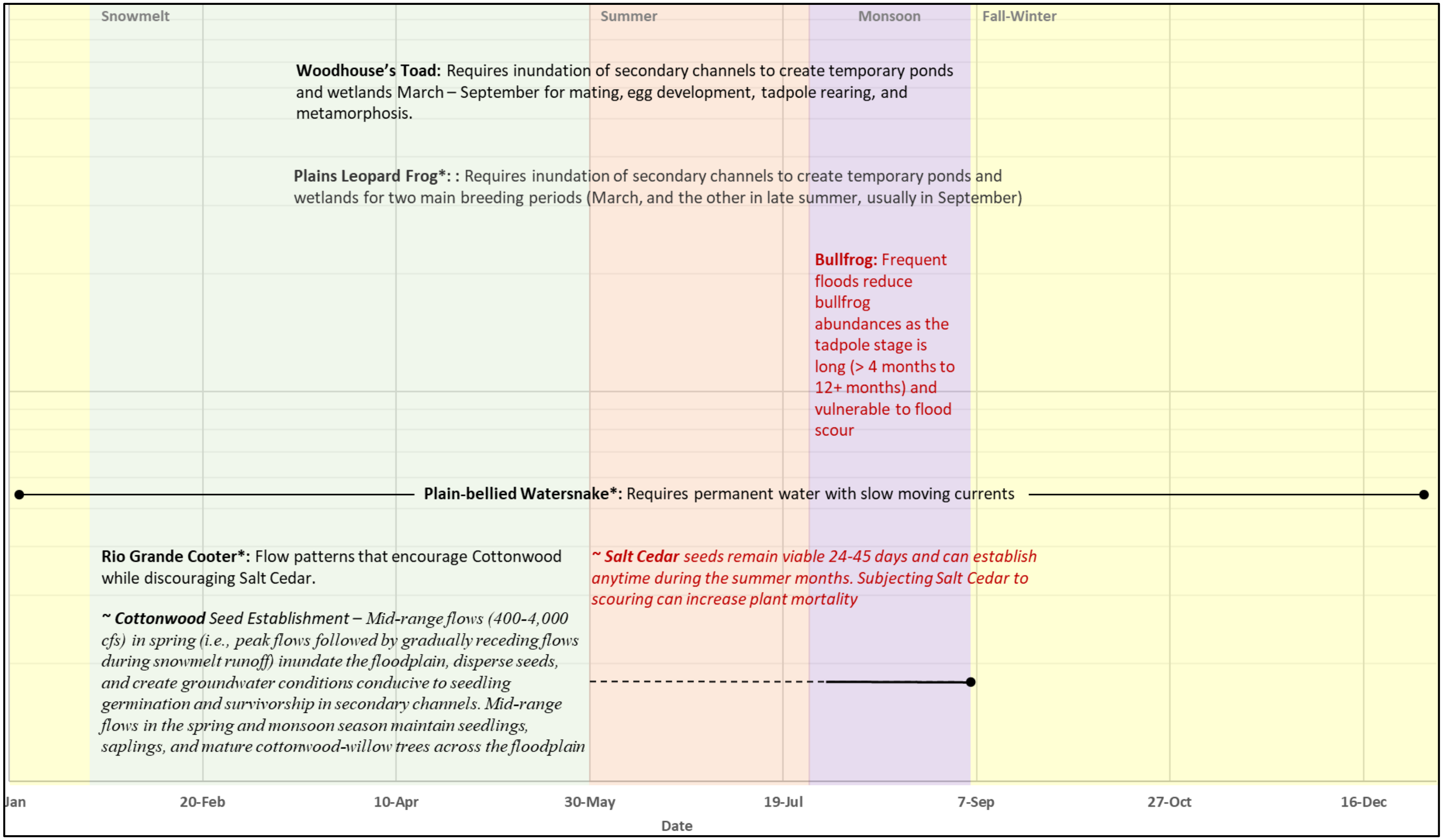

Figure 32: Known amphibian and reptile seasonal water needs. Species shown in red are considered invasive in New Mexico. *On both the New Mexico list of Species of Greatest Conservation Need and listed as Sensitive by the U.S. Forest Service.

