Climate Change impacts on the San Juan River and native fish management

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Introduction

The San Juan River (SJR) is a major tributary of the Colorado River and is a crucial source of water for a variety of uses including industry, hydropower, agriculture, drinking water, and native species (BOR, 2012; Bennett et al. 2019). It is a lifeline in a desert that is particularly essential for many unique native flora and fauna including several endemic fish species found nowhere else in the world (Prost and Gido, 2004). Sustaining these native species populations contributes to ecosystem resilience and protects ecosystem services (Thompson et al. 2021). Unfortunately, the impact of climate change will make the management of water and native species in the San Juan River increasingly challenging and management strategies will need to be adapted to these new environmental conditions. The goal of this paper is to review the impacts of climate change on the SJR and then examine how strategies used in the Navajo dam case study could be applied to SJR native fish management in a changing climate.

Current and future impacts of climate change in the San Juan River

Climate change has already and will continue to impact stream flow in the San Juan River through several different avenues including changes in air temperature, drought frequency, vegetation, river baseflow, and snowmelt. The SJR originates as snowmelt in the San Juan Mountains of Colorado and flows for 383 miles through northern New Mexico and southeastern Utah until it eventually joints the Colorado River at Glen Canyon in Arizona, and it accounts for 15% of steam flow and 22% of area of the Upper Colorado River Basin (UCRB) (Bennett et al. 2018). I will present relevant climate projection studies that were performed at a variety of scales including the Western U.S. states (Colorado, Arizona, Utah, New Mexico, California, Oregon, Washington, Idaho, Montana, and Wyoming), the Colorado River Basin (encompasses parts of Wyoming, Utah, Arizona, New Mexico, Colorado, and California), and the San Juan River Basin.

Air temperature

Air temperature in the UCRB has increased 1.4ºC from 1913-2017 (Figure 1) and models from the Bureau of Reclamation in 2016 predict it will continue to increase (Figure 2) (Milly and Dunne, 2020; BOR, 2016). Studies by both Udall and Overpeck (2017) and Milly and Dunne (2020) link a decrease of 19% in CO River flow to these rising temperatures and it is predicted that as air temperature continues to increase there will be a decline in river flow ranging from 11 – 55% by the end of the century. While precipitation predictions are highly uncertain (Figure 2), researchers expect that even a modest increase in precipitation will not be sufficient to offset the temperature-driven declines in flow (BOR, 2016; Udall and Overpeck, 2017).

Drought

Rising air temperatures also result in increased evapotranspiration, leading to less soil moisture and less surface water and increasing the likelihood and severity of drought. The Udall and Overpeck 2017 found that the 2000-2014 southwest drought was the worst on record and the U.S (Figure 3). drought monitor shows that as of May 2022 the West is still experiencing severe to exceptional drought (the worst category). Unfortunately, a 2021 study by Cook and others found that drought occurrence is also predicted to increase. The study predicted the occurrence of single- year droughts would increase 7% under low emission scenarios and 25% under high emissions as well as 21-year megadroughts increasing almost 50% under low emissions and 53% under high emissions (Cook et al. 2021). These results indicate that if we can lower greenhouse gas emissions the occurrence of single year droughts may remain relatively low, but we are potentially locked in to an almost 50% increase in megadroughts in the West.

Vegetation

Forests contribute to improving water quality and regulating water supply for rivers. While the San Juan River Basin is only about 17% forested, the loss of this vegetation type which is predicted from higher rates of wildfire and drought, could negatively impact stream flow and water quality. Bennett and others (2018) found that modeling stream flow under coupled climate-forest disturbance scenarios resulted in 6-11% lower flow projections than climate change alone (Figure 4).

Baseflow

Baseflow is estimated to contribute over 50% of total streamflow in the UCRB and has many essentially functions in the river including maintaining surface water during non-runoff periods, providing cold water essential for some aquatic species, and delivering dissolved solids (Miller et al. 2021). Miller and others modeled how baseflow will change under three different climate scenarios (warm/wet, median, and hot/dry) in 2030, 2050, and 2080. The researchers found even under the warm/wet scenario where precipitation increases across the basin, baseflow for the UCRB outlet will decline by 2080 (Figure 5). They also found that increased evapotranspiration will lead to in-stream baseflow transport decreases of 1-5%.

Snowmelt

The UCRB and the San Juan River both rely on snowmelt from western mountain slopes to deliver much needed summer run-off from May-July. As of May 2022, the Westwide SNOTEL snow water equivalent tool showed many parts of the Southwest below 50% of their normal snowpack (USDA). Climate driven increases in air temperature will result in more precipitation falling as rain instead of snow, ultimately reducing the snowpack and resulting in decreased albedo effect as well as runoff earlier in the season and a decrease in critical summer flows (Figure 2, BOR, 2016; Milly and Dunne 2020).

