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Gila River Flow Needs Assessment

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Abstract

The substantially natural hydrograph of the upper Gila River supports the largest complement of native fishes and some of the best remaining riparian habitat in the lower Colorado River Basin. Changes to the river's flows may significantly degrade the aquatic and riparian ecosystem. The Arizona Water Settlements Act (AWSA) authorizes federal funds to build a New Mexico Unit that could divert up to 14,000 acre-feet annually. The goal of Flow Needs Assessmentwas to define the ecosystem water needs of the upper Gila River in New Mexico and to evaluate the impact of the proposed diversion and climate change. To achieve this goal, a team of academic partners synthesized scientific literature on hydrology, geomorphology, riparian vegetation, wildlife, and flow-ecology relationships and conducted new analyses. Diversion allowed under the AWSA and climate change would reduce the number and magnitude of mid-size flows in the 150–4,000 cubic feet per second (cfs) range. If the frequency of these flows is reduced, the floodplain would be inundated less often, with decreases in alluvial aquifer recharge. The most pronounced seasonal impact from the proposed diversion would occur during the snowmelt runoff period. Reduced flows and abrupt changes in flow as snowmelt recedes would reduce the cleaning of fine sediments from gravel and cobbles, and limit the re-sorting of these substrates to create suitable spawning habitat for native fish. This would reduce spawning success and diminish aquatic invertebrate production. Invertebrates are an important food source for fish, birds, amphibians, reptiles, and mammals. The Gila River Flow Needs Assessment offers a comprehensive overview of projected impacts of climate change and water diversion on the ecosystem in the Cliff-Gila Valley; this paper provides a summary of this report.

Index Descriptors: Gila River, hydrology, ecology, diversion, Arizona Water Settlements Act.

Introduction

The Gila River is widely recognized for the habitat it provides for people and wildlife in southwest New Mexico. Flow variability is the defining feature of the Gila River in New Mexico—creating a multi-aged riparian forest and floodplain wetlands that support rich bird diversity (Hubbard 1971; Baltosser 1986; USFS 2002) and provide habitat for numerous mammals (Simpson 1964; Frey 2010). An array of aquatic habitats supports native fishes (Propst et al. 2008). Numerous federally protected species are found in the Cliff-Gila Valley: Southwestern Willow Flycatcher (*Empidonax traillii extimus*) (USFWS 1995), spikedace (*Meda fulgida*) (USFWS 1986b), Western Yellow-billed Cuckoo (*Coccyzus americanus*) (USFWS 2014a), loach minnow (*Tiaroga cobitis*) (USFWS 1986a), northern Mexican gartersnake (*Thamnophis eques megalops*) (USFWS 2014b), and narrow-headed gartersnake (*Thamnophis rufipunctatus*) (USFWS 2014b). The Gila is a rare example of a southwestern river with a natural flow pattern that sustains its high biodiversity.

The Arizona Water Settlements Act of 2004 (AWSA) provides an opportunity to augment water supply in southwest New Mexico, authorizing diversion of an additional 14,000 acre-feet annually from the upper Gila River in exchange for Central Arizona Project water (US Congress 2004). Terms of diversion are described in the Consumptive Use and Forebearance Agreement (CUFA) in the AWSA. AWSA was accompanied by an appropriation to New Mexico that may be used for either "other water utilization alternatives to meet the water supply demands" of the region or a permanent river diversion and other associated facilities (US Congress 2004). The Gila River Flow Needs Assessment (the "Assessment") is intended to help water and natural resource managers effectively weigh the ecological impacts of a permanent diversion and adapt to climate change.

Description of Study

The Nature Conservancy and a team of academic partners received funding for the Assessment from Bureau of Reclamation's WaterSMART Program and the Desert Landscape Conservation Cooperative. The Assessment describes the existing condition of the Gila River in the Cliff-Gila Valley, New Mexico, and examines the potential impacts of additional diversion and climate change on the riparian and aquatic ecosystem of the 35 km (22 mi) Cliff-Gila Valley (Fig. 1). The project team completed a draft report summarizing river flows and ecological attributes. A workshop brought together 35 scientists from 24 agencies, universities, and organizations with expertise in some aspect of the Gila River's hydrology and ecology (Table 1). Workshop participants reviewed and contributed to the report. The report includes a summary of workshop findings, focusing on how flows shape the ecosystem and how these interactions may be affected by flow alterations due to CUFA diversion and climate change.

River Flows and Floodplain Processes

The Gila River in New Mexico fluctuates between extraordinarily high and low flows within years and over the course of years (Propst et al. 2008). Native flora and fauna have evolved life history strategies and life cycles in direct response to the natural flow regime (Poff et al. 1997; Bunn and Arthington 2002). Flows during each season play distinct ecological roles that support the diversity of the aquatic and riparian ecosystem (Yarnell et al. 2010). The annual hydrograph was delineated into four seasonal blocks: snowmelt runoff, late spring and early summer low flow, monsoon, and fall and winter (Fig. 2) (Kelly et al. 2005). Flow patterns within each seasonal block and their ecological functions were then characterized for important riparian and aquatic species.

