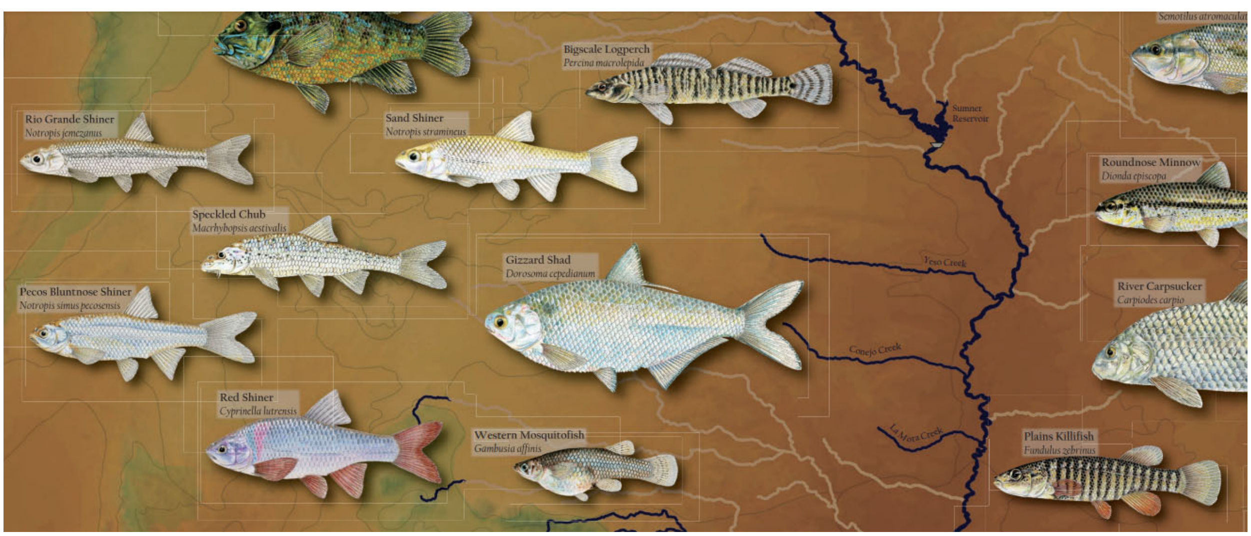
Identifying Environmental Flow Requirements for the Pecos River

Ecosystem Flow Workshop Summary

Workshop (virtual) held July 2022

Report date September 2023



Cover images: New Mexico Game and Fish. Pecos River Native Fish poster. https://www.wildlife.state.nm.us/download/fishing/maps/Pecos-River-Native-New-Mexico-Fish-Poster.pdf

US Army Corps of Engineers®
Albuquerque District

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Ecosystem Flow Workshop Summary

19 - 20 July 2022

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Acknowledgments

Pecos Sustainable Rivers Program (SRP) E-flows Workshop – Applying the HEC Regime Prescription Tool to Explore E-flow Targets

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Other Agencies Involved: Hydrologic Engineering Center (HEC), TNC, U.S. Bureau of Reclamation (USBR), U.S. Fish and Wildlife Service (USFWS), Fort Sumner Irrigation District (FSID), Carlsbad Irrigation District (CID), Pecos Valley Artesian Conservancy District (PVACD), and others

A cactus blooms along the Pecos River in April (photo by Pam LeBlanc/American-Statesman).

1 Introduction and Background

The mission of the Sustainable Rivers Program (SRP) is to "improve the health and life of rivers by changing dam operations to restore and protect ecosystems, while maintaining or enhancing other project benefits" by working towards advancing, implementing, and incorporating e-flow strategies at U.S. Army Corps of Engineers (USACE) reservoirs.

SRP attempts to identify opportunities to modify dam or other operations that can benefit the health of rivers. SRP has developed a process for identifying opportunities to manage water and land-water interactions to achieve ecological or environmental goals (Figure 1). Flow recommendations workshops are a core step (See Figure 1, Step 3) in the SRP ecological flows (e-flows) process. Workshops bring together experts, scientists, managers, and others knowledgeable about various aspects of river ecology and management to identify and discuss potential ways to improve or modify operations to generate ecological benefits or outcomes.

Building on the Pecos River State of the Science Literature Review, the goal of the Pecos River Ecosystem Flows workshop was to explore the e-flow relationships and flow-related habitat needs for the Pecos River. E-flows are scientific prescriptions for the timing, quantity and quality of flows and water levels downstream and upstream of dams, designed to restore ecologically important components of the natural flow regime to benefit native biota, including fish and other aquatic species; riparian and floodplain species and habitats; as well as birds, amphibians, and reptiles.

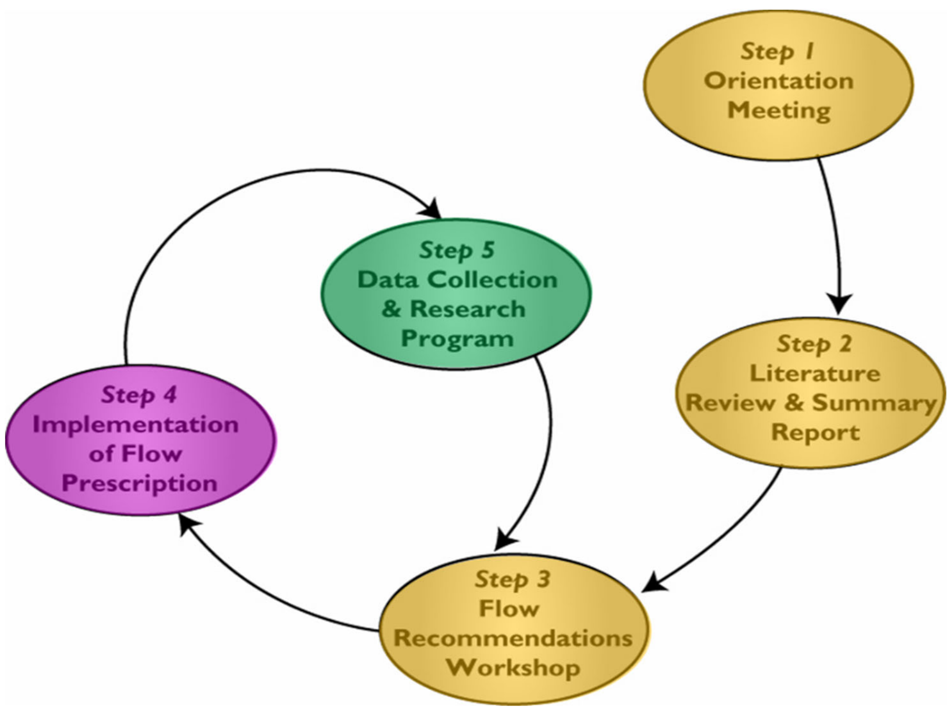

Figure 1. Sustainable Rivers Program process for developing e-flow recommendations as described by Richter et al. 2006.

1.1 Workshop Summary and Purpose

The Pecos River Ecosystem Flow Workshop was held virtually on 19-20 July 2022. A key deliverable under the Pecos River SRP Project, the workshop was designed to discuss e-flow needs for native species along the riverine corridor, and to identify potential opportunities in the dam-influenced reaches below the Santa Rosa and Fort Sumner Dams. The workshop was sponsored by the SRP and the USACE Albuquerque District. Approximately thirty participants attended the workshop, representing multiple agencies and institutions involved in various aspects of Pecos River management. Originally planned to be held in person in Roswell, New Mexico (NM), the workshop was conducted in virtual format due to concerns about travel feasibility and potential complications of the Covid-19 pandemic still ongoing in the spring of 2022. Workshop participants included experts with specialties in water operations and water resources, hydrology, geomorphology, water quality, riparian vegetation, fish, birds, and related ecological disciplines.

A mini-workshop meeting was held a week prior (13 July) to walk through the process with water operators and irrigators. During the mini-workshop meeting, the team was able to define flow needs and constraints for irrigators and other downstream users. This information was used as input to the breakout group discussions and final recommendations developed from the e-flow workshop.

Both the mini-workshop and the e-flow workshop began with presentations by core SRP project staff, Albuquerque District USACE Pecos River operators, and other experts. Presentations covered the purpose and structure of the process, expected products, and how the products could potentially be used to guide management decisions. At the 19-20 July e-flow workshop, opening presentations went into greater detail summarizing water operations on the Pecos, historical changes associated with construction and operation of dams on the Pecos, potential climate change impacts to the system, introductions and overviews of SRP, flow ecology, and how to use the Regime Prescription Tool (see Section 1.2) to facilitate discussion of ecological flow needs. In addition, the Bill Williams project in southern Arizona was briefly presented as a case study example of a complete SRP process in an arid region. In opening remarks, workshop participants were presented with the charge of identifying flow requirements to improve biodiversity and ecological health, with reference to natural flows for guidance.

Attendees were prepared for the discussion on e-flows with a State of Science Report/Literature Review distributed approximately a month in advance, as well as virtual presentations during the opening plenary session of the workshop. Flow requirements defined during the workshop therefore build on the State of the Science Report, as well as many years of flow-related work on the Pecos and other southwest river systems. These reports and summaries should be considered resources that can inform future adaptive management of Pecos River dams and the broader watershed.

1.2 HEC-RPT Software

The Hydrologic Engineering Center's (HEC) Regime Prescription Tool (RPT) is a software program to help teams reach agreements on managing the flow regime of a river. Development of RPT was sponsored by the Hydrologic Engineering Center, Portland District and The Nature Conservancy (TNC) in support of the

SRP. Sustainable Rivers is an ongoing nationwide partnership between the USACE and TNC to improve the rivers by changing the operations of USACE dams, while maintaining or enhancing project benefits. RPT was designed to provide an easy way to capture and present evolving flow recommendations in a workshop context. RPT meets these needs by facilitating entry, display and documentation of flow recommendations and justifications in real-time public settings--rapidly displaying, adjusting, and documenting hydrographs, accessing and plotting historical hydrologic data to guide scientists and managers in developing flow recommendations. It is a visualization tool and not intended to perform the quantitative analyses already performed by other software packages. Instead, RPT seeks to complement those packages by making it easier to create flow times series that other software can import and use in analyses.

During a typical SRP e-flow workshop, participants are divided into breakout groups and use the RPT to identify and capture suggestions for environmental flow improvements to sustain species and ecological processes on the three key reaches. For the Pecos River, groups were formed to define the river flows needed to sustain water rights and downstream irrigation needs as well as to keep specific aspects of the ecosystem healthy and functioning: (1) Fish, (2) Floodplain/Riparian vegetation and (3) Birds, reptiles, and amphibians.

Each group began by capturing hypotheses about flow needs, discussing life history of key species and taxa in relation to the “natural” (unregulated) versus regulated flow pattern. Connections between the species and flows were identified and incorporated into a set of environmental flow recommendations.

A strength of RPT is its ability to display and navigate hydrologic data sets. For the workshop, scientists imported data to RPT that showed how the river has been managed since construction of the dams, as well as how the river would have flowed if there were no reservoirs. During the workshop, RPT was used to build and display the flow recommendations, in real-time. Ideally, when a flow component was proposed, its magnitude, duration and timing were entered into text fields. Plots in RPT update automatically with new entries, which allowed the groups to review and revise their findings.

Recognizing the inherent variability of flows in response to climate, the RPT software is designed to allow for flow prescriptions to be tailored to wet, dry, and average years. Given that “natural” flows have been altered by dam operations, climate change and land use, RPT operators and workshop facilitators generated a set of “reference flow conditions” for the purposes of the workshop projects based on extrapolating unregulated inflows to the drainage area at the upstream end of each reach (i.e., the dam sites). The regulated and unregulated flow series water year data were used to divide the historical flow record into thirds: wet, average, and dry. This analysis was completed prior to the workshop in setting up the software “project” for full functionality during the workshop.

The final step in the workshop was to unify the environmental flow recommendations from each separate group. The merging feature in RPT allowed expert findings to be brought into the same project and plotted together.

2 E-flows Workshop

2.1 Water Operations Mini-workshop

- **Facilitators/Hosts:** Sarah Moore, Ryan Gronewold
- **Lead Presenter and RPT Facilitator**: John Hickey
- **Attendees:** Aron Balok, Aubrey Harris, Coley Burgess, Carlos Aragon, Carolyn Donnelly, Dagmar Llewellyn, Danielle Galloway, Frank Scott, Jim Howe, Justin Reale, Kelli Goodpasture, Kristen Blann, Mark Doles, Nabil Shafike, Rick Young, and Wade Holdeman

At a typical SRP e-flow workshop, working groups are charged with attempting to define flow needs as much as possible without consideration of existing constraints (e.g., existing water allocations). For the Pecos River e-flow workshop, however, facilitators wanted to have a good mix of participation in each of the breakout groups of both water operators, irrigators, managers, and experts on the respective systems and ecological needs. To ensure that there would be both adequate representation in each group at the 19-20 July workshop, as well as to enable discussion at the workshop to go beyond existing constraints, the workshop organizing group decided prior to the main e-flows workshop to host a 2-hour mini-workshop on 13 July. The 13 July workshop focused on defining water operators and irrigators' needs. This water operators mini-workshop (held virtually) involved working with water operators and representatives of irrigation districts to better understand and document their constraints in relation to the hydrologic period of record, using the RPT software. Additional participants at the mini-workshop included workshop organizers, facilitators and RPT modelers.

The Water Operations mini-workshop began with a welcome and review of the WebEx logistics with Sarah Moore. Ryan Gronewold, Albuquerque District Planning Chief, facilitated introductions (name, agency, and role), and introduced the SRP river reaches (Reaches A, B, and C) described in the previous section. Jim Howe (TNC) and John Hickey (USACE, HEC), representing their respective organizations as party to the SRP memorandum of understanding, gave brief overview presentations covering the mission, purpose, history, and processes under SRP. This included examples of past outcomes and a discussion of potential example meeting outcomes. Kristen Blann, TNC gave a brief primer on ecohydrology / flow ecology as it informs development of e-flow hypotheses in SRP.

After this brief (40 minute) overview, John Hickey introduced the RPT software (see Section 1.2) and began demonstrating how it is used to explore the historical flow record in relation to flow requirements for water operations and irrigators. Because current flows on the Pecos River below the dams are largely dependent on downstream water rights and water use agreements, workshop organizers all considered existing and recent operational history as the basis for understanding flow needs and opportunities. It was felt that although these would be straightforward, it would be helpful to the overall process if they were fully defined and articulated prior to the development of ecological flow hypotheses during the later workshop. With support from Albuquerque District, John Hickey operated the RPT software and demonstrated the approach to represent irrigators' needs and options for block-release operations. Flow "prescriptions" developed during this session were carried forward into the e-flow workshop and included in the Unification step (Figure 2).

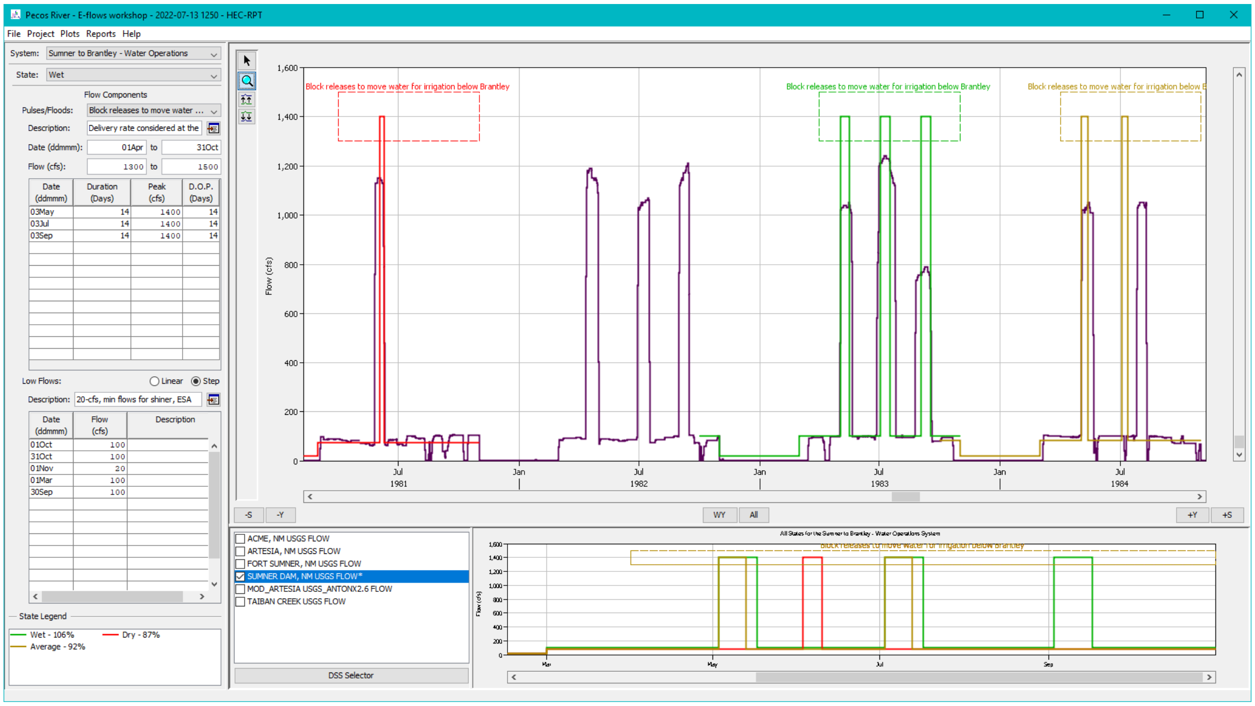

Figure 2. Prescribed flows of the Water operations group for wet (green), average (brown), and dry (red) conditions. Gaged flows from below Sumner Dam (USGS) are shown in purple.

2.2 Description of the Ecosystem Flow Workshop Agenda

Opening remarks for the Pecos River Ecosystem Flow workshop were followed by five presentations highlighting key sections of the State of the Science that was disseminated to all participants prior to the workshop in semi-final draft form. Full agenda and attendee lists for the water operations and ecosystem flows workshops provided in Appendix A.

Day 1, 19 July 2022:

- Welcome & logistics
- Introductions (in breakout rooms as planned)
- Review of SRP process and discussion of outcomes
- Overview of Pecos River Operations
- Hydrologic analysis and flow ecology relationships as background for developing environmental flow recommendations
- Case study of the Bill Williams SRP
- Overview or the HEC-RPT Software (See Section 1.3)
- Start of e-flows breakout groups
- Review of Tasks
- Close Day 1

Day 2, 20 July 2022:

- Welcome and logistics
- Future Conditions of Pecos Basin (Climate Change)
- Continue e-flow breakout groups
- Breakout groups present findings
- Unification of e-flow recommendations
- Conclusion and Parting Discussion
- Close Day 2

2.3 Breakout Groups

Participants self-selected into breakout groups based on their interest and expertise, beginning with the opening introductory session. Each breakout group was assigned a facilitator as well as an RPT operator skilled in navigating and using the HEC-RPT tool (hereafter "RPTer") to construct e-flows. Attendees were encouraged to take notes on a real-time whiteboard platform (Mural^{TM}; Web link and whiteboard images available in Appendix C). Breakout groups convened during several sessions on Tuesday afternoon and Wednesday. Flow recommendations and ideas were merged during the Unification period over lunch time on Day 2. The breakout groups included:

1) Fish
2) Riparian vegetation
3) Birds/Reptiles/Amphibians

Each breakout group was given information regarding RPT parameter inputs, including generalized hydrologic conditions (wet, dry, average categories), drainage area for reaches along the Pecos River, and a "natural flow" regime to aid in the development of e-flows for each hydrologic condition and river reach (see Appendix B for RPT information). During the workshop "operational windows" needed to be defined. Operational windows represent relevant timing and magnitudes for flow as they relate to life stages of native species. This can include food and habitat resources.

Breakout groups were given the charge to focus on defining flow requirements designed to enhance ecosystem health on the river and attempt to articulate ecosystem flow needs as much as possible without reference to existing operational or legal constraints. Each group was charged with the following tasks:

- Clarify hypotheses for each focus reach regarding flow-related issues and potential flow changes or enhancements that could be made, i.e., identify where current flow prescriptions may be in conflict, or where there is greatest opportunity to enhance benefits via flow manipulations
- Develop environmental flow hypotheses based on specific Environmental Flow Components (low flows, flood pulses, small floods, and large floods), understanding of the existing flow prescriptions, and how existing flows could be modified.
- Identify significant knowledge and information gaps and potential monitoring needs.

Each group was charged with addressing flow needs for at least 2 distinct geographic reaches on the Pecos River, Reach B and Reach C (Table 1; Figure 3). In the context of RPT, flow records for each reach designed to represent both existing flows (historical record reflecting dam operations) as well as "unmodified" flows (i.e., a reconstruction of what flows would look like if the dams were not in place).

Table 1: Reaches of the Pecos River for workshop.

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%

When defining environmental flow needs, participants were encouraged to consider, at a minimum, high and low flow components in terms of their ecological function. They were encouraged to define baseflows and flood events in terms of *magnitude, timing, duration*, and *frequency* of flows, as well as *rates of change* between different flow conditions. They were also encouraged to consider "contingencies" and "uncertainties", or knowledge gaps. Example environmental flow components for which groups were encouraged to develop flow recommendations included:

a) Low flows/minimum flows (seasonal, annual, and extreme low flows
b) High flow pulses (up to bank full discharge)
c) Small Floods (overbank flows, approximately 2- to 10-year return period)
d) Large Floods (floodplain maintenance flows, > approximately 10-year return period).

Table 2 has examples of ecological functions performed by specific environmental flow components.

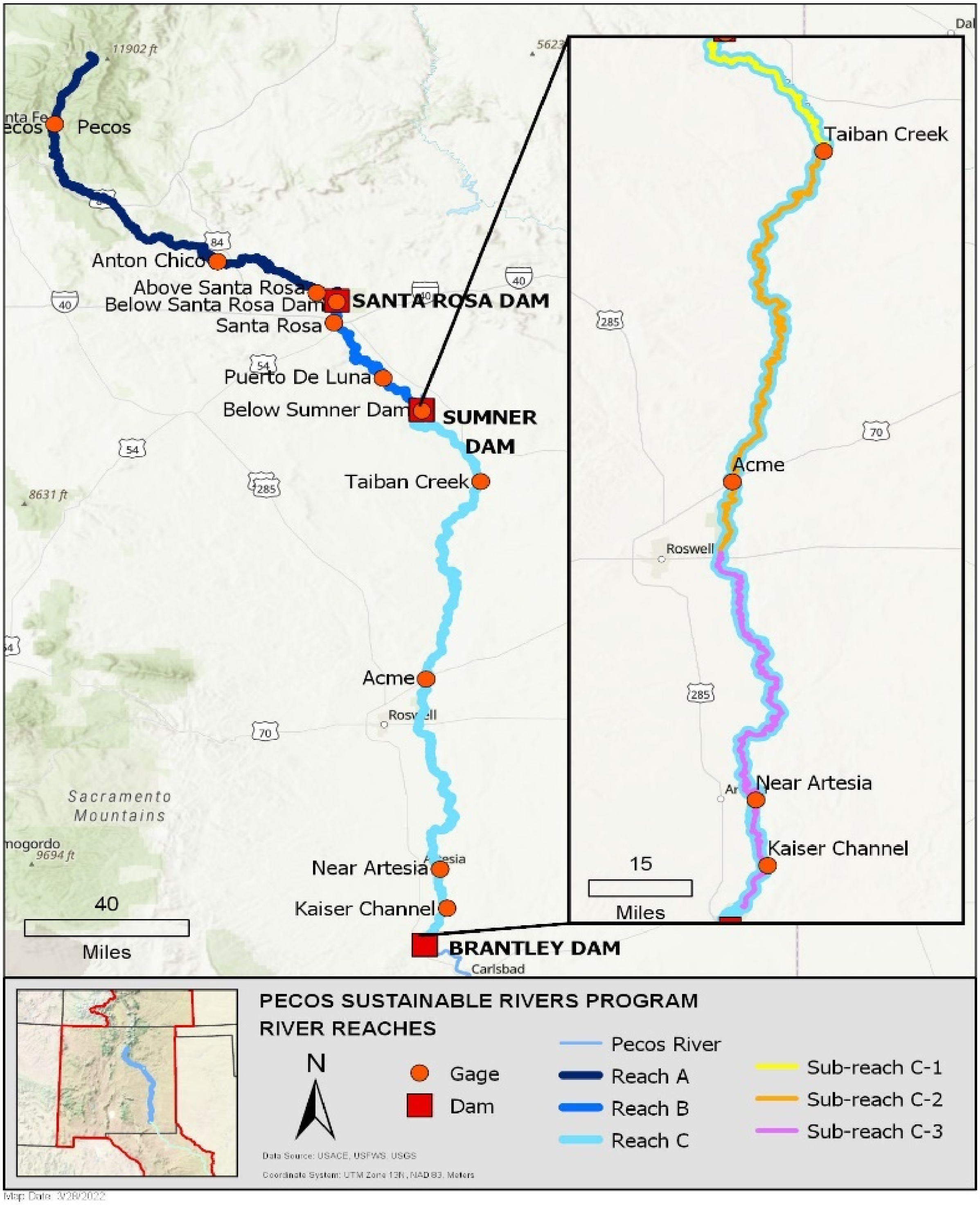

Figure 3. Map of the study area, subreaches, and gages (Moore et al. 2022. Identifying environmental flow requirements for the Pecos River: Background literature review and summary. https://www.hec.usace.army.mil/sustainablerivers/publications/docs/Pecos%20-%20Identifying%20environmental%20flow%20requirements.pdf)

Table 2. Ecological functions performed by different flow components.

