Meadows Report 24-003

State of the Devils River Report

The Meadows Center for Water and the Environment
Texas State University

MEMBER THE TEXAS STATE UNIVERSITY SYSTEM

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State of the Devils River Report

Prepared by

(listed in alphabetical order)

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Produced by The Meadows Center for Water and the Environment in Partnership with

The Devils River Conservancy

The Nature Conservancy-Texas

The Texas Parks and Wildlife Department

December 2024

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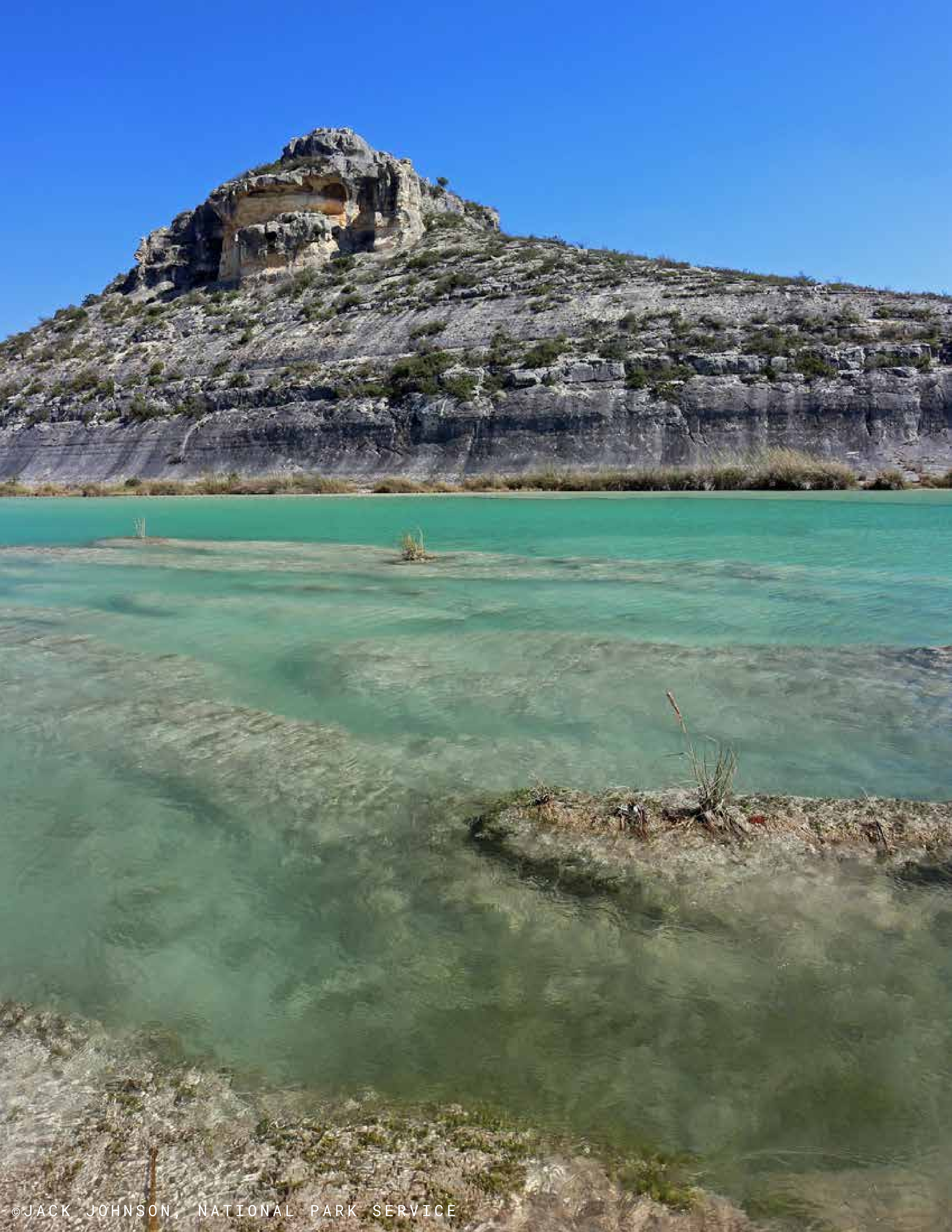
This report was produced by The Meadows Center for Water and the Environment at Texas State University, in partnership with The Devils River Conservancy, The Nature Conservancy-Texas, and the Texas Parks and Wildlife Department.

This collaborative science endeavor was shaped by four distinct Technical Teams and the report carries the voices of our diverse expert contributors, as well as the region's stakeholders and stewards.



Acknowledgments

This report is dedicated to the stakeholders and committed professionals whose passion shaped the contents and whose commitment to the ongoing stewardship of the river inspires us all.

The Project Team would like to offer special acknowledgments to several individuals whose vision for this effort guided us through tumultuous waters as the project changed shape to address the complex needs and history of the region. Our gratitude goes to the previous Executive Directors of the Devils River Conservancy: Julie Lewey, who identified the opportunity to bring the communities of the region together to organize around shared priorities, and Mandy Krause, who launched the effort and helped to anchor it in community trust and relationship-building. Additionally, we would like to honor Skip Newsom, a dedicated advocate for the Devils River whose legacy has served as a guiding light and needed bolster in ensuring that this report be the spark for meaningful action for the benefit of the river and those who steward it.

We also extend our heartfelt gratitude to the 12 members of the Stakeholder Jury (listed below) for their dedication and invaluable contributions. This report benefits immensely from your diverse perspectives, which have helped ensure it reflects the wide-ranging interests and concerns of the community. We appreciate the time and effort you have volunteered to guide this work towards a balanced and representative outcome. Thank you for your thoughtful participation and for shaping a shared vision for the watershed's future.

- Romey Swanson (Foreman)
- Amanda Evridge
- Beau Nettleton
- Dell Dickinson
- Frank Tambunga
- Jim Norman
- Merily Keller
- Philip Walker
- Randy Nunns
- Ruthie Russell
- Tino Pruneda
- Thad Jarrett

Contents

List of Figures

List of Tables

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List of Acronyms and Abbreviations

cfs	Cubic Feet per Second
DAH Unit	Dan Allen Hughes Unit
DRAP	Devils River Access Permit
DRC	Devils River Conservancy
HUC	Hydrologic Unit Code
IBWC	International Boundary and Water Commission
Meadows Center	The Meadows Center for Water and the Environment-Texas State University
NGO	Non-Profit Organization
NPS	National Park Service
RACA	River Access and Conservation Areas
State Natural Area	Devils River State Natural Area
TCEQ	Texas Commission on Environmental Quality
Texas Parks and Wildlife, TPWD	Texas Parks and Wildlife Department
TNC	The Nature Conservancy, Texas Chapter

Glossary

Aquifer: A geologic formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Baseflow: The component of sustained natural surface water flow, in the absence of direct runoff from precipitation, that can be attributed to natural groundwater discharge from an aquifer to streams.

Bathymetry: The study of the depth of a body of water, such river and essentially refers to the "topography" of the underwater terrain, just like topography describes the shape and features of the land above water.

Benthic: Relating to, or occurring at the bottom of a body of water

Cubic Feet Per Second (cfs): A unit of flow rate commonly used for measuring water flow in rivers and streams.

Confined Aquifer: An aquifer that is fully saturated, where the water is under pressure.

Edwards-Trinity Plateau Aquifer: A karst aquifer that underlies the Devils River in Texas. Recharge in karst terrain such as this occurs primarily through episodic flows in drainage channels, and the aquifer discharges at springs and seeps into the Devils River.

Eurythermal: The ability to tolerate or adapt to a wide range of temperatures.

Evapotranspiration: The combined process of evaporation (water turning into vapor) from the Earth's surface and transpiration (water vapor released from plants).

Groundwater: Water that fills the pore spaces of rock or soil beneath the Earth's surface.

Groundwater-Dependent Ecosystem: An ecosystem that relies on groundwater for its survival.

Hydrologic Landscape Region: A framework for regionalizing streamflow assuming that watersheds with similar slopes, soils, geology, and climate respond in the same way to precipitation and groundwater and surface-water interactions.

Inter-Aquifer Flow: Groundwater flow between aquifers.

Karst: A type of landscape that is formed by the dissolving of bedrock, such as lime-stone and characterized by springs, sinkholes, and caves.

LiDAR: An acronym for Light Detection and Ranging, a remote sensing method that uses light pulses to measure distances and create detailed maps of the Earth's surface.

Major Aquifer: An aquifer that produces large amounts of fresh groundwater over large areas of the state.

Mesohabitat: A relatively homogeneous area within a stream that is visually distinct from other areas and differs in characteristics such as depth, velocity, and substrate.

MODIS: An acronym for Moderate Resolution Imaging Spectroradiometer, a satellite-based sensor that collects data on various Earth observation parameters, including land surface temperature and vegetation.

Permeability: The ability of rock or soil to allow fluids to pass through.

PRISM: An acronym for Parameter-Elevation Relationships on Independent Slopes Model, which provides data on various climate factors, including precipitation.

Groundwater Storage: In confined aquifers consists of water stored under pressure in the saturated system (confined groundwater) plus water released as the aquifer physically drains under atmospheric pressure (unconfined groundwater).

Groundwater Availability Model: A computer model that simulates the movement and storage of groundwater in an aquifer.

Recharge: The process of adding water to an aquifer. This can happen through various ways, such as rainfall infiltrating the ground or surface water soaking into the ground.

Soil Conservation Service Method: A simple method for estimating recharge based on precipitation, soil type, and land use Tributary aquifer: An aquifer that discharges groundwater to surface water.

Soil & Water Assessment Tool: A complex hydrologic model that simulates various water cycle components, including evapotranspiration, runoff, and recharge.

Specific Conductance (SC): A measure of the ability of a substance to conduct electricity. In water, it is influenced by the concentration of dissolved ions.

Stenothermal: The ability to tolerate only a small range of temperature.

Telemetry: Collecting measurements or data points at remote locations and automatically transmitting it to receiving equipment for monitoring.

Total Maximum Daily Load: A regulatory term that refers to a plan for restoring water quality by identifying the maximum amount of pollutants a body of water can receive.

Watershed: An area of land that drains into a specific body of water, such as a river, lake, or ocean.

INTRODUCTION

Nestled in the rugged expanse of southwest Texas, the Devils River sets a gold standard in natural beauty and ecological significance among the state's river systems. Renowned for its crystalline waters and the diverse ecosystems it sustains, the river transcends geography to embody a cherished heritage that unites a diverse community of stewards, including landowners, ranchers, conservationists, and public leaders.

This report emerges from a collaborative effort to weave together historical data, ongoing research, and community insights to forge a comprehensive understanding of the current state of the Devils River. It aims to provide a transparent overview that not only details the river's condition and our understanding of its functions but also to highlight the opportunities and information still needed to safeguard this vital shared resource.

As stewards of the Devils River, stakeholders face a complex array of challenges, ranging from the impacts of land use changes to the pressures of recreational overuse. This report intentionally focuses on known data and attempts to present areas of conflicting understanding of some of the river's history, threats, and functions – the aim is to establish a singular resource for the stakeholders of the region to reference in any future efforts to identify, prioritize, and or implement management strategies in the region.

The purpose of the State of the Devils River report is to 1) create a centralized reference regarding the current state of knowledge of the Devils River watershed; 2) identify information gaps; 3) gather experts to make recommendations for how information gaps can best be addressed; and 4) engage stakeholders in sharing their expertise, strengthening relationships with fellow stakeholders and experts working in the region, and identifying areas for possible future collaboration.

The report that follows represents the work and trust of over 30 contributing authors and dozens of stakeholders from across the region. The story of the Devils River is both informative and inspiring and shares a collective commitment to preserve the character of the communities, families, and ecosystems nurtured and defined by this precious resource.

History of the Project

The Devils River Conservancy, with support from conservation partners, was awarded a 2021 WaterSMART Phase I Grant[1] to support the development of a watershed group who would identify restoration and conservation priorities for the Lower Devils River watershed in Southwest Texas. The primary objectives were to 1) identify and incorporate all stakeholder interests, 2) create a shared vision for a sustainable and resilient watershed, 3) build community trust and resolve conflict, 4) jointly identify, prioritize, and carry-out projects to address watershed data gaps and restoration needs, and 5) identify water supply management solutions to protect the varied interests and the water supply for future generations.

The project was intended to address critical watershed conservation, restoration, and planning issues in the Lower Devils River watershed, which is comprised of approximately 482 square miles in the Hydrologic Unit Code (HUC) 13040302,

1 *Lower Devils River Watershed Restoration and Conservation Planning Group Proposal; Phase I Grant FY2021; Funding Opportunity Announcement (FOA): BOR-DO-21-F003; Opportunity Package ID: PKG00264154.*

located in Southwest Texas in rural Val Verde County along the Texas-Mexico border. The perennially flowing reach of the river begins south of the ghost town of Juno, Texas at Pecan Springs. The river flows south for approximately 60 miles before reaching the Amistad International Reservoir and Recreation Area formed by the Amistad Dam on the Rio Grande. The project area was defined by the lower watershed's hydrologic bounds, as illustrated in Figure 1.

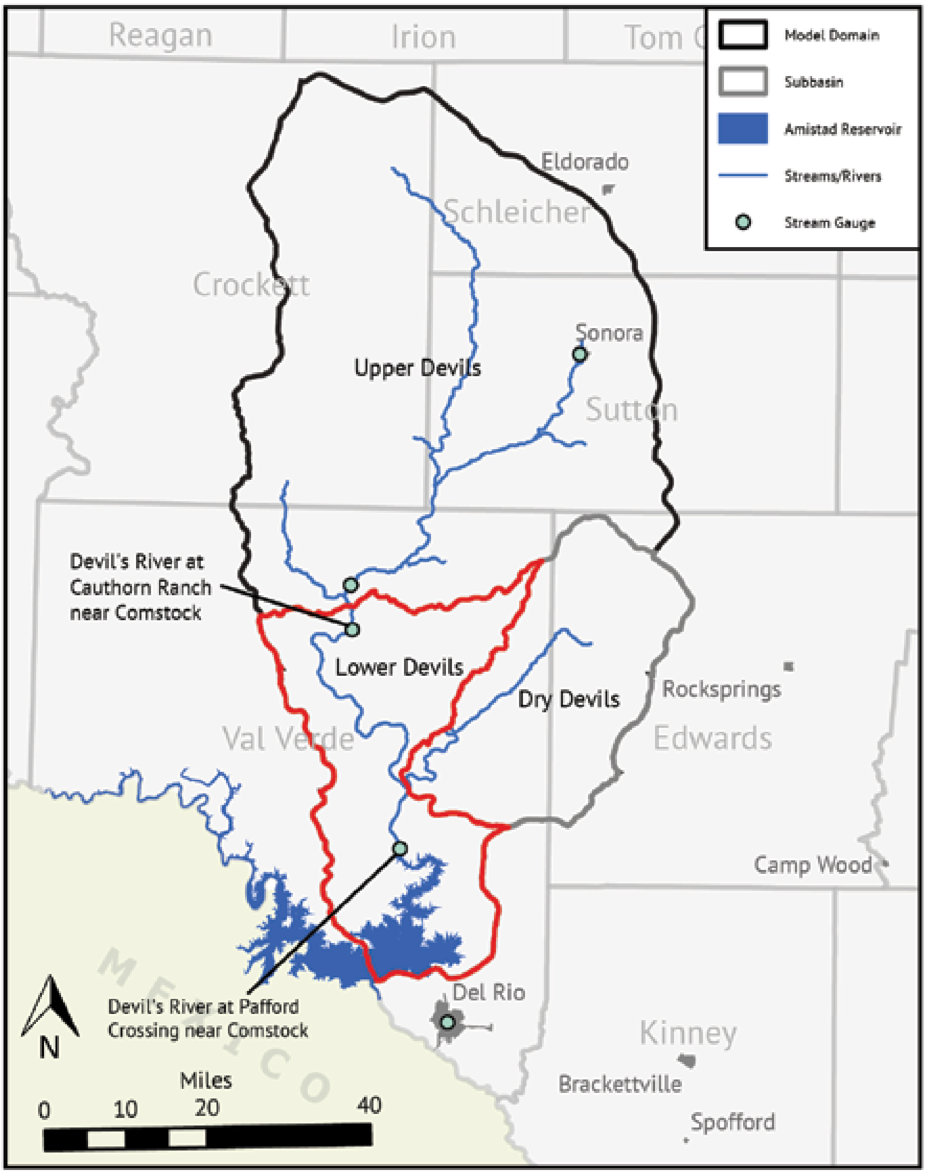

Figure 1. Map showing the project area – Lower Devils River watershed outlined in red (Devils River Conservancy [DRC], 2021).

While all of the perennially flowing waters occur within the Lower Devils River HUC, the Devils River watershed contains two additional 8-digit HUCs (13040301 and 13040303). Stakeholders who affect or are affected by water quantity or quality in the entirety of the Devils River watershed, including the Upper and Dry Devils HUCs, will be included. A detailed map that consists of these stakeholder "boundaries" was developed and is illustrated in Figure 2.

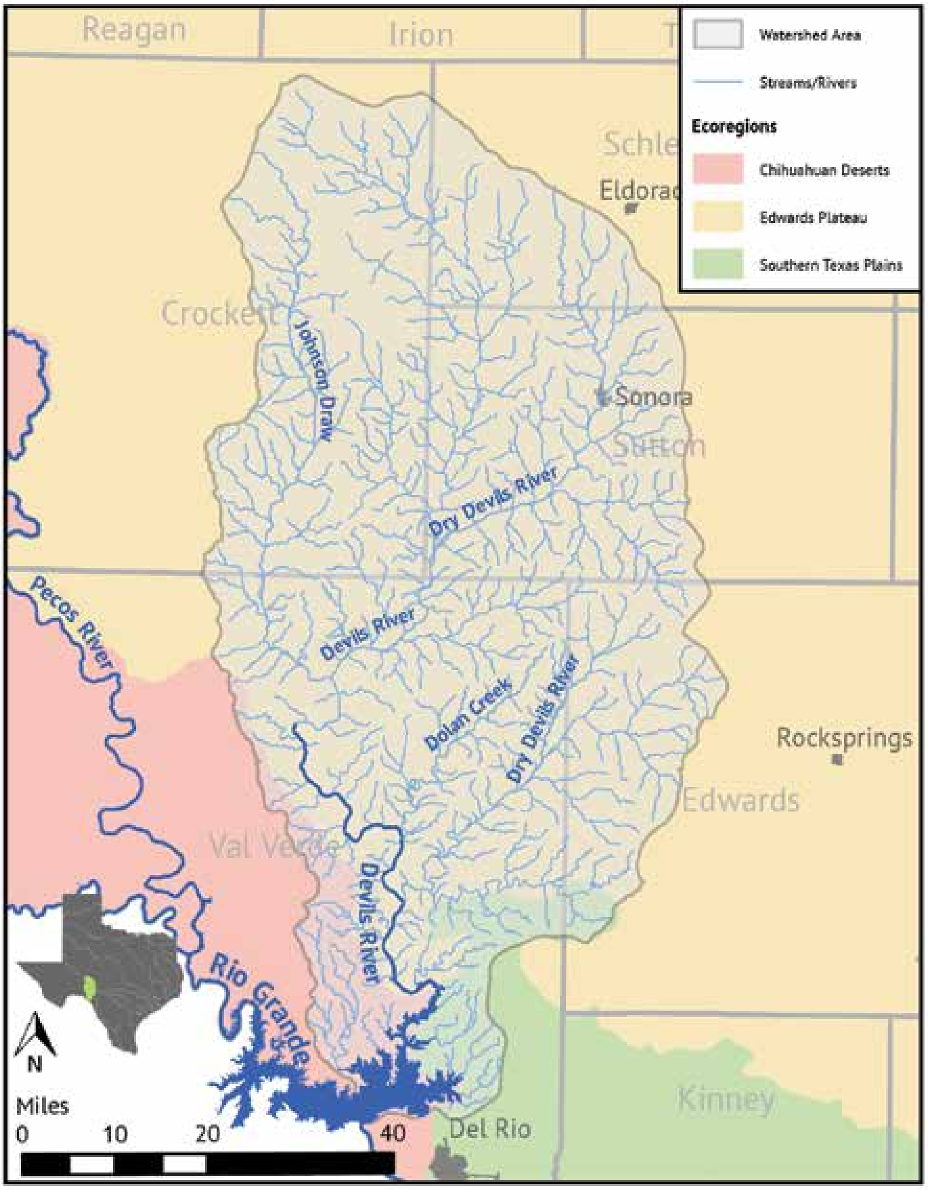

Figure 2. Watershed area, ecoregions, and perennially flowing reaches (darker blue line) of the Devils River, Texas (DRC, 2024; adapted from Robertson et al., 2019).

Early feedback (February 2023) on this effort from the region's stakeholders revealed the need to establish greater trust in both the process and the information referenced before engaging in any identification or prioritization of watershed needs or attempts at creating a shared vision for the watershed.

The region has been at the crossroads on several important watershed management questions in the recent past, only to find that data and/or research related to the nature of the river or associated groundwater was itself in dispute. This project presented an opportunity to build trust and bolster relationships amongst stakeholders through the creation of a comprehensive resource that could everyone to 'sing from the same hymnal.' The Meadows Center for Water and the Environment, acting as the project's neutral third party, initiated a collaborative research effort engaging four teams of technical experts (both academic and stakeholder) to summarize the current understanding of the Devils River regarding four priority topic areas: groundwater science, water quality, species and flow needs, and sustainable recreation. Each team was led by a member of the project's sponsoring partners (Devils River Conservancy, The Nature Conservancy–Texas, and Texas Parks and Wildlife) and facilitated by a member of the Meadows Center team.

While the project team aimed for full participation from everyone in the watershed, the large size of the Devils River watershed and the time commitment required raised concerns about collecting feedback that is both fair and representative of the region's diversity. To address this, the Meadows Center created a "Stakeholder Jury", and after making an open call for volunteers/nominations, selected 11 jurors by a live random drawing on July 2024. The Executive Director of the Devils River Conservancy was appointed as the jury's foreman to encourage continuity for any future planning efforts identified by the jury.

This Jury was established to ensure that diverse stakeholder voices are represented and have vetted the report's content and engagement process. The Jury is not superior to other stakeholders, and stakeholders not participating in the jury process were continuously queried for their feedback. The jury approach was intended to ensure that this effort received review that at least approximated the diverse viewpoints from across the watershed. Additionally, the formation of the jury allowed an opportunity representatives of the region to collaboratively develop a vision statement for future collaborative work in the region and add additional content to the report in a dedicated "Stakeholder Jury Chapter" that would not be influenced or constrained by the content produced by the Technical Teams or the Meadows Center.

This State of the Devils River report follows the following format:

Chapters 1-4: State of the Science and Future Research and Collaboration Opportunities

This section characterizes the current state of knowledge on the Devils River. It includes an overview of the existing literature pertaining to groundwater science, water quality, species and their flow needs, and sustainable recreation in the Devils River watershed. Overall conclusions from the existing literature are summarized, and areas of conflicting opinions are discussed.

This section identifies data gaps in the existing literature and highlights the remaining questions facing the watershed. Recommendations for future research and monitoring are summarized.

Chapter 5: Stakeholder Chapter

This section was crafted by the Stakeholder Jury and informed by the feedback received from stakeholders throughout the process. This chapter includes: Jury findings regarding the report process and content, a shared vision for future collaboration in the watershed, a list of priority actions and next steps for the safeguarding of the Devils River.

Chapter 6: Devils River Annotated Bibliographies by Topic

This section provides a primer on the most important published literature related to each of our four topic areas: Groundwater Science, Water Quality, Species and Flows, and Sustainable Recreation. The project's Technical Teams selected and summarized these resources to further the shared understanding of the watershed.

Appendices

- *Appendix A: Historic Spring Conditions*
- *Appendix B: Facilitation Process and Project Design*
- *Appendix C: Jury Materials*
- *Appendix D: Stakeholder Comments*
- *Appendix E: Recommendations for Further Research, Monitoring, and Collaboration in the Devils River Watershed*

Comprehensive Devils River Literature List

This section includes citations for the known literature associated with the Devils River. (Physical copies of all available resources were obtained and catalogued by the Meadows Center as a part of this project and will be shared with the Devils River Conversancy for long-term storage and stakeholder access.)

This report was compiled by the Meadows Center for Water and the Environment in coordination with the grant's planning team (representing the Devils River Conservancy, The Nature Conservancy, and Texas Parks and Wildlife) and 30 additional volunteer experts who conducted literature reviews, identified and described priority references, and highlighted the remaining research needs and opportunities for the report's study areas: groundwater science, water quality, species and flows, and sustainable recreation.

Special appreciation goes to these distinguished subject matter experts who generously gave their time to serve on the project's four Technical Teams and continue to make significant contributions to this project and the Devils River:

Groundwater Science Team

facilitated by Carrie Thompson, Meadows Center:

- Abi Bhattachan, Texas Tech University
- Bill Hutchison, Independent Groundwater Consultant
- Brian Hunt, University of Texas–Bureau of Economic Geology (Team Lead)
- David Young, Texas Parks and Wildlife
- Dimitrios Stampoulis, Southwest Research Institute
- Jennifer Badhwar, Texas Water Development Board
- Marcus Gary, Edwards Aquifer Authority (Team Lead)
- Ron Green, Contractor–Southwest Research Institute
- Ryan Smith, The Nature Conservancy–Texas (Team Lead)
- Tom Keller, Devils River Association
- William Asquith, U.S. Geological Survey–Lubbock

Sustainable Recreation Team

facilitated by Sarah Wingfield, Meadows Center:

- Adam Munoz, National Park Service–Amistad National Recreation Area
- Alli Hatten, Texas Parks and Wildlife

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- Andy Iverson, Devils River Conservancy and River Landowner
- Asa Vermeulen, Texas Parks and Wildlife–State Natural Area (Team Lead)
- Dani Miller, Devils River Conservancy (Team Lead)
- Jack Johnson, National Park Service–Amistad National Recreation Area
- Jordan Vincent, Devils River Conservancy
- Nicki Carr, Amistad Expeditions
- Nora Padilla, Texas Parks and Wildlife

Species and Flows Team

facilitated by Anna Huff, Meadows Center:

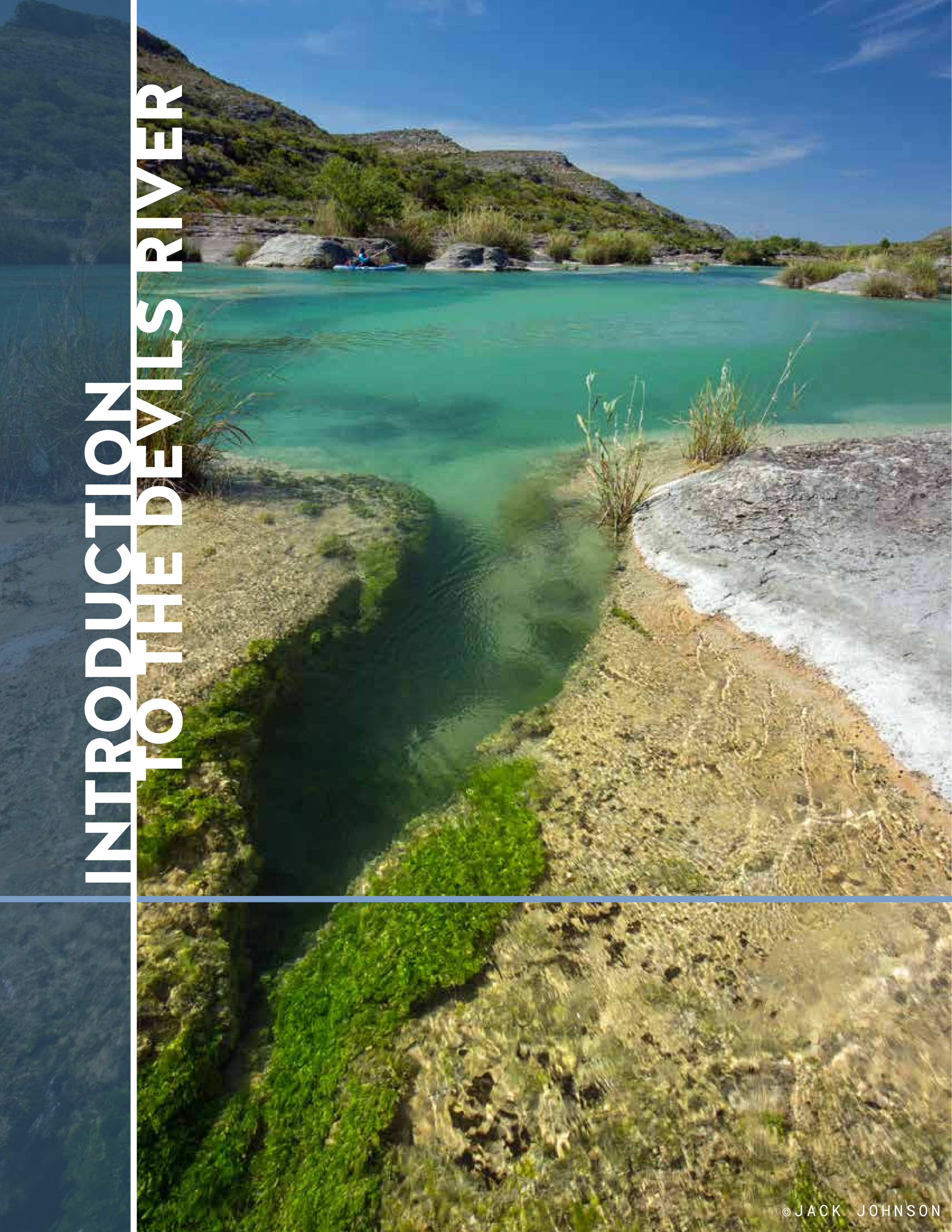
- Charles Randklev, Texas A&M University Natural Resources Institute
- Clay Richardson, Landowner
- Clint Robertson, Texas Parks and Wildlife
- Courtney Dvorsky, U.S. Fish and Wildlife Service–Austin
- Craig Farquhar, Texas State University (Team Lead)
- Louis Harveson, Borderlands Institute
- Maritza Mallek, U.S. Fish and Wildlife Service–Austin
- Mike Montagne, U.S. Fish and Wildlife Service–San Marcos
- Peter Diaz, U.S. Fish and Wildlife Service–San Marcos
- Randy Gibson, U.S. Fish and Wildlife Service–San Marcos
- Sarah Robertson, Texas Parks and Wildlife (Team Lead)

Water Quality Team

facilitated by Desiree Jackson, Meadows Center:

- Romey Swanson, Devils River Conservancy (Team Lead)
- Sam Stiffler, International Boundary and Water Commission

INTRODUCTION TO THE DEVILS RIVER



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Legend has it that, in the fall of 1848, former Texas Ranger Captain John Coffee "Jack" Hays, upon arriving at the edge of the gorge, said "Saint Peter, hell! It looks more like the devil's river to me!" giving the Devils its name (Dearen, 2011). Captain Hays referred to Saint Peter because that was the name—San Pedro—early Spanish explorers bequeathed to the river in 1675. Before that, the Native American guides for the 1675 Spanish expedition referred to the river as the Dacate, although the origin and meaning of this term are unknown (Cox, 2014). The Devils moniker stuck and is an homage to the rough terrain on either side of the river.

The name "Devils" is, in a way, ironic in that the river bottom is a linear oasis of springflow that shimmers in emerald and azure before quietly slipping into Lake Amistad and the Rio Grande. There is at least a 13,000-year long history of human activity in the area due to spring-fed creeks and rivers in a typically dry and dusty landscape (Boyd et al., 2023). Numerous cliffs in the valley reveal vivid paintings of Native Americans telling their history and honoring their gods.

The Devils River watershed is about 3,961 square miles in area and is entirely underlain by the Edward-Trinity (Plateau) Aquifer, a regional aquifer extending as far west as 17 miles east of Van Horn. The Edwards-Trinity is known to host springs at its margins, where erosion at the edges of the plateau daylights younger geologic formations and, in places, the water table.

Rising in northwest Sutton County, the Devils River flows south through Val Verde County to join the Rio Grande near Del Rio. The total length of the river is approximately 100 miles. Because of the arid nature of the region through which it flows, the Devils River is intermittent for much of its length. The Devils River, where it flows, is defined by its cool, seafoam to blue-green, spring-fed waters. These waters provide an oasis for the local ecology, sustenance for limited agriculture and livestock, a refuge from the summer heat for residents and recreationists, a high-quality contribution to an internationally shared water resource, and an indelible tie to thousands of years of human history. The Devils River is also one of the most remarkably beautiful bodies of water you will ever see, an unexpected gem in the middle of a rough and tumble Texas desert.

The Devils, like every other freshwater resource in Texas, has drawn new attention in our modern era as a desperately thirsty state looks for ways to meet its water needs. The current equilibrium (of pumping and springflow) has been maintained for about 50 years but may be threatened as conditions change (Meadows Center, work in progress).

Geographic Scope

The Devils River watershed's 3961.4 square miles span Schleicher, Crockett, Sutton, Edwards, and Val Verde counties in Texas (Figure 3) (Devils River Conservancy [DRC], 2021; United States Geo-logical Survey [USGS], 2000). The geography of the Devils River watershed makes water the most im-portant resource for all life and activity in the area. Most surface water in the region comes from the Devils River and Amistad Reservoir, and groundwater comes from the Edwards-Trinity (Plateau) Aquifer (De La Cruz, 2004; George et al., 2011). The Edwards Plateau is characterized by its composition of oak, juniper, mesquite, and range grasses.

The watershed is divided into the Upper (HUC 13040301), Lower (HUC 13040302), and Dry (HUC 13040303) Devils River drainage basins, which help drain a large portion of the southern Edwards Plateau ecoregion (Toll et al., 2017). The headwaters of the Devils River rise in northcentral Val Verde County at Pecan Springs and run southwest for 60 miles before discharging into the Rio Grande River at Amistad International Reservoir, a dam and recreational area managed by the United States and Mexico, in southern Val Verde County (DRC, 2023a; Texas Water Development Board [TWDB], n.d.)

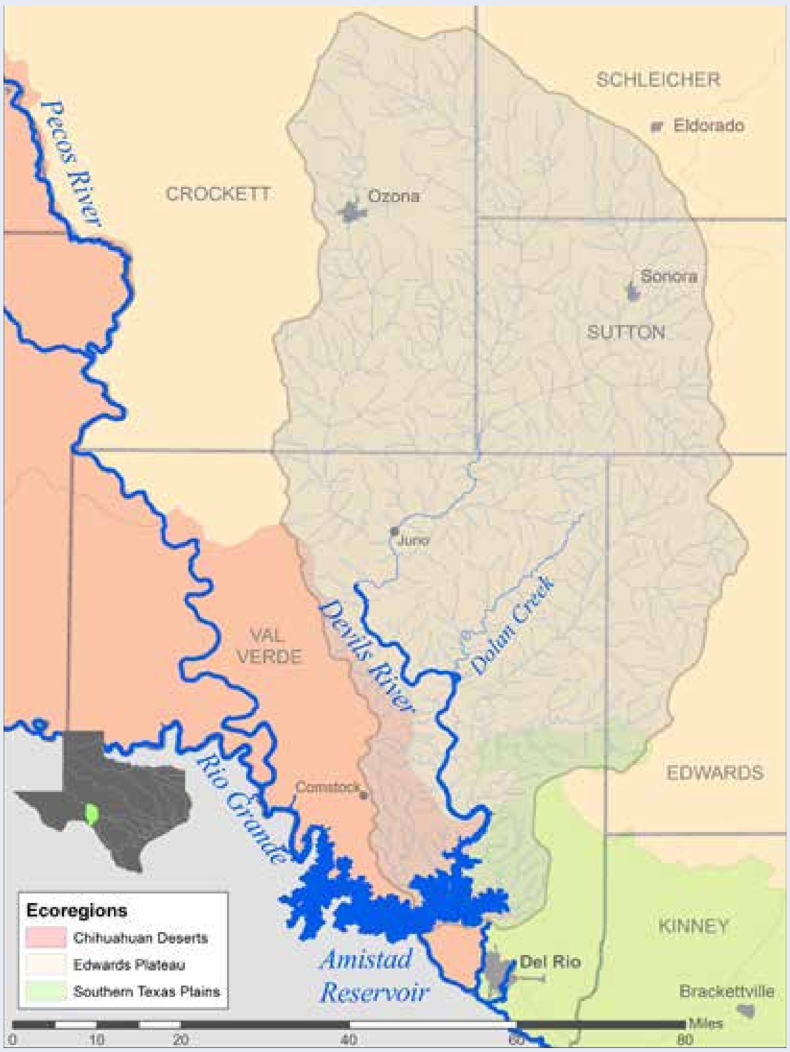

Figure 3. Watershed area, ecoregions, and perennially flowing reaches (darker blue line) of the Devils River, Texas (Robertson et al., 2019).

The **Upper Devils River** watershed is contained primarily in Crockett and Sutton counties but also expands into Schleicher, Edwards, and Val Verde counties (Figure 3). Located within southwest Texas, the landscape is described as rolling to hilly to steep terrain with flat divides and karst topography (Hosmer, 2021; Smith, 2021; USGS, 2000). Soils supporting the landscape are generally shallow and stony but also include stony clays and clay loams. Mineral resources in the area include dolomite, limestone, and moderate-sized oil and gas reserves.

The **Lower Devils River** watershed is contained entirely in Val Verde County (Figure 3). The landscape is described as a flat "plateau cut by many arroyos and canyons" (Smith, 2020). The Southern Texas Plains vegetation is comprised of thorny shrubs and mesquite grasslands (Texas Parks and Wildlife Department [TPWD], n.d.). The Chihuahuan Desert vegetation is comprised of desert scrub and grasses. Soils that support the landscape are stony clays and clay loams. Mineral resources in the area include dolomite and limestone (USGS, 2000).

The **Dry Devils River** watershed is contained within Edwards and Val Verde County (Figure 3). The landscape is described as flat to rolling terrain "with many hills and caves" (McCrain, 2020). The Southern Texas Plains vegetation is comprised of thorny shrubs (TPWD, n.d.). Soils that support the landscape are stony clays and clay loams. Mineral resources found in the area include iron, sulfur, and silver deposits. (The Dry Devils watershed is not to be confused with an intermittent segment of the upper Devils River in Sutton and Schleicher counties, also known as the Dry Devils River. Both features are labeled in Figure 4.

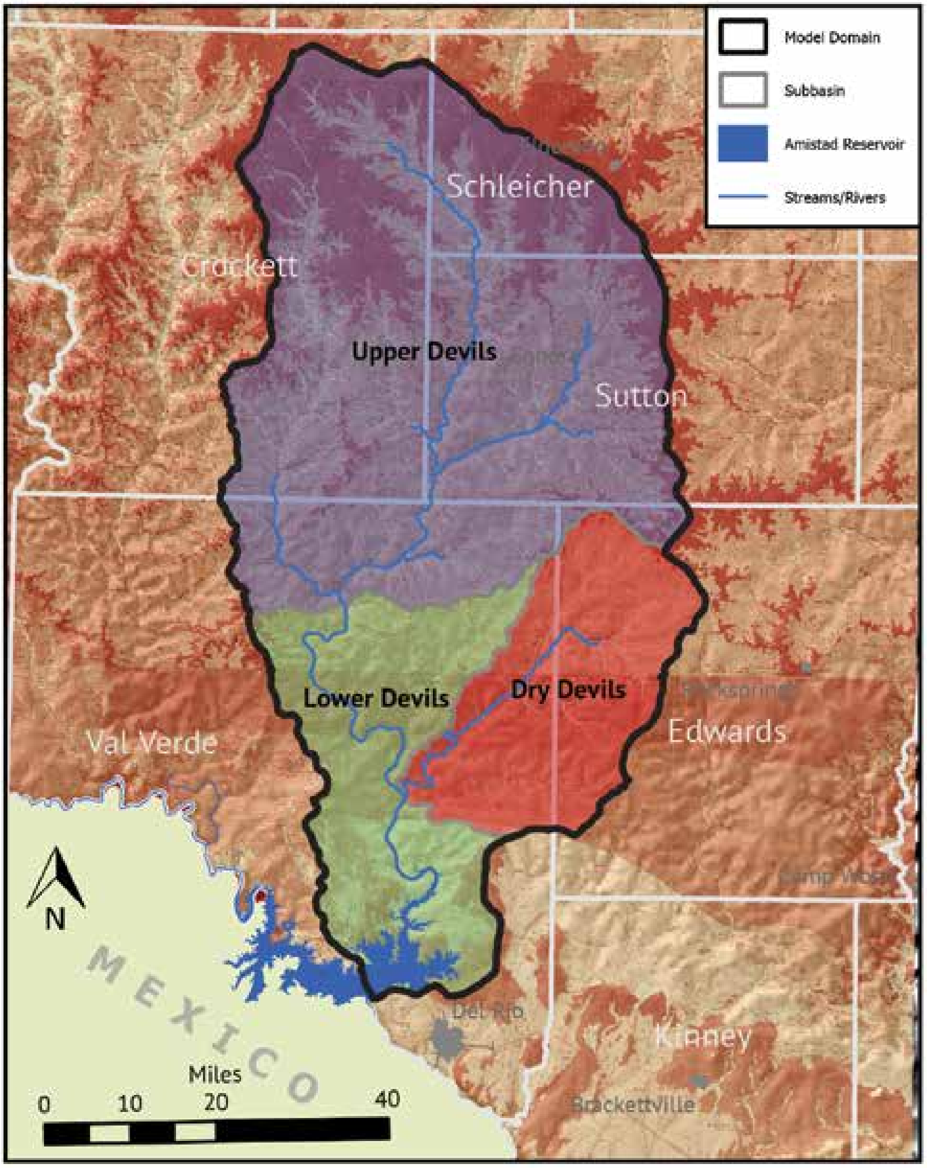

Figure 4. Location map of the sub-basins included in the Devils River watershed groundwater model (DRC, 2024; adapted from Toll et al., 2017).

The Devils River watershed supports diverse wildlife, including mountain lions, bobcats, coyotes, deer, javelina, foxes, raccoons, opossums, armadillos, porcupines, squirrels, ringtails, badgers, skunks, gophers, several species of rabbit, several species of bat, and several species of rats and mice (Brant & Dowler, 2001). The area provides habitat for many bird species, including black-capped vireo, golden-cheeked warblers, bald eagles, golden eagles, roadrunners, great horned owls, and more (Bird Watcher's Digest [BWD], n.d.; DRC, 2021). The area also provides habitat to an array of fish species, with the Devils River being named a Native Fish Conservation Area to protect freshwater species, including largemouth bass, longear sunfish, bluegill, headwater catfish, largespring gambusia, and many more (Kollaus & Bonner, 2012).

Indigenous History

The Lower Pecos River Archeological region (Lower Pecos region) encompasses an area of nearly 7,900 square miles in southwestern Texas and northwestern Coahuila, Mexico, and is centered at the confluence of the Pecos and Devils Rivers with the Rio Grande (Howard, 2016; Steelman et al., 2021; Turpin & Eling, 2018) (Figure 5). The State Natural Area, located about 60 miles north of Del Rio along the lower Devils River, is near the east edge of the Lower Pecos Cultural Area, which contains nearly all of Val Verde County and parts of the adjoining counties. The region is considered to hold one of the longest, best-preserved, and most detailed records of human activity in Texas and North America (Turpin, 1994).

On and adjacent to the DAH Unit of the State Natural Area, a total of 143 archeological sites are now recorded, with 92 percent of these known sites located

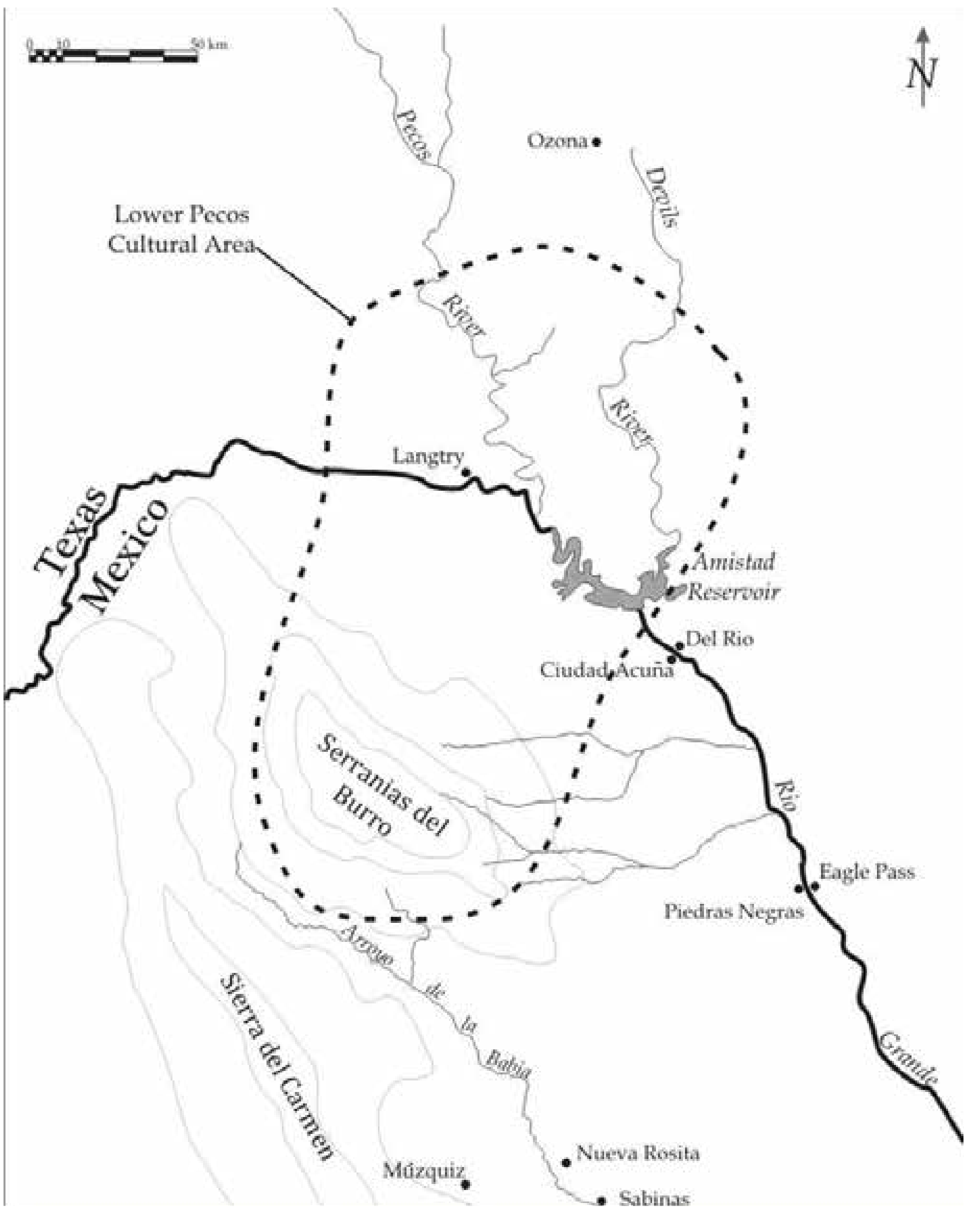

Figure 5. Map of the Lower Pecos Region (Turpin & Eling, 2018).

entirely on the DAH Unit. Texas Parks and Wildlife archeologists found many of these sites during surveys conducted between 2010-2014. The earliest human occupation in the Lower Pecos region, dating back between 14,500 and 12,000 years ago in the Paleoindian period, is evidenced by artifacts found in rockshelters, including broken and burned animal bones as well as chipped stone tools and flakes. Various cultural lance and dart points found in the area show evidence of activities during the late Paleoindian period dating back between 9,400 and 8,800 years ago. These Paleoindian hunting and gathering activities were rare on the DAH Unit and took place in the uplands (Howard, 2016).

During the Early Archaic period in the Lower Pecos region, between 8,800 and 5,500 years ago, Indigenous communities developed diverse dart point styles, began baking in rock-lined pit ovens, established weather-protected camps in rockshelters, and engaged in various ritual practices, including the creation of portable spiritual items. Popular foods during this time were deer and prickly pear cactus (Howard, 2016).

The distinctive, multicolored Pecos River rock art style first appeared in the region during the Middle Archaic period, between 5,500 to 3,200 years ago. These pictographs featured human and animal forms, as well as geometric shapes (Figure 6). Many pictographs were produced using paint recipes, mainly consisting of inorganic, mineral-based pigments with additions of organic materials as binders. Little is known about the organic materials used in paintings, as most organic materials cannot be chemically identified. However, these materials are detectable, with some being identified as ungulate (deer or bison), tallow, or marrow (Howard, 2016; Steelman et al., 2021). During this time, human activities in the canyonlands increased while activities in the uplands decreased. As such, many rockshelters and rock art sites are documented in the Lower Pecos Canyonlands (Boyd et al., 2023).