Flows of different magnitudes have different functions in creating and maintaining topographic and vegetative complexity (Poff et al. 1997; Bunn and Arthington 2002; Tockner and Stanford 2002). Infrequent large floods rework the floodplain (Soles 2003), support nutrient cycling (Poff et al. 1997; Tockner et al. 2000), scour out secondary channels, and create off-channel pools and wetlands (Fig. 3) (Makaske 2001). Frequent mid-size flows inundate these secondary channels (Makaske 2001), transport nutrients across the floodplain (Tockner et al. 2000), rehydrate wetlands, and raise groundwater levels that support floodplain forests and dense thickets of vegetation (Junk et al. 1989; Stromberg et al. 1992; Hupp and Osterkamp 1996; Poff et al. 1997; Tockner et al. 2000; Stella et al. 2006; Wilcox and Shafroth 2013).

Changes to Flows

The New Mexico Consumptive Use and Forbearance Agreement (CUFA), ratified by the AWSA (US Congress 2004), sets forth specific Terms of Diversion under which New Mexico may divert surface water from the Gila River, referred to as the "CUFA diversion." This Assessment evaluates the potential impact of diverting an average of 14,000 acre-feet annually, with an additional constraint that 150 cubic feet per second (cfs) of water be allowed to bypass the diversion to meet downstream obligations. The most significant effect of CUFA diversion is to reduce the number and magnitude of mid-size flows and flood pulses (400–4,000 cfs range), particularly during snowmelt runoff and monsoon (Fig. 4) (SSPA 2013). The number of days that flows in this range occur in the historic gage data (1937–2012) is 2,049; with diversion, the number is reduced to 1,364, a 33% decrease. In addition, a high proportion of flow can be diverted within this range: 350 cfs removed from a 500 cfs flow results in 70% reduction in flow.

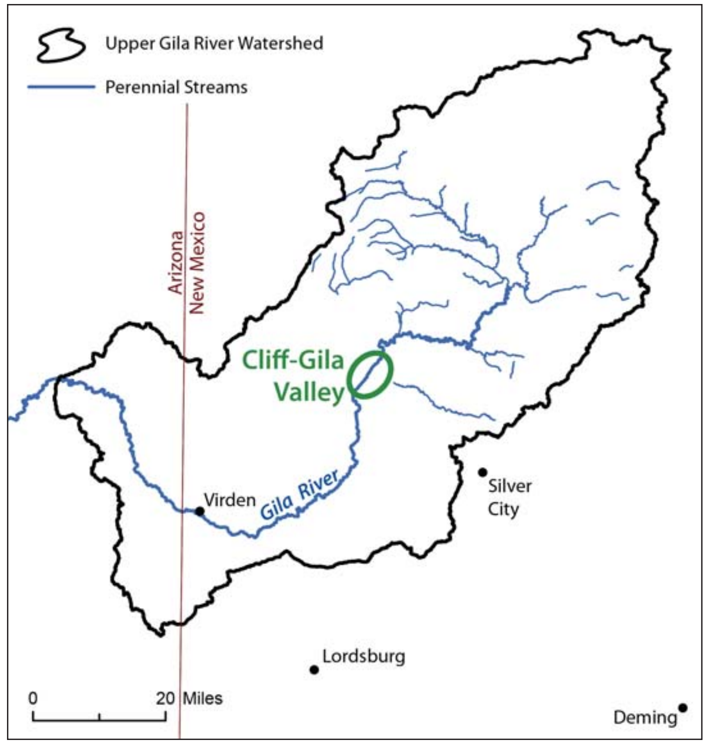

Fig. 1. Upper Gila River watershed, showing extent of perennial flow and the Cliff-Gila Valley.

Results from climate models project reduced snowpack, earlier snowmelt, and lower overall annual streamflow due to increases in temperature (evapotranspiration) and slight decreases in precipitation, aligned with trends reported in other recent climate change modeling studies for the Southwest (Seager et al. 2007; Barnett et al. 2008; Cayan et al. 2008; Barnett and Pierce 2009; Gershunov et al. 2013). These changes will result in smaller peak flows in the spring, a more rapid decrease in flows during snowmelt runoff, lower flows during the summer, and higher-magnitude monsoon flood events. The summer low-flow period is projected to begin earlier and last considerably longer, a time of significant stress for both aquatic and terrestrial organisms.

CUFA diversion and climate change will reduce flows in the mid-size range (400–4,000 cfs), with direct negative effects on many ecological processes: the floodplain will be

Table 1. Workshop Participants. Participants of the Silver City Workshop (January 8–9, 2014) and Albuquerque Workshop (April 14, 2014).