Navajo dam as a case study for native fish management adaptation to climate change

Many of the climate impacts described above will change the amount and timing of stream flow in the San Juan River. These changes to the flow regime will be especially detrimental to native fish in the San Juan that are uniquely adapted to the natural flow and thermal regime. Natural resource managers tasked with managing these fish populations are consequently very interested in finding ways to adapt management to climate change. The operation of Navajo dam is one particularly interesting case study of how managers adapted to anthropogenically caused changes in the San Juan River flow regime and how they may do so again in the context of climate change.

San Juan River native fish habitat requirements and Navajo dam impacts

There are two native endangered species in the San Juan river, the Colorado Pikeminnow (Ptychocheilus Lucius), and the Razorback Sucker (Xyrauchen texanus). Authors of the 2020 USFWS Colorado pikeminnow assessment report looked at both spring peak flow and baseflow requirements for different life stages of the Colorado pikeminnow (USFWS 2020). Naturally occurring spring peak flows function to scour out cobble spawning bars where Colorado pikeminnow can lay their eggs in the interstitial spaces. Once the eggs hatch, larvae are then dependent on nursey habitats which are also created by peak flows which scour the channel and remove vegetation, forming backwater habitats that larvae prefer. After spring peak flows subside, baseflows then maintain these backwater habitats through the summer as well as provide riverine habitat with sufficient depth for adult Colorado pikeminnow to move between foraging and spawning areas. A 2018 report by USFWS summarized some similarities in habitat requirements for Razorback suckers such as their reliance on low velocity habitats like backwaters, floodplains, and river pools. While Razorback suckers were also found to prefer cobble substrate for spawning, they have been observed using their bodies to clear sediment from cobble when conditions are not ideal and are therefore less reliant on high spring flows for successful spawning (USFWS, 2018a).

Construction of Navajo dam was completed in 1963 and it significantly altered the natural flow regime of the San Juan River by reducing spring peak flows by 46% and increasing mean base flows in the summer through winter by 168% (Holden 1999). These changes to the natural flow regime result in several impacts to the Colorado pikeminnow and Razorback sucker. As previously mentioned, peak flow reduction will not allow for scouring of the cobble spawning bar and while Razorback suckers can cope with this, Colorado pikeminnow eggs can be more easily washed away or predated on, lowering the reproductive success of Colorado pikeminnows. Additionally, without peak flows to scour river channels and control vegetation there are less backwaters and nursery habitats which reduces the survival of larvae and Razorback suckers. An increase in base flows can also have negative effects such as inundating backwaters and increasing their velocity which negatively effects both fish that rely on these habitats. While base flows have increased in some areas of the mainstem they have also decreased in some tributaries leading in some cases to dewatering. Dewater of tributaries shrinks habitats for all life stages of both endangered fish and favors non-native fish such as bass that both prey on the natives and compete for resources (USFWS 2020).

Native fish assessment and flow mimicking

While there is evidence the Colorado pikeminnow and Razorback sucker were present in the San Juan River there were no formal surveys conducted until 1978. This study was conducted by the USFWS along with the New Mexico Fish and Game and Utah Department of Wildlife Resources over three years and found both species still present in the San Juan River at reduced numbers. These finding prompted requirements from the Endangered Species Act that resulted in a 1991 agreement from BOR to reoperate Navajo dam and fund seven years of research on the effects of flow changes that would benefit these endangered species. To carry out this study the San Juan River Basin Implementation Program (SJRIP) was formed of state, federal, and tribal groups with the goal of recovering the listed Colorado pikeminnow and Razorback sucker while continuing to manage current and future water projections.

The SJRBIP lead by Holden and others in 1999 compiled a report on flow recommendations for the San Juan River based on a seven-year research project to determine fish and habitat response to a mimicked natural flow regime. While both fish require a variety of complex habitats the two key components Holden and others focused on for this study were cobble bars and backwaters. As previously discussed, cobble bars are important for both species as spawning grounds and the study found that Colorado pikeminnow in San Juan have high spawn site fidelity to an area of "clean" (low sediment in between the cobbles) bars called "the Mixer" (Figure 3). Additionally, the study found Colorado pikeminnow in backwater 60% of the time, highlighting their importance as habitat. The study therefore focused on assessing what flows were needed to build and maintain cobble bars and backwaters and it found that relatively high flows were needed to build and clean these habitats, but that lower flows at the right time of year were needed to make them more abundant (Holden et al. 1999). The study also found that during high flow year the abundance of Colorado pikeminnow, as well as the native bluehead sucker and speckled dace increased, corroborating the need for high flows. Propst and Gido conducted a similar study in 2004 to assess the response of native and nonnative fishes to natural flow regime mimicry in the San Juan. The authors compared the autumn densities of these fish in San Juan secondary channels to those during spring runoff and summer base flow over a nine-year period and found that total native fish density was 10 times greater in 1993 (a high low year) compared to 2000 (a low flow year). However, both Holden et al. 1999 and Propst and Gido 2004 found that non-native fish were not particularly negatively affected by the mimicked flow regime, and it therefore may not be an effective method for controlling their populations. A generic hydrologic model called RiverWare was used to develop the flow recommendation by simulating the flow at various gages over the past, present, and future from 1929 to 1993 and the flow recommendation results are summarized in Table 1.