4.7 Bird Communities

As discussed in previous sections, riparian systems and waterbodies make up only a small amount of the landscape in New Mexico but provide refuge to roughly 50% of the avian species known to frequent the state [2]. The Pecos River is no exemption, providing a variety of habitat types ranging from lakes to accommodate waterfowl, to mature woody canopy to accommodate raptors. The Pecos River also offers a valuable migration corridor for avian species, providing resting locations to forage and find temporary cover and shelter. The microclimate provided by the hydrology, moist soils, vegetation composition and canopy cover all play a part in providing foraging and sheltering conditions for nesting activities. Some avian species are opportunistic, taking advantage of insect outbreaks that occur after flashy river flows following a monsoon event. While others require a consistent source of small invertebrates or fish species found in a lake environment. Over 400 bird species have been observed along the Pecos River corridor[2&3]. These species along with their habitat associations, reaches where located, and temporal nature are listed in Appendix D.

Understanding the species requirements associated with flood dynamics and hydrology needs provides a foundation of knowledge that can inform management decisions pertaining to river systems. Hydrology needs for different habitat or behavior associations (i.e. shore/wading, riparian forest, predator/scavenger, grasses/chaparral) are presented below in Sections 4.7.1 through 4.7.4, respectively. Federally at-risk, threatened, and endangered avian species affected by flood dynamics are identified and discussed in each Section where applicable.

4.7.1 Shorebird and Wading Habitat

Shorebirds such as the federally threatened status piping plover (*Charadrius melodus*) have been observed migrating through Pecos SRP Reaches A and C, potentially breeding in Reach C[3]. The recently de-listed interior least tern (*Sterna antillarum*) is also known to commonly breed in reach C[3]. Both shorebird species, as well as a variety of other species indicated in Appendix E, construct nests along the shoreline that are small depressions in the sand. Nesting typically begins in mid to late April (USFWS 2015) with peak hatching occurring in June and early July at which time the young can leave the nest within hours. For interior least terns, egg laying typically begins by late May with hatching three to four weeks later. Interior least tern young typically stay at the nest for one week after hatching and then wander further and further from the nest over the course of approximately 3 weeks. Departure from colonies occurs by early September (USFWS 1990). Considering water implications to accommodate avian species needs, ideally water levels in Lakes and Reservoirs would increase outside of the breeding

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[2] For more information on the avian species known to occupy the Pecos and rest of New Mexico, visit: https://www.bison-m.org/

[3] For more information on avian species detection information, visit: https://ebird.org/home

season and either stay consistent or slowly recede during the breeding season or until young are able to leave from the nests.

In events causing higher turbidity such as storm and/or flood events, avian species requiring fish prey base will have a harder time locating prey during these times. Flooding events can also redistribute sediments, creating opportunities for dynamic environments that may temporarily remove vegetation and scour sandbars in some areas and deposit new sandbars or create backwater marshes and pools in other areas. This pattern is largely considered beneficial.

4.7.2 Riparian Habitat

This grouping has the greatest number of and largest variety (highest species diversity) of avian species, and the greatest impact associated with flow components in the river. This grouping also includes species such as the endangered southwestern willow flycatcher (*Empidonax traillii extimus,* flycatcher) and threatened yellow-billed cuckoo (*Coccyzus americanus,* cuckoo) (though it is important to note that the Pecos River is home to the non-listed distinct population segment of the species, however, intermixing of the two populations along the Pecos River may occur (USFWS 2014).

Both flycatchers and cuckoos require dynamic riverine processes that provide opportunities for alteration and regrowth from periodic disturbances such as flooding. Their habitat is closely tied to vegetative species such as coyote willow (*Salix exigua*), gooddings willow (*Salix gooddingii*), cottonwood (*Populus* spp.), and invasive species such as saltcedar (*Tamarix* spp.) and/or Russian olive (*Elaeagnus angustifolia*) for example. For native vegetation to have environmental conditions that allow them to outcompete exotic species, saturated soils present during seed dispersal and initial emergence is critical. During drought conditions, ground water levels should remain at least within six to seven feet of the surface for healthy conditions (Table 14).