Base Flows and Seasonal Flows
• Provide adequate habitat space for aquatic organisms • Maintain suitable water temperatures, dissolved oxygen, and water chemistry • Maintain water table levels in floodplain, soil moisture for plants • Provide drinking water for terrestrial animals • Keep fish and amphibian eggs hydrated, aerated, and/or suspended • Enable fish to move to feeding and spawning areas • Support hyporheic organisms (living in saturated sediments)
Low Flows (drought)
• Enable recruitment of certain floodplain plants • Disproportionately stress introduced and nonnative aquatic and riparian species • Concentrate prey into limited areas to benefit predators
High Pulse Flows
• Shape physical character of river channel including pools, riffles and runs (channel forming /bankfull flows) • Promote movement and redistribution of stream bed substrates (sand, gravel, cobble) • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants • Aerate benthic habitats by flushing accumulated silts and sediments
Floods
• Provide migration and spawning cues for fish • Trigger new phase in life cycle (e.g., insects) • Enable fish to spawn on floodplain, provide nursery area for juvenile fish • Provide new feeding opportunities for fish, waterfowl • Recharge floodplain water table • Control distribution, diversity, and abundance of floodplain vegetation • Deposit nutrients on floodplain • Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Deposit gravel and cobbles in spawning areas • Flush organic materials (food) and woody debris (habitat structures) into channel • Purge invasive, introduced species from aquatic and riparian communities • Disperse seeds and fruits of riparian plants • Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) • Provide plant seedlings with prolonged access to soil moisture *(Based on Richter et al. 2006)*

Breakout groups convened for the afternoon of Day 1 as well as the morning of Day 2. On the afternoon of the 2nd day, participants came back together in plenary to report out on individual flow recommendations and needs. Each of the working group facilitators and RPT operators presented the results of their working groups to the group. Flow recommendations and notes from the 4 different RPT projects (from each breakout group) were then integrated and displayed in a single RPT project representing unified / overlapping set of environmental flow definitions for each reach.

Recommendations and potential follow-up needs and next steps, including evaluating the unified recommendations in relation to the historical flow record using volume tracking, were discussed in plenary.

The workshop concluded with a summary of results and discussion of next steps, facilitated by Dagmar Llewellyn. This report is intended as a summary record of the discussion and results through the close of the workshop, which can be used to inform additional planning and next steps.

3 Breakout Group Notes and Reports

3.1 Water Operations and Irrigators (Mini-workshop Meeting, 13 July 2022)

As summarized also in the State of the Science Report, the Pecos River is a dry semi-arid southwestern system. Most flows occur as large pulses during the monsoonal season, typically from July to August. With the construction of the dams at Santa Rosa and Fort Sumner, these pulses are managed as block releases designed to optimize downstream water delivery to downstream water rights holders. Although there are several irrigation districts, the Carlsbad Irrigation District (CID) holds the rights to conservation storage in the Santa Rosa Reservoir (operated by USACE) and can call for releases at any time within the irrigation season (typically 1 March to 31 October), limited only by dam safety concerns and weather conditions. Most of the discussion of operational needs was focused, therefore, on these releases. Reclamation is required to release the water as efficiently as possible. As currently interpreted, block releases are optimized at a peak discharge rate of 1,400 cfs, as this is the flow rate that most "efficiently" conveys water allocations downstream while minimizing evaporative losses, and typically are maintained for 8-15 days. Lower block releases lead to greater evaporative losses. There may be multiple releases in a wet year, or none in a very dry year. Minimum flows and limits on releases have also been determined as part of the 2016 Biological Opinion to minimize Pecos bluntnose shiner egg and larval displacement.

In general, irrigators and other workshop participants expressed a great deal of skepticism regarding the potential for flexibility in the management and timing of block releases, as in most years CID can use 100% of the water allocated. In the unlikely event that there is "surplus" water in any given year, it can generally be stored in the reservoirs for use in the following year. Any avoidable upstream seepage, evaporative losses, or riparian vegetation uses are in direct conflict with the downstream water allocation.

3.2 Fish Breakout Group

The Fish breakout group heavily referenced the Background Literature Review and Summary. As noted in that document, "fish are [the group of organisms] most immediately affected by flood, drought, and other flow events." The Fish breakout group chose largely to focus on the flow-ecology relationships of the Pecos bluntnose shiner (shiner; *Notropis simus pecosensis*) as representative of the guild of native, pelagic spawning fishes of the Pecos River. These fishes are uniquely adapted to an often-challenging hydrology including periods of extreme conditions and events. As a listed species under the Endangered Species Act, as amended, the shiner was central to our discussion as it is 1) again, a representative pelagic spawning species and 2) a species where the effects of low-flow and intermittent hydrology are well documented in the U.S. Fish and Wildlife Services' 2016 Biological Opinion.[1]

The Pecos is typical of many arid river systems. Often characterized as flashy, the Pecos routinely experiences extended periods of summer low-flow conditions followed by flood events that arise from the North American Monsoon. Except in the headwaters, which are located to the north in the Sangre de Cristo Mountains, winter precipitation is typically sparse due to the partial rain shadow created by mountains to the north and west which tend to intercept winter storm tracks. However, in summer months, warm, humid air masses that originate over the Gulf of Mexico bring in the monsoon rains. Due to the monsoonal pattern, large variations in river discharge are not uncommon in the Pecos. Further, given the arid nature of the region, spring pulses associated with snowmelt runoff are generally less dramatic than monsoon storm peaks. Native fishes, including the Pecos bluntnose shiner, have evolved life history strategies and adaptations to this natural flow regime.

However, with the closure of the dams at Fort Sumner (1939) and Santa Rosa (1979), there have been significant alterations to the natural flow regime. For Reach B (below Santa Rosa), the primary changes the flow regime have been a dramatic decrease in the frequency and magnitude of the higher flow events (e.g., the 1% exceedance flow has declined ~40%, as has the maximum instantaneous peak discharge, with implications primarily for channel, habitat, and sediment work. Flows during the summer and monsoon seasons are now more constant, at 100-200 cfs, whereas prior to the closure, peaks would often bring the average to 400 cfs or more. There is also more variation in the fall-winter baseflows (for a full description of these changes, see pages 25-26 of the literature review).

Reach C, which is much longer, is affected by the operation of both Santa Rosa and Sumner Dams and has experienced alterations to the natural flow regime for a far longer period of time. As with Reach B, there have been significant decreases in the frequency, magnitude, and duration of the high flow events that do the bulk of episodic channel work, sediment transport, and habitat formation associated with shifting from a highly variable to a much more regular and less frequent pattern of sustained block releases. This has had implications for aquatic habitat that vary slightly across different subreaches of Reach C. Namely, channel narrowing and degradation are occurring in response to the artificial, high-flow hydrology—i.e., the block releases In other words, over time, channels have adjusted to be in equilibrium with the typical magnitude block release (~1,400 - 1,500 cfs), so even during these events there is very little opportunity for fish to access secondary channels/floodplain/low-velocity habitat, and therefore eggs and larvae are more readily flushed downstream. This is true for both the spring

[1] The 2016 Biological Opinion for the Bluntnose Shiner had two environmental determinations, Critically Dry and Normal, made monthly from January to June. The January determination is based on the drought classification for the Pecos Basin, D3 and D4 drought classification > 50% of the Basin is Critically Dry; < 50% is determined to be Normal. February through May is based on the NRCS snowmelt runoff forecast at the above Santa Rosa gage compared to the 30-year average; the June determination is the percentage of time bypass is available from 15 February to 30 June and that determination sets the conditions for the rest of the year. For example, this year there was no bypass available during that period, so this year is determined to be a Critically Dry year. Bypass is available when the FSID two-week entitlement is set at 100 cfs by the NM Office of the State Engineer and prior to and post irrigation season, normally 1 March through 31 October.

snowmelt pulses and the monsoon spates. For the Pecos bluntnose shiner in particular, these flow and habitat changes are thought to have greatly increased the rate of downstream egg and larval transport into areas of poor habitat (Subreach C-3), reduced recruitment, and drastically increased predation (Brantley Reservoir). In combination, these factors threaten long-term shiner survival. A major need is therefore to improve egg and larval retention and recruitment, particularly in upstream reaches.

There have also likely been reductions in tributary sediment inputs due to both short and long-term drought cycles. From the point of view of instream and riparian communities, these represent declining habitat trends. However, a recent Tetra Tech geomorphology study[2] indicated that sediment inputs from tributaries appears adequate and the system is generally in geomorphic equilibrium with contemporary hydrology.

Currently, 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. Under the current, highly regulated Pecos, block releases during the spring and early summer are the closest remaining flow component to a natural spring runoff spawning pulse. Thus, in addition to being the most geomorphically significant, they are an ecologically important attribute of the annual hydrograph. Conversely, summer block releases are typically smaller and of shorter duration. These are more like monsoon spates which can supplement annual recruitment by stimulating smaller spawning events.

3.2.1 E-flow Hypotheses and Prescriptions

For initial flow hypotheses and recommendations, the Fish breakout group focused on Reach C (i.e., below Ft. Sumner Dam), as participants felt this the more relevant and habitat limited reach, as well as much longer than Reach B. Furthermore, any flow recommendations developed for this reach would more likely apply to Reach B than vice versa.

The group developed separate flow magnitude targets and operational windows for dry, average, and wet years designed to be potentially compatible with block releases (see Appendix B for description of wet, dry, and average states/conditions). Flow components identified included low flows, spring and monsoonal pulses, and flows needed for recruitment and connectivity. Flow components and windows initially proposed by the group for low flows and baseflows are summarized in Table 3 below. Example depictions of operational windows and flow prescriptions for seasonal pulses and high flows for dry, average, and wet years, as depicted graphically in RPT, are in Figure 4a-c below.

Low flow / Baseflows

The goal of low flow / baseflow recommendations is to maintain connectivity of river flows to avoid mortality and metapopulation loss in the fish community. Especially during dry years, if baseflows are

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[2] TetraTech. 2020. Pecos River geomorphology: Phase II - A sustainable habitat approach for the Pecos Bluntnose Shiner (*Notropis simus pecocensis*). https://www.sciencebase.gov/catalog/item/5ed7d84482ce7e579c66e404

not maintained, it will result in drying of the river, leading to declining numbers of shiners and other fishes. Multiple years of this can result in complete population collapse, leading to local or reach-wide extirpation or extinction. During extreme drought years, low flows can have major impacts to the aquatic ecosystem. Under these conditions, there may not be enough water to support recommended flow prescriptions. Adequate baseflows also help prevent vegetation encroachment on the active channel and thus guard against loss of minimum habitat.

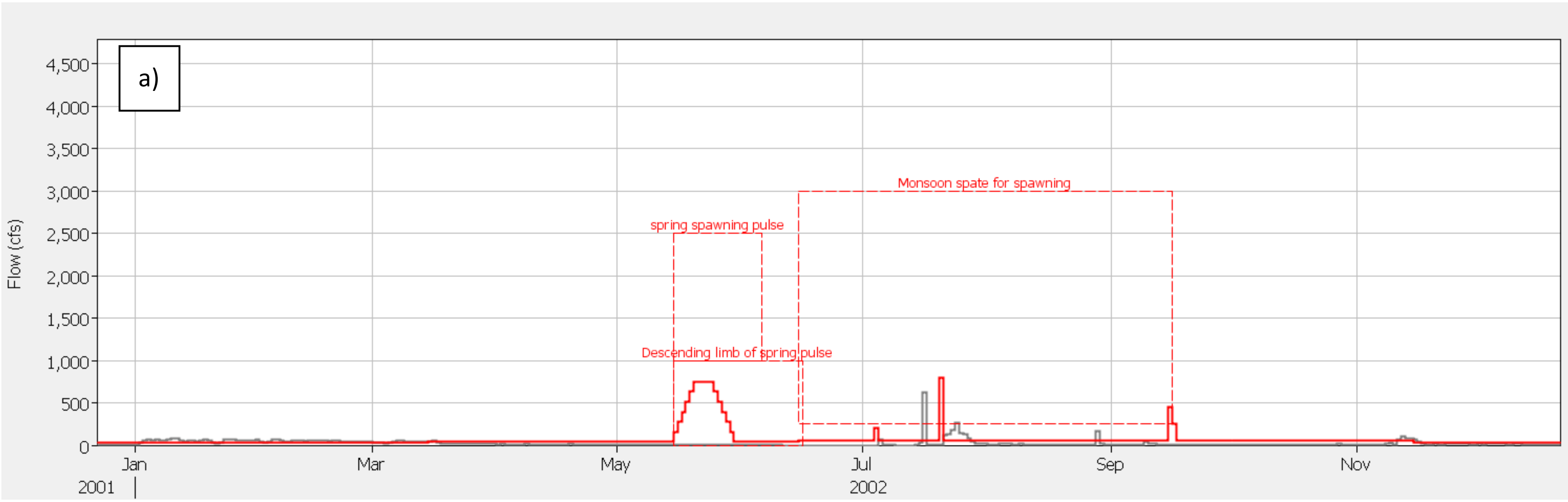
Starting with winter baseflows in dry years, the fish group recommended a target baseflow of 25 cfs, designed to maintain connectivity of habitats. This target was then increased to 40 cfs starting around 15 March, roughly coinciding with the onset of spring snowmelt. For summer base flows, the group recommended increasing to 50 cfs starting 15 June and extending through approximately 15 November, when baseflows could be reduced back to ~25 cfs.

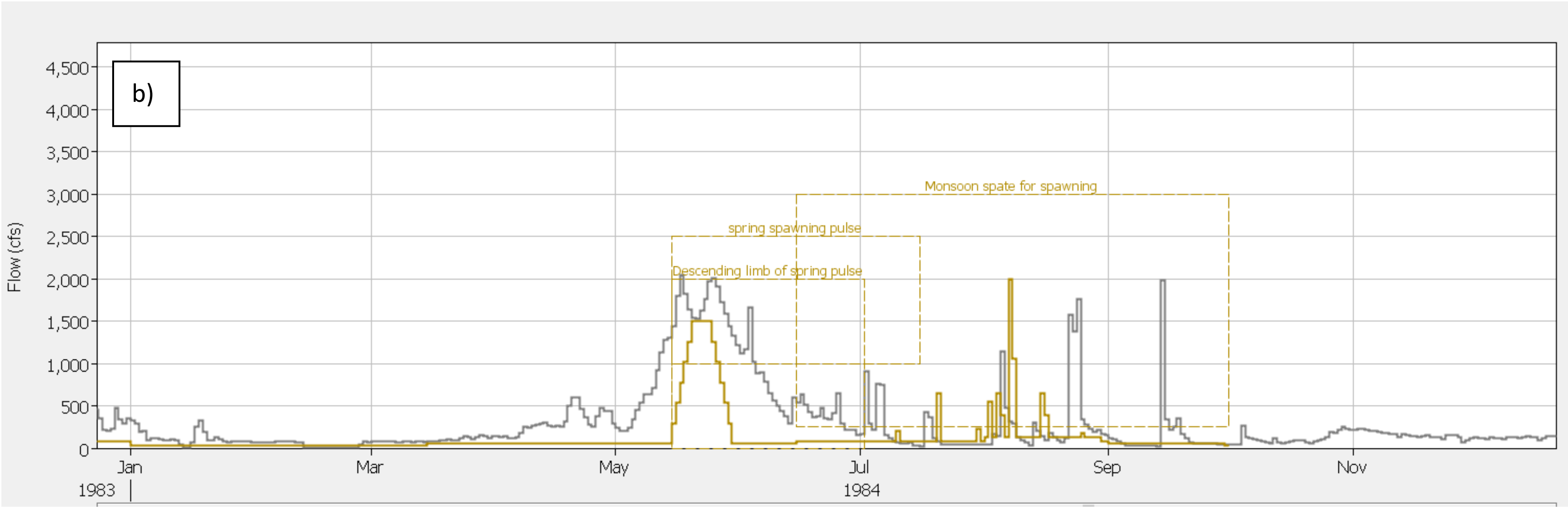
For average and wet years, the group set slightly higher target baseflows based on presumably higher availability of water. For average years, the winter baseflow could be increased to 30 cfs but in wet years an even higher target of 75 cfs would be more ideal.

Baseflow recommendations in average and wet years were also increased to correspond with the onset and ramp down of the monsoon season peak flows. In average and wet years, baseflow targets for the monsoon season ranged from 75 cfs to up to 250 in wet years, in between storm driven peak flow events.

Table 3. Description of low flow components for fish in Reach C and for dry, average, and wet years from RPT.

Date	**Dry year flow (cfs)**	**Average year flow (cfs)**	**Wet year flow (cfs)**	**Description**
01Jan	25	30	75	winter baseflow to maintain connectivity
15Mar	40	50	100	
15Jun	50	-	-	Summer baseflow to maintain connectivity
15Jun	-	75	100	early monsoon (ramp up)
30Jun	-	75	150	early monsoon (ramp up)
01Jul	-	75	175	peak monsoon
15Jul	-	75	200	peak monsoon
01Aug	-	125	250	peak monsoon
15Aug	-	125	200	late monsoon
30Aug	-	75	150	late monsoon
01Sep	-	60	60	influence of trib inflow during monsoon (ramp down)
30Sep	50	30	50	
15Nov	25	75	75	


a)
Flow (cfs)
Monsoon spate for spawning
spring spawning pulse
Descending limb of spring pulse
Jan
Mar
May
Jul
Sep
Nov
2001
2002


b)
Flow (cfs)
Monsoon spate for spawning
spring spawning pulse
Descending limb of spring pulse
Jan
Mar
May
Jul
Sep
Nov
1983
1984

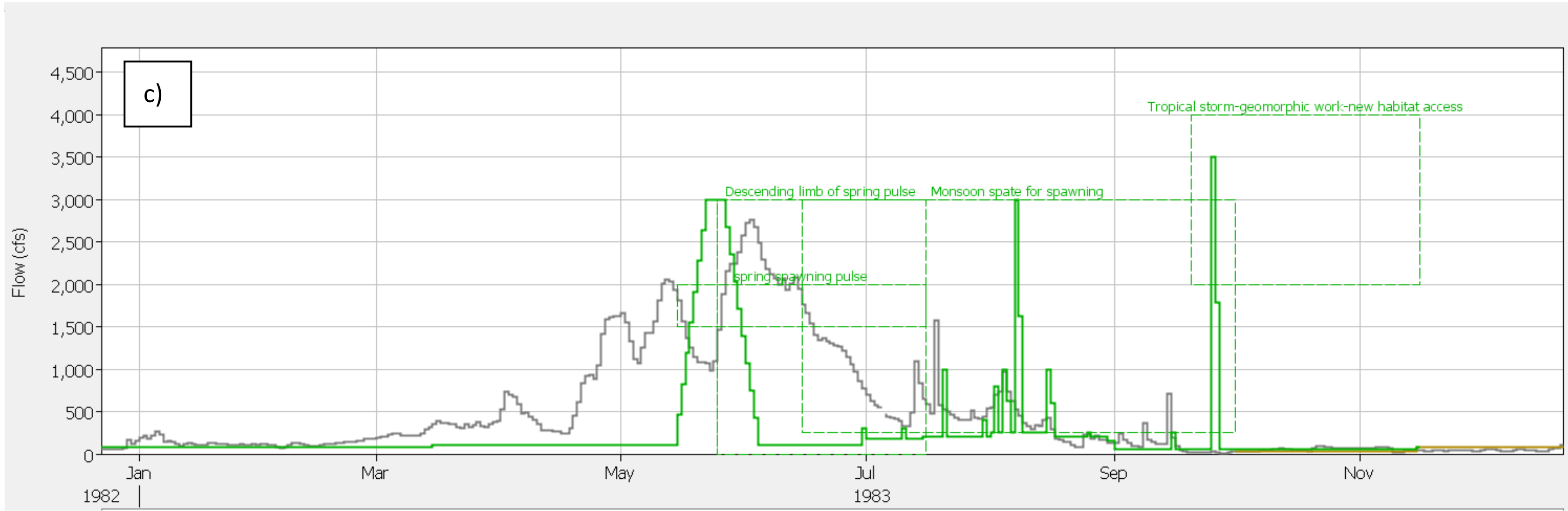


Figure 4. E-flow needs for fish in Reach C as represented graphically in RPT by flow component and operational window for an example (a) dry, (b) average, and (c) wet state / year. In each panel, "natural" flows for years classified as dry, average, and wet, respectively, are shown in gray (Appendix B, Mod_Artesia USGS_Antonx2.6 Flow). E-flow needs for dry, average, and wet years are represented by red, gold, and green lines, respectively.

Spring Spawning Pulse and Monsoonal Spates for Spawning

For Pecos River fishes, as in many systems, the spring runoff pulse is an important ecological cue for fish to spawn. In the Pecos River Literature Review this season was identified as occurring from March to April, when minimum (baseflow) and median discharge affect the amount of habitat fish can access. Under the current operational regime, block releases during this period would be highly unusual. However, in the Pecos River, the monsoonal pattern of flows also provides important spawning cues for many fish.

In theory, both the spring and monsoonal spawns would have been equally important ecologically in terms of annual population levels and recruitment. Unfortunately, given how long flows have been regulated by the dams, a complete understanding of the importance of spring runoff relative to monsoon spawns is lacking. The absence of a real spring pulse in Reaches B and C led the fish group to place greater emphasis on monsoon pulses (and therefore summer block releases) to support fish spawning, as these events are more numerous and of generally greater magnitude. In most years, to coincide with typical block releases from the dams, the flow magnitudes needed to trigger spawning and provide access to additional in-channel and off-channel habitat would need to be timed to overlap more with early summer monsoon storm events. The onset of this spring spawning pulse, therefore, was represented as starting roughly in late May to early June. This timing (as represented in Figure 4a-c) generally coincides with female egg production but could be moved slightly later to better match early summer block releases. In dry and average years, the magnitude of the peak was set at 600 and 1,500, respectively, with flows up to 2,500 cfs, whereas in wet years, the pulse might go as high as 3,000 cfs. Furthermore, in average and wet years, several smaller additional monsoon spates were recommended, ranging from 500 to 2,000 cfs.

In general, the e-flow representation of spring and summer spawning pulse flow needs should depict a more natural descending limb for the spring pulse via natural attenuation that would mimic pre-dam flood attenuation, to give fishes time to move back in to wetted channel as conditions return to baseflow via a gradual descending limb, as would happen in the unregulated system. Due to time constraints and the learning curve on the software during the workshop, the spawning flood pulse flow component as currently represented in RPT, depicting an abrupt step-down of releases, does not accurately represent this gradual descending limb.

Large spring (or early summer) pulses, as shown in the average and wet scenarios, need not happen every year. If an appropriately timed spring (or early summer) block release, with extended ascending and descending limbs, could be used as the "spring runoff pulse", this would obviously represent a significant volume of water that would have to be paid back to CID, given how water is allocated under the existing system. That said, if an early spring pulse could be added to the annual hydrograph, it would most certainly benefit the native fish community.

Tropical Storm-geomorphic Work and New Habitat Access

The fish group also developed a large flood flow prescription to accomplish the geomorphic habitat work provided by occasional dissipating tropical storms during the late monsoon season. Although they represented this as a wet year flow prescription, they acknowledged that this would not be needed or desirable in every wet year, but would only be needed every 10-20 years, designed to coincide with or mimic the 5-10% exceedance flow associated with very occasional strong tropical storms, which do the work of scouring the channel, reshaping and creating new habitat, and redistributing sediment.

3.3 Riparian/Vegetation Breakout Group (also called Floodplains Group)

The Riparian Vegetation/Floodplain breakout group began with each participant introducing themselves and sharing their role, relevant background, and experience, as well as their primary interest in defining environmental flow needs for Pecos River riparian communities. The group was then reminded of the key task / objective of the workshop, i.e., not just to support and preserve the system as it exists today, but to explore opportunities to enhance or restore ecological systems through management, flow operations, or in combination. As such, the focus for the RPT work in breakout groups was to be those reaches influenced by reservoir operations, primarily defined as Reach B (Santa Rosa to Sumner) and Reach C (Sumner to Brantley).

