

## SUPPLEMENTAL MATERIALS

*ASCE Journal of Water Resources Planning and Management*

# Opportunities for Restoring Environmental Flows in the Rio Grande–Rio Bravo Basin Spanning the US–Mexico Border

Brian D. Richter, Enrique Prunes, Ning Liu, Peter Caldwell,  
Dongyang Wei, Kyle Frankel Davis, Samuel Sandoval-Solis,  
Gabriela Rendon Herrera, Ramon Saiz Rodriguez, Yufei Ao,  
Gambhir Lamsal, Maria Amaya, Natalie Shahbol, and  
Landon Marston

**DOI:** 10.1061/JWRMD5.WRENG-6278

© ASCE 2023

[www.ascelibrary.org](http://www.ascelibrary.org)

**Table S1. Species imperiled by flow depletion.** Each of these species have been impacted by hydrological alteration and is now listed as being imperiled, either by the US Endangered Species Act (US Fish & Wildlife Service, 2003<sup>1</sup>), the Mexican Standard for Endangered Species (SEGOB, 2019)<sup>2</sup>, or by state-based natural heritage programs collaborating with NatureServe (2022).<sup>3</sup> List based on Richter et al. (2016),<sup>4</sup> with recent updates from Fullerton and Batts (2003),<sup>5</sup> NatureServe (2022), SEGOB (2019), and De la Maza Benignos (2009).<sup>6</sup> Global threat status ranges from G1 (least imperiled) to G5 (most imperiled); “T” rankings indicate subspecies status. Federal (US) ESA status categories include “LE” (listed endangered), “LT” (listed threatened), “XN” (presumed extirpated), and “C” (candidate for listing). Mexican status includes “E” (probably extinct in the wild), “P” (in danger of extinction), “A” (threatened), and “Pr” (subject to special protection).

Common Name	Taxonomic Name	GLOBAL STATUS	USESAs STATUS	MX STATUS
Aparique	<i>Oncorhynchus sp.</i>			E
Arizona Willow	<i>Salix arizonica</i>	G2		
Arkansas River Shiner	<i>Notropis girardi</i>	G2	LT	
Bagre de canal	<i>Ictalurus cf. punctatus</i>			
Bagre lobo	<i>Ictalurus cf. lupus</i>			Pr
Big Bend Gambusia	<i>Gambusia gaigei</i>	G1	LE	
Bluntnose Shiner	<i>Notropis simus</i>	G2		E
Brune Spring Snail	<i>Tryonia brunei</i>	G1		
Cachorrito cabezón	<i>Cyprinodon pachycephalus</i>			P
Cachorrito de Julimes	<i>Cyprinodon julimes</i>			P
Cachorrito del Conchos	<i>Cyprinodon eximius</i>			A
Cachorrito escamudo	<i>Cyprinodon macrolepis</i>			P
Caliente Tryonia	<i>Pseudotryonia alamosae</i>	G1	LE	
Carpa obispa	<i>Dionda cf. episcopa</i>			P
Carpa pecosa	<i>Macrhybopsis aestivalis</i>			A
Carpita adornada	<i>Codoma ornata</i>			A
Carpita chihuahuense	<i>Notropis chihuahua</i>			A
Carpita del Bravo	<i>Notropis jemezanus</i>			A
Carpita del Conchos	<i>Cyprinella panarcys</i>			P
Carpita roja	<i>Cyprinella lutrensis</i>			A
Carpita tamaulipeca	<i>Notropis braytoni</i>			A
Carpita texana	<i>Notropis amabilis</i>			A

Chihuahua Chub	<i>Gila nigrescens</i>	G1	LT	A
Chiricahua Leopard Frog	<i>Lithobates chiricahuensis</i>	G2	LT	A
Chupadera Springsnail	<i>Pyrgulopsis chupaderae</i>	G1	LE	
Comanche Springs Pupfish	<i>Cyprinodon elegans</i>	G1	LE	
Devils River Minnow	<i>Dionda diaboli</i>	G1	LT	P
Diamond Tryonia	<i>Pseudotryonia adamantina</i>	G1	LE	
Dorado mexicano	<i>Etheostoma pottsi</i>			A
Dorado, matalote chato o cuino común	<i>Carpiodes carpio</i>			A
Dune Flatsedge	<i>Cyperus onerosus</i>	G2		
Gonzales Springsnail	<i>Tryonia circumstriata</i>	G1	LE	
Guayacón de Dolores	<i>Gambusia hurtadoi</i>			Pr
Guayacón de San Gregorio	<i>Gambusia alvarezi</i>			P
	<i>Sternula antillarum</i>			
Interior Least Tern	<i>athalassos</i>	T2	LE	
Koster's Springsnail	<i>Juturnia kosteri</i>	G2	LE	
Least Tern	<i>Sternula antillarum</i>	G4	LE	Pr
Leon Springs Pupfish	<i>Cyprinodon bovinus</i>	G1	LE	
Limpia Creek Springsnail	<i>Pyrgulopsis davisii</i>	G1		
Little Aguja Pondweed	<i>Potamogeton clystocarpus</i>	G1	LE	
Many-stemmed Spider-flower	<i>Cleome multicaulis</i>	G2		
Matalote azul	<i>Cycleptus cf. elongatus</i>			Pr
Matalote bocón	<i>Ictiobus bubalus</i>			A
Matalote del Bravo	<i>Catostomus (Pantosteus) plebeius</i>			A
Matalote yaqui	<i>Catostomus bernardini</i>			Pr
Mexican Fawnsfoot	<i>Truncilla cognata</i>	G1		
Mogollon Clover	<i>Trifolium neurophyllum</i>	G2		
Naegele Springsnail	<i>Pyrgulopsis metcalfi</i>	G1		
Noel's Amphipod	<i>Gammarus desperatus</i>	G2	LE	
Organ Mountain Evening-primrose	<i>Oenothera organensis</i>	G2		
Parish's Alkali Grass	<i>Puccinellia parishii</i>	G2		