Table 14: Depth to groundwater for native and nonnative riparian vegetation using results from the Middle Rio Grande as an example (Horton et al. 2001, Parametrix 2008, Caplan et al. 2012).

Riparian species and separation from groundwater effect	Healthy (feet)	Stressed (feet)	Crown dieback (feet)	Mortality (feet)
Willows	0-6.5	6.6-7.4	7.5-9.8	>10
Cottonwood	0-7.4	7.5-9.8	9.9-16.4	>16
Saltcedar	0-7.4	7.5-8.2	>8.2	>100

Overall, river conditions that can occasionally allow for sediment movement and deposition provide for successional age classes of vegetation and a variety of habitat patches which provide cover, shelter and foraging opportunities (USFWS 2013, USFWS 2020). Moist and humid environments that consistently provide emergence of insects and protect nests from environmental stressors is also important for riparian obligates. With increased or consistent water availability, canopy cover can provide protection from sun/heat exposure and concealment from predators.

4.7.3 Predators and Scavengers

Predators and scavengers generally increase as available prey (such as birds and small mammals for example) increases. Therefore, any positive relationships between flow components and bird numbers will enhance numbers of predators and scavengers (Shafroth and Beauchamp 2006). For example, large flood events that cause injuries in prey base would make it easier for predators to capture prey and scavengers to find food resources in species that parish from the event.

Typically, the number of avian species to establish nests or small mammals to frequent the floodplain would increase with an abundance of water. When conditions allow for increased foraging opportunities and general health of smaller birds, they produce more eggs per nest and have higher success in raising young, which theoretically would increase populations. In drought conditions, migratory birds are generally not able to bulk up fat resources and have less of a chance to successfully complete migration.

Bald and Golden eagles have been known to migrate through all reaches of the Pecos SRP during winter months[3]. Though no longer listed under the Endangered Species Act, Bald and Golden eagles are protected under the Migratory Bird Treaty Act and the Bald and Golden Eagle Act. In winter, the birds congregate near open water in tall trees for spotting prey and night roosts for sheltering[4].

4.7.4 Avian Grass and Chaparral Species

Avian species correlated with more upland, grassland and chaparral habitat is largely not directly influenced by flow components. Species such as the Greater roadrunner for example, may venture into riparian areas for foraging opportunities temporarily. Other species (i.e. quail spp.), may have similar patterns for finding water and other food sources (i.e. seeds) and also providing protective cover when needed. Pecos river flow patterns that may provide for a consistent water resource would then also provide for a consistent source of water, cover and food. In drought conditions in the growing season, less foliage cover may be present. In flooded conditions, herbaceous vegetation productivity and increased associated food resources such as seeds or insects would be expected.

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[4] For more information on migratory birds, visit: https://www.fws.gov/birds/management/managed-species/bald-and-golden-eagle-information.php

Figure 33 summarizes flow needs for some of the avian species/groups discussed in this section.