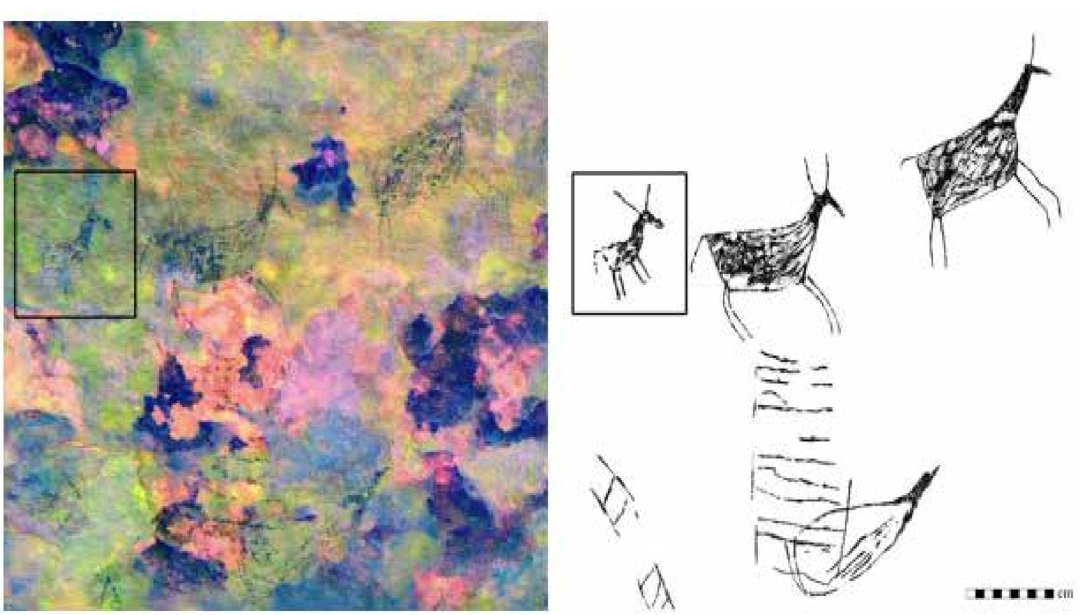

Figure 6. Charcoal dry-applied drawings of deer and geometric figures (Rowe, 2003; Boyd et al., 2014). The dated pictograph is the small quadruped with short legs located in the upper left corner of the photograph and illustration. The photograph is enhanced using DStretch color channel ybk (Harman, 2005) (Boyd et al., 2023).

During the Late Archaic period in the region, between 3,200 and 1,300 years ago, indigenous populations increased substantially along with baking and fishing activities, while the distinctive Pecos River rock paintings came to an end. The Late Prehistoric period began in the region around 1,300 years ago with the use of bows and arrows. During this time, pottery appeared in the region, along with the new Red Monochrome rock art style featuring handprints and detailed human forms (Figure 7). Indigenous populations began declining during this period for reasons unknown (Howard, 2016).

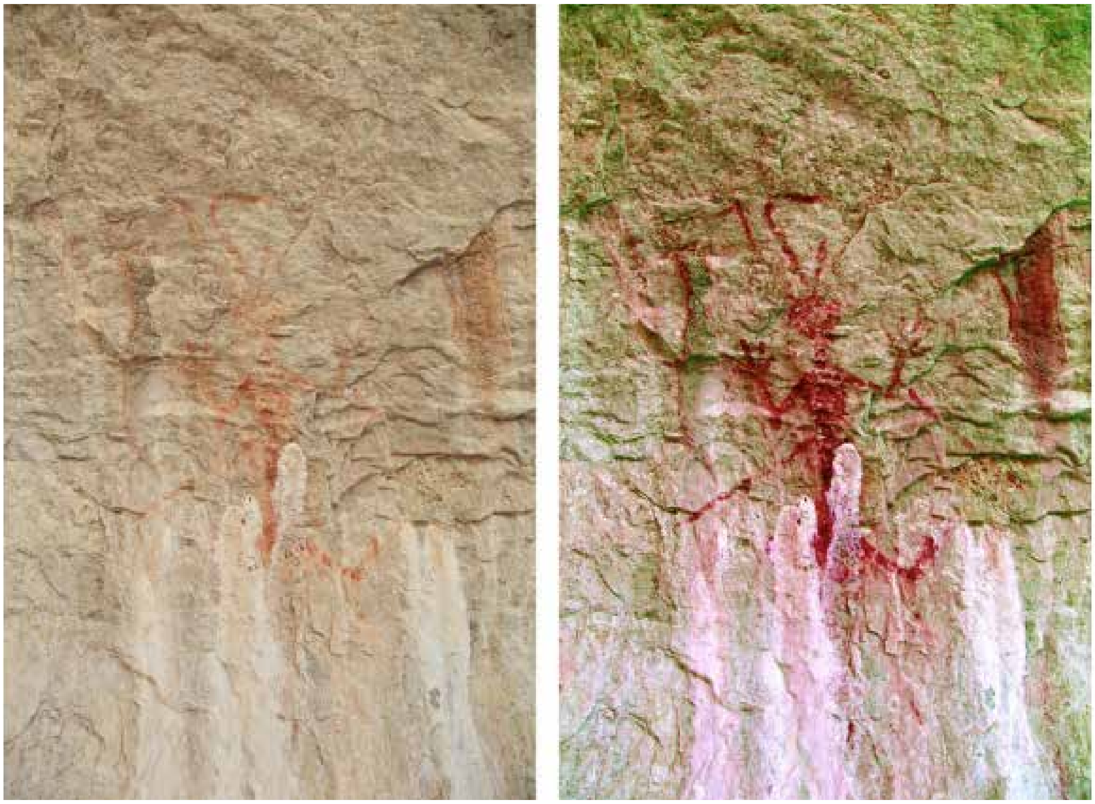

Figure 7. Red anthropomorph at the Lewis Canyon Tinaja site (currently unclassified; previously classified as Red Monochrome) The right photograph is enhanced using DStretch color channel crgb (Harman, 2005) (Boyd et al., 2023).

By the Historic Native American period, between 349 and 144 years ago, many Indigenous groups had either left the region and/or merged with larger groups. Groups that occupied the region included Mescalero and Lipan Apache, while groups that infrequently passed through the region included Tonkawa, Comanche, Kickapoo, and Kiowa Indians. The United States' Indian removal policy relocated most of these groups to Oklahoma by the 1890s, but Seminole and Kickapoo Indians continue to reside in the region today (Howard, 2016).

Spanish History

Spanish Texas, stretching from the Nueces River to the Medina River headwaters and into Louisiana, existed from 1519 to 1821, a period characterized first by Spain's exploration and by colonial missions by the end (Joseph & Chipman, 2023).

The Spanish were initially drawn to the Americas because of the abundance of gold and silver, which was more of a rarity in Europe (Brading & Cross, 1972). After successfully establishing colonial mines across Latin America, the Spanish turned their attention to Texas after hearing rumors of wealthy Indigenous communities (Joseph & Chipman, 2023). Throughout the 16th and 17th centuries, Spanish explorers conducted mining expeditions in the Devils River watershed but were unsuccessful (Smith, 2021; Smyrl, 2021). Undeterred by the lack of gold and silver, the Spanish settled for holding Texas as a defensive borderland between French Louisiana and Spanish Mexico and began focusing their efforts on converting Indigenous peoples to Christianity.

Establishing missions in the Devils River watershed was largely unsuccessful because many Native American communities exhibited a decentralized social structure and were not receptive to conversion efforts (Texas Almanac, 2021). In Schleicher County, the Spanish did missionary work among the Jumanos in the 1630s, but these native peoples disappeared by the early 1700s and were likely absorbed into the Lipan Apache people (Smyrl, 2021). In 1673, the Spanish opened a mission school at a location between Del Rio and Eagle Pass, but with the main purpose of teaching agriculture to the native peoples, and closed shortly after (Smith, 2020). In Edwards County, the Spanish established the mission of San Lorenzo de la Santa Cruz in 1762. They were able to attract 400 Lipan Apache within the first week (Mission San Lorenzo, n.d.), but only for protection from enemy tribes rather than as a place of conversion (Chipman, 2019).

The Spanish began to issue private land grants to influential citizens in South Texas in the mid-18th century at the request of settlers. Due to the lack of water and the need for irrigation in South Texas, many of these holdings were long and thin strips of land located along water frontage (Lang & Long, 2016) (The Dolph Briscoe Center for American History in Austin has physical copies of Land Grants from 1542-1610 titled “Photostat copies of viceregal land grants in Spanish colonial America”).

Mexican History

Following the Mexican War of Independence (1810-1821), Mexico faced many challenges as an independent nation including how to improve its economy, how to politically organize and govern itself, and how to deal with the growing interest in Texas land by foreign speculators (León and Teja, 2023). In 1821, there was an estimated population of 2,500 in Texas, mostly of Hispanic descent and largely residing in south and central Texas (León and Teja, 2023). Texas indigenous communities were largely reduced at this point by disease, conflict, or by moving west (León and Teja, 2023). However, these communities would remain to outnumber Tejanos (Texans of Hispanic descent), and Anglo settlers combined until well after the Texas Revolution (Barker et al., 2024).

In 1825, Mexico passed the State Colonization Law, which allowed the Anglo-American colonization of Texas (Lang & Long, 2016; Barker, 2020). These land grants brought an influx of settlers into Texas as the land grants provided more land at a cheaper cost compared to American land grants (Henson, 2021). During this time, Tejano settlement occurred in three major centers: Nacogdoches, the San Antonio-Goliad region, and the ranching frontier between the Rio Grande and Nueces River (Raat, 1996). By 1830, there was an estimated Tejano population of 4,000 (PBS, n.d.). By 1831, Anglos outnumbered Tejanos ten to one, and by 1834, there was an estimated Anglo population of 20,000 in Texas (León & Teja, 2023).

Settlement of the Devils River watershed would not occur until well after the annexation of Texas to the United States in 1845 and not until after the Civil War in 1865 in some areas.

Settlement of Schleicher County began in 1852, but permanent ranches were not established until the mid-1870s (Smyrl, 2021). Settlement of Edwards County did not occur until the mid-1800s with the first land sold in 1876 (McCrain, 2020). Settlement of Val Verde County was attempted on San Felipe Creek in 1834 but attacks by Indigenous groups and drought brought its end, delaying permanent settlement until the 1850s with the establishment of several military bases (Smith, 2020). Settlement of Sutton County did not occur until the 1870s, and ranchers were so successful that by the 1880s the region was known as Cattleman's Paradise and Stockman's Paradise (Hosmer, 2021). The settlement of Crocket County began following the Civil War.

Western Culture and "Wild West" Heritage

The Texas frontier was a place of wide-open land, rich natural resources, and abundant opportunities. It attracted Anglo-American descendants of English, Scottish, and Welsh colonists and settlers from Alabama, Arkansas, Kentucky, Louisiana, and other states (Bullock Museum, n.d.a; University of Texas at San Antonio Institute of Texan Cultures [UTSA ITC], 2018). With the help of the Mexican government offering large swaths of land for cheap prices, thousands of settlers moved west into Texas between the 1820s-1830s, though settlement would occur well into the early 20th century (Henson, 2021).

The move for most settlers was difficult. Families said goodbye to their relatives and friends and made the long journey by wagon. Upon arrival, the Mexican government granted each head of a family nearly 200 acres for farming and nearly 4,500 acres for stock raising (Bullock Museum, n.d.a).

With the arrival of more immigrants taking land, Native American communities indigenous to Texas often came into conflict and skirmishes with settlers (León & Teja, 2023). Settlers also came into conflict with native Tejanos (Mexican Texans) who resided in the territory since the 1500s (Bullock Museum, n.d.a). The Mexican government offered little help because it was difficult for the newly independent nation to enforce its own laws.

Aside from facing threats from other people, settlers faced threats from nature. Farming and ranching involved backbreaking physical labor for as long as the sun provided light; settlers had to hunt and catch daily food, hides needed tanning and sewing into buckskin clothing, trade with other Texas settlements required weeks of travel, and school and church services had to be organized (Bullock Museum, n.d.a).

Agriculture was the dominant industry in Texas from the early to mid-19th century as settlers had brought their plantation practices from the southeastern United States with them (Curlee, 1932). Vaqueros (cattle drivers) were the original cowboys, and their techniques of roping and driving cattle would not only be adopted by Anglo ranchers in the 19th century but would spark the expansion of "Wild West" culture throughout Texas and the western United States (Brazoria County Historical Museum [BCHM], 2020; Gutierrez, 2021).

With the growing demand for beef in the United States, Texas landowners quickly learned from Vaqueros how to round up wild cattle on their land and drive them North (often to Kansas) to be sold to packing plants. On the hazardous cattle trails, cowboys faced difficult weather and crossings, cattle thieves, and conflicts with Native Americans (Bullock Museum, n.d.b). The first successful cattle drive was completed in 1867, but by 1887, railroad expansion would end the drives (BCHM, 2020).

Texans had learned much more than cattle driving from Vaqueros as these original cowboys were also skilled in caring for and breeding cattle. During this time, what we know today as range management and animal husbandry began to expand. Cowboys were skilled laborers and, during social occasions like Fourth of July celebrations, would challenge the skills of other cowboys in the area (BCHM, 2020; Mahoney, 1952). These competitions would expand into rodeos and livestock shows. Two of the earliest recorded rodeos were held in Pecos, Texas in 1883. By the 1890s, rodeos had become popular and were an annual event in many communities.

The rise of industrialization and the expansion of national infrastructure would bring an end to the open range by the 1880s as ranchers required less land to cultivate crops and raise livestock (Bullock Museum, n.d.b). However, the "Wild West" legacy remains in the culture of many communities in the region. In the Devils River watershed, ranching continues to dominate the economy, with most land used for stock raising (McCrain, 2020; Smith, 2020).

Demographic Change

The Devils River region was home to a predominantly Native American population from 11,000 BCE to the mid-1800s (Barker et al., 2024; Boyd et al. 2023). Today, only one percent of the region's population is American Indian (Texas Demographic Center [TDC], 2022; U.S. Census Bureau, 2020). Tejanos occupied a small portion of the population beginning in the early 1800s (Raat, 1996; Public Broadcasting Service [PBS], n.d.). Today, nearly 80 percent of the region's population is Hispanic.

Anglo-American settlers occupied some portion of the region's population beginning in the mid-1800s (Hosmer, 2021; McCrain, 2020; Smith, 2020, 2021; Smyrl, 2021). Today, the U.S. Census Bureau categorizes nearly 18 percent of the population as "white" (TDC, 2022; U.S. Census Bureau, 2020). African Americans occupied a small portion of the population beginning in the mid-1800s with the arrival of Anglo-American settlers. Today, the U.S. Census Bureau categorizes less than one percent of the watershed's population as "black."

Counties in the Devils River watershed generally saw a steady increase in population from the late 19th century to the early 20th century, but a declining trend started to occur in most areas during the Great Depression in the 1930s (Hosmer, 2021; McCrain, 2020; Smith, 2020, 2021; Smyrl, 2021). Crockett County was the only county to experience a population rise in the 1930s, resulting from the discovery of oil. During this period, most of these county populations were of Anglo-American descent, with the second largest group being of Mexican ancestry.

All counties in the Devils River watershed experienced a growing population in the last few decades of the 20th century, with most growth occurring in county seats. However, after the 2010 United States Census, all counties in the watershed are experiencing a steady population decline, and population projections for all counties are expected to decrease between 2020-2060 (TDC, 2022). Table 1 summarizes the 2020 census results for counties in the watershed and the estimated population change between 2020-2060. In 2020, the estimated population of Schleicher County was 2,451, Sutton County was 3,372, Crockett County was 3,098, Edwards County was 1,422, and Val Verde County was 47,586.

Table 1. 2020 Census of Counties in the Devils River Basin, Texas (TDC, 2022; U.S. Census Bureau, 2020).

County	Race	2020 Population Estimate	2020-2060 Population Change Estimate
Schleicher	Hispanic	55%	-75.80%
	White	42%	
	Black	2%	
	American Indian*	1%	
	Some Other Race*	<1%	
Sutton	Hispanic	66%	-60.3
	White	32%	
	Black	1%	
	American Indian*	1%	
	Some Other Race*	<1%	
Crockett	Hispanic	67%	-53.80%
	White	28%	
	Black	2%	
	American Indian*	3%	
	Some Other Race*	<1%	
Edwards	Hispanic	53%	-78.60%
	White	43%	
	Black	1%	
	American Indian*	3%	
	Some Other Race*	<1%	
Val Verde	Hispanic	83%	-12.80%

* "American Indian" and "Some Other Race" is the language used by the U.S. Census

Land Use Change

Before settlers moved into the watershed in the mid- to late- 19th century, Indigenous peoples used the land for hunting and gathering activities for thousands of years (Hosmer, 2021). These communities also used caves for shelter and to display art (Smith, 2020, 2021). Throughout the 16th and 17th centuries, Spanish explorers conducted mining expeditions and established several missions in the watershed, but attacks from Indigenous peoples stopped the Spanish from establishing any permanent settlements (Smyrl, 2021).

Anglo-American settlers, attracted by the grazing potential of the watershed, began moving into the area in the mid- to late- 19th century (Hosmer, 2021; Smith, 2020; Smyrl, 2021). Most settlers established large ranching operations and some minor farming operations, many of which were operated by the owner and some operated by hired managers. Farming was restricted to grains, fruit, and vegetable crops. For a short time, pecan production flourished in the upper watershed but was halted by runoff in the Devils River and overgrazing which eroded much of the topsoil. The most important venture to the watershed's economy during this period was livestock production with sheep, cattle, and goat ranching dominating the industry. Other livestock included chickens, hogs, mules, and horses. By the end of the 19th century, most of the region's population lived on ranches. To protect these enterprises, predators such as mountain lions, coyotes, and bobcats had been heavily hunted, diminishing their populations significantly by the 1930s.

In the early 20th century, the discovery and extraction of mineral resources caused the oil and gas industry to become an important component of the region's economy (Hosmer, 2021; McCrain, 2020; Smith, 2020, 2021; Smyrl, 2021). During this time, the expansion of stagecoach and rail services helped connect the region's industries to northern markets and attracted manufacturing establishments. Between the Great Depression and World War II, the watershed experienced a declining trend in the number of farms and ranches. However, mineral exploration brought a second oil boom to the watershed, particularly in Sutton and Edwards counties.

In Val Verde County, during World War II, Laughlin Airfield opened to train pilots and continues to train U.S. Air Force pilots to this day (Smith, 2020). After World War II, the watershed began to experience an increasing trend in the number of farming and ranching operations (Hosmer, 2021; McCrain, 2020; Smith, 2020, 2021; Smyrl, 2021). In the latter half of the 20th century, the expansion of the state and federal highways systems expanded the watershed's wool and mohair industries' access to markets.

Ranching remains the primary economic activity in the watershed, with most land used for livestock and little under cultivation (McCrain, 2020; Smith, 2020). The natural gas industry is the second major contributor the watershed's economy. Ecotourism is a growing sector, but some stakeholders view it with concern as managing the environmental impacts of tourism has become increasingly difficult as the Devils River gains popularity.

Water Use and Change

For thousands of years, Indigenous peoples relied on surface waters of the Devils for various uses, including securing water and food supplies, transportation, and art (Turpin, 1988). Burned rock middens are archeological heaps containing the burned debris of human activity resulting from the usage of earth ovens (Koenig, 2012; Verostick, 2013). These have been found in the watershed and represent how Indigenous communities established themselves around local waterways processing plant food and eating fish, reptiles, and mussels regularly. Other than food remnants, these middens also contained arrowheads and other tools used at the time.

Throughout the 16th and 17th centuries, Spanish explorers would navigate the Rio Grande and Devils Rivers to conduct mining expeditions and missionary work (Metz, 2020; Smith, 2021; Smyrl, 2021; Texas State Historical Association [TSHA], 1994).

When the Anglo-American settlers moved into the watershed in the mid- to late-

19th century, they established large farming and ranching operations around rivers and watering holes (Hosmer, 2021; Richardson & Hinton, 2019). Between the late 19th to early 20th centuries, the shift from open range to fenced grasslands sparked conflict over limited access to water (Welborn, 1996). To find a solution, some ranchers began drilling wells and using windmills to reach groundwater supplies. After Christoper Doty in Schleicher County successfully pumped groundwater to supply water to 4,000 heads of livestock, first from shallow wells then from a deeper 42-foot well, windmill use spread rapidly across the Devils watershed and expanded ranching operations further away from surface water resources.

In the early 20th century, stagecoach and rail services often developed near or around local waterways such as the Devils River to ensure water supplies for travelers and steam engines (DRC, 1800s; Werner, 2017). Other than agriculture and transporting goods, the watershed's waterways provided game such as fish, waterfowl, and other animals. This fostered not only a hunting culture throughout the watershed but also a recreation culture (Hosmer, 2021; McCrain, 2020; Smith, 2020, 2021; Smyrl, 2021).

In 1965, the United States and Mexican governments jointly began constructing the Amistad Dam and Reservoir on the Rio Grande for a variety of purposes, including improved water storage (International Boundary and Water Commission [IBWC], n.d.; Thurmond, 2020). The Dam and Reservoir were completed in 1969 and remain an important supply of water to the region today (TWDB, n.d., 2024).

The 2023 Texas Water Plan projects water demand to significantly increase as we move closer to 2070 (Texas Comptroller, 2023c). The top usage of water in Sutton, Edwards, and Val Verde Counties is municipal and is expected to remain the top user (TWDB, 2022). The top usage of water in Crockett County is mining, but this is expected to decrease until municipal water becomes the top user in 2050. The top usage of water in Schleicher County is irrigation, and it is expected to remain the top user.

Water Management

Water rights are the rights of users to take water from a source for the purpose of using or selling the water (Smolen et al., 2017; Water Information Program [WIP], 2018). Texas divides water rights into surface water and groundwater categories (Texas Comptroller, 2023c).

Surface Water

In the United States, surface water rights are governed by the states which have
In the United States, surface water rights are governed by the states which have
generally adopted two approaches: Riparian Doctrine and Doctrine of Prior Appropriation (Smolen et al., 2017; WIP, 2018). The Riparian Doctrine gives the landowner who owns the bank of a waterbody the right to the water with reasonable use limitations varying state by state and is most prevalent in the eastern United States where water resources are typically more abundant.

The Doctrine of Prior Appropriation gives the first in time appropriator the right to the water independent of land ownership as long as the water is applied to a beneficial use (definitions of beneficial use vary by state) and is most prevalent in the western United States where water resources are typically more scarce

(Smolen et al., 2017; WIP, 2018). Many states govern water rights following one or a combination of these approaches, and Texas follows a combination.

Texas surface water is defined as "lakes, bays, ponds, impounding reservoirs, springs, rivers, streams, creeks, estuaries, wetlands, marshes, inlets, canals, the Gulf of Mexico, inside the territorial limits of the state, and all other bodies of surface water, natural or artificial, inland or coastal, fresh or salt, navigable or non-navigable, and including the beds and banks of all watercourses and bodies of surface water, that are wholly or partially inside or bordering the state or inside the jurisdiction of the state," (Texas Water Code [Tex. Wat. Code] §11.021, 2015). Of all the water we use in the state, about 40 percent is surface water[2] (Lesikar et al., 2011). Surface water is owned by the state and held in trust for state citizens, meaning the state has the legal ownership and responsibility to manage surface water, but state citizens retain beneficial ownership (Texas Comptroller, 2023c). In other words, landowners can use Texas surface water but only with the state's permission. The applicable law governing Texas surface water is the Doctrine of Prior Appropriation. Surface water use permits are managed by the Texas Commission on Environmental Quality and given a priority date so, in times of water shortage, senior water rights holders receive their allotted amount of water before junior water rights holders (Lashmet, 2018).

There are currently no surface water rights holders within the Devils River watershed, and any diversions from the River are restricted by law to domestic and livestock use at properties with river access (United Research Services Corporation [URS], 2004). Because the Devils River discharges into the Rio Grande, it is included in the Treaty of 1944 which distributed the waters in the international segment of the Rio Grande between the United States and Mexico (IBWC, n.d.). According to the Treaty of 1944, "all waters reaching the main channel of the Rio Grande from the Pecos and Devils Rivers, Goodenough Spring, and Alamito, Terlingua, San Felipe and Pinto Creeks" are allotted to the United States alone (United States Government Printing Office [USPGO], 1946).

Groundwater

Texas groundwater is defined as "water percolating below the surface of the earth," and is managed either individually by landowners under the Rule of Capture or collectively by landowners and groundwater conservation districts (Lashmet, 2018; Lesikar et al., 2011; Tex. Wat. Code §36.001, 2015). Approximately 60 percent of the water used in the state comes from groundwater. The Rule of Capture, established by the Texas Supreme Court in 1904, is the primary legal doctrine governing groundwater in Texas. This rule permits landowners to pump unlimited amounts of groundwater from beneath their property for any purpose, as long as it does not involve malice, waste, or cause subsidence, without liability to neighboring landowners (Texas State Library and Archives Commission [TSLAC], 2016). This Rule also permits landowners to sell their withdrawn groundwater for export to any location "for off-site use by a third party," (Caroom & Maxwell, 2004). Essentially, groundwater is considered the private property of the landowner, who has the right to extract and sever it from the surface estate of the property.

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2 *Thirty percent of surface water flow in Texas (and up to 72 percent in some regions) is inextricably linked with groundwater which sources many of the state's waterways (Anaya et al., 2016).*

In 1949, the Texas Legislature authorized the creation of local groundwater conservation districts as a "method of groundwater management in order to protect property rights, balance the conservation and development of groundwater to meet the needs of this state, and use the best available science in the conservation and development of groundwater," (Jasinski, 1995; Tex. Wat. Code §36.00159(b), 2015).

Groundwater conservation districts manage groundwater within their boundaries by "permitting water wells, developing a comprehensive management plan, and adopting the necessary rules to implement the management plan," which often include well reporting requirements and production rules (Lashmet, 2018; Texas Commission on Environmental Quality [TCEQ], n.d.). These rules modify the Rule of Capture and are a form of correlative rights managed by the local groundwater conservation districts. "Correlative (water) rights refer to rights of landowners over a common groundwater basin that are coequal...so that any one owner cannot take more than his share even if the rights of others are impaired," (Stone, 2021). In many Texas districts, correlative pumping limits are in place (Mace, 2016). Some regions have chosen not to establish such districts (TWDB, n.d.). For example, local water resources in Val Verde County continue to be managed independent of groundwater conservation districts.

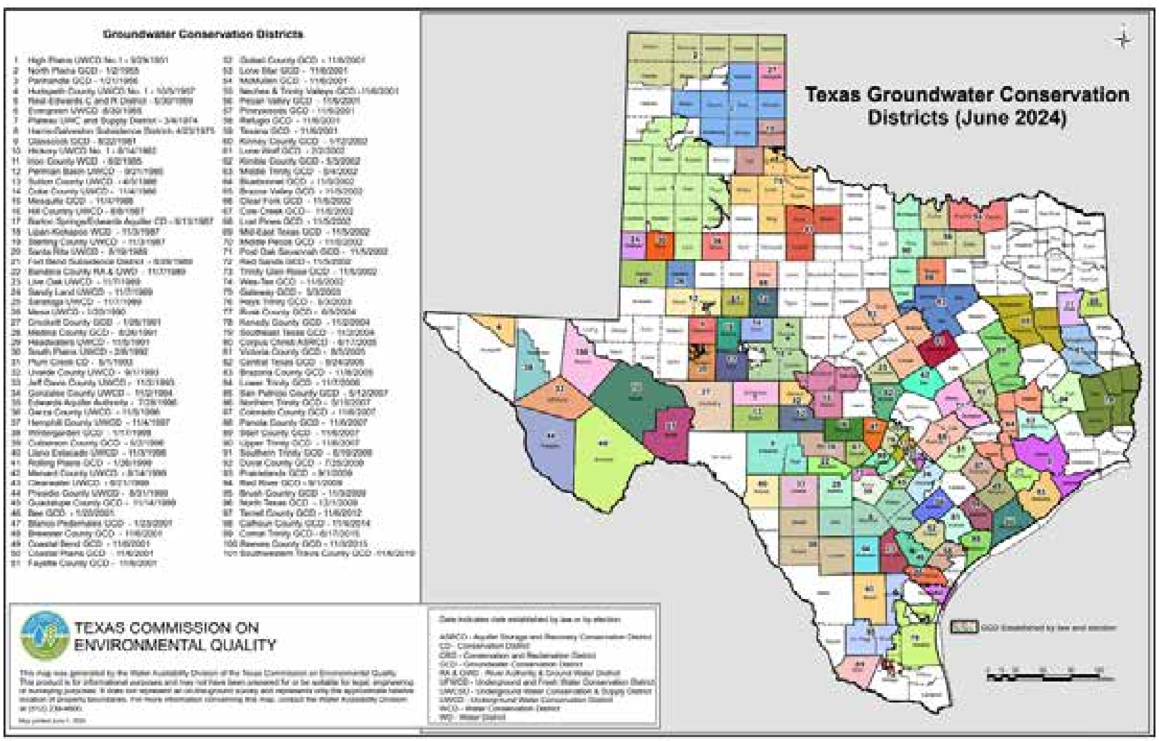


Figure 8. Texas Groundwater Conservation Districts, June 2024 (TCEQ, 2024). 173 of Texas' 254 counties are located partially or fully within a groundwater conservation district (TWDB, n.d.)

In the Devils River watershed, four of the five counties have groundwater conservation districts (Figure 9):

1. The Plateau Underground Water Conservation and Supply District in Schleicher County, established in 1965 (PUWCSD, 2014);
2. The Sutton County Underground Water Conservation District in Sutton County, established in 1985 (SCUWCD, 2014);

3. The Crockett County Groundwater Conservation District in Crockett County, formerly Emerald Underground Water Conservation District and established in 1989 (CCGCD, 2018); and
4. The Real-Edwards Conservation and Reclamation District in Edwards County, established in 1959 (RECRD, 2020).

Additionally, the Plateau, Sutton County, and Crockett County districts are members of the West Texas Regional Groundwater Alliance. Established in 1996, the Alliance was formed to coordinate regional efforts to conserve and preserve groundwater in West Texas. It has since grown to include 18 groundwater conservation districts that are "locally created and locally funded" (CCGCD, 2018; PUWCSD, 2014; SCUWCD, 2014).

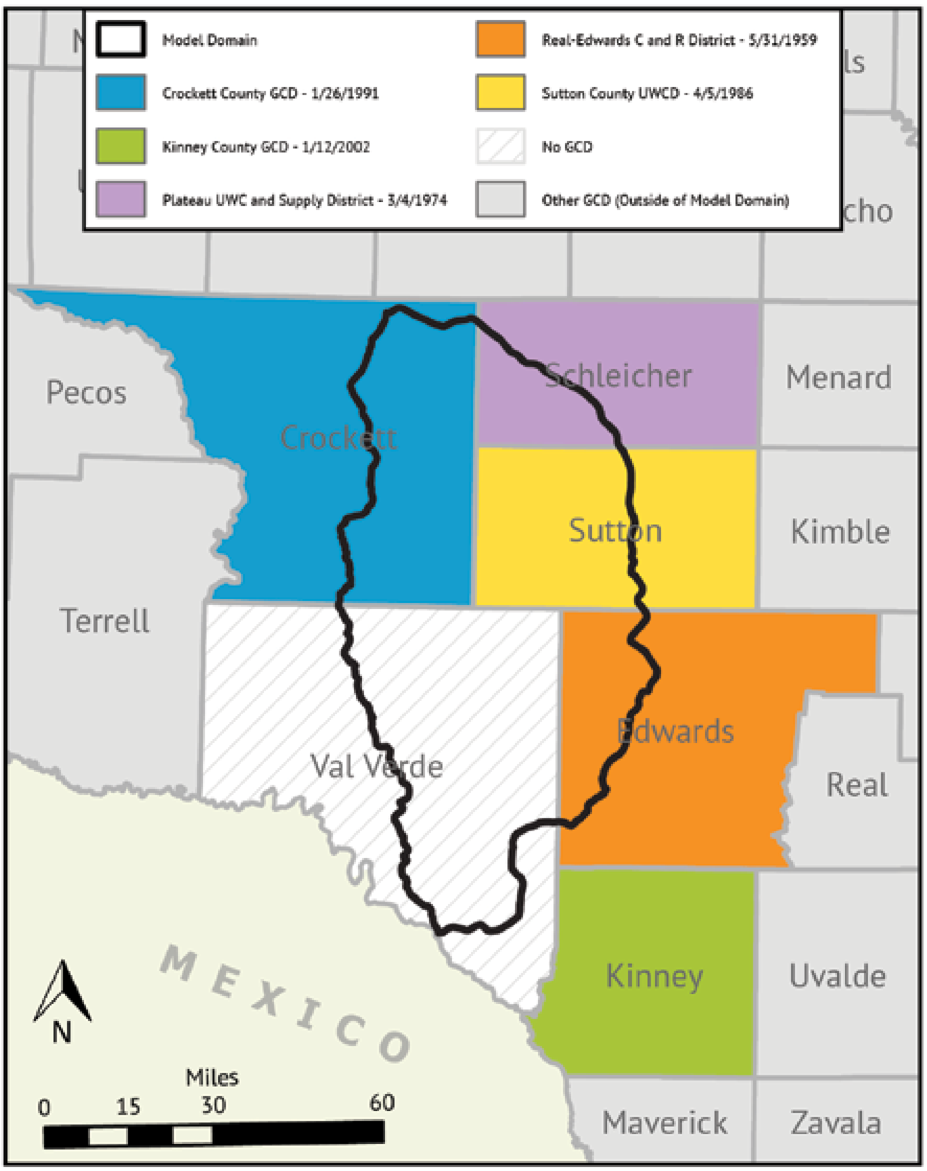


Figure 9. Texas Groundwater Conservation Districts located within the Devils River watershed.

It is important to recognize that over the past decade, there have been several unsuccessful attempts to establish groundwater export pipelines as well as a groundwater conservation district in Val Verde County. There is ongoing debate among regional stakeholders about whether having no district, a single county-wide district, a single district with multiple watershed-based management zones, or multiple districts would best fit the needs of the region as it faces critical groundwater supply issues (Weinberg and French, 2018). However, evaluating the specific management options is beyond the scope of this report.

Climatic Changes

The climate in this part of the state is described as semiarid, with hot summers and dry winters (USGS, 2000). Average annual precipitation ranges from 12-19 inches, with peaks generally occurring in May and September. The average warmest and coldest months of the year are July (30.4 degrees Celcius) and January (10.4 degrees Celcius), respectively.

According to the State Climatologist, John Nielsen-Gammon, Texas has been historically vulnerable to weather and climate events and this vulnerability will only increase in the future (Nielsen-Gammon et al., 2024). No one knows which specific weather and climate events Texas will experience in the future, but researchers can model and predict these events based on how the climate is currently changing when compared to historical records. Table 2 summarizes the likely future trends to 2036 based on historic observations of temperature and precipitation in the 1959-1999 and 1991-2020 periods.

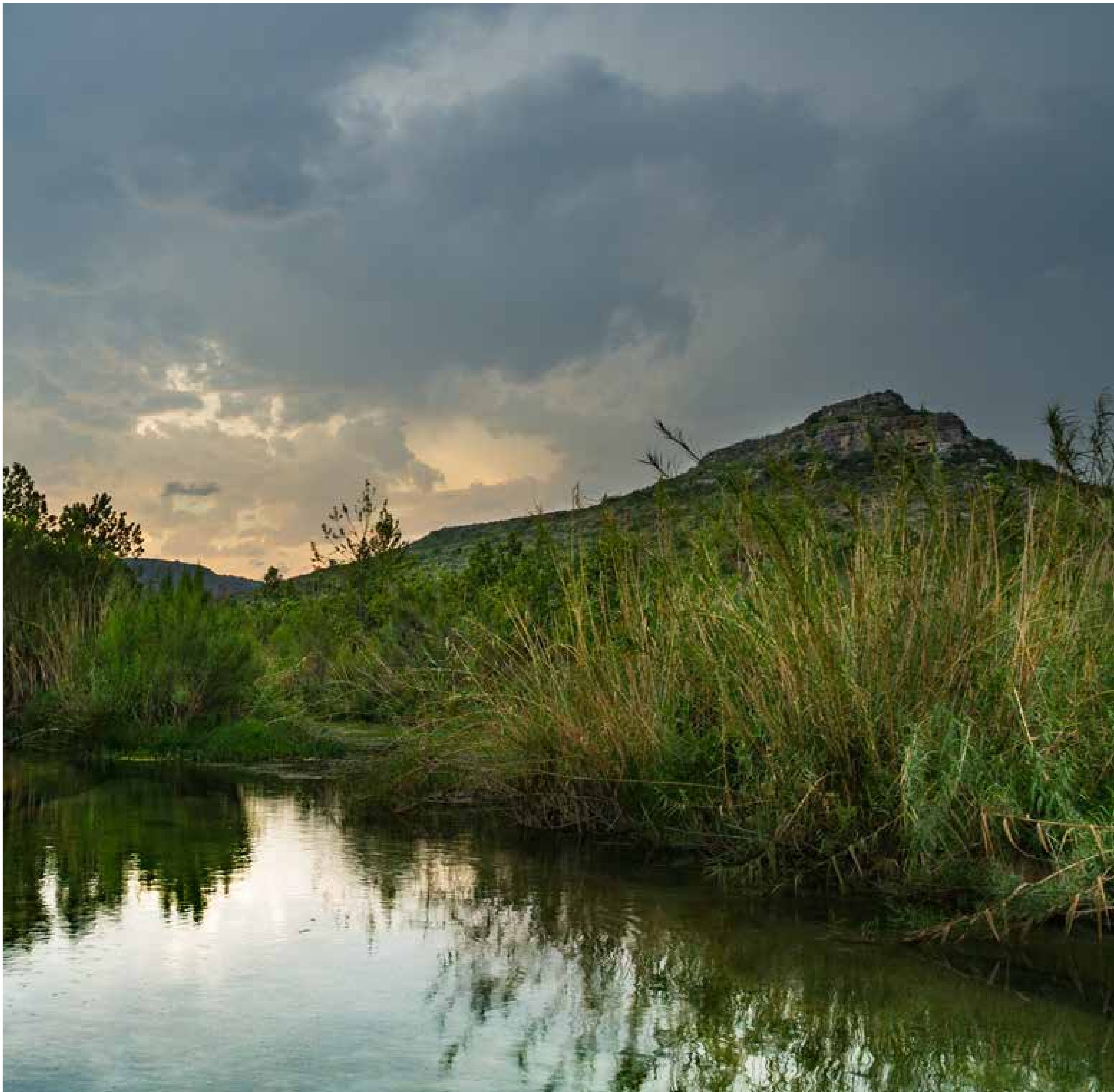
Table 2. Projected Temperature and Precipitation Climatic Conditions in 2036 in Texas (Nielsen-Gammon et al., 2024). 2020).

Climatic Condition Category	2036 Projected Climatic Condition
Average Surface Temperature	3.0 degrees Fahrenheit warmer than the 1950-1999 average. 1.8 degrees Fahrenheit warmer than the 1991-2020 average. Quadruple 100-degree days compared to 1970-1989.
Extreme Precipitation	20 percent increase in intensity relative to 1950-1999. 10 percent increase in intensity relative to 2001-2020. 100 percent increase in frequency relative to 1950-1999. 50 percent increase in frequency relative to 2001-2020.

Texas is also expected to experience increased extreme summer month temperatures, increased extreme winter month temperatures, acute and highly sector-specific drought impacts, increased extreme flood events in areas with a history of flooding, increased risk of wildfires, decreased extreme winter weather events (e.g. February 2021 Winter Storm), increased severity of storm surges from hurricanes, and increased extreme hurricane intensity (Nielsen-Gammon et al., 2024).

State climate summaries released by the National Oceanic and Atmospheric Administration (NOAA, 2022a, b) to address climate change in each state back up Nielsen-Gammon's work. The Texas climate summary highlights that temperatures are expected to rise throughout the next century, which could contribute to more frequent and extreme heat events, and projections show an increase in extreme rain events.

Potential climate impacts in the Devils River watershed are concerning because the region received a U.S. climate vulnerability index score in the 80th percentile (Environmental Defense Fund [EDF], 2023). This score combines the "environmental, social, economic, and infrastructure effects on neighborhood-level stability," and this Southwestern Texas region is more vulnerable to climate impacts than 80 percent of the nation.



Watershed Threats and Challenges

The project's Technical Teams and stakeholders were asked to identify threats and challenges related to the future of the Devils River. While this list is not conclusive, it represents key areas of concern facing all of the report's focus areas (i.e., groundwater science, water quality, species and flow needs, and sustainable recreation):

Climatic Changes Impacts to the Water Cycle

INCREASING DROUGHT

Because of its location in a semi-arid environment, the Devils River is particularly vulnerable to drought. While the river has never gone dry, significant reductions have occurred in droughts of the 30's, 50's, 2010's, and since 2022 (Weinberg & French, 2018; Hunt et al., 2022). While future climate conditions are uncertain, it is projected that droughts in West Texas will become more frequent and more severe (Nielsen-Gammon et al., 2024).

GROUNDWATER RECHARGE IN THE DESERT

The Devils River is in a semi-arid environment, occurring in a transition zone from the Edwards Plateau to the Chihuahuan Desert. Because the river is wholly dependent on groundwater for base flow, it is particularly vulnerable to the limited and highly episodic precipitation of a desert environment. Recharge to the aquifer occurs mostly during infrequent high-intensity precipitation events, when surface runoff initiates flow in ephemeral reaches of the Devils River and its tributaries. Smaller, yet more frequent precipitation events provide limited recharge when surface runoff is limited and antecedent soil moisture is low.

WARMING TRENDS IN SURFACE WATER TEMPERATURES

The many springs along the Devils River maintain a consistent year-round temperature of 22.6 ± 0.3 degrees Celsius (~72-73 degrees Fahrenheit), which provides thermal stability to aquatic habitats (Caldwell et al., 2020; Roca & Baltanas, 1993). These springs help buffer temperature extremes, cooling the river during the summer and warming it during the winter, reducing temperature fluctuations by 50-70 percent (Caldwell et al., 2020).

By linking short-term monitoring data with long-term temperature models, researchers were able to extend surface water temperature records for the Devils River to 30 years (Caldwell et al., 2020). This analysis revealed a long-term warming trend, with daily maximum water temperatures increasing by 0.16 degrees Celsius (~0.28 degrees Fahrenheit) per decade. Such trends indicate that the river is increasingly susceptible to climate change.

This is concerning because many aquatic species in the Devils River, such as fish and freshwater mussels, are highly sensitive to significant changes in stream temperatures.

Changes in Land Use, Springflow and River Flow

HISTORIC GRAZING

Early ranchers in the Devils River watershed grazed thousands of cattle, sheep, and goats using open range techniques through significant drought periods. The management practices of this era in the ranching industry were uninformed and limited by access to water which led to significant impacts to soil health, vegetation, and hydrologic processes within the watershed. Current ranching practices have been informed by these hard learned lessons and continue to improve.

LAND AND LAND OWNERSHIP FRAGMENTATION/SUBDIVISION

As large, single owner parcels are divided into smaller patches with multiple owners, often due to changes in land use, ecosystems are disrupted, and natural processes and habitat connectivity are altered. Land fragmentation drives increased development and a patchwork of management practices resulting in habitat degradation and loss of biodiversity.

Land fragmentation also disrupts natural hydrological patterns, increasing runoff and erosion. This degradation leads to poorer water quality, affecting both terrestrial and aquatic ecosystems.

WATER QUANTITY

Water is the heart and lifeblood of any river, and this is especially true for the Devils River. As a spring-fed river, groundwater breathes life into its riparian corridor and sustains its flow. A healthy, functioning river is supported by a natural flow regime comprising the unimpaired pattern of quantity, timing, and stream flow variability throughout time (Poff et al., 1997). These flows are characterized as subsistence (low flows), base (average flows), flow pulses (in-channel high flows), and overbanking flows (out-of-channel flood events).

Each flow component plays an important role in maintaining the form and function of a river and riparian area, including maintaining species diversity, recruitment, and habitat. In the Devils River, lower flows (subsistence and base) are almost entirely supported by groundwater inputs, while higher flows (flow pulses and overbanking flows) occur during precipitation events and runoff. In other rivers, instream flows are altered by impoundments or water withdrawals, but the Devils River is free-flowing until it reaches Amistad Reservoir and has no major surface water withdrawals (TCEQ, 2024). Aquifer levels and climate are currently the largest drivers of stream flows in the Devils River. It might seem like a simplistic system; however, understanding the interactions between groundwater, surface water, and climate is complex and crucial for understanding future ecosystem health and advising water management.

The population of Texas is predicted to increase by 73 percent over the next 50 years. Water demand is projected to rise by 9 percent over that same time, while statewide groundwater supply is projected to decrease by 32 percent (TWDB, 2022). The ability to accurately model groundwater supplies under various climate and use scenarios is critical for predicting the future stability of our spring-fed rivers. Groundwater in Val Verde County is unregulated, adding further uncertainty to forecasting local aquifer conditions. This also opens up the possibility of outside municipalities exploiting the groundwater that supports the Devils River to secure their own future water needs, with several already having explored purchasing groundwater over the past decade (URGBBEST, 2012). Large-scale groundwater exports of this nature could significantly impact local aquifer levels and baseflows supporting the Devils River (Weinberg and French, 2018). This, coupled with more frequent or severe drought conditions, could lead to habitat degradation and species loss from the river ecosystem.

PUMPING AND GROUNDWATER EXPORT

Data from 84,544 monitoring wells across the country, tracking trends since 1920 (Rojanasakul et al., 2023) revealed that nearly half of these sites have experienced significant declines in water levels over the past 40 years. Drinking water for cities was identified as a major contributor to this decline.

The Devils River watershed does not have as extensive development of groundwater as other areas of the state, such as the Texas Hill Country and Permian Basin. However, groundwater is utilized for domestic and livestock use, small amounts of irrigated agriculture from Sonora to Juno, municipal supplies, surface impoundments, and limited pumping for sale for hydraulic fracturing, bottled water and spirit production (Devils River Whiskey). The greatest development of the aquifer is by the city of Del Rio. While this occurs at the downgradient end of the watershed, groundwater modeling suggests that it does have limited potential to impact the flow of the Devils River where it discharges to Amistad Reservoir (EcoKai 2014, SWRI 2017). A significant potential threat to groundwater resources would be development of the aquifer in Val Verde County for export to outside of the watershed.

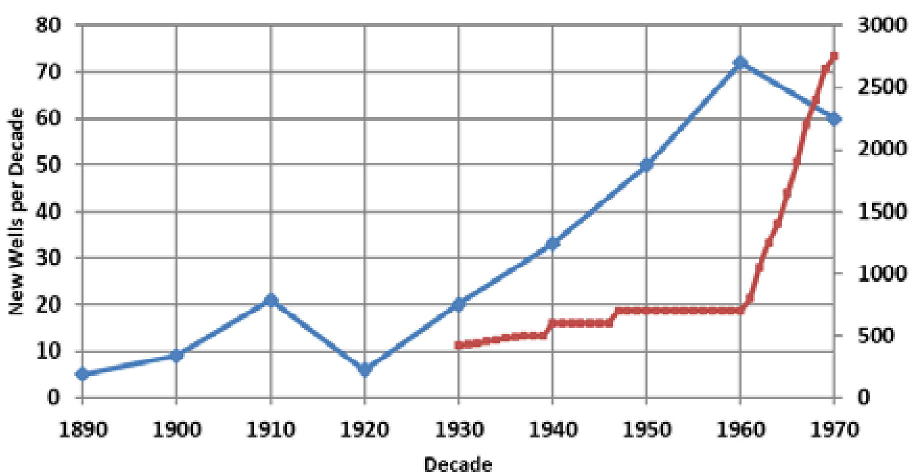


Figure 10. Number of new water wells per decade in Sutton County (blue line) (Muller and Pool, 1972) and estimated annual pumping in Sutton County (red line) (Hutchison et al., 2011)

WATER QUALITY

Water quality is a concern for both humans and animals within the Devils River watershed. Human activities and materials can introduce a variety of contaminants into the environment. The presence of water often dictates the fate and transport of environmental pollutants. These pollutants follow the path of natural surface and subsurface flows, resulting in exposure to soil, vegetation, and wildlife (Gregory and Hatler 2008). Pollutants can indirectly affect aquatic organisms, such as increasing organic matter production, which can deplete dissolved oxygen in a water body, causing stress or death to sensitive species. They can also have direct impacts, such as toxicity leading to a rapid fish kill (Moriarty, 1983). Toxins can biomagnify in aquatic species, leading to an increased concentration of toxins in species with higher trophic positions, such as sportfish, which is a concern for those species and the humans consuming them (Moriarty, 1983).

Sources of pollution may include oil and gas development (Boyer, 1986; Ashworth, 1990; Scanlon et al., 2020), inadequate wastewater management by developments, municipalities, and industrial users (Contreras-Balderas and Lozano-Vilano, 1994; Hogan, 2013), and irrigation return flows (Ashworth, 1990; Miyamoto et al., 2006; Plateau Water Planning Group, 2020). Fortunately, the Devils River has no history of contamination and is at low risk of hazardous materials spills, leaks, or high salinity today (Houston et al. 2019; Railroad Commission of Texas, 2020; TCEQ, 2020). However, it may be at risk of wastewater contamination from failing or inadequate stream side septic systems and wastewater discharge proposals from package treatment plants. There are three existing wastewater discharge permits into the Devils River below Sonora, Texas.

Water quality in the Devils River watershed is repeatedly described as excellent or pristine (Davis 1980; Upper Rio Grande BBEST, 2012; Green et al., 2019). According to the most recent data from the Texas Commission on Environmental Quality, no water quality concerns were identified for the Devils River or Dolan Creek (TCEQ, 2022). The water quality parameters assessed included dissolved oxygen, nutrients, dissolved solids, water temperature, toxins, pH, and bacteria. Elevated chloride levels were documented in Amistad Reservoir, including the Devils River arm (Segment 2305_02), and it is noted that more data will be collected to assess this impairment.