Current vs Historic Riparian System

The general SRP workshop process for developing e-flow hypotheses and defining flow needs is to start by building as much as possible a shared understanding of what the historic riparian system looked like, i.e., how it was generally structured prior to the impacts from dam and reservoir operations, and how it has changed since the onset of dam operations. Having a shared understanding of what the riparian system looked like can be helpful for developing targets for future potential conditions.

For the Pecos River, the historic riparian community would have consisted largely of short grass prairie, dominated by species such as blue grama, saltgrass, and alkali sacaton, interspersed with occasional clumps of Fremont cottonwood and narrow-leaf cottonwood. Salt grass was especially prominent in the lower reaches, where there are and were salt marshes and flats, “bitter” lakes. Participants did not know how extensive these riparian communities might have been historically.

Alkali sacaton typically grows where groundwater levels are higher, such as bottomlands where moisture collects, and is hearty once established. When growing, it provides good forage for livestock and wildlife. However, once established, it benefits from a periodic fire regime to prevent it from getting woody. Blue grama is a prairie grass and is an excellent groundcover and forage crop. Generally, it is an upland species and doesn’t require a flood regime but can germinate and grow in response to very small amounts of rain.

The primary changes observed since the advent of operational control by the dams at Santa Rosa and Fort Sumner have been reduced community mosaic and patchiness; reduced native seed dispersal and recruitment; and increased saltcedar (*Tamarix* species) cover, as well as increased costs of controlling saltcedar. Saltcedar is an invasive tree, introduced to the American southwest at least since the 1800s, that is now ubiquitous in riparian areas where it frequently outcompetes native vegetation as well as interfering with downstream water rights, in part due to its exceptional ability to access desert water tables through its intricate and deep root system. As its name suggests, saltcedar also has a relatively high tolerance for salinity[3]. The river corridor itself in Reaches B and C is currently a saltcedar dominated system. There are also stretches of taller trees, which are typically juniper, an upland species.

Unlike the pre-dam river system, the current riparian system is not supported by regular overbank flooding. This change in the flow regime, i.e., loss of overbank flooding, has contributed to the replacement of native vegetation—primarily willows and cottonwoods—with saltcedar, which is more drought tolerant. Reach B includes some clusters of cottonwood, Russian olive, and willows, esp. around tributary inflows and a few areas managed for fish and wildlife. For example, where Highway 60 crosses the river in Fort Sumner (near Truchas Creek), a cluster of cottonwoods, Russian olive, saltcedar, and a few willows persist. Truchas Creek is uncontrolled, which may be why cottonwoods and other native species are present there. In the backwaters of Sumner Lake, there are wider riparian areas, and communities of grasses and willows near the water. Reach C is almost entirely dominated by saltcedar, with a few localized areas of wetlands. The current salt-cedar-dominated system supports avian species richness that is comparable to that provided by the native riparian community (willow flycatcher, yellow-billed cuckoo).

Review of Operational Constraints

"It is very hard to suspend our knowledge of the system completely."—Irrigation District Managers

Because the prior riparian system has been largely eliminated and replaced by monotypic stands of saltcedar, especially in Reach C, the Riparian Vegetation group spent considerable time in the initial breakout period reviewing operational needs and constraints, while negotiating how to temporarily suspend those constraints for the purposes of brainstorming. Ultimately, the question for the breakout group to explore was re-framed as: "How would [could] we use flows to restore cottonwood and willow?"

Currently, most of the water stored in the system is destined for use in Carlsbad Irrigation District (CID), and is moved from Santa Rosa Reservoir, through Sumner Reservoir down to Brantley Reservoir through "block releases", the high-flow pulses moved through the system several times a year. Block releases are done when there is water in the reservoirs and a need for that water in CID. USACE then releases the water out of Santa Rosa, and Reclamation releases the water out of Sumner, to send it down to Brantley Reservoir (the release is continuous between the two reservoirs, so that Sumner levels don't increase, wet the reservoir banks, and then drain back out, which is viewed as inefficient). Outside of block releases, Santa Rosa gates are typically closed (i.e., releases are 0 cfs). Flows in Reach B are mainly from groundwater inflow.

The current river channels in Reaches B and C have adjusted to the normal discharge of the block releases, which is 1,400 cfs below Santa Rosa and below Sumner, or about 1,000 cfs by the time the water gets to the Acme Gage. This means that these block releases largely do not support the type of

[3] Note: Saltcedar plants are actually able to extract salt from the soil and sequester it in the leaves at concentrations up to 15%; when the leaves fall off they can increase salt concentrations in the top layers of soil, benefitting saltcedar at the expense of its native competitors (McFerraz 2004, McDaniel et al. 2005; NMSU 2022).

overbank flows needed to drive floodplain and riparian reestablishment. Channel capacity in reach below Santa Rosa is, in fact, 13,000 cfs. The Fort Sumner Irrigation District Manager observed that he had only seen flows go overbank (i.e., exceed channel bankfull) after a rain event once in the last 8 years.

Typical flows in Reach B (between Santa Rosa and Sumner) during summer range from 65 to 70 cfs, punctuated by monsoon pulses. All the flow at these low flows—up to 100 cfs—is sustained by groundwater baseflow, and this is Fort Sumner Irrigation District's water supply. Although physical operational (gate) capacity at the Santa Rosa Dam is 3,000 cfs, current block releases are set at capacity of the release gates at Sumner Dam. Peak discharges above 1,400 cfs below Sumner are not possible without modifications to Sumner Dam.

Under the current system, available water supplies are fully allocated. Furthermore, climate projections suggest there will be even less water in the future than there has been for the past 15 to 20 years.

Reach C, from Sumner to Brantley, is a long reach, with significant stretches where there is no riparian system left. There was consensus that it would not be feasible or desirable to try to create a continuous corridor of cottonwoods where there is nothing now, nor to create a riparian corridor where the system is dominated by saltcedar, as the system does not have enough water for that.

For Reach C, releases from Sumner of greater than 1,400 cfs – enough to create overbank flows to establish cottonwoods - would also intercept water that was bound for Brantley Reservoir and use by CID. The timing of block releases is also designed to minimize storage at Brantley because the reservoir is hot and therefore inefficient (evaporative loss rates are high). In addition to being viewed as inefficient due to bank and/or evaporative losses, increased volume or altered timing of releases from Sumner for establishment and use by cottonwoods (since Reach C really doesn't currently have a riparian system) would essentially constitute a new "use". Any new use would be in direct conflict with existing uses and require retirement of another use.

Climate change projections also suggest that there will likely be more sediment in river in the future, due to fires in the watershed, as well as loss of vegetation through low soil moisture. Sediment loads are likely to increase both on the mainstem and from tributary inflows. Higher, flushing flows will be needed to move sediment; however, this also poses a potential issue for reservoir maintenance and storage.

Potential Opportunities to Enhance Ecological Values

Once the above conditions and constraints had been fully laid on the table, the group shifted discussion to the possibility of fostering local areas of cottonwood establishment, with shrubs and grasses, expanding from areas that still have some cottonwoods and willows. It might be possible to focus cottonwood and riparian restoration at specific, limited locations, e.g., the mouths of uncontrolled tributaries. Temporary dams could be designed at the mouths to hold back the water from monsoon storms, so that the rate of recession is low enough for the cottonwoods to get their roots down to the water table.

Several ideas were floated for getting cottonwood established in specific areas. Some thought there would be a need to use mechanical/ chemical interventions to prepare the area and control saltcedar, followed by pole planting of cottonwoods, to create a seed source.[4] To keep native vegetation alive for establishment, especially during the dry periods, small releases from the reservoirs might be needed. In general, releases could be timed to coincide with / take advantage of storm events. In some areas, it could help to establish dense grasses that provide erosion control and suppress reestablishment of saltcedar. Riparian grasses can be supported by the base flows, with occasional pulses overbank to make roots go deeper into the groundwater. This is particularly true in a few places where groundwater levels are high enough to support cottonwoods and willows, assuming saltcedar can be adequately controlled. There has been some success with ecological control due to the saltcedar beetle, which is keeping some of the stands in check. As an alternative to mechanical interventions, the group was encouraged to think about geomorphic work that might be accomplished by high / overbank flows, and the resulting cleansing of spaces for new recruitment. Some combination of thinning via saltcedar beetle and mechanical control, along with high, scouring flows coinciding with cottonwood seed dispersal and establishment, was proposed. For example, in the Bill Williams River, operators were able to take advantage of the difference in the seed dispersal time window between cottonwoods and saltcedar. Cottonwood seed dispersal starts in late April to early May, extends into June or July, whereas saltcedar seed dispersal, although continuous, is often more concentrated in the mid to late summer. Scouring flood flows during flashy events, such as those that occasionally occur with remnant tropical systems, could benefit cottonwood and potentially help recharge marshes.

In addition to timing block releases to coincide with cottonwood seed set and dispersal, it might also be possible to release water on top of flood flows, to accomplish occasional overbank flooding. Because CID times the flows for maximum efficiency, however, changing the timing would come at a cost, as would releasing extra water that would then sit in Brantley and evaporate.

There was consensus that Reach B has more opportunity for riparian rehabilitation efforts, at least in the short term. It would be physically feasible to make the block releases from Santa Rosa larger and shorter, so that more riparian areas get inundated between Santa Rosa and Sumner. Running a block release this way would wet the banks of Sumner reservoir, and then drain them. Furthermore, Sumner is shallower and hotter; therefore, using water in this way is considered inefficient.

A few riparian areas could be irrigated with water allocations purchased or reallocated from the agricultural rights holders. Several specific locations were discussed: One at north end of PVACD, where river is almost level with ground around it, the water table is only ~6" below the ground surface, and there is potential for drastic changes to the plant communities with very little water. Other potential locations included the mouth of the Taiban Creek and Truchas River.

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[4] See also: U.S. Forest Service (USFS). 2014. Field Guide for Managing Saltcedar in the Southwest (TP-R3-16-02). Saltcedar in New Mexico. https://web.nmsu.edu/~harpua/saltcedar/index.html

Upstream of Sumner (Reach B) there are some wider backwater areas with grasses and willows near the water. In this area, complete filling of Sumner Reservoir could potentially support cottonwood recruitment and riparian vegetation, especially if timing were to mimic seasonal flood dynamics. Floods might also help control the saltcedar if the pool could be held for a long enough period.

Historically, there were some extensive "swamps" located all along the river corridor from Highway 70 south around 15 miles, although not directly along the river. It might be possible to restore or recreate these wet meadows and other wetland features in old river bends and oxbows. Marsh grasses, once established, tolerate long periods of dry based on shallow groundwater; and don't require regular flooding or scour.

Discussion then returned to whether and how saltcedar could be controlled. Even where groundwater or flows could be sufficient to support native riparian species, some initial removal of saltcedar would likely be needed to permit their establishment. Effective control of invasive saltcedar could free up some water for restoring native vegetation. However, saltcedar currently does provide habitat for riparian species such as flycatchers, so there are some ecological benefits of allowing saltcedar where native riparian vegetation cannot be reestablished. It was noted that at one point the state of NM had forbidden the use of state funds to control saltcedar.

Cattle are another important factor to consider; whether cattle are present in the landscape or not can be a big determinant of vegetation type, especially the response to flow events. There might be an opportunity for adaptive management experiments with grazing as well in some of these places, e.g., if a cooperative landowner would be willing to fence out cattle to encourage the establishment of natives that could compete with the saltcedar. Fencing out cows in certain areas could create the opportunity to get some native vegetation re-established in places that could compete with saltcedar, because cows currently have a significant effect on vegetation composition in the riparian areas. Historically, native buffalo (bison) were known to move through in large herds and denude everything, then give it time to heal. It might be possible to experiment with multispecies grazing or managed grazing in the floodplain, as has been done in other places, such as Jornada Station.

Summary: Principles and Areas of Agreement

- A continuous riparian corridor along the entire river length is neither feasible nor necessarily representative of historic conditions. A cottonwood willow riparian system would need to be a patchwork mosaic. Work to restore these patchy forests should focus on places where success is most likely, such as at the mouths of uncontrolled tributaries that have occasional high flows. Temporary water storage such as small dams at these mouths of tributaries could help slow the recession and allow cottonwood roots to establish.
- Saltcedar is extremely resilient and will typically win out unless conditions are actively managed for cottonwood, willow, and grass recruitment. Participants largely agreed that this likely can't be accomplished without some degree of mechanical / chemical intervention.
- There is some potential to take advantage of situations that arise opportunistically – e.g., set up to put a block release on top of a rain event, or clear saltcedar before a spring pulse that might

germinate cottonwood, but try to have cover on it by the time saltcedar is reproducing in hot part of summer.

- In some areas, dense grasses that provide erosion control could be established, and may prevent saltcedar establishment. Riparian grasses can be supported by the base flows, with occasional pulses overbank to make roots go deeper into the groundwater.
- Concentrate on reach B, where a riparian system seems most plausible (Reach A is out of our control; Reach C would be a much bigger project). Also, flows there can be manipulated without altering the releases from Sumner. For example, a single release out of Santa Rosa could potentially become 2 block releases out of Sumner (noting that storage in Sumner would result in higher losses, and that Sumner releases are restricted to 1,400 cfs and can't go for more than 2 weeks per the 2016 USFWS Biological Opinion).
- Incorporate new ideas to create habitat, and to monitor effects
    - Could vary size of block releases, so that river isn't so perfectly tailored to 1,400 cfs.
    - Have aerial / drone photographs have been taken during a block release? Drone flights during block releases would be informative.
    - River trips can also help us to understand the river between road crossings (there aren't other ways to see it directly).
- More information and analyses are needed to identify places where native riparian vegetation would have maximum potential to reestablish with minimal investments of dollars and water from operational changes.
- Look for overlap in desired conditions for other biological system components, particularly timing and magnitude of disturbance events.

3.3.1 E-flow Hypotheses and Prescriptions

Having acknowledged and thoroughly summarized constraints and principles above, the riparian vegetation breakout group began working within the RPT to develop initial ecological flow "prescriptions". While acknowledging that water in the system is fully allocated, the question was framed as 'what is the minimum amount of extra water we would have to release to get habitat and water quality benefits?'

Ultimately, the riparian vegetation group proposed three environmental flow components and operational windows to enhance riparian vegetation, developed for conditions not directly corresponding to wet, average, and dry years as defined for RPT (see Appendix B), but corresponding to more specific enabling conditions. Recommendations were developed primarily for Reach B, but then loosely transferred to Reach C, recognizing, however, that only Reach B is a gaining reach. Low flows for both reaches were set as 10, 25, and 50 cfs during the growing season (1 March to 31 October) for dry, average, and wet years, respectively (Figure 5).

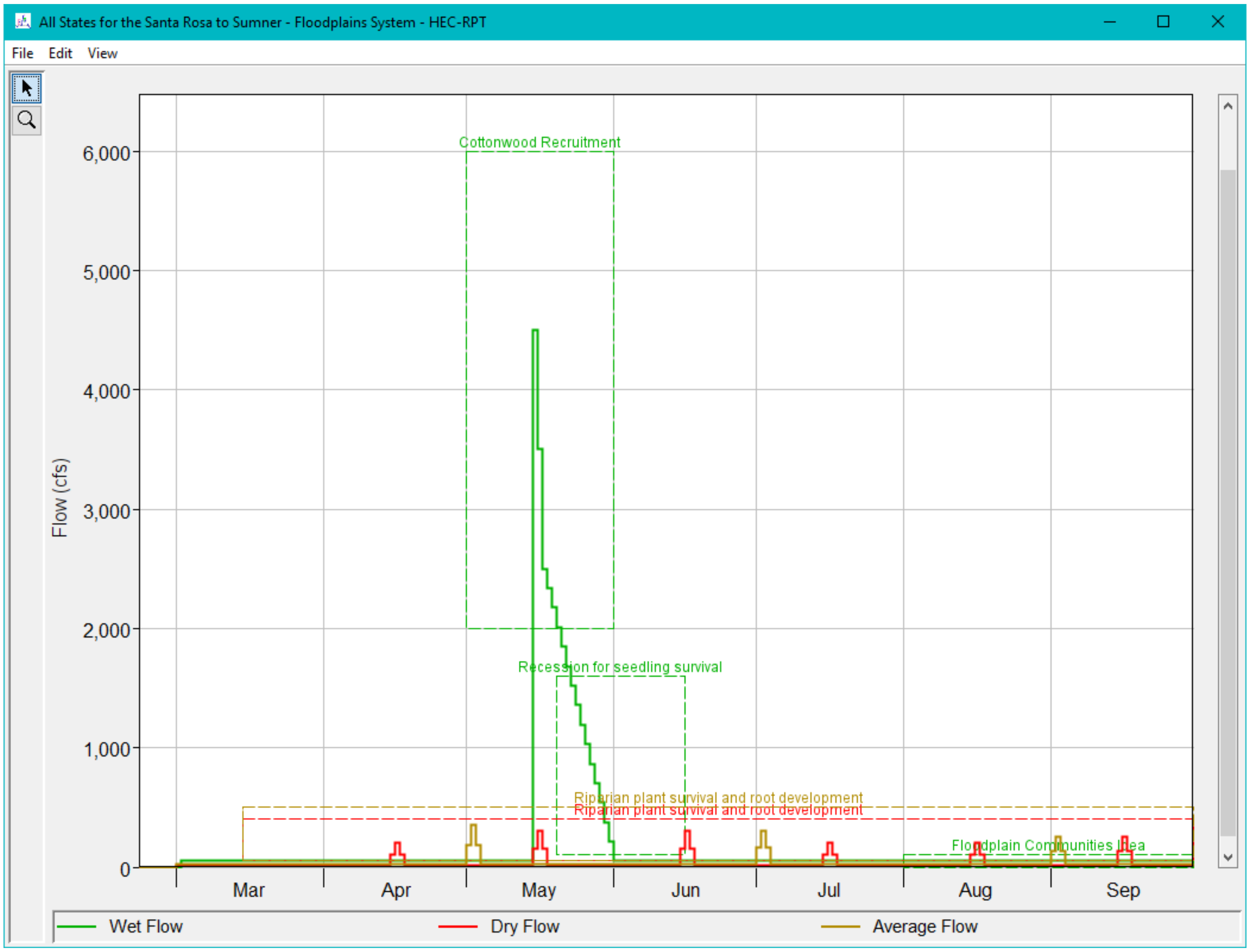


Figure 5. E-flow needs for floodplains in Reach B as represented graphically in RPT by flow component and operational window for wet (green), average (brown), and dry (red) years.

Large Flood Pulse for Cottonwood Recruitment

The bulk of the discussion of hypothetical flow prescriptions centered on defining a high flow component designed to enable or enhance cottonwood recruitment. Such a flow prescription would require a release of sufficient magnitude to cause overbank flooding, at the right time(s) to benefit cottonwood seed dispersal, and a slow flow recession to support establishment of seedling roots (ideal conditions are for groundwater levels to drop about 1 inch per day). If current channels in Reaches B and C have largely adjusted to 1,400 cfs as the dominant channel forming flow, the group speculated that flows of 2,000 cfs would be sufficient to go overbank, but that flows up to 4,500 cfs would be ideal. The recession would then need to last from 10 to 30 days.

Building on the experience of the Bill Williams River, the ideal timing of this flow component would be between May and early June, to maximize cottonwood seed dispersal ahead of peak saltcedar seed set. Although the hydrograph for this prescription was represented in RPT as a wet year prescription, the group emphasized that this level of flow would not even be needed in every wet year. If conditions were cooperative, accomplishing this flow prescription would only need to happen once every 8 to 10 years, in years with maximum chance of success. This might be a combination of very intense monsoonal storms occurring at a time when the reservoirs were already largely full / at storage capacity.

Riparian Plant Survival and Root Development – Low Flows/Baseflows and Small Pulse Flows

Some minimal amount of base flow and associated shallow groundwater would be required to sustain new riparian seedling recruits and to benefit native species such as alkali sacaton, which could help to discourage saltcedar. A low base flow is recommended during growing season for vegetation maintenance. Because Reach B is a gaining reach, baseflows could work in favor of establishment. However, to sustain riparian and floodplain plant communities during summer months, it would be useful or perhaps necessary to have occasional small pulse flows to prevent dieback. These small pulses were described as short releases designed to inundate old oxbows and lower elevation floodplain areas. There should be multiple pulses with particular attention paid to dry season pulses or during a monsoon season with a prolonged lack of rainfall. It might be possible to take advantage of the opportunity to time releases to coincide with precipitation events to prolong any inundation and moisture benefits for the riparian plants. This could also have advantages for transport efficiencies of water in the system.

The group acknowledged that the greatest need for these pulses would coincide with the greatest need for water rights holders. In the average state, the need might be less, but again that would be a function of prevailing conditions. These maintenance small flow pulses were represented in RPT as a set of 3-5 flow pulses of 50 to 500 cfs (the exact magnitude of these flow targets would need to be verified), spaced approximately 1-2 months apart in average years, and perhaps even more frequently (monthly) in dry years. There might be ecological benefits to higher, less frequent pulses. To free up water for these higher episodic flows, it may be advantageous to reduce low flows (e.g., ~25 cfs from March to October, with potential to go even lower in winter). (In general, riparian vegetation in the system was thought to be resilient to low flows/drying in the winter, though it was acknowledged this was not likely to be true for fish.) To gage the potential of this approach, it would be important to monitor the balance between low flows and higher episodic flows in terms of mortality of riparian plants.

3.4 Birds/Reptiles/Amphibians Breakout Group (also called Fauna Group)

The Bird/Herp group immediately launched into RPT hypothetical flow "prescriptions", starting with defining and designing operational windows (timing and flow magnitudes) for each hydrologic state and subreach downstream of the USBR and USACE dams at Santa Rosa (Reach B) and Sumner (Reach C). Breakout group participants consulted figures from the Literature Review (Moore et al. 2022) to help suggest specific recommendations (see Mural board; Figure 6 below from Literature Review)

On Day 1, the group focused on Reach C when creating hypothetical e-flows for each hydrologic state (see Appendix B for RPT context).

On Day 2, e-flow prescriptions and components proposed and defined for Reach C were adapted and transferred to Reach B, with minor adjustments.

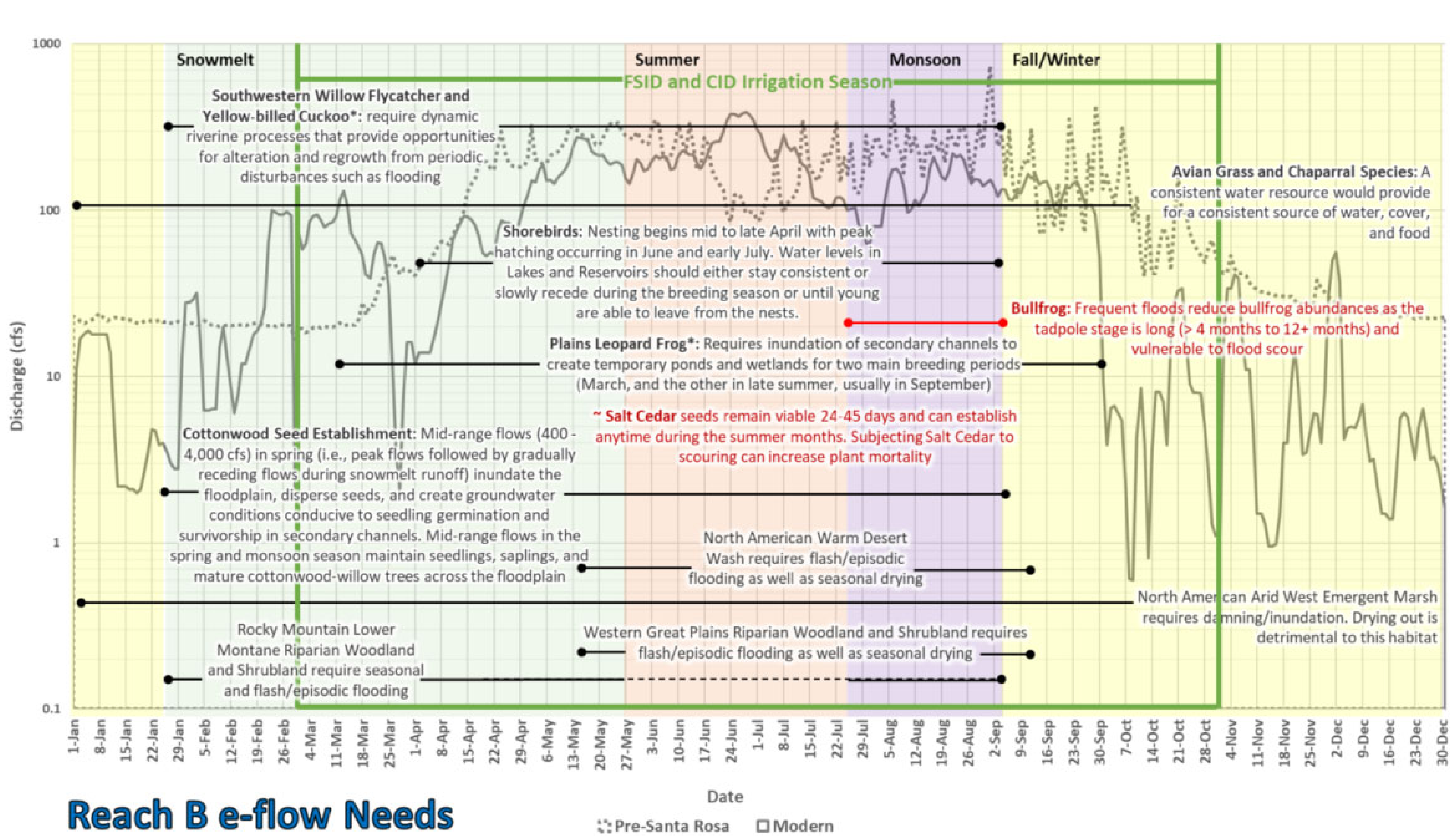
General ecosystem flow components and needs identified by the group include:

- Floodplain inundation during the snowmelt period, primarily to enable seed dispersal and recruitment for cottonwood and other native riparian plants as the key structural component for bird habitat.
- Flow pulses from rainfall events are critical to create and maintain key habitat components for birds, reptiles, and amphibians needed in different life stages, e.g., off-channel ponding critical to the reproductive success of amphibians. The high amplitude of these pulses also tends to discourage invasive species recruitment while benefitting native species that are adapted to these dynamic monsoonal spates.
- Sustaining floodplain-river interaction and connectivity requires periodic overbank flooding during high flows as well as maintenance of high-water tables in the immediate riparian area and channel.
- Baseflows, or minimum flows, are important particularly during dry periods and seasons (i.e., fall and winter months) to ensure that river reaches do not desiccate, which would negatively impact aquatic fauna.