When the study began no Razorback suckers were present in the San Juan and there were fewer than 100 Colorado pikeminnow (Holden et al. 1999). Response of native Colorado pikeminnow and Razorback suckers to research flows were therefore too small to measure. However, to compensate for the low native population size researchers stocked juvenile fish of both species from conservation hatcheries. Researchers were able to observe the effects of flow changes on these stocked fish and found that survival of stocked young of year Colorado pikeminnow and stocked juvenile/subadult Razorback sucker were high, which is particularly impressive given their failed survival in other parts of the CO River (Masslich and Holden 1996). These results indicate that research flows were effective in creating needed habitat for these species. Additionally, a small subset of Colorado pikeminnow were tagged with radio-telemetry to collect habitat usage data which identified use of newly created cobble bars for spawning (Holden et al. 1999).

Adaptive management and climate change

Science is constantly evolving. When the Navajo Dam was build in 1963 researchers were focused on identifying and maintaining minimum flows to sustain target fish populations. However, by 1999 research had emerged on the importance of natural variable flow regimes with both base and peak flow events (Arthington et al. 2015) and Holden and his team attempted to adapt the management of endangered fish to incorporate this new strategy. The 1999 report explicitly addressed the importance of adaptive management, the concept that managers should set a project goal, study the best way to achieve that goal, assess the immediate success of the project in meeting the goal, and then continually to monitor the project to ensure it continues to achieve their goals as conditions and circumstances change (Derepasko et al. 2021). Holden and his team suggested that continued monitoring of both the fish populations and water availability in the San Juan River would be key to ensuring the long-term effectiveness of the flow regime program. As climate change continues to impact the way we manage water and fish populations (Palmer et al. 2009; John et al. 2021), adaptive management will be key to ensuring effective management.

Following the adaptive management model, in 2018 the Bureau of Reclamation (BOR) called for a modification to the original Holden 1999 flow release plan. The BOR expressed concern that they were frequently unable to meet the higher flow requirements given increasing water shortages caused by increased demand and decreased supply due to climate change. The San Juan River Basin Recovery Implementation Program (SJRIP) held several meetings to reassess the flow release plan and found that short-duration high flow were not very effective in creating habitat benefits to native fish and therefore the original high flow requirements should be kept in place but only when there was enough water for the entire duration of the high flow (Figure 7). These changes also included assessing water availability at the end of year water and ceasing the spring release of 5,000 cfc with durations less than 21 days to ensure there was enough water for future longer duration high flow (USFWS, 2018b).

Conclusion

As climate change continues to impact the West, all water users will experience differences in the timing and availability of water in the San Juan River Basin. Changes to water availability and the timing of flows will be especially difficult for native flora and fauna, including the endangered Colorado pikeminnow and Razorback sucker, to adapt to. To protect the unique and important biodiversity of the San Juan River, people will need to both mitigate climate change impacts and adapt to them. While adaptation can take many forms, it has been shown that following an adaptive water management framework can allow managers to constantly revaluate and improve water and native fish management strategies based on changing environmental conditions (Thompson et al. 2021).

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Category	Duration	Frequency	Purpose
Flows > 10,000 cfs during runoff period	Minimum 5 days A between March 1 and July 31	20% of the years on average	Provide out-of-bank flow, generate new cobble sources, change channel configuration and provide nutrients
Flow > 8,000 cfs during runoff period	Minimum of 10 days between March 1 and July 31	33% of the years on average	Bankfull discharge to maintain channel cross-section, provide sufficient stream energy to move cobble and build cobble bars
Flow > 5,000 cfs during runoff period	Minimum of 21 days between March 1 and July 31	50% of the years on average	Clean backwaters and maintain low-velocity habitat in secondary channels maximizing nursery habitat.
Flow >2,500 cfs during runoff period	Minimum of 10 days between March 1 and July 31	80% of the years on average	Cause cobble movement in higher gradient areas on spawning bars, provide sufficient movement to produce clean cobble, provide sufficient peak flow to trigger spawning in Colorado pikeminnow
Target Base flow 500 cfs from Farmington to Lake Powell, 250 cfs min from Navajo Dam	Mean weekly nonspring runoff flow		Maintaining, low stable base flows enhance nursery habitat, optimize backwater habitat
Flood control releases	Spikes in precipitation from 1,000 to 5,000 cfs		Flood control releases were made by increasing fall and winter base flows, periodic clean-water spike flows improve low-velocity habitat quality by flushing sediment and may suppress red shiner and fathead minnow abundance

Table 1. Summary of flow recommends from Holden et al. 1999.