The U.S. Geological Survey undertook a significant water quality study from 2005 to 2007 (Moring 2012, entire). They sampled water quality at the U.S. Geological Survey gage "Devils River at Pafford Crossing," located approximately three miles upstream from the section of the Devils River that feeds into the Amistad Reservoir pool when the reservoir is full. The analysis focused on total dissolved solids, major ions, nutrients, trace metals, and pesticides and compared the data to historical data collected by the U.S. Geological Survey Hydrologic Benchmark Network from 1978 to 1995 (Moring, 2012). All of the constituents tested were well below state standards, and those compared were lower than the median of the historical data (Moring, 2012). The analysis also tested for the presence of 162 pesticides; none were detectable (Moring, 2012).

The land cover in the U.S. Geological Survey HUC6 watershed, which includes the Devils River, was assessed using remote sensing data. The Rangelands Analysis Platform (University of Montana, 2022) and the National Land Cover Dataset (Dewitz and USGS, 2021) were used to analyze land and vegetation cover changes over time. The proportion of area classified as bare ground, assumed to be the most likely cover type to lead to erosion and sedimentation, decreased from 1986 to 2023 (University of Montana, 2022). The influence of impervious cover was considered through the lens of development classes in the National Land Cover Database. Development across high, medium, and low intensities changed little, rising from 1.0 percent in 2001 to 1.4 percent in 2021 (Dewitz and USGS, 2021). The low levels of impervious cover in the watershed are assumed to correlate with low risks to surface water from pollution via runoff, and the slight change over time suggests that this risk is not likely to increase significantly in the future. The risk to water quality from other threats associated with human habitation of the area, such as leaking septic systems or improper waste management, also appears to be low currently (De La Cruz, 2004; Moring, 2000).

Pollution from oil and gas development poses a potential threat to water quality within the watershed. The watershed includes approximately 9,500 active oil and gas wells, 590 miles of oil pipelines, and 90 miles of gas pipelines (S&P Global, 2024a; 2024b). While only a few of these wells are within the portion of the watershed containing perennial streamflow, the vast majority are concentrated in Sutton and Crockett counties. The primary risk to water quality within the watershed is more likely to occur through leaks into a water conduit leading to the river rather than from a surface spill (Gregory and Hatler, 2008; Scanlon et al., 2020).

The indirect impacts of climate change on the Devils River are numerous, with the primary concern being changes in water quantity rather than water quality. Changes in water quality result from changes, particularly reductions, in water quantity (i.e., flows). While the temperature of the groundwater and springs that feed the Devils River is unlikely to be significantly impacted by changes in air temperature alone, some increase is possible (Kløve et al., 2014). However, if water quantity in the Devils River decreases, it becomes much more likely that stream temperature will increase and dissolved oxygen will decrease (Mace and Wade, 2008; Mahler and Bourgeais, 2013; Kløve et al., 2014). In addition, anticipated changes in precipitation patterns, such as more droughts and more intense downpours, could have adverse water quality outcomes by increasing sheet flows, movement of pollutants into stream systems, and otherwise degrading water quality (Mahler and Bourgeais, 2013; Kløve et al., 2014; Nielsen-Gammon et al., 2021).

INVASIVE SPECIES

The expansion of invasive species or non-native species, both on land and in the river, poses a significant threat to the watershed and are described below:

Aquatic

Several known invasive species exist in the Devils River and Amistad National Recreational Area, including mollusks, fish, and aquatic and terrestrial plants. Arguably, the biggest threat to the ecological integrity of the system is zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*), which were first detected in Amistad Reservoir in 2022 and 2021, respectively (TPWD, 2024). Amistad Reservoir was classified as infested with zebra mussels in March 2024; however, quagga mussels have not been detected since May 2022 despite continued sampling. It is thought these species were transported to Amistad Reservoir via boats moving from infested waters.

Both zebra and quagga mussels have had catastrophic impacts on freshwater ecosystems in other parts of the United States, causing bottom-up impacts on food webs. Zebra mussels' significant ability to colonize and filter has reduced phytoplankton biomass by up to 90 percent in other parts of the United States (MacIsaac, 1996). This reduction causes cascading effects through higher levels of the food web and is documented to substantially impact native mussels' ability to obtain food and survive (Strayer and Malcom, 2007). This is especially concerning as the Devils River is home to a native freshwater mussel, Texas hornshell, with a narrow range within the Rio Grande Basin. While zebra mussels do not typically thrive in flowing waters, it remains unknown if they could colonize in lotic portions of the Devils River. However, if they did become established, it could pose significant challenges to the species, landowners, and recreationalists utilizing the river.

Asian clams (*Corbicula sp.*) first appeared in Texas in 1958 when they were discovered in B.A. Steinhagen Lake. They were later observed in the Rio Grande River in 1964 and the Devils River before 1985 (Howells, 2001; Karatayev et al., 2005; Benson and Williams, 2021). Another invasive mollusk known in the Devils River is the red-rim snail (*Melanoides tuberculatus*) (Howells, 2001; Bowles and Bowles, 2017), which serves as an intermediate host for an exotic trematode that infects fish in spring systems in West Texas (McDermott et al., 2014).

Blue tilapia is a known invasive fish inhabiting the Devils River (Howells, 2001). They first appeared in Texas waters in the 1960s and were introduced through bait buckets and fish farm releases. The first self-sustaining population was described in 1975, and now nearly all tilapia found in Texas waters are reported as blue tilapia (Howells, 2001). Waterthymes (*Hydrilla verticillate*) is a highly invasive aquatic plant within the Amistad reservoir (Poole, 2013). In addition, several terrestrial invasive plants were identified during surveys in the 1990s, including purple threeawn (*Aristida purpurea*), an invasive grass, and a variant of brickellbush (*Brickellia ischaemum var. songarica*) (Hedges and Poole, 1999).

Giant reed (*A. donax*) is another invasive, non-native riparian species that can be detrimental to the function and habitat of a river system. A native species to Asia and parts of Africa, it was first documented in the United States in the 1950s (Guthrie, 2007). Giant reed has yet to be reported in the Devils River, but it is worth noting as it has caused substantial impacts to neighboring streams, including San Felipe Creek and the Rio Grande. Giant reed can outcompete native vegetation, leading to a single-species population along riverbanks (USFWS, 2017). This can result in bank armoring, river channel erosion, and lack of diversity in instream and riparian habitats. It can cause further impacts on humans and the broader ecosystem by increasing flooding and fire risk and limiting access to the river (Guthrie, 2007; USFWS, 2017). Giant reed is very near in appearance to *Phragmites*, the native reed, which is prevalent on the Devils River.

Upland

Wild hogs are an invasive species in North America with an estimated U.S. population of over six million (Vernin, 2024; USDA, n.d.). Nearly half of the U.S. population resides in Texas (an estimated 2.6 million Wild hogs) (Salinas, 2023). Wild hogs are one of the 100 worst invasive species globally (responsible for billions of dollars' worth of destruction to agriculture in the U.S. annually) and they are increasingly causing damage to waterways and reducing water quality in Texas (Brown et al., 2012; Peters and Undark, 2020; Salinas, 2023). Wild hogs serve as ecosystem engineers and impact ecosystems in three major ways, including habitat degradation, competition and predation with other species, and the spread of infectious diseases; however, the level of impact varies by ecosystem and region of the country (Keiter and Beasley 2017).

A leading disturbance caused by wild hogs is "rooting," which is when they push their nose through the soil in search of food items. It is thought that rooting may alter soil chemistry, arthropod and vegetation composition, including facilitation of invasion by establishment of nonnative plant species (Arrington et al. 1999;

Keiter and Beasley 2017). However, other studies show rooting may enhance plant species richness in wetland habitats (Arrington et al. 1999). Further research would be needed to better understand the impact of wild hogs in the Devils River region and to determine appropriate management strategies to mitigate impacts of hog invasion (Adams et al. 2010).

Wild hogs' wallowing behavior near and in water sources to keep cool and remove ectoparasites reduces water quality in several ways (Timmons, 2011). The hogs tear up the riparian areas to cover themselves in mud and to eat plant and animal matter. This not only reduces the various ecosystem services provided by riparian areas (e.g., water storage, groundwater recharge, filtering contaminants, and more), but also increases sedimentation in waterways. The hogs also defecate near and in waterways which increases bacteria levels and nutrient concentrations.

When seasonal temperatures rise in Texas, the activity of feral hog populations becomes concentrated around water sources (Salinas, 2023). This is cause for concern because climatic trends indicate hotter and longer summers for the state (Nielsen-Gammon et al., 2024). As such, feral hog population growth and activities pose a challenge for managing water quality in state watersheds.

Wild hogs persist in the Devils River region. Currently, there are no specific studies or comprehensive data on the number and abundance of other terrestrial invasive species within the Devils River watershed. More research is needed into the estimated feral hog population for the Devils River watershed, along with a greater understanding of their movements, how they are currently impacting water quality, how they could impact water quality, and a long-term population management plan. (Brown et al., 2012; Mersinger and Silvy, 2007).

Captive and free-ranging exotic ungulates (non-native hoofed mammals) have become widespread in Texas over the past century with the Aoudad (*Ammotragus lervia*) being one of the most successful in establishing free-ranging populations (Wright et al., 2024). In West Texas, population estimates range from 5,000 to 20,000 individuals (Marks, 2019; Traweek & Welch, 1992; Schmidly & Bradley, 2016; Butts, 1979). Originally from the dry, mountainous regions of North Africa, aoudads were first introduced to Texas in the late 1950s. They were released in the Palo Duro Canyon by Texas Parks and Wildlife to provide hunters with a more challenging and visually appealing game animal. Since then, aoudads have established growing population in the area. Their success is largely because the rocky, desert-like terrain of West Texas closely resembles their native habitat. They are adept at navigating difficult landscapes and have a broad diet, allowing them to exploit a wide range of food resources and evade hunting efforts.

While their environmental impact is not fully understood, aoudads are considered, aoudads pose a significant threat to native desert bighorn sheep and can compete with mule deer due to overlapping habitats and diets (NPS, 2020; Schmidly & Bradley, 2016; Wilcox et al., 2022). Unlike desert bighorn sheep and mule deer, aoudads forage in larger flocks, can thrive in lean habitat conditions, and range across both high elevations and low foothills, making them less impacted by competition (Wilcox et al., 2022). They also present a potential health risk to bighorns by transmitting lethal respiratory diseases (Thomas et al., 2024; Price, 2024).

Researching free-ranging aoudads is challenging due to the rocky terrain they inhabit (Gray & Simpson, 1982). However, further studies are needed to better estimate their population in the Devils River watershed, understand their movements, and assess their environmental impacts. This information is essential for creating a long-term management strategy that balances ecological health with economic priorities.

INCREASED RECREATIONAL PRESSURES

As awareness of the Devils River has grown, increases in visitorship have brought an array of human impacts to the river and surrounding landscape. Some human impacts include but are not limited to litter and trash pollution, improper use of fire, light and sound pollution, as well as trespassing and damage to Indigenous cultural sites. The extent of these impacts is currently unknown due to limited research in the area. These increases in visitation may also threaten the unique, isolated wilderness experience that draws visitors to the area, a possible deterrent for future recreation and a potential negative impact to the regional river tourism economy.

ENERGY DEVELOPMENT

Texas is a state abundant in fossil fuels and renewable sources of energy. Three important sources of energy in the Devils River watershed are hydroelectric, natural gas, and wind power.

Hydroelectric Power

Hydroelectric power on the Devils River was the first major source of power for Southwest Texas. In 1927, three hydroelectric power plants were built on the Devils River by the Central Power and Light Company. The Devils Lake Hydro Plant, Lake Walk Hydro Plant, and Steam Plant significantly contributed to population and economic growth in the region.

Figure 11. Devils Lake Dam (National Park Service [NPS], n.d.)

Figure 12. Lake Walk Plant Construction (NPS, n.d.)

Figure 13. Steam Plant at Night in 1929 (NPS, n.d.)

The three hydroelectric power plants withstood many floods, including the flood of 1954 caused by Hurricane Alice (NPS, n.d.). The flood of 1954 caused significant damage to the region, particularly for communities near the Rio Grande River. To control flood waters and improve water storage, the United States and Mexican governments jointly began constructing the Amistad Dam and Reservoir on the Rio Grande in 1965. In the same year, the three Devils hydroelectric plants were shut down as they were no longer needed. The Dam was completed in 1969 and continues to be jointly managed by the United States and Mexico to this day. The Dam features two hydroelectric power plants, one in the United States and the other in Mexico, and the plant in the United States provides power to the region today (IBWC, n.d.; Thurmond, 2020).

Natural Gas

Because natural gas is often found alongside oil deposits, the natural gas industry in the Devils River watershed did not begin until the early 1920s with the discovery of moderate-sized oil reserves in the region (Olien, 2022; Hosmer, 2021; Smyrl, 2021). Natural gas pipelines were built to provide service to communities near the gas fields, attracting businesses and residents to the area. Communities utilized the new income to improve public infrastructure including schools and roads. As the industry steadily grew in the 1950s, so did the state pipeline system.

In most areas, the natural gas industry peaked in the 1970s (Hosmer, 2021). At the beginning of the 21st century, the industry remained an important element of the economy in Edwards and Crockett counties (McCrain, 2020; Smith, 2021). As drilling techniques advance and natural gas becomes one of the most dominant sources of energy in the world, the industry is expected to expand throughout the 21st century (Texas Comptroller, 2023a).

Wind Energy

Wind power has been harnessed by humans for centuries, initially for milling grain and pumping groundwater. In the United States, the development of wind energy gained momentum in 1850 with the founding of the U.S. Wind Engine Company, which designed the Halladay Windmill for use in the American West. Wind energy was initially developed to support farmers and ranchers, helping them pump water for irrigation and generate electricity for their homes and businesses. By the 1890s, the invention of steel blades made windmills more efficient, contributing to the westward expansion of settlers. The installation of utility-scale wind turbines to generate electricity did not begin until the 1980s following the energy crisis of the 1970s (Texas Comptroller, 2023b; U.S. Department of Energy [USDOE], n.d.).

Today, the Devils River watershed has become a focal point for wind energy development, thanks to its large expanses of sparsely populated land and the growing energy demands of nearby cities (Sharpley, 2013). Two wind farms currently operate in this area: the Rocksprings wind farm, developed in 2017 in Val Verde County, and the White Mesa wind farm, developed in 2021 in Crockett County (USGS, 2023). Some counties and stakeholders in the regions view these projects favorably, citing their role in generating clean energy, keeping taxes low, and supporting local infrastructure. However, others express significant concerns about potential drawbacks, including alterations to the natural landscape, diminished ecotourism, disruptions to migratory pathways for various wildlife species, and interferences with Air Force training routes (DRC, 2023b; Gibbons, 2018). This mix of opinions underscores the complexity of balancing renewable energy projects with environmental and community needs.

The U.S. Department of Energy has been actively researching how to minimize the environmental impact of wind energy. Studies show that properly located wind projects contribute minimally to annual bird mortalities from human activities, though more research is needed to understand impacts on other wildlife, such as bats, to further reduce any negative effects (USDOE, n.d.). This is especially relevant in the Devils River watershed, as Texas lies on major migratory pathways for species like monarch butterflies and migratory birds (TPWD, n.d.). In terms of human health and community impact, wind farms can produce noise and alter visual aesthetics. Wind turbines emit a mechanical hum from the generator and a "whooshing" sound as blades rotate. While no direct physical health impacts have been linked to these sounds, further study could help assess their influence on mental well-being, and work is ongoing to develop sound-mitigation strategies. Wind turbines may also cause a shadow flicker effect as blades pass between the sun and an observer, which some residents in the Devils River area find disruptive, along with the flashing red lights required on turbines at night that could impact the local State Natural Area's night sky designation (see Section 'Night Skies') (USDOE, n.d.). Additionally, there are concerns about the turbines' impact on scenic and culturally significant views, highlighting a need for further research to preserve these landscapes (Keefe, 2019).

Wind Energy and Night Skies

The development of wind energy has impacted some of the darkest skies across the globe, and similar changes in the Devils watershed may impact some of the darkest skies in Texas (British Broadcasting Corporation [BBC], 2013; DRC, 2023b; Kachur, 2015). Red lights are placed on top of wind turbines to prevent pilots from crashing into the structures, which can be more than 200 feet tall. In the Devils watershed, Greenalia, a Spain-based renewable energy company, has proposed the installation of windmills at Carma Ranch that will stand 700 feet tall (DRC, 2023b). If approved, these windmills would become the largest inland windmills in the country. While these stark red lights against the dark skies of the region create more safety for aircraft, they have a dramatic impact on the night sky in what is otherwise one of the last "wild" places in Texas. States across the country are creating laws to limit the use of these lights to times when aircraft are detected nearby, but Texas has no limitations on such lights.

> *"I can tell you from experience when I was a kid. It was purely dark skies. There were no lights, not even Del Rio on the horizon. It was absolutely dark - and talk about looking up and seeing the Milky Way and billions of stars. Light has been encroaching at night. There's no such thing as dark anymore.*
>
> *The first night they turned those lights on, it looked exactly like a runway lighting system. Imagine 69 of these things along the 12-mile line, viewed from 18 miles away. Those things are so big and tall that I can actually see [them] from the deck - the individual blades turning around. Those turbines are directly in the in the way of the sun coming up. It takes away from watching a beautiful sunrise when you sit there and watch those industrial monsters turning.*
>
> **- Dell Dickinson, 2024**

The 700 foot height of the 46 turbines are as tall as the San Antonio Tower of the Americas and have blinking red lights all night. It destroys the fabric of the landscape, and they just may be the first of many.

- Randy Nunns, 2024

The State Natural Area, located about 60 miles north of Del Rio along the lower Devils River, received the first Dark Sky Sanctuary[3] designation in Texas in 2019 (Reaves, 2019). A Dark Sky Sanctuary is public or private land with an exceptionally starry nocturnal environment and is protected for its scientific, natural, educational, cultural, or public value (Harrison, 2023). While the designation increases awareness of this nearly untouched place and hopefully promotes the conservation of its night sky quality, it also highlights the tensions between "natural areas" and the realities of these land use changes as these lighted windmills are squarely in the viewscape of the new visitor's center at the State Natural Area's DAH Unit.

Currently, there are no nationally or internationally defined standards for wind turbine setbacks, which are the minimum separation distances between wind turbines and various features such as roads, property lines, and homes. Consequently, the responsibility falls on individual organizations or local governments to establish their own standards, often integrated into town or county ordinances. With the majority of U.S. wind farm projects located in the Midwest and Texas, stakeholders in the Devils River watershed are increasingly seeking legal frameworks to address current and future challenges related to wind farms (USDOE, n.d.). Future research is needed to identify these frameworks. Some stakeholders in the watershed are interested in exploring the use of Tax Increment Reinvestment Zones (TIRZs) as a tool to guide wind energy development. The idea is to encourage projects in preferred areas, restrict them in less suitable locations, and use this strategy to boost property values and manage growth effectively.

3 *Dark-Sky International is a nonprofit organization whose mission is to protect people and nature from light pollution through the restoration of natural nighttime darkness (DarkSky, n.d.). One way the organization does this is by certifying and conserving starry places globally with five types of certifications.*

Solar and Emerging Energy Technologies

> *There are solar projects in the queue in Val Verde County with start dates scheduled for around 2027. Solar farms use less acres than wind, but it will still be a blight on the landscape.*
>
> **- Randy Nunns, 2024**

Innovations in the energy sector continue to emerge in this region, largely due to its abundant open land. During the writing of this report, local news highlighted ongoing developments, including solar farm projects, a potential "green hydrogen" plant, and a battery storage facility in Comstock. The proposed hydrogen plant to be located in the upper watershed has the potential to significantly impact groundwater resources (with an estimated need of approximately 5,000 acre-feet to start) (Hyde, 2024).

For some stakeholders in the Devils River area, these types of renewable energy projects raise concerns due to voluntary investment from some regional communities, minimal state regulations governing renewable energy, and limited research on the long-term impacts of such energy projects on human, wildlife, and environmental health (Foxhall, 2023). Additionally, these projects may conflict with the ecotourism expansion, as changes to the natural environment could affect the region's appeal to tourists (Pan et al., 2018). Further study of these impacts is recommended.

Public and Private Land Challenges

Private and public landowners—as well as the residents of nearby communities—are grappling with a myriad of other challenges related to the systems that rely on the Devils River and its source waters.

Several groups have organized to address some of these challenges:

> The **Devils River Association** was formed by legacy landowners and stewards of the Devils River to advocate and promote, through information and education, a reasonable balance between the need to protect and preserve the Devil's River watershed and its various ecosystems and the desire of the public to utilize the river and its immediate surroundings for recreational purposes, while recognizing and respecting the property rights of the watershed landowner.
>
> The **Devils River Conservancy** is a non-profit organization advocating for the preservation of the Devils River. Through education, outreach, and research, the Devils River Conservancy contributes to the understanding of the river's value and promotes respectful use and responsible policymaking throughout the 2.24-million-acre watershed. The Devils River Conservancy is governed by a nine-member board of directors comprised of landowners, engaged citizens, and conservation professionals, and the organization is supported by government grants, foundations, and private donors.

Stakeholders may wish to consider future research or action to address questions related to these issues (which are not addressed in this report), which were identified by the project's technical teams and vetted by the project's Stakeholder Jury:

1) LAND AND HABITAT FRAGMENTATION

Land and habitat fragmentation is a growing concern, driven by rising land prices, estate taxes, maintenance of rural working lands, inconsistent land management strategies, urban development, and local regulations on subdivision, septic, and well spacing. Additional challenges include engaging absentee landowners and preserving the role of rural lands in providing essential ecosystem services. Val Verde County, once known as the sheep and goat capital of the world, has seen its agricultural industry decline, replaced by unregulated development. Over the last decade, 44,808 acres have been subdivided into 694 lots, with another 86,000 acres recently listed for sale, potentially adding 500 to 1,500 new lots. Each subdivision increases demand for septic systems and water wells, while county enforcement is hindered by limited staffing and resources. Although the county has the authority to regulate septic compliance for parcels of 640 acres or less and zoning within the Amistad Land Use and Zoning Order, it lacks broader zoning authority, leaving much of the development unchecked. Without mechanisms to balance growth with environmental stewardship, these trends pose significant long-term threats to rural sustainability and land management across the watershed.

2) WATER SUPPLY

The water supply is adversely affected by decreasing flows and a heightened risks of well failures during periods of drought, which are exacerbated by excessive and commercial groundwater extraction. Increased water withdrawals, disjointed regulation of surface and groundwater, and fluctuating river flow and closure conditions compound these challenges.

SPRING-FED HABITATS UNDER LOW FLOW CONDITIONS ADJACENT TO DOLAN CREEK, NOVEMBER 2023.©SARAH ROBERTSON, TEXAS PARKS AND WILDLIFE

3) LANDSCAPE, ENVIRONMENTAL, AND INDUSTRIAL IMPACTS

The region's natural landscape is undergoing significant transformations due to the expansion of energy and industrial developments such as pipelines, fracking, hydrogen and green ammonia projects, wind turbines, and solar farms. These industrial activities are occurring alongside climate-related vulnerabilities like drought, warming surface waters, and altered watershed flow, posing substantial challenges to the ecosystem.

4) "THE HUMAN FACTOR"

The watershed experiences considerable ecological strain from recreational pressures, with issues such as trash accumulation and damage during low flow conditions brought on by paddlers. Additionally, the area is affected by inadequate wastewater management and insufficient irrigation return flows (e.g., land application of treated wastewater), which pose risks of water contamination and ecosystem disruption.

5) COMMUNITY EDUCATION AND AWARENESS

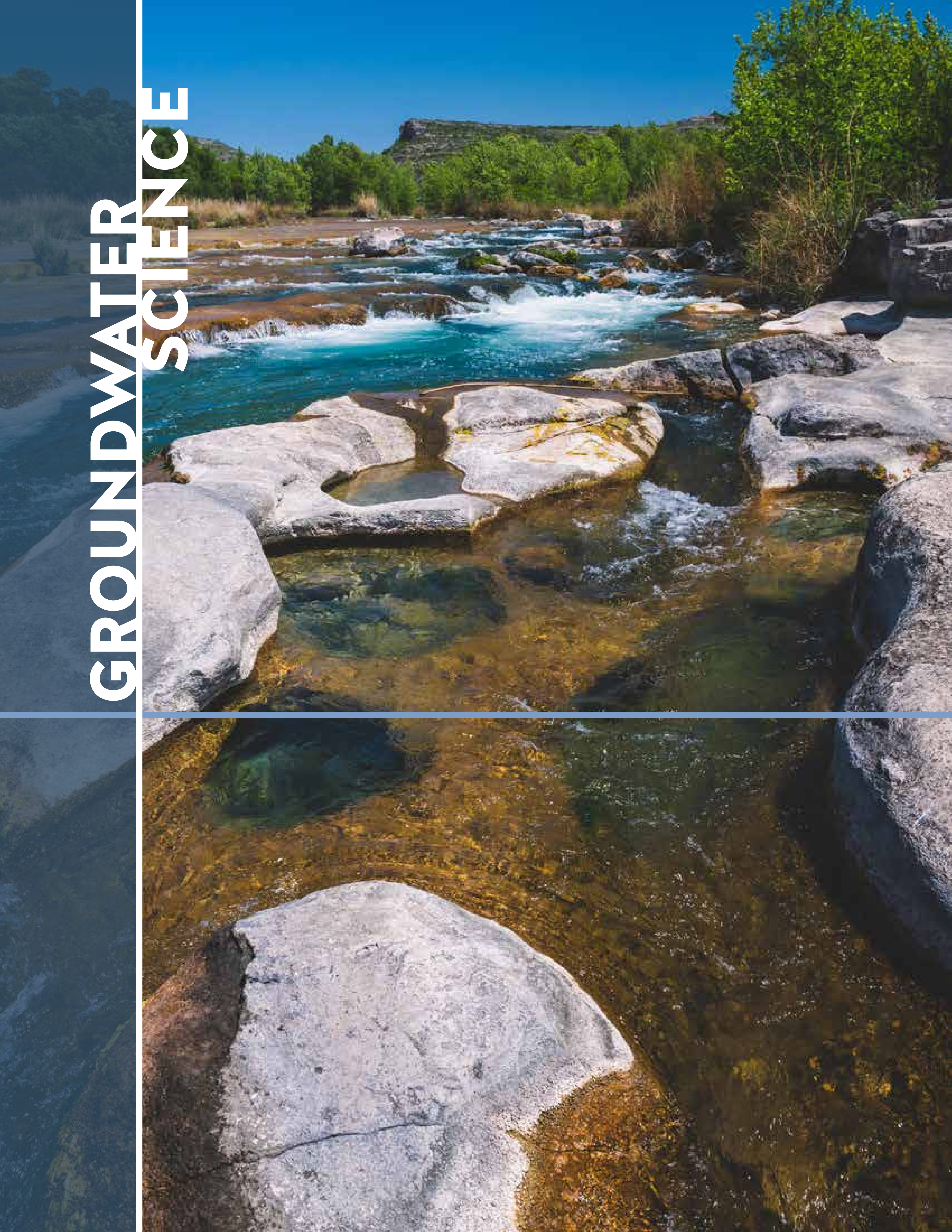
There is a lack of awareness and engagement among local communities (e.g., Laughlin Air Force Base, the City of Del Rio) about water issues and the importance of private lands in the Devils River watershed. This disconnect presents challenges in building an informed community focused on watershed protection.

6) INVASIVE SPECIES MANAGEMENT & INTERSECTION OF PRIVATE LANDS AND NATIVE PREDATOR SPECIES

The watershed is impacted by upland invasive species such as wild pigs and unmanaged aoudad populations, along with in-stream invasive threats like zebra mussels. Additionally, the interactions between native predator species and managed livestock require careful management to balance ecological and economic interests. As land use changes and ranching declines in the region, there are opportunities to reevaluate the role of native predators in current land management practices with emerging income streams from wildlife viewing and recreational activities.

DOLAN FALLS ©JACK JOHNSON

GROUNDWATER SCIENCE



Perhaps the most important challenge facing the future of the Devils River is the need to better understand the factors that impact the connection between the groundwater and surface water that may reduce flow of the Devils River. Droughts, combined with potential future significant increases in commercial or permitted groundwater pumping, threaten the loss of species habitat, recreational resources, and surface water and groundwater supplies (Weinberg and French, 2018).

Baseflow[4] in the Devils River is derived from springs sourced in the Edwards-Trinity Aquifer System in west-central Texas. The Devils River is an important water resource that contributes a large fraction of surface water to the Rio Grande/Amistad Reservoir, supports critical habitats for threatened and endangered aquatic species, and is a treasured and pristine recreational resource.

The goals of this section are to:

1. synthesize available information and the state of the science on groundwater resources from the literature and previous synthesis reports (e.g., Weinberg and French, 2018);
2. explore data gaps in context to the challenges facing the aquifer system feeding the Devils River; and
3. outline priority data and research needs and opportunities for collaboration in better understanding the groundwater resources feeding the Devils River.

This section builds upon the 2018 assessment of groundwater resources of Val Verde County conducted by the Texas Water Development Board to include the entire Devils River watershed and more recent information (e.g., Caldwell et al. 2020; TWDB, 2023; TPWD in preparation).

Background and Setting

The study area is unique, in part, because of significant perennial baseflows in the lower reaches of the Devils River within a semi-arid region with average annual precipitation ranging from 18-22 inches per year (PRISM, 2018b) and mean annual temperature of 64-68 degrees Fahrenheit (PRISM, 2018a).

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4 *Baseflow is groundwater flowing to streams.*

INSERT MAP with labeled segments of the region for reference (Domains of the River: Perennial Reach, Dolan Creek, Devils, Major losing reach (upper and lower); Highlight the tributaries.

Land Cover

Land cover in Val Verde County is comprised of shrub/scrub (approximately 94 percent), grasslands/herbaceous (approximately two percent), deciduous forest (approximately one percent), with little developed land (Del Rio and other towns, approximately one percent) (MRLC, 2018). The region has undergone large-scale woody shrub encroachment in the last 140 years and currently has higher shrub cover than in any period in the past, despite a substantial decline in grazing pressure since the 1960s (Diamond and True, 2008; Wilcox et al., 2010).

Geology

The study area is located along the southern and central portion of the regional Edwards-Trinity (Plateau) Aquifer, a karstic aquifer system. The aquifer geology is composed of the Lower Cretaceous Edwards Group, specifically, the Fort Lancaster and underlying Fort Terrett formations in the upper watershed, the Devils River Limestone within the middle, and the Salmon Peak Limestone in the lower watershed (Barnes, 1977; Hunt et al., 2023).

INSERT GEOLOGIC MAP (Basin, Topo base (e.g. shaded hillside DEM overlain with 250k GAT) and springs. Weight the size of the spring dots relative to these values. (average springflow for period of record)

The region's geology consists of thin, rocky soils over flat-lying fractured, karstic limestone that forms plateaus with increasingly dissected valleys and tributaries that deepen in the sub-watersheds of the lower Devils. Beginning in the Oligocene and continuing during the Miocene, the Cretaceous-age limestones were uplifted which fomented development of the incised river channels (Rose, 2015). River and tributary channels contain thick, discontinuous alluvial fan and fluvial terrace sediments cemented to various degrees. Fracturing occurs throughout the watershed, but faulting is limited. The exception is the Carta Valley, and Slaughter Bend fault zone that trend generally east to west across the lower-middle of the watershed (Webster, 1980).

Springs

Spring discharge occurs where stream channels have incised into the limestone and intersected the water table (Abbott, 1975; Green et al., 2014; Woodruff, 1977). The Edwards-Trinity (Plateau) aquifer supplies water to these springs that provide baseflows in the river that ultimately reaches Amistad Reservoir and the Rio Grande, which is subject to international treaty (Weinberg and French, 2018). Combined springflow from Husdpeth, Pecan, Finegan, and Dolan averaged ~120 cfs during 2015-2022 (Hunt et al., 2022), making it one of the largest spring complexes in Texas (Brune, 2002). Because of this springflow, the Devils River is considered an “Ecologically Significant Stream Segment” due to its relatively pristine ecosystem and high species diversity (Omernik and Griffith, 2014; TPWD, 2012). Perennial baseflow in a semi-arid environment provides habitat for threatened and endangered fish and mussel species (FWS; 1999, 2021; TPWD, 2012, 2014). Commercial groundwater pumping and climate change are significant potential threats to the groundwater resources, springflow, and habitat of the Devils River watershed (Wolaver et al., 2018). These issues, and others, are described below.

The State of Groundwater Science in the Devils Region

Given the importance and appreciation of the ecological value of the Devils River watershed, its resources have been studied and evaluated by a number of researchers in recent years (Green et al., 2014; Toll and others (2017); Weinberg and French, 2018; Wolaver et al, 2018; Hunt et al., 2022; Young et al., in preparation). Although insight of the system has been gained by this work, additional effort is needed to resolve some remaining technical uncertainties regarding the surface and groundwater interactions of this complex karst aquifer system.

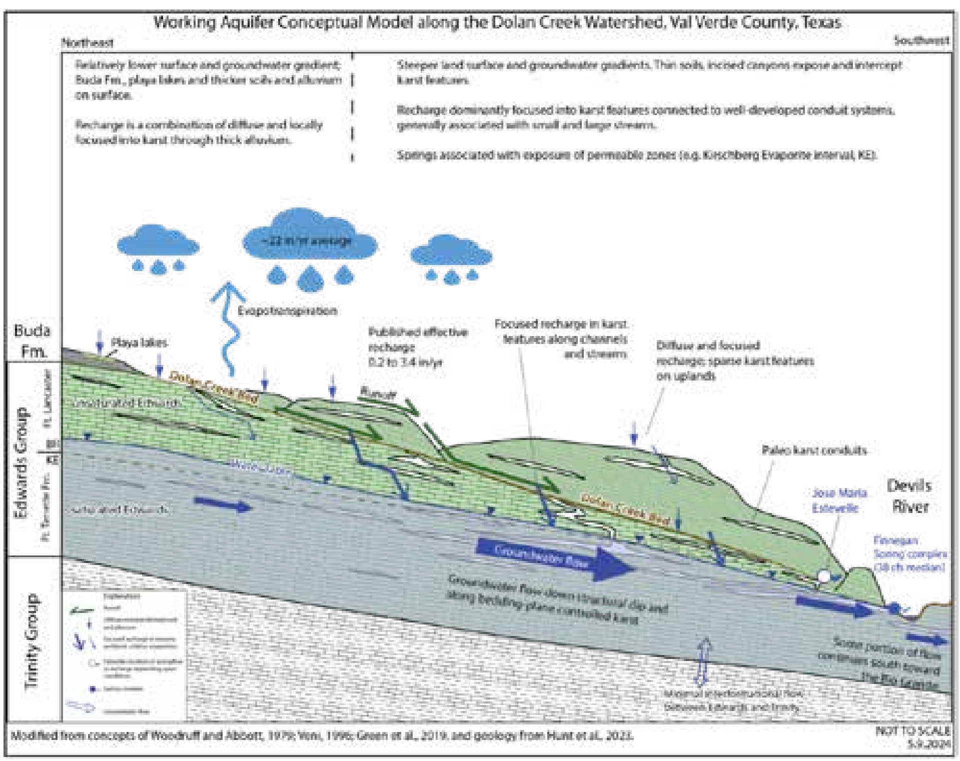

Figure 14. Diagram of the working “conceptual model” for the aquifer along Dolan Creek.

Figure 14 summarizes the current conceptualization of the Devils River drainage and aquifer system and simplifies the hydrogeology and key processes of the watershed (climate, runoff, recharge, groundwater storage, and flow) that control the mechanisms that convey precipitation to stream discharge in a karst terrain. This "conceptual model" is based on field studies specific to the watershed in addition to relevant knowledge from similar settings (Anderson et al., 2015). The example depicted is from the more studied Dolan and Finegan Springs area, which likely shares some similarities with other parts of the watershed.

The "state of the science" for groundwater is presented from raindrop to springflow, in the following three sections: Recharge Processes, Groundwater Flow, and Discharge.

Recharge Processes

Recharge to groundwater systems under most circumstances is difficult to quantify. Quantifying recharge to a karst carbonate aquifer in a semi-arid environment can be especially challenging. Recharge is hypothesized to occur throughout most of the watershed, including within the dry portion of the Devils River (upstream of the headwater springs), tributaries (such as Dolan Creek), and the upland plateaus. It is further hypothesized that recharge occurs primarily through infiltration of episodic flows in ephemeral stream channels (Anaya and Jones, 2009). Concentrated flow along the surface drainage system provides recharge to the aquifer through discrete or focused karst openings, such as sinkholes and solution-enlarged fractures. Focused recharge in conduit systems would produce rapid responses in water levels and springflow. Recent studies in the State Natural Area (Del Norte Unit) have demonstrated that groundwater levels respond to recharge and correlate well to increases in springflow (Hunt et al., 2022). Recharge into the matrix (diffuse) is thought to occur broadly through precipitation percolating through soils and smaller fractures (Weingberg, 2018). Overall, the river is mostly gaining with perennial water due to the inputs of springs. Recent studies have demonstrated that loss (recharge to the aquifer within the stream system) is occurring in at least two sections of the perennially flowing reach, where streamflow decreases by 17 percent and 39 percent on average (Young et al., in preparation). Historic water level maps (Weinberg and French, 2018) suggest that the losses in the Devils River at these locations provide recharge to the aquifer system that flows southward toward the Rio Grande.

Karst features in the State Natural Area were mapped in 2015-2016. Several dozen caves, sinkholes, and related karst features were identified during these surveys (Texas Speleological Survey, 2024). Although the entire watershed was not included in the surveys, results are suggestive that significant karst development (caves, etc.) is likely throughout the entire watershed. The presence of karst features increases the potential for focused, discrete recharge and development of preferential high-permeability flow pathways in the groundwater regime. These flow pathways discharge to the springs found in the river channel. Recent geologic mapping (Hunt et al., 2023) used LiDAR (laser measurement) and GIS mapping tools to identify closed depressions greater than one meter within the State Natural Area Del Norte Unit. Most of the closed depressions were concentrated within the large tributaries, such as Dolan Creek, with sparse development in the plateau regions. Field inspection revealed that many of depressions were in fact karst features, and most of those inspected had evidence of recharge (Figure 15).

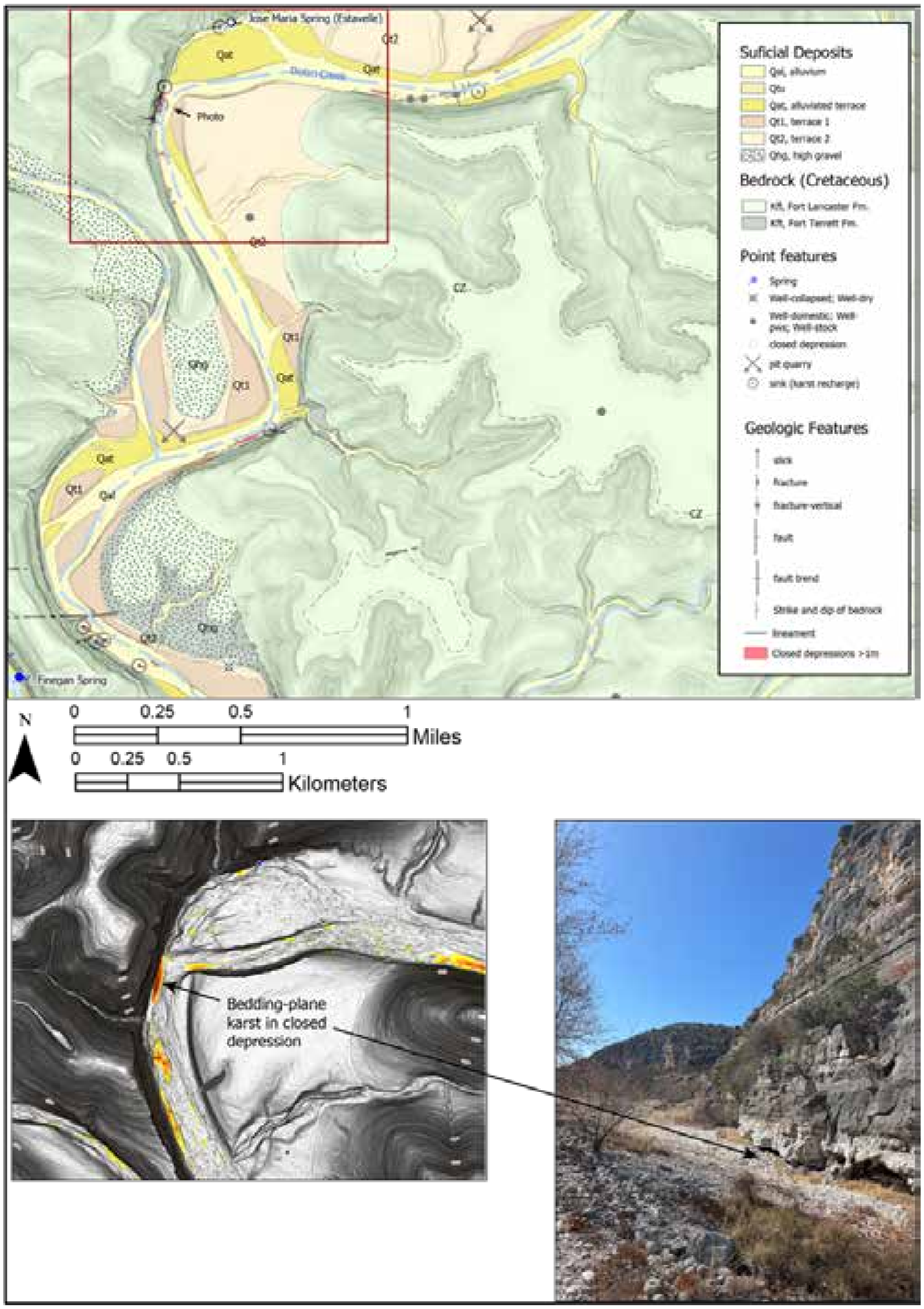

Figure 15. Portion of the Geologic Map of the Dolan Springs quadrangle (Hunt et al., 2023). The closed depressions in red and confirmed karst recharge features located on map are all located in the incised valley, with few found in the table uplands. Inset map on lower left hillshade with GIS-mapped closed depressions (red). Inset photo is a large bedding-plane karst (recharge) feature shown on the map and hillshade figure. Evidence for flow into such features includes imbricated sediments.

Supporting the idea that recharge predominantly occurs at discrete locations, Weinberg (2018) hypothesized that the chemistry of spring discharge indicates that most recharge to springs occurs through large fractures and sinkholes, and flows through a system of conduits, with minor interaction with the rock matrix under normal flow conditions.

Another conceptualization about recharge processes of the Edwards-Trinity Aquifer is a “threshold” model for groundwater recharge (Toll and others, 2017). This threshold model posits that recharge essentially goes to zero when mean annual precipitation falls below about 16 inches, based on correlations between precipitation and estimated recharge. This correlation is based on long-term averaged precipitation and spring discharge measurements and does not account for important factors such as precipitation duration and intensity, antecedent moisture conditions, and any other factor that could impact evapotranspiration.[5]

Reitz et al. (2017a) provided annual estimates of recharge, quick-flow runoff, and evapotranspiration for the region and provided mapping products that are useful in a regional study of groundwater, recharge, streamflow and springflow processes (Reitz et al., 2017a, b). In addition, Sen et al. (2022) provides a comparison of available techniques and models available to estimate recharge in the region. That work demonstrated that different models provide similar recharge estimates when averaged across large areas, but not at smaller (watershed) scales.

The current state of the science does not allow for a more focused estimate of recharge (both spatially and temporally) due to the lack of granular hydrologic data to quantify and characterize focused and distributed recharge, runoff, and evapotranspiration for the semi-arid landscape of the Devils River Watershed. In addition, the lack of understanding of the source areas or springsheds (groundwater source areas) for the various spring complexes of the river limits the ability to provide water-budget constraints and input into other recharge estimation techniques.

In summary, there is a clear lack of understanding of groundwater recharge processes and dynamics across space and time in the semi-arid karstic Devils River Watershed. That lack of understanding makes evaluating the stress from pumping and climate-related variability, a significant challenge.

Groundwater Flow

Groundwater in the Edwards-Trinity Aquifer generally flows north to south and feeds springs that provide baseflows to the Devils River which flows into the Amistad Reservoir on the Rio Grande (Weinberg, 2018; Veni et al., 1996). As mentioned, the springsheds and flow pathways to springs within the system are poorly understood because of the lack of groundwater monitoring wells and detailed potentiometric (water level) maps under various hydrologic conditions.

Weinberg and French (2018) posit that recharge to the regional aquifer occurs through infiltration of episodic flows in dry ephemeral stream channels (Veni and Associates, 1996; Anaya and Jones, 2009) into karst features. Recharge that flows through and is delayed by the epikarst[6] may be another significant source of recharge. The pathways of groundwater flow are poorly characterized because of a lack of detailed water level maps spanning hydrologic conditions, and other data such as dye tracing. However, preferential flow pathways are thought to

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5 *Evapotranspiration is the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration (water evaporation from the soil, from the water bodies including the groundwater table, and water taken from the soil by plants and released as water vapor into the air from their leaves.*

6 *Epikarst can be thought of as the skin of the aquifer, the active and protective shallow part of karst areas, in which climate, tree roots, etc. fracture and enlarge rock joints and cracks, creating a more permeable zone over the infiltration zone (Bakalowicz, 2003).*

occur along river channels based on the strong correlation between wells with high-yield and proximity to higher-order stream channels (Green et al., 2015).

Groundwater flow is controlled by the hydraulic properties of the rock—that is, the gradient and how porous and permeable the rock is. Those hydraulic properties have been conceptualized to either be broadly distributed (Hutchison et al., 2011) or distributed based on the karst landscape evolution (Woodruff and Abbott, 1979). The later conceptualization suggests preferential pathways are developed below stream channels where recharge is focused and is less developed in the tablelands separating those surface stream channels Green et al. (2014, 2019). This conceptualization was corroborated with groundwater chemistry, well hydraulics, and near-surface geophysics (Green et al., 2015). Based on this conceptualization, the hydraulic permeability architecture of the Devils River watershed would generally mirror the surface topography. Continuous and relatively long-term water level hydrographs from wells in the State Natural Area are cited in support of this conceptualization. Wells located within the Dolan Creek valley have dynamic karstic responses to recharge that correlate to the springs. This is in contrast to wells in the uplands that have a more gradual response to recharge and appear isolated from the dominant flow system (Hunt et al., 2022).

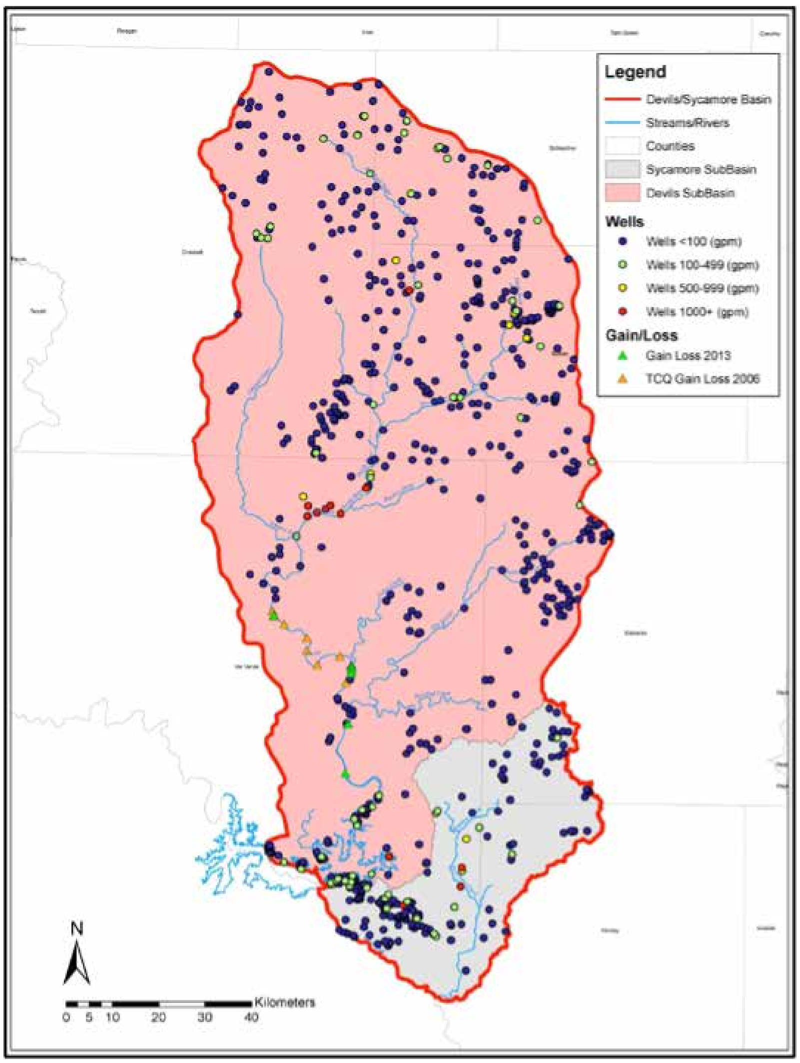


Figure 16. Map of well capacity (gallons per minute) in the Devils River watershed (Green et al., 2014).