Pecos Assimineia	<i>Assimineia pecos</i>	G1	LE	
Pecos Bluntnose Shiner	<i>Notropis simus pecosensis</i>	T2	LT	E
Pecos Gambusia	<i>Gambusia nobilis</i>	G2	LE	
Pecos Pupfish	<i>Cyprinodon pecosensis</i>	G2		
Pecos Springsnail	<i>Pyrgulopsis pecosensis</i>	G1		
Pecos Sunflower	<i>Helianthus paradoxus</i>	G2	LT	
Perca o dardo del Conchos	<i>Etheostoma australe</i>			P
Phantom Cave Snail	<i>Pyrgulopsis texana</i>	G1	LE	
Phantom Tryonia	<i>Tryonia cheatumi</i>	G1	LE	
Rio Grande Darter	<i>Etheostoma grahami</i>	G2		A
Rio Grande Silvery Minnow	<i>Hybognathus amarus</i>	G1	LE, XN	E
Roswell Springsnail	<i>Pyrgulopsis roswellensis</i>	G2	LE	
Sacramento Mountains Thistle	<i>Cirsium vinaceum</i>	G2	LT	
Salina Mucket	<i>Potamilus metnecktayi</i>	G1		
San Felipe Gambusia	<i>Gambusia clarkhubbsi</i>	G1		
Sangre de Cristo Peaclam	<i>Pisidium sanguinichristi</i>	G1		
Smith's Whitlow-grass	<i>Draba smithii</i>	G2		
Socorro Springsnail	<i>Pyrgulopsis neomexicana</i>	G1	LE	
Southwestern Willow Flycatcher	<i>Empidonax traillii extimus</i>	T2	LE	
Stalkflower	<i>Nesaea longipes</i>	G2		
Texas Hornshell	<i>Popenaias popeii</i>	G1	C	
White Mountain Larkspur	<i>Delphinium novomexicanum</i>	G2		
White Sands Pupfish	<i>Cyprinodon tularosa</i>	G1		
Wright's Marsh Thistle	<i>Cirsium wrightii</i>	G2	C	

**Table S2. Natural flow depletion by month.** All flows are median values, in cubic meters per second. Based on 1990-2014 period. Daily natural flow estimates from Sandoval-Solis et al. (in preparation); measured flow data from US Geological Survey gauging stations.