3.4.1 E-flow Hypotheses and Prescriptions

Wet Years

The group chose to start by looking at the "wet year" state to explore e-flow hypotheses for high flow components that could potentially be enhanced with slight modifications of block releases, as it was expected that there would be higher perceived opportunity to experiment during periods of relatively higher water availability. Based on the estimated "natural" or "unregulated" flow pattern (i.e., prior to construction and operation of the dams) as represented in RPT, initial discussion focused on characterizing the high volume, long duration flows that occurred during the snowmelt period, versus the more frequent but variable flow pulses and large floods that would have occurred in response to rainfall events primarily during the monsoon season. Early season snowmelt floods would have been important for seed dispersal and recruitment of riparian trees such as cottonwood as well as raising riparian water tables to support native shrubs and grasses, all of which were viewed as habitat surrogates for riparian dependent birds, reptiles, and amphibians.



Reach B e-flow Needs

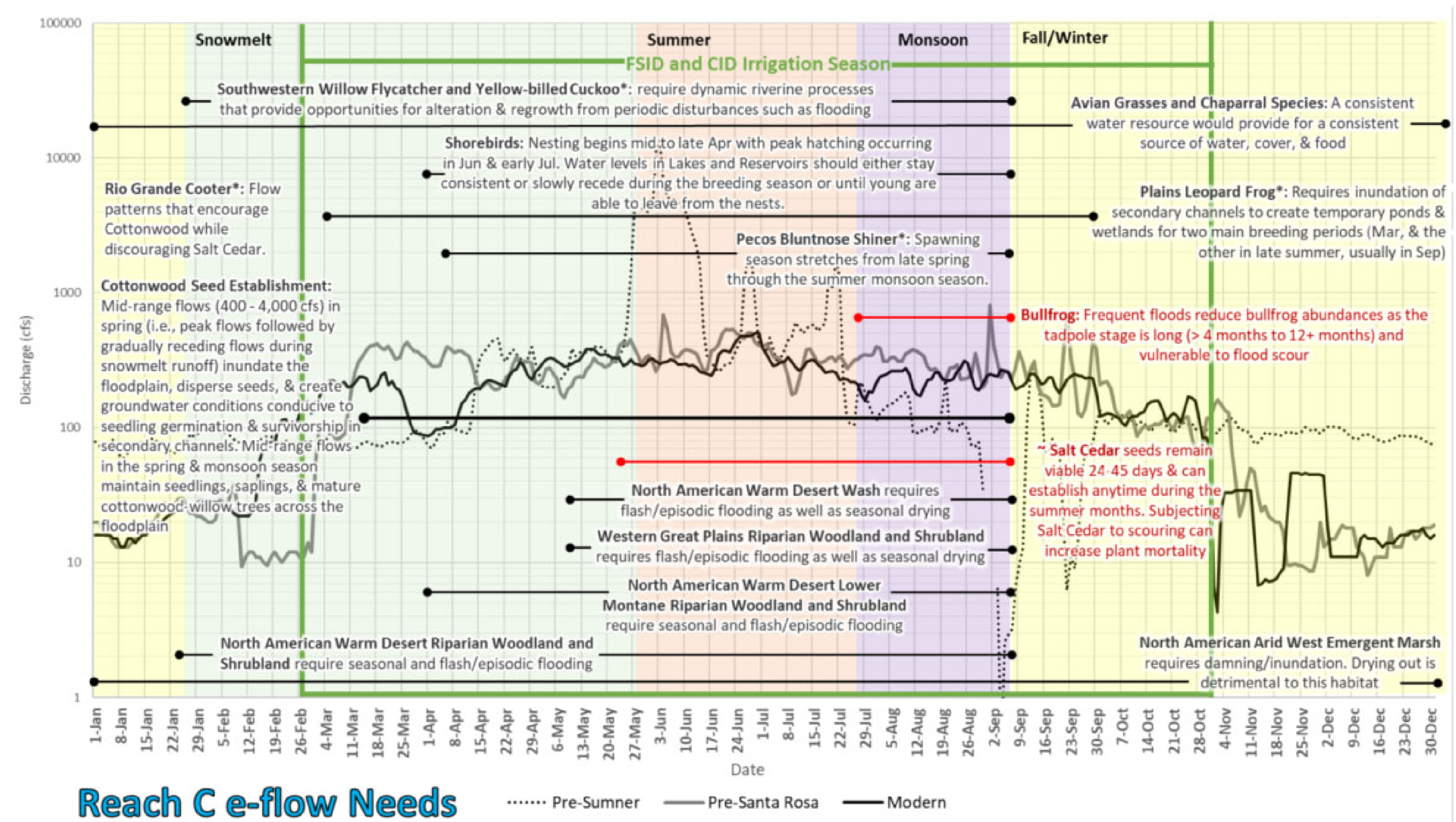


*Figure 6. Ecosystem flow needs of species found in Reach B (at top) and Reach C (bottom; copied as Figures 34 and 35 from the Literature review, Moore et al. 2022). The pre-dam hydrograph (i.e., pre-Santa Rosa for top and pre-Sumner at bottom) is represented with the dashed gray line. The "Modern" hydrograph is shown with a solid gray line for Reach B (post-Santa Rosa) and a black line for Reach B (post-Santa Rosa). For Reach C, the solid gray line shows the hydrograph post-Sumner but pre-Santa Rosa. Species in red are considered invasive. *Species are listed as endangered. Green solid lines delineate irrigation season.*

Flow pulses from rainfall during the monsoon help create and maintain riparian habitat needed by birds, reptiles, and amphibians, particularly for reproduction. The dynamic magnitude of flows that occurred prior to the dams and standardized block releases would, the group thought, hypothetically benefit native riparian grasses and trees (such as cottonwood and willows) at the expense of saltcedar. Flashy flood pulses would discourage invasive species recruitment, such as bullfrogs, which are vulnerable to high flows as tadpoles. This in turn would benefit native amphibians and reptiles on which bullfrogs prey, such as Western ribbon snake and plains leopard frog. Dynamic high flows of varying magnitude support the floodplain-river interactions critical to native fauna, by generating overbank flows that inundate the floodplain, maintain the riparian water table, and support native riparian vegetation.

Based on the discussion above, the group described three wet year environmental flow components with overlapping operational windows (Table 4; Figure 7).

1. “Cottonwood as bird habitat – seed recruitment”. A proposed interval of 8-10 years for inundation to promote riparian vegetation recruitment was thought to be sufficient for maintaining native riparian species, primarily represented by cottonwood. Benefitting native riparian vegetation, in turn, would benefit riparian birds and other species, such as western ribbon snake. Although there was uncertain about timing of seed availability for cottonwood versus saltcedar, the operational window for this event was defined as extending from 15 March to 30 May, based on the Gila River and the expectation that earlier peak runoff would have a greater relative benefit for cottonwood. Magnitude of the peak was represented as 3,500 cfs, in a band from 400 to 4,000 cfs, a range which would have been reached or exceeded 12 years out of 21 from 1980-2020 (1981, 1986, 1991, 1994, 1995, 1996, 1997, 2004, 2005, 2006, 2014, and 2017) based on the computed “pre-dam” time series (drainage area-based, extrapolated) at the Anton Chico gage.
2. “Plains leopard frog breeding season”. Based on information in the Literature Review suggesting that the plains leopard frog can have either an early or a late breeding season, the group created two operational windows for flow pulses of sufficient magnitude to create on or off-channel ponded breeding habitat. The first of these overlaps the snowmelt period from late-March to mid-April, while the second extends through the latter part of the monsoon season from August through October. Peak magnitude was represented as 1,750 cfs (1,500 to 2,000 cfs) based on the need to fill secondary channels or ponded areas in the main channel, without necessarily inundating the entire floodplain. Duration of 2-5 days was selected without a great deal of discussion, though the modeled natural flow regime suggests that these flows would have happened more often during the monsoon season.
3. “Monsoon to control bullfrogs”. Based on the Literature Review, dynamic monsoon flood flows were seen as key to many ecohydrologic functions. Bullfrogs prefer breeding in the river channel and can breed throughout the season. However, tadpoles are poor swimmers, and large flows flush them downstream and significantly reduce adult recruitment. For bullfrog control, at least one large pulse would be necessary, though the more the better, preferably spaced far enough apart to hit successive reproductive events. This flow component was represented as 2 or more peak events reaching 3,000 to 4,000 cfs (with a minimum magnitude of 2,000 cfs, hypothesized as the minimum for overbank flow accomplishing floodplain inundation), occurring between June through 1 September.

Table 4. Wet year operational window characteristics identified for fauna from Santa Rosa to Sumner Dams (Reach B).

Operational Window Title	Operational Window range in dates and flows	Description	Idealized Hydrograph Entry			
			Date (ddmmm)	Duration (days)	Peak (cfs)	Duration of Peak Flow (days)
"Cottonwood as bird habitat - seed recruitment"	15Mar - 30May; 400 - 4,000 cfs	This operating window is based on a citation on the Gila River. Driven by snowmelt; so, this Operating Window recommendation does not change from Reach C. • Tamarix (invasive, less desirable) and cottonwood compete. Tamarix benefits from steady flows. • Western ribbon snake will benefit from the riparian habitat; predated on by bullfrogs. • Cooter is not in Reach B. • This flow scours and supports re-generation of vegetative habitat. **Uncertainties:** • Bankfull flow rate in this Reach, assumed at 1,200 cfs • Timing of seed availability of cottonwood and tamarix. Expect an earlier peak runoff to support the cottonwood over tamarix (when compared to the Figures of the SOS).	01Apr	14	3,500	8
"Monsoon to control bullfrogs"	01Jun - 01Sep; 1,000 - 3,000 cfs	• At least one large pulse, although more would be better. This flow should at least cause flushing in the channel. • Flushes the bullfrog tadpoles, which cannot swim well. Bullfrogs prefer breeding in the river (less concerned with predation). **Uncertainties:** • If 2,000 cfs is the overbank flow, so this operating window is designed to accomplish some floodplain inundation if available in the narrow valley.	01Jul	4	2,000	1
			01Aug	4	2,000	1
"Plains leopard frog breeding season 1"	01Mar - 01Apr; 1,500 - 2,000 cfs	Inundation in secondary channels, ponded areas in the main channel. This area needs to be connected to inundation, so not on floodplains.	05Mar	5	1,750	2
"Plains leopard frog breeding season 2"	01Aug - 31Oct; 1,500 - 2,000 cfs	See notes for PLF breeding season 1. If water remains in these inundated ponds after flow recession.	01Sep	5	1,750	2

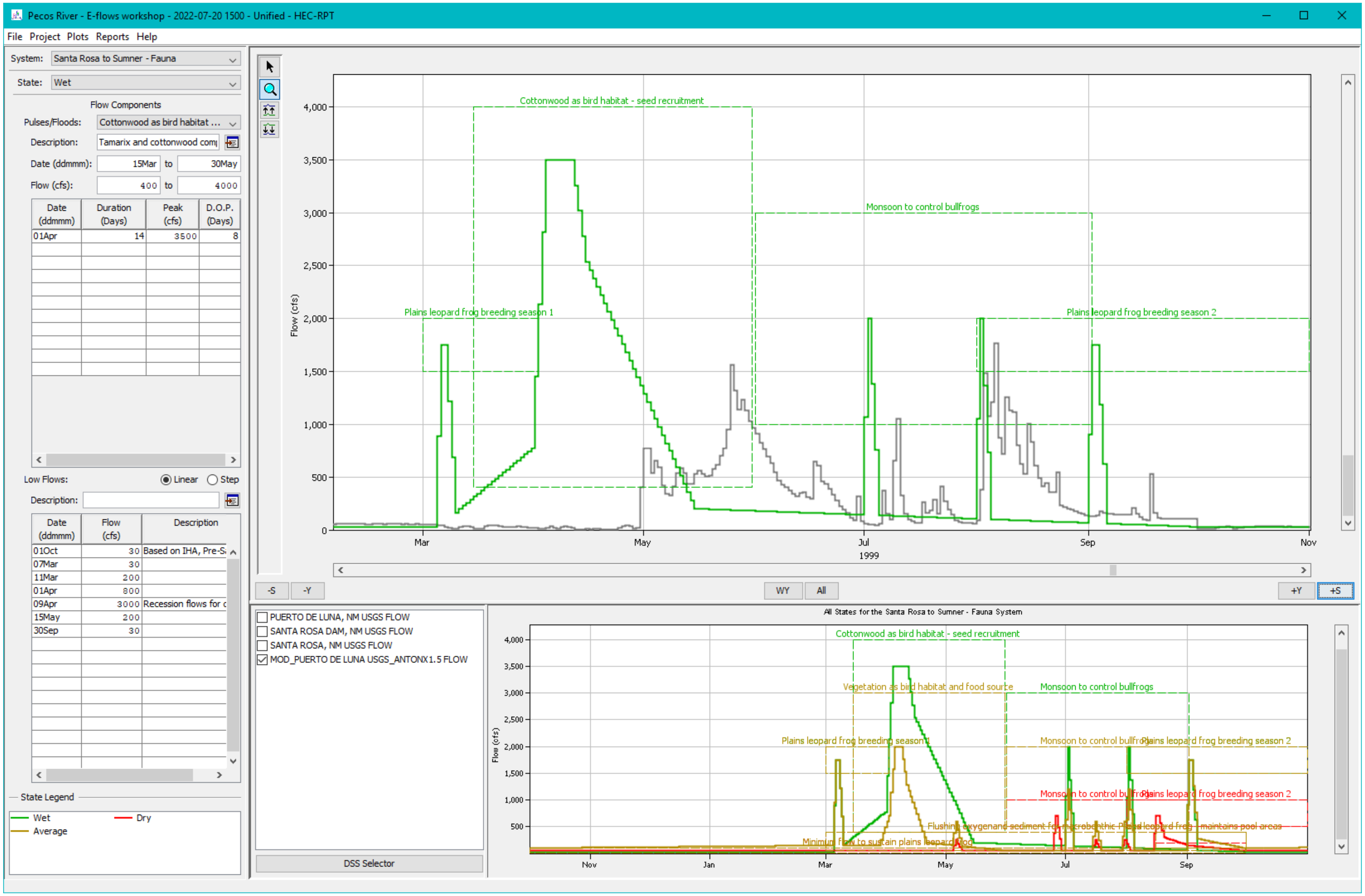


Figure 7. Example of a wet (green) year hydrograph for the Santa Rosa to Sumner reach developed by the Birds/Reptiles/Amphibian Group. Dashed line boxes are operational windows (see Table 4 for corresponding operational window characteristics for the wet hydrologic state).

Dry Years

The group assumed dry years had lower flow volume available, with a small snowmelt runoff and fewer rain fall events.

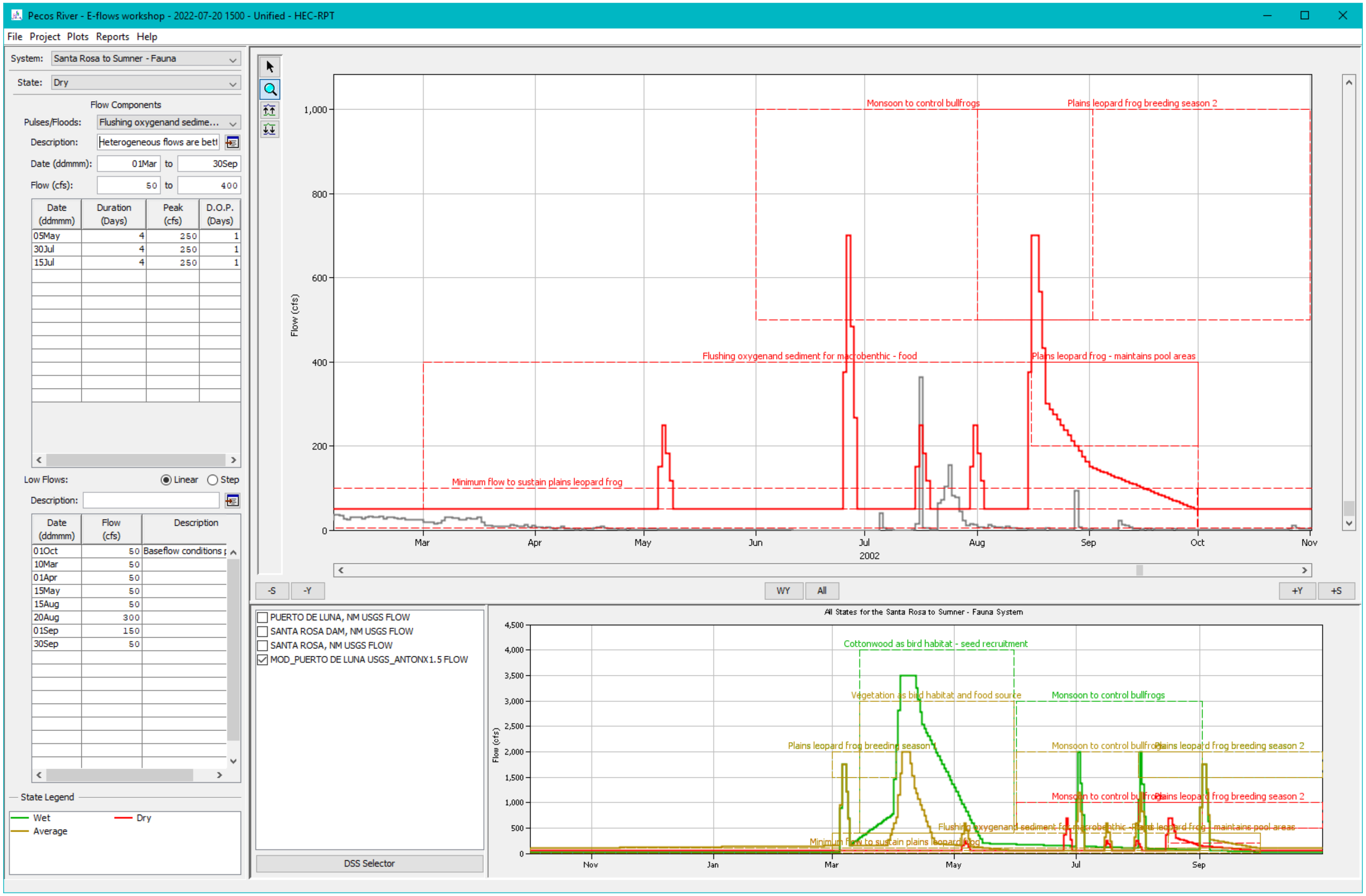
- Maintaining a minimum baseflow (~50 cfs) during fall and winter is hypothesized as essential for ensuring that river reaches do not desiccate, which would negatively impact aquatic fauna.
- Recruitment of flora and fauna would be reduced compared to dry and average years caused by reduced water availability, especially during the snowmelt period.
- Summer flow pulses would also be reduced offering a short time window for native recruitment and management of nonnative species (i.e., bullfrog).
- In dry years, overbank flows (flows that escape the channel) are even less likely.

Based on the above flow hypotheses, the group described the following “dry year” environmental flow components with overlapping operational windows (Table 5; Figure 8).

1. “Minimum flow to sustain plains leopard frog”. In dry years, minimum flows are needed to prevent the channel from becoming desiccated, not just for fish but for amphibians and reptiles (e.g., turtles) as well. Most species also benefit from low, stable base-flows in the winter, to prevent inundation or stranding of hibernating species.
2. “Flushing sediment and oxygen for microbenthos/food.” Although dry years would lack water availability for large floods, the group proposed a series of small pulses above the minimum flow (~250 cfs, or anywhere from 50 to 400 cfs) to help flush benthic sediment and maintain some oxygen in the benthos.
3. “Plains leopard frog breeding season”. Even in dry years, some breeding habitat would be needed to support native amphibians. The group proposed one early (mid-March) and one late season flow pulse (anywhere from 1 August to 31 October) of 500 to 1,000 cfs, since plains leopard frogs have two potential windows for breeding. Though lower than the wet year magnitude, this flow could potentially create ponded areas in the main channel, without necessarily inundating the entire floodplain, and that water remains in these inundated ponds after flow recession.
4. “Monsoon to control bullfrogs”. A mid-summer flow pulse during the natural period of the monsoons (late June - July) would also be valuable in dry years to help control tadpole populations.

Table 5. Dry year operational window characteristics identified for fauna from Santa Rosa to Sumner Dams (Reach B).

Operational Window Title	Operational Window range in dates and flows	Description	Idealized Hydrograph Entry			
			Date (ddmmm)	Duration (days)	Peak (cfs)	Duration of Peak Flow (days)
"Flushing Oxygen and Sediment for macrobenthic - food"	01Mar - 30Sep; 50 - 400 cfs	Heterogeneous flows are better than uniform flows	05May	4	250	1
			30Jul	4	250	1
			15Jul	4	250	1
"Minimum flow to sustain plains leopard frog"	01Oct - 30Sep; 5 - 100 cfs	• Cannot be desiccated. Turtles and PLF require at least some flow. • Most species benefit from low, stable base-flows in the winter. • High flow pulses can be disruptive to hibernating species.	-	-	-	-
"Monsoon to control bullfrogs"	01Jun - 01Sep; 500 - 1,000 cfs	• At least one large pulse, more is better. Flushes the bullfrog tadpoles, which cannot swim well. • Bullfrogs prefer breeding in the river (less concerned with predation). Assumes monsoon occurs later.	25Jun	4	700	1
"Plains leopard frog - maintains pool areas"	16Aug - 30Sep; 200 - 400 cfs	NA				
"Plains leopard from breeding season 2"	01Aug - 31Oct; 500 - 1,000 cfs	See notes for PLF breeding season 1. If water remains in these inundated ponds after flow recession.	15Aug	5	700	2



Date (ddmmm)	Duration (Days)	Peak (cfs)	D.O.P. (Days)
05May	4	250	1
30Jul	4	250	1
15Jul	4	250	1

Date (ddmmm)	Flow (cfs)	Description
01Oct	50	Baseflow conditions ...
10Mar	50	
01Apr	50	
15May	50	
15Aug	50	
20Aug	300	
01Sep	150	
30Sep	50	

Figure 8. Example of a dry (red) year hydrograph for the Santa Rosa to Sumner reach developed by the Birds/Reptiles/Amphibian Group. Dashed line boxes are operational windows (see Table 5 for operational window characteristics corresponding with the dry hydrologic state).