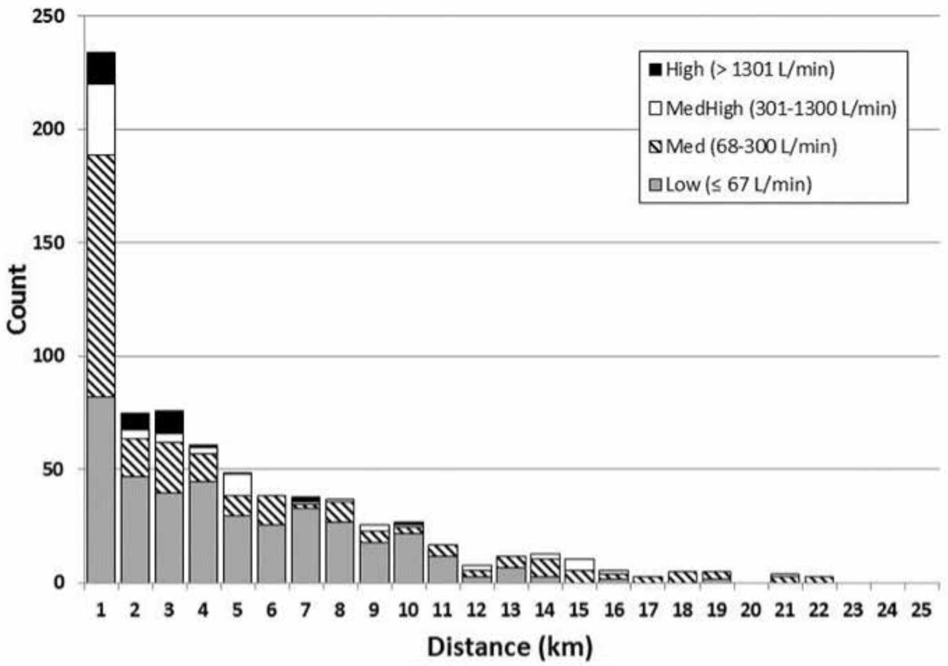


Figure 17. Capacity of wells (liters per minute) based on distance from river channels (Green et al., 2014).

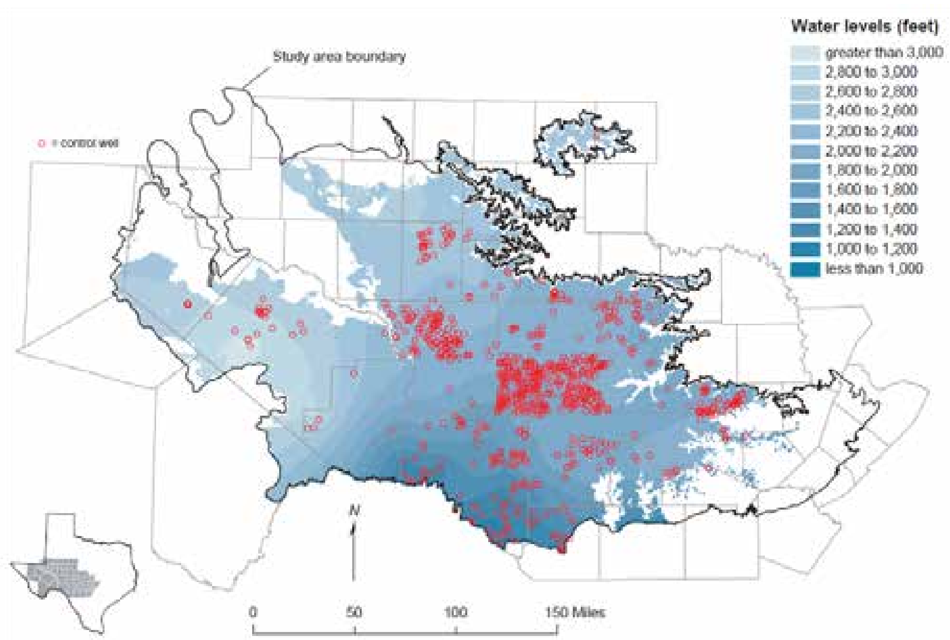


Figure 5-14. Average winter water levels for the Edwards hydrostratigraphic unit of the Edwards-Trinity (Plateau) Aquifer.

Figure 18. Potentiometric Surface Map from the Groundwater Availability Model Report.

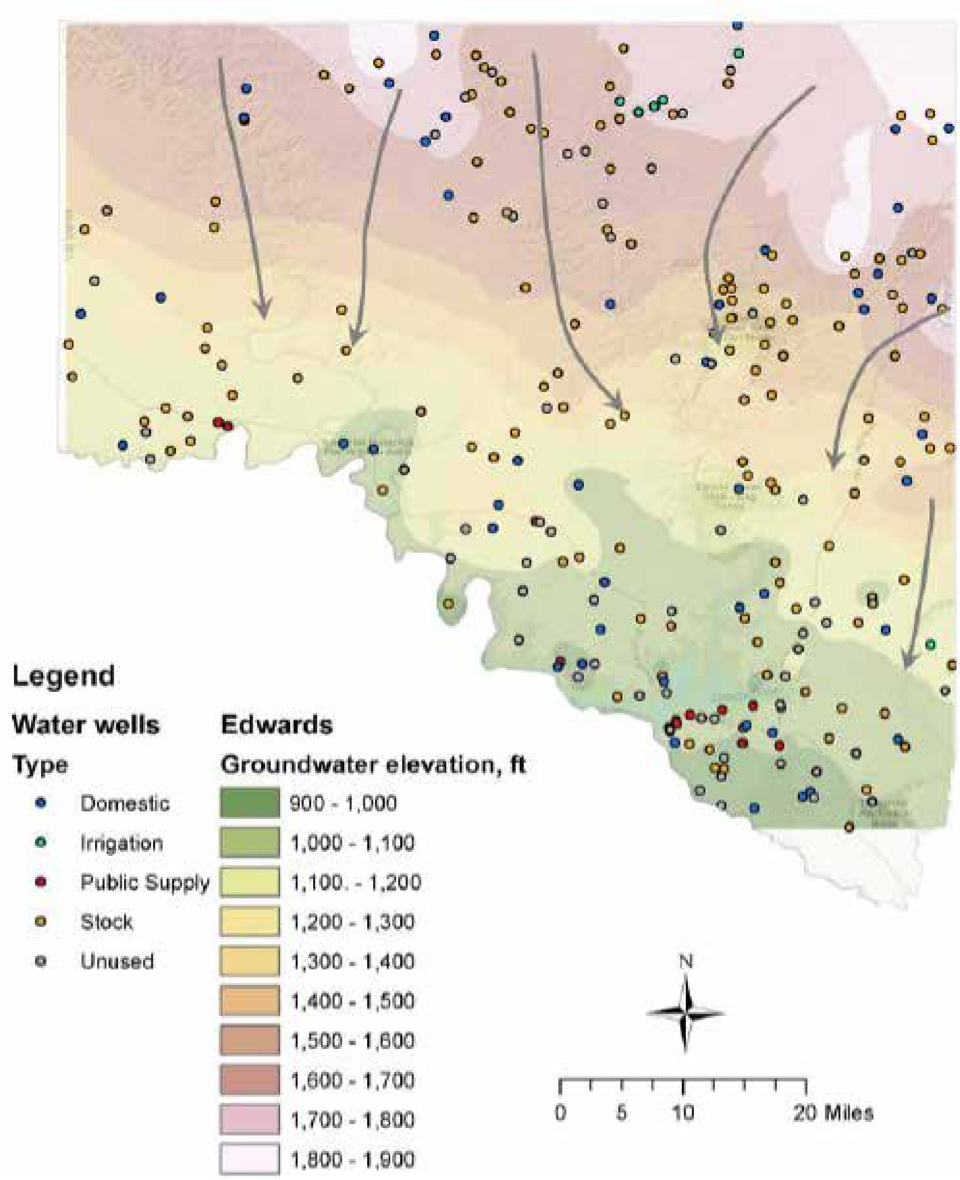


Figure 19. Water level contour map constructed from average winter water levels in wells completed in the Edwards Aquifer. Arrows indicate general flow paths. Data from the Texas Water Development Board groundwater database (Weinberg and French, 2018).

Available water level records throughout Val Verde County do not demonstrate widespread, long-term effects of pumping on streamflow or river flows (Weinberg and French, 2018). However, the lack of long-term monitor wells, particularly in the Devils River watershed, make that assessment uncertain. Recent studies in the State Natural Area's Del Norte Unit have demonstrated that groundwater levels respond to recharge and correlate to changes in springflow (Hunt et al., 2022) and demonstrate the hydrologic connection of the groundwater levels and springflow. Thus, changes in water levels from drought and pumping would have effect on springflow for a given springshed. The correlation of water levels in wells to the springs varies depending on location and suggests some compartmentalization of the aquifer (Hunt et al., 2022). This difference may reflect their location in different springsheds, or conduit versus more diffuse permeability fields for that study area. The mean residence time of groundwater discharged at Goodenough Springs and San Felipe Springs is estimated to range between 2 and 34 years (Weinberg and French, 2018). This is consistent with a complex conduit system carrying both young and mixtures of young/older groundwater. However, studies and data on the geochemistry are limited.

Consistent with other Edwards karst areas, the flow through the rock matrix is much slower than in the conduit system (Hunt et al., 2019). Accordingly, groundwater originating from the rock matrix represents a small fraction of the overall volume of groundwater discharged from the major springs under normal flow conditions; however, the matrix contains a larger fraction of the total groundwater in storage (Weinberg and French, 2018).

In summary, groundwater flow is primarily understood conceptually, with a lack of quantitative metrics used to detail the system. The springshed areas contributing to the various springs are not delineated, which makes the assessment of water budgets, correlations of aquifer levels to springflow, and the impacts of hydrologic stresses a challenge. Better characterization of the karst flow networks in the system and more detailed potentiometric maps (and dye tracing) would further help in the delineation of the springsheds and understanding the overall permeability of the fabric of the system.

Discharge

Aquifer discharge at springs provides the baseflows to the Devils River. Numerous springs historically occurred in the Devils River watershed (Brune 2002, LBG Guyton 2005, Weinberg and French 2018, MCWE 2024), many of which still occur in Val Verde County from the area of Juno south to the confluence with the Rio Grande (Figure 20). A recent report by the Meadows Center (Meadows Center, 2024; Meadows Center, in preparation) updated information on historical springs from Brune 2002. Appendix A: Historic Spring Conditions catalogs and updates information from this report for the Devils River watershed.

The Devils has lost springs on both ends of its perennial flow segment, upstream to lower water levels likely caused by increased groundwater production and downstream due to inundation first by Devils Lake and Lake Walk and then by Lake Amistad, although lower lake levels occasionally reveal “lost” springs. It appears that the spring system is in equilibrium with changes in pumping that occurred some 80 years ago, as evidenced by continuing flows at Cedar Springs. Flows in the Devils River close to upper reaches of Lake Amistad have been consistent for much of the past 50 years except since 2010, where flows are only 60 percent of long-term flow averages. This decrease in flow is most likely due to a continuing drought in the area (Meadows Center, in preparation).

The river is both a source of discharge and recharge to the aquifer system. Under baseflow conditions (when springs are contributing to the streamflow), the river is not influenced by runoff-producing rain events and streamflow is entirely sourced from springflow. Perennial flow in the Devils River begins at Pecan and Hudspeth springs (Figure 20). There is uncertainty in the historic record whether the current headwaters of the perennial flow was always Pecan Springs.

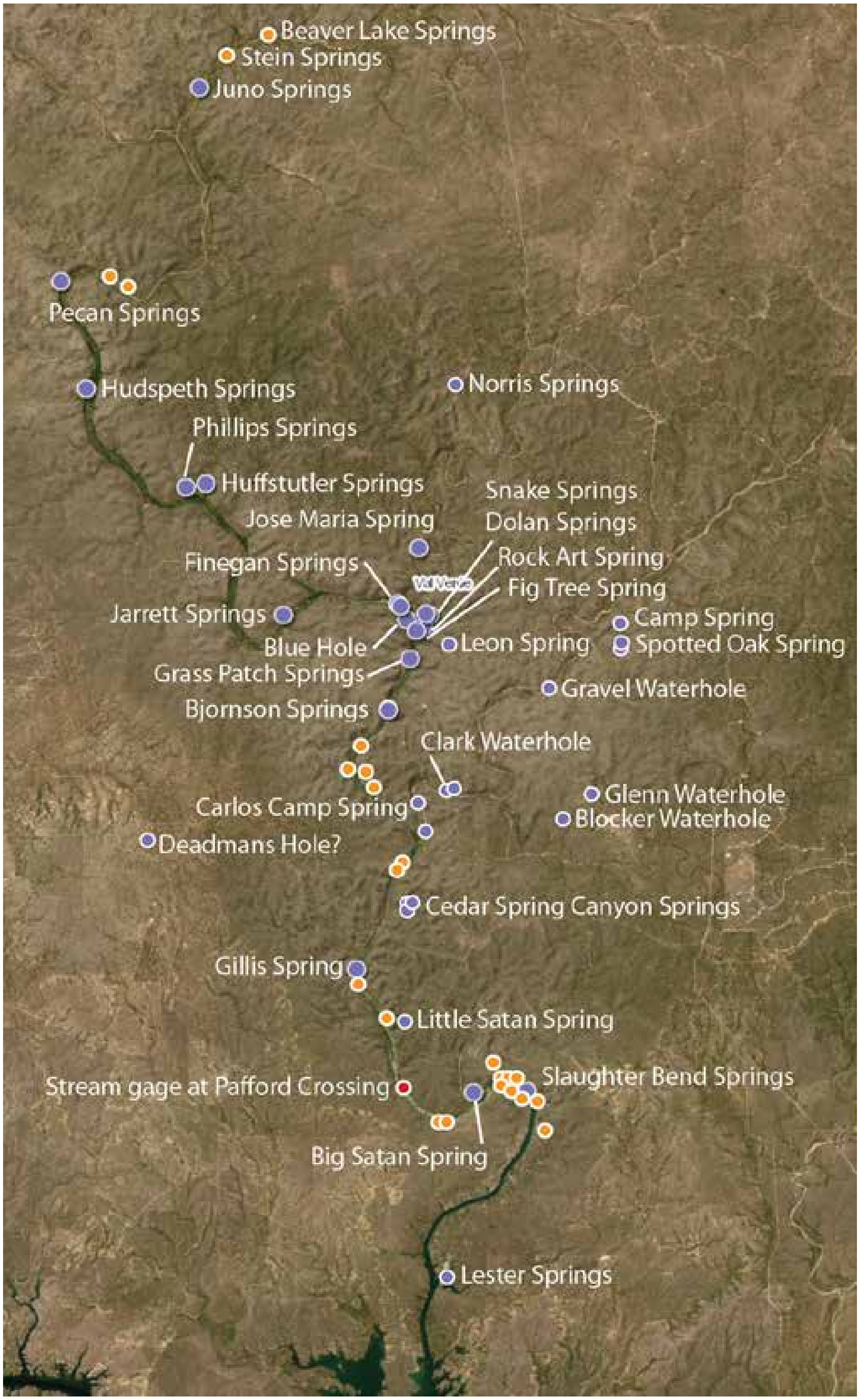


Figure 20. Springs and the lowermost stream gauge in the Devils River approximately between Juno and inundation by Lake Amistad. Purple dots indicate named springs, orange dots are locations of unnamed springs, and the red dot is the stream gauge (Meadows Center, in preparation).

Beaver Lake

Reports dating to the middle 19th century note that Beaver Lake, located approximately ten miles upgradient from Hudspeth Springs, was a source of perennial water, although the reach from Beaver Lake to Pecan springs was ephemeral (Finnegan, 2007). Beaver Lake has effectively been dry since the early to mid-20th century. This dewatering has been attributed in Green et al (2015; 2017) to either reduced recharge due to changes in climate, or to increased pumping in the upper Devils River watershed due to development in Sutton County.

Local accounts attribute the disappearance of the lake to catastrophic floods in 1932 and 1948 which buried the lake in gravel, with the process being completed in the 2000-year flood of 1954 (Kochel, et al. 1982) following a severe drought. Accordingly, the hydrogeologic character of Beaver Lake is not understood—the feature may possibly be an estevelle, which is a karst feature that behaves as a spring or as a recharge feature based on hydrologic conditions. Additional study of the Juno area is warranted to better assess the hydrogeologic function of the river, aquifer, and Beaver Lake.

DEL NORTE UNIT OF THE STATE NATURAL AREA ©JACK JOHNSON

MEASURING SPRINGFLOW/SPRING DISCHARGE IN THE DEVILS RIVER

Spring discharge occurs where stream channels have incised into the limestone strata and intersected the water table (Abbott, 1975; Green et al., 2014; Woodruff, 1977). Overall, the river is mostly gaining across the study area (Young et al., in preparation) from springflow. This is consistent with average baseflow estimates for creeks and rivers within the outcrop of the Edwards Plateau Aquifer region, which is 55 percent of total streamflow. This ranks third highest among the 30 major and minor aquifers in Texas (Anaya et al., 2016). It is reported that up to 75 percent of Devils River streamflow into Lake Amistad is comprised of groundwater (Green et al., 2014).

However, as noted above, important exceptions to this characterization of the Devils River as a “gaining” river can be found in at least two reaches of decreased streamflow (losing) by 17 percent and 39 percent on average (Young et al., in preparation and Green et al., 2014).

INSERT MAP/FIGURE SHOWING GAIN-LOSS AREAS, SPRINGS, GAUGES, KEY WELLS.

The total springflow from the headwaters area is generally captured by the Bakers Crossing (IBWC) flow gage under baseflow conditions. However, flow measurements have only been discontinuously gauged for the last 100 years, with measurements by both the U.S. Geological Survey and the IBWC, complicating interpretation of any long-term trends (Weinberg and French, 2018). During that time baseflows appear to fluctuate based on natural variability of seasonal and short-term climatic changes. Weinberg and French (2018) found that available evidence suggests the starting point of perennial flow has been near Pecan Spring since the early 20th century and has not changed significantly in response to pumping from irrigation wells near Juno, which started in the 1950s.

A study by Texas Parks and Wildlife along the entire perennial river provides granular data on streamflow gains and losses for the entire river (Young et al., in preparation). Focused flow studies on springs have occurred in two areas in the upper portion of the perennial river, including the headwaters area (Pecan Springs area), and the State Natural Area (Del Norte unit) (Hunt et al., 2022; Hunt et al., in preparation). Total springflow from the headwaters region for the limited recent studies ranged from about 38 to 70 cfs (Hunt et al., 2022; Hunt et al, in preparation).

The Finegan-Blue Hole spring complex and the Dolan Springs complex are about 15 river miles downstream from Bakers Crossing gage. Recent studies measure springflow from the Finegan-Blue Hole complex ranged from 25 to 62 cfs with a median flow of 38 cfs. Dolan Springs is a complex of springs within Dolan Creek near its confluence with the Devils River. A U.S. Geological Survey gage measures total springflow from the complex and had a springflow range of 5 to 32 cfs and median flow of 15 cfs (Hunt et al., 2022).

Two streamflow gages managed by the IBWC are located on the perennial (flowing) reach of the river: 1) Bakers Crossing - about 7.5 miles downstream from the headwater springs (Hudspeth and Pecan springs), and 2) Pafford Crossing - at the lower end of the perennial (flowing) river where the river flows into Amistad Reservoir. Other IBWC gages exist in the study area, but are located within ephemeral (dry) portions of the river or large tributaries. The U.S. Geological Survey has a gage on Dolan Creek near the confluence with the Devils River that measures the total flow from the Dolan Springs complex. A recent (2015-2023) low flow gage has been placed on the Devils River above Dolan Creek (Dolan Crossing) and above Finegan Spring as part of a Texas Parks and Wildlife-funded study (Hunt et al., 2022).

Total net springflow for the perennial river is measured at the lowermost gage, maintained by the IBWC, is located at a weir at Pafford Crossing about 1.5 miles south of Little Satan Creek. Measured flow in the Devils River at Pafford Crossing increased after Amistad Reservoir filled and a potential hydrologic connection of the reservoir to local streamflow levels may not be a good indicator of conditions in the upper, spring-fed reaches of the river (Weinberg and French, 2018). There could be lake-level effects on flows in springs along the Devils River, at least among the springs on the lower reaches. Higher lake levels cause water levels in the aquifer bordering the lake to rise which in turn would cause springflows to increase. For example, flows at San Felipe Springs in Del Rio rose about 50 percent after Lake Amistad filled (Ashworth and Stein, 2005). Note: The period of record for this gage is January 1, 1960, to present; we analyzed up to June 2, 2024. The minimum flow at this gage was 54 cfs as measured on August 20, 1969, with a maximum flow of 123,105 cfs as measured on September 18, 1974. Medium flow—probably the best estimate of typical baseflow for this dataset—is 223 cfs (Meadows Center, in preparation).

Flows in the Devils River have been in low flow, drought conditions since 2010 based on the change in slope in the cumulative flow plot, conditions not seen since the 1960s when the lowest flow during the record was measured. From 1975 through 2010, about 133,500 cfs flowed past the gage (and into Lake Amistad) on an average annual basis. Since 2010, about 80,000 cfs have flowed past the gage on an average annual basis, only 60 percent of the previous 35 years. This contribution is slightly less than the about 82,000 cfs that flowed past the gage from 1960 through July of 1971. Flows in recent weeks (relative to June 3, 2024) have been as low as 83.4 cfs, with drought conditions expected to continue (Meadows Center, in preparation).

Temperature and specific conductance (SC) were continuously measured at select springs in the 2022 University of Texas at Austin Bureau of Economic Geology study. The data demonstrate a very good correlation of temperature, and specific conductance to recharge and increases in springflow. In addition, certain wells contain groundwater levels that correlate with spring flow, suggesting connections between specific wells and springs.

Pumping

Groundwater is generally fresh and found at depths ranging from a few feet below ground surface along major watercourses and near springs, to several hundred feet below ground surface at higher elevations and between drainage systems. Well yields vary from less than one gallon per minute to over 2,000 gallons per minute.

Groundwater pumping in Val Verde County is currently less than 5,000 acre-feet per year, significantly lower than the modeled available amount of 50,000 acre-feet per year (a regional water planning value). Using Val Verde County as representative for the Devils Watershed, public water supply and irrigation are the main uses, while domestic and oil and gas use are minimal, and represents less than 10 and 5 percent, respectively (Weinberg and French, 2018). Groundwater pumping for all uses in Val Verde County has averaged about 4,700 acre-feet per year since 2001. Total county water demand is expected to grow 26 percent over 50 years, from 16,777 acre-feet per year in 2020 to 21,127 acre-feet per year in 2070 (State Water Plan, 2017). It is important to note that the City of Del Rio sources their water from San Felipe Springs as surface water and therefore usage is not quantified in these groundwater pumping calculations.

Future water demand is expected to grow, and in recent years, several groundwater well fields have been proposed to supply water outside the county (Weinberg and French, 2018). Wells producing groundwater from an aquifer that is hydrologically connected to springs (e.g., within its springshed) directly impact spring flows—a well-established and fundamental hydrogeologic concept known as capture (Theis, 1940). Accordingly, groundwater pumping in the study area can potentially impact springflow and therefore streamflow due to the highly interconnected nature of surface and groundwater. Concentrated high-volume pumping along or upgradient of perennial river reaches could induce the capture of springflow or surface water (Weinberg and French, 2018).

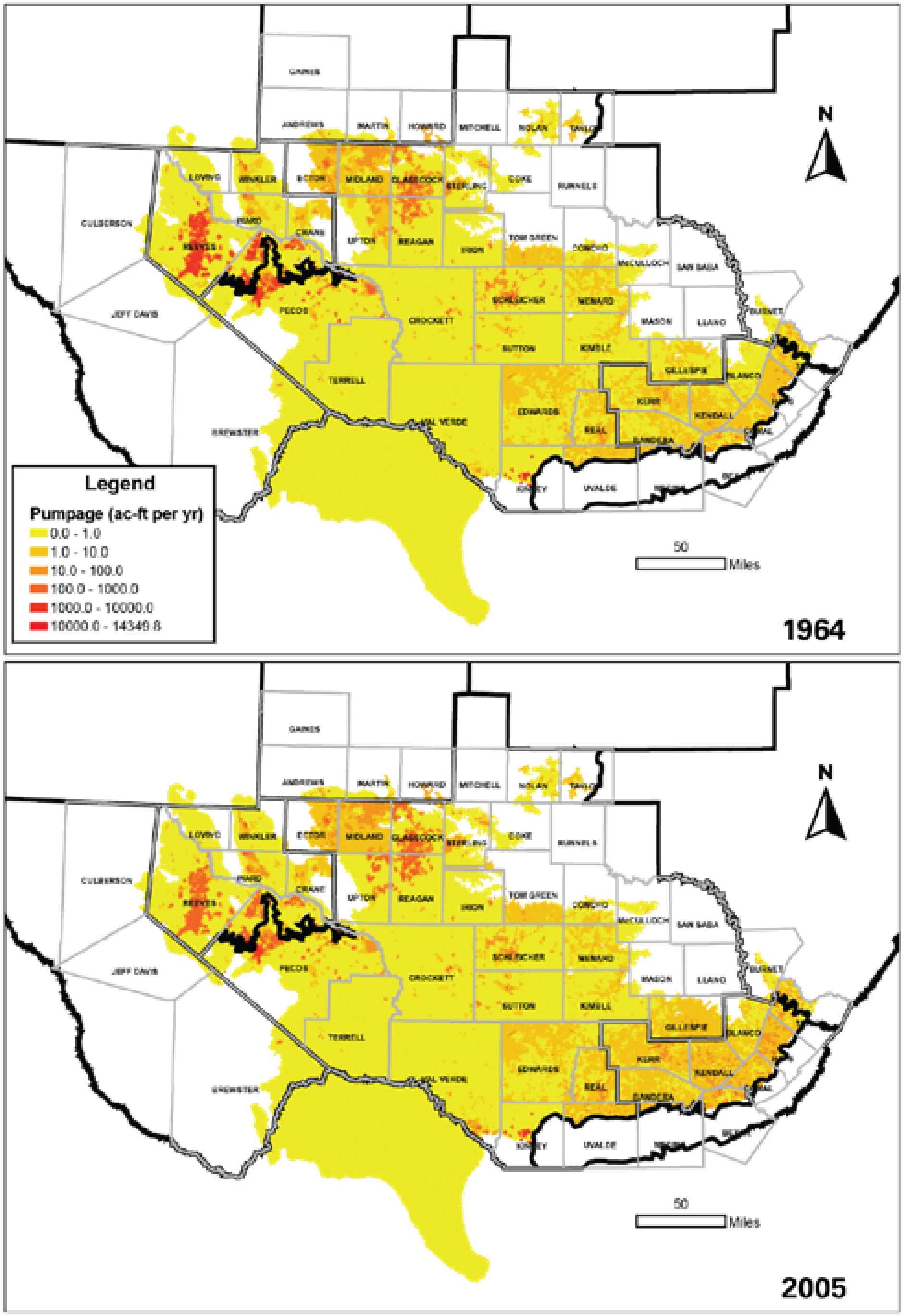


Figure 21. Pumping from 2011 one-layer Edwards-Trinity Plateau Groundwater Availability Modeling Report.

Numerical Groundwater Modeling

Numerical groundwater models are one of the primary tools used by water resource scientists and planners to aid in the sustainable management of an aquifer. In the Devils River basin, three separate groundwater models have been developed independently to simulate the water budget under varying stresses such as drought and pumping. Key results include changes to springflow and aquifer water levels. Each model was built by a different entity and had different scales and questions to address. Thus, results from the models are not directly comparable.

Table 3. Overview of three existing groundwater models.

Groundwater Model	Developer	Date	Highlights
TWDB Groundwater Availability Model	TWDB	2009	Large-scale, multiple aquifers and numerous counties included; coarse resolution; two-layer (Edwards and Trinity); steady-state and transient; ModFlow finite difference model.
Val Verde County Model	Eco-Kai	2014	Smaller-scale, limited to Val Verde County; shows impact of Amistad Reservoir to San Felipe Springs; several future pumping scenarios were predicted; ModFlow finite difference model.
Devils River Watershed Model	SWRI	2014-2017	Watershed-scale integrated surface water/ groundwater model; used to model springflows in Devils River watershed; FEFlow finite element model.

Each of these three models have strengths and weaknesses with respect to studying the hydrogeology of the Devils River watershed. The larger-scale Groundwater Availability Model (GAM) is not useful to predict critical springflow in the Devils River watershed, but addresses long-term regional impacts to water levels and storage from pumping and recharge to the broader aquifer system on an annual basis. The Val Verde County (Eco-Kai and Hutchison, 2014) groundwater model, which is derived from a Texas Water Development Board model of Kinney County and surrounding areas (Hutchison, Shi, and Jigmond, 2011), represents the best starting point for a Val Verde County groundwater management model. The Val Verde County model employs a finer spatial grid than the Texas Water Development Board Groundwater Availability Model and has monthly time steps, includes calibration to several major springs, and specifies considerable hydrogeological detail for both the U.S. and Mexican portions of the Edwards-Trinity (Plateau) Aquifer system. The Devils River Watershed Model, a combined surface water/groundwater model developed by Toll and others (2017), has daily timesteps and a much finer grid around critical areas, but covers only the Devils River watershed. In addition, the model specifies considerably more detailed aquifer properties than are supported by available data, making model calibration uncertain and complicating application to the remainder of the county, for which even less data are available.

All three groundwater models are limited by the availability of data used to calibrate and verify the hydrologic properties that are used to represent the aquifer.

Expanded data records in the Devils River area, including aquifer water levels, continuous spring/river flows, pumping, geologic and hydrologic features, and evapotranspiration are required to improve existing and future models used to predict future conditions. One of the biggest challenges in groundwater modeling is understanding the temporal and spatial controls on recharge of water into the model, particularly with the uncertainty about climate change impacts to the hydrologic cycle.

Continued refinement of the conceptual framework used to link all the components of the water budget in the system is necessary along with inclusion of higher density and frequency data to improve the ability to predict future conditions of the aquifer feeding springs and base flow to the Devils River.

AGENCIES AND ENTITIES WORKING ON UNDERSTANDING THE HYDROGEOLOGY OF THE DEVILS RIVER

A variety of agencies and entities are working to better understand the Devils River watershed and its resources. A list of many of those entities most active in the Devils River area includes:

- The Texas Water Development Board has funded ongoing work to characterize the hydrology and hydrogeology of the Devils River and the groundwater system that supports it. Work in-cludes updating numerical models that augment groundwater management, such as the Groundwater Availability Models (GAMs), which are stewarded by the Texas Water Devel-op-ment Board.
- Texas Parks and Wildlife conducts research and management for threatened and endangered species that are dependent on spring-flow in the Devils River Watershed and also carries out hydrologic studies and funds other research through their grant programs.
- The IBWC and U.S. Geological Survey have overlapping, yet distinct, data missions.
- Universities such as the University of Texas at Austin Bureau of Economic Geology, Texas A&M University, Texas State University are conducting important research on aquifers, the river, and its ecosystems and operating some smaller-scale monitoring programs.
- Private institutes, contractors and consultants such as Southwest Research Institute are con-ducting additional research and other studies.
- Groundwater Districts in the upper watershed include Sutton County Underground Conservation District, Plateau Underground Water Conservation District (Schleicher County), Edwards-Real Con-servation Reclamation District, and Crockett County Groundwater Conservation District.

The following tables list and provide links to many readily available Devils River watershed groundwater-related datasets and GIS/mapping resources from state and federal agencies as well as universities, non-governmental organizations, and other organizations.

Table 4. Summary of Available Data Resources.

Type of Data	Source Entity	Description	Link to Data Source
Water Well and Groundwater Monitoring Well Reports	TWDB	Submitted Drillers Reports Database- Groundwater well reports submitted online by registered water well drillers can be found in The Submitted Driller's Reports Database. The database contains reports from 2003 to present.	SDR Reports and Downloads | Texas Water Development Board
Water Well and Groundwater Monitoring Well Reports	TCEQ	Reports submitted prior to 2003 were submitted by paper and have been scanned and can be accessed through TCEQ Water Well Report Viewer	Water Well Report Viewer (arcgis.com)
Select Digital and Geophysical Well Logs	TWDB	Brackish Resources Aquifer Characterization System Database (BRACs). The BRACS database is designed to store well and geology information in support projects to characterize the brackish resources of Texas.	BRACS Database | Texas Water Development Board
Groundwater Database (GWDB)	TWDB	The Groundwater Database contains information on select water wells, springs, oil/gas tests (wells originally intended to be or converted into water wells), water levels, and water quality data. Any reports and the entire groundwater database can be downloaded.	GWDB Reports and Downloads | Texas Water Development Board
Weather Station data	TWDB	Weather station data is available through a statewide network called TexMesonet. It is comprised of over 3,741 stations maintained by the National Weather Service and various regional and local entities.	TexMesoNet | Texas Water Development Board
Historical Water Use and Pumping Estimates	TWDB	This information is generated annually through surveys to 4,650 public water supply systems and 2,600 industrial facilities to determine the volume of surface and groundwater used. The information is used to guide water supply studies and regional and state water planning. Methods for estimating water use and pumping based on water use surveys are described at: http://www.twdb.texas.gov/waterplanning/waterusesurvey/faq.asp.	Historical Water Use Estimates | Texas Water Development Board Historical Water Use Survey Data | Texas Water Development Board Historical Groundwater Pumpage | Texas Water Development Board
Current State Water Plan Interactive Viewer	TWDB	The State Water Plan serves as a guide to state water policy and is completed on five-year cycles. Based on 16 regional water plans, the plan addresses needs of all water user groups in the state-municipal, irrigation, manufacturing, livestock, mining, and steam-electric power-during a repeat of the drought of record that the stated suffered in the 1950s.	Statewide Summary | 2022 Texas State Water Plan
Monitor Well and Stream Gauging Information	IBWC	Water records and current river conditions monitored at select locations within the Rio Grande, Colorado, and Tijuana river basins	Water Data - IBWC Specific link to the Water Portal: Data - USIBWC Water Data
Groundwater Availability Models (GAMs)	TWDB	Comprehensive source for all GAMs for major and Minor aquifers of the state. Includes downloadable GAM databases, conceptual and numerical model reports, alternative models, research projects.	GAMs | Texas Water Development Board
Streamflow Gauges	USGS	Historical and current conditions for streamflow gages operated by the U.S. Geological Survey. Includes supplemental information (e.g., stream channel measurements) for some locations.	USGS National Water Information System
Real-Time Water Quality Monitoring	TCEQ	Real-time water quality monitoring stations operated by the Texas Commission on Environmental Quality. Includes parameters useful to groundwater/surface water context.	TCEQ Real-time Water Quality Stations

Table 5. Other Available Resources for Viewing and Mapping Data.

Type of Data	Source Entity	Description	Link to Data Source
Applications for Viewing Data	TWDB	Interactive Apps and Maps including Texas Water Service Boundary Viewer, TexMesonet, Texas Flood Viewer, ASR or AR Statewide Suitability, Groundwater Data Viewer, 2022 State Water Plan, Water Data for Texas, INFRM Flood Decision Support Toolbox, EDAP Interactive Story Map	Data, Apps and Maps | Texas Water Development Board
Base Map and Groundwater Layers	TWDB	GIS Data Sets. Includes downloadable shape files for various types of natural features and boundaries for various administrative units including Regional Water Planning Areas and Groundwater Conservation Districts	GIS Data | Texas Water Development Board
Historic and Current Geographic Maps of Texas	TWDB-TXGIO	TXGIO is a division of the TWDB (formerly TNRIS) and is the resource for any geographic mapping. It houses high quality historic and current geospatial data. Includes strategic mapping methods such as LiDAR and bathymetry mapping.	Home | Texas Geographic Information Office

Understanding the Groundwater System: Data Gaps and Research Needs

While there has been significant study of the aquifer system feeding the Devils River, notable information gaps still exist. These range from the need for a more refined understanding of groundwater flow pathways, the full extent of the areas contributing recharge to the springs (i.e., the springsheds), to the amount of current pumping in the Devils River watershed. Many of these information gaps need to be filled to refine the understanding of the surface water/groundwater system and to be able to track the effects of meaningful changes in climate, water development, and land uses. To meet this need, additional monitoring wells, springflow and river flow gages, and other monitoring locations are necessary. The primary objective of a monitoring well is to provide an access point for measuring groundwater levels and to permit the procurement of ground-water samples that accurately represent in-situ groundwater conditions at the specific point of sampling (Aller et al., 1991). Unlike active pumping wells, passive monitoring (or observation) wells do not impact adjacent wells or springflows. It is important to note that cooperation with private properties should occur on a strictly voluntary basis, ensuring full transparency of methods and data use are conveyed to the property owner.

Specifically, the following questions need to be more fully addressed:

1. **How does the aquifer system function? / Can we refine our conceptual model of the aquifer system?**
   Refinement of the overall conceptual model of the aquifer system of the Devils watershed is ultimately what is needed to address the fundamental questions and challenges facing the resource. Uncertainty in the hydrogeology includes recharge (diffuse vs. focused processes), groundwater flow (conduits along valley bottoms vs. diffuse flow), and the extent of springshed areas, among other subjects. A list of specific studies to refine our conceptual model is provided in the Recommendation section below.

2. **What are the effects of climate change / extended drought?**
   Climate change is expected to affect the timing, frequency, and intensity of precipitation, evapotranspiration, and changes in vegetation, among other effects to regional hydrology (Kloesel et al., 2018). How will the river and its watershed respond to changes in climate (i.e., how will climate change impact recharge)? How sensitive is river flow to modest changes in precipitation/recharge?

3. **How does the system respond to pumping, and can we better understand and quantify the effects of groundwater withdrawal?**

4. **What are hydrologic indicators of a healthy Devils River and supporting groundwater resources, and where do we monitor these?**
   Though not a goal of this report to propose options for management of the groundwater resources of the Devils River watershed and/or Val Verde County, this technical team wishes to highlight the need for more work on using river and groundwater conditions to define a healthy Devils River and supporting aquifer. Many of the study recommendations outlined below provide important information related to this need, and this type of information needed for designing any management approach and to avoid threats such as groundwater export out of the watershed.

Recommendations for Groundwater Research, Monitoring, and Collaboration

1. **Recommended Research**

   A. Research to Refine the Geologic Framework

      a. Build upon the recent Dolan Springs Quadrangle, expanding geologic mapping of bedrock and surficial deposits for select key areas. Faults, fractures, and karst would be part of the mapping. Define the role of the geologic framework with regards to every aspect of the water budget, outlining the characteristics of the hydrostratigraphy and diagenetic history that influence the permeability structure of the aquifer.

      b. Create regional structure contour maps of the aquifer. Use geophysical logs, outcrops, publications, and drillers logs to refine the structure contours of the aquifer system.

   B. Research to Better Understand Recharge

      a. Further examine rainfall-runoff relationships. Utilize current IBWC stations and instrument small tributaries within the Dolan Creek watershed (near TxMesonet sites) to characterize runoff. In addition, instrument and focus should be placed in an area(s) of the dry reaches of the river in the upper portion of the watershed.

      b. Complete additional gain-loss studies building upon the recent Texas Parks and Wildlife gain-loss data and other flow gauging sites, and refine and quantify the gains and losses for the Devils River.

      c. Create additional surficial and karst maps. Use remote sensing and GIS to map closed depressions and karst features-this can be done for selected portions of the watershed, representative of key parts of the watershed.

      d. The effects of climate change on karst aquifer recharge are not well or understood. Conduct an assessment of historic long-term climatic changes and potential effects on water levels and spring discharge for the area. This information could help refine our understanding of the future effects of climate change on groundwater recharge in karst aquifers. Additional research in this area should also include the downscaling of climate models for the region.

      e. Recent studies of groundwater resources in the region have only focused on total recharge, not the recharge mechanisms (Sen et al., 2022). Expanded research to characterize and quantify the effects of climate change (e.g., extended drought, more frequent extreme rainfall events) on this system is needed to understand the aquifer's recharge mechanisms (focused vs. diffuse, etc.).

   C. Research to Better Characterize Groundwater Flow:

      a. Refine and augment the existing regional potentiometric map.

      b. Localize potentiometric maps, ensuring that cooperation with private properties is strictly voluntary and that full transparency of methods and data use is conveyed to the property owners. Perform detailed potentiometric mapping around the spring complex of Dolan Springs, Finegan

Springs, and Pecan Springs. Continue to instrument wells in the Dolan and Pecan Springs area (particularly the possible new well near Juno) to track groundwater response to recharge.

c. Perform dye traces within the Dolan and Finegan Springs complexes to expand the definition of springshed(s), flow pathways, and variable residence times. Begin with tracing from the Jose Maria Spring (estavelle feature) within Dolan Creek to the spring complex.

d. Geochemistry (water chemistry) can provide insight into the matrix-conduit interaction and other geochemical processes that would provide insight into groundwater-rock interactions and, thus, the pathways of groundwater flow and recharge source areas. Sample select wells and springs for geochemical and isotopic data under both low-flow and high-flow or post-storm conditions.

e. While San Felipe Springs was out of this chapter's geographic scope, we recommend additional study of the San Felipe Springs system to better understand the relationship between Amistad Reservoir levels and both surface and groundwater extraction. Included in this is a better understanding of the capture area for this system and the Devils River, which could include dynamic water level maps and dye tracing.

D. Research on Discharge (Springflow)

a. To further delineate and quantify springflow, continue and develop springflow measurements and rating curves for known (e.g., Pecan, Dolan, Finnegan) and possibly new spring complexes. Explore tools like baseflow separation to better understand springflow.

b. Utilize existing wells in the State Natural Area to refine the water level-springflow index relationship. In the headwaters area (Pecan Springs), drill and install a new monitor well at the IBWC site. Instrument with telemetry and incorporate into the Texas Water Development Board recorder well program.

c. Evaluate the region's historical pumping and water budgets to better assess the potential range of response of this system to pumping, especially during drought. This is needed to better answer questions like "How long could a drought be sustained and keep flows in the perennial reach?".

d. Create and maintain a map of monitoring points that is available to stakeholders.

2. Expanded Monitoring of Aquifer Conditions, Springs/Tributaries, and the Devils River

A. Expand the well-monitoring network throughout the Devils River watershed farther upgradient of the perennial springs, ensuring that cooperation with private properties is strictly voluntary and full transparency of methods and data use are conveyed to the property owners. These data will help with aquifer and spring discharge trends, recharge, overall aquifer storage, and source area delineation. Include monitoring wells in the Dry Devils River watershed, which flows infrequently but may have important groundwater flows paralleling the ephemeral stream channel (Green et al., 2014).

B. **A new stratigraphic and monitor well drilled (est. 3-400 feet deep) north of Pecan Springs in the Juno area, perhaps within the IBWC easement at Cauthorn's Crossing, would provide key hydrogeologic data (e.g., Fort Terrett vs. Segovia) data for regional structure contour mapping. In addition, it would be co-located with the IBWC site to provide key surface-groundwater interaction data. A rating curve could be developed for the Pecan Springs complex.**

   a. Establish real-time springflow and river data where key data gaps exist. Instrument select stream and spring sites intended to be permanent monitor locations moving forward.

   b. Maintain and improve the Dolan Crossing site with telemetry for real-time data.

   c. Conduct bi-annual visits to various spring reaches and well sites for manual measurements of springflow and well levels and to maintain and download probes, ensuring that cooperation with private properties is strictly voluntary and full transparency of methods and data use are conveyed to the property owners. Examples include Pecan Springs, etc.

   d. Maintain stream and springflow gaging stations at the State Natural Area for the Finegan-Blue Hole spring complex.

   e. Further explore the connection between spring flows and levels in Lake Amistad.

Key Takeaways – Groundwater Science

These recommendations are based on a comprehensive literature review and reflect the collective expertise of a technical team from 2023-2024.

- The Devils River is a crucial water source for the Rio Grande and Amistad Reservoir.
- The aquifer beneath the river is made up of limestone formations from different periods, which vary as you move downstream.
- Combined flow from several springs in the area averaged about cfs from 2015 to 2022, making it one of Texas' largest spring complexes.
- Water recharge happens throughout most of the watershed, including within the dry portion of the Devils River (upstream of the headwater springs), tributaries (such as Dolan Creek), and the upland plateaus.
- Most of the river gains water from springs, but certain sections lose water back into the aquifer, reducing streamflow by 17 percent and 39 percent in some areas.
- For most of the past 50 years, flows in the Devils River near Lake Amistad were steady. However, since 2010, flows have dropped to just 60 percent of the long-term average, likely due to an ongoing drought in the area.
- Up to 75 percent of the river's flow into Lake Amistad comes from groundwater.
- The perennial flow in the Devils River has consistently started near Pecan Spring since the early 1900s and has remained largely unaffected by irrigation well pumping near Juno, which began in the 1950s.
- The Finegan-Blue Hole and Dolan Springs complexes provide major springflows downstream. Finegan-Blue Hole flows range from 25-62 cfs, and Dolan Springs ranges from 5-32 cfs.
- Since 2010, flows have been low, similar to drought levels last seen in the 1960s.
- The Groundwater Availability Model (GAM) is useful for assessing long-term regional impacts on water levels and storage from pumping and recharge across the broader aquifer system. The Val Verde County Groundwater Model provides a more precise tool for Val Verde County, using a finer grid and monthly updates. It is calibrated to several major springs and includes detailed hydrogeological data for both U.S. and Mexican parts of the Edwards-Trinity (Plateau) Aquifer. The Devils River Watershed Model offers the highest spatial and temporal resolution, with daily updates and a very fine grid focused on the Devils River watershed, providing a detailed view of critical areas.

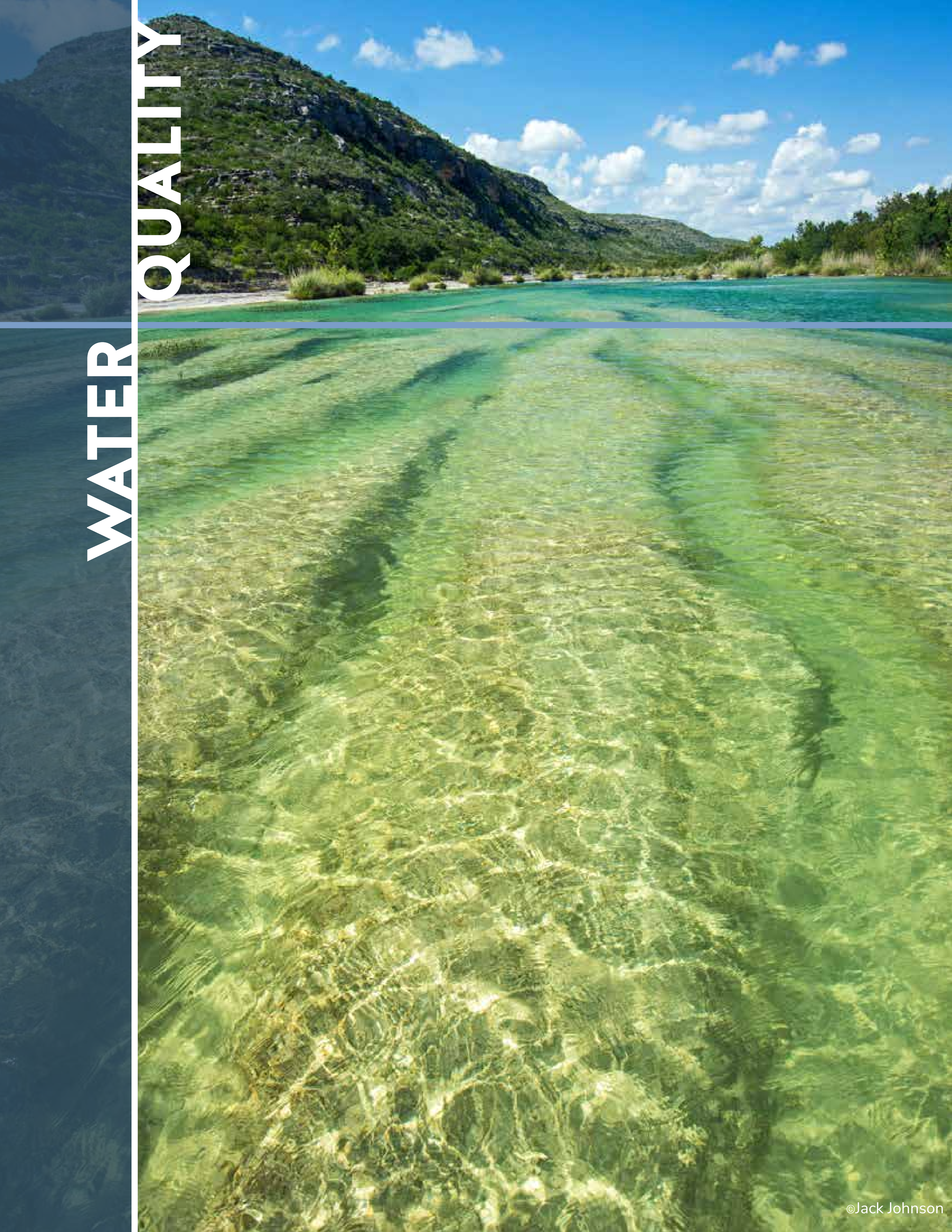
Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

Research priorities are:

- Increase voluntary well monitoring across the watershed, adding real-time data at important spring sites, to better understand the links between water levels, springflow, and flow sources.
- Update existing maps using a variety of data sources to get a clearer picture of how water moves through the aquifer.
- Conduct studies on rainfall-runoff, water gains and losses, and the impacts of climate change to better understand how groundwater is replenished and flows through the system.

Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

WATER QUALITY



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The subsequent sections characterize the river's water quality, clarify historical trends that have shaped its current state, and review the standards established to ensure its future preservation. The purpose of this section is to present the current state of water quality of the Devils River watershed based on historical data trends and state standards, determine remaining questions facing the region, discuss areas of conflicting opinions, and highlight future research needs based on data gaps.