Name	Affiliation
Leslie Bach	The Nature Conservancy
Dr. Mike Bogan	University of California, Berkeley
Jim Brooks	US Fish and Wildlife Service
Dr. Carol Campbell	New Mexico State University
Rob Clarkson	US Bureau of Reclamation
Martha Cooper	The Nature Conservancy
Dr. Cliff Dahm	University of New Mexico
Matt Ely	US Geological Survey, New Mexico Water Science Center
Carol Evans	US Bureau of Reclamation
Dr. Deb Finch	US Forest Service, Rocky Mountain Research Station
Dr. Jennifer Frey	New Mexico State University
Mike Fugagli	Private consultant (Ornithology)
Dr. Gregg Garfin	University of Arizona
Dr. Keith Geluso	University of Nebraska
Dr. Keith Gido	Kansas State University
Dr. Dave Gori	The Nature Conservancy
Dr. Dave Gutzler	University of New Mexico
Jeanmarie Haney	The Nature Conservancy
Dr. Mary Harner	Crane Trust
Deb Hathaway	S.S. Papadopulos and Associates
Jennifer Holmes	Northern Arizona Univ./ Colorado Plateau Research Center
Dr. Mark Horner	University of New Mexico
Dr. Jerry Jacobi	Highlands University
Dr. Randy Jennings	Western New Mexico University
Matt Johnson	Northern Arizona Univ./ Colorado Plateau Research Center
Dr. Kelly Kindscher	University of Kansas
Dale Lyons	The Nature Conservancy
Steve MacDonald	University of New Mexico
Dr. Paul Marsh	Marsh & Associates
Melissa Mata	US Fish & Wildlife Service
Laura McCarthy	The Nature Conservancy
Jerry Monzingo	Gila National Forest
Dr. Ryan Morrison	University of New Mexico
Dr.Esteban Muldavin	NM Natural Heritage Program
Nathan Myers	US Geological Survey, New Mexico Water Science Center
Nessa Natharius	Gila National Forest
Dr. Dave Propst	University of New Mexico
Mary Richardson	US Fish and Wildlife Service
Craig Roepke	NM Interstate Stream Commission
Dr. Phil Rosen	University of Arizona
Jeffrey Samson	University of New Mexico
Dr. Roland Shook	Western New Mexico University
Ellen Soles	Northern Arizona University
Dr. Mark Stone	University of New Mexico
Dale Turner	The Nature Conservancy
Dr. Tom Turner	University of New Mexico
Hanna Varani	New Mexico Natural Heritage Program
Dr. Hira Walker	Colibri Consulting
Andy Warner	The Nature Conservancy
Dr. Meg White	The Nature Conservancy
Dr. Kathy Whiteman	Western New Mexico University
Jill Wick	New Mexico Department of Game and Fish