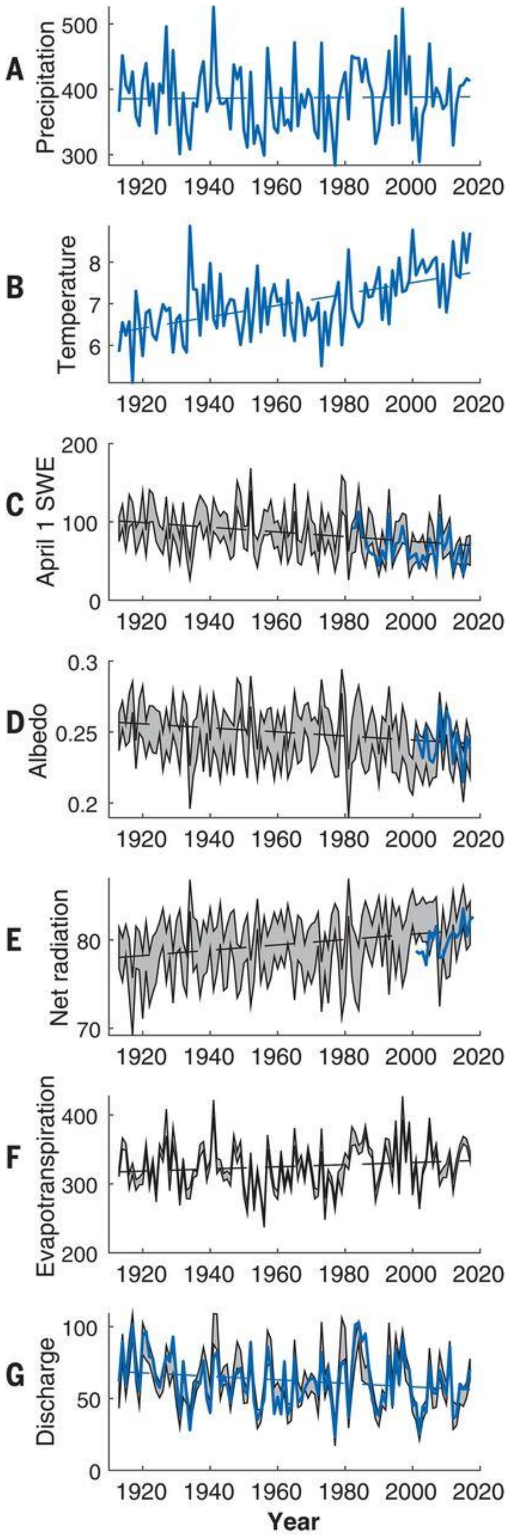

Figure 1. Water-year time series of Colorado River Basin mean and annual mean values. Blue curves are estimates from observations, and gray bands are ensemble range of model outputs. Least-squares linear fits also shown.