The Pristine Devils

Many claim the Devils is one of the most, if not the most, pristine river in Texas (Caldwell et al., 2020; De La Cruz, 2004; DRC, 2023). This is because the river is primarily spring fed with clear blue to aquamarine waters featuring cool temperatures. However, some are hesitant to tout the Devils as pristine because there have been few studies that have comprehensively investigated the hydrological, physical, chemical, and biological properties of the river (Diaz et al., 2018).

Sampling Station 08449400 on the Devils River at Pafford Crossing is a part of the U.S. Geological Survey Hydrologic Benchmark Network and details historical water quality trends at that specific station between 1978-1995 (Moring, 2000). This is a significant historical period of record that indicates water quality in the Devils River is excellent. Additionally, several water quality assessments have taken place along the Devils River and have indicated that water quality trends have remained relatively unchanged compared to historical data, and these trends indicate good water quality.

The water quality of the Devils River, from the perennial headwaters at Pecan Springs to its confluence with the Rio Grande at Amistad Reservoir, faces imminent threats from groundwater pumping, watershed alteration, wastewater discharge, and the introduction and expansion of invasive species. To protect the aquatic environment and beneficial uses of the Devils River, including its tributaries, water quality criteria have been established by the Texas Commission on Environmental Quality (TCEQ) for *Escherichia coli* (*E. coli*) bacteria, dissolved oxygen, pH, temperature, chloride, sulfate, and total dissolved solids. Overall, water quality conditions are excellent with no exceedances of the state criteria.

Key water quality characteristics of the lower Devils River are as follows:

1. Springs contribute approximately 75 percent of total river discharge;
2. Water in the watershed contains an excess calcium content and is prone to scaling;
3. Nitrate-nitrogen and nitrate plus nitrite concentrations typically exceed screening levels which are likely naturally elevated from the springs flowing through limestone formations;
4. There is a long-term warming trend of surface water temperature increasing 0.16 degrees Celsius per decade; and measurements of water quality parameters have remained relatively unchanged when compared to historical data records.

Potential Sources of Contamination

Water quality is a concern for both humans and animals within the Devils River watershed. Anthropogenic activities and materials can introduce a variety of contaminants into the environment. Often, the fate and transport of environmental pollutants is dictated by the presence of water following the path of natural surface and subsurface flows, resulting in exposures to soil, vegetation, and wildlife (Gregory & Hatler, 2008). Sources of pollution may include oil and gas development, inadequate wastewater management by municipal and industrial users, and irrigation return flows (Boyer, 1986; Ashworth, 1990; Scanlon et al., 2020; Contreras-Balderas & Lozano-Vilano, 1994; Hogan, 2013; Miyamoto et al., 2006; Plateau Water Planning Group, 2020).

Fortunately, the Devils River does not have a history of contamination and is at low risk of hazardous materials spills or leaks or high salinity today (Houston et al., 2019; Railroad Commission of Texas [RRC], 2020; TCEQ, 2020). Water quality in the Devils River watershed has been repeatedly described as excellent or pristine (Davis, 1980; Upper Rio Grande Basin and Bay Expert Science Team [BBEST], 2012; Green et al., 2019).

Agricultural Chemicals and Animal Waste

The Devils River watershed is predominantly rural with ranching as the historical and dominant element of the watershed's economy (McCrain, 2020; Smith, 2020). Because of this, there is general hearsay that agricultural practices could be contributing sources of nonpoint source pollution to the Devils River.

The livestock industry involves raising animals to produce animal products for consumers such as meat, eggs, milk, fat, and wool (USDA, 2022). The demand for animal products grows alongside the world population, making the industry one of the fastest-growing agricultural sectors (World Bank, 2021). Unfortunately, the livestock industry has a complicated history with environmental damage and is one of the top three contributors to the global environmental crisis, including water pollution (Hooda et al., 2000). It is common knowledge that fertilizers, herbicides, pesticides, and livestock manure can impact water quality in local waterways if not managed properly, particularly in agricultural watersheds (USEPA, 2023; Ross & Rupe, 2016). Additionally, it is estimated that 80 percent of water bodies globally are affected by agricultural nonpoint source pollution (Wang et al., 2023).

Water quality studies on the Devils River indicate that concentrations of pesticides and herbicides are low to undetectable in sediment and water samples (De La Cruz, 2004; Moring, 2012). Historical nitrogen levels typically exceeded screening levels; however, the concentrations have remained relatively unchanged for the historical record and there are no known point sources or consistent nonpoint sources of nutrients in the watershed. This data suggests that the high nitrogen levels are likely due to springs flowing through limestone formations, which contain nitrogen that is released as water interacts with and weathers the rock, rather than being caused by human activities.

Because the Devils River watershed is predominantly rural with ranching being the dominant land use, it is important to continue monitoring for pesticide/herbicide concentrations including nitrogen to catch any potential agricultural contaminants. Presently, agricultural contaminants are not impairing water quality in the Devils River and are not a cause for concern.

Wastewater

A major source of fecal contamination and algal blooms in surface water comes from human waste, which can result from raw sewage and treated waste (Damashek et al., 2022). This contamination can come from failing septic tanks, aging wastewater infrastructure (such as plumbing, pipes, and sewer mains), and effluent discharges from wastewater treatment plants (Field & Samadpour, 2007; Jeong et al., 2019). Wastewater effluent is typically higher in phosphorus than the waters of the receiving stream. In oligotrophic systems[7] such as the Devils River, added phosphorus causes algal blooms and can result in fish kills, bacterial growth and other hazards. Strategies to reduce human fecal contamination include repairing and upgrading wastewater infrastructure, as well as encouraging routine septic system maintenance for homeowners (Malakoff, 2002; Teaf et al., 2011). However, implementing these measures requires adequate staffing, which can be particularly challenging in rural areas like the Devils River watershed, where large, remote tracts of land make access and oversight difficult.

Wastewater includes used water from domestic, commercial, and industrial sources (Tuser, 2021). In Texas, the discharge of treated domestic wastewater into state waters or onto land must be authorized by the TCEQ (TCEQ, 2024a).

In the Devils River watershed, there are three facilities permitted to discharge treated wastewater upstream of the International Amistad Reservoir: Crockett County Water Control and Improvement District (WCID), City of Sonora, and Multi-Chem Group LLC (TCEQ, 2024b). These discharge permits are into the ephemeral section of the Devils River and Johnson Draw, a major tributary. (The Four facilities located downstream of the Amistad Reservoir - Val Verde Utility Company LLC, the U.S. Department of the Air Force, and two facilities operated by the City of Del Rio – are outside of the Devils River watershed.

Water quality studies on the Devils River show that *E. coli* concentrations generally meet the segment criteria and do not exceed state standards (De La Cruz, 2004). Although historical nitrogen levels have typically exceeded screening levels, the concentrations have remained relatively unchanged over time. This data suggests that the high nitrogen levels are likely due to springs flowing through limestone formations rather than human activities. Consequently, it is highly likely that these facilities are not significantly affecting the water quality of the Devils River. Monitored Total Phosphorus levels in the Devils River have historically been below the detectable limit.

It remains important to continue monitoring total phosphorous, E. coli bacteria and nitrogen concentrations to detect any potential wastewater contamination. Currently, wastewater discharges in the watershed are not impairing water quality in the Devils River and are not a cause for concern.

Sediment

In the Devils River watershed, communities have faced the impacts of uninformed agricultural practices in the past. Overgrazing eroded much of the topsoil in the watershed, and during flood events, this soil was deposited in the river result-

7 *Oligotrophic ecosystems are characterized by low nutrient levels, particularly nitrogen and phosphorus, which limit the growth of aquatic plants and algae. They often occur in environments where nutrient input is minimal.*

ing in sedimentation and turbid conditions (Hosmer, 2021). This history, which is common for many ranching communities throughout the United States during the Dust Bowl era, may be impacting how people perceive agricultural impacts on water quality in the watershed.

Other sources of sediment include fragmentation and energy infrastructure, such as roads, powerlines, and overgrazing and erosion caused by non-native and invasive species.

Land cover was assessed using remote sensing data available for the U.S. Hydrologic Survey HUC 6 watershed covering the Devils River. The Rangelands Analysis Platform (University of Montana, 2022) and the National Land Cover Dataset (Dewitz & USGS, 2021) both allow for an analysis of change in land and vegetation cover over time. The proportion of area classified as bare ground, which we assume is the most likely cover type to lead to erosion and sedimentation, is declining over the 1986–2023 time period (University of Montana, 2022). We considered the influence of impervious cover through the lens of development classes in the National Land Cover Database dataset. Development across high, medium, and low intensities changed little, rising from 1.0 percent in 2001 to 1.4 percent in 2021 (Dewitz & USGS, 2021). The low levels of impervious cover in the watershed are assumed to correlate with low risks to surface water from sedimentation via runoff, and the small change over time suggests that this risk is not likely to significantly increase in the future. The risk to water quality from other threats associated with human habitation of the area, such as transportation and energy infrastructure, leaking septic systems or improper waste management, also appears to be low currently but bears continued monitoring.

Oil and Gas

Pollution from oil and gas development poses a potential threat to water quality within the watershed. Currently, there are approximately 9,500 active oil and/or gas wells, 590 miles of oil pipelines, and 90 miles of gas pipelines within the watershed (S&P Global, 2024a, b). Very few are within the portion of the watershed containing perennial streamflow, and the vast majority are in Sutton and Crockett counties. The primary risk to water quality within the watershed is more likely to be through leaking into a water conduit leading to the river, rather than a surface spill (Gregory & Hatler, 2008; Scanlon et al., 2020).

The impact of oil and gas injection wells on water quality in the watershed is still uncertain. Further investigation is needed to assess the severity of the threat. In the United States, there are several classes of injection wells, classified by the Underground Injection Control (UIC) Program based on the "type of fluids they receive, the purpose of the injection, and the location of the injection relative to underground sources of drinking water," (USEPA, 2020). The public generally classifies these wells into two categories: injection or recovery wells, which inject fluids into reservoirs to enhance oil recovery, and disposal wells, which inject waste fluids into underground zones for safe disposal (USEPA, 2024a).

According to the Texas Railroad Commission's UIC Query, there are currently 233 active injection and disposal wells in Crockett County, 29 in Schleicher County, ten in Sutton County, four in Edwards County, and one in Val Verde County within the Devils River watershed (RRC, 2024).

For decades, scientists believed that subsurface geological formations could safely store waste from oil and gas development (Lustgarten, 2012). However, recent events have led scientists and stakeholders to question this assumption. In Texas, several counties have experienced environmental impacts related to oil and gas activities, especially from decommissioned, plugged, and capped wells.

From 2021 to 2023, in Crane County, wastewater erupted from wells and flowed onto ranches, including the Antina Cattle Ranch (Cunningham, 2024). This raised concerns not only about the ruined land but also about the effects on surface water and groundwater quality. Similarly, in Pecos County, a growing number of abandoned oil wells have been leaking gassy water onto ranch land, including the toxic surface pool known as Lake Boehmer, which originated from a leaking oil well in the mid-1990s and has since expanded to nearly 60 acres (Baddour, 2024; Borden, 2024).

In Reeves County, residents have experienced steady earthquakes since 2010, likely due to injection wells, raising additional concerns about potential impacts on water quality (Baddour, 2023). These occurrences in West Texas, all linked to oil and gas development, have led some to believe that the source of the Midessa Groundwater Plume—an area of contaminated groundwater in Midland County—is also related to oil and gas activities (USEPA, n.d.; Pskowski, 2023).

Research on the impact of injection wells on water quality is very limited, but recent incidents in West Texas highlight the need for further investigation into the safety of storing oil and gas development waste underground.

Contaminants of Emerging Concern

The U.S. Environmental Protection Agency reports that contaminants of emerging concern (CECs), such as pharmaceuticals, are increasingly being found at low levels in surface water (USEPA, 2024b). Many of these contaminants can harm aquatic life by disrupting normal reproductive and hormonal functions. To address this issue, the USEPA has identified challenges and developed recommendations related to CECs as a basis to update the 1985 national water quality criteria guidelines (USEPA, 2008). However, per- and polyfluoroalkyl substances (PFAS), also known as “forever chemicals,” are not included in these recommendations. Despite this exclusion, PFAS is still discussed as a CEC as a following subsection.

Pharmaceuticals

Pharmaceuticals have been present in natural waters worldwide since humans began experimenting with medicines. The proliferation of products and increased accessibility have contributed to the rising concentration of these substances in the environment. While the rigorous clinical trials required for pharmaceuticals provide some understanding of their potential negative impacts on aquatic and human health, there are currently no federal regulations governing their concentration in wastewater, drinking water, or surface waters (National Association of Clean Water Agencies [NACWA], 2009; USGS, 2018).

The TCEQ has implemented rules for managing hazardous waste pharmaceuticals, but these do not include established water quality standards or criteria (30 Tex. Admin. Code §335, Subchapter W, 2022). Consequently, there is no historical water quality data on pharmaceuticals in the Devils River, as there are no standardized monitoring or reporting requirements.

Per- and Polyfluoroalkyl Substances (PFAS)

PFAS, a group of synthetic chemicals known as “forever chemicals” due to their slow breakdown, have been used in industry and consumer products since the 1940s. As a result, they are now widespread in the environment, found in food products, and present in the blood of people and wildlife worldwide. With thousands of PFAS chemicals used in various products, fully assessing their potential environmental and health impacts is challenging. While some studies have linked PFAS exposure to harmful health effects in humans and wildlife, much remains unknown about their overall harm, levels of exposure, detection, measurement, and effective management or disposal (USEPA, 2023; Agency for Toxic Substances and Disease Registry [ASTDR], 2024).

In April 2024, the U.S. Environmental Protection Agency issued a final rule establishing a National Primary Drinking Water Regulation for six types of PFAS under the Safe Drinking Water Act (USEPA, 2024c). Following this, the TCEQ has started updating state regulations to incorporate the new rule for all community and non-transient, non-community water systems, with adoption planned by 2027 (TCEQ, 2024c).

The State of the Science - The Water Quality Parameters of the Devils River

Water quality standards are developed by the Texas Commission on Environmental Quality and established in Title 30, Chapter 207 of the Texas Administrative Code (TCEQ, 2024d).

The Texas Surface Water Quality Standards establish explicit goals for the quality of streams, rivers, lakes, and bays throughout the state. The standards are developed to maintain the quality of surface waters in Texas to support public health and protect aquatic life, consistent with the sustainable economic development of the state. Water quality standards identify appropriate uses for the state’s surface waters, including aquatic life, recreation, and sources of public water supply as drinking water.

The Texas Surface Water Quality Standards also contain narrative criteria (general descriptions) that apply to all state waters and are used to evaluate support of applicable uses. Narrative criteria include general descriptions such as the existence of excessive aquatic plant growth, foaming of surface waters, taste- and odor-producing substances, sediment build-up, and toxic materials. Narrative criteria are evaluated by using screening levels, if they are available, and other information, including water quality studies, existence of fish kills or contaminant spills, photographic evidence, and local knowledge. Screening levels serve as a reference to indicate when water quality parameters may be approaching levels of concern.

Waters that do not meet the state water quality standards are added to the 303(d) impaired waters list and a Total Maximum Daily Load pollutant management plan is developed, as required by the Clean Water Act (USEPA, 2023a). The Draft 2024 Texas Integrated Report for Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) includes an index of water quality impairments. The classified segments, Devils River (Segment 2309) and International Amistad Reservoir (Segment 2305), and unclassified segment, Dolan Creek (Segment 2309A), do not have any impairments (TCEQ, 2024e).

Table 6 summarizes the state water quality criteria for the Devils River watershed by parameter, and Table 7 presents the state-designated uses and numeric criteria for the Devils River watershed. The following section provides more information on these parameter criteria.

Table 6. State water quality criteria by parameter for classified stream segments in the Devils River watershed.

Parameter	Water Quality Criteria
E. coli Bacteria	Geometric mean concentration < 126 colony forming units per 100 mL sample water for primary contact recreation.
Dissolved Oxygen	Minimum 24-hour mean >5.0 mg/L for Amistad Reservoir; Minimum 24-hour mean of >6.0 mg/L for Devils River.
pH	Between 6.5 and 9.0 standard units.
Temperature	Maximum temperature <90°F or ~ 32°C.
Chloride	Annual average ≤ to 30 mg/L.
Sulfate	Annual average ≤ to 20 mg/L.
Total Dissolved Solids	Annual average ≤ to 300 mg/L.

Table 7. Devils River Watershed Designated Uses and Numeric Criteria (30 Tex. Admin. Code §307.10(1), 2022).

Segment No.	Segment Name	Recreation Use	Aquatic Life Use	Domestic Water Supply Use	Cl-1 (mg/L)	SO4 -2 (mg/L)	TDS (mg/L)	Dissolved Oxygen (mg/L)	pH Range (SU)	Indicator Bacteria #/100 mL	Temperature (ºF)
2305	International Amistad Reservoir	PCR1	H	PS	150	270	800	5.0	6.5-9.0	126	88
2309	Devils River	PCR1	E	PS	50	50	300	6.0	6.5-9.0	126	90

Bacteria (*E. coli*)

E. coli is a rod-shaped, gram-negative bacterium that is commonly found in the digestive tract and feces of warm-blooded animals, including humans (Rock and Rivera, 2014; Jang et al., 2017). It is used as an indicator of fecal contamination in surface and groundwater both internationally and in the United States (Standridge, 2008; Schwarzenbach et al., 2010; Khan and Gupta, 2020). The presence of *E. coli* in freshwater indicates the potential presence of pathogens causing waterborne disease (Odonkor and Mahami, 2020). A pathogen is a biological agent that causes disease.

State *E. coli* Standards

The TCEQ has established water quality standards in freshwater using *E. coli* bacteria as the indicator bacteria for assessing the health risks associated with recreational use (Table 8). The primary contact recreation standard is applied in areas presumed to involve a significant risk of water ingestion while swimming, wading, tubing, diving, and other activities associated with the water. The state's *E. coli* bacteria water quality standard for the primary contact recreation use for a perennial freshwater stream is 126 most probable number of bacteria per 100 milliliters of water (MPN/100 ml) and is compared to the geometric mean of a minimum of 20 bacteria samples collected over seven years when the flow is greater than or equal to 0.1 cfs (TCEQ, 2024e). A water body is considered impaired if the geometric mean is higher than the corresponding water quality standard.

Table 8. State *E. coli* bacteria water quality criteria by recreational use category.

Recreational Use Category	*E. coli* Bacteria Geometric Mean Criterion (CFU/mL)
Primary Contact Recreation 1	126 colony forming units per 100 milliliters
Primary Contact Recreation 2	206 colony forming units per 100 milliliters
Secondary Contact Recreation 1	630 colony forming units per 100 milliliters
Secondary Contact Recreation 2	1,030 colony forming units per 100 milliliters
Noncontact Recreation	2,060 colony forming units per 100 milliliters

E. coli in the Devils River

The current recreational water quality criteria for bacterial indicators of fecal contamination were issued by the U.S. Environmental Protection Agency in 2012 (USEPA, 2024d). Recreational water quality criteria for bacteria were not issued by the U.S. Environmental Protection Agency until 1986 (USEPA, 1984). As such, standardized monitoring of bacterial indicators was not adopted in the states until then, and bacterial monitoring data for the Devils River was not found prior to 1993 (Moring, 2000; De La Cruz, 2004). Despite changes in analytical methodology since 1986, the concentration of *E. coli* bacteria in the Devils River has remained relatively unchanged. Recreational use criteria for *E. coli* bacteria are met at all locations in the Devils River watershed, and no Total Maximum Daily Loads will be established.

E. coli bacteria averages for the Devils River are not specified in the reviewed literature, however, it is stated that *E. coli* bacteria in the Devils generally conforms to segment criteria and does not exceed state standards (De La Cruz, 2004). In a TCEQ assessment of water quality, bacteria counts in the Devils River were extremely low at less than 75 colony forming units/100 milliliters (De La Cruz, 2004).

These values have remained relatively unchanged.

Dissolved Oxygen

Dissolved oxygen is a measurement of the amount of oxygen in the form of microscopic bubbles dissolved and freely available in water (TCEQ, 2018a). It is used as an indicator of an aquatic ecosystem's ability to support aquatic life

(USEPA, 2023b). Dissolved oxygen naturally fluctuates diurnally in most water bodies, increasing throughout the day as aquatic plants produce oxygen and decreasing throughout the night as aquatic organisms consume oxygen. Changes in dissolved oxygen occur during times of low flow because stagnant water reduces aeration (USGS, 2018). Excessive nutrients can also reduce the concentration of dissolved oxygen by creating algal blooms, which die and are eaten by bacteria, consuming oxygen.

The concentration of dissolved oxygen is one of the most important measures of water quality because it correlates with the abundance of aquatic life as it is essential for all plants and animals inhabiting a water system. The amount of oxygen required to support aquatic life varies according to species and stage of life. Typically, dissolved oxygen levels of 5.0 to 6.0 milligrams per liter (mg/L) are required for growth and activity. Dissolved oxygen levels near 3.0 mg/L may cause difficulty for aquatic organisms when reproducing, feeding, or surviving. When dissolved oxygen levels fall below 2.0-1.0 mg/L, most aquatic life will not be able to survive (TST, 2023).

State Dissolved Oxygen Standards

The TCEQ has established water quality standards using dissolved oxygen as the indicator for assessing the sufficient support associated with aquatic life use (Table 9). Alongside dissolved oxygen as an indicator, aquatic life attributes are also considered and include habitat characteristics, species assemblage, sensitive species, diversity, species richness, and trophic structure. A water body is considered impaired if the 24-hour mean is lower than the corresponding water quality standard.

Table 9. State aquatic life use subcategories (30 Tex. Admin. Code §307.7(b)(3)(A)(i), 2022).

Aquatic Life Use Subcategory	Dissolved Oxygen Criteria, mg/L			Aquatic Life Attributes					
	Freshwater mean/minimum	Freshwater in Spring mean/minimum	Saltwater mean/minimum	Habitat Characteristics	Species Assemblage	Sensitive Species	Diversity	Species Richness	Trophic Structure
Exceptional	6.0/4.0	6.0/5.0	5.0/4.0	Outstanding Natural Variability	Exceptional or Unusual	Abundant	Exceptionally High	Exceptionally High	Balanced
High	5.0/3.0	5.5/4/5	4.0/3.0	Highly Diverse	Usual Association of regionally Expected Species	Present	High	High	Balanced to Slightly Imbalanced
Intermed.	4.0/3.0	5.0/4.0	3.0/2.0	Moderately Diverse	Some Expected Species	Very Low in Abundance	Moderate	Moderate	Moderately Imbalanced
Limited	3.0/2.0	4.0/3.0		Uniform	Most Regionally Expected Species	Absent	Low	Low	Severely Imbalanced
Minimal	2.0/1.5								

The TCEQ has also established critical low-flow values for dissolved oxygen for the eastern and southern Texas ecoregions, specifically defined by Interstate Highways 35 and 35W from the Red River to the community of Moore in Frio County, and by US Highway 57 from the community of Moore to the Rio Grande. These critical low-flow values apply to the Devils River and are presented in Table 10.

Table 10. Critical low-flow values for dissolved oxygen for the eastern and southern Texas ecoregions, including those associated with the Devils River watershed (30 Tex. Admin. Code §307.7(b)(3)(A)(ii), 2022).

Bedslope (m/km)	6.0 Dissolved Oxygen (cfs)	5.0 Dissolved Oxygen (cfs)	4.0 Dissolved Oxygen (cfs)	3.0 Dissolved Oxygen (cfs)
0.1	*	18.3	3	0.5
0.2	*	7.7	1.3	0.2
0.3	28.6	4.7	0.8	0.1
0.4	20	3.3	0.5	0.1
0.5	15.2	2.5	0.4	0.1
0.6	12.1	2.0	0.3	0.1
0.7	10	1.6	0.3	0.0
0.8	8.4	1.4	0.2	0.0
0.9	7.3	1.2	0.2	0.0
1.0	6.4	1.0	0.2	0.0
1.1	5.7	0.9	0.2	0.0
1.2	5.1	0.8	0.1	0.0
1.3	4.6	0.8	0.1	0.0
1.4	4.2	0.7	0.1	0.0
1.5	3.9	0.6	0.1	0.0
1.6	3.6	0.6	0.1	0.0
1.7	3.3	0.5	0.1	0.0
1.8	3.1	0.5	0.1	0.0
2.1	2.5	0.4	0.1	0.0
2.4	2.2	0.4	0.1	0.0

Dissolved Oxygen in the Devils River

Ambient water quality criteria for dissolved oxygen were not issued by the U.S. Environmental Protection Agency until 1976 (USEPA, 1976). As such, standardized monitoring of dissolved was not adopted in the states until then, and dissolved oxygen monitoring data could not be found in the Devils River prior to 1993 (Moring, 2000; De La Cruz, 2004).

Dissolved oxygen averages for the Devils River are not specified in the reviewed literature, however, it is stated that measurements of dissolved oxygen in the Devils River conforms to numerical criteria established for the segment and does not fall outside the range of state standards (De La Cruz, 2004). In a TCEQ assessment of water quality, measurements of dissolved oxygen in the Devils River from 1993-1994 were typically high above 8.0 milligrams per liter (De La Cruz, 2004).

The current recreational water quality criteria for dissolved oxygen were issued by the USEPA in 1986 (USEPA, 2024d). Despite changes in analytical methodology since 1986, measurements of dissolved oxygen in the Devils River have remained relatively unchanged. Aquatic use criteria for dissolved oxygen are met at all locations in the Devils River watershed and no Total Maximum Daily Loads will be established.

pH

The pH is a measurement of how acidic or basic (alkaline) a solution is based on the concentration of hydrogen ions. The pH scale spans from 1.0 to 14.0 standard units (SU) with a value less than 7.0 being acidic and a value greater than 7.0 being basic (alkaline). A pH value of 7 is neutral. The pH of surface waters in Texas is generally between 5.0 and 9.0 (TCEQ, 2018b). The pH range required to support aquatic life varies according to the species and stage of life. Typically, a pH range of 6.5 to 8.2 is considered optimal for most organisms. As pH becomes greater than 9.0 or less than 5.0, it may cause difficulty for aquatic organisms when reproducing, feeding, or surviving (TST, 2023).

State pH Standards

The TCEQ has established site-specific numerical criteria for pH as absolute minima and maxima. For the Devils River this minima and maxima is 6.0 and 9.0, respectively (30 Tex. Admin. Code §307.7, 2022).

pH in the Devils River

Ambient water quality criteria for pH were not issued by the U.S. Environmental Protection Agency until 1976 (USEPA, 1976). As such, standardized monitoring of pH was not adopted in the states until then. However, pH monitoring did previously occur on Texas surface waters including in the Devils River watershed before Amistad Dam's 1968 completion with a median value of 7.55 at Goodenough Spring (Kamps et al., 2008).

Averages of pH for the Devils River are not specified in the reviewed literature, however, it is stated that measurements of pH in the Devils River conforms to numerical criteria established for the segment and does not fall outside the range of state standards (Moring, 2000; De La Cruz, 2004). The historical median of pH values in the Devils River for samples collected by the U.S. Geological Survey Hydrologic Benchmark Network during 1978-1995 was 7.0 standard units (Moring, 2000). In a TCEQ assessment of water quality, measurements of pH in the Devils River from 1993-1994 were between 7.4-7.7 standard units (De La Cruz, 2004).

The current ambient water quality criteria for pH were issued by the U.S. Environmental Protection Agency in 1986 (USEPA, 2024d). Changes in analytical methodologies since 1986 reflect a period of low pH values in the first part (1978-1986) of the historical U.S. Geological Survey Hydrologic Benchmark Network record for the Devils River, and high pH values in the second part (1987-1995) of the historical record (Moring, 2000). Similar trends in pH measurements were reported at surface waters across Texas during this time, likely caused by changes in analytical methods. (Moring, 2000). Beneficial use criteria for pH are met at all locations in the Devils River watershed and no Total Maximum Daily Loads will be established.

Temperature

Temperature is a measurement of heat present in a substance or object. The state measures and records water temperature in degrees Celsius. The temperature of water is an important measure of water quality because it controls biological and chemical processes (TCEQ, 2018c). Temperature can influence the feeding, reproduction, and the metabolism of aquatic animals; the solubility of compounds in water; rates of chemical reactions; movement of currents; and much more. The temperature range required to support aquatic life varies according to the species and stage of life, but all species can tolerate slow and seasonal changes better than rapid changes in temperature (TST, 2023).

State Temperature Standards

The TCEQ has established site-specific temperature criteria as absolute maxima. For the Devils River this maxima is 90 degrees Fahrenheit or about 32 degrees Celsius (30 Tex. Admin. Code §307.7, 2022).

Temperatures in the Devils River

Ambient water quality criteria for water temperature were not issued by the U.S. Environmental Protection Agency until 1976 (USEPA, 1976). As such, standardized monitoring of water temperature was not adopted in the states until then. However, monitoring water temperature did previously occur on Texas surface waters including in the Devils River watershed before Amistad Dam's 1968 completion with a median value of 28.3 degrees Celsius (82.9 degrees Fahrenheit) at Goodenough Spring (Kamps et al., 2008).

Water temperature averages for the Devils River are not specified in the reviewed literature, however, it is stated that measurements of water temperature in the Devils River conforms to numerical criteria established for the segment and does not fall outside the range of state standards (De La Cruz, 2004; Caldwell et al., 2020). In a TCEQ assessment of water quality, measurements of water temperature in the Devils River from 1993-1994 were typically between 21.0-24.5 degrees Celsius (69.8-76.1 degrees Fahrenheit) and the lowest measured value was 18.5 degrees Celsius (65.3 degrees Fahrenheit) (De La Cruz, 2004). In a collaborative research study with the University of Texas at Austin, Texas Parks and Wildlife, and the U.S. Geological Survey, Devils River spring temperatures were consistently 22.6 ± 0.3 degrees Celsius (~72-73 degrees Fahrenheit) (Caldwell et al., 2020). This research study also found that over the past 30 years, Devils River surface water temperatures are increasing 0.16 degrees Celsius per decade (~0.28 degrees Fahrenheit).

The current ambient water quality criteria for water temperature were issued by the USEPA in 1986 (USEPA, 2024d). Despite changes in monitoring methodology since 1986, measurements of water temperature in the Devils River have remained relatively unchanged but do indicate a warming trend. The criteria for temperature are met at all locations in the Devils River watershed and no Total Maximum Daily Loads will be established.

Nutrients

Excess nutrients are one of the most common pollutants affecting surface waters in the United States. When a water system becomes over enriched in nutrients, excessive undesirable growth of aquatic vegetation can occur which can negatively affect human and ecosystem health. The excess of nutrients also affects other water quality parameters including pH and dissolved oxygen, which can have drastic developmental and survival impacts on aquatic organisms (USEPA, 2021a).

State Nutrient Standards

The TCEQ has established site-specific numeric and narrative criteria for nutrients to protect multiple uses such as contact recreation, aquatic life, and public water supplies. These criteria are established to control nutrients in individual watersheds where appropriate after notice and opportunity for public participation and proper hearing occurs. Conventional nutrient parameters include nitrate-nitrogen (milligrams per liter), ammonia-nitrogen (milligrams per liter), total phosphate (milligrams per liter), and chlorophyll-a (µg/L) (30 Tex. Admin. Code §307.7, 2022).

Nutrients in the Devils River

Nitrate plus nitrite concentrations in the Devils River are typically high with a historical median of 1.4 milligrams per liter, likely naturally elevated from the springs flowing through limestone formations (De La Cruz, 2004; Moring, 2000).

The concentration of total phosphorus in the Devils River is typically low with an average of 0.01 milligrams per liter, however, water samples are sometimes less than laboratory reporting levels of 0.004 milligrams per liter (De La Cruz, 2004; Moring, 2012).

There are no established site-specific nutrient criteria for stream segments in the watershed.

Metals

Metals are naturally occurring elements found in the environment, and many are essential for sustaining life in small amounts (USEPA, 2021b; USGS, 2019). However, all metals can be toxic at high levels, and some are harmful even in small quantities (USEPA, 2024e). In water, both dissolved and particulate metals can be absorbed by aquatic organisms, bioaccumulating in their tissues faster than they can be eliminated. This process, known as bioaccumulation, can lead to biomagnification, where the concentration of metals increases as they move up the food chain. This not only affects aquatic organisms but also larger species, such as birds and humans, outside of aquatic ecosystems.

State Metals Standards

The TCEQ has established specific numeric aquatic life criteria for metals and metalloids (Table 11). For numerical acute aquatic life criteria, a water body is considered impaired if the 24-hour mean exceeds the corresponding water quality standard. For numerical chronic aquatic life criteria, a water body is considered impaired if the seven-day mean exceeds the corresponding water quality standard. Metal samples can be collected in water and in sediment (TCEQ, 2012).

Table 11. Criteria in Water for Specific Toxic Materials: Aquatic Life Protection (All values are listed or calculated in micrograms per liter) (Hardness concentrations are input as milligrams per liter) (30 Tex. Admin. Code §307.6(c)(1), 2022).

Parameter	CASRN	Freshwater Acute Criteria	Freshwater Chronic Criteria	Saltwater Acute Criteria	Saltwater Chronic Criteria
Acrolein	107-02-8	3.0	3.0	---	---
Aldrin	309-00-2	3.0	---	1.3	---
Aluminum (d)	7429-90-5	991w	---	---	---
Arsenic (d)	7440-38-2	340w	150w	149w	78w
Cadmium (d)	7440-43-9	(1.136672-(ln(hardness)(0.041838)))(w$e^{(0.9789(\ln(hardness)}$)-3.866))	(1.101672-(ln(hardness)(0.041838)))(w$e^{(0.7977(\ln(hardness)}$)-3.909))	33w	7.9w
Carbaryl	63-25-2	2.0	2.0	1.6	---
Chlordane	57-74-9 and 12789-03-6	2.4	0.004	0.09	0.004
Chlorpyrifos	2921-88-2	0.083	0.041	0.011	0.006
Chromium (Tri)(d)	16065-83-1	0.316w$e^{(0.8190(\ln(hardness))+3.7256)}$	0.860w$e^{(0.8190(\ln(hardness))+0.6848)}$	---	---
Chromium (Hex)(d)	18540-29-9	15.7w	10.6w	1,090w	49.6w
Copper (d)1	7440-50-8	0.960m$e^{(0.9422(\ln(hardness))-1.6448)}$	0.960m$e^{(0.8545(\ln(hardness))-1.6463)}$	13.5w	3.6w
Cyanide2 (free)	57-12-5	45.8	10.7	5.6	5.6
4,4'-DDT	50-29-3	1.1	0.001	0.13	0.001
Demeton	8065-48-3	---	0.1	---	0.1
Diazinon	333-41-5	0.17	0.17	0.819	0.819
Dicofol	115-32-2	59.3	19.8	---	---
Dieldrin	60-57-1	0.24	0.002	0.71	0.002
Diuron	330-54-1	210	70	---	---

Note: View parameters E-Z at https://texreg.sos.state.tx.us/fids/202203625-1.pdf

Metals in the Devils River

In a 1993-1994 study, values for heavy metals in sediment samples were less than the established screening levels and results indicated no potential problems related to the accumulation of heavy metals in sediment (De La Cruz, 2004). The heavy metal measured included aluminum, arsenic, barium, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, and zinc.

In a 2005-2007 study, values for trace metals in water samples were well below state standards (Moring, 2012). The trace metals measured included aluminum, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, silver, strontium, vanadium, zinc, antimony, arsenic, boron, and selenium.

Routine and more frequent water quality monitoring is needed to determine the historical medians of metals in the Devils River.

Past Water Quality Studies

Based on the site-specific standards established by the TCEQ, the state considers the Devils River as a pristine system vulnerable to environmental changes (De La Cruz, 2004). Perhaps it is the river's vulnerability that is prompting the desire for more water quality studies to take place in the watershed. The water quality monitoring network on the Devils River has only recently expanded to several stations and more data is needed to properly maintain the flow and pristine quality of water in the river. The collection of more data is crucial as population trends, land use patterns, and climatic conditions change.

The following section summarizes the most recent and pertinent studies for characterizing water quality within the Devils River watershed.

INSERT MAP OF WATER QUALITY MONITORING STATIONS AND AFFILIATED AGENCIES.

1970-1975 (Pearson and Rettman, 1976)

From 1970-1975, water quality monitoring was conducted to develop a fuller understanding of the hydrology of the Edwards aquifer. Ninety-two samples were collected from wells, springs, and streams in the Edwards aquifer system and analyzed for chemical properties. Following sample analysis, the Edwards water samples were categorized into five chemical groups:

- Recharge
- Main Fresh Water
- Varied
- Transitional Waters
- Saline Waters

Monitoring took place in Hays, Comal, Bexar, Medina, Uvalde, Kinney, and Val Verde counties. One monitoring site was in Val Verde County and will be this subsection's focus. The Val Verde County site was a spring site near the Edwards outcrop and was sampled three times between October 1972 to October 1973 before being categorized in the Recharge chemical group.

Water in the Recharge group is saturated with calcite and undersaturated with dolomite. Calcite saturation means the water has an excess calcium content and is prone to scaling. This is likely a result of the karst limestone of the Edwards aquifer. Monitoring dolomite levels can help researchers understand the chemistry of a water system and geological processes.

1978-1995 (Moring, 2000)

This report, published by the U.S. Geological Survey in 2000, details historical water quality trends between 1978-1995 on the Devils River at Pafford Crossing near Comstock (Station 08449400). This station is one of the approximately 50 stations in the Hydrologic Benchmark Network, a U.S. Geological Survey initiative to provide long-term monitoring data on waterways draining undeveloped lands.

The evaluated gauging station is almost 11.5 miles east of Comstock, Texas. The 1.2-mile reach of the main channel upstream from the gaging station is in the boundaries of the Amistad National Recreation Area. The analyzed data for this report includes 104 water quality samples collected from January 1978 through August 1995. Sampling frequency was monthly from 1978 through 1980, bimonthly from 1981 through 1986, and quarterly from 1987 through 1995.

The median discharge for the record period was 8.7 cubic meters per second, or 307 cfs. Stream water in the Devils River is fairly ion concentrated and well buffered by its salt content; specific conductance ranged from 250 to 460 microsiemens per centimeter, and alkalinity was between 1,800 and 4,760 microequivalents per liter. Data suggests that salt content in the Devils River is derived from sources in the watershed rather than atmospheric deposition, including dissolution of salts in the carbonate bedrock or perhaps oil field activities in the northern part of the watershed.

1993-1994 (De La Cruz, 2004)

From 1993-1994, TCEQ conducted an evaluation of water quality in the Devils River (Segment 2309) to characterize water quality within the river, evaluate sediment quality in relation to drainage into the river, to evaluate compliance with the Texas Surface Water Quality Standards, to compare current data with historical water quality data, and to identify real or potential nonpoint source pollutants.

The collected water quality data included flow measurements, field measurements, water chemistry samples, sediment chemistry samples, and fecal coliform bacteria counts.

There are numerous springs along the Devils River, all contributing to the flow of the river, and several range from moderately large (1 to 10 cfs) to large (10 to 100 cfs including the Dolan and Finegan Springs. A discharge of 163 cfs was measured at the uppermost station, while a discharge of 399 cfs was measured at the lowermost station. The historical average flow for the lowermost station between 1960-1993 was 369 cfs.

The collected water quality field measurements indicated excellent water quality conditions from 1993-1994. The lowest dissolved oxygen concentration measured was 6.5 milligrams per liter. All pH values were within the criteria range of 6.5-9.0 standard units. All water temperature measurements were within the maximum criterion of 90 degrees Fahrenheit. The fish and macroinvertebrate populations exhibited high overall diversity, which is indicative of clean and healthy environmental conditions.

An analysis of water quality data revealed over 81 percent of the total nitrate-nitrogen values and 100 percent of the nitrate plus nitrite values exceeded screening levels. Because there are no known point sources or consistent nonpoint sources of nutrients in the study area, these exceeded screening levels are likely naturally elevated from the springs flowing through limestone formations.

Chloride and sulfate grab samples were within the water quality standards. All organics (including pesticides/herbicides) in sediment were undetectable, thus the potential for organic chemical contamination in the sediment appears to be low from 1993-1994. Values for heavy metals in sediment were less than the established screening levels.

During the initial sampling, all stations exhibited low fecal coliform concentrations except for Station 3 (Blue Sage Subdivision). The value of 800 colonies per 100 milliliters of sample water at Station 3 was high, exceeding the single sample criterion of 400 colonies per 100 milliliters of sample water. A follow up survey was conducted in 1994, for which additional sampling sites were established in the Blue Sage Subdivision area, and samples exhibited low fecal coliform concentrations. The previous elevated value could have resulted from domestic and wild fowl that frequent the area, malfunctioning septic systems, or analytical error.

Water quality standards for the Devils River (Segment 2309) are among the most stringent in Texas, and water quality in the river has historically been excellent.

2005 (Kamps et al., 2008)

In the summer of 2005, direct measurements of discharge and water quality were taken from Goodenough Spring for the first time in 37 years.

Goodenough Spring is located on the shared border between Texas and Mexico and discharges into Amistad Reservoir. There is a historical record of water quality data for the spring from 1928-1968 for the purpose of allocating water between the United States and Mexico. After the spring was submerged under Amistad Reservoir, indirect measurements of spring discharge have been estimated by the IBWC. This study utilized advanced self-contained underwater breathing apparatus (SCUBA) techniques to collect the first direct measurements of spring discharge and water quality since 1968.

Cross-sectional and velocity measurements were taken near the mouth of the underwater cave system Goodenough Spring flows from. Spring discharge was calculated at 71.6 cfs, approximately one-half of the historical mean of 139.1 cfs. For August 2005, the IBWC estimated a deduced discharge of 104.8 cfs for Goodenough Spring. This estimate was very close to the study's direct measurements. However, it is difficult to compare the two values beyond similarity because the IBWC's estimate is an average for the entire month of August while the study's estimate is for a single day in August.

In situ water quality measurements included temperature, pH, specific conductance, and dissolved oxygen. The measurements were compared to the historical record and remained relatively unchanged. Laboratory measurements included alkalinity, nitrate-nitrogen, dissolved solids, chloride, sulfate, fluoride, phosphorus, calcium, sodium, potassium, magnesium, and iron. The measurements were compared to the historical record and remained relatively unchanged. Overall, the results indicated that the spring water quality is good for human consumption and crop irrigation.

One last key finding of the study was the present relationship between the flow in the Devils River and flow in Goodenough Spring. Before the construction of Amistad Reservoir, the flow in the Devils River was a good predictor of the flow in Goodenough Spring. However, after the Reservoir was constructed, the flow in the Devils River drastically changed and can only be used as a general indicator of regional climatic conditions.

2005 – 2007 (Moring, 2012)

A significant water quality study was undertaken by the U.S. Geological Survey, in cooperation with the National Park Service and Amistad National Recreation Area, from 2005 to 2007 (Moring, 2012). Water quality was sampled at the U.S. Geological Survey gage "Devils River at Pafford Crossing," located around three miles above the portion of the Devils River that is impacted by the lake effect of Amistad Reservoir when the reservoir is full. The analysis focused on total dissolved solids, major ions, nutrients, trace metals, and pesticides, and compared the data to historical data collected by the U.S. Geological Survey Hydrologic Benchmark Network from 1978 to 1995. All constituents tested were well below state standards and those compared were lower than the median of the historical data. The analysis also tested for the presence of 162 pesticides; none were detectable (Moring, 2012). The study included an assessment of water quality and fish and macroinvertebrate communities in the Devils and Pecos River near the National Recreation Area. At one site on the Devils River, water quality conditions were assessed in 2005 while the composition of fish and macroinvertebrate communities was assessed during 2006 and 2007.

The study was primarily focused on the following water quality parameters: total dissolved solids, chloride, sulfate, ammonia plus organic nitrogen, nitrate plus nitrite, orthophosphate, phosphorus, selenium, and selected pesticides.

The concentrations of total dissolved solids ranged from 208 to 232 milligrams per liter in samples from the Devils River and did not exceed the maximum criterion of 300 milligrams per liter. Sulfate concentrations ranged from 7.55 to 8.20 milligrams per liter and did not exceed the state water quality standards. Nitrate plus nitrite concentrations remained relatively unchanged when compared to the historical record. Selenium concentrations did not exceed the state water quality standards for the protection of aquatic life. Total phosphorus, orthophosphate, and selected pesticides concentrations were low and undetectable by the current laboratory analytical methods.

Chloride and ammonia plus organic nitrogen concentrations in the Devils River were examined by their amounts and by a comparison to the larger U.S. Geological Survey Hydrologic Benchmark Network program historical record for the Devils River between 1978-95. Based on this type of analysis, both chloride and ammonia plus organic nitrogen concentrations were less than the first quartile (25th percentile) of the larger U.S. Geological Survey Hydrologic Benchmark Network program data set. In other words, when compared to historical sampling on the Devils River, chloride and ammonia plus organic nitrogen concentrations were less than the lowest 25 percent of numbers. Chloride concentrations were less than 14.0 milligrams per liter and did not exceed state water quality standards. Ammonia plus organic nitrogen concentrations were less than 0.23 milligrams per liter.

2016-2018 (Caldwell et al., 2020)

Over three years, from January 2016 to December 2018, a study assessed the impacts of spring discharge on instream temperatures in the Devils River. These impacts were assessed because groundwater discharge to streams generally stabilizes flows, mediates water temperatures, and supports riverine ecosystems. The Devils River was used as a case study for this research because it is a spring-fed river in a karst environment where climate change and groundwater development threaten to reduce spring flows and aquatic habitats of protected species.

The study site was a section of the perennial reach of the Devils River within the State Natural Area (State Natural Area) and The Nature Conservancy Dolan Falls Preserve in Val Verde County, Texas. The study site focused on the Finegan Springs complex and the confluence of the Devils River and Dolan Creek, about 37 miles north of Del Rio.

Monitoring data revealed that the Finegan Springs complex contributed approximately 40 percent of total river discharge. Spring temperatures were consistently 22.6 ± 0.3 degrees Celsius (~72-73 degrees Fahrenheit) providing thermal buffering to aquatic habitats. Springs reduced temperature extremes by 50-70 percent, cooling the streamflow in summer and warming it in winter. By correlating short-term monitoring data with modeled long-term temperature data, the surface water temperature records were extended to 30 years, revealing a long-term warming trend with daily maximum water temperature increasing 0.16 degrees Celsius (~0.28 degrees Fahrenheit) per decade. This long-term air and water temperature evaluation suggests susceptibility to climate change; however, extreme drought and groundwater depletion represent more acute problems in the near-term for such karst environments.

Water Quality Data Gaps and Research Needs

The full impact of climate change on the Devils River is not yet well understood. Water quality changes are closely tied to shifts in water quantity, particularly reduced flows. While groundwater and spring temperatures feeding the Devils River may not be significantly affected by air temperature changes alone, some minor increases are possible (Kløve et al., 2014). However, if water quantity decreases, it is likely to lead to higher stream temperatures and lower dissolved oxygen levels (Mace & Wade, 2008; Mahler & Bourgeais, 2013). Additionally, anticipated changes in precipitation patterns—such as more frequent droughts and heavy downpours—could negatively impact water quality. These changes may lead to increased surface runoff, greater movement of pollutants into streams, and overall water quality degradation (Mahler & Bourgeais, 2013; Kløve et al., 2014; Nielsen-Gammon et al., 2021).

Key data gaps identified include the need for:

- **Land Use and Land Cover Analysis:** Create a detailed map of land use changes in the Devils River watershed.
- **Nutrient Source Inventory:** Identify both point and nonpoint sources of nutrients in the watershed.
- **Expanded Water Quality Monitoring:** Improve monitoring with a focus on sentinel groundwater wells across the watershed.
- **Development of Hydrologic Models:** Enhance both groundwater and surface water models for better prediction and planning.
- **Understanding Surface and Groundwater Interaction:** Study the hydrogeological relationship between surface water and groundwater.
- **Continuous Monitoring of Key Parameters:** Implement continuous monitoring of water velocity, pH, turbidity, temperature, and specific conductance at major springs in the watershed.

Generational and local landowners have reported a decline in water quality, noting increased silt and turbidity along with a decrease in aquatic plant populations. Although historical data suggests the Devils River has excellent water quality, these records are sparse and collected from only a few sites in the expansive watershed. To address this gap, several recommendations for expanding the water quality monitoring network are described below. Collaboration with private property owners should occur on a strictly voluntary basis ensuring full transparency of methods and data use are conveyed to the property owner.

- **Adding Sampling Locations:** In cooperation with voluntary landowners, identify and establish sampling sites in areas of concern spotlighted by stakeholders. This should include defining the start and end points for monitoring stations along the Devils River.
- **Developing Monitoring Objectives:** Tailor monitoring goals to address stakeholder concerns, including adding or prioritizing specific water quality parameters such as metals, turbidity, and fish counts.
- **Increasing Sampling Frequency:** Enhance the frequency of long-term monitoring to capture seasonal and annual variations.

- **Focusing on Targeted Studies:** Conduct studies that focus on specific issues and details rather than broad, general assessments.
- **Creating a Communication Plan:** Develop a strategy for effectively sharing data and findings with local communities.

It is important to note that future research studies looking to address these data gaps and needs should collaborate with landowners and stakeholders in the watershed.

DEVILS RIVER FROM THE RYLANDER RANCH, NEAR COMSTOCK TEXAS.
©JACK JOHNSON

Recommendations for Water Quality Research, Monitoring, and Collaboration

The water quality of the Devils River serves as a benchmark for conservation excellence. The standards and monitoring practices outlined in this report provide a foundation for ongoing evaluation and action. As stakeholders address challenges from land use and climate change, agricultural impacts, and recreational pressures, collaboration among landowners, ranchers, conservationists, and public officials is essential. Regular monitoring of water quality indicators and proactive management of potential contamination sources are key to preserving the watershed's health for future generations.