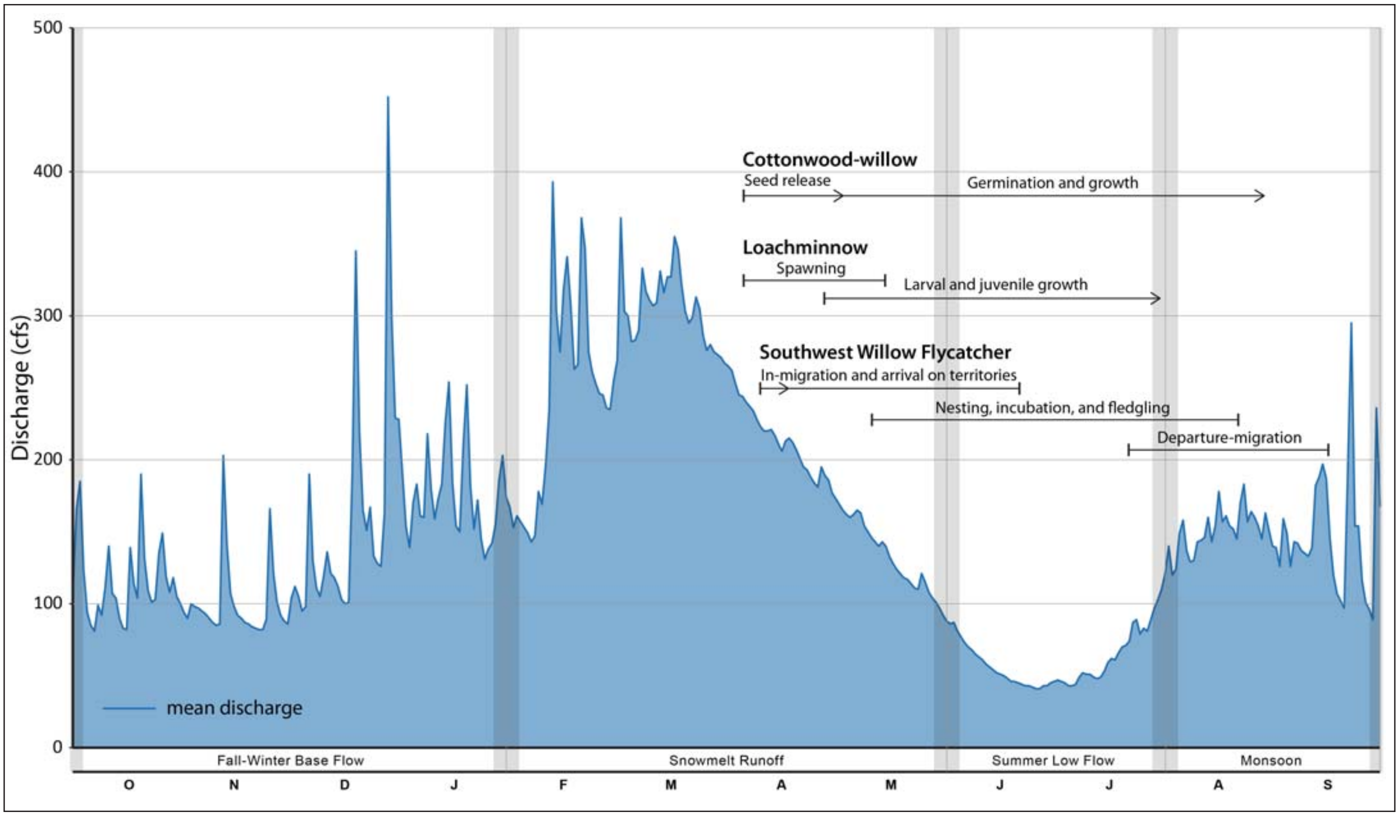

Fig. 2. Conceptual ecological model for the upper Gila River. The mean daily flow for the period of record (1929–2013) at the Gila near Gila gage is divided into four seasonal blocks. The black lines and arrows show the approximate timing of life history events and life stages of important riparian and aquatic species (Mahoney and Rood 1998; Propst et al. 2008; Sogge et al. 2010). These events and stages are tied to flows in the river that created and maintain habitat, provide food, and promote environmental conditions necessary for survival and reproduction. River-dependent species have evolved life history strategies in direct response to the natural flow regime.

inundated less often, reducing alluvial aquifer recharge; surface water and groundwater levels will decline faster, surface water temperatures will increase, and nutrient cycling will be decreased, resulting in a less productive ecosystem (Hughes 1980; Junk et al. 1989; Ward and Stanford 1995; Naiman and Decamps 1997; Tockner et al. 2000; van der Nat et al. 2003; Heffernan and Sponseller 2004; Ficklin et al. 2013).

Results

Existing conditions, flow-ecology relationships, and the associated impacts of CUFA diversion and climate change on each community type are described below.

Riparian and Wetland Plant Communities

Flow is a major determinant of physical habitat in rivers and on the floodplain (Poff et al. 1997). Infrequent high-magnitude flows (> 11,000 cfs) are needed to reconfigure the floodplain periodically and remove woody riparian vegetation, maintaining the compositional and structural diversity of riparian vegetation in the floodplain. Mid-size flows (400–4,000 cfs) in the snowmelt runoff and summer monsoon periods that periodically inundate the floodplain through secondary channels (Fig. 3) and recharge groundwater are necessary for growth and survival of woody and herbaceous riparian vegetation.

Groundwater levels in the floodplain rise and fall with fluctuating river flows. Floods recharge groundwater; the amount of recharge depends on the size and duration of flows. Extended dry periods drop groundwater levels; mortality of riparian trees occurs when groundwater levels remain too low (Stromberg et al. 1992; Leenhouts et al. 2006).

Vegetation in the Cliff-Gila Valley is characterized by multi-aged stands of numerous native tree and shrub species, dominated by Fremont cottonwood (*Populus deltoides* var. *fremontii*) and willow (*Salix gooddingii*, *S. exigua*, *S. irrorata*, etc.) (Fig. 5). Regeneration of cottonwood and willow occurs episodically, requiring the alignment of a particular set of circumstances: a large flood to prepare a seedbed of fine sediment and slow recession of flows during the snowmelt runoff period to keep soil moist as seeds germinate, take root, and grow (Mahoney and Rood 1998; Rood et al. 2003).

Reduced floodplain inundation and abrupt changes in flow from CUFA diversion would lead to rapid declines in groundwater that will decrease the survivorship and vigor of seedlings, saplings, and mature riparian trees (Mahoney and Rood 1998). A decrease in the number of cottonwood recruitment events, together with impacts to survivorship and vigor,