Average Years

For average spring snowmelt and summer monsoon rainfall hydrologic seasons,

- A winter and fall baseflow of 100 cfs would be needed to maintain stable water levels for hibernating aquatic species.
- The snowmelt period offers dynamic flows (although reduced compared to wet years) to accomplish floodplain inundation via channel overbanking which serves to increase food resources and habitat (native tree recruitment) for native fauna.
- During the summer monsoon period, flow pulses need to be sufficient to create bank full hydraulic conditions, as opposed to overbanking, so that scour occurs as a strategy for managing against nonnative species.

Based on the above flow hypotheses, the group described the following "average year" environmental flow components (Table 6; Figure 9).

1. "Vegetation as bird habitat and food source". Although large floods sufficient to drive cottonwood recruitment were recognized as only needed occasionally (i.e., every 8-15 years), there is a need for minimum flows and pulses to sustain riparian vegetation and invertebrates that serve as habitat and food sources (plants, seeds, invertebrates, i.e., entire food chain) for riparian fauna, especially birds. This flow component was represented with an operational window extending throughout the growing season, as at least one flow pulse of 400 to 3,000 cfs (target ~2,000 cfs).
2. "Flushing sediment and oxygen for microbenthos/food." As in dry years, a series of small pulses above the minimum flow (~250 cfs, or anywhere from 50 to 400 cfs) would be needed to help flush benthic sediment and maintain some oxygen in the benthos during average years. Heterogeneous flows would be better than uniform flow targets.
3. "Plains leopard frog breeding season". As in dry years, some breeding habitat is needed every year to support native amphibians. The group proposed one early (mid-March) and one late season flow pulse (anywhere from 1 August to 31 October) of 500 to 1,000 cfs. Though lower than the wet year magnitude, this flow could potentially create ponded areas in the main channel, without necessarily inundating the entire floodplain, and that water remains in these inundated ponds after flow recession.
4. "Monsoon to control bullfrogs". A mid-summer flow pulse during the natural period of the monsoons (late June - July) would also be valuable in dry years to help control tadpole populations.
5. "Tern nesting and hatching" (Brantley Reservoir / Bitter Lake Wildlife Refuge only). During the Tern nesting and hatching period (mid-April to 1 July as a placeholder for more specific seasonal needs), high flood pulses should be avoided to avoid flooding out nests. The group was uncertain about the magnitude of the flow (stage discharge relationship) that would negatively impact the species. This flow prescription would also apply to piping plover (same nesting period).

Differences between Reach B (Santa Rosa to Sumner Dam) and Reach C (Sumner to Brantley Dam)

For the most part, e-flow recommendations were thought to be analogous for Reach B and Reach C but scaled to lower flow volumes in the upstream (Reach B) reach based on lower upstream drainage area. However, e-flow recommendations for terns are only relevant/applicable for the Brantley Dam Pool area of Reach C.

Native and invasive species of interest to restore for or manage against using targeted e-flows for both river reaches. Native species and operational windows included:

- Rio Grande cottonwood seed recruitment during snowmelt (March - June).
- Plains leopard frog breeding season (spring and/fall depending hydrologic condition).
- Rio Grande cooter and yellow-billed cuckoo food sources (March - May with peak flow in April).
- Tern species were only evaluated at Reach C, in the Brantley Dam Pool area.

Table 6. Average year operational window characteristics identified for fauna from Santa Rosa to Sumner Dam (Reach B).

Operational Window Title	Operational Window range in dates and flows	Description	Idealized Hydrograph Entry			
			Date (ddmmm)	Duration (days)	Peak (cfs)	Duration of Peak Flow (days)
"Flushing Oxygen and Sediment for macrobenthic - food"	01Mar - 30Sep; 50 - 400 cfs	Heterogeneous flows are better than uniform flows	05May	4	600	1
			30Jul	4	600	1
			15Jul	4	600	1
"Plains leopard frog breeding season 1"	01Mar - 01Apr; 1,500 - 2,000 cfs	• Inundation in secondary channels or ponded areas in the main channel. • Areas need to be connected to inundation, so not on floodplains.	05Mar	5	1,750	2
"Vegetation as bird habitat and food source"	15Mar - 30May; 400 - 3,000 cfs	• Encourages recruitment of cottonwood • Raises groundwater table to support. young cottonwoods and grasses. • Vegetation supports invertebrate spp. as food source for birds.	03Apr	8	2000	4
"Minimum flow to sustain plains leopard frog"	01Oct - 30Sep; 5 - 100 cfs	• Cannot be desiccated. Turtles also require at least some flow. • Most species benefit from low, stable base-flows in the winter. • High flow pulses can be disruptive to hibernating species.	-	-	-	-
"Monsoon to control bullfrogs"	01Jun - 01Sep; 500 - 1,000 cfs	• At least one large pulse, more is better. • Flushes the bullfrog tadpoles, which cannot swim well. • Bullfrogs prefer breeding in the river (less concerned with predation) • Assumes monsoon occurs later.	01Jul	4	1,200	1
			01Aug	4	1,200	1
"Plains leopard frog - maintains pool areas"	16Aug - 30Sep; 200 - 400 cfs	NA	-	-	-	-
"Plains leopard frog breeding season 2"	01Aug - 31Oct; 500 - 1,000 cfs	See notes for PLF breeding season 1. If water remains in these inundated ponds after flow recession.	01Sep	5	1,750	2

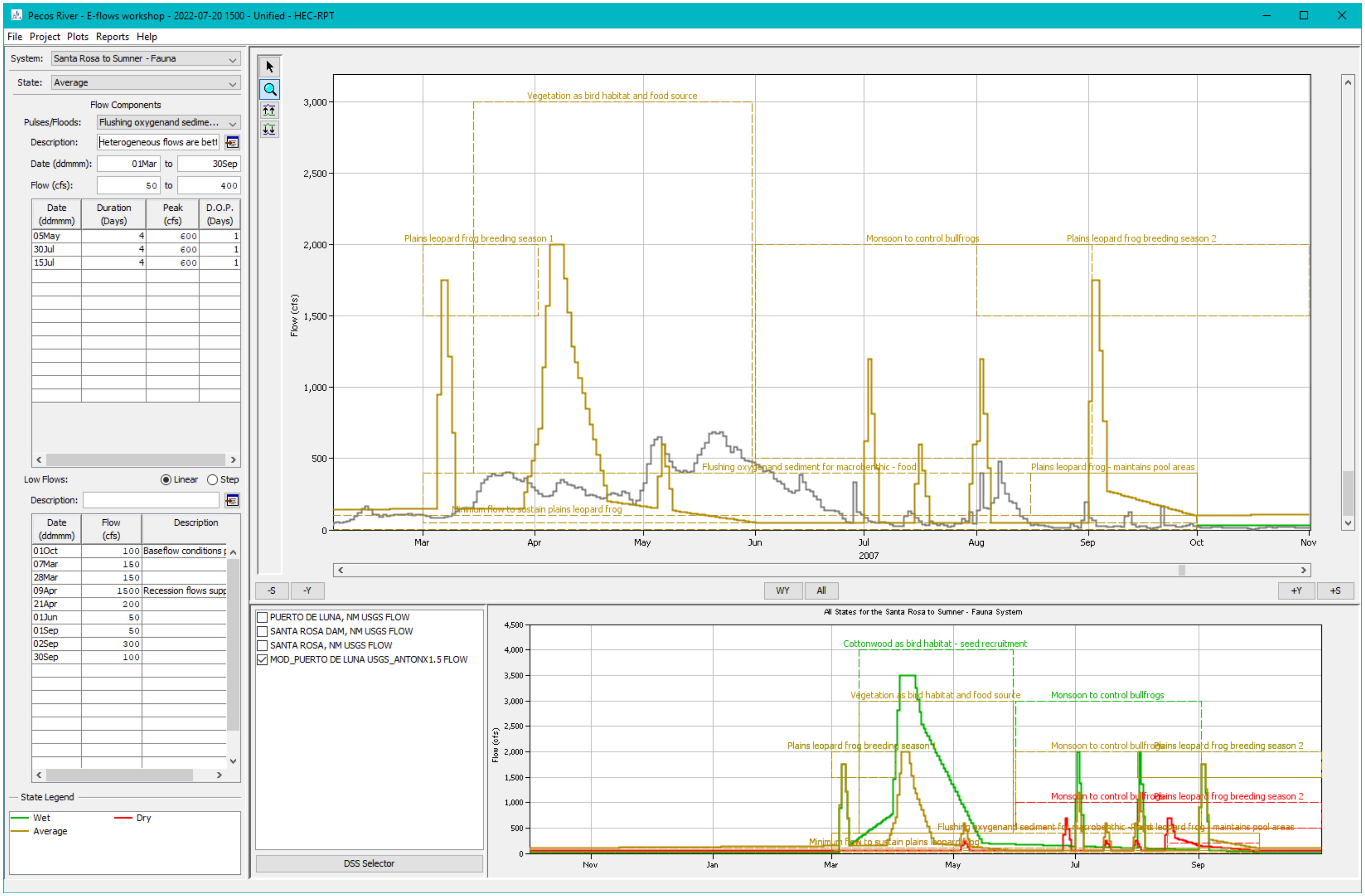


Figure 9. Example of an average (brown) year hydrograph for the Santa Rosa to Sumner reach developed by the Birds/Reptiles/Amphibian Group. Dashed line boxes are operational windows (see Table 6 for operational window characteristics corresponding with the average hydrologic state).

4 Unified Flow Needs and Proposals

Unification of initial ecological flow recommendations from the breakout groups was initiated during the lunch break on Day 2 and presented at 1330 MT after each breakout group presented their findings. During the unification process, group leaders identify similarities and overlap between flow needs/hydrographs hypothesized in RPT in the different breakout groups. Ideally areas of overlap can be found that represent potential opportunities to improve ecological outcomes.

The unification process for the Pecos River combined flows recommendations from the three ecological breakout groups (fish, floodplains, and fauna) into a single unified set of e-flows (per reach, for reaches B and C). Unified e-flows were then compared with flows formulated by the water operations group (see Section 2.1) to get a general sense of alignment and opportunities. Through this unification process, flow recommendations were considered for all four groups:

- Birds, reptiles, and amphibians (also called fauna group)
- Riparian and vegetation (also called floodplains group)
- Fish
- Water operations

John Hickey, USACE HEC and RPTer, led the initial unification discussion by demonstrating how flow requirements from each subgroup could be merged for each river reach in RPT, allowing some editing to explore where flow recommendations overlap, are compatible, and could be combined, versus where they are not easily reconciled.

All system components require some sort of flow pulse event. The three ecological groups identified spring runoff and monsoonal pulses as hydrologic events that support habitat functions. Under current water operations, block releases are made at the peak flow rate of 1,400 cfs, which is the currently determined optimized flow rate. Block releases, as indicated by the name, are made as a consistent discharge throughout, designed to minimize “inefficiencies”, defined as evaporative or seepage losses. There is therefore no “ramping” up or down. Many of the recommended ecological flow pulses were characterized with some level of more gradual recessions. For example, the floodplain group included a recession as part of an e-flow designed to enable cottonwood seedlings to develop a root structure as they attempt to “establish”. It was questioned whether a more gradual recession of a block release would be a feasible operational change that could yield ecological benefits. In practice, attenuation through bank storage leads to flow recessions that are already more gradual than a true block release from a reservoir though resulting recessions may still be too steep to support establishment.

Each of the ecological groups started by acknowledging that under dry years/conditions, there might be no block releases at all. However, under hypothetically ideal conditions (e.g., full conservation storage in reservoirs combined with well-timed monsoonal storm events), there may be potential for flows designed to mimic small pulse events for habitat, water quality, fish, birds, reptiles, or amphibians (e.g., plains leopard frog). Although each of the ecological breakout groups proposed slightly different magnitude, timing, and duration for pulse events, during the unification discussion, it was recognized these might be combined for multiple purposes. Even without reservoir releases, small pulses from monsoon events, which are a natural part of the flashy hydrologic system in the Pecos River, may occur due to inflows from uncontrolled tributaries under any conditions (dry, average, or wet).

4.1 Dry Years

Ecological systems and communities (riparian vegetation, fish, etc.) in the Pecos are adapted to low-flow conditions and some level of periodic drought. Some participants noted anecdotal evidence (supported by the reconstructed unregulated flow record showing very low flows in some reaches prior to the dams) suggesting that some reaches of the Pecos may have had intermittent dry periods in the past. However, others countered that there has long been a baseflow from the artesian aquifer, so intermittency was probably unlikely, or at least infrequent. Outside of the growing season, the floodplains can likely withstand some river drying.

Although the Pecos bluntnose shiner and other Pecos fishes are adapted to these low-flow conditions, the vulnerability of endangered fish species and populations in response to much more frequent and prolonged low flows now requires some level of maintaining connectivity in both summer and winter. However, fish are less vulnerable to loss during the cooler winter season, so winter low flows/baseflows can be lower.

Santa Rosa to Sumner (Reach B). Both the fauna and floodplains groups designed e-flows for Reach B. Specific changes to the e-flow recommendations of those groups during unification included: 1) low flows from the fauna group were adopted, 2) operational windows from the fauna group (flushing oxygen and sediment) and the floodplains group (riparian plant survival) were similar and therefore merged into a single component called "Flushing O2 and sediment for macrobenthos - Riparian plant survival", and 3) a recession recommended by the fauna group to support plains leopard frog breeding in late summer was reduced to better align with river dynamics in dry years (Figures 10 and 11).

Sumner to Brantley (Reach C). Fish, fauna, and floodplains groups each designed e-flows for Reach C. In addition to the changes mentioned for Reach B, the following changes were made during unification: 1) unified low flows were a combination of fish and fauna group recommendations, 2) operational windows from the fish group (monsoon spate for spawning) and fauna group (monsoon to control bullfrogs) were similar and therefore merged into a single component called "Monsoon spates – Fish spawn and bullfrog control", and 3) the traced pulse for spring fish spawn was adjusted to shorten the rising limb and duration of peak (peak magnitude and recession limb were maintained) in order to reduce associated volume while maintaining the primary characteristics of that component (Figures 12 and 13)

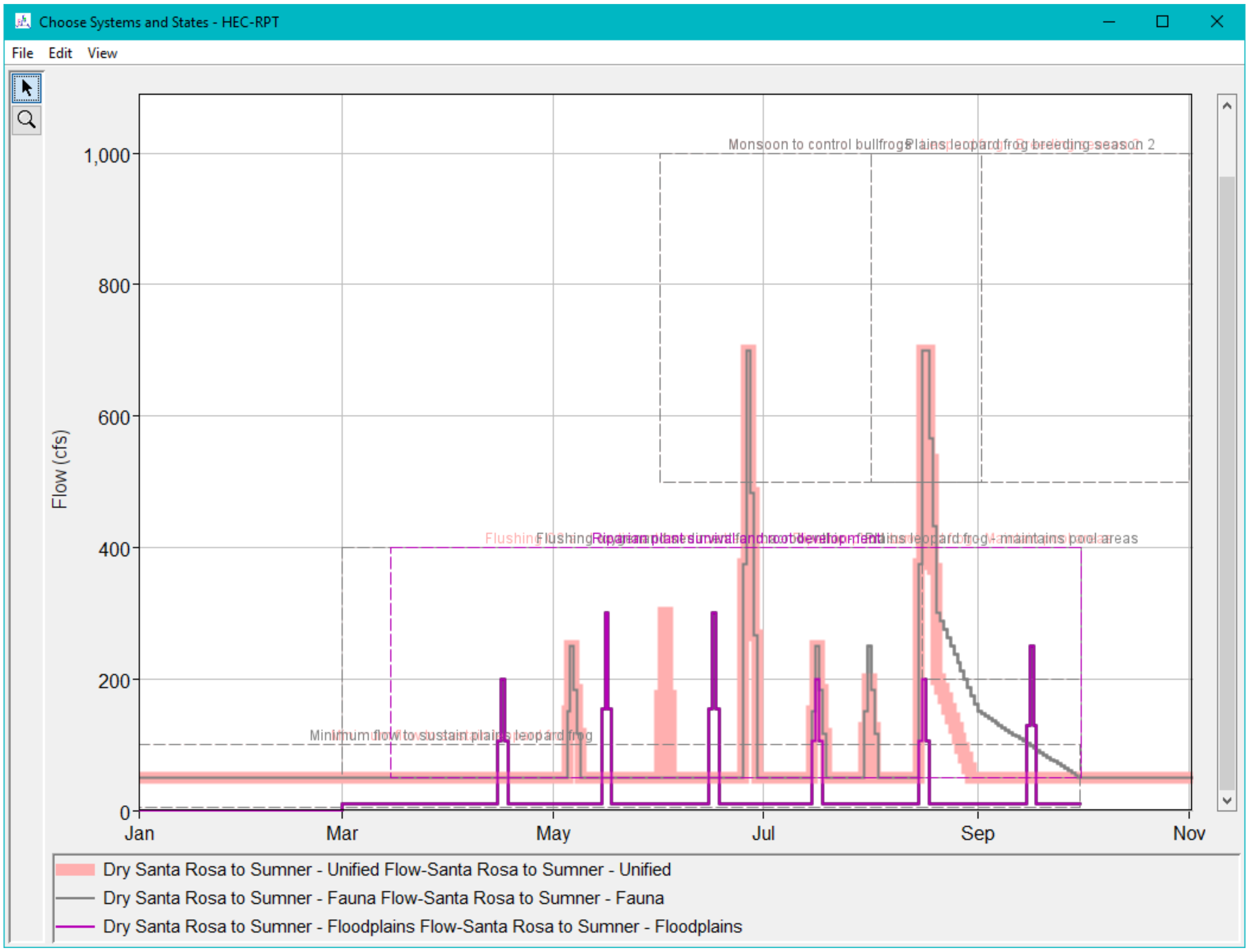


Figure 10. Unification of e-flows for dry years, Santa Rosa to Sumner (Reach B). Unified e-flows shown in pink.

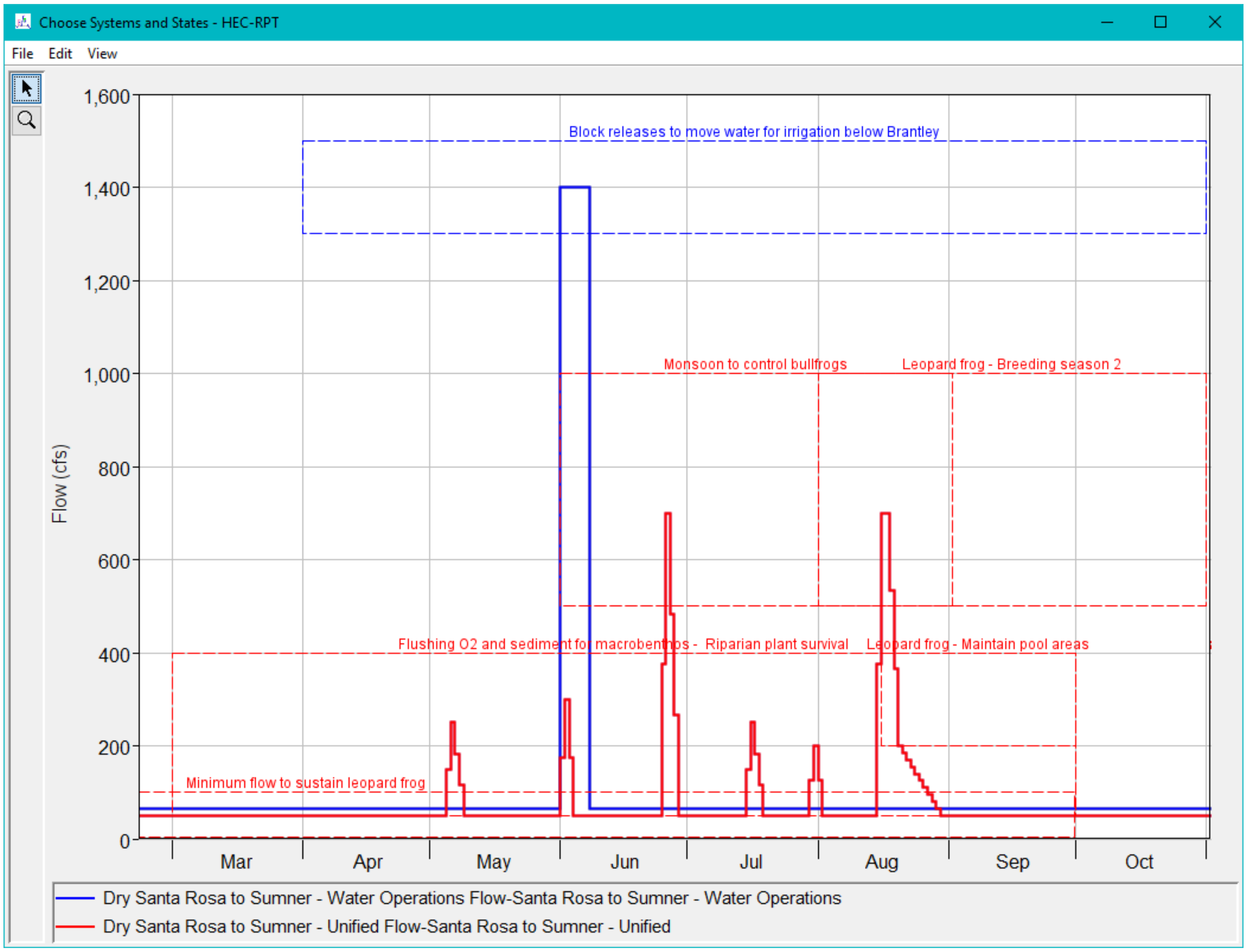


Figure 11. Unified e-flows (red) and flows prescribed by the water operations group (blue), dry years, Santa Rosa to Sumner (Reach B). Unified e-flows are identical to the series shown in Figure 10 (pink).

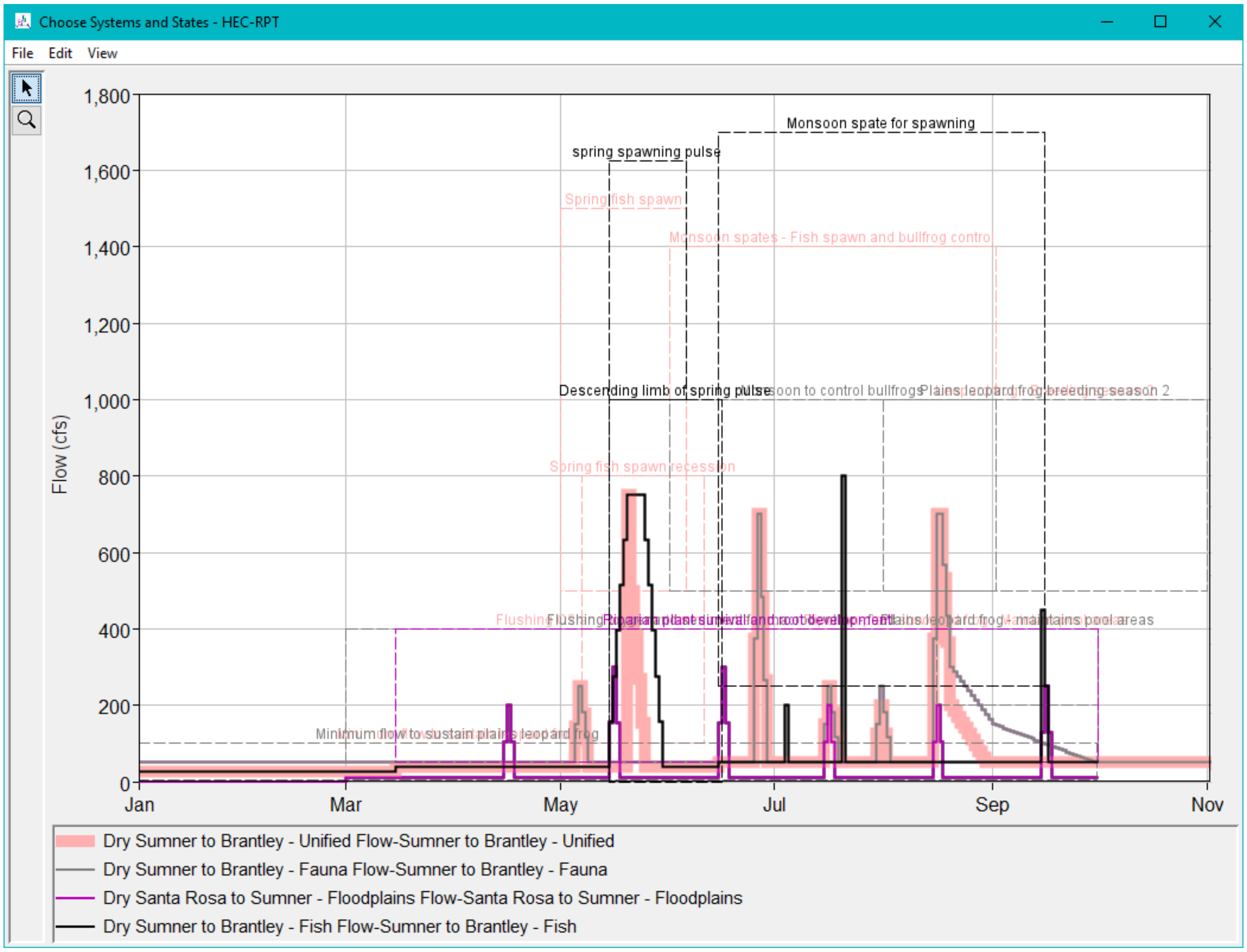


Figure 12. Unification of e-flows for dry years, Sumner to Brantley (Reach C). Unified e-flows shown in pink. The upper extents of the spring spawning pulse and monsoon spate for spawning operational windows were reduced for plotting purposes.