However, the river's remote location presents a significant challenge for future research. Recommendations for addressing regional trends and potential threats include:

- **Access Land Use Changes:** Assess impacts from new septic systems and other introduced contaminants.
- **Evaluate Climate Change:** Evaluate changes in precipitation and runoff patterns.
- **Monitor Riparian Health:** Monitor the condition of riparian vegetation and its role in river stability.
- **Investigate Increased Recreational Use:** Investigate the effects of growing recreational activities on water quality.
- **Review Water Quality of Permitted Wastewater Discharges:** Review water quality from facilities such as the Crockett County WCID and the City of Sonora. Explore opportunities to convert discharge permits into land application permits.
- **Foster River Education and Stewardship:** Foster stronger connections between local communities and the broader region to promote river care and stewardship.
- **Study Oil and Gas Disposal Wells:** Study the potential impact of disposal wells on groundwater and surface water.
- **Study Emerging Contaminant of Concern:** Study the potential impact of emerging contaminants of concerns including pharmaceuticals and per- and polyfluoroalkyl substances (PFAS).
- **Invasive Species and Sedimentation:** Address the rise of invasive species, like feral hogs, and their contribution to sedimentation.

By addressing these issues, stakeholders can better protect the Devils River and its surrounding ecosystem.

Water Quality Questions Facing the Region

1) What is the quantity of surface water in the Devils River watershed?

Water quantity in a river or stream refers to the timing and total yield of water from a watershed and is measured by total yield and peak flow over a specified period (Neary, 2002). Water quantity may be affected by myriad factors, such as:

- Precipitation (amount, intensity, duration, and spatial distribution)
- Vegetation changes (type, extent, and condition of vegetation influences rainfall deposition patterns and interception rates, as well as evapotranspiration rates)
- Soil type (infiltration capacity and surface runoff)
- Human caused changes (land use and management activities, roads, impoundments, drainage systems, channel alterations, diversions, pumping, etc.)
- Groundwater

Changing watershed conditions can create cumulative effects. Water quantity may affect water quality through:

- Dilution/concentration of pollutants
- Change in pH (acidity/alkalinity)
- Low water – increased temperatures, increased algae blooms, decreased dissolved oxygen, less/altered aquatic life
- Land use change can introduce new contaminants or new non-point source pollution locations, or increase sediment loads (affecting specific conductance and turbidity)
- Microbial pathogens and parasites

Stream gage datasets of average daily discharge (Figure 22) and yearly volume (Figure 23) were downloaded for analysis from the United States Section of the IBWC. Gages used include Devils River at Pafford (08449400), Big Satan Creek near Comstock (08449440), Rough Canyon near Del Rio (08449480), North Fork San Pedro Creek near Del Rio (08449485), Evans Creek near Comstock (08449590), and the Middle Fork San Pedro Creek near Del Rio (08449490). The data for all listed gages were combined to determine a total value for the Devils River entering the Rio Grande, as the creeks below the Devils River gaging station at Pafford would have originally flowed into the Devils River before the impoundment of Amistad Dam.

Data of daily average discharge on the Devils River between January 1, 1968, and October 1, 2023, visually appear to indicate smaller peak flows in recent years (Figure 22). However, statistical analysis has not been conducted, and will be required to determine if there is a statistically significant change over time.

The yearly volume of the Devils River, based on data from the aforementioned gages for water years 1968-2022, was analyzed using a Mann Kendall trend analysis (Figure 23). This test indicated a significant ($p \leq 0.05$) declining trend in yearly volume between 1968 and 2022 (Kendall's Tau = -0.304, 2-sided p-value = 0.0011). However, trend analyses are sensitive to starting and ending values of the data, so further statistical analysis is recommended to confirm that this significant declining trend is not a spurious detection.

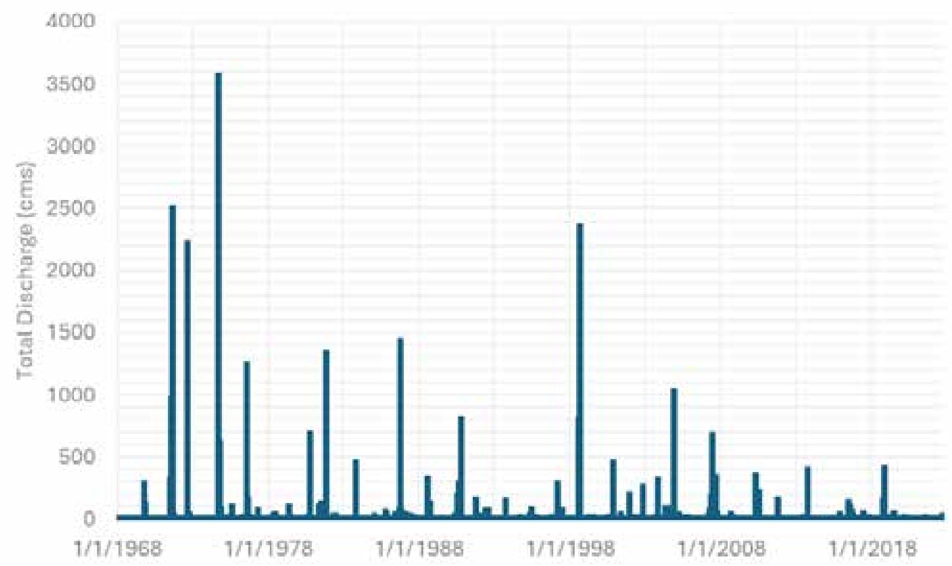


Figure 22. IBWC Graph of Daily Average Discharge from the Devils River between January 1, 1968, and October 1, 2023.

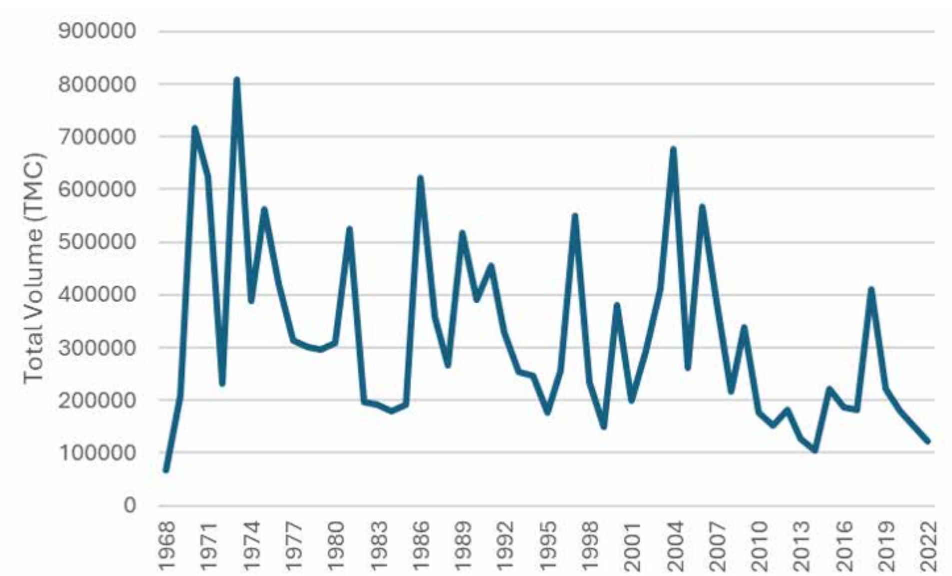


Figure 23. IBWC Graph of Yearly Volume of the Devils River between January 1, 1968, and October 1, 2023.

2) How are feral hog populations impacting water quality in the Devils River?

Feral hogs are an invasive species in North America with an estimated U.S. population of over six million (Vernin, 2024; USDA, n.d.). Nearly half of the U.S. population resides in Texas (an estimated 2.6 million feral hogs) (Salinas, 2023). Feral hogs are one of the 100 worst invasive species globally (responsible for billions of dollars' worth of destruction to agriculture in the U.S. annually) and they are increasingly causing damage to waterways and reducing water quality in Texas (Brown et al., 2012; Peters and Undark, 2020; Salinas, 2023).

Feral hogs' wallowing behavior near and in water sources to keep cool and remove ectoparasites reduces water quality in several ways (Timmons, 2011). The hogs tear up the riparian areas to cover themselves in mud and to eat plant and animal matter. This not only reduces the various ecosystem services provided by riparian areas (e.g., water storage, groundwater recharge, filtering contaminants, and more), but also increases sedimentation in waterways (TST, 2022). The hogs also defecate near and in waterways which increases bacteria levels and nutrient concentrations (Timmons, 2011).

When seasonal temperatures rise in Texas, the activity of feral hog populations becomes concentrated around water sources (Salinas, 2023). This is cause for concern because climatic trends indicate hotter and longer summers for the state (Nielsen-Gammon et al., 2021). As such, feral hog population growth and activities pose a challenge for managing water quality in state watersheds.

More research is needed into the estimated feral hog population for the Devils River watershed, along with a greater understanding of their movements, how they are currently impacting water quality currently, how they could impact water quality, and a long-term management plan (Brown et al., 2012; Mersinger and Silvy, 2007).

Key Takeaways – Water Quality

These recommendations are based on a comprehensive literature review and reflect the collective expertise of a technical team from 2023-2024.

- Springs provide about 75 percent of the river's water flow.
- Waters in the area are high in calcium (causing scaling) and often naturally high in nitrates from limestone, which can exceed standard levels.
- Surface water temperatures have increased by 0.16 degrees Celsius (~0.28 degrees Fahrenheit) per decade, but other water quality measures have stayed stable over time.
- Potential future contaminants to keep an eye on include agricultural runoff, animal waste, wastewater, sediment, oil and gas pollution, pharmaceuticals, and PFAS ("forever chemicals").
- Levels of *E. coli*, dissolved oxygen, pH, and temperature generally meet state water quality standards, though specific averages are not detailed in the historical data.
- Trace metal levels are well below state limits.
- Regular, more frequent water quality checks are needed to track historical averages for bacteria, oxygen, pH, temperature, and trace metals.
- Several water quality studies occurring between 1970-2018 show that water quality in the Devils River has remained excellent and relatively unchanged.

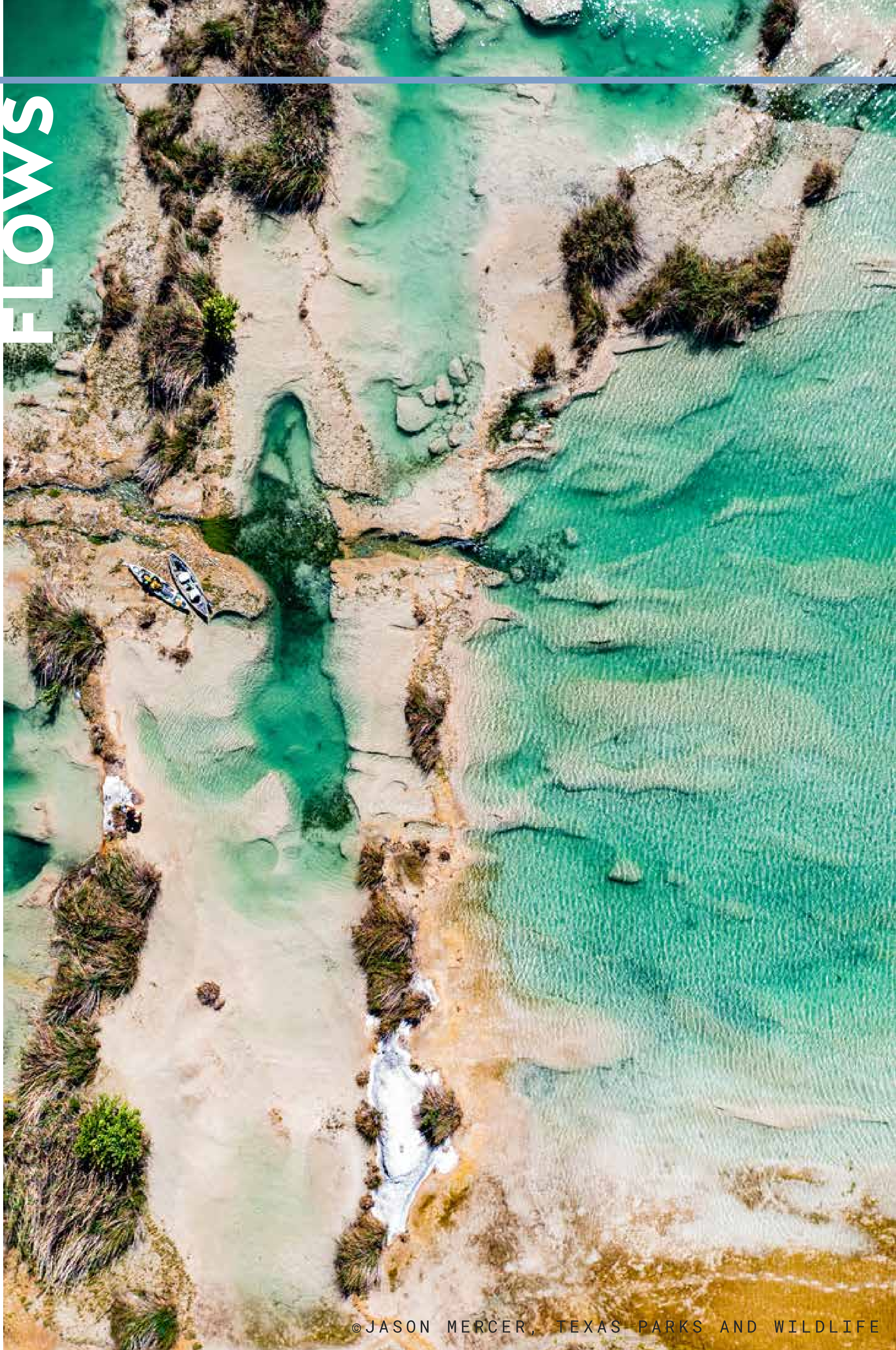
Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

Research priorities are:

- Assess the impact of increased recreation, climate change, and land use changes on water quality.
- Review treated wastewater discharges and consider safer land application alternatives.
- Study the effects of disposal wells on groundwater and river health.
- Control invasive species that increase sediment and harm riverbank vegetation.
- Enhance community education to support river conservation efforts.

Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

SPECIES AND FLOWS



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Elegantly referred to as “a desert resonance of the Aegean” (Smith, G.S. in Kenard et al., 1975), the Devils River has a perennially flowing reach of approximately 40 miles and a range in elevation from 1,130 feet to over 2,600 feet above sea level (Mast and Turk, 1999). Remarkably, it stands as one of the last free-flowing rivers in Texas. The watershed is primarily underlain by Lower Cretaceous limestone, most of which is referred to as Devils River Limestone, regularly appearing as outcrops along the many deeply incised canyons and drainages (Kenard et al. 1975, Howard 2016). Underneath regions to the south are upland pockets of caliche-cemented gravel from the Tertiary (Pliocene). The area boasts a diverse range of arid biotic communities, which can be broadly classified as subtropical shrub-steppe (Carr, 1992).

The diversity of habitats within the watershed’s relatively small footprint lends itself to high species richness across taxa groups. Moreover, the river provides diverse habitats due to the complexity of spring inputs along its length, creating eurythermal riverine reaches alongside stenothermal spring-influenced reaches (Brune, 1981). Each thermal regime and habitat type supports a different aquatic community (Kollaus and Bonner, 2012).

The Devils River watershed is located at the meeting point of three ecoregions: Chihuahuan Desert, Edwards Plateau, and Southern Texas Plains (Robertson et al., 2019; Griffiths et al., 2004), fostering assemblages that are uniquely biodiverse:

1. The **Edwards Plateau (Semiarid Edwards Plateau)** covers most of an area north and slightly west of the Devils River from the southern limits of the State Natural Area’s DAH Unit. Upland soils are typically shallow, gravelly, dark alkaline clays, clay loam, dolomites, and marl from the Ector-Tarrant-Rock Outcrop group. Soils on slopes, generally of the Ector-Rock outcrop group, are moderately alkaline, dark, and gravelly in texture, providing rapid runoff and with low water retention (Carr, 1992).
2. Adjacent to the west is the **Chihuahuan Desert (Chihuahuan Basins and Playas)**, whose soils are mostly silty, medium-gray shale with some limestone from the Gulfian Epoch of the Cretaceous in addition to more fine-grained, bioclastic (skeletal fragments) and glauconistic (containing iron and potassium giving it a greenish color) soils (*Buda Limestone*) recognized as Langtry-Rock Outcrop-Zorra. Lechuguilla (*Agava lechuguilla*) and ocotillo (*Fouquieria splendens*) are common representatives of this sub-ecoregion along the Devils River watershed.
3. Southeastward are biotic elements of the **Southern Texas Plains (Semiarid Edwards Bajada).** Here, soils are similar to the above but can be classified as gravelly caliche (Olmos-Langtry group), but some in the uplands are deep and loamy (Elindio group) (USGS, 2007). Blackbrush acacia (*Vachellia rigidula*), evergreen sumac (*Rhus virens*), and Brazilian bluewood (*Condalia hookeri*) are typical representatives from this sub-ecoregion along the Devils River watershed.

The area of southwest Texas that the Devils River falls within supports several endemic fish, invertebrates, and plant species, many of which rely on the water of the Devils River (Robertson et al., 2019). Additionally, the river supports numerous sport fish and game species, providing recreational opportunities to landowners and the public.

Freshwater habitats and their inhabitants are among the most imperiled on the planet, with data showing an 83 percent decline in the relative abundance of representative freshwater species in the last 50 years worldwide (WWF, 2022). These declines are generally attributed to water quality and quantity declines, flow modification, overexploitation of commercial species, and invasive species impacts (WWF, 2020; WWF, 2022). With one-third of the planet's vertebrate species residing in freshwater habitats and countless terrestrial species relying on freshwater, addressing these threats and conserving these habitats is crucial for preserving biodiversity.

Specific to the region surrounding the Devils River, approximately half of the fish species native to the Chihuahuan Desert are extinct or at considerable risk of extinction (Hubbs, 1990). The vast establishment of non-native riparian plants has changed the form and function of many river channels, impacting instream habitat diversity (Cohen et al.). Reduction in baseflows due to local groundwater extraction (Donnelly, 2007; BBEST) and reduced frequency of flow pulses due to drought further exacerbate this. The Devils River is a relatively intact and functioning river ecosystem. It lacks populations of the most harmful riparian invaders, such as giant reed (*Arundo donax*) and salt cedar (***Tamarix ramosissma***). It also benefits from largely unregulated streamflow, with minimal dams or other human interventions. However, impacts of threats such as urban development, giant reed colonization, agricultural runoff, altered flow regimes, and climate change are potentially significant, as evidence shows from surrounding watersheds. Understanding these threats will help guide conservation and restoration actions to protect the biodiversity of the Devils River watershed.

This chapter summarizes the flora and fauna found in the watershed. It characterizes species by broad habitat type, including riverine communities, spring communities, riparian communities, and upland communities, based on their primary use. Groupings were also selected for the key function these habitats and communities play in the larger Devils River watershed ecosystem. The chapter also discusses the importance of these sub-communities and habitat types, highlighting key taxa within each group, current research relevant to each habitat and taxa group, and future research needs.

RIVERINE HABITATS UNDER LOW FLOW CONDITIONS WITH AN OVERGROWTH OF FILAMENTOUS ALGAE, JUNE 2024.©SARAH ROBERTSON, TEXAS PARKS AND WILDLIFE

The State of the Science on Species of the Devils River

Riverine Communities

The Devils River is sustained by groundwater from numerous springs from the headwaters to its confluence with Amistad Reservoir (Brune, 1981). The heterogeneous distribution of these springs supports a diversity of habitats along the river course, from stenothermal spring outflows to dynamic riverine reaches. The riverine habitats support several species across taxa groups, including fish, invertebrates, and reptiles, that are important members of the broader ecosystem. Riverine habitats provide riffle, run, and pool mesohabitats with a dynamic temperature regime regulated by the season, stream flow, and distance from spring outflow.

Figure 24. Riverine Habitat, Jason Mercer, Texas Parks and Wildlife

The Devils River is recognized as a Native Fish Conservation Area for its high species richness and number of endemic species. There are 48 native fish species reported from the Devils River and 25 non-native species (Hendrickson and Cohen, 2022). Fishes in the Devils River are distributed throughout the river channel based on velocity, depth, vegetation, and stream temperature, with stream temperature being a strong driver in times of extreme air temperature, such as summer and winter (Kollaus and Bonner, 2012). Riverine species include regionally endemic, rare species such as the federally-listed (threatened) Devils River minnow (*Dionda diaboli*) and state-listed (threatened) species such as the Conchos pupfish (*Cyprinodon eximius*) and headwater catfish (*Ictalurus lupus*). Other species of importance that occur in riverine habitats of the Devils River are sportfish that offer angling opportunities, such as largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), and flathead catfish (*Pylodicus olivaris*), otherwise known as yellow cats.

Texas Parks and Wildlife, with the support of the Nature Conservancy and Devils River Conservancy, has completed annual fish assemblage surveys and biannual sport fish surveys at multiple locations along the river since 2011. These surveys seek to build a baseline data set to track changes in riverine fish species through time and correlate any significant changes to changes in environmental variables such as flow, water quality, etc.

While comprehensive fish assemblage surveys are current, most recent species-specific research has focused on the federally listed Devils River minnow (*Dionda diaboli*) due to the availability of funding at state and federal levels to address its recovery plan. The Devils River minnow has been the subject of numerous research efforts in its natural habitat and laboratory settings. This small-bodied minnow, first collected in Las Moras Creek in 1951 (Hubbs and Brown, 1956), resides in vegetated pools where it feeds on algae (McMillan, 2011). Laboratory studies have focused on understanding the culture of this species, including reproduction and rearing in captivity (Gibson et al., 2004; Gibson and Fries, 2005; Hulbert et al., 2007; Phillips et al., 2009; Fries and Gibson, 2010). Field studies within the Devils River have documented spawning behavior in the wild (Phillips et al., 2011), assessed abundance and distribution (Hubbs and Garrett, 1990; Garrett et al., 1992), investigated life history (McMillan, 2011; Robertson et al.), explored habitat associations (URGBBEST, 2012; Kollaus and Bonner, 2012), genetics (Schonhuth et al., 2012), and parasite infections (McDermott et al., 2014). Initially found in seven Rio Grande tributaries in the United States and Mexico, the species is believed to have been extirpated from Las Moras and Sycamore creeks in the United States and the Rio San Carlos in Mexico (USFWS, 2005). The Devils River remains a stronghold for this species.

Figure 25. Devils River Minnow (Dionda diaboli), Sarah Robertson, Texas Parks and Wildlife

The river also serves as a critical habitat for the only freshwater mussel species known to occur in the watershed, the federally endangered Texas hornshell (*Popenaias popeii*). This species was described in 1857 and has a historical range throughout the Rio Grande Basin in Texas and Mexico (Lea 1857; USFWS 2018).

Freshwater mussels, such as Texas hornshell, serve as important indicators of aquatic health given that they are generally more sensitive to habitat alterations and poor water quality than fish and benthic macroinvertebrates. In addition, because their reproductive cycle depends on fish as an intermediate host for larval development, they require habitat and water quality conditions that support a healthy fish community. Understanding the species' habitat, water quality, and host fish requirements remains critically important.

Karatayev et al. (2012) documented some of the earliest recent records of live Texas hornshell in the Devils River. While their longitudinal ("top-to-bottom") survey from Bakers Crossing to Lake Amistad only found 11 live Texas hornshells, survey efforts were focused on boulder habitats similar to those found in the Rio Grande, where Texas hornshells are abundant. However, as subsequent surveys have found (Diaz 2017), Texas hornshells in the Devils River utilize riffle-type habitats with embedded gravel and cobble substrates and are more abundant than initially reported by Karatayev et al. (2012).

Figure 26. Right: Texas hornshell, Sarah Robertson, Texas Parks and Wildlife ; Left: Texas hornshell underwater, Clint Robertson, Texas Parks and Wildlife

Freshwater mussels, especially in early life stages, are sensitive to poor water quality. Temperature, particularly high water temperature, can be lethal and is a critical water quality parameter for mussels, given its direct link to flow. For Texas hornshells, critical thermal maxima have been assessed for glochidia (larval mussels) and juveniles from the Devils River population (Rangaswami et al., 2023). Rangaswami et al. (2023) found that water temperatures of approximately 33 degrees Celsius (91.4 degrees Fahrenheit) were lethal to 50 percent of glochidia and juveniles tested for 12, 24, and 96-hour exposures. Additionally, they identified flows of approximately 85 cfs frequently exceed this temperature criterion during high air temperature months.

Another riverine species of note is the Rio Grande cooter (*Pseudemys gorzugi*), found in the Rio Grande, Pecos, and Devils rivers. It prefers flowing reaches with deep pools and aquatic vegetation (Bailey et al. 2014). The U.S. Fish and Wildlife Service recently assessed this species and found it has maintained populations across its historic range (USFWS 2022). In the Devils River, the species is restricted to one population unit. However, it was assessed to be at low risk due to their intact habitat, which included sufficient water quantity and good water quality.

In 2006, the U.S. Geological Survey collected aquatic macroinvertebrate data from four sites on the Devils River from Dolan Falls to Little Satan Canyon, all within the riverine portions of the river. They documented 100 macroinvertebrate taxa, with Pafford Crossing being the most taxa-rich site, with 57 documented (Moring 2012). They observed no longitudinal pattern. Riffle beetles (*Elmidae*) were the most abundant group observed at all sites, and Chironomidae were the most diverse.

Spring Communities

Springs along the Devils River facilitate interactions between different types of organisms from different ecosystems. One such ecosystem is the underground aquifer and the hyporheic zone, home to odd and ancient organisms. The second is the riverine species that inhabit the Devils River. These ecotones, or regions of transition between two biological communities, create a niche where species that rarely interact can be found together. In the desert, the springs provide a window into the aquifer and offer the opportunity to study the communities present and how they interact to maintain the pristine aquifer water feeding the Devils River.

Figure 27. Springs habitat, Maegan Lanham, Texas Parks and Wildlife

The surrounding geology and the size of the conduit feeding the orifice influence the many springs along the Devils River. These springs range from small muddy seeps to large orifices, creating the baseflow of the Devils River and providing an oasis to many terrestrial animals. Many springs are offset from the river channel and form their own runs, which vary in length and empty into the river. The spring runs form an ecological niche as they mix with the river water. The springs maintain a constant temperature year-round (Roca and Baltanas, 1993) near the orifice, providing an area where a spring-adapted community persists (Hubbs, 1995).

The aquifer community is not the most diverse ecosystem component on the Devils River, but it has many rare and geographically unique organisms (Diaz et al., 2018). Part of the overall community comprises organisms that only inhabit caves or underground aquifer habitats, termed stygobionts. These organisms mainly consist of blind crustaceans that have evolved to persist in the underground aquifer after the ancient seas retreated. Other types of organisms that inhabit the underground streams and caves of the Devils River include the riffle beetle (*Typhloelmis finegan*) (Barr et al., 2015) and a few species of aquifer snails (Alvear et al., 2020). New species are still being discovered in these springs, which need to be described to add to the overall diversity and understanding of the community structure.

The surface portion of the community has many species that are considered spring-associated in that they require the stenothermal environment around the spring opening. One of these organisms is a small salamander, which is considered *Eurycea Sp3* and similar to the Barton Springs salamander (Devitt et al., 2019). These salamanders have been shown to inhabit the springs near the orifice along the Devils River and Dolan Creek (Diaz et al., 2018). These neotenic salamanders are considered sensitive to anthropogenic activity (Diaz et al., 2020) and have been shown to have a negative correlation between surface abundance and residential development (Bendik et al., 2014). This species is environmentally sensitive and has a potentially narrow geographic range.

Figure 28. *Eurycea Sp3*, Peter Diaz, U.S Fish and Wildlife Service

While some research has been accomplished on the Devils River and Dolan Creek regarding fish, mussels, and turtles, the work on the spring-associated invertebrates (e.g., *Heterelmis glabra*) or Eurycea is minimal. In 1998, Nelson Stringer did valuable work on the Devils River and Dolan Creek to determine the health of the systems at that time using benthic macroinvertebrates to conduct an EPA Rapid Bioassessment Protocol III (Diaz et al., 2018). Their findings, similar to those of Diaz et al. (2018), indicated that the system was in pristine condition and showed differences in filter feeders and EPT taxa between Dolan Creek and the Devils River. EPT stands for *Ephemeroptera* (mayfly), *Plecoptera* (stonefly), and *Trichoptera* (caddisfly), which are macroinvertebrates that are sensitive to water pollution. Moring (2012) conducted a study on benthic macroinvertebrates in the Devils River, using a dip net to sample invertebrates, providing a presence-absence list of benthic invertebrates that can be added to the list of known inhabitants. Additional invertebrate research includes the mesohabitat associations of *Tryonia diaboli* (Diaz et al., 2020) and the temperature tolerance of *Heterelmis spp.* (Nair et al., 2023). Finally, Diaz et al. (2018) provide a template using benthic invertebrates to monitor the system's health over time as water becomes less available and land use changes occur.

Research on the salamander, *Eurycea Sp3*, remains limited. First discovered during the work by Nelson Riley (Chippindale et al., 2000) in 1998, a 2018 study examined the basic ecological questions of distribution and abundance for the salamanders in Finegan and Dolan springs. Diaz et al. (2018) found that the salamanders distributed longitudinally along Finegan Springs and the springs along Dolan Creek. A total of 50 salamanders were documented with no recaptures during the study, potentially indicating a large population. They observed that these salamanders used root mats for shelter along both systems (Diaz et al., 2024; in press). It is hypothesized that these salamanders may be using root mats for cover due to the lack of gravel or cobble within the shallow spring runs caused by flood pulses in these systems. This type of habitat association is different from that of other documented species to the east.

Some members of the Devils River fish community are considered spring-associates. These species live in and around spring outflows, and it is believed that their habitat selection is primarily driven by thermal stability (Hubbs, 2001). In the Devils River, fish species shown to prefer spring-associated habitats include Mexican tetra (*Astyanax mexicanus*), Texas shiner (*Notropis amabilis*), proserpine shiner (*Cyprinella proserpina*), manantial roundnose minnow (*Dionda argentosa*), and Rio Grande darter (*Etheostoma grahami*) (Kollaus and Bonner, 2012). These species are often found in shelf habitats supported by spring outflows but adjacent to the main river channel or in spring runs supplied directly from spring outflows. It is predicted that prolonged significant reductions in spring flows would likely directly affect these species' populations.

Figure 29. Rio Grande Darter (*Etheostoma grahami*), Sarah Robertson, Texas Parks and Wildlife

Riparian Communities

Riparian corridors play a significant role in maintaining the health and functionality of our rivers. These areas encompass the land and communities along the banks of rivers, where they serve many important roles. These important zones only occupy about two percent of the land area in the southwestern United States (Albright et al., 2022) but are unique in that their soils, flora, and fauna are developed and maintained almost entirely by the presence of water. They serve as migration corridors for numerous wildlife species, and their native riparian plants stabilize stream banks, trap sediment, slow and dissipate flood waters, filter and store water, help maintain stream temperatures, and provide food and habitat for birds, mammals, fish, amphibians, reptiles, and invertebrates. In light of this, it is not difficult to understand why riparian areas exhibit the greatest species richness and density of any habitat in the region. Undoubtedly, the Devils River's notoriety as the most pristine river in Texas is largely due to the river's intact riparian corridor.

Figure 30. Riparian habitat, Jason Mercer, Texas Parks and Wildlife

The Devils River watershed, in general, is too dry to support the ready fuel sources provided by grasslands and open understory woodland, so it is unlikely that fire maintains most riparian communities here. Instead, strong hydrologic cycles, such as floods, are thought to be responsible for major natural disturbance regimes. Over-browsing by introduced ungulates (e.g., Spanish and Angora breeds of domestic goat, *Capra hircus*) from around the mid-twentieth century has been generally curtailed along the river, allowing for gradual natural revegetation and erosion control. However, Barbary sheep ('Audad;' *Ammotragus lervia*) remain prevalent in many areas and pose an ecological concern given their tendency to denude landscapes and transmit diseases, including anthrax ("Anthrax Confirmed in Uvalde County Barbary Sheep").

RIPARIAN-ASSOCIATED PLANT COMMUNITIES

Carr (1992) succinctly characterized seven major plant communities at Dolan Falls Preserve in Val Verde County, which are likely representative of most of the watershed in the above ecoregions, including:

1. level to gently rolling uplands or ridgetops
2. dry, rocky slopes
3. gentle colluvial slopes and flats
4. mesic canyon bottoms
5. mesic cliffs and slopes along streams and around springs
6. alluvial terraces
7. streambeds and creekbanks

The latter four could be considered more strictly riparian and are briefly described below (see Carr, 1992 for greater detail, including an extensive species lists).

Mesic Canyon Bottoms

Especially near the river, there may be a few deep, steep-sided canyon drainages containing many rock outcrops, deep alluvial gravel, and little soil for herbaceous ground cover but with sufficient available moisture and shade to support small patches of closed canopy woodland consisting of plateau live oak (*Quercus fusiformis*), pecan (*Carya illinoiensis*), Texas mountain laurel (*Sophora secundiflora*), Mexican buckeye (*Ungnadia speciosa*), and golden leadball tree (*Leucaena retusa*). Notably, in one of these canyon bottoms (Grass Patch Springs, Dolan Falls Preserve), there exists a small, disjunct population of Mexican white oak (*Q. polymorpha*) dominating the canopy to heights of 40 feet or more and is the only known occurrence of this species north of Mexico.

Mesic Cliffs and Slopes Along Streams and Around Springs

Carr (1992) considered these areas "mostly evergreen woodlands found in narrow bands on steep cliffs and talus slopes along streams and in the vicinity of springs." Here, we have a mix of a few woody plant species unique to this topography and a larger number of taxa encountered in drier areas outside this vicinity., are Small stands of federally endangered Texas snowbells (*Styrax platanifolius ssp. texanus*) occur in limited, typically north or east-facing aspects of exposed rocky outcrops. This federally listed endangered woody shrub is endemic to a few counties along the southwestern edge of the Balcones Canyonlands. When listed in 1984, there were less than 25 known individuals from five locations. However, recovery efforts and intensive surveys now catalog over 950 individuals from 22 localities of the upper reaches of the Devils, Nueces, and West Nueces rivers in Real, Edwards, and Val Verde counties (2018; FR Vol. 83, No. 150: 38164-38166). Fourteen of these localities occur in the Devils River watershed (USFWS, 2017). Mesic slopes like the ones containing Texas snowbells slope can be heavily shaded by large plateau live oaks along with dense shrub thickets typically consisting of Texas kidneywood (*Eysenhardtia texana*), Texas persimmon (*Disopyros texana*), Mexican buckeye, catclaw (*Senegalia roemeriana*), guajillo (*S. berlandieri*), coyotillo (*Karwinskia humboldtiana*), and ocotillo. Dense shade and limited soil preclude much ground cover here. Downslope, along river edges there, one finds plateau live oak and pecan (*Carya illinoinensis*) in the overstory, along with a rich understory of Texas mountain laurel, Mexican buckeye, goldenball leadtree, gum bumelia (*Sideroxylon lanuginosum*), elbowbush (*Forestiera angustifolia*), and many others, including introduced fig trees (*Ficus carica*) near springs.

Alluvial Terraces

Howard (2016) described three often intermixed landforms associated with Devils River edges and defined by periodic catastrophic floods: bare rock surfaces, deposits consisting primarily of boulders, pebbles, and cobbles, and terraces composed of fine-grained sediments. Some of these associations, especially downstream from tributaries, may be of ancient Pleistocene origin (Kochel et al., 1982). Typically, little soil accumulates on the extensive gravel rock beds. However, in certain stretches, there are notable deposits of Riverwash and Dev Soils, which are dark, brown, very gravelly clay loam form to a depth of approximately 25 inches and on top of deeper layers of similar but paler brown layers. Here one can often find significant stands of closed canopy woodland characterized as hardy evergreen-deciduous gallery forests of sycamore (*Platanus occidentalis*), plateau live oak, and pecan, many exceeding 30 feet in height, in addition to Mexican ash (*Fraxinus berlandieriana*), and black willow (*Salix nigra*). At the open edges are abundant shrubs, including huisache (*Vachella farnesiana*), granjeno (*Ehrenbergiana pallida*), guajillo, and guayacan (*Guaiacum angustifolium*); understory shrubs often include Texas mountain laurel, Texas persimmon, and Vasey oak (*Q. vaseyana*). The deep soils in this community allow extensive, grassy groundcover primarily consisting of speargrass (*Stipa leucotricha*), Virginia wildrye (*Elymus virqinicus*), and non-native, invasive grasses such as bermudagrass (*Cynodon dactylon*), King Ranch bluestem (*Bothriochloa ischaemum*), and Johnsongrass (*Sorghum halepense*).

Streambeds and Creekbanks

Streambeds and creekbanks are likely the most frequently encountered riparian community, often consisting of flood-scoured limestone benchrock, large boulders, gravel and scattered pockets of Riverwash and shallow Dev soils supporting black willow and short-statured sycamore interspersed with various shrubs and small trees, including false willow (*Baccharis neglecta*), buttonbush (*Cephalanthus occidentalis*), Mexican ash, desert willow (*Chilopsis linearis*) and splitleaf brickelbrush (*Brickellia laciniata*) and Texas black walnut (*Juglans macrocarpa*). Dense tall grasses form around the many ephemeral pools, invariably consisting of switchgrass (*Panicum virgatum*), sawgrass (*Cladium jamaicense*), and giant reed (*A. donax*). Several rooted aquatic plants inhabit pools that retain water, including yellow spatterdock (*Nuphar lutea*) and knotty pondweed (*Potamogeton nodosus*). Tussock sedge (*Eleocharis rostellata*) regularly form clumps approximately two feet high, and as many wide in the water near gravelly rapids, and more swiftly flowing waters may have the submersive American waterwillow (*Justicia americana*), along with water cress (*Nasturtium officinale*) and common duckweed (*Lemna minor*).

ANIMAL LIFE

Few terrestrial animal inventories have been completed in the Devils River watershed, restricted mainly to the Del Norte Unit of the State Natural Area and Dolan Falls Preserve. Under a request by the Texas Historical Committee, the Texas General Land Office, and Texas Parks and Wildlife, Kenard et al. (1975) conducted a preliminary survey of the region, including its archaeology, geology, karst features, vegetation, and select vertebrate groups. These studies were probably the most intensive to date and serve as a good baseline for this overview and future inventories. Selected species relevant to the watershed will be described below, along with any updated material.

In times of sufficient moisture, several amphibian species have been recorded, including Couch's spadefoot (*Scapiophus couch*), red-spotted toad (*Anaxyrus punctatus*), Texas cliff frog (*Syrrhophus marnocki*), cricket frog (*Acris crepitans*), Great Plains narrow-mouthed toad (*Gastrophryne olivacea*), and likely the westernmost occurrence of Gulf Coast toad (*Bufo valliceps*).

Turtles recorded include yellow mud turtle (*Kinosternon flavescens*), red-eared slider (*Trachemys scripta*), river cooter (*Pseudemys concinna*), ornate box turtle (*Terrapene ornata*), spiny softshell (*Apalone spinifera*), and state threatened (G4S2) Texas tortoise (Gopherus berlandieri). Many snakes (approximately 32 species), including several elegant ones such as gray-banded kingsnakes (*Lampropeltis alterna*), Mexican milksnake (*L. gentilis*), and the vulnerable Trans-Pecos black-headed snake (G3S3; *Tantilla cucullate*). Texas banded geckos (*Coleonyx brevis*) are also recorded here along with at least 15 species of lizards, including collared lizard (*Crotophytus collaris*), Texas horned lizard (*Phrynosoma cornutum*), round-tailed horned lizard (*P. modestum*), alligator lizards (*Gerrhonotus infernalis*).

Data compiled from eBird, including all observations (Figure 31) mapped from checklists provided by participants in Texas AgriLife's "Birding the Border," reveals to date a total of 364 species for the Riparian area (see species table in eBird, 2024). Many interesting species are on this list, including over 20 species of waterfowl have been recorded, including many ducks such as cinnamon teal (*Spatula cyanoptera*), Bufflehead (*Bucephala albeola*), and red-breasted merganser (*Mergus serrator*); along with uncommon sightings of pelagic birds, such as red-throated loon and Pacific loon (*Gavia stellata*, *G. pacifica*, respectively. Green kingfishers (*Chloroceryle americana*) excavate nests into the deeper soil banks near the river. Belted kingfisher (*Megaceryle alcyon*), the rarer ringed kingfisher (*M. torquata*) may use tree limbs along the river as perch sites.

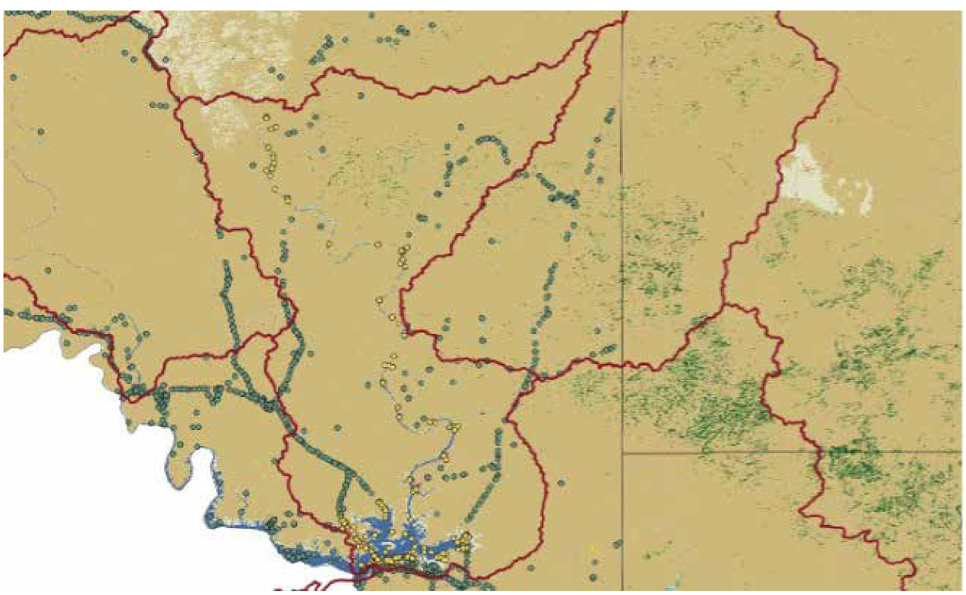

Figure 31. eBird observations for Lower Devils River riparian localities (yellow dots) along with those (green dots) outside of this area mapped from eBird data (accessed September 25, 2024) for Val Verde County, Texas. U.S. Geological Survey Lower Devils watershed boundary (in red; HUC8 13040302) surrounds mapped riparian eBird localities. The base layer is represented by Google Satellite imagery (https://mt1.google.com/vt/lyrs=s&x={x}&y={y}&z={z}).

The larger stands of trees along the river can be a suitable stopover habitat for migrating neotropical songbirds such as Northern parula (*Setophaga americana*), black-throated green warbler (*S. virens*), yellow warbler (*S. petechia*), and occasionally, golden-cheeked warblers (*S. chrysoparia*; not appearing on the above eBird list). An uncommon Mexican species, the rufous-capped warbler (*Basileuterus rufifrons*), has been detected irregularly near Dolan Falls. Breeding birds surveyed from 1997 to 2001 at Dolan Falls Preserve tallied 88 species, with approximately 50 percent consisting of (in decreasing order of abundance): turkey vulture (*Cathartes aura*), Northern cardinal (*Cardinalis cardinalis*), painted bunting (*Passerina ciris*), black-throated sparrow (*Amphispiza bilineata*), Bewick's wren (*Thryomanes bewickii*), rufous-crowned sparrow (*Aimophila ruficeps*), yellow-breasted chat (*Icteria virens*), canyon wren (*Catherpes mexicanus*), and Bell's vireo (*V. belli*) (Farquhar, 2001). Diurnal raptors include the common black hawk (*Buteogallus anthracinus*), zone-tailed hawk (*B. albonotatus*), golden eagle (*Aquila chrysaetos*), and peregrine falcon (*Falco peregrinus*), along with a few nocturnal raptors such as elf owl (*Micrathene whitneyi*), both Eastern and Western screech-owls (*Megascops asio, M. kennicottii,* respectively), and barn owl (*Tyto alba*), great horned owl (*Bubo virginianus*). Bald eagles (*Haliaeetus leucocephalus*) have occasionally been sighted in the area (Kenard et al. 1975). However, no nesting had been documented until recently when a team of Texas Nature Trackers spotted a huge bald eagle's nest (estimated at 15 feet in diameter) on a cliff along the Devils River in December 2023 (Price, 2024). This nest surpasses the largest previously recorded bald eagle nest in Florida, which measured approximately 9.5 feet in diameter (Buehler, 2022), making it the widest nest ever reported for bald eagles and is truly exceptional. A likely explanation might be that the nest was originally built by golden eagles, which have been seen nesting in that same area since at least 2012 (Farquhar, unpublished data) and was recently usurped and expanded by bald eagles. This discovery is fascinating and merits further attention.

Black-capped vireos (*Vireo atricapilla*) have nested consistently but in varying densities over the years in shrubs and trees in areas with over 30 percent woody cover, especially along drainages and alluvial terraces (Farquhar 2011; Smith 2011). The Devils River watershed is typical of habitat in the arid southwestern portion of the black-capped vireo's range where mature shrubland suitable for breeding may persist in perpetuity absent major disturbance, thus providing long-term persistence for this formerly endangered species (Reemts et al., 2020). Conversely, vegetation free from major disturbance (e.g., catastrophic floods) in deeper soils, such as on alluvial terraces, while serving as prime habitat for vireos in the middle stages of succession can become open understory woodland no longer suitable to them (Farquhar, 2011; Reemts et al., 2020).

Brief mammal surveys were conducted at the Del Norte Unit of the State Natural Area by Kenard et al. (1975; 19 families, 39 species) and updated by Brent and Dowler (2001; 18 families, 39 species). These surveys revealed many interesting taxa, including eight species of bats. However, that total was recently raised to 13 (Allred 2016), including commonly encountered Mexican free-tailed bat (*Tadarida brasiliensis*), lesser seen pallid bat (*Antrozous pallidus*), silver-haired bat (*Lasionycteris noctivagans*), Western pipistrelle (*Parastrellus hesperus*), and the migratory hoary bat (*Lasiurus cinereus*). American badgers (*Taxidea taxus*) have been recorded in the watershed, as have a few Western spotted skunks (*Spilogale gracilis*), whose populations may be declining (Schmidly and Bradley 2016). Mountain lions (*Puma concolor*) are top predators in the watershed, with the bobcat (*Lynx rufus*) and gray fox (*Urocyon cinereoargenteus*) filling the mesopredator role. American beaver (*Castor canadensis*) and the non-native nutria (*Myocastor coypus*) are tied to the wetter regions. Raccoons (*Procyon lotor*) are plentiful along the river. After dark, with patience, one may also sight ringtails (*Bassariscus astutus*) picking their way along rocky outcrops and trees in the drainages. Rock squirrels (*Spermophilus variegatus*) abound in the plentiful rocky outcrops, and the less common Texas antelope squirrel (*Ammospermophilus interpres*). There are also collared peccary (*Pecari tajacu*) along the drainages and alluvial terraces, as well as several mouse species. Additionally, introduced ungulates in the area include fallow deer (*Dama dama*), axis deer (*Axis axis*), sika (*Cervus nippon*), wapiti (*C. elaphus*), blackbuck (*Antilope cervicapra*), mouflon (*Ovis orientalis*), Barbary sheep, and domestic goats.

Upland Habitat

Upland habitats represent the terrestrial habitat beyond the riparian corridor, and they may include varying elevations. This area contains a mix of woodland, grassland, and shrubland habitats, providing essential ecosystem functions and habitat for a wide diversity of plant and animal species. Upland vegetation can help slow surface runoff, allowing it to absorb into soils and recharge aquifers, which is critical for sustaining arid spring-fed rivers such as the Devils River. Changes to upland habitats, such as over-grazing or land use changes, can affect the functionality of upland habitats and species.