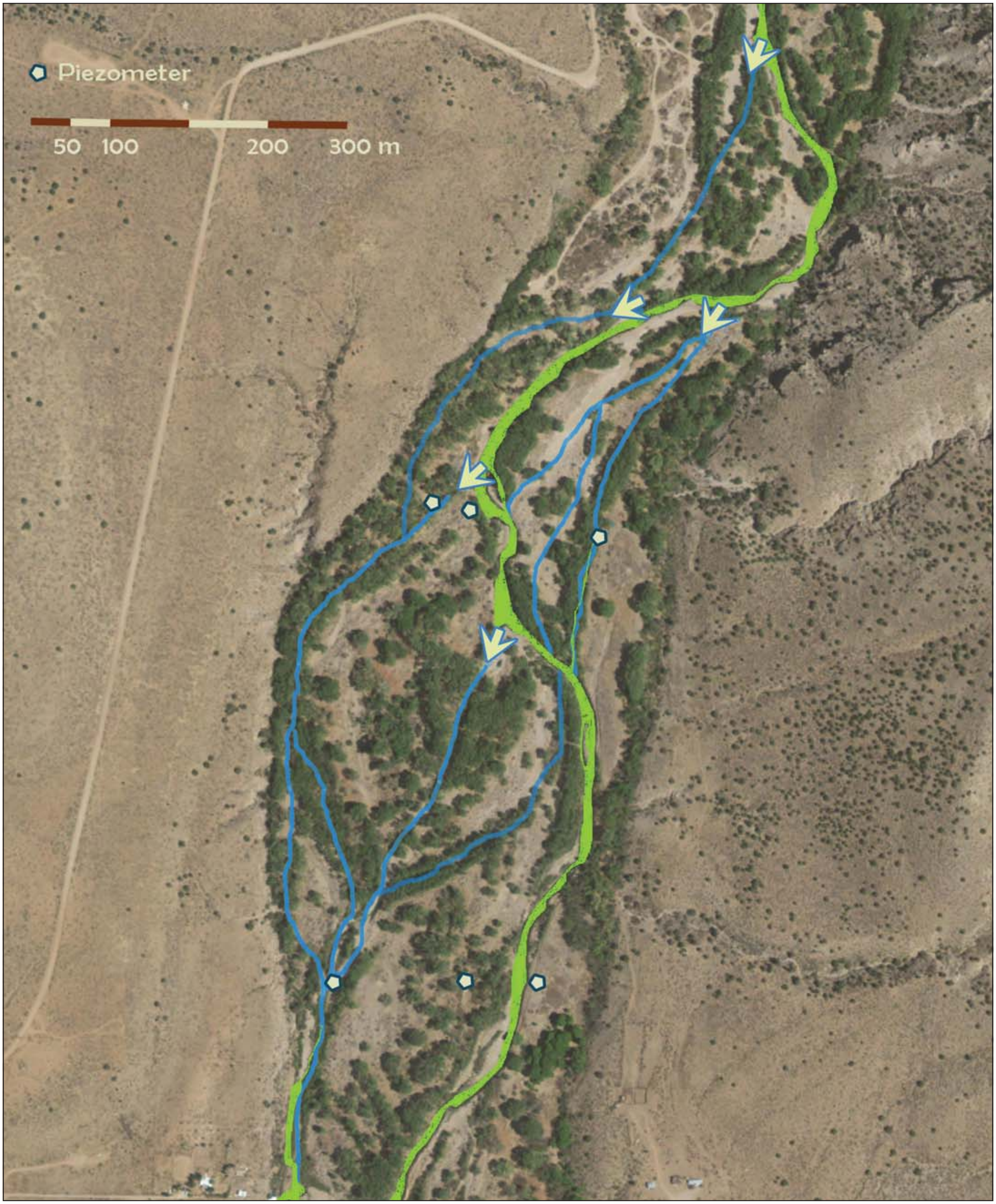

Fig. 3. The position of the main Gila River channel in 2011 is shown in green. The location of this photo is just downstream of the Gila National Forest Box Canyon recreation area. Blue lines indicate some of the secondary channels present on the floodplain. Arrows mark points where flow diverges from the main channel into secondary channels when flows in the river rise. The majority of riparian vegetation (80%) is located along secondary channels away from the main channel.

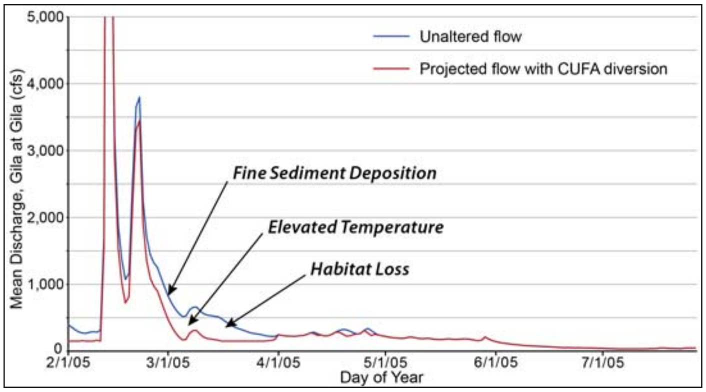

Fig. 4. The snowmelt runoff period is the seasonal block most affected by diversion. Reduced flows would lead to increased silt deposition on gravel and cobble substrates, elevated water temperatures, and habitat loss for aquatic species (Yarnell et al. 2010).

will lead to an overall reduction in the areal extent, structural diversity, and canopy cover of the riparian forest.

Floodplain wetlands are depressions that hold water for all or part of the year. Mid-size river flows inundate and rehydrate wetlands, transport nutrients that maintain their productivity, and maintain groundwater and surface water conditions that wetland herbaceous plants need for growth and survival (Ward and Stanford 1995; Naiman and Decamps 1997; Tockner et al. 2000; van der Nat et al. 2003). Reduced floodplain inundation and nutrient transport would reduce the size and productivity of wetlands.

Climate change will also lead to reduced floodplain inundation and alluvial aquifer recharge, increased evapotranspiration, and more rapid declines in groundwater. Like diversion, this will likely reduce the extent, structural diversity, and vigor of the riparian forest. Wetlands are also likely to decrease as the floodplain dries, while the abundance of plants that thrive in drier habitats is expected to increase. Groundwater decline, drought, and higher temperatures create conditions favorable for the establishment and spread of nonnative salt cedar (*Tamarix*) (Leenhouts et al. 2006), which is currently largely absent in the Cliff-Gila Valley.

Aquatic Invertebrates

The upper Gila River supports diverse aquatic invertebrate communities. Aquatic invertebrates are the base of the aquatic and riparian food chain, supporting amphibians, fish, birds, and mammals (Cummins et al. 2008). Aquatic invertebrates live in the interstitial spaces among gravel and cobbles. Receding flows in the spring after peak snowmelt remove silt and fine sediments and help maintain this habitat (Yarnell et al. 2010).