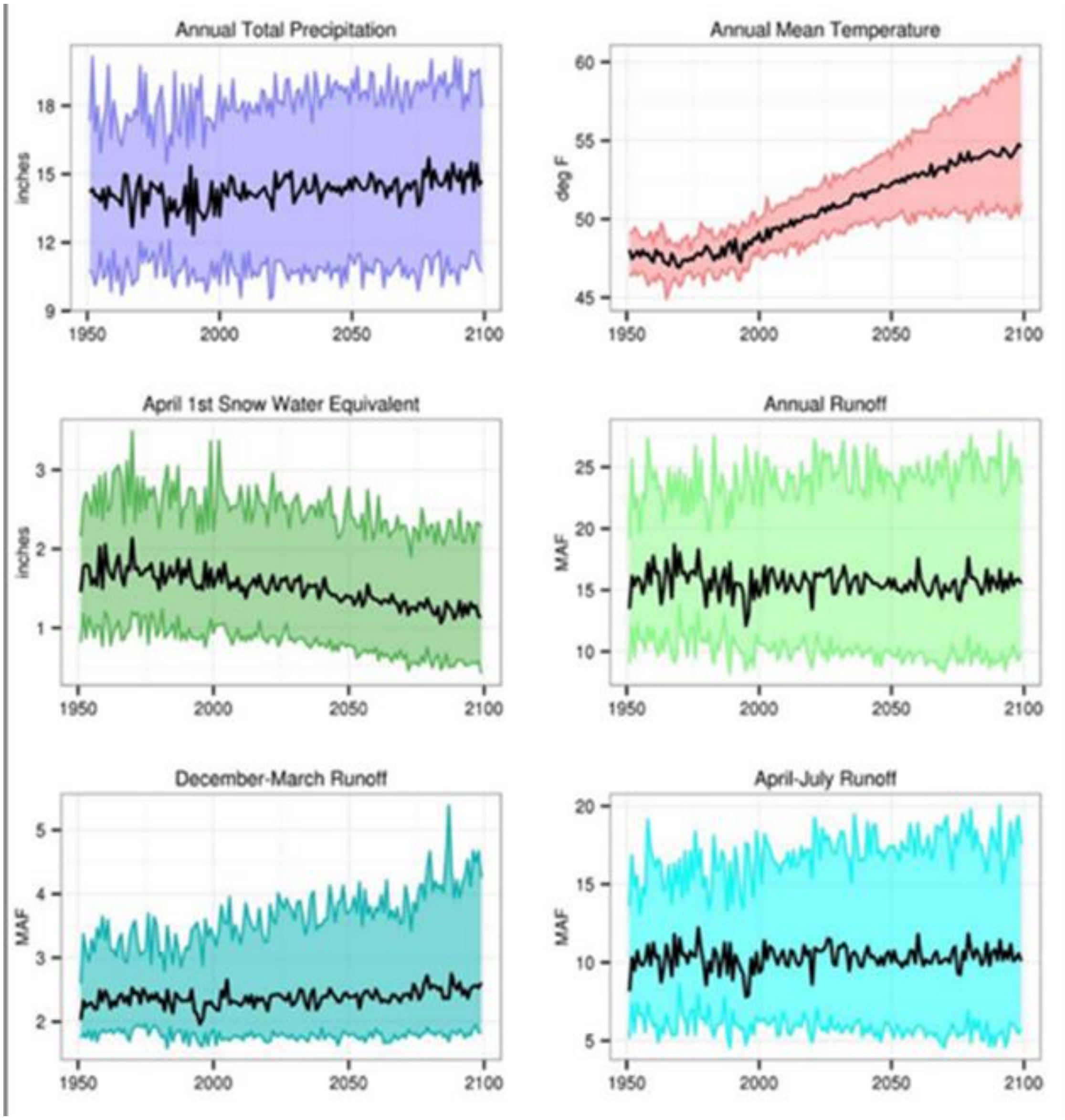

Figure 2. Bureau of Reclamation 2016 time series plots for 6 projected hydroclimate indicators in the Colorado River basin from 1950-2100. The black line shows annual time-series median value with the 10th and 90th percentiles shaded.