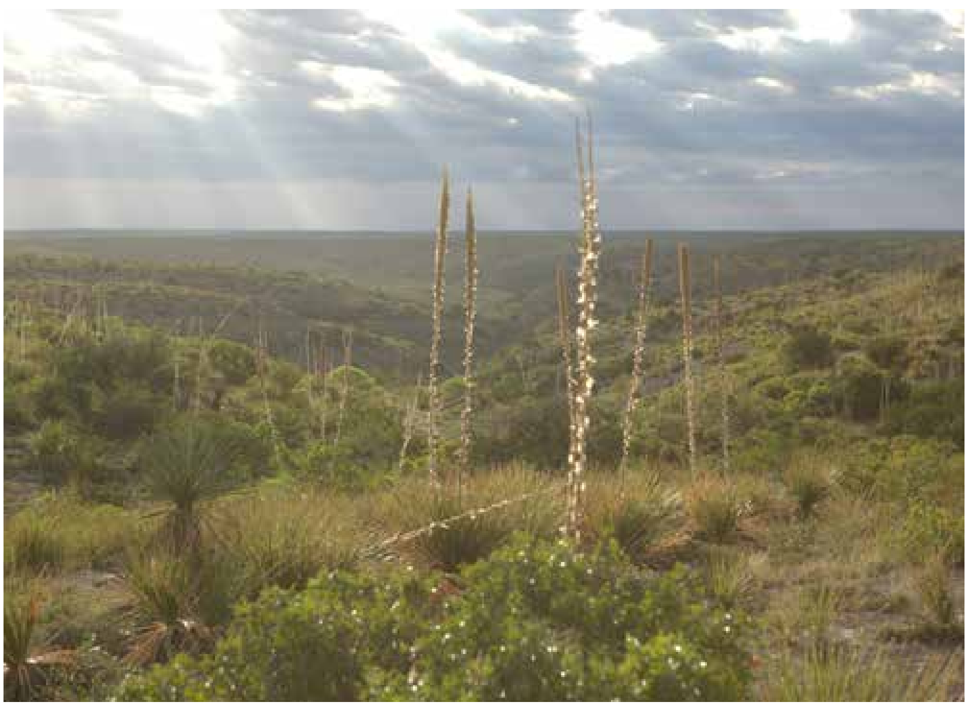

Figure 32. Upland habitat, Earl Nottingham, Texas Parks and Wildlife

PLANTS

The upland plant community varies by slope and soil composition (Reemts et al., 2020). In total, 565 plant taxa were observed throughout surveys conducted in Amistad National Recreation Area, of which 66 have been found exclusively on the State Natural Area property (Hedges and Poole, 1999).

The lowest soil/elevation gradient described is "level ground to gently rolling uplands or ridgetops," which is composed of mostly shortgrass grasslands (three-awns, hair tridens, curlymesquite, and buffalograss), midgrasses (sideoats grama, green sprangletop, and spikemosses), and various cacti throughout the habitat (huisache, coyotillo, and yucca, among others) (Carr, 1992; Hedges and Poole, 1999). Another soil/elevation gradient is dry, rocky slopes where the vegetation is primarily shrubs, most commonly guajillo, cenizo, and coyotillo (Carr, 1992; Hedges and Poole, 1999). There are also woodlands that consist of larger leafy species, including ashe juniper (*Juniperus ashei*) and vasey scrub oak (*Quercus pungens var. vaseyana*) (Hedges and Poole, 1999; Poole et al., 2013). The park area is home to several species of concern, including two federally and state-listed endangered plants, the Tobusch fishhook cactus (*Ancistrocactus tobuschii*) and Texas snowbells (*Styrax texanus*). Other species of concern include the polymorphos white oak (*Quercus polymorpha*), which represents the only wild population known in the United States, and the Anacacho orchid (*Bauhinia congesta*) (Carr, 1992).

Figure 33. Texas Snowbell, Chase Fountain, Texas Parks and Wildlife

BIRDS

A total of 62 bird species was observed during surveys conducted from July 2 to July 9, 1975, of the Devils River and Dolan Creek areas, so it is important to note that this survey represents a snapshot of birds located on site and not a full report on species that are present across various seasons annually (Scudday and Hanselka, 1975). Common species observed include several herons (great blue heron and green heron), kingfishers (belted kingfisher and green kingfisher), vireos (black-capped vireo and white-eyed vireo), and several hawks (red-tailed hawk, zone-tailed hawk, and common black hawk). Several bald eagles were observed during the survey, and while no golden eagles were observed, they are known to inhabit the area. A complete list of observed species can be found in Scudday and Hanselka 1975.

Figure 34. Black-capped vireo, Chase Fountain, Texas Parks and Wildlife

AMPHIBIANS AND REPTILES

The survey conducted by Scudday and Hanselka in 1975 observed a total of 55 reptile species and eight amphibians, including five frog and three toad species (Couch's spadefoot, barking frog, Texas cliff frog, cricket frog, leopard frog, Great Plains narrow-mouthed toad, Gulf Coast toad, and red spotted toad). Another survey conducted over two years (2003 and 2004) in the Amistad National Recreation Area inventoried 45 native herptile species, including 15 lizards, 17 snakes, four turtles, and one non-native gecko. Four state-threatened species were including the Texas horned lizard (*Phrynosoma cornutum*), the Texas indigo snake (*Drymarchon melanurus erebennus*), Trans-Pecos black-headed snake (*Tantilla cucullata*), and Berlandier's tortoise (*Gopherus berlandieri*) (Prival and Goode, 2011).

MAMMALS

A survey of bats was conducted from July 2013 to December 2014 in the State Natural Area, and 13 species were observed, including pallid bat (*Antrozous pallidus*), Townsend's bid-eared bat (*Corynorhinus townsendii*), Eastern red bat (*Laisurus borealis*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), ghost-faced bat (*Mormoops megalophylla*), cave myotis (*Myotis velifer*), yuma myotis (*Myotis yumanensis*), evening bat (*Nycticeius humeralis*), big free-tailed bat (*Nyctinomops macrotis*), canyon bat (*Parastrellus hesperus*), Mexican free-tailed bat (*Tadarida brasiliensis*), and tricolored bat (*Perimyotis subflavus*) which is currently federally proposed as an endangered species (Allred, 2016).

Common mammals found in the Devils River-Amistad National Recreation Area are generally associated with the woodland habitat in the park. They include raccoons, opossums, white-tailed deer, eastern fox squirrel, armadillo, mountain lion, beaver, and several species of mouse (Merriam pocket mouse, Nelson pocket mouse, deer mouse, white-footed mouse, and white-ankled mouse). A full list of mammals observed across several survey efforts can be found in the following citations (Scudday and Hanselka, 1975; Brant and Dowler, 2001; Halstead, 2004).

A subspecies of American black bear (*Ursus americanus*), Mexican black bears (*Ursus americanus eremicus*) range includes West Texas, and they have been observed in Big Bend National Park (TPWDa 2024). In West Texas, they are typically found in desert scrub or woodland habitats within scattered mountain ranges (TPWDa 2024). The status of the subspecies is not well understood and warrants further research and monitoring.

The Return of Black Bears in the Devils River Watershed

According to Austin Stolte, a wildlife biologist for Texas Parks and Wildlife, black bears (Ursus americanus) are gradually reestablishing themselves in Texas, particularly in remote regions like the Devils River watershed. Tracking local black bear occurrences relies on a voluntary reporting system managed by Texas Parks and Wildlife, where sightings are confirmed through game camera footage or physical evidence like tracks or scat. While precise population numbers are unknown, sightings are most common along river corridors like the Devils, Pecos, and Rio Grande rivers. These riparian zones serve as vital travel corridors, providing resources and shelter. Stolte notes that, although black bears are known to be transient in the region, there is evidence of a resident breeding population, with confirmed sightings of sows with cubs along the Pecos River. This indicates that some bears are not merely passing through but establishing permanent residency in the area. As black bears are a protected species in Texas, it is illegal to hunt them. Stolte encourages landowners to report sightings and work with Texas Parks and Wildlife to mitigate conflicts, particularly around deer feeders, which bears are known to target.

At the state level, mountain lions are listed as a species of greatest conservation need but are not classified as threatened or endangered in Texas. While mountain lions range includes West Texas and the Devils River region, they are elusive animals with large home ranges, making it difficult to detect and monitor individuals regularly (TPWDb 2024). There currently is not sufficient data to understand the status of breeding populations of mountain lions in Texas (TPWDb 2024).

Toward a Sustainable Future for Mountain Lions in Texas

In 2023, Texas Parks and Wildlife formed a Mountain Lion Stakeholder Group to address conservation and management of mountain lions. This group, which included landowners, hunters, biologists, conservationists, trappers, and livestock producers, emphasized the need for comprehensive data on mountain lion populations. Their Final Report highlighted the importance of studies on population trends, mortality causes, genetic diversity, and the movement of mountain lions between Texas and Mexico.

A key recommendation was for Texas Parks and Wildlife to create a science-based mountain lion management plan emphasizing data collection and balancing protection efforts with human-wildlife conflict management. There was debate over harvest reporting, with some members supporting mandatory reporting for better data while others preferred a voluntary system. Ethical concerns regarding trapping practices included proposals for mandatory 36-hour trap checks to reduce animal suffering. However, there was consensus that “canned hunts,” where animals are confined for hunting, should be banned.

Finally, the group stressed that the future of Texas’ mountain lions depends on private land stewardship, as most of the state’s mountain lion habitat is privately owned. Collaborative efforts among landowners, hunters, conservationists, and policymakers will be critical to the species’ long-term viability in Texas. The group’s findings reflect both common ground and ongoing debate about the best path forward for conserving this iconic predator.

Biological Data Gaps and Research Needs Related to In-Stream Flows

In addition to taxa inventories and monitoring, additional research needs exist related to instream flow science, which is the nexus between biology, hydrology, water quality, geomorphology, and connectivity as it relates to river stream flow and function. The following are identified research and modeling needs that would be useful in refining science-based instream flow recommendations for the Devils River, protective of native species, their habitats, and the ecological integrity of the river.

1. **Refinement of habitat suitability criteria and flow-ecology relationships for fish and mussels.** Habitat data has been collected in concert with fish and mussel surveys by Texas Parks and Wildlife, The Nature Conservancy, U.S. Fish and Wildlife Service, and Texas A&M University over the past five to ten years. This data should be used to update basin-specific habitat suitability criteria for fish and develop criteria for mussels. Additional flow ecology relationships (such as flow values necessary to complete an aspect of a species' life history) should be identified and compiled. This information will inform future development of instream flow recommendations for the protection of native fish and mussel species.
2. **Updated hydraulic-habitat modeling in priority reaches of the river.** Updates to the 2014 hydraulic habitat models produced by Texas State University and Texas Parks and Wildlife are underway, encompassing a more comprehensive range of environmental and flow conditions. This updated, and more robust, modeling is critical to understanding the impact of future water and climate scenarios on the sustainability of fish and mussel assemblages in the Devils River. The 2014 models predicted changes in available habitat for priority fish species as a result of changes in stream discharge; however, these models were only capable of predicting habitat over a narrow range of flows due to the limited hydrologic conditions captured during the study period. Updated bathymetry, incorporation of spring-inflows and water temperature, and a wider range of input data should make the updated model more capable in forecasting changes in habitat under a wider range of environmental and flow conditions and for a wider range of species (i.e. spring-dependent species).
3. **Longitudinal surveys and continued population monitoring to better understand the current distribution and abundance of Texas hornshell.** Population estimates and monitoring for Texas hornshell began in 2018 at two locations on the Devils River as a joint effort by the U.S. Fish and Wildlife Service, Texas Parks and Wildlife, The Nature Conservancy, and Texas A&M University. This study also collected fine-scale habitat data to help elucidate habitat suitability criteria for this species. Additionally, between 2015 and 2020, Texas Parks and Wildlife and Texas A&M University did surveys to identify additional Texas hornshell populations in the lower river (unpublished data). Due to the limited range of this species and its vulnerability to threats, population monitoring, and habitat data collection should continue annually to ensure persistence of this species. Additional continuous water temperature and stream flow data are necessary to better identify low flow trigger values in which critical thermal maximum temperatures for Texas

hornshell are exceeded. Monitoring of Texas hornshell benefits this species, but also serves as a potential indicator to alert researchers of deteriorating instream conditions for other riverine species during times of drought or poor water quality. Due to the limited range of this species and its vulnerability to threats, population monitoring and habitat data collection should continue annually to ensure persistence of this species. Additional continuous water temperature and stream flow data are necessary to better identify low flow trigger values in which critical thermal maximum temperatures for Texas hornshell are exceeded. Monitoring of Texas hornshell benefits this species, but also serves as a potential indicator to alert researchers of deteriorating instream conditions for other riverine species during times of drought or poor water quality.

4. **Host-fish testing for Texas hornshell from the Devils River.** Freshwater mussels need host fish to complete their life cycle, and some species of mussels require very specific species of fish to successfully recruit young. Laboratory studies using fish and Texas Hornshell from the Devils River is necessary to confirm host fish utilization for this population of Texas hornshell. When managing or conserving native mussel populations, which play an important role in keeping our rivers clean, the populations of host fish species must be considered as well.
5. **Assessing the impact of recreation on riverine species.** Little research exists to identify or quantify impacts to fish and mussel species from canoe and kayak recreation on rivers. Of particular concern are impacts to shallow-water habitats where canoes and kayaks are routinely drug through the sediment and cobble beds are disturbed by pedestrians in times of low flow. Texas hornshell, Rio Grande Darter, and Proserpine Shiner reside in these areas, and it is unclear if recreational traffic is impacting their populations or habitats. Texas hornshell are the least mobile of these species, and likely to experience the greatest impacts from disturbances to their habitats. It is recommended that research be conducted to assess impacts to riffles and other shallow water habitats and the species that reside in those habitats from recreational traffic. Special consideration should be taken to investigate potential impacts on habitats during times of low flow, which could exacerbate stress to species. If impacts are suspected, it is recommended that a list of best practices be developed to guide recreation and reduce or minimize negative impacts to these areas.
6. **Assessing the hydrology of the Devils River for historic changes.** The Devils River is free-flowing and largely unregulated; however, it is unclear if other factors have led to changes in the natural flow regime of the river. Landowners often refer to the lack of “flushing flows” or high flow pulses that anecdotally would flush out fine sediments from the river channel and maintain instream habitats. A full hydrologic assessment should be conducted for the period of record to determine the level of hydrologic alteration of the river through time, including changes to timing, magnitude, and duration of baseflows, high flow pulses, and overbanking flows. Attempts should also be made to identify any contributing factors to alterations.

Recommendations for Biological Research, Monitoring, and Collaboration

Species Inventories and Monitoring of Priority Habitats

Due to the remote location of the Devils River, difficulty traversing the terrain, and the dominance of privately owned properties, it is challenging to have research and monitoring surveys completed with regularity. Many of the surveys documented throughout the "Species and Flows" section are more than 40 years old. Additionally, some surveys focus on a small subset of taxa, often rarer species such as those listed as threatened or endangered. While it is critically important to update information on these more vulnerable taxa to gain a better understanding of current threats, population trends, and to inform conservation actions for recovery and delisting, there is also a critical need to document and track all taxa within the watershed to understand inter-species interactions, identify invasive or non-native species, and to implement conservation actions to preserve ecosystem diversity. This report highlights the prominent need for continued monitoring and more comprehensive survey efforts across all taxa and habitat zones surrounding the Devils River.

Specific biological inventory and monitoring recommendations are as follows:

1. **Biological inventories of taxa groups should be repeated at least every ten years.** This should include inventories of fish, aquatic and terrestrial invertebrates, plants, birds, mammals, reptiles, and amphibians across riverine, spring, riparian, karst, and upland habitats. Sites from the upper, middle, and lower watershed should be included to capture the climatic gradient and diversity of habitats throughout the watershed. Surveys at public lands (State Natural Area and Amistad National Recreation Area) should be prioritized due to repeatability of surveys; however, private properties should also be surveyed on a strictly voluntary basis ensuring full transparency of methods and data use are conveyed to the property owner. Physical and photo vouchers should be collected and georeferenced and any physical vouchers should be deposited in an accredited museum for research. With landowner

permission, species inventories should be quality-checked and deposited in the Devils River Digital Repository in perpetuity. Specific location data can be obscured to address any data privacy concerns by landowners.

2. **Population tracking and habitat assessments for species vulnerable to extirpation or extinction every one to five years.** Depending on the species-specific lifespan and life history of rare taxa, targeted data collection efforts should be made on a shorter cycle to ensure populations are stable and habitats remain able to support them. For short-lived species, such as Devils River minnow, or those that are more susceptible to rapid habitat degradation, such as Texas hornshell, it is recommended that targeted monitoring continue annually. For longer-lived or more adaptable species, monitoring could occur on a longer cycle. Data collection should include abundance or population estimates at multiple sites within the watershed, identification of recruitment and age class strength, and an assessment of habitat condition.
3. **Population and harvest tracking for game and sport fish species.** For species utilized for food or recreation purposes, including game species and sport fish, regular monitoring of populations and harvest helps landowners implement informed harvest practices and informs Texas Parks and Wildlife in setting regulations protective of stable populations. Voluntary creel surveys conducted through the DRAP survey for paddlers or conducted in-person at river access points should be continued to measure fishing pressure by species. Longitudinal angling surveys were conducted by Texas Parks and Wildlife every two years from 2012 through 2016. These surveys should resume and be completed to complement creel surveys to assess adult sport fish populations along the river. Similar population estimates and creels should be done for target game species such as whitetail deer, turkey, etc.
4. **Non-native species surveys, treatment, and monitoring.** Any non-native species identified as part of the taxa inventories should be mapped for the location and full extent of the organisms. Non-native species should be prioritized based on potential impact on habitat, river function, and native species. A treatment plan should be developed for those considered at high risk for spread and ecosystem disruption. Follow-up surveys and re-treatment should be conducted to monitor effectiveness and mitigate spread. Non-native species considered a low risk in terms of environmental impacts should be monitored, and future taxa inventories should document any spread.

Key Takeaways – Species and Flows

These recommendations are based on a comprehensive literature review and reflect the collective expertise of a technical team from 2023-2024.

- → The Devils River watershed is located at the meeting point of three ecoregions: Chihuahuan Desert, Edwards Plateau, and Southern Texas Plains.
- → The river flows for approximately 40 miles with an elevation range from 1,130 to over 2,600 feet.
- → It is one of the last free-flowing rivers in Texas, underlain primarily by Lower Cretaceous limestone (known as Devils River Limestone).
- → The river is recognized as a Native Fish Conservation Area for its high species richness and number of endemic species.
- → The watershed includes various habitats, such as riverine, spring, riparian, and upland communities, which support high species richness, including endemic fish and invertebrates, as well as sport fish that sustain local recreation.
    - → The **riverine** habitat supports a dynamic fish and invertebrate community.
    - → The **springs** habitat provides a stable temperature niche for rare organisms, including spring-adapted fish and salamanders. The river is sustained by groundwater from numerous springs from the headwaters to its confluence with Amistad Reservoir (Brune, 1981).
    - → The **riparian** habitat stabilizes banks, supports migration corridors, and hosts the highest species density.
    - → The **upland** habitat is critical for water absorption, groundwater recharge, and soil retention.
- → Species of note found within the watershed include:
    - → **Fish:** Hosts 48 native and 25 non-native fish species, including the federally threatened Devils River minnow (*Dionda diaboli*), as well as other rare species such as the Conchos pupfish (*Cyprinodon eximius*) and headwater catfish (*Ictalurus lupus*).
    - → **Mussels:** The river serves as a critical habitat for the only freshwater mussel species known to occur in the watershed, the federally endangered Texas hornshell (*Popenaias popeii*).
    - → **Reptiles:** Surveys have recorded 55 reptile species, including state-threatened species like the Texas horned lizard (*Phrynosoma cornutum*) and Texas tortoise (*Gopherus berlandieri*).

Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

- **Birds:** Over 364 bird species, including bald eagles and migratory neotropical songbird species, utilize the riparian habitats. The black-capped vireo (*Vireo atricapilla*), formerly endangered, continues to nest in the riparian areas.
- **Mammals:** Surveys in the watershed have documented 39 mammal species, including mountain lions, bobcats, baths, and gray foxes and several introduced ungulates, such as axis deer and Barbary sheep.

Research priorities are:

- Conduct biological inventories of fish, aquatic and terrestrial invertebrates, plants, birds, mammals, reptiles, and amphibians across riverine, spring, riparian, karst, and upland habitats every ten years to provide essential data on species presence, invasive species, and ecosystem health to support inter-species interactions and detect any emerging conservation concerns.
- Targeted monitoring of vulnerable species on a one to five year cycle to ensure populations are stable and habitats remain viable, allowing for timely intervention if populations show signs of decline.
- Monitor population and harvests for game and sport fish species to enable sustainable management by setting harvest limits that protect species stability and support local regulations to manage fishing pressure.
- Perform non-native species surveys, treatment, and monitoring to prevent them from spreading and disrupting native habitats and ecosystem functions and ensure that native species retain critical resources and preserve the ecological balance.

Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

SUSTAINABLE RECREATION

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The Devils River has been a local recreation attraction to communities in the region for well over a century, but in more recent decades, concerns have been raised over increasing visitation to the river watershed. Stories of the river's spring-fed, crystal-clear waters, dramatic limestone canyons, and rich biodiversity continue to spread across Texas and beyond as recreational tourists return home with tales of their experiences paddling, fishing, hunting, wildlife-watching, and stargazing. The remote and rugged landscape surrounding the Devils River appeals to those who seek challenging outdoor adventures as well as those who wish to experience the tranquility of pristine wilderness.

The unique qualities that make the Devils River a recreational gem also necessitate a careful balance between recreation demand and sustainable use. Increased activity can contribute to habitat degradation, such as bank erosion, water pollution, and disturbances to wildlife and plant communities, among other environmental impacts. Additionally, landowners along the river have faced challenges from trespassing, littering, and interpersonal altercations that infringe on private property rights and lead to negative perceptions of recreation within the resident community. Within the last few decades, protective measures, including visitor regulations and permitting, have been implemented to protect the river's ecological and cultural integrity and manage recreational use. As circumstances in the region evolve, the communities and ecosystems in the area may benefit from continued adaptation of these protective measures through collaborative stakeholder processes. Sustainable use of the Devils River ensures that recreational opportunities remain accessible while preserving the natural beauty, ecological health, and cultural history of this treasured resource for both current and future generations.

In the following section, this report will describe the parameters of sustainable recreation, including within the specific context of the Devils River watershed. It will provide a summary compilation of what is known about recreational activities, policies and regulations, and impacts, as well as what information is needed to further understand the effects of these activities on the Devils River watershed and its residents.

It is important to note that data collection, storage, and accessibility are generally managed by public entities that are subject to reporting requirements while private users are less likely to keep or share records. This section has aimed to provide balanced information collected from both public and private sources about recreation on both public and private lands within the Devils River watershed; however, due to the nature of record-keeping and access limitations, much of the information provided is sourced from public records. To better represent informal knowledge on this topic, the authors of this report consulted subject matter experts and storytellers to document their experiences living and working in proximity to recreational activities in the region. During the development of this section, several data gaps were identified. These data gaps are explored in their own section and in the recommendations section at the end of the chapter.

What is Sustainable Recreation?

Sustainability can feel like a buzzword. Its definition is often different depending on the industry or field in focus. This malleability has led to uncertainty and skepticism regarding its legitimacy in practice, but the Sustainable Recreation

Technical Team has used a broad definition which encompasses three pillars of sustainable development, optimizing positive environmental, economic, and social impacts and minimizing negative ones.

For the purposes of this report, the following definition of "sustainability" will be used to operationalize the concepts of sustainability and sustainable recreation and tourism: "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Bruntland Report, 1987).

This was further expanded to encompass economic growth, environmental protection, and social equity (Stenzel, 2010), three basic pillars required to uphold a working application of sustainability within a community. This definition allows for assessments of sustainability to cross the public land boundary and include private properties, communities, and the larger society for a more comprehensive, regional scope. The Devils River watershed has a mix of both public and private lands, the latter of which includes individual, non-profit, and corporate owners and managers, and as such, this report attempts to encompass recreation activity and impacts across all working lands in the region.

Recreation and Tourism

Due to the remote nature of and limited access to the Devils River, much of the recreation within the Devils River watershed can also be categorized as Nature Tourism, defined by Texas Parks and Wildlife as "responsible travel to natural areas, which conserves the environment and improves the welfare of local people." In the U.S., travel is measured in terms of person-trips, defined as "one person on a trip away from home overnight in paid accommodations or on a day or overnight trip to places 50 miles or more [one-way] away from home" (U.S. Travel Association, 2020). Therefore, any recreationist who completes a person-trip with the intent to recreate at the Devils River can be categorized as a tourist as well. The associated economic and sociocultural impacts of tourism on a destination and its surrounding communities makes this a vital component of this report's examination of sustainable recreation within the region. For the purposes of this report, the terms recreation and tourism can be used interchangeably.

Texas Parks and Wildlife applies one objective of Nature Tourism as providing "incentives for local communities and landowners to conserve wildlife habitats upon which the industry depends," further emphasizing the same three pillars of economic, sociocultural, and environmental concerns that should be assessed in discussions of sustainable management systems.

In the context of recreation in a natural destination, i.e., activities in nature conducted for the purpose of leisure, 'sustainability' should involve the "provision of desirable outdoor opportunities for all people, in a way that supports ecosystems, contributes to healthy communities, promotes equitable economies, respects culture and traditions, and develops stewardship values now and for future generations" (Cerveny et al., 2020). Ultimately, the goal is to optimize positive impacts and minimize negative impacts across all metrics for all stakeholders.

The U.S. Forest Service (USDA, 2010) describes the parameters to adaptively manage recreation within the principles of sustainability:

- connecting people with their natural and cultural heritage, using recreation as a portal to educate and motivate the public to become citizen stewards
- facilitating recreational activity to promote healthy lifestyles and improve physical and mental health along with spiritual and emotional wellbeing
- engaging the community in partnerships and decision-making processes
- developing relationships in the context of the larger landscape, across diverse stakeholders
- ensuring operational and program decisions uphold and protect the sustainability pillars of environmental, economic, and social resiliency

This framework also includes areas of focus relevant to recreation along the Devils River. It outlines the steps to restore and adapt recreation settings using a combination of channeling visitor traffic through a carefully developed network of roads, trails, and facilities disseminating educational messaging to encourage a stewardship mindset and ensuring a tangible field presence of recreation managers for both visitor support and regulation enforcement.

Texas Parks and Wildlife also includes sustainability considerations in their strategic planning (TPWD Land and Water Resources Conservation and Recreation Plan, 2024). Related to recreation management on the State Natural Area, Texas Parks and Wildlife aims to:

- "practice, encourage, and enable science-based conservation and stewardship of natural and cultural resources," with specific objectives that seek to both protect and preserve cultural resources such as the Indigenous rock art sites in the Devils River region.
- "increase access to and participation in the outdoors" through providing diverse recreational opportunities that "optimize visitation and visitor experience while protecting natural and cultural resources" and "manage public lands for sustainable use and enjoyment compatible with Texas Parks and Wildlife conservation goals."
- balances the dual purposes of sites such as the State Natural Area, to "educate, inform, and engage Texans in support of conservation and recreation," a process which includes fostering support for natural and cultural resources conservation through a variety of strategies.

Nature-based Recreation and Conservation

Nature-based tourism can be a significant source of revenue to support protected areas in reaching and maintaining conservation and biodiversity goals (Snyman & Bricker, 2019). Additionally, opportunities to improve ecological conditions of natural recreation sites increase when visitors participate in stewardship practices as part of their outdoor recreation and nature-based tourism experiences. (Schild, 2019). Because the Devils River has such an iconic identity as a natural and cultural resource, it can also engender strong place-based attachment in both landowners and visitors alike. While the effects of these attachments can vary among individuals due to multiple factors, they have been shown to significantly increase conservation-minded attitudes and behaviors (Cartwright et al., 2018). When recreationists engage in nature-based pursuits, it can both foster meaningful connections to a specific place and lead to engagement in conservation actions such as restoration, stewardship, and volunteerism activities at and for that site (Larson et al., 2016).

Outdoor recreation in the U.S. is trending towards an increase in accessible day-use trips that require shorter routes between origin and destination (White et al., 2016). Due to the remote nature of the Devils River and its location in the state, multiple hours away from any major metropolitan area, this pattern may mitigate current and future visitation rates. Guided tours are also becoming more frequent in visitor decision-making over independent travel. Combined with the more hazardous aspects of the watershed's terrain and the State Natural Area's funneling of paddlers through its system of approved river outfitters, also referred to as concessionaires, this trend further increases the likelihood that recreationists will receive responsible use education as well as oversight while at the river. Furthermore, recreationists visiting the Devils River who receive education from outfitters are made aware of the limits placed on the frequency and intensity of visitors. While these limits were implemented to prevent undue pressure on both ecological resources and recreation infrastructure, they may also mitigate a perception of crowding by recreationists, a social phenomenon which has been associated with decreased enjoyment in an experience (Manning et al., 2017). Visitors seek out the Devils River for a true wilderness experience, and normalizing access limits may reinforce the desired perception of isolation. This expectation could lead to greater support from informed recreationists, some of whom may have traveled farther than average to escape the increasing density of recreationists at other sites closer to urban populations.

Technological enhancements have expanded access to backcountry recreation opportunities on a global scale, which can lead to increased negative environmental impacts in addition to the benefits associated with general participation in nature-based recreation. The novel aspects of the experience and the challenge of high-risk, high-reward activities in natural spaces can also lead to greater awareness of and protectiveness towards wilderness areas (Ewert & Shultis, 1999; Watson et al., 2016). In the case of the remote reaches of the Devils, backcountry activities are restricted in many of the public sites and are limited to landowner-provided admittance on private lands. Therefore, improvements in transportation, clothing and gear, communication capabilities, and information access more generally contribute to increased safety for recreationists but may not significantly increase backcountry use rates at this destination.

Nature-based recreation and tourism can support the conservation efforts of a wilderness destination like the Devils River when recreation managers, recreationists, and other stakeholders implement and maintain sustainable recreation policies. Educational efforts that encourage recreationists to uphold responsible use practices, combined with place-based attachment fostered through experiential learning and oversight by recreation managers in cooperation with landowners, can significantly mitigate many of the negative environmental impacts that occur from human presence in the ecosystem. The dual goals of a) protecting the ecological integrity of the Devils River, and b) providing opportunities for recreational visitation and economic gain are not diametrically opposed when a stewardship ethic underpins decision-making processes among stakeholders.

The impacts of recreationists as well as general human activity on the ecosystems contained within the Devils River Watershed are in need of concerted research efforts. Because of the remote environment coupled with the amount of privately owned land, research has proven difficult to recruit and fund, leaving many questions unanswered. Many of those involved in the region share a common concern about human activity, particularly as it increases, resulting in negative effects on the natural diverse ecosystems contained within the watershed. While there have been a few studies on the life histories of several species, an impact study comprehensively exploring the effects of human activities, including recreation, on ecological systems in the region has not yet been conducted. Another concern in need of further investigation are the potential impacts of current and future recreation activities on the conservation of the region's Indigenous cultural sites. Fire and smoke, rock dust, oils deposited from touching, and other substances deposited on indigenous rock art from site visitation are known to be detrimental to the preservation of the sites, in addition to site degradation from unauthorized artifact excavation and rock art defacement; however, anticipating the risks of general visitation and endangerment of sites in this particular region is difficult, largely due to challenges associated with mitigating trespass and other forms of unmanaged access at remote sites.

The State of Recreation in the Devils River Watershed

Public Lands for Recreation The public areas that offer recreation access in the Devils River watershed include the State Natural Area, managed by Texas Parks and Wildlife and comprising of two non-adjacent units along the river, and Amistad National Recreation Area, which is managed by the National Park Service and covers the U.S. side of the International Amistad Reservoir, including along a stretch of the Devils River, from its mouth upriver to an elevation of 1,144 feet. The boundaries of these areas, operational definitions of site designations by the associated managing agencies (e.g. "state natural area" vs. "state park"), and their development as public properties will be described in this section.

The Devils River State Natural Area

There are two units of the State Natural Area, each acquired separately by the state 22 years apart. The northern unit, the Del Norte Unit, was purchased in 1988 and includes 20,000 acres (an area larger than the size of Manhattan Island) on the east side of the Devils River. The Del Norte Unit has riverfront access approximately half a mile on either side of River Mile 15 of the Devils River, including Finegan Springs just before River Mile 15 and San Pedro Paddler Camp just after. Del Norte is currently open to the public for day-use access and overnight camping four days a week. It is also accessible as a put-in site for paddlers through the DRAP.

Also located on the river's eastern side, fourteen miles downriver, the DAH Unit of the State Natural Area was acquired in 2010 and consists of 18,000 acres. It was previously operated as a private hunting ranch and stretches along the river from approximately River Mile 28 to River Mile 38, but due to the elevation of the riverbanks, part of the riverfront is federal land within the boundary of Amistad National Recreation Area. These banks are cooperatively managed by both the National Park Service and Texas Parks and Wildlife, and recreationists will be able to access the river through the DAH Unit. At the time of this report's publication, the unit is currently under construction and closed to the public, but recreationists operating under the DRAP system may access the Mile 29 Paddler Camp and Texas Parks and Wildlife-approved concessionaires may pick up these paddlers at the Pafford Crossing takeout site at River Mile 33. Once construction of the takeout site known as Devils Back, near River Mile 30, is completed, it will become the primary site and Pafford Crossing will be used as an alternative when conditions necessitate it. The DAH Unit is expected to open to the public in late 2024 or early 2025.

Because the stretches of river between the publicly accessible Bakers Crossing put-in point and the State Natural Area's Del Norte Unit (~15 river miles) and between Del Norte and DAH Units (~14 river miles) are privately owned, trespassing continued to be an issue even after the State Natural Area units became accessible, due to the long paddling distances between the sites on a river known for its challenging terrain. Texas Parks and Wildlife's River Access and Conservation Area program reported "the average paddler often had to find additional campsites to complete river trips. The lack of available legal camping areas, coupled with gradient boundary laws that can be difficult for the public to interpret, sometimes led to trespassing by paddlers and eroded trust between landowners and paddlers. Texas Parks and Wildlife received complaints from landowners regarding paddler trespassing and from paddlers regarding confrontational landowners." Consequently, in 2016, Texas Parks and Wildlife worked with a private landowner to lease riverbank property through the River Access and Conservation Area program and develop designated stopover points for paddlers between the existing public access points. These sites are now referred to as Mile 12 and Mile 20 Paddler Camps. The former is a stopping point between Bakers Crossing and Del Norte and has a privacy fence WAG bag restroom and signage with campsite rules, emergency contact info, and a river map. The latter is a stopover between Del Norte and the DAH Unit and has similar amenities to Mile 12. State Natural Area staff are responsible for maintaining these sites and regularly monitor them for signs of misuse.

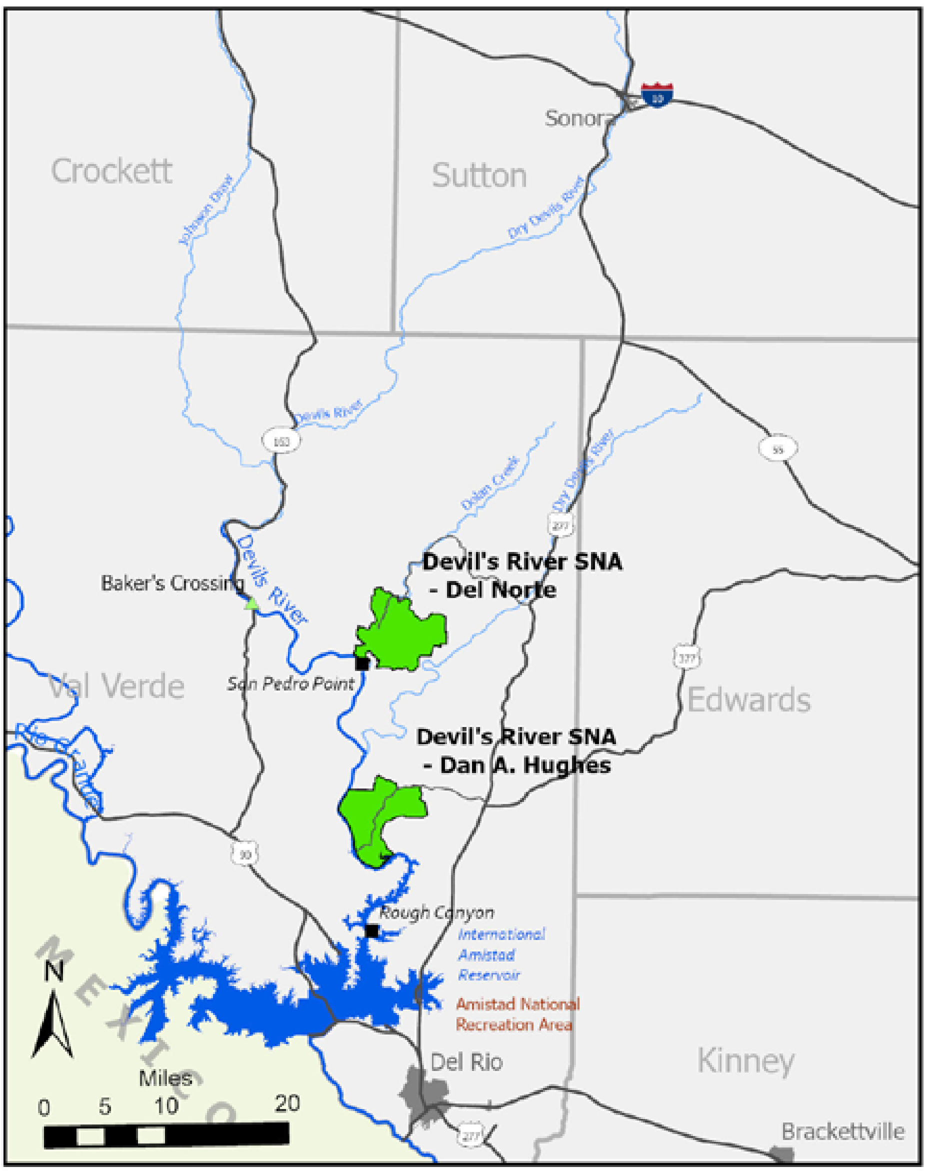

Figure 35. Vicinity Map showing both the Del Norte and DAH units of the State Natural Area (DRC, 2024; adapted from TPWD, 2015).

What is a State Natural Area?

Per the Texas Administrative Code (Title 31, Part 2, Chapter 59 Subchapter D Rule §59.64 b) "State Natural Areas are areas established for the protection and stewardship of outstanding natural attributes of statewide significance, which may be used in a sustainable manner for scientific research, education, aesthetic enjoyment, and appropriate public use not detrimental to the primary purposes."

State Natural Areas are managed by the State Parks Division of Texas Parks and Wildlife but differ from lands designated as state parks in both their purpose and operations. In short, the purpose of a State Natural Area is to protect unique or special natural features and to provide funding for the ways that protection is accomplished. The State Natural Area, for example, is open to the public four days per week and is closed three days per week to allow the ecosystem to rest. This schedule allows for recreational and educational components but also ensures continued protection of the natural resources. Both State Parks and State Natural Areas have significant overlap in their purpose and Code, though State Parks focus more on recreational opportunities and State Natural Areas focus on natural resource protection while providing a recreational component.

(1) Selection.

(A) State Natural Areas should encompass examples of natural scenic beauty, natural communities, biological features, sensitive areas, or geological formations of statewide significance, or possess exceptional educational or scientific values.

(B) State Natural Areas should be large enough to protect the integrity of the features being protected, with adequate buffers to provide for public access and resource protection, and where feasible, include sufficient area to provide for a wilderness-type experience.

(C) New acquisitions should be selected on a priority basis determined by statewide significance, natural condition, and the degree to which the resource is threatened.

(D) State Natural Areas which duplicate the primary significance of a site presently preserved in public ownership will receive a lower priority for acquisition than those types of areas currently unrepresented in the public domain.

(2) Development.

(A) Development in State Natural Areas should be low-density in nature and limited to that appropriate for adequate control and sustainability of the resource, and for visitor access.

(B) Recreational development should be provided only where it facilitates additional appreciation of the unique resource and should not be detrimental to the natural environment nor encroach upon, damage or impair the scenic or natural features concerned.

(3) Operation.

(A) State Natural Areas should be operated economically efficiently, emphasizing resource protection over public use and revenue generation.

(B) Visitor information and interpretation should be emphasized to increase the visitor's understanding and appreciation of the resource being preserved.

(4) Use.

(A) State Natural Areas should accommodate low impact, resource-oriented recreation, not detrimental to the continued preservation and stewardship of the natural and cultural features as outlined in the site management plan.

(B) State Natural Areas may provide public hunting opportunities when such use is not detrimental to the primary goals and management of the area and as sound biological management, location, physical conditions, safety and other uses permit.

(5) Management.

(A) State Natural Areas should be managed, consistent with the site management plan, to insure the protection and perpetuation of the scenic or outstanding natural features.

(B) Habitat management should emphasize maintenance or restoration of natural communities and natural biodiversity, consistent with the primary goals of the area.

(C) State Natural Areas should be managed, consistent with the site management plan, to address habitat needs of indigenous flora and fauna including species and communities listed as threatened or endangered or species of special concern as identified by staff.

Devils River State Natural Area Easement Restrictions

Both the Del Norte and DAH Units of the Devils River State Natural Area are managed under conservation easements held by The Nature Conservancy [Val Verde County Deed Records 796:109 (2001); 850:88 (2003); 1013:560 (2006)]. The easements prioritize protection of natural resources and require the provision of interpretive and educational programming to visitors to increase their understanding and appreciation of the intrinsic environmental value of the property contained within the state natural area.

The easements allow existing structures and roads to be maintained, updated, and rebuilt as needed, though construction of new infrastructure is limited under specific use parameters. The Nature Conservancy reviews site and resource management plans in partnership with the managing agency, Texas Parks and Wildlife, before implementation. The Nature Conservancy also conducts intermittent monitoring of both units to verify these plans are being adhered to under the agreements on record.

Amistad National Recreation Area

While the State Natural Area belongs to the State of Texas and is managed by Texas Parks and Wildlife, Amistad National Recreation Area is federal land managed by the National Park Service. Amistad National Recreation Area is one of 429 units of the National Park Service, as of 2024. All units may be commonly referred to as 'parks,' though only 63 have "National Park" in the name. "National Park" and "National Recreation Area" are two of at least 19 different naming designations for NPS units, which also include others such as "National Monument," "National Preserve," "National Seashore," and "National Historic Site." Many National Recreation Areas were created around reservoirs impounded by dams built by other federal agencies and this was also the case with Amistad (NPS, 2016).

The Rio Grande is the boundary between the United States and Mexico, and the Amistad Reservoir is one of a series of international reservoirs along the Rio Grande called for in the 1944 water treaty with Mexico. As such, the volume of water in the reservoir and operation of the Amistad Dam are co-managed by the IWBC (IBWC; a branch of the US Department of State), and its Mexican counterpart agency, the Comisión Internacional de Limitas y Aguas (CILA). Article III of the 1944 treaty (Utilization of waters of the Colorado and Tijuana Rivers and of the Rio Grande, 1944) prioritizes uses of the international reservoir waters as follows:

1. Domestic and municipal uses
2. Agriculture and stock-raising
3. Electric Power
4. Other Industrial Uses
5. Navigation
6. Fishing and Hunting
7. Any other beneficial uses which may be determined by the Commission

The final design of the Amistad Dam was a response to the devastating flood of 1954, when torrential rains from Hurricane Alice caused significant destruction and loss of life on both sides of the Rio Grande. Thus, in addition to the uses of water listed above, the most important function of the Amistad Reservoir is for flood control to protect lives and property downstream. The reservoir impounds water not only from the Rio Grande but also from the Devils River and Pecos River, which flow directly into the reservoir.

The Amistad Dam was built immediately below the confluence of the Devils River with the Rio Grande, and because of this the project was originally called the Diablo Reservoir. It was later decided that Amistad (meaning friendship in Spanish) was a more appropriate name for a jointly constructed and operated international reservoir than Diablo (meaning devil), and the name was changed.

The reservoir was designed for a normal or 'conservation pool' level of 1,117 feet above sea level (above the NGVD 29 datum); this is the level of the reservoir typically shaded blue on maps to represent water. The top of the reservoir 'super storage pool' is over 27 vertical feet higher, at an elevation of 1,144.3 feet. This is the highest water level to which the reservoir might fill, so the federal government purchased most of the surrounding lands up to 1,144.3 feet. Exceptions include some portions of the Devils River arm of the reservoir below Rough Canyon (where land was only purchased to 1,117 feet with a flowage easement allowing it to be flooded up to 1,144.3 feet) and developed areas of the park such as boat ramps, campgrounds, and hunting areas where additional land was purchased above 1,144.3 feet to facilitate public recreational use. This is the portion typically shaded green or otherwise delineated on maps to represent park lands. This (typically) narrow ribbon of land follows the 1,144.3 foot contour about 20 miles up the Devils River from its confluence with the Rio Grande, and about 15 miles up the Pecos from its confluence. The park extends about 79 miles up the Rio Grande from Amistad Dam, and for four miles below it.

The National Park Service has been involved with the Amistad Reservoir from very early on, funding the initial 1958 archeological survey of the reservoir basin and the subsequent ten years of archeological salvage excavations performed by the University of Texas at Austin. The Amistad Dam would not be completed until 1969, but a 1965 agreement with the IBWC established NPS responsibility

What is a National Recreation Area?

The U.S. has 40 national recreation areas, each designated by a Congressional Act or Presidential Proclamation and managed by either the National Park Service, the Bureau of Land Management, or the U.S. Forest Service. National recreation areas differ from other federal land designations in that they are always located near large reservoirs and can offer public access to water-based recreation opportunities. They also often include unique natural and cultural features that should be protected. Each national recreation area has its own enabling legislation that specifies its purpose, boundaries, and operating conditions, which may differ between different units.

Amistad National Recreation Area is managed by the National Park Service and was designated through Public Law 101-628-Nov. 28, 1990, 16 USC 460fff, Sec. 505. Establishment of Amistad National Recreation Area. This mandate requires the National Park Service to "(1) provide for public outdoor recreation use and enjoyment of the lands and waters associated with the United States portion of the reservoir known as Lake Amistad, located on the boundary between the State of Texas and Mexico, and (2) protect the scenic, scientific, cultural, and other value contributing to the public enjoyment of such lands and waters." Section 506 of this law describes the administrative parameters for Amistad. See appendix for complete enabling legislation.

for managing recreation and the federal lands around the reservoir. The IBWC, in turn, would focus on operating the dam and the water accounting required to meet treaty obligations. In 1990, Congress passed the park's enabling legislation (Public Law 101-628-Nov.28 1990; 16 USC 460 fff, Sec. 505), and the formerly IBWC federal lands became National Park Service, except for the area around the dam itself.

The part of Amistad National Recreation Area most relevant to discussions of the Devils River is the Devils River Arm of the reservoir, from the boat ramp at Rough Canyon up to the farthest extent of the 1,144.3 foot boundary, about a mile above Pafford Crossing.

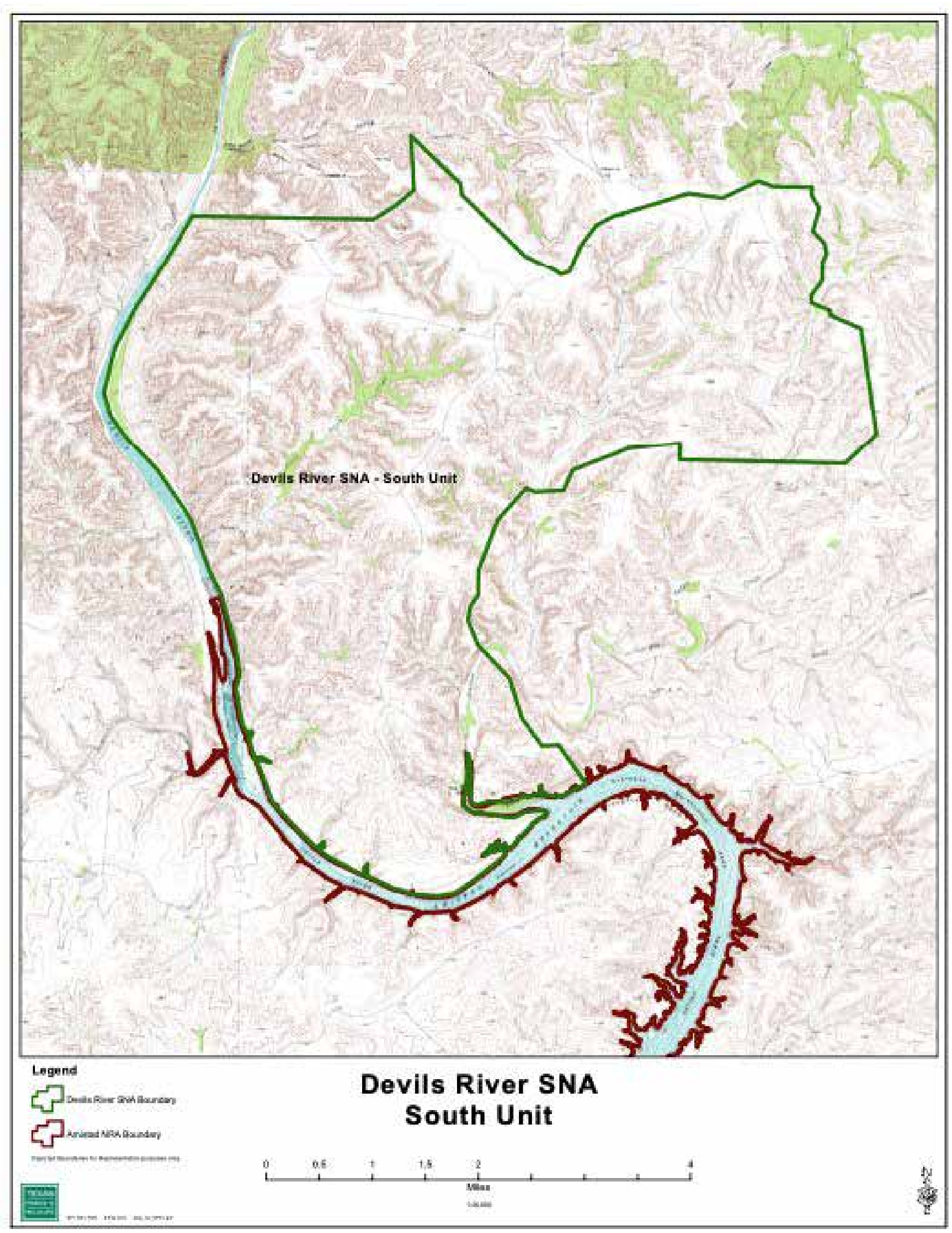

Figure 34. Map depicting jurisdictional boundaries between Texas Parks and Wildlife and the National Park Service along the Devils River (TPWD, 2011)

Jurisdictional Boundaries of Public Lands

It is convenient to say that the DAH Unit of the State Natural Area has around ten miles of river frontage, but this is strictly true only for the upper four miles. For the lower six miles, heading upstream from near the mouth of Big Satan Canyon, the river and a widening sliver of riverbank fall below the 1,144.3 foot elevation boundary of Amistad National Recreation Area and are therefore under the federal jurisdiction of the Amistad National Recreation Area (relative to NAVD 29) (USGS, 2022). When the lake is low (such as in 2024), the Devils River flows freely (but very shallowly) throughout this entire stretch of shared boundary. When the lake is high, the reservoir backs up the Devils River channel through much of this section. This shared elevation boundary creates a necessity for close coordination and co-management between National Park Service and Texas Parks and Wildlife staff.