Abrupt flow changes during snowmelt runoff from CUFA diversion could reduce cleansing of gravel and cobbles and blanket these substrates in silt, reducing the abundance of aquatic invertebrates (Dewson et al. 2007). A truncated snowmelt recession limb could also contribute to a more rapid increase in water temperatures, leading to reduced and earlier emergence of aquatic invertebrates (Durance and Ormerod 2007). In addition, reduced floodplain inundation and connectivity diminishes exchange of organic and inorganic material between the river and floodplain (Hughes 1980; Tockner et al. 2000; Ficklin et al. 2013). Altering nutrient cycles reduces productivity, leading to a decrease in abundance and size of aquatic invertebrates (Ward and Stanford 1995). Wildlife that depends on aquatic invertebrates for food would be negatively impacted.

Native Wildlife

Mid-size flows sustain a multi-aged mosaic of riparian forest patches that provides habitat for hundreds of birds, including Southwestern Willow Flycatcher and Western Yellow-billed Cuckoo (Shook 2013). The Southwestern Willow Flycatcher

Fig. 5. Multi-aged riparian forests of cottonwood, willow, and other native trees and shrubs provide habitat for numerous wildlife species in the Cliff-Gila Valley. This photo was taken in 2013 downstream of the Hwy. 180 bridge on the Iron Bridge Conservation Area.

nests in stands of mature riparian forest and needs moist or saturated soils during the summer months to sustain conditions necessary for successful reproduction—specifically, thermoregulation of eggs and nestlings (USFWS 2002). Mid-size and larger flows also stimulate germination and growth of herbaceous plants in wetlands that provide habitat and food for reptiles, amphibians, and mammals (Bunn and Arthington 2002; Poff et al. 1997). CUFA diversion and climate change would negatively impact numerous species dependent on riparian forests and wetlands.

Changes in the structure and vigor of the riparian forest, coupled with increased air temperature and evapotranspiration from diversion and climate change, would increase stress on many riparian-obligate birds while they are breeding and raising young (McKechnie and Wolf 2010). Higher temperatures can stress nesting birds and lower humidity can reduce the abundance of insects that birds eat (Durance and Ormerod 2007). Earlier emergence of aquatic insects due to increased water temperatures may cause a temporal asynchrony between peak invertebrate abundances and the time when riparian birds are feeding their young (Anders and Post 2006). These factors would likely result in increased mortality and reduced reproductive success for riparian-obligate birds, particularly Western Yellow-billed Cuckoo and Southwestern Willow Flycatcher (Stoleson and Finch 2000; Shook 2013).

Fish

The Gila River in New Mexico supports one of the two most intact native fish communities in the lower Colorado River Basin (Fig. 6), including important populations of spikedace (Fig. 7) and loach minnow (Fig. 8) (Propst et al. 2008; Whitney et al. 2014).

Flow variability over the course of the year supports the persistence of native fishes (Propst et al. 2008). Mid-size

Fig. 6. Annual fish surveys have occurred for 24 years at permanent monitoring sites in the Cliff-Gila Valley. This data set is particularly useful for understanding how seasonal flows affect the reproduction success and population sizes of loach minnow and spikedace (Propst et al. 2008).

Fig. 7. Spikedace. (W.H. Brandenburg for New Mexico Department of Game and Fish)

flows in the winter and snowmelt runoff period sort gravel and cobble, restructuring aquatic habitat in the main channel that native fish use for spawning and as larvae, juveniles, and adults (Poff et al. 1997; Yarnell 2010). When daily discharge is greater in the spring, reproductive success for spikedace, loach minnow, and desert sucker (*Catostomos clarki*) is greater (Stefferud et al. 2011). The lowest flows occur in June and July. During this time, loach minnow and spikedace are especially threatened by nonnative fish, which compete for food and prey on natives as both become concentrated in the dwindling river. Monsoon rains restore flows to the river and fish benefit from increased habitat and food sources.

A change in the magnitude and frequency of seasonal flows from CUFA diversion will degrade fish habitat and reduce reproductive success. Reduced flows and abrupt changes in flow (by up to 350 cfs) as snowmelt recedes will diminish the cleaning of silt and fine sediments from gravel and cobbles, and limit the re-sorting of these substrates to provide suitable spawning habitat for native fish (Yarnell et al. 2010).

Reduced flows in spring due to diversion would also convert exceptionally good years for spikedace and loach minnow recruitment into bad years. These fish live 2–3 years, and 2 years without good reproductive success could decimate the population. A diversion structure will prevent or inhibit movement of native fish upstream and reduce population connectivity. Dispersal and gene flow from core populations in the Cliff-Gila Valley are necessary to sustain the genetic diversity of spikedace and loach minnow populations in the Gila Forks Area and to augment the population following disturbances such as wildfires and debris flows. A diversion structure would impede movement and increase the likeli-

Fig. 8. Loach minnow. (W.H. Brandenburg for New Mexico Department of Game and Fish)

hood of extinction of these upstream populations, in addition to compromising Cliff-Gila Valley populations of these two species.

Smaller peak flows and a greater rate of flow decline during spring runoff due to climate change will likely result in increased stranding of aquatic invertebrates, larval native fish, and amphibians as main-channel and floodplain aquatic habitats dry up. Truncation of the snowmelt recession period and lower flows overall will extend and exacerbate the summer low-flow period, leading to increased water temperatures, reduction in the extent of some aquatic habitats, and reduced water depth and velocity in remaining wet areas (Yarnell et al. 2010). Aquatic habitats would likely shrink down to pools interspersed and connected by shallow-water habitats. Nonnative species would be concentrated in the pools with native fish and narrow-headed gartersnakes, increasing competition and predation on native species (Pool and Olden 2014). Altered flows and thermal regimes will favor nonnative species like northern crayfish (*Orconectes virilis*) (Whitney et al. 2014).