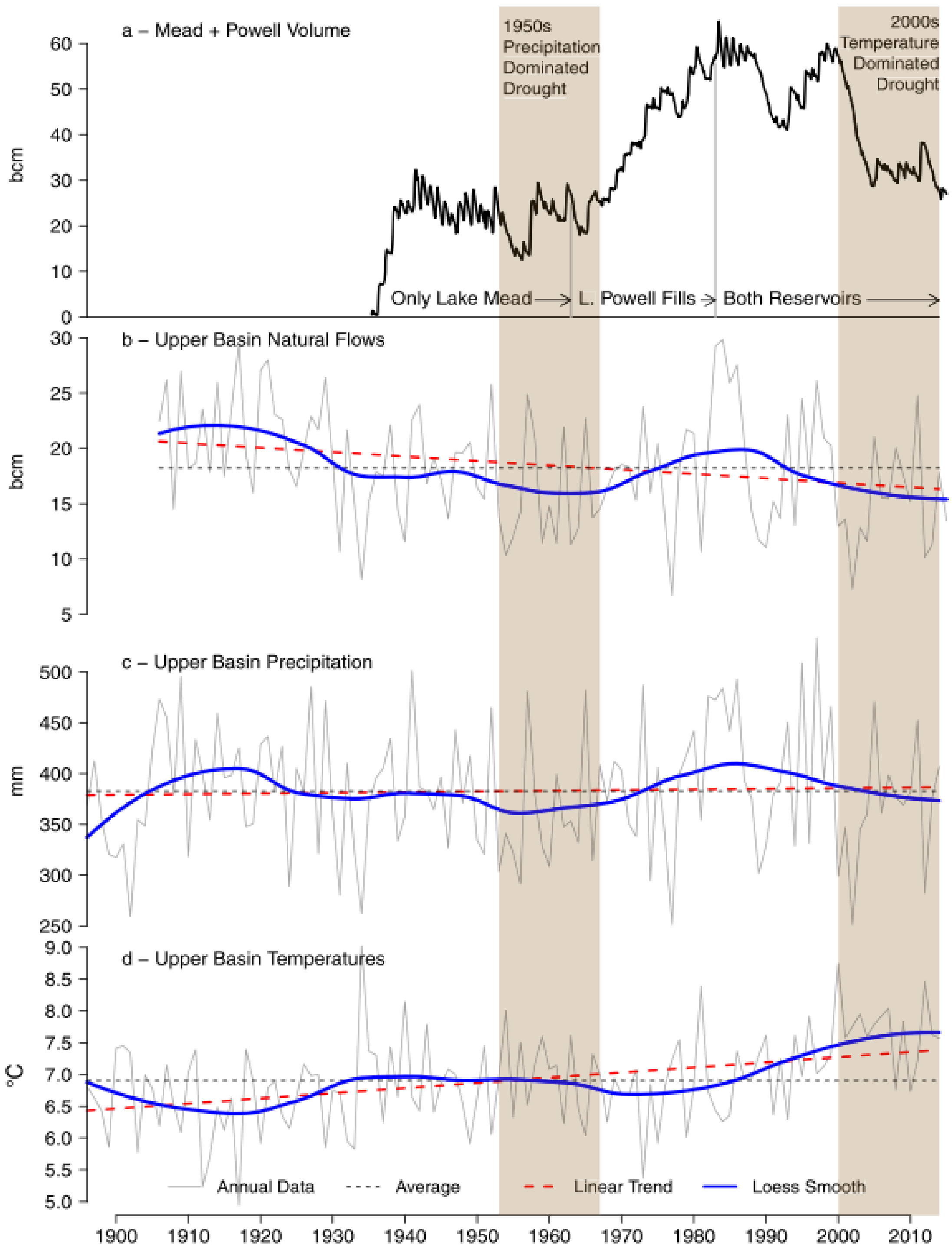

Figure 3. (a) Lake Mead and Powell combined monthly model. UCRB (b) runoff at Lees Ferry from 1906 to 2014, (c) precipitation and (d) temperatures from 1896 to 2015.

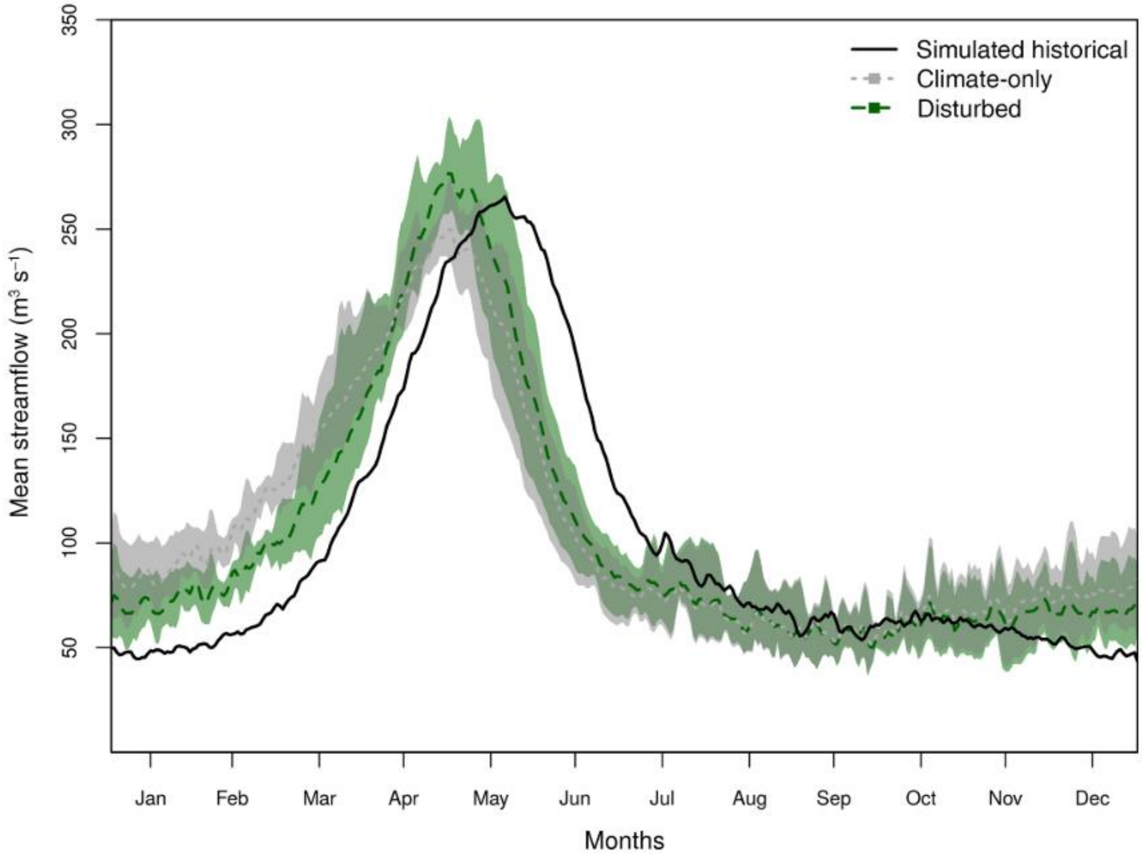

Figure 4. Monthly average future streamflows (2070-2099) compared to historical (1970-1999) for the San Juan River basin at Bluff, UT. The range of responses for each model is represented by the envelope around the lines, the black line is the simulated historical streamflow, the grey line is the climate-only scenario, and the green line is the disturbed scenario.