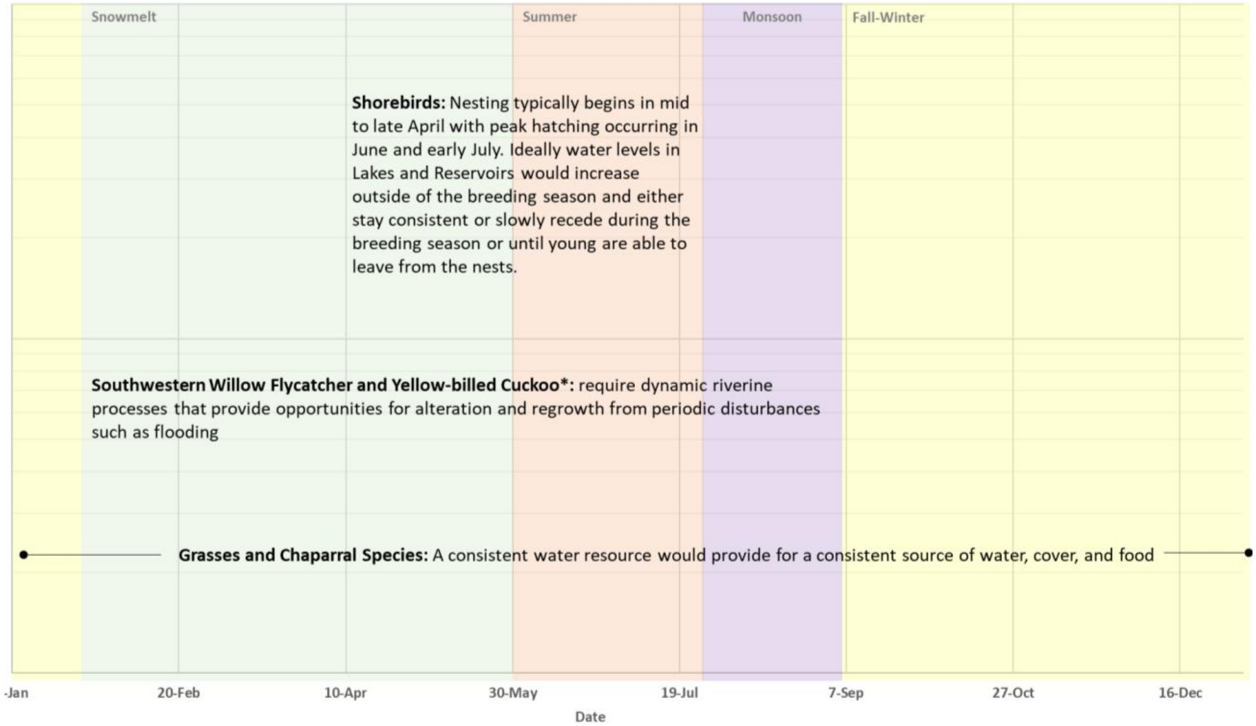

Figure 33: Avian seasonal water needs. * Endangered/Threatened Species

5 DEFINING ECOSYSTEM PROCESSES AND INTERRELATIONSHIPS

5.1 Geomorphic Flows

Since 1997, channel area has decreased, and the channel has narrowed substantially on the Pecos River in New Mexico. The Pecos River has adjusted to the dominant block release hydrology and the reduced sediment inputs brought about by the construction of Sumner and Santa Rosa Dams. Flow regulation has drastically reduced the magnitude of all flood events and hence the channel forming flows necessary to dynamically access relic channels in the floodplain. As a result, vegetation encroachment has greatly increased in some areas making avulsive behavior more difficult (and less frequent) thus further isolating the floodplain and riparian zones. Currently, flows exceed 1,400 cfs (typical block release discharge rate) only 3% of the time and extremely low flows are more frequent.

Nonetheless, the channel remains dynamic in some areas and aquatic habitat is accordingly more robust. In other areas, the response to the altered hydrologic and sediment regime has trended toward a narrower, straighter, and deeper channel. Overall, the Pecos appears to have reached a quasi-state of equilibrium between river morphology (i.e., plan view), sediment flux, and the current block release hydrology. Of concern, is the trend of reduced channel capacity being roughly equivalent to the standard block release discharge rate.

5.2 Ecosystem Flows

Reach A's ecosystem flows are not discussed due to this reach being a natural run of the river system.

Reaches B and C will be the focus for the e-flows workshop. Figures 34 and 35 are based off of the literature review. Final e-flow needs will be included after the e-flows workshop being held 19-20 July 2022. The summary e-flows report for the Pecos River is due out October 2022.

Reach B's ecosystem flow needs are detailed in Figure 34. Historic and modern hydrographs are shown as well as the flow needs of relevant species discussed in this report. Reach C's ecosystem flow needs are detailed in Figure 35. Historic and modern hydrographs are shown as well as the flow needs of relevant species discussed in this report.