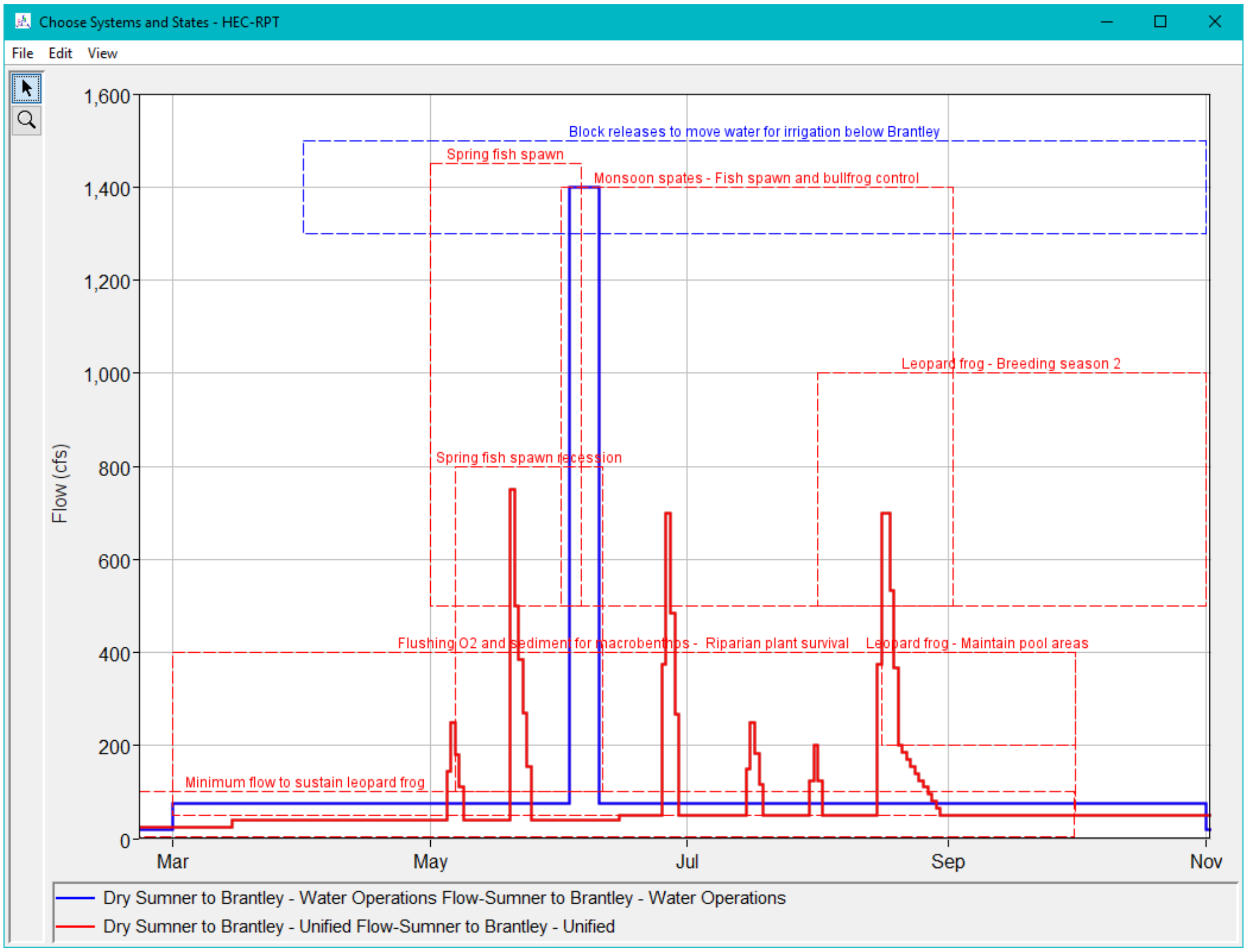


Figure 13. Unified e-flows (red) and flows prescribed by the water operations group (blue), dry years, Sumner to Brantley (Reach C). Unified e-flows are identical to the series shown in Figure 12 (pink).

4.2 Average Years

Conceptually, each group agreed that for any magnitude flow peak proposed, any pulse of similar magnitude proposed by another group could accomplish multiple ecological objectives. In practice, this would require making sure that the timing and seasonality of functions intended to be met by the proposed releases (e.g., cottonwood seed release, fish spawning, temperature or daylight cues, etc.) coincide with the timing of the pulse.

From the fauna group, pulses were proposed in average and wet years to control invasive bullfrogs, whose tadpoles tend to be not well adapted to the monsoonal flow regime and get washed out. Although timing is not critical, multiple flood peaks in a given season would be ideal, as tadpoles develop throughout the warm season. For the native amphibians, such as plains leopard frogs or spadefoot toads, that breed and take refuge in backwater channels or temporary ponds, some level of flow that produces off-channel ponding would be beneficial.

Santa Rosa to Sumner (Reach B). The fauna and floodplains groups designed e-flows for Reach B. Specific changes to the e-flow recommendations of those groups during unification included: 1) unified low flows were a combination of fauna and floodplain group recommendations, 2) operational windows from the fauna group (flushing oxygen and sediment) and the floodplains group (riparian plant survival) were similar and therefore merged into a single component called “Flushing O2 and sediment for macrobenthos - Riparian plant survival”, 3) a recession recommended by the fauna group in support of plains leopard frog breeding in late summer was reduced to better align with river dynamics in average years, and 4) a general thinning of pulses and associated recessions to align volumes with historical Pecos flows (Figures 14 and 15).

Sumner to Brantley (Reach C). The fish, fauna, and floodplains groups designed e-flows for Reach C. In addition to the changes mentioned for Reach B, the following changes were made during unification: 1) unified low flows were based primarily on fish group recommendations, 2) operational windows from the fish group (monsoon spate for spawning) and fauna group (monsoon to control bullfrogs) were similar and therefore merged into a single component called “Monsoon spates – Fish spawn and bullfrog control”, and 3) the traced pulse for spring fish spawn was adjusted to shorten the rising limb and duration of peak (peak magnitude and recession limb were maintained) in order to reduce associated volume while maintaining the primary characteristics of that component (Figures 16 and 17).

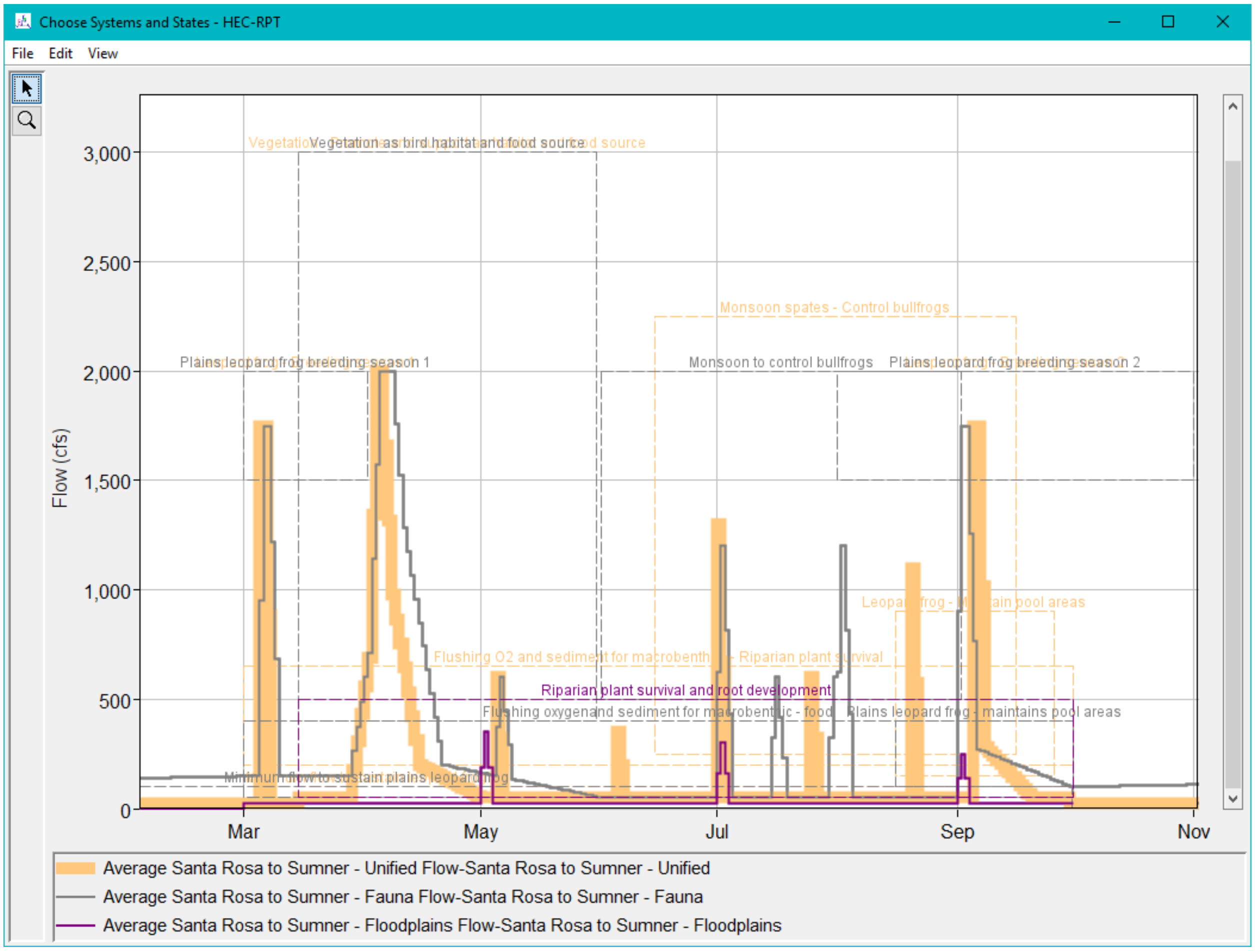


Figure 14. Unification of e-flows for average years, Santa Rosa to Sumner (Reach B). Unified e-flows shown in orange.

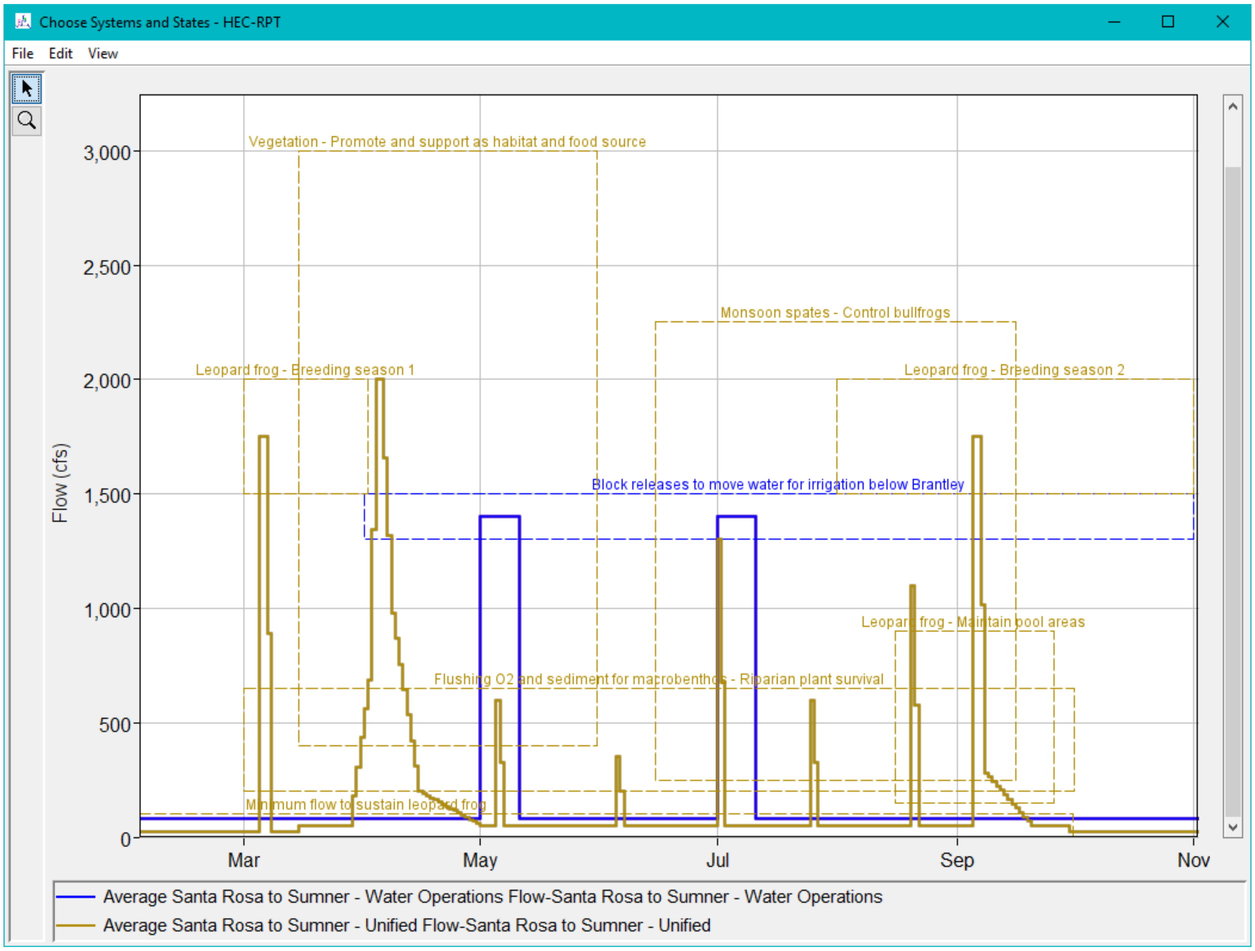


Figure 15. Unified e-flows (brown) and flows prescribed by the water operations group (blue), average years, Santa Rosa to Sumner (Reach B). Unified e-flows are identical to the series shown in Figure 14 (orange).

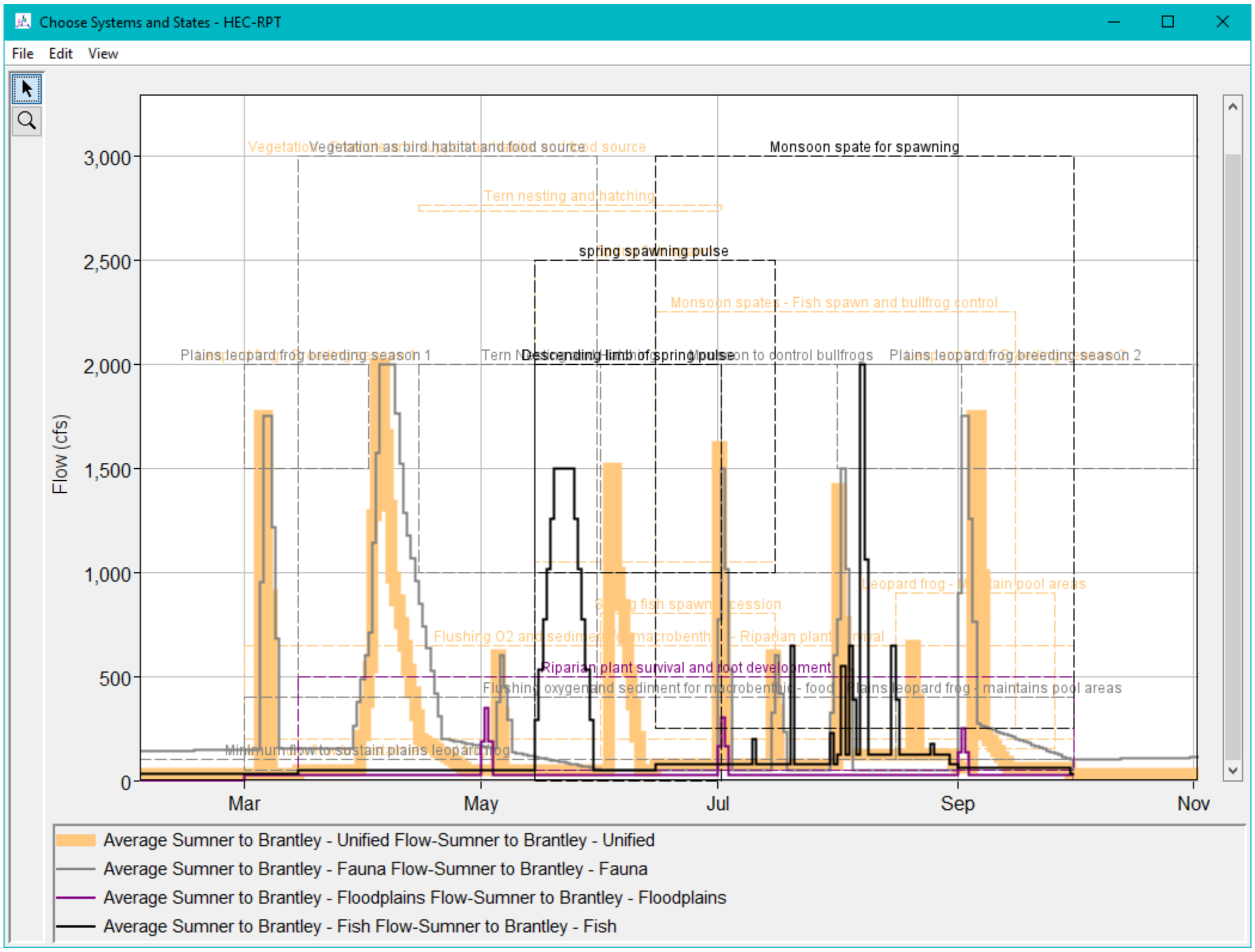


Figure 16. Unification of e-flows for average years, Sumner to Brantley (Reach C). Unified e-flows shown in orange.

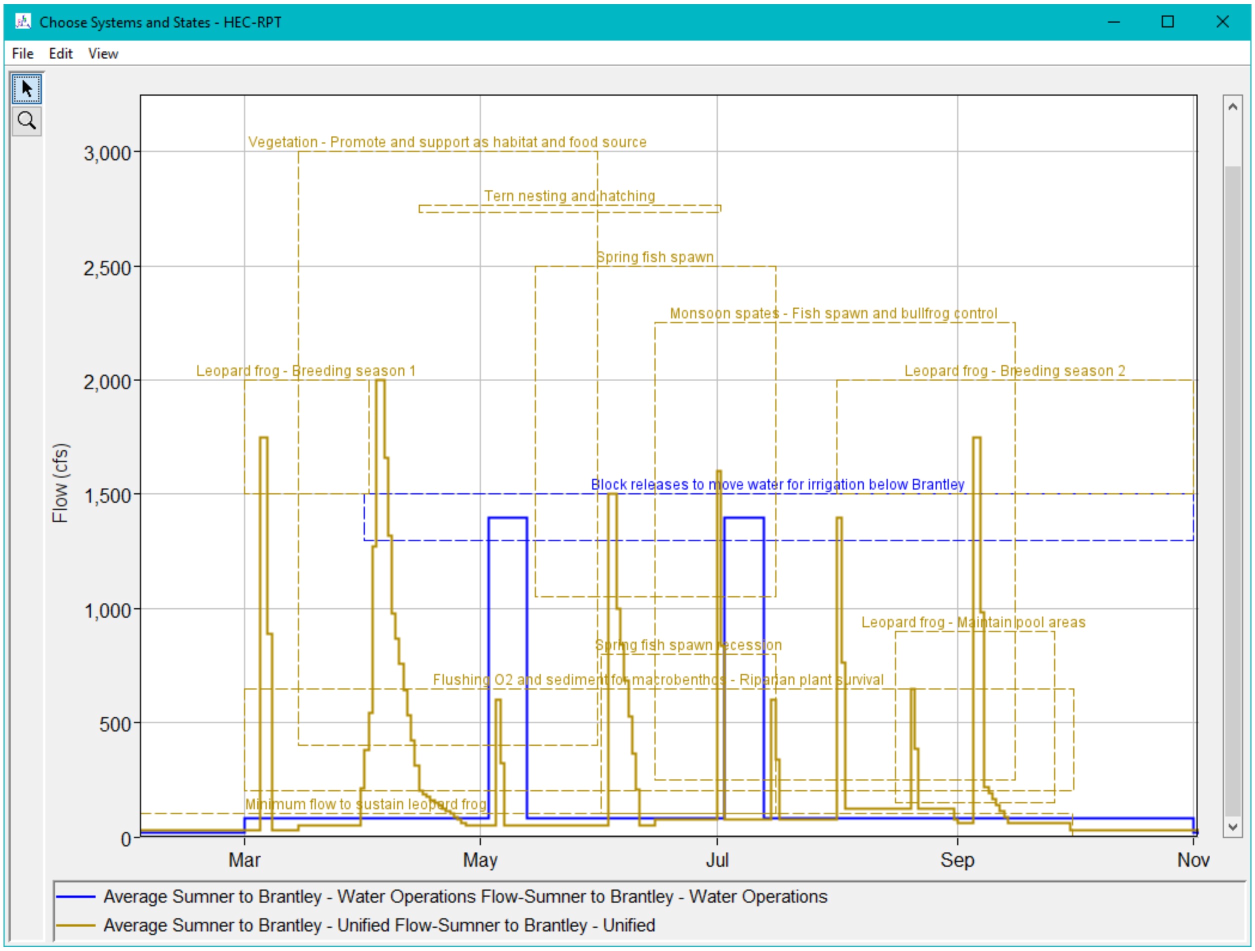


Figure 17. Unified e-flows (brown) and flows prescribed by the water operations group (blue), average years, Sumner to Brantley (Reach C). Unified e-flows are identical to the series shown in Figure 16 (orange).

4.3 Wet Years

Generally, the idealized hydrographs look similar to the dry and average years with higher and larger volume pulse releases. Tweaking the timing and magnitude of block releases in wet years to provide multiple benefits may be the most feasible way to adjust flows for environmental benefits.

Any flow pulses above 3,000 cfs would be considered a high-flow event, i.e., when managers need to start closely monitoring flows throughout the system. Although channel capacity ranges from 8,500 cfs up to 13,000 cfs, 3,000 cfs triggers monitoring, as flows at this level or above are generally in response to a rain event somewhere in the system. At this point, there is also the potential for more flow to be entering downstream.

For fish (as represented by the Pecos bluntnose shiner), block releases are the closest remaining analog to the pre-dam high flow dynamics that support spawning. Ideally, block releases would have more of a recession "tail". Multiple block releases have potential to benefit fish that do not spawn until mid-June.

For the riparian group, flood pulses designed to support cottonwood seed dispersal and recruitment needs to be timed early enough to catch cottonwood seed set, but potentially avoid the season of maximum tamarisk (salt cedar) seed dispersal, based on the observation from the Bill Williams and other sites that there is a window earlier in the season.

One hypothesized approach to unifying riparian and fish e-flow needs would be a double block release out of Santa Rosa during the early summer.

An interesting observation was that the target peak flow magnitudes hypothesized as necessary to mimic pulses for macrobenthic and oxygen rejuvenation, accomplish bullfrog control, etc., were often actually lower than the magnitude of the block releases. This indicates that there may be sufficient water in the system to support that ecosystem function.

Santa Rosa to Sumner (Reach B). The fauna and floodplains groups designed e-flows for Reach B. Specific changes to the e-flow recommendations of those groups during unification included: 1) unified low flows were a combination of fauna and floodplain group recommendations, 2) operational windows from the fauna group (cottonwood as bird habitat – seed recruitment) and the floodplains group (cottonwood recruitment) were similar and therefore merged into a single component called "Cottonwood - Seed dispersal and seedling recruitment for future habitat", and 3) a general thinning of pulses and associated recessions to align volumes with historical Pecos flows (Figures 18 and 19).