Conclusion

The high biodiversity of the Gila River in the Cliff-Gila Valley is a function of the natural flow regime in the upper watershed. This Assessment concludes that CUFA diversion and climate change create risk of significant ecological impact. The snowmelt runoff period is predicted to be the most strongly affected, a critical period of time in the life cycle of multiple species and communities in the Cliff-Gila Valley. Mid-size flows that would be diverted most frequently are critical for recharging groundwater, supporting riparian plants, and maintaining the quality and diversity of aquatic habitats. Reducing these frequent elevated flows could have a cascading negative effect on the aquatic and riparian ecosystem.

Riparian and aquatic species in the Cliff-Gila Valley face numerous challenges, including nonnative aquatic species, drought, and the downstream effects from large, high-severity wildfires in the upper watershed. Climate change will impose additional severe stresses. Diversion will significantly exacerbate these challenges. Numerous species, particularly fishes, will be at increased risk of extirpation and ultimately extinction.

For More Information:

The 500-page Gila River Flow Needs Assessment is available at http://nmconservation.org/Gila/GilaFlowNeedsAssessment.pdf.

Acknowledgments

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Literature Cited

Anders, A. D., and E. Post. 2006. Distribution-wide effects of climate on population densities of a declining migratory landbird. Journal of Animal Ecology 75:221–227.

Baltosser, W. H. 1986. Seasonal analysis of a southwestern New Mexico riparian bird community. Western Birds 17(3):115–132.

Barnett, T. P., and D. W. Pierce. 2009. Sustainable water deliveries from the Colorado River in a changing climate. Proceedings of the National Academy of Science 106:7334–7338.

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirtin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science 319:1080–1083.

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492–507.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. Climate Change 87:21–42.

Cummins, K. W., R. W. Merritt, and M. B. Berg. 2008. Ecology and distribution of aquatic insects. Pages 105–122 in An introduction to the aquatic insects of North America, 4th ed. R.W. Merritt, K. W. Cummins, and M. B. Berg (eds.). Kendell/Hunt, Dubuque, Iowa.

Dewson, Z. S., A. B. James, and R. G. Death. 2007. A review of the consequences of decreased flow for instream habitat and macroinvertebrates. Journal of the North American Benthological Society 26:401–415.

Durance, I., and S. J. Ormerod. 2007. Climate change effects on upland stream macroinvertebrates over a 25-year period. Global Change Biology 13:942–957.

Ficklin, D. L., I. T. Stewart, and E. P. Maurer. 2013. Effects of climate change on stream temperature, dissolved oxygen, and sediment concentration in the Sierra Nevada in California. Water Resources Research 49:2765–2782.

Frey, J. K. 2010. Mammals of the upper Gila River watershed, Arizona and New Mexico: Patterns of diversity and species of concern. Proceedings of the Second Natural History of the Gila Symposium, New Mexico Botanist, Special Issue 2:67–87.

Gershunov, A., B. Rajagopalan, J. Overpeck, K. Guirguis, D. Cayan, M. Hughes, M. Dettinger, C. Castro, R. E. Schwartz, M. Anderson, A. J. Ray, J. Barsugli, T. Cavazos, and M. Alexander. 2013. Future climate: Projected extremes. Pages 126–147 in Assessment of climate change in the southwest United States: A report prepared for the National Climate Assessment. G. Garfin, A. Jardine, R. Meredith, M. Black, and S. LeRoy (eds.). Island Press, Washington, DC.

Heffernan, J. B., and R. A. Sponseller. 2004. Nutrient mobilization and processing in Sonoran desert riparian soils following artificial rewetting. Biogeochemistry 70:117–134.

Hubbard, J. P. 1971. The summer birds of the Gila Valley, New Mexico. Nemouria 2:1–35.

Hughes, D. A. 1980. Floodplain inundation: Processes and relationships with channel discharge. Earth Surface Processes 5:297–304.

Hupp, C. R., and W. R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology 14:277–295.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences, Proceedings of the International Large River Symposium 106:110–127.

Kelly, M., A. Munson, J. Morales, and D. Leeper. 2005. Proposed minimum flows and levels for the upper segment of the Myakka River, from Myakka City to SR 72. Southwest Florida Water Management District, Brooksville, Florida. http://www.swfwmd.state.fl.us/

Leenhouts, J. M., J. C. Stromberg, and R.L. Scott (eds.). 2006. Hydrologic requirements of and consumptive groundwater use by riparian vegetation along the San Pedro River, Arizona. US Geological Survey Scientific Investigations Report 2005-5163.

Mahoney, J. M., and S. B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment: An integrative model. Wetlands 18:634–645.

Makaske, B. 2001. Anastomising rivers: A review of their classification, origin and sedimentary products. Earth Science Reviews 53:149–196.

McKechnie, A. E., and B. O. Wolf. 2010. Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. Biology Letters 6:253–256.