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	AVERAGE
<b>Lobatos, Colorado</b>													
Natural flow	8.2	9.6	16.1	42.4	124.1	97.9	38.3	23.2	20.4	18.9	10.7	8.2	34.8
Observed flow	7.8	9.1	13.1	12.1	21.2	21.6	9.8	5.0	4.4	5.3	8.0	7.7	10.4
% Change	-5.0%	-6.0%	-18.4%	-71.6%	-82.9%	-77.9%	-74.4%	-78.5%	-78.3%	-71.9%	-25.4%	-6.7%	-70.1%
<b>San Marcial, New Mexico</b>													
Natural flow	26.3	28.8	49.1	107.5	226.0	164.6	68.6	47.8	41.5	38.4	32.6	26.9	71.5
Observed flow	16.9	18.1	16.2	25.7	46.0	38.1	13.2	11.8	7.0	6.4	18.5	19.0	19.8
% Change	-35.5%	-37.2%	-66.9%	-76.1%	-79.6%	-76.9%	-80.7%	-75.3%	-83.2%	-83.4%	-43.2%	-29.2%	-72.4%
<b>El Paso, Texas</b>													
Natural flow	29.8	31.6	51.1	106.9	226.1	172.5	74.5	54.6	47.5	44.5	37.8	31.1	75.7
Observed flow	2.8	4.2	17.3	16.8	16.0	26.5	29.0	25.2	17.7	8.9	3.4	2.5	14.2
% Change	-90.6%	-86.7%	-66.1%	-84.2%	-92.9%	-84.7%	-61.1%	-53.9%	-62.7%	-80.0%	-91.0%	-92.0%	-81.3%
<b>Johnson Ranch, Texas</b>													
Natural flow	59.8	67.2	103.2	215.9	241.8	125.8	179.8	278.7	281.4	123.0	67.2	60.4	150.3
Observed flow	15.3	14.4	11.1	9.1	14.7	26.0	31.5	45.9	91.6	56.9	15.6	10.7	28.6
% Change	-74.4%	-78.6%	-89.2%	-95.8%	-93.9%	-79.4%	-82.5%	-83.5%	-67.5%	-53.8%	-76.7%	-82.3%	-81.0%
<b>Anzalduas, Texas</b>													
Natural flow	198.4	205.9	260.7	448.3	482.2	338.2	574.2	520.2	772.9	480.3	269.1	189.8	395.0
Observed flow	32.5	34.3	38.3	64.6	77.6	70.4	85.0	71.2	43.5	58.9	26.8	21.3	52.0
% Change	-83.6%	-83.4%	-85.3%	-85.6%	-83.9%	-79.2%	-85.2%	-86.3%	-94.4%	-87.7%	-90.0%	-88.8%	-86.8%

**Table S3. Consumptive water use by individual crops in the western US.** Percentages are based on the volume of water consumed by the 30 crops included in Richter *et al.* (in review).

<b>Crop</b>	<b>% of irrigated area in western US</b>	<b>Volume of water consumed (km<sup>3</sup>)</b>	<b>% of irrigation consumption in western US</b>
Alfalfa	18.0	11.33	17.620
Other hay	5.7	2.320	3.608
Almonds	2.0	3.96	6.16
Apples	0.5	0.58	0.90
Barley	2.5	1.36	2.11
Canola	0.1	0.04	0.07
Corn	29.7	14.00	21.78
Cotton	7.4	7.26	11.3
Dry beans	0.9	0.46	0.7
Grapes	1.6	2.48	3.9
Lentil	0.02	0.01	0.01
Millet	0.1	0.04	0.1
Oat	0.5	0.48	0.7

Orange	0.4	0.69	1.1
Peanut	0.5	0.38	0.6
Peas	0.1	0.05	0.1
Pecan	0.1	0.21	0.3
Potato	1.9	0.66	1.0
Rice	1.7	1.59	2.5
Sorghum	2.6	1.69	2.6
Soybean	9.5	5.20	8.1
Sugar beets	1.1	0.86	1.3
Sugarcane	0.1	0.10	0.2
Sunflower	1.0	0.54	0.8
Sweet corn	0.2	0.15	0.2
Tomato	0.7	0.60	0.9
Walnut	0.7	1.19	1.9
Durum wheat	0.6	0.34	0.5
Spring wheat	1.9	1.16	1.8

Winter wheat	7.9	4.57	7.1
<b>Total</b>	<b>100</b>	<b>64.30</b>	<b>100</b>



## References

US Fish & Wildlife Service. 2003. “Endangered Species Act of 1973 as Amended Through the 108<sup>th</sup> Congress.”

<https://www.fws.gov/sites/default/files/documents/endangered-species-act-accessible.pdf>

SEGOB (Secretario del Gobernacion). 2019. “Anexo Normativo III, Lista de Especies en Riesgo de la Norma Oficial Mexicana

NOM-059-SEMARNAT-2010.” [https://www.dof.gob.mx/nota\\_detalle.php?codigo=5578808&fecha=14/11/2019#gsc.tab=0](https://www.dof.gob.mx/nota_detalle.php?codigo=5578808&fecha=14/11/2019#gsc.tab=0)

NatureServe. 2023. “Our Work.” <https://www.natureserve.org/our-work>

Richter, B.D., E.M. Powell, T. Lystash, and M. Faggert. 2016. “Protection and Restoration of Freshwater Ecosystems.” In: *Water Policy and Planning in a Variable and Changing Climate*, edited by Kathleen A. Miller, Alan F. Hamlet, Douglas S. Kenney, and Kelly T. Redmond, Chapter 5: 81-106. Boca Raton, FL: CRC Press - Taylor & Francis Group.

<https://www.taylorfrancis.com/chapters/edit/10.1201/b19534-5/protection-restoration-freshwater-ecosystems-brian-richter-emily-maynard-powell-tyler-lystash-michelle-faggert>

Fullerton, W. and D. Batts. 2003. “Hope for a Living River.” Albuquerque, New Mexico: The Alliance for the Rio Grande Heritage.

De la Maza Benignos, M. (editor). 2009. Los Peces del Río Conchos. Alianza WWF - FGRA y Gobierno del Estado de Chihuahua.