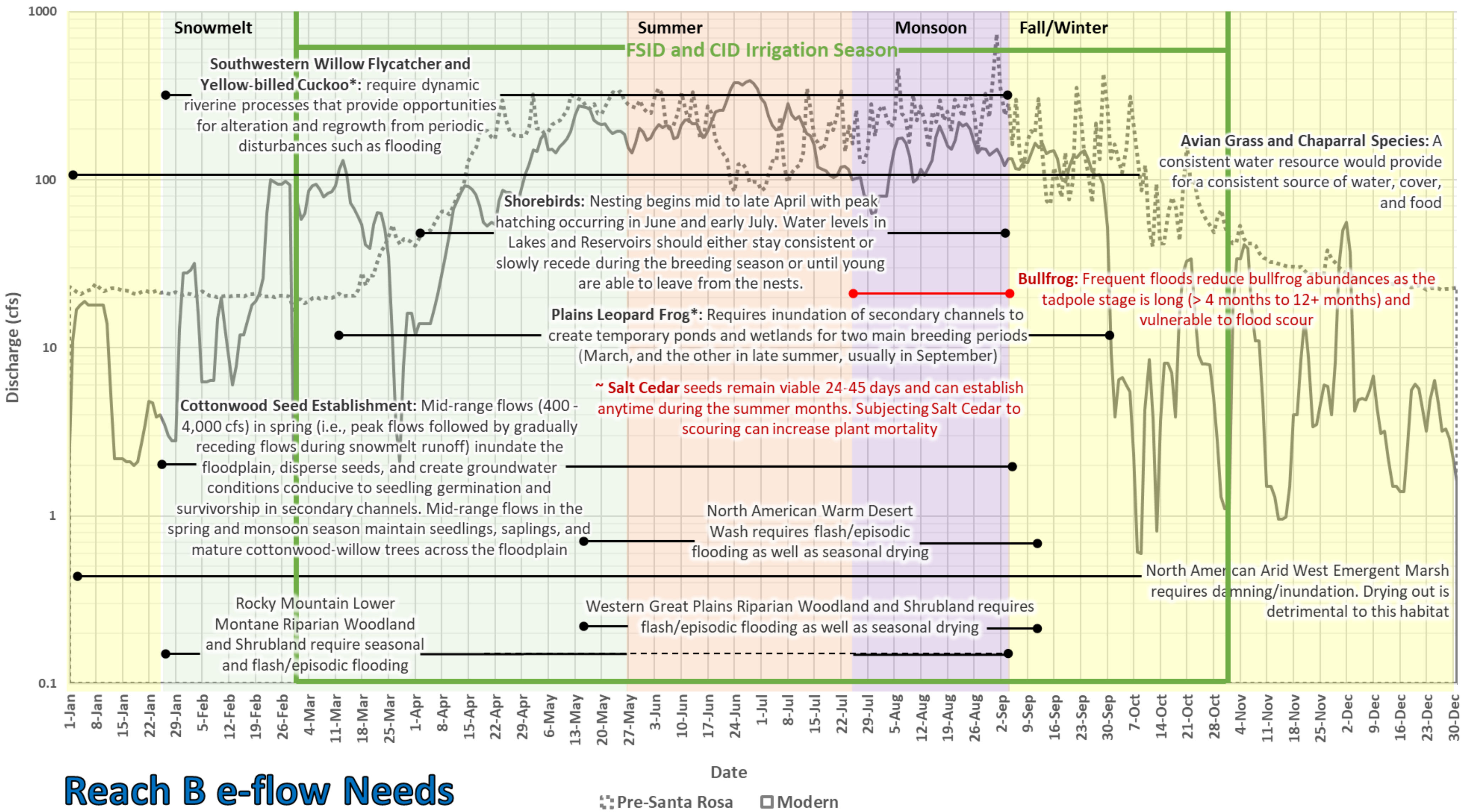

Figure 34: Ecosystem flow needs of species found in Reach B. Pre-Santa Rosa Dam hydrograph is shown with the dashed gray line. Post-Santa Rosa Dam is shown with a solid gray line. Species in red are considered invasive. *Species are listed as endangered. Green solid lines delineate irrigation season.