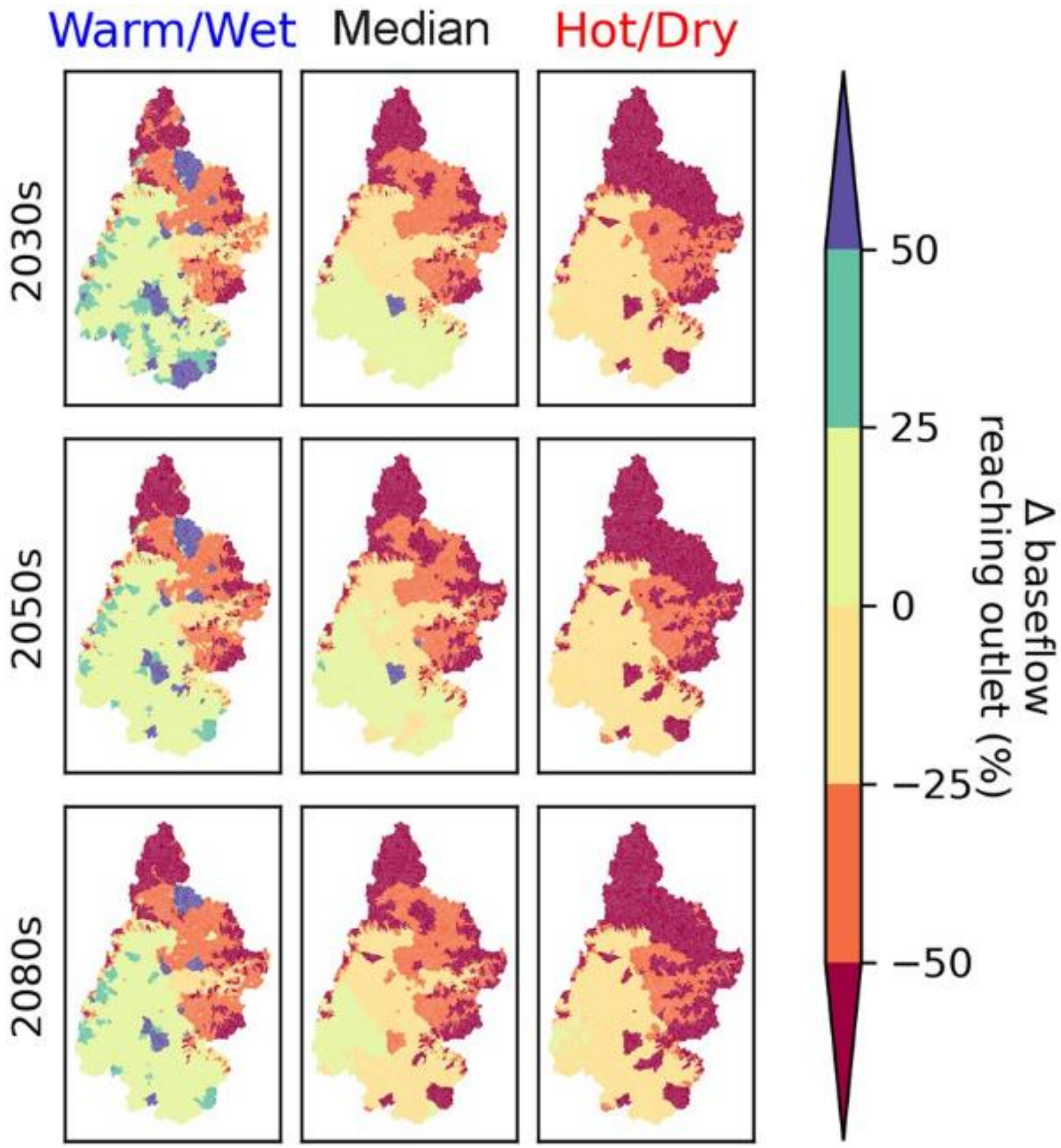

Figure 5. Maps under three different climate scenarios and three different time periods showing the percent change in the fraction of baseflow leaving a reach that is delivered to the basin outlet for each catchment in the UCRB.