Sumner to Brantley (Reach C). The fish, fauna, and floodplains groups designed e-flows for Reach C. In addition to the changes mentioned for Reach B, the following changes were made during unification: 1) unified low flows were based primarily on fish group recommendations, 2) operational windows from the fish group (monsoon spate for spawning) and fauna group (monsoon to control bullfrogs) were similar and therefore merged into a single component called "Monsoon spates – Fish spawn and bullfrog control", and 3) the traced pulse for spring fish spawn was adjusted to shorten the rising limb and duration of peak (peak magnitude and recession limb were maintained) in order to reduce associated volume while maintaining the primary characteristics of that component (Figures 20 and 21).

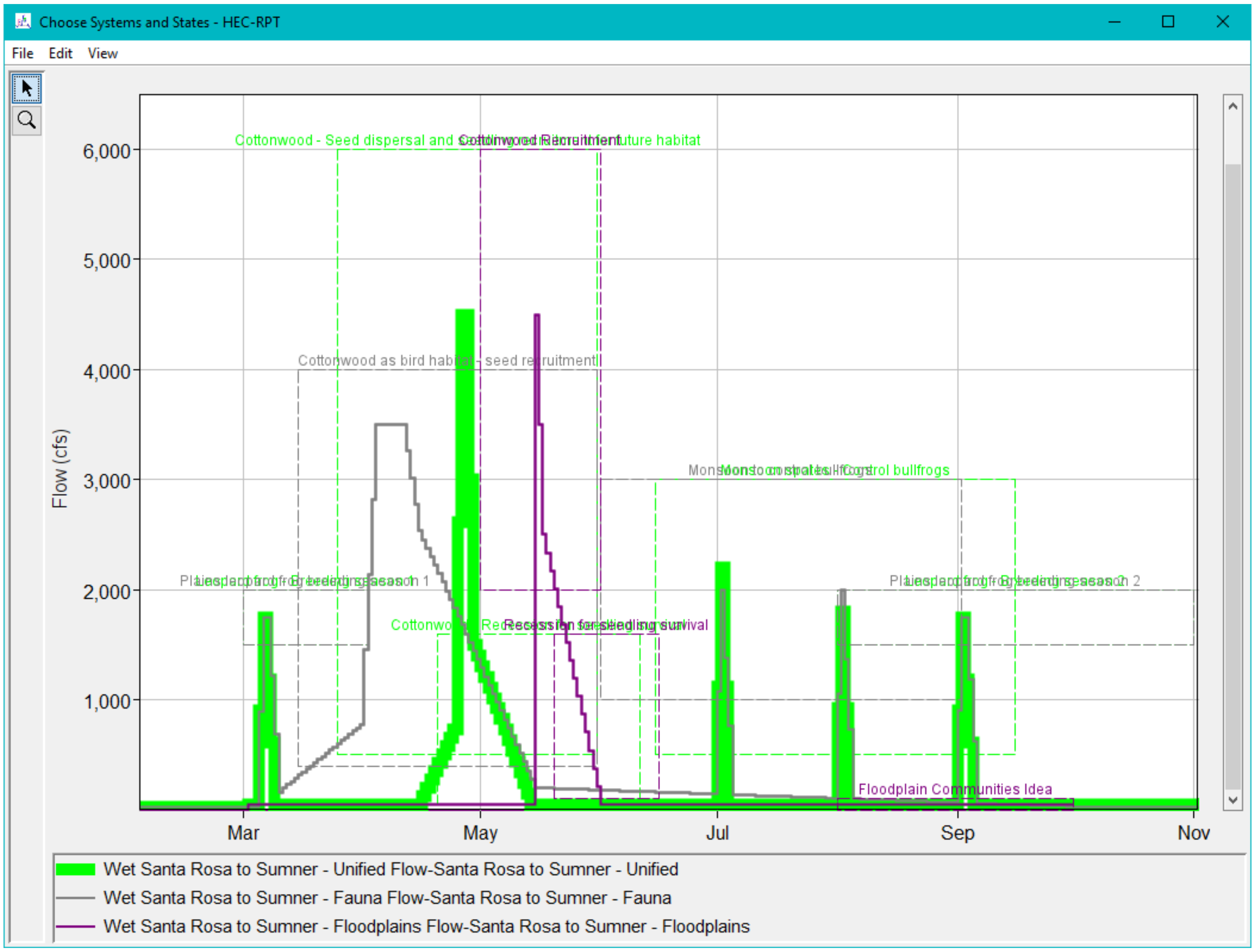


Figure 18. Unification of e-flows for wet years, Santa Rosa to Sumner (Reach B). Unified e-flows shown in green.

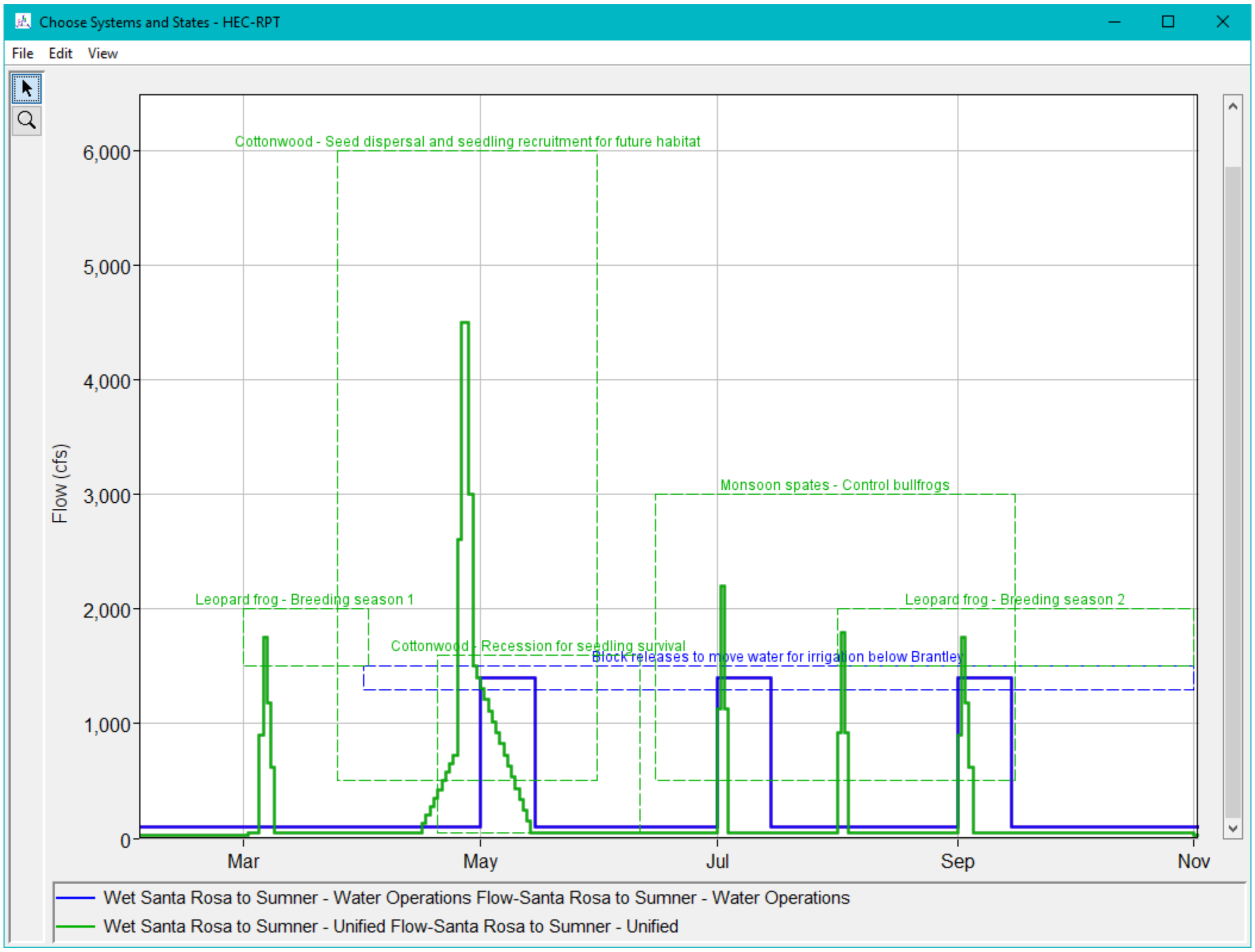


Figure 19. Unified e-flows (green) and flows prescribed by the water operations group (blue), wet years, Santa Rosa to Sumner (Reach B). Unified e-flows are identical to the series shown in Figure 14 (green).

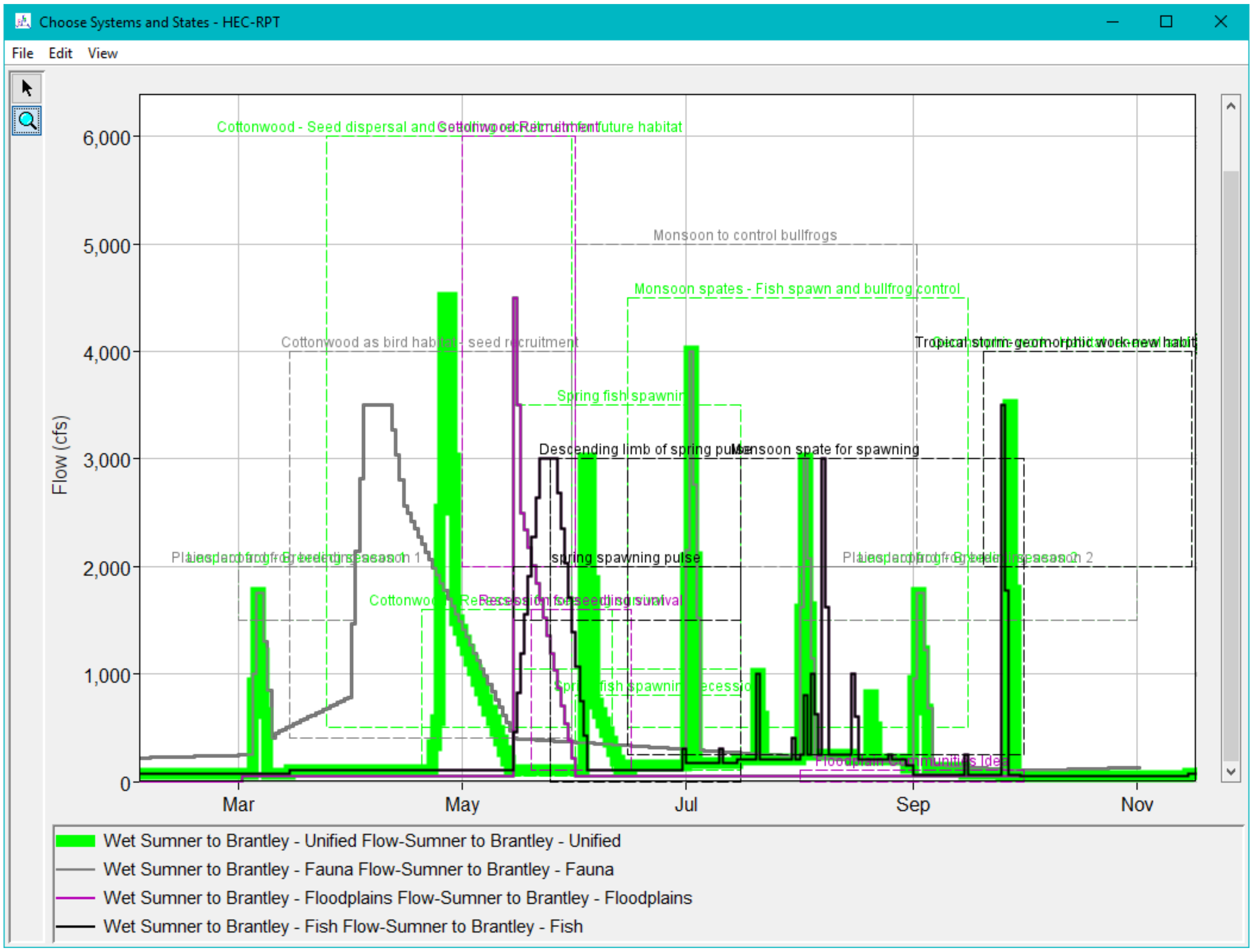


Figure 20. Unification of e-flows for wet years, Sumner to Brantley (Reach C). Unified e-flows shown in green.

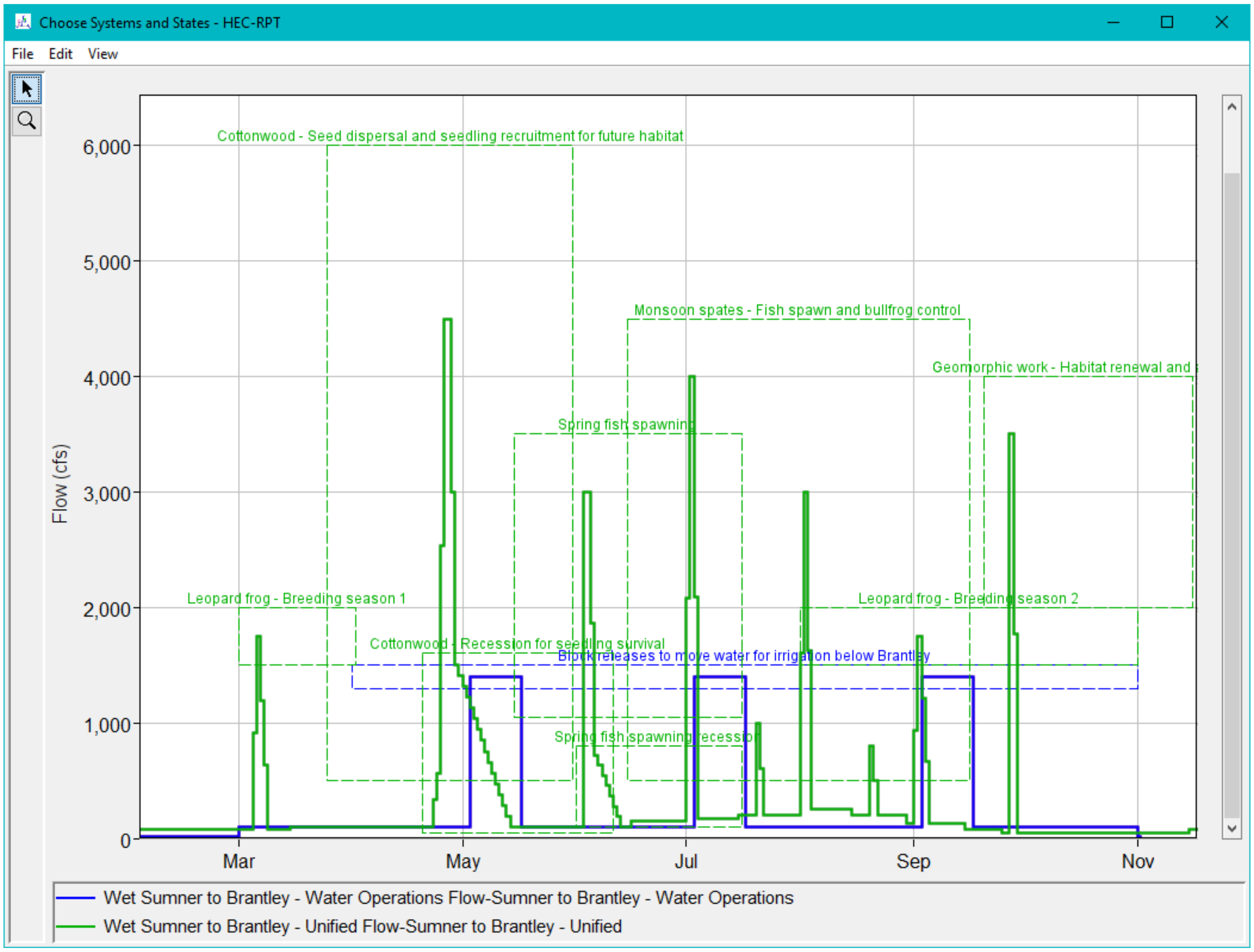


Figure 21. Unified e-flows (green) and flows prescribed by the water operations group (blue), wet years, Sumner to Brantley (Reach C). Unified e-flows are identical to the series shown in Figure 17 (green).

4.4 Discussion - Opportunities and Tradeoffs

Figures 17, 19, and 21 provide a visual comparison of unified e-flows and flows prescribed by the water operations group. The two sets of flows are quite different, which is not surprising. The two represent different paradigms – e-flows to provide water to sustain aquatic ecosystems and water operations to efficiently deliver water for use in irrigation lower in the basin – and both are worthy endeavors.

Overall and for all reaches and year types, unified e-flows are more variable with seasonal pulses of differing magnitudes, durations, and recessions shaped for specific ecological purposes. Low flows of the unified low flows are also more variable seasonally, though all are comparable to water operations low flows for all reaches and year types.

Interesting, even the highest dry year unified e-flow pulses are smaller in magnitude than the block release prescribed by the water operations group. This changes in average years as the highest unified e-flow pulses exceed but are comparable in magnitude to block releases. The highest wet year unified e-flow pulses are significantly higher in magnitude than block releases.

RPT was used to compare volumes of the Reach C unified e-flows and the flows prescribed by the water operations group to USGS gaged flows below Sumner Dam. Volumes of the two scenarios were comparable. Unified e-flows required less volume than water operations flows in dry years (~-20%), were nearly identical (volumetrically) in average years (~+10%), and required more volume than water operations flows in wet years (~+30%). The differences in volume are not especially important. Both sets of flows could be adjusted to minimize volumetric differences between the gage below Sumner without significantly altering the character of the flow recommendations (e.g., a block release could be 12 days instead of 14 if volume needed to be reduced). It is, however, a useful confirmation that both sets of flows are volumetrically-grounded based on past Pecos River gage records.

The timing and magnitude of block releases intersects with several e-flow components during average years. Operational windows for “Plains leopard frog breeding (seasons 1 and 2)”, “Vegetation - Promote and support as habitat and food source”, “Spring fish spawning”, and “Monsoon spates - Fish spawn and bullfrog control” all intersect with the operational window for “Block releases to move water for irrigation below Brantley” (Figure 17). Discounting bullfrog control, as block releases seem as or perhaps more likely to discourage bullfrog success than the associated average year e-flows, still leaves leopard frogs, vegetation, and fish spawning as potential points of discussion regarding whether block releases might be altered to produce more ecological benefits while still providing water for irrigation.

Figure 22 attempts to depict a simplified summary of Pecos River unified flow needs and operational windows from each of the breakout working groups. In general, there are opportunities in some years for block releases to provide some ecological flow needs, if conditions allow for block releases to be timed within the operational windows needed for fish spawning, amphibian breeding, or vegetation management. Minimum flows required for the endangered Pecos River shiner do help ensure a stable minimum amount of water in the channel, but smaller pulses and spates provided by inflows from the uncontrolled tributaries help sustain riparian plant communities, provide flushing flows for benthic habitats, and provide some beneficial flow variability. However, accomplishing overbank flows for cottonwood dispersal, geomorphic work and scour, and off-channel floodplain habitat maintenance, as well as allowing for a more gradual recession rate for fish spawning and recruitment, is generally viewed as in conflict with irrigator water needs. Additional analysis could help quantify how often historically there has been sufficient water in the system to accomplish different ecological flow objectives with small changes in timing or magnitude of releases.

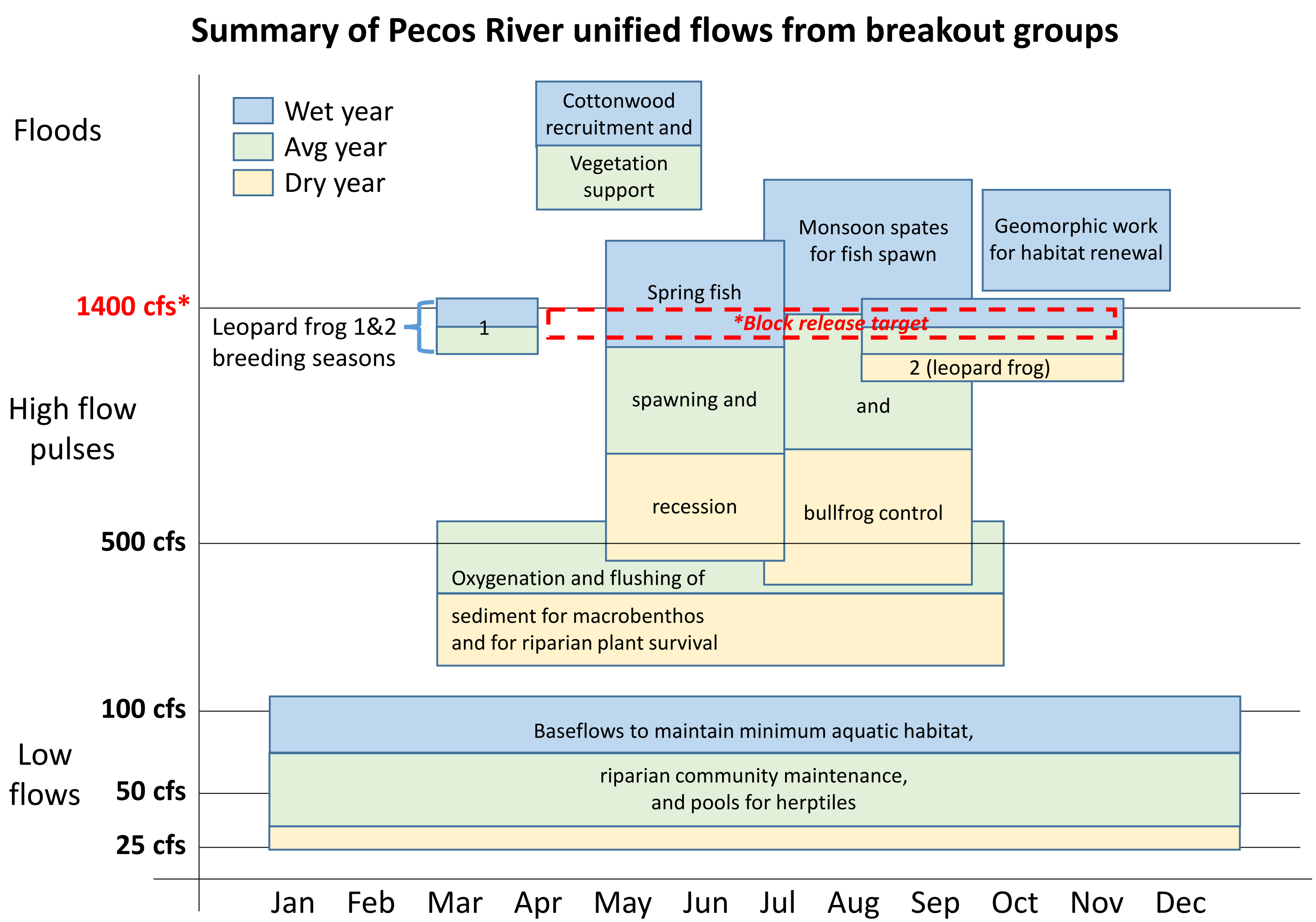


Figure 22. Simplified representation of Pecos River unified flow needs and operational windows from breakout groups.

5 Implementation and Monitoring Needs

In the final session of the workshop, participants attempted to summarize needs and opportunities based on the report out from the working group sessions and unified flow needs discussion. Several ideas were deemed potentially feasible in the short-term, primarily around opportunistic monitoring and adaptive management.

There was broad consensus, for example, that the highly variable monsoonal events that happen naturally under existing climate conditions create some potential for opportunistic adaptive management experiments. It should be possible to take advantage of natural variability in the timing of block flow releases, even under current operations, to evaluate various e-flow hypotheses by monitoring responses of native and nonnative species. For example, monitoring bullfrog population dynamics in response to block releases for 5-10 years could test the hypothesis that large flows help to reduce nonnative bullfrog recruitment by downstream displacement of bullfrog tadpoles, as well as shed light on the ideal timing and frequency of events.

Several participants acknowledged that additional analysis and modeling may be useful to refine and synthesize e-flow hypotheses and evaluate implications of recommendations and ideas proposed during the workshop. For example, additional synthesis of unified flow needs would be needed post workshop to assess compatibility of timing and magnitude of wet year flow pulses proposed by the different breakout groups. Further analysis would also be needed to explore the implications of the refined, unified flow prescriptions using the volume tracker. The historical flow record - both modified and unmodified - could be used to refine flow prescriptions based on actual water availability, as well as evaluate how often the historical record would have provided - even theoretically - the opportunity to experiment with specific proposed e-flows.

A combination of modeling and additional flow scenarios may help identify times of sufficient risk tolerance within the system to allow for experimentation with different size block releases, e.g., to move sediment or create flows that escape the channel. If it could be shown through monitoring and/or modeling that varying the size of block releases could accomplish some habitat benefits or nonnative species control, it is theoretically possible that benefits of an experimental flow releases could outweigh costs, factoring in ongoing routine maintenance costs that are currently built into the existing operational system, such as routine mowing of saltcedar.