Naiman, R. J., and H. Decamps. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28:621–658.

Poff, N. L, J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience 47:769–784.

Pool, T. K., and J. D. Olden. 2014. Assessing long-term responses and short-term solutions to flow regulation in a dryland river basin. Ecology of Freshwater Fish 24:56–66. doi: 10.1111/eff.12125

Propst, D. L., K. B. Gido, and J. A. Stefferud. 2008. Natural flow regimes, nonnative fishes, and native fish persistence in arid-land river systems. Ecological Applications 18:1236–1252.

Rood, S. B., C. R. Gourley, E. M. Ammon, L. G. Heki, J. R. Klotz, M. L. Morrison, D. Mosley, G. G. Scoppettone, S. Swanson, and P. L. Wagner. 2003. Flows for floodplain forests: A successful riparian restoration. BioScience 53:647–656.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181–1184.

Shook, R. S. 2013. Southwestern Willow Flycatcher (*Empidonax traillii extimus*) survey results. U Bar Ranch, The Nature Conservancy, U.S. Forest Service Cliff/Gila Valley, New Mexico—2013 Alta Cabral Property Redrock, New Mexico—2013. Freeport McMoRan, Tyrone Inc., Tyrone.

Simpson, G. G. 1964. Species density of North American Recent mammals. Systematic Zoology 13:57–73.

Sogge, M. K., D. Ahlers, and S. J. Sferra. 2010. A natural history summary and survey protocol for the Southwestern Willow Flycatcher: US Geological Survey techniques and methods 2A-10. US Department of Interior, Geological Survey, Reston, Virginia.

Soles, E. S. 2003. Where the river meets the ditch: Human and natural impacts on the Gila River, New Mexico, 1880–2000 [MS thesis]. Northern Arizona University.

S. S. Papadopulos & Associates (SSPA). 2013. Hydrologic alteration analysis of Gila River under potential CUFA conditions. Technical memorandum prepared for the New Mexico Interstate Stream Commission, October 2013.

Stefferud, J. A., K. B. Gido, and D. L. Propst. 2011. Spatially variable response of native fish assemblages to discharge, predators and habitat characteristics in an arid-land river. Freshwater Biology 56:1403–1416.

Stella, J. C., J. J. Battles, B. K. Orr, and J. R. McBride. 2006. Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California. Ecosystems 9:1200–1214.

Stoleson, S. H., and D. M. Finch. 2000. Landscape level effects on habitat use, nesting success, and brood parasitism in the Southwestern Willow Flycatcher: Report to the National Fish and Wildlife Foundation, Grant No. 99–254. USDA Forest Service, Rocky Mountain Research Station, Albuquerque, New Mexico.

Stromberg, J. C., B. D. Richter, D. T. Patten, and L. G. Wolden. 1992. Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53:118–130.

Tockner, K., F. Malard, and J. V. Ward. 2000. An extension of the flood pulse concept. Hydrological Processes 14:2861–2883.

Tockner, K., and J. A. Stanford. 2002. Riverine floodplains: Present state and future trends. Environmental Conservation 29:308–330.

United States Congress. 2004. Arizona Water Settlements Act, Public Law 108-451, 118 Stat. 3478 et seq.

United States Fish and Wildlife Service (USFWS). 1986a. Endangered and threatened wildlife and plants; Determination of threatened status for the loach minnow; Final rule. Federal Register 51:39486–39478.

———. 1986b. Endangered and threatened wildlife and plants; Determination of threatened status for the spikedace; Final rule. Federal Register 51:23769–23781.

———. 1995. Endangered and threatened species: Southwestern Willow Flycatcher; Final rule. Federal Register 62:39129–39147.

———. 2002. Southwestern Willow Flycatcher recovery plan. US Department of Interior, Fish and Wildlife Service, Albuquerque, New Mexico.

———. 2014a. Endangered and threatened wildlife and plants; Determination of threatened status for the western distinct population segment of the Yellow-billed Cuckoo (*Coccyzus americanus*); Final rule. Federal Register 79:59992–60038.

———. 2014b. Endangered and threatened wildlife and plants; Threatened status for the northern Mexican gartersnake and narrowheaded gartersnake; Final rule. Federal Register 79:38678–38746.

United States Forest Service, Southwest Region (USDA). 2002. Birds of the Gila National Forest: A checklist. Gila National Forest, Silver City, New Mexico.

van der Nat, D., K. Tockner, P. J. Edwards, J. V. Ward, and A. M. Gurnell. 2003. Habitat change in braided flood plains (Tagliamento, NE-Italy). Freshwater Biology 48:1799–1812.

Ward, J. V., and J. A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers 11:105–119.

Whitney, J. E., K. B. Gido, and D. L. Propst. 2014. Factors associated with the success of native fish species in an arid-land riverscape. Canadian Journal of Fisheries and Aquatic Sciences 71:1134–1145. doi: 10.1139/cjfas-2014-0153

Wilcox, A. C., and P. B. Shafroth. 2013. Coupled hydrogeomorphic and woody-seedling responses to controlled flood releases in a dryland river. Water Resources Research 49:2843–2860.

Yarnell, S. M., J. H. Viers, and J. F. Mount. 2010. Ecology and management of the spring snowmelt recession. BioScience 60(2): 114–127