Gradient Boundary Description

“Thus gradient boundary is the point where private property and publicly held property meet. It is a point on the inner side of the fluvial (or cut) bank of a river. Riverbanks confine the waters of a river and preserve the course of the river. Gradient boundary also is established as a point on and along the riverbank midway between the bottom of the river at the bank and the lowest point where the river would wash the bank without overflowing it. Gradient boundary ls parallel to the surface of the water. Gradient boundary thus establishes the edges or extent of the riverbed, the public held land.” (Nagel, n.d.)

Texas courts have adopted the “gradient boundary” as the usual dividing line between public ownership of a stream’s bed and lower bank area, and private ownership of the higher bank area and the uplands beyond. Thus, there is generally no question as to the public’s right to use the bank area up to the gradient boundary (TPWD.

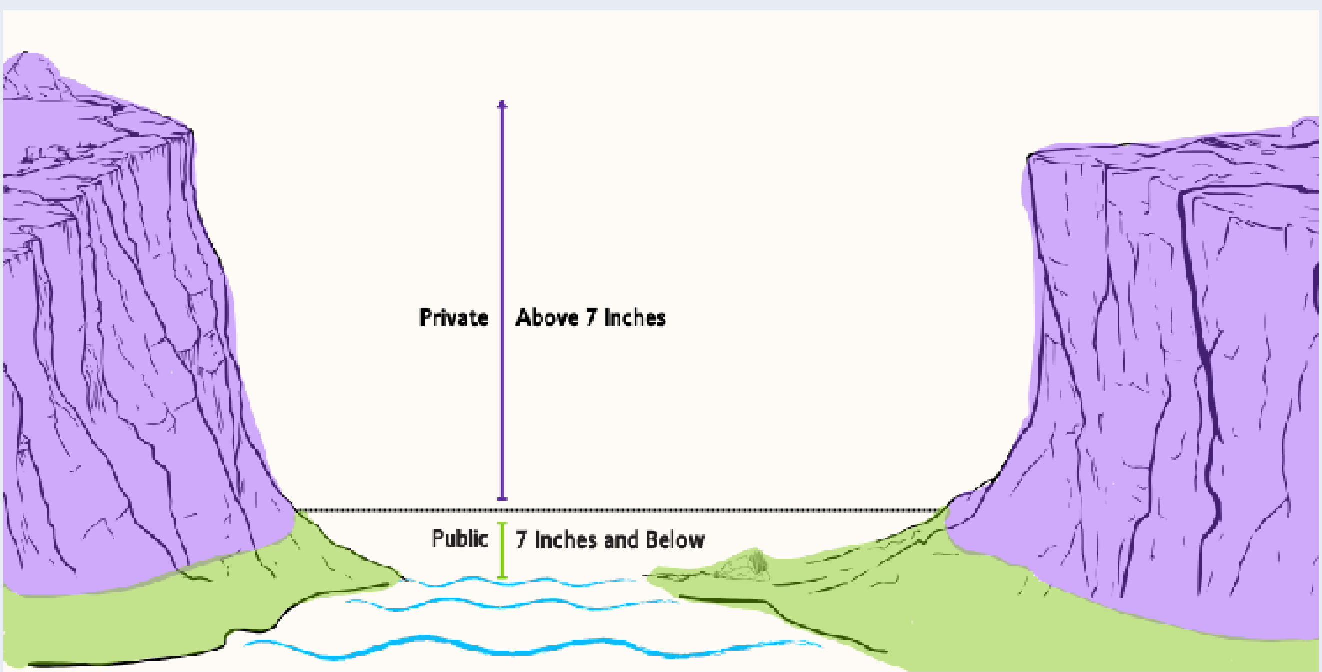

Figure 35. Illustration of the “Seven-Inch Rule” as agreed upon after the 2013 Working Group.

In 2010 and 2013, Texas Parks and Wildlife convened the Devils River Working Group to identify issues, opportunities, and obstacles within the watershed, and to advise the Department on long-term conservation efforts. In 2013, Texas Parks and Wildlife, in conjunction with Devils River Conservancy, hired and hosted Shine & Associates (well known for their history of specializing in Gradient Boundary surveying) to come out to the Devils River and do a presentation on the history and logic of Gradient Boundary policy. They were also hired to conduct informal surveying measurements on various places along the Devils River to help the Working Group understand how an actual Gradient Boundary measurement is formed. They conducted surveys on four different parts of the Devils River over a 10-mile stretch of the river, and the measurement at each of these locations resulted in the same calculation – 6/10th of a foot, or approximately seven inches. In laymen's terms, if you go out to the riverbank, measure seven-inches from the surface of the water and then draw a horizontal line from that mark over to where it hits land, everything below that seven-inch mark is considered part of the navigable water and publicly held land, and everything above that mark is private property.

"The right to use a watercourse must always be subordinate to the principle that it shall not be so used as to damage others."

- Shine & Associates presentation on Gradient Boundary Law, 2013

All the parties within the Devils River Working Group (officials, landowners, and paddlers) agreed that this seven-inch reference was very helpful to use as a standard measurement to help guide all parties regarding public vs private land ownership/usage along the river. Since 2013, the "Seven-Inch Rule" has been used with Texas Parks and Wildlife law enforcement, outfitters, and the paddling community online as well as during river orientation to paddlers on the Devils River (TPWD, 2013).

Dell Dickinson, owner of Devils River waterfront Skyline Ranch, with family ties to the land going back to 1892, has observed a rapid increase in the prevalence of trash, evidence of fires, and trespass issues from people on the river over the past 20-25 years. He noted that it reached an apex around 2010-2012, and after purchasing the DAH Unit in 2010, Texas Parks and Wildlife responded by forming the first Devils River Working Group in 2012. Dickinson reflected on the implementation of the DRAP as a result of the Working Groups, commenting that "at least it was a start in educating people to become other than conquerors of the river, rather to be good stewards of the river...that was a good starting point." A few years later, when Parks and Wildlife approached Dell to inquire about Skyline Ranch's participation in the RACA program to provide public access for

Figure 36. Shine & Associates measuring gradient boundaries on the Devils River – Andy Iverson

overnight paddler camps, Dickinson shared his perspective, “We at first refused. I didn’t want anything to do with it, but after giving it some thought, we were willing to give it a try to see if it would, in fact, help the situation on the river... that’s where we’ve always been coming from: the sanctity and the longevity of this pristine river. And so...then we entered into an agreement with Texas Parks [and Wildlife] for River Mile 12 and 20 camps, and it was almost miraculous... because the trash issues, the fire issues and the trespass issues almost disappeared overnight, at least along that stretch of the river. I can’t speak to what was happening on the rest of the river there, but that was a pretty good shot...on what was happening around us.”

However, he also noted that since the implementation of the two RACA sites – River Mile 12 and 20 Paddler Camps on Skyline Ranch – there have been fluctuations in paddler behavior over the years. He attributes it to corresponding availability of law enforcement: “One of the things that I had insisted on as a part of this [RACA] agreement was that we all had to recognize that even though you could have all the DRAP permits in the world, without appropriate law enforcement, they won’t be worth anything. So, Texas Parks and Wildlife agreed to initiate a very strong program on [enforcement] and I think that’s what made that work. Unfortunately, over the years as other issues came up...those particular law enforcement folks officers that had been supporting enforcement on the river kept being pulled off and it was happening more and more ..and more. And when that happened, the same issues started coming back up and that’s what we’re faced with today, where between River Mile 12 and 20, we keep finding evidence of fires, trespass issues, trash. We’re always picking up trash. So, it’s there again. You’ve got to have strong law enforcement. That’s bottom line.”

Alli Hatten, a game warden in Val Verde County for over 12 years, confirms that the level of law enforcement monitoring nature recreation has shifted during her time in the region. When she arrived, there had always been one or two game wardens to cover the entire county, “and then over the years, partially because of border funding and partially because of the popularity of the river, they’ve added more game wardens.” She went on to mention other fluctuations in law enforcement in the watershed but stated there have been recent increases. With the possible addition of another park police officers assigned to the soon-to-open State Natural Area, several officers are enforcing recreational regulations within the watershed at the time of this report’s publication. Hatten noted she and other game wardens track campsites they find along the river outside of the DRAP sites, saying “I want every one of my guys to know where every single thing is along the river, because the more eyes on the river, the better.”

In managing recreation across the public-private boundary, both Dell Dickinson and Alli Hatten noted the importance of communication among the people living and working along the river, Dickinson recalling, “when we first made the agreement with Texas Parks, both sides communicated very, very well. As a matter of fact, I could remember on random occasions that’s how it always was. I would meet the Superintendent of the Del Norte unit there at the Dolan Falls and we can sit there and have a sandwich and talk about how things were going, and he would let me know what he had been doing in terms of maintaining the camps... I was provided with data on a monthly basis such that I knew how many people were coming...and this and that and the other. Also, I had full warning of people coming in case someone got in trouble or something like that. We’re always ready to help if we know someone’s in trouble.”

Private Lands Recreation

Prior to the establishment of the State Natural Area, there was no public access to Devils River between Bakers Crossing, where a bridge on Hwy 163 crosses the river, and its confluence with either the Amistad Reservoir (after the construction of Amistad Dam in 1969) or the Rio Grande (pre-1969), over 45 river miles away. Therefore, most recreation in the watershed occurred through access to private property. Most of the recreation population would have consisted of landowners and their family and friends, along with visitors who received landowner-permitted access through hunting leases or outfitters. Historical accounts of recreation activities on private lands are largely anecdotal, shared via oral storytelling among generational landowners as well as written narratives in biographical and historical collections from the region. This section includes a collection of these written accounts and excerpts from interviews with current landowners sharing their knowledge.

Anecdote 1: *Rhodes S. Baker III wrote about his grandfather, Rhodes S. Baker and friend, F. George Allen's cycling and fishing adventures on the Devils River in the late 1800s. Before the 425-mile trip from San Angelo to Villa Acuna, Mexico was paved, the two cyclists made the trek, often stopping off at the Devils River to camp, fish, and hunt for their food (Baker, 2016).*

Anecdote 2: *John Finegan, the previous owner of the now Del Norte Unit of State Natural Area, Penned multiple family histories. The historical sheep farming operation eventually became an internationally renowned hunting lease with native and exotic species. The family had a passion for the outdoors and hosted Boy Scouts river events to prepare for paddling trips as far away as Canada.*

> *"Partnering with Dell and opening the paddler camps really changed the face of the trespass concerns, not down to zero, but pretty close; that all came through working with the Inland Fisheries and partnering with Skyline Ranch. In addition, these RACA sites are a safe and legal destination*
>
> **- Beau Hester, 2024**

Historic Relationships Between Landowners and Recreationists on the Devils River

"As a landowner of Devils River property for 75 years, I can assure you, Mr. Gwynne, that the only reason the Devils River is the pure and pristine river it is today is because of those ornery landowners, who were, and still are, trying their best to preserve for future generations what we have ["Run With the Devils," June 2005]. Had it not been for those landowners, this jewel would be like most of the rest of the rivers in Texas: full of trash, beer cans, and Styrofoam cups. I know what John Q. Public does to rivers and the land. Believe me, I have cleaned up after him too many times.

"Your mention of the sound of a bowling ball hitting the water was only a beaver expressing his displeasure at your having invaded his territory. You see, even wildlife have feelings!"

J. K. Finegan, Kerrville

"Devils Advocate," 2005 Texas Monthly

"In a state where property owners have historically clashed with recreational river users, the Devils is arguably the most hostile. 'You didn't just risk getting shot, you might be held under fire for six hours,' one retired boater claimed, in relating what happened to him 20 years ago shortly after he put in at Baker's Crossing and got separated from his canoe. 'Even touching the bank can get one arrested for trespassing.'"

Texas Parks and Wildlife Article "Undammed and Unforgiving, July 2002

Anecdote 3: *As a legacy landowner on the Devils River, the Baker family controlled the only public river access with their campground at Bakers Crossing for many years. In the early 1990s, Randy Nunns, a paddler and downstream landowner, corresponded with Mary Baker Hughey to correct the river landmark guide she provided for paddlers and to inquire about how many paddlers she had allowed to launch that year.*

Mary responded with monthly totals of paddlers in March-2, April-21, May-13, June-0, July-2, Aug-4, and September-8. She also added that she tried to prevent ill-equipped paddlers to protect the downstream neighbors who were displeased when they detected trespassing or received requests for rescue.

While there is no longer a campground and canoe outfitter stationed at Bakers Crossing, it is still a popular put-in location, likely due in part to its history as such, in addition to its current status as one of three public access sites on the river, the other two being the Devils River SNA's Del Norte and DAH Units.

> *…It wasn't until people started coming on to the river, things started changing and I'm going to say that's been in the last 20-25 years. In the greater numbers, people had always managed to come down the river in one and two… When I was a kid, even that was very remarkable to even see that.*
>
> **- Dell Dickinson, 2024**

Because of its remote location and the large ranches that surround the river, landowners have been very protective of this truly pristine river and their property alongside it. In the late 1980s, there were only about 50-100 overnight/multi-day paddlers floating this river per year. In 2023, there were more than 1,200 documented overnight/multi-day paddlers on the river (TPWD, 2013). On one hand, this concerns landowners greatly, but over the years, in cooperation with Texas Parks and Wildlife, more procedures have been put in place that are helping river landowners build more and more confidence regarding management of the paddling public. The implementation of the DRAP program, along with more qualified outfitter operations, has resulted in a more prepared, informed, and respectful paddling group on the river. Some landowners feel as though the norm has shifted away from uninformed, ill-prepared paddlers.

Today's paddlers are better packed with less gear and smaller kayaks that were made for this river. They also have something even more important: more accurate directions and information about how to complete their trip with minimal impact on the river as well as an improved understanding of how to avoid trespassing issues during multi-day trips. The increased quality of concessionaire services, which are required to meet Texas Parks and Wildlife's qualifications to operate through the State Natural Area, have also helped a great deal. While other outfitters and paddlers may continue to operate outside of the State Natural Area units and therefore Texas Parks and Wildlife's jurisdiction, the majority appear to operate under the DRAP system, based on anecdotal reporting by law enforcement. It is not currently known how many total paddlers traverse the river annually, and what percentage are paddling independently or through other private outfitters or landowners without accessing the State Natural Area units and paddler camps.

Types of Recreation in the Devils River Watershed

Leave No Trace© is an organization (https://lnt.org/) that has identified 7 Principles that describe minimum impact practices for anyone visiting the outdoors. Many of these principles have been embraced by public land managers and outfitters of the Devils River region. In addition to these guidelines, recreationists visiting public lands are required to follow the regulations defined by the managing agency. Violation of any of these guidelines or regulations falls into the category of misuse and can be detrimental to both the environment's health, and the safety and well-being of visitors and residents alike.

Figure 37. Icons depicting various recreational activities in the Devils River region.

TEXAS PARKS AND WILDLIFE REGULATIONS FOR THE DEVILS RIVER STATE NATURAL AREA

Responsible recreation within the State Natural Area begins with the established Texas Parks and Wildlife State Parks Rules and Regulations (31 Tex. Admin. Code §59.134, 2022). Park rules and regulations are put in place to protect natural and cultural resources and help preserve the safety and security of visitors. While recreating on land at either unit, the Texas State Park Rules & Regulations is the governing document. The DRAP system provides the primary regulations for paddlers accessing the river through the State Natural Area. Paddlers must apply for and receive a permit before accessing the river when planning to put in or take out through a State Natural Area unit with the intention of paddling beyond the boundaries of one unit and/or use an SNA-designated paddler camp. Paddlers found to not have a required permit or in violation of the following permit conditions can receive citations for violation of State Park Rules of Conduct: 59.134 (F) Entrance and User Fees and Permits. The State Natural Area limits access to the river via public sites for overnight paddling to twelve persons maximum per day as one effort to balance access and preservation.

After receiving a permit, paddlers must continue to follow permit requirements while on the river. DRAP requirements are:

- Waste Alleviation and Gelling Bags (WAG Bags) must be carried and utilized to remove human waste from the river corridor, including proper disposal into a garbage receptacle after the paddle trip.
- Garbage containers must be carried and utilized. A secure container, durable mesh bag, or dry bag that will prevent the loss of garbage into the river as well as prevent wildlife from accessing the garbage should be used. All garbage must be carried out of the river corridor and disposed of in a proper receptacle at the end of the paddle trip.
- Glass containers are not allowed.
- Gear and equipment must be adequately secured to or inside your boat so that it will remain attached in the event of a capsized or flooded boat. Collection of all gear, equipment and garbage lost when a boat floods or capsizes is the responsibility of the permittee.
- Self-shuttling paddlers must deposit the copy of the completed permit/itinerary in the box at either the Bakers Crossing or Del Norte Unit headquarters locations.

- All paddlers are to practice good outdoor ethics, striving to leave no trace of their presence during their trip.
- Open fires are prohibited along the State Natural Area waterfront. Fires are allowed only within the gradient boundary elsewhere when Val Verde County is not under a burn ban. (When a fire is legal, use of a fire pan and charcoal is ideal to limit resource damage). Containerized fuel camp stoves are recommended.
- No trespassing is allowed on private property. The majority of the Devils River frontage is private property. It is the responsibility of permit holders to familiarize themselves with gradient boundary law and respect private property by not trespassing.
- All state boating laws apply.
- For a permit to be valid, it must be signed.

Visitors to the State Natural Area who will not be engaging in paddling trips that extend beyond a given unit, such as day-use paddlers and those planning to hike, camp, swim, and fish within a unit, are not required to have an access permit to visit the river. At the time of publication, the Del Norte Unit is open for day-use and overnight camping from 8 a.m. on Friday to 5 p.m. on Monday, and is closed on Tuesdays, Wednesdays, and Thursdays. Advance reservations are recommended to guarantee entry, as the day-use limit at Del Norte is 70 visitors and there are ten campsites total.

While DAH is still under development, the anticipated daily visitor limit has been set to 95 day-users when it opens. This number of visitors, at the date of publication, is not expected to impact the DRAP permitting numbers, as day-users are not allowed to leave the boundaries of the unit along the river without a permit. The DRAP is specifically for paddlers traveling outside the bounds of a given unit during their trip and is expected to remain limited to 12 permits per day. National Park Service Regulations for the Amistad National Recreation Area

Where Amistad National Recreation Area's river frontage overlaps with the State Natural Area – DAH Unit's jurisdiction, some regulations between the two do not align and may cause confusion for recreationists who are unaware of the elevation-dependent boundaries (see Jurisdictional Boundaries subsection). As an example, consumption of alcohol and the use of open fires are prohibited within state-owned protected areas, whereas the National Park Service does not prohibit these activities (provided Val Verde County is not under a burn ban). National Park Service and Texas Parks and Wildlife personnel are co-developing a Superintendent's Compendium, which will provide a cohesive policy for recreation activities that applies the same regulations across the overlapping jurisdictional boundaries.

> *"[One landowner] drops people at Bakers and takes them out from his place...so, [the landowner] does not have to give out the [DRAP] permits."*
>
> **-Alli Hatten, Game Warden, 2024**

Paddlers found not to be in possession of a required permit or found to be in violation of the following permit conditions can receive citations for violation of State Park Rules of Conduct: 59.134 (F) Entrance and User Fees and Permits.

PADDLING

The pristine water of the Devils River is sought out by paddlers worldwide. Immaculate spring-fed water rolls through rugged terrain making it a difficult, sometimes unforgiving, but unforgettable trip. The remote, limited access keeps the river wild yet peaceful. Paddlers have approximately 47 miles of navigable river starting at River Mile Zero, Bakers Crossing, and ending at River Mile 47, Rough Canyon Marina in Amistad National Recreation Area. It is a challenging river to navigate due to its numerous sudden drop-offs and rock-strewn course and is therefore considered suitable only for experienced paddlers. Currently, between the State Natural Area's Del Norte and DAH Units, there are additional river access sites which also serve as designated camping locations and are referred to as: "Mile 12 Paddler Camp" and "San Pedro Point at Mile 15" in the Del Norte Unit and "Mile 20 Paddler Camp" and "Mile 29 Paddler Camp" in the DAH Unit.

Paddlers who want to utilize either State Natural Area units or any of the paddler camps while paddling down the river are required to obtain a DRAP. Texas Parks and Wildlife grants 12 people permits to launch each day. Because most of the river's adjacent land is privately owned, paddlers have limited launch (put-in) and extraction (takeout) points. Paddle trips that utilize public launches are generally divided into 15 mile stretches up to 47 miles. Paddlers may launch at Bakers Crossing or privately-owned land (with landowner permission) and paddle the full 47 miles to Rough Canyon Marina or take out on private lands without a DRAP as long as they do not touch any State Natural Area or designated paddler camps.

Launching from Bakers Crossing (River Mile 0): This crossing is where Hwy 163 crosses the Devils River, 21 miles north of Comstock, Texas. The site does not have regulated or monitored access and any member of the public may enter the river here. However, paddlers should consider the following factors when evaluating Bakers Crossing as a launch site:

- The first 15 miles after Bakers Crossing are privately owned and extremely remote. Additionally, for self-shuttlers or those using guide/outfitter services outside the DRAP system, there are no non-DRAP public access stopovers excepting islands and riverbanks below the seven-inch gradient boundary until Rough Canyon Marina, 47 miles downriver.
- At the time of publication, Bakers Crossing has not been a put-in site for DRAP paddlers for over a year due to low flow levels, as these conditions can lead to higher risks for paddler safety due to injury and exposure as well as environmental damage from the dragging of boats and related disturbances.
- The flow gauge located at Bakers Crossing is not a reliable metric for evaluating the full 15-mile stretch before reaching Del Norte. In other words, conditions for the entire stretch may not be apparent from observing conditions at Bakers Crossing. Paddlers should be aware that the most severe low flow conditions generally occur between River Mile 13 and River Mile 15, which is usually reached on the second day of paddling for those starting from Bakers Crossing.

Launching from Del Norte: San Pedro Point is located at approximately River Mile 15.5 and is the put-in location for DRAP paddlers launching from Del Norte.

- San Pedro Point is just south of Finegan Springs and as such, has improved flow conditions from the previous stretch (see the Groundwater section of this report for more details about spring flows).

> *"The Devils is not a trip for the novice - things can be dangerous, you're going through different hazards; rapids, rocks, cuts, scrapes, bruises, dislocated shoulders, shoes falling off, heat, snakes, bugs...There's a lot of blood, sweat, and tears shed up and down the [Devils] River.*
>
> **- Beau Hester, 2024**

- DRAP paddlers are encouraged to use the River Mile 20 Paddler Camp as the overnight stopover point. Paddlers may then proceed to the River Mile 29 Paddler Camp or directly to the takeout point further south. There are also multiple large islands within the navigable waterway, and therefore accessible to the public, between River Mile 20 and the takeout site at the DAH Unit. Additionally, Amistad National Recreation Area has seven suggested paddle trails independent of the Devils River (NPS, 2024):
    - Spur 454 to San Pedro Creek
    - Spur 406 to Evans Creek
    - Box Canyon to Cow Creek
    - Rough Canyon to Indian Springs
    - Pecos to Parida Cave
    - Pecos to Panther Cave
    - Pecos to Pecos Railroad Bridge

Types of Paddling

The pristine waters and rugged landscape of the Devils River make it an ideal location for various paddling activities, including:

- **Kayaking and Canoeing:** Adventurers can navigate the river's challenging rapids and enjoy the serene landscapes. The river is publicly accessible from Bakers Crossing and designated access points within Texas Parks and Wildlife's State Natural Area, which maintains the area's natural beauty and wilderness. Recreationalists also access the river from private property if granted permission from landowners with waterfront access.
- **Stand-Up Paddling (SUP):** Offering a different perspective of the river, SUP is a popular activity for those looking for a quieter, more contemplative experience on the water. However, long and rugged sections of rapids and reeded areas can make it challenging for SUP recreationists to travel beyond immediately proximal pools of water around a designated access point.
- **Overnight Excursions:** For the more adventurous, overnight trips downriver provide full immersion into the wild and untouched nature of the Devils River. These excursions require careful planning and preparation due to the remote conditions of and controlled access to overnight campsites. Possession of a valid DRAP is required for any paddler utilizing either the Del Norte or DAH Units of the State Natural Area. A number of designated campsites on public and privately owned land are available to visitors in possession of a valid DRAP. Visitors without DRAPs must obtain permission from landowners to use private land for camping overnight or find public access locations which are below the gradient boundary. Visitors have the option to rent equipment from local outfitters or bring their own gear. This flexibility allows both seasoned paddlers and newcomers to enjoy the river at their own pace. Visitors also have the option to navigate the river with the support of a guide or on their own. With limited access points and proximity to support in case of emergency, outfitters and guides provide critical support to the welfare of the river and safety of recreationalists.

FISHING

Devils River offers a rich and diverse fishing experience, appealing to anglers of all skill levels. The clear waters of the river make it an ideal spot for sight casting, adding an exciting visual element to fishing experiences. The river's diverse insect life and clear waters create ideal conditions for fly fishing, attracting enthusiasts from across the region.

Both largemouth and smallmouth bass are popular targets for anglers due to their prevalence and the challenge they present. From Bakers Crossing to the river's confluence with Big Satan Creek (between River Mile 37 and 38), all black bass fishing is catch and release only. Outside of this special regulation zone, the minimum length limit for largemouth and smallmouth bass is 14 inches. Daily bag limit is five in any combination, including Alabama, Guadalupe, and spotted bass in addition to largemouth and smallmouth. Visit https://tpwd.texas.gov to view current freshwater bag and length limits for regulated fish species.

Crappie and sunfish provide a fun and accessible fishing experience, ideal for families and casual fishers. Both black and white crappie can be found in the Devils, and common species of sunfish include bluegill, redear, and warmouth.

The river is also home to other native fish species of interest to anglers, including multiple species of catfish and gar as well as white and striped bass. The most common non-native invasive species are common carp and tilapia. Given the sensitivity of the region, catch and release practices for other species in addition to black bass are highly encouraged and supported by recreationists and other stakeholders across the watershed, with the exception of invasives. Please do not put those back!

HUNTING

Public Land Hunting

State Natural Area hosts varying annual drawn hunts to reduce invasive non-native species, as well as to maintain healthy whitetail deer populations. Applicants pay a small fee to apply for a random draw, building loyalty points for each hunt they are not drawn. These loyalty points compound future entries for each specific hunt applied for. These hunts are sought after, with some hunters having applied for 20 years before drawing a permit. The primary target species other than white-tailed deer are aoudad, mouflon sheep, ibex goats, scimitar-horned oryx, fallow deer, axis deer, Spanish goats, wild hogs, Catalina goats, and Corsican sheep.

Private Land Hunting

Hunting in the Devils River watershed was a necessity before it became a sport. Numerous archeological sites around the Lower Pecos Canyonlands depict hunting as a source of food for the Indigenous peoples of the region. Today, private landowners along the Devils River hunt for both food and recreation. White-tailed deer, javelina, turkey, dove, quail, duck, and rabbit are among the native game species you can find in the Devils River watershed. Most of these animals have laws governed by Texas Parks and Wildlife on the season in which you can hunt them, the way you can harvest them, and the number you can harvest.

However, many ranches along the river have introduced species, including exotics from around the world, that are available to hunt year-round. Because of the arid climate and large elevation changes, animals from Africa, the Middle East and even Asia thrive well in this environment. Some of the most notable exotic species include aoudad and mouflon sheep, axis and fallow deer, blackbuck antelope, red stag, scimitar-horned oryx, and addax. Reintroduced natives such as bison and elk are also hunted in the region. These wild game ranches are normally high fenced but offer a free-range, fair-chase environment due to the lack of fencing where the properties abut the river. Declining fence conditions coupled with low water levels often lead to escaped non-native species roaming the watershed.

Also prevalent in the region are feral hogs, commonly referred to as wild pigs. These feral hogs are an unprotected exotic species and are hunted frequently across private lands in the area. It is legal to hunt this species at any time of year. There are currently no bag limits on this species, though hunting licenses are required.

Alli Hatten, Val Verde County game warden, confirms the popularity of hunting in the region, most of which occurs on private lands. She spoke of an interaction about ten years ago where she met a family at Bakers Crossing who had recently purchased a ranch for hunting and hadn't heard of the river before becoming landowners. She said they "just wanted to come down and see it [at Bakers Crossing]." And [she] hears a lot more about where people are buying these properties and then hearing about the Devils River. "[The region] is drawing people because land is cheap around here. You can buy 100-200 acres for not what you can around [Dallas-Fort Worth], often in any of those areas. So, they're coming out, they're buying these hunting ranches and then that's when they kind of hear a little bit more about the Devil River. So that, too, is something else that's bringing people in is all these huge ranches that are subdividing into smaller areas...The popularity of just coming out here and either buying a place or leasing a place is exponentially growing."

She notes an apparent land use shift from ranching to hunting during her 12 years living and working in the watershed. "All this was just ranching country because what good is any of this land? It's either good for ranching or hunting. Other than that, it's not great for agriculture or much of anything else as far as monetary gain like nothing else. So, a lot of ranching is getting phased out because these landowners can make more money leasing their ranches for hunting or subdividing these properties and selling."

Hatten describes her monitoring of hunting activity focusing on "Dolan Creek Road... just getting out of that park, Miers Ranch Road, as well as HWY 163 which all basically border the river and watersheds contain probably a couple hundred deer camps. So, hunting season from September, October on to January... that's our bread and butter. That's the majority of what we do [during that period]."

WILDLIFE WATCHING

The Devils River is uniquely situated at the intersection of three distinct ecoregions and provides a high level of biodiversity across varied habitats. This relatively small geographical area housing abundant wildlife yields a high probability of. Wildlife watching is one of the most popular forms of nature-based recreation in the United States. Birding, in particular, is a notable and growing subset of this form of recreation. Currently, at least one local annual birding festival, Birding the Border, takes small-group excursions to the State Natural Area, as well as other hotspots in Val Verde County. Birding the Border is operated through Texas A&M


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University's AgriLife Extension program, which also runs an annual youth birding camp, Rio Diablo Birding Camp, that stops at the Del Norte Unit of the State Natural Area for a similar excursion. Birding the Border celebrated its 5th event in May 2024, and the camp hosted its fourth group of high schoolers in June 2024.

One pair of nesting bald eagles nesting on a cliff above the river has caught the attention of Devils River residents and visitors alike. Anecdotally, the nest was originally built by golden eagles before being claimed by the bald eagle pair and is now considered the largest and western-most bald eagle nest in Texas. During the 2024 breeding season, the pair hatched and raised two chicks, and Birding the Border participants observed one chick successfully fledged in May. There are some concerns about the impact of recreation on the eagles in future years due to its location across the river from the DAH Unit. While future impacts are unknown, the eagles' success in 2024 while DRAP paddlers were taking out at DAH may indicate that at least some activity on the river through that area is not enough of a deterrent for the eagles to nest elsewhere.

Educational programs for youth groups frequently incorporate wildlife watching in lessons and activities. School groups, and extracurricular clubs such as Boy Scouts of America have visited the State Natural Area for wildlife-watching in addition to other activities, all of which provide skill-building and increased environmental awareness. Visits by these groups are expected to increase when the DAH Unit opens due to its greater proximity to the Del Rio community compared to the Del Norte Unit, allowing for quicker access by local youth groups for day-use excursions as an important component of their environmental education and connection to nature.

CAMPING

Currently, the State Natural Area's Del Norte Unit offers eight primitive drive-up campsites and two primitive hike-in sites. The site capacity is four people per site. The River Corridor Paddler Camps (RM 12, SPP, 20, 29) offer a legal and sustainable place to camp for DRAP holders while paddling the river. These sites each allow for sixteen people per night and can be reserved when applying for a DRAP permit.

All campsites, including Paddler Camps, are maintained and monitored by Texas Parks and Wildlife personnel, and campers are expected to abide by all Texas Parks and Wildlife regulations when visiting these sites.

HIKING

State Natural Area's Del Norte Unit offers fifteen miles of hiking, backpacking, and mountain biking trails. The 12-Mile Loop and Firebreak Trail make up the majority of land suitable for hiking. Once opened, the DAH Unit will also offer trail hiking. Backcountry off-trail hiking is not offered at the State Natural Area.

There are three main trail systems within Amistad National Recreation Area, all accessible from Hwy 90 W and in proximity to the confluence of the Devils River with Amistad Reservoir. The Diablo East Loop and Sunrise Trail are located east of Governor's Landing Bridge, and Figueroa Trail begins just west of the bridge.

INDIGENOUS CULTURAL SITE VISITATION

Devils River Del Norte rock art sites are difficult to reach and not open to independent visitation but can be enjoyed through periodic guided tours by park staff. Some of the DAH Unit shelters are more easily accessible from the river and will be monitored by law enforcement-approved cameras for trespassing. Operational policies for guided tour access to certain Indigenous cultural sites are currently in progress and will follow best practices for protecting the integrity of these

sites, based on a report commissioned by Texas Parks and Wildlife during the early development of the unit (Howard, 2016)

Visitation to Indigenous cultural sites, on both public and private land, should be managed through the lens of preserving the intactness of associated cultural artifacts by landowners and managers. Foot traffic can contribute to rock art damage by killing sediment-anchoring vegetation, which leads to increased erosion, and can also exacerbate negative impacts caused by airborne dust settling on and degrading the pigment.

While early attempts were made in the latter half of the 20th Century to remove rock art panels before rising water levels following the development of Amistad Reservoir, these efforts generally resulted in failure to preserve the pieces due to the lack of structural integrity of the limestone canvas. After these outcomes were reported, in addition to continued monitoring from public land managers and documentation of known rock art panels by archaeological researchers, sites above the water line have remained intact. Many rock art sites on private lands have also been documented and are protected by associated landowners.

Dark Skies and Stargazing

An International Dark Sky Sanctuary since 2019, the Del Norte Unit was the first in Texas, and only the 6th global designation, bringing attention to the darkest and most ecologically fragile sites in the world. Stargazers across the country have sought out the dark skies of Devils River, a favorite for astrophotography. This specific Dark Sky Place certification recognizes the outstanding quality of the starry skies as well as the natural and cultural significance of the area's nighttime environment and its value to science, education, and recreation.

The Del Norte Unit holds a Class 2 Bortle Dark-Sky Scale rating (1-darkest; 9-least dark). Under a Class 2 night sky, stargazers can see the Milky Way and countless constellations, as well as nebulae and other astronomical objects. However, International Dark Sky Sanctuaries are identified to not only celebrate these dark skies but also bring awareness to the fragility of their preservation. This designation can be revoked if light pollution increases significantly, which is often caused by industrialization and other development within the associated region has.

> *I can tell you from experience when I was a kid - it was purely dark skies. There were no lights, not even Del Rio on the horizon...it was absolutely dark. And talk about looking up and seeing the Milky Way. I mean, there wasn't anything between me, sight-wise, and the Milky Way...billions of stars to look at. They're just...gorgeous to be able to sit outside at night and view the night skies...*
>
> **- Dell Dickinson, 2024**

Impacts on Recreation Experience

Recreationist Expectations

Generally, visitors to the Devils River expect a pristine and natural experience characterized by the area's rich riparian setting with native plants and wildlife, the rugged and arid landscape of the desert, clear and waste-free waters, and limited human interaction on land with minimal signs of human development.

Recreation Quality Factors

The quality of the recreational experience along the Devils River may be influenced by property boundaries, weather and water conditions, as well as local landowners, safety concerns, and the presence of other people or waste:

- **Property Boundaries:** The uncertainty about gradient boundaries and private property rights can limit access to certain areas of the riverbank, impacting

> *To me, [the Devils River] is one of the last remnants of the Old West here in Texas. And the country itself is wild. You've got to know what you're doing. If you're not careful... this country will bite you and that river will bite you.*
>
> **- Dell Dickinson, 2024**

the overall experience. The gradient boundary between public and private property along the banks of a navigable river can be confusing to apply in practice, but the "Seven-Inch Rule" is the working definition along the Devils River. See the previous "Jurisdictional Boundaries of Public Lands" section for a description and history of this rule.

- **Weather Conditions:** The area is prone to thunderstorms and flash flooding, as well as extreme heat, all of which can affect safety and enjoyment. For recreationalists camping overnight, flash floods exist as a significant point of concern, as areas below the gradient boundary are at high risk of unpredictable and violent flooding events.
- **Natural Environment and Water Conditions:** Fluctuations in water level and clarity can significantly affect both paddling and fishing activities. Low water flow levels can result in sections of the river becoming impassible without portaging or potentially damaging impacts to elements of the natural environment.
- **Local Landowners and Safety Concerns:** Issues with landowners, fears of wildlife, and concerns about emergency assistance often deter visitors.
- **Presence of Other People and Trash:** The presence of other visitors and any litter left behind can detract from the wilderness experience.

Highlighted Issues, Threats, Opportunities for Sustainable Recreation in the Devils River

Alli Hatten, Val Verde County game warden, reported on the most common types of misuse she observes and cites recreationists for on the Devils River, clarifying that "[law enforcement] have all of our violations and citations broken down by different areas. And one of them is a water body code. There have been around 200 citations written in association with the Devil's River water body code. The most common violation by far is trespass at around 48 percent. The second most frequent violation is insufficient number of personal floatation devices (not having a lifejacket on a boat, kayak, or canoe) at 30 percent. This is followed by no fishing license at 12 percent and littering at six percent. Some violations that are not as common are DRAP violations, keeping largemouth or smallmouth bass, and Drug paraphernalia. These do not take in to account the written and verbal warnings issued by Texas Parks and Wildlife Law Enforcement."

When asked about the procedure for citing trespassing violations, Hatten clarified, "So how trespass works…A landowner has to call us in order for us to even file it. Like I can paddle down the river - and this is very rare - and actually see somebody that I think might be trespassing but it's a landowner that has to initiate that. And then I can file that. So, it's landowner-driven so it probably happens a little bit more. When I kayak down the river, I'll see certain spots. I'll see fire rings like, 'Oh yeah, there's been someone here.' So, do we miss it? Yeah, we miss it sometimes, but not a whole lot."

She also notes that it is not only visitors from outside the region who receive citations for misuse: "The amount of recreation that strictly comes out of Blue Sage has been a lot higher because you know they all buy those properties and their friends come out, I'd say a lot. A big part of my violations come from Blue Sage, believe it or not. So, it's not just…like everybody's blaming the paddlers, but it's not always that way. A lot of times it's people with ranches on the Devils

River. We try to be as fair and as even as possible; you know what I mean? Like enforce - 'Hey, that's the law.' - Enforce it with everyone equally...that's hard to do because a lot of times that's your access point [referring to private land and landowner permission], you know what I mean? So, it's hard."

Even when law enforcement does not directly observe a person actively violating regulations on the river, legal action can be pursued after the fact. If evidence of a violation is found, public land personnel photograph and formally detail the violations via sworn statement, which is then shared directly with law enforcement for citation even if the perpetrator has already left the area. This applies commonly to behaviors such as littering, illegal campfires, and evidence of illegal fish take, such as for largemouth and smallmouth bass within the catch-and-release special regulation zone.

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Issues

Litter

Litter is one of the most noticeable forms of misuse at the Devils River due to the visibility of much of the debris in stark contrast to the surrounding wilderness. Litter can be left intentionally or unintentionally, with the latter often resulting from a lack of preparation in tying down paddling gear in cases of flipped or flood-

Figure 38. Aluminum beer cans in the Devils River - Andy Iverson.

> *"If I don't have anybody with me, then I'll just go do my hike-in spots, and then, especially at night, hopping down on folks, they're like 'Where did you come from?" Walking up on people at night, they're always focused on the fire. If there's a fire or a gas burner or something like that, they're so mesmerized by that, you can walk behind them in a full circle, and nobody will realize you're there. That's probably one of my favorite parts of this job. And I am a clumsy son of a gun so it's not me being sneaky*
>
> **- Alli Hatten, Game Warden, 2024**

ed vessels. Additionally, securing supplies and trash at campsites helps prevent wind, water, or scrounging wildlife from incidentally spreading litter.

Microplastics

Microplastic introduction is one of the reasons the DRAPs are cancelled during low flow. The scraping of kayaks and canoes across the mineral encrusted stone deposits plastics into the river ecosystem. This can have negative impacts on water quality, and subsequently, aquatic wildlife including sensitive fish and mussel species. See the Species & Flows section of this report for a comprehensive overview of these impacts.

Human Waste

Recreationists should pack out all solid human waste and associated WAG bags are required for disposal of human waste at the Devils River when a toilet is not accessible. Leaving waste along the river can be hazardous to human and wildlife health in addition to negative impacts to recreationists' experiences.

In-River Vehicle Use

Although in violation of [State Natural Area/National Park Service Permitting], vehicle use in the Devils River does occur. Often, UTV or trucks are seen parked in the water to ease access. This act introduces petroleum products to the water in addition to damaging the riverbed's natural structures. Multiple landowners require driving in the riverbed to access their properties. It is unclear if easements supersede the law in these cases.

Trash and Gear Left Behind

Over the years, landowners on the Devils River have collected and photo-documented extensive incidences of trash and gear lost or left behind by the paddling community. Fishing rods, fishing gear, tackle boxes, contents from inside coolers, and clothing are common examples; basically, this category includes everything that sinks in the river versus floats when paddlers flip their vessel in the river,

Figure 39. Objects recovered from the Devils River – Andy Iverson

which is more than likely going to happen to every paddler at least once on their trip. Even the most seasoned paddler loses items to this river.

Light pollution

Light pollution from residential areas along the river corridor, oil and gas transfer stations, Border Patrol stations, and the Del Rio city light dome are the biggest threats to the area's night skies. The State Natural Area International Dark Sky Sanctuary is a temporary designation that can be revoked if annual light monitoring does not meet requirements. Sky darkness is measured annually with handheld devices by park staff.

Use of Fire (Outside Permitted Parameters)

Where legal, open fires should be vigilantly maintained and carefully extinguished. Leaving a fire unattended or not fully extinguished can lead to damaging groundfires and even escalation into devastating wildfires. No open fires should be lit during an active burn ban anywhere within the associated county, or along Texas Parks and Wildlife-owned or leased property at any time. Even where open fires are legal outside of burn bans, such as within the Amistad National Recreation Area, it is recommended to use a fire pan and charcoal to limit negative environmental impacts and ensure fuel is on hand. Cutting down live trees and shrubs or even removing branches from them where there is limited dead wood can lead to difficulties building a fire, but more importantly, contribute to bank erosion from accumulated loss of root stabilization.

Figure 40. Groundfire Discolor and Limestone Fracture, 2020 – Jack Johnson, National Park Service

Damage to Indigenous Cultural Sites

There is concern that public access to Indigenous rock art sites may lead to degradation of these cultural resources. No reports of intentional damage to or removal of rock art on public lands in the Devils River watershed have been observed or reported in the past two decades, but damage from earlier incidents remains to this day, and suggests the risk remains high for future degradation of these sites, particularly those which can be observed from the river.

Indigenous cultural sites on both the DAH Unit and Amistad experienced negative impacts from human visitation in the late nineteenth and twentieth centuries. During a 2000 survey by National Park Service archaeologists, multiple sites visible and accessible from the river had evidence of significant damage from intensive camping, including the digging of pit latrines in close proximity to valuable cultural deposits (Howard, 2016). The report also noted vehicle use at some of these sites further contributed to the damage. In addition to these behaviors that might be described as causing damage unintentionally, some visitors pursued more active forms of harm to the sites, in pursuit of commemorating their visit through unauthorized artifact collection and/or graffiti. Excavation of sites outside of permitted archeological research is prohibited.

> *"...when I see people floating down the river...I'll just wave and, you know, as long as you know they're not trespassing or anything like that, don't have any problem with them. The river does, in fact, belong to the people of Texas.*
>
> **- Dell Dickinson, 2024**

Trespassing

Trespassing has been a leading cause of conflict between landowners and recreationists along the Devils River for many years. Trespassing may be intentional or unintentional, with the latter often occurring due to recreationists' lack of awareness or confusion regarding the gradient boundary between the publicly navigable waterway and adjacent private property. Intentional trespassing can also be a result of ill-preparedness rather than pure disregard for private property rights, when recreationists reach a point of exhaustion or otherwise encounter an urgent need to pull out onto the riverbank along a private property. Regardless of

Legal Protections for Cultural Sites

Documenting and protecting archeological sites is the responsibility of the Texas Parks and Wildlife for land under their management, including both units of the State Natural Area, with additional oversight from the Texas Historical Commission. The State Antiquities Landmark designation (Antiquities Code of Texas, Subchapter A, Section 191.002) is the mechanism under which this protection is enacted. The exemption of archeological site locations from the Open Records Act and enforcement through criminal penalties for vandalism, including defacement and other damages to rock art sites provide additional defenses for these invaluable cultural resources. Furthermore, the Texas Parks & Wildlife Department State Park Operational Rules (Texas Administrative Code, Title 31, Part 2, Chapter 59, Subchapter F) provide a separate set of regulations, violations of which can result in additional penalties. These rules include prohibition of metal detector operation on state parks and state natural areas without a permit. For archeological sites on federal land, such as those found on the Amistad National Recreation Area, separate laws and regulations apply, as well as penalties for violations. The Archaeological Resources Protection Act of 1979 (16 U.S.C. 470aa-mm) is the primary federal legislative protection by which damages to archeological sites are penalized. Whether the sites are on state or federal public lands, violations of the associated archeological site protections can result in significant fines as well as a jail term (Howard, M., 2016).

Enforcement of these protections on public land by managers is necessary to preserve these cultural deposits, and landowners play an equally critical role on private land by limiting access to sites on their property. Provision of access to any sites with moderate to high research potential, often associated with a high degree of site intactness, as well as susceptibility to vandalism and other negative impacts should be avoided when developing interpretive programming on public land (Howard, 2016).

intent, it is the recreationist's job to familiarize themselves with the route, including where they can and cannot legally access the riverbank, and adhere to that knowledge unless human safety is at imminent risk and emergency aid is needed. See previous "Jurisdictional Boundaries of Public Lands" section for clarification on how to apply gradient boundary law along the Devils River.

Some stakeholders have outlined instances of trespassing occurring when visitors who previously gained permission from landowners to visit sites on private property fail to seek permission on return trips (Randy Nunns, personal communication, 2024). Visitors who receive permission to access a landowner's private property should prioritize clear communication with the landowner to determine the parameters of their access. Visitors should not assume that permission given for one visit applies to future access; permission can also be revoked at any time.

Landowners are responsible for documenting and reporting trespassing incidents to law enforcement.

Illegal and/or Irresponsible Alcohol/Drug Use

Alcohol use is common for paddlers and other recreationists at the river but is not recommended as a practice due to the associated risks to human health and safety in the context of the remote and harsh conditions of the Devils River. Recreationists often need to bring their own water if they do not have a sizeable filtration system, but this can pose difficulties when consuming a diuretic like alcohol leads to an increased need for hydration. Recreationists may ration their water to preserve it for the duration of their trip, but limiting water intake is not advisable, especially in warm weather. In conjunction with alcohol consumption, it can lead to significant negative health effects stemming from dehydration and exposure. Additionally, consuming alcohol can contribute to decreased capacity for cognitive function and decision-making, which further contributes to increased safety risks, particularly in an environment known for its mercurial conditions. Recreationists who choose to consume alcohol or other drugs while at the Devils River should be mindful of the challenges in receiving timely emergency aid in such remote settings, particularly where cell service is minimal, as well as the additional risk to emergency services personnel this causes in rescue scenarios.

Alcohol use is prohibited on state lands, including the State Natural Area.

Visitor Safety

Per agency policy, the State Natural Area maintains an emergency plan annually for response to emergency situations. These plans cover topics ranging from bomb threats and robberies recoveries.

Texas Parks and Wildlife concessionaires are required to update park staff regarding trip plans if they are running clients through Texas Parks and Wildlife land. These plans include how many people are in the group, the date and location of launch and extraction. This helps all parties involved know where paddlers are while on the river.

Concessionaires are also required to:

- comply with all Texas Boating Laws and the Texas Water Safety Act in the conduct of all guide service operations that are governed by these laws
- instruct all persons riding on or in water-related equipment in the safe use and operation of that equipment

- ensure that each person riding on or in water-related equipment has and uses an appropriately sized life-saving device that is U.S. Coast Guard-approved
- maintain all such equipment in good, usable condition according to a regular and documented program of inspection and repair
- review and provide the Department's "Devils River Map Critical Paddler Information" to clients
- ensure that their clients have or are provided the following required gear/equipment: rope and/or straps for securing gear/equipment; appropriate size and Coast Guard-approved personal floating device (life jackets; heavy duty trash bag(s)/containers that will be durable for the trip; and a 'Waste Alleviation and Gelling' (WAG) Bag for proper disposal of human waste. Guide Service