Furthermore, because most operational decisions are based on reservoir storage, not channel flow, integrating storage conditions into the wet/average/dry framework may help refine e-flow hypotheses and feasible management actions based on antecedent storage in the system.

Better characterization of hydraulic conditions at a range of different flow magnitudes would provide the means to more accurately define flow thresholds for environmental flow processes (floodplain inundation, channel flushing). This could be determined (assuming it is not already known) by collecting aerial imagery of the entire channel during block releases. River trips could also help water managers better understand the river between road crossings, given difficult access throughout much of the river's course. Models based on high resolution topography could also be developed to explore inundation profiles at different block release magnitudes (e.g., HEC-RAS model) prior to actual experimentation.

Several participants noted that proposed operations to support e-flow needs - e.g., smaller pulses, ramping of block releases - would likely result in seepage losses relative to existing operations and conditions and that it would be very helpful to decision makers to be able to model those volume effects.

Finally, while hydrology has historically been the major driver of habitat, geomorphology, and life history adaptations, given current constraints and how significantly dams and water management have altered the system, there was discussion of how much potential there might be to make the system more hospitable for native plant species through earthwork for physical alteration and habitat manipulation, in conjunction with existing operations or possibly minor "tweaks" in operations.

5.1 Next Steps and Recommendations for Future Work

Following the workshop, ideas were consolidated into four follow-up proposals considered feasible in the short-term:

- Continue to build relationships in the basin between irrigation districts, water operators, state agencies, and federal agencies.
- Develop a white paper on e-flow needs for the Pecos Shiner that consolidates, evaluates, and synthesizes recommendations and potential opportunities based on the Literature review and the workshop.
- Develop a 5-10 year monitoring plan (white paper) for control of invasive bullfrogs based on monitoring response to block flow releases.
- Development of a conceptual model to determine key physical, chemical, or biological processes that are impacted by the block releases.

APPENDIX A - E-Flows Workshop Agenda and Attendees

E-Flows workshop agenda and attendees for the Water Operations and E-Flows workshops.

Pecos River, Sustainable Rivers Program
Environmental Flows Workshop Agenda

19 July 2022 – 0900-1600
20 July 2022 – 0900-1500

Virtual Meeting Space:
https://usace1.webex.com/usace1/j.php?MTID=m5822c6e984a495343b811eb4d953b438

Join by phone
+1-844-800-2712 US Toll Free; Access code: 2762 676 5059

19 July 2022, 0900 - 1600

0900	Welcome & Introductions	
0935	Review of SRP Process & Discussion of Meeting Outcomes	
0950	Overview of Pecos Operations	
1015	Hydrologic Analysis & Flow/Ecology Relationships as Background for Developing Environmental Flow Recommendations	
1045	BREAK (15 min)	
1100	Case Study – Bill Williams SRP	
1120	Overview of Regime Prescription Tool Software (*Software to be used in working groups*)	
1140	Water Operations / Irrigation RPT Example	
1200	LUNCH BREAK (1 Hour)	
1300	Instructions for Breakout Groups	
1315	Breakout Groups (15 min break at 1430)	Fish
		Floodplain Riparian Vegetation
		Birds, Reptiles, Amphibians
1550	Rejoin in Main Room – Review Tasks for Next Day, Discuss any Issues	
1600	Close Day 1	

20 July 2022, 0900 - 1500

0900	Welcome	
0905	Future Conditions	
0920	Breakout Groups (15 min Break at 1030)	Fish
		Floodplain Riparian Vegetation
		Birds, Reptiles, Amphibians
1200	Lunch (30 min)	
1230	Fish Present Findings	
1250	Floodplain Riparian Vegetation Present Findings	
1310	Birds, Reptiles, Amphibians Present Findings	
1330	Unification of Ecological Flow Recommendations	
1450	Conclusion & Parting Discussion	
1500	Close Day 2	

Pecos SRP E-Flows Workshop Attendance

Water Operators Meeting -- 13 July 2022

Name	Organization
Aron Balok	PVACD
Aubrey Harris	USACE
Coley Burgess	CID
Carlos Aragon	USACE
Carolyn Donnelly	USBR
Dagmar Llewellyn	USBR
Danielle Galloway	USACE
Frank Scott	NMISC (Interstate Stream Commission)
Jim Howe	TNC
John Hickey	USACE
Justin Reale	USACE
Kelli Goodpasture	PVACD
Kristen Blann	TNC
Mark Doles	USACE
Nabil Shafike	USACE
Rick Young	USBR
Ryan Gronewold	USACE
Sarah Moore	USACE
Wade Holdeman	FSID

E-Flows Workshop -- 19 July 2022

Name	Organization
Alec Norman	NM (Office of the State Engineer)
Aron Balok	PVACD
Aubrey Harris	USACE
Betsy Summers	USACE
Coley Burgess	CID
Carlos Aragon	USACE
Carolyn Donnelly	USBR
Coley Burgess	CID
Dagmar Llewellyn	USBR
Dale Turner	TNC, retired
Danielle Galloway	USACE
Enrique Prunes	WWF (World Wildlife Fund)
Frank Scott	NMISC
Jane Rogosch	USGS
Jim Howe	TNC
John Hickey	USACE
Justin Reale	USACE
Katie Sandbom	USFWS
Kelli Goodpasture	PVACD

Kristen Blann	TNC
Lisa Henne	NM (State Land Office)
Logan Huse	USACE
Mark Doles	USACE
Mark Horner	USFWS
Martha Schumann Cooper	TNC
Mick Porter	USACE
Nabil Shafike	USACE
Nate Clifton	USBR
Rick Young	USBR
Rico Blea	NMISC
Ryan Gronewold	USACE
Ryan Smith	TNC
Sara Goldstein	NMISC
Sarah Moore	USACE
Wade Holdeman	FSID
Eric Gonzales	USBR
Stephen Davenport	USFWS

E-Flows Workshop -- 20 July 2022

Name	**Organization**
Alec Norman	NM (Office of the State Engineer)
Aron Balok	PVACD
Aubrey Harris	USACE
Betsy Summers	USACE
Carlos Aragon	USACE
Carolyn Donnelly	USBR
Coley Burgess	CID
Dagmar Llewellyn	USBR
Dale Turner	TNC, retired
Wade Holdeman	FSID
Frank Scott	NMISC
Jane Rogosch	USGS
Jim Howe	TNC
John Hickey	USACE
Justin Reale	USACE
Katie Sandbom	USFWS
Kelli Goodpasture	PVACD
Kristen Blann	TNC
Lisa Henne	NM (State Land Office)
Logan Huse	USACE
Mark Doles	USACE
Mark Horner	USFWS
Martha Schumann Cooper	TNC
Mick Porter	USACE
Nate Clifton	USBR
Rick Young	USBR
Rico Blea	NMISC
Ryan Gronewold	USACE
Ryan Smith	TNC
Sarah Moore	USACE
Eric Gonzales	USBR
Stephen Davenport	USFWS

APPENDIX B - Regime Prescription Tool Datasheet

Definition of RPT "systems" (geographical and ecological focus areas) and "states" (hydrologic condition) creates a framework for formulating flow recommendations. For workshop and RPT purposes, the Pecos River was divided into reaches or segments based on dam locations (Table A1; Figure A1).

Table A1. Reach labels, locations, lengths, and slopes for the Pecos River.

Reach	Location	Length	Slope
A	Headwaters of Pecos to Santa Rosa Dam	144 miles	0.5%
B	Santa Rosa Dam to Sumner Dam	54.5 miles	0.1%
C	Sumner Dam to Brantley Dam	220 miles	0.08%

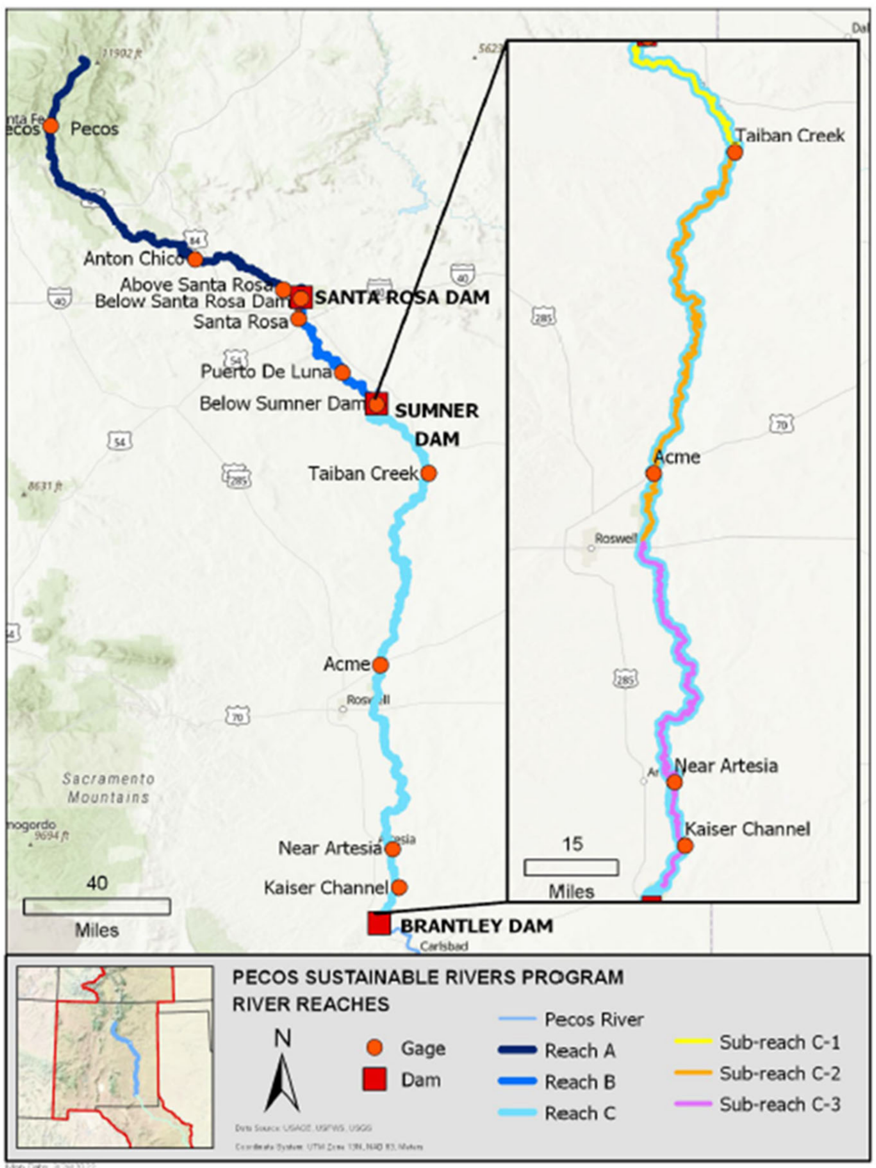


Figure A1. Map of the study area, subreaches, and gages (Moore et al. 2022, as in Figure 2).

Systems are geographical areas (Reaches A, B, C) AND ecological areas of interest. Breakout Groups will be working together to discuss environmental flows for the system.

For ease of unification between Breakout Groups, preset Systems have been defined in the bullet list below. If the Breakout Group so chooses, Reaches A-C can be "duplicated" to create more systems.

- Reach A: (Headwaters of) Pecos to Santa Rosa
- Reach B: Santa Rosa to Sumner Dam
- Reach B: Santa Rosa to Sumner Dam – Water Operations
- Reach C: Sumner to Brantley Dam
- Reach C: Sumner to Brantley Dam -- Fauna (Birds, Reptiles, Amphibians)
- Reach C: Sumner to Brantley Dam -- Fish
- Reach C: Sumner to Brantley Dam – Floodplain (including Riparian Vegetation)
- Reach C: Sumner to Brantley Dam – Water Operations

In addition, for information purposes, historical data of reservoir storage from the three dams are presented in the system named **"Reservoir Storage".** *Be aware that the units of these data are "acre-feet", not "cfs". The data is misrepresented as "flow" as required to be visualized in RPT.*

States reflect hydrographic conditions. Some years are "Dry" or "Wet", and this affects environmental flows for the systems. A period of 1980 to 2020 were segmented as different States. Breakout groups will develop environmental flows for each state for each system.

- **Dry**: Defined from flow at Acme and Anton Chico gages. Since a record of "Critically Dry" determination was not available at the time of the workshop, dry years were selected based on hydrology that reflects water operations actions when a critically dry condition is condition. For purposes of the e-flows workshop, this was focused during the spring/early growing season. For Acme: Reflects USBR actions during critically dry[5] conditions with some buffer (<10 cfs) during the April-June. Computed based on median flow for two time periods (April-May and June). The years designated as dry also were the first Quartile (driest years from 1980-2020) of annual summed flow for Anton Chico Gage.
- **Average**: Defined from Acme gage and Anton Chico Gage. Does not meet the "Wet" or "Dry" state definition.
- **Wet**: Defined from flow at Acme gage and Anton Chico Gage. For Acme: Greater than 100k acre-feet annual flow volume. Computed by summing the daily average discharge x86400 s/day, then converted from cubic feet to acre feet. The years designated as wet were also fourth Quartile (wettest years from 1980-2020) of annual summed flow for Anton Chico Gage.

[5] The 2016 Biological Opinion for the Bluntnose Shiner has two environmental determinations, Critically Dry and Normal, made monthly from January to June. The January determination is based on the drought classification for the Pecos Basin, D3 and D4 drought classification > 50% of the Basin is Critically Dry; < 50% is determined to be Normal. February through May is based on the NRCS snowmelt runoff forecast at the Above Santa Rosa gage compared to the 30-year average; the June determination is the percentage of time Bypass is available from 15 February to 30 June and that determination sets the conditions for the rest of the year.

<u>USGS Gage data</u> is provided in the RPT to help develop environmental flows (Table A2). The flow volumes at these gages can be compared to the environmental flows in order to determine what flows are achievable or realistic.

Table A2. USGS gages and their corresponding analysis reaches available in RPT.

Pecos River Gages	USGS Number	Start of Record	Analysis Reach	Drainage Area
Near Pecos, NM	08378500	10/1/1919	A	189 mi^2
Near Anton Chico, NM	08379500	10/1/1910	A	1050 mi^2
Above Santa Rosa Lake	08382650	10/1/1990	A	2,340 mi^2
Below Santa Rosa Dam	08382830	1/17/1980	B	2,430 mi^2
Santa Rosa, NM	08383000	10/1/1912	B	"same as above"
Near Puerto de Luna, NM	08383500	5/1/1938	B	3,970 mi^2
Below Sumner Dam, NM	08384500	10/1/1912	C	4,390 mi^2
Near Fort Sumner, NM	08385500	10/1/1994	C	4,949 mi^2
Below Taiban Creek	088385522	8/12/1992	C	5,908 mi^2
Near Acme, NM	08386000	7/1/1937	C	11,380 mi^2
Near Artesia, NM	08396500	10/1/1905	C	15,300 mi^2

In addition to historical river gages, a "natural flows" dataset was created for Reaches B and C. This "natural flows" dataset is based on the unregulated Anton Chico gage. The daily flow from Anton Chico is multiplied based on Mean Annual Flow ratios from downstream gages from the beginning of the period of record to 1959. This range was selected as it provides at least 20 years of data and is assumed to be the period of least diversion/regulation relative to the entire period of record. Only (1) "natural flow" was computed for each reach (Table A3).

Table A3. Analysis of Mean Annual Flow (MAF) for gages in reaches A-C that was used to create a "natural flow" hydrograph in RPT. Ref = Reference, WY = Water Year

Pecos River Gages	MAF (entire period of record)	# of yrs from beginning to WY1959	MAF (beginning-WY1959)	MAF Ratio (River Gage: Ref Gage)
Near Anton Chico, NM	106.5	35	114	-- Reference gage--
Near Puerto de Luna, NM	168.5	21	166.7	1.5
Near Artesia, NM	197.3	53	292.9	2.6

These "natural flows" are named as following in their respective reaches for use in RPT:

- Reach B: Santa Rosa to Sumner Dam – Mod_Puerto de Luna USGS_Antonx1.5 Flow
- Reach C: Sumner to Brantley Dam—Mod_Artesia USGS_Antonx2.6 Flow

APPENDIX C - Mural Boards used in Virtual Workshop

Workshop attendees were encouraged to take notes on real-time whiteboards. The platform used was Mural^{TM}. The associated weblink is:

https://app.mural.co/t/cbd20learning5057/m/cbd20learning5057/1657911514395/2729f6b579349c334229c9971e6b54f9909c2a14?sender=5d3162d6-6a03-4f6e-acee-847cb53c7e06

Draft whiteboards were created for each of the ecological breakout groups. Whiteboards were designed as a virtual collaborative space for groups to formulate and refine e-flow recommendations. Each group used the whiteboards differently. Images for whiteboard content are provided for each breakout group (Figures B1 to B3).

Figure B1. Virtual whiteboard notes of the Fish group.

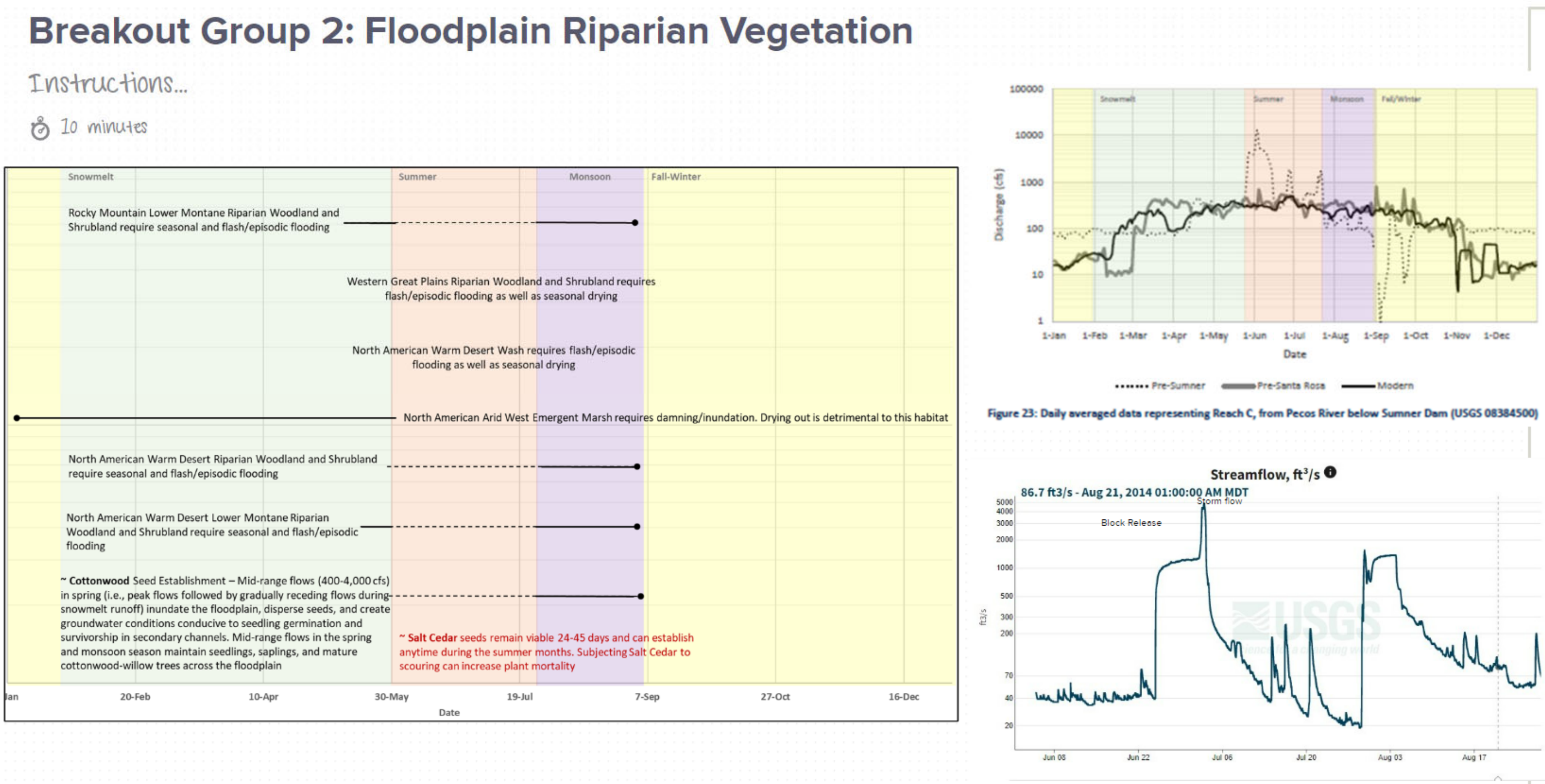


Figure B2. Virtual whiteboard notes of the Riparian group.

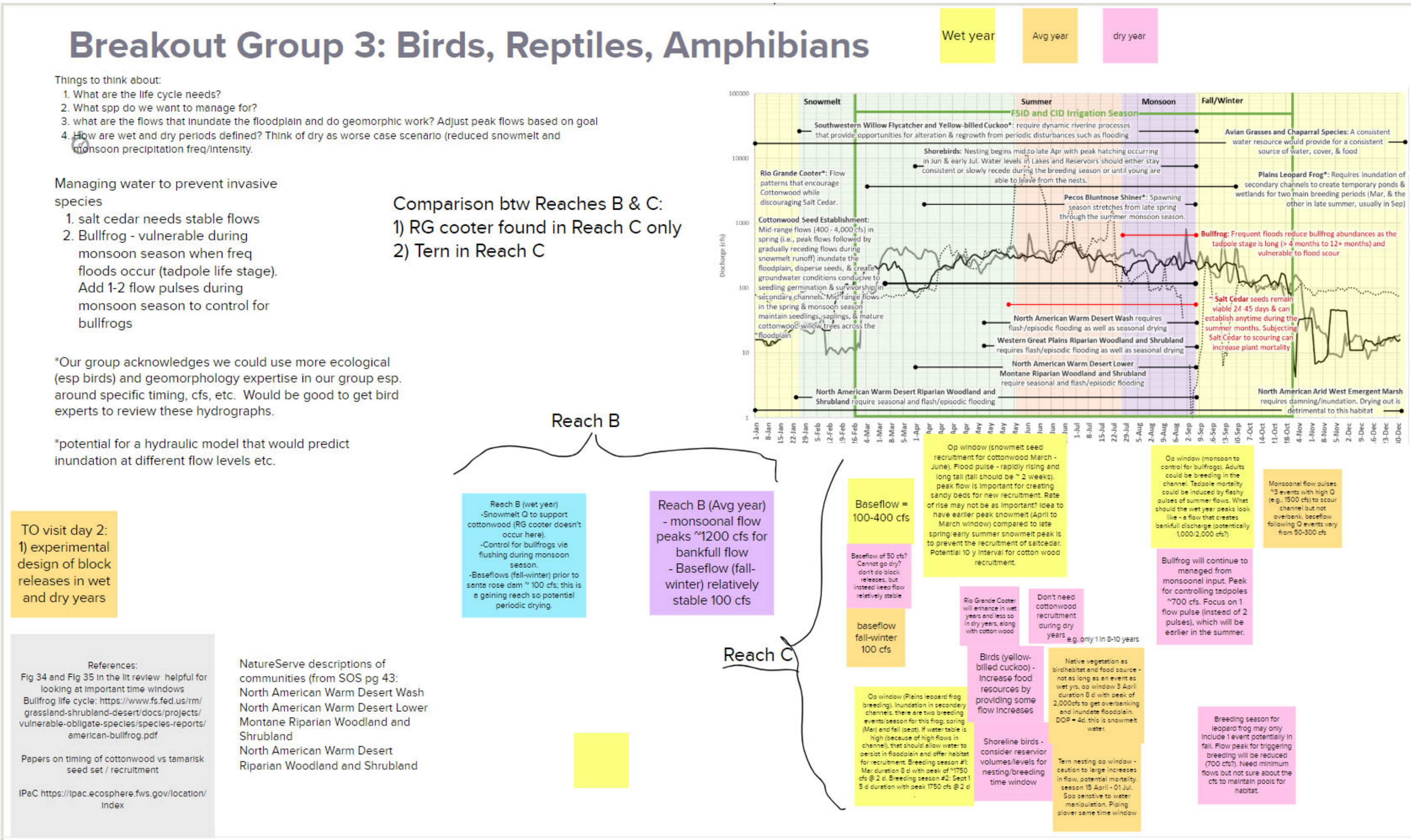


Figure B3. Virtual whiteboard notes of the Birds, Reptiles, and Amphibians group.