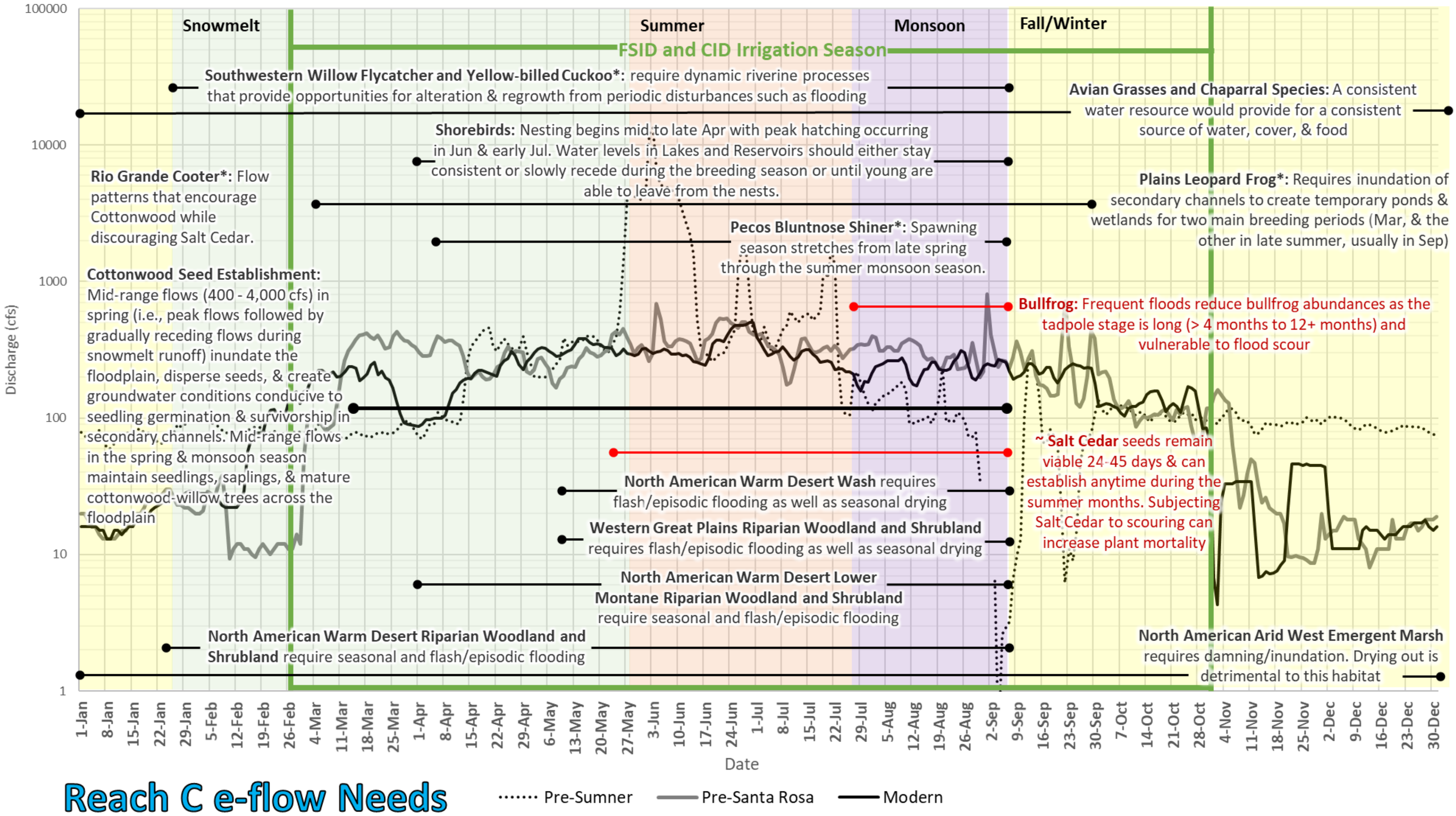

Figure 35: Ecosystem flow needs of species found in Reach B. Pre-Santa Rosa Dam hydrograph is shown with the dashed gray line. Post-Santa Rosa Dam is shown with a solid gray line. Species in red are considered invasive. *Species are listed as endangered. Green solid lines delineate irrigation season.

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