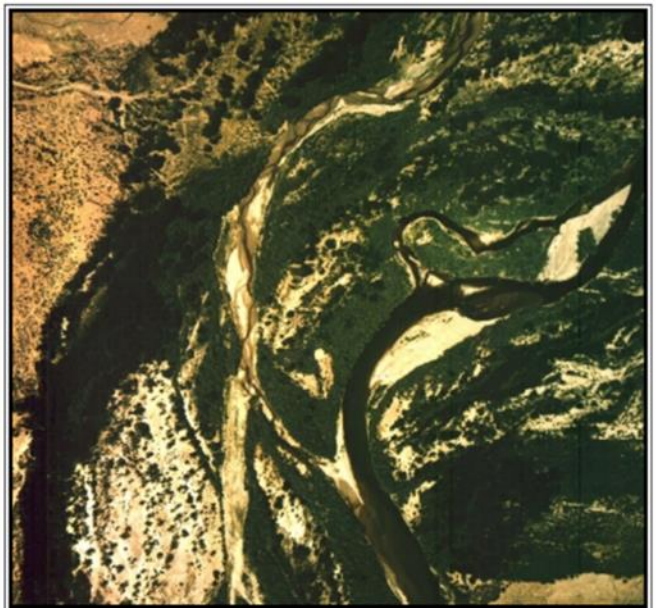

Figure 6. “The Mixer a Colorado pikeminnow spawning ground in the San Juan River.

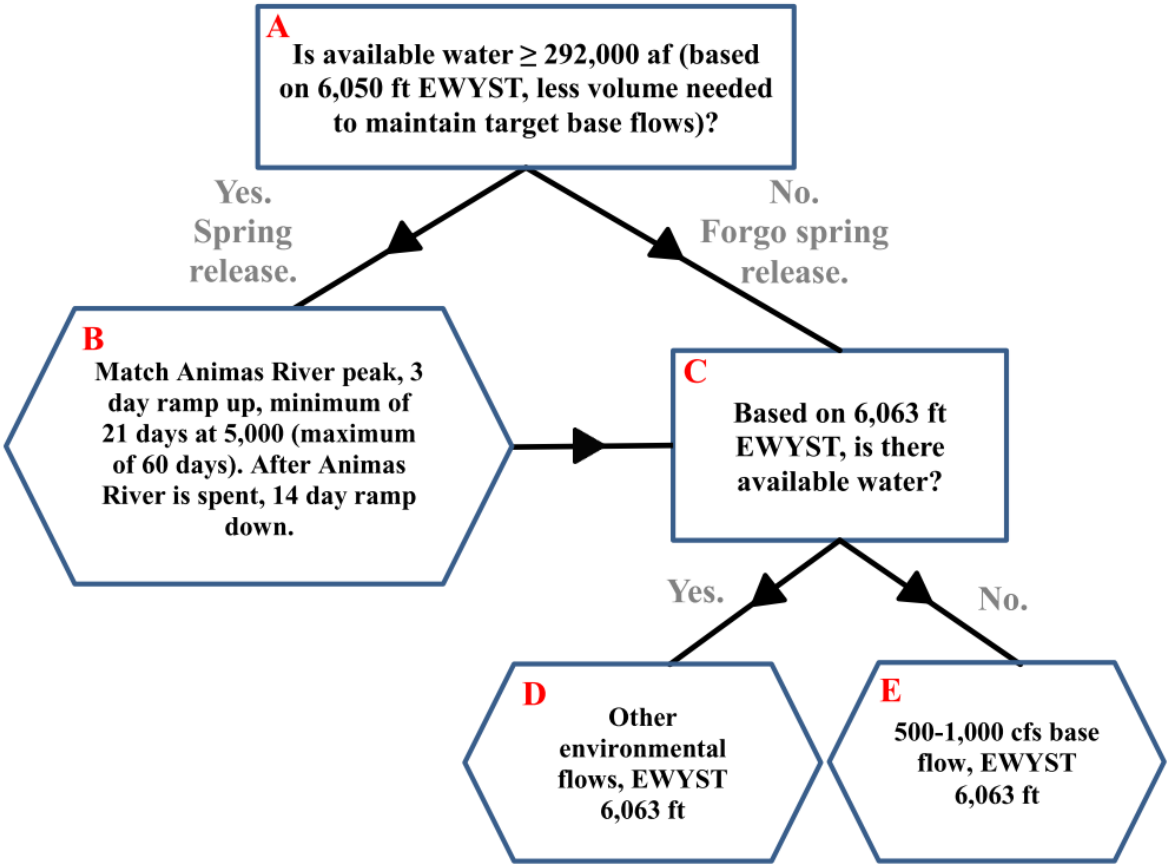

Figure 7. San Juan River Basin Recovery Implementation Program revised flow recommendations for the Navajo dam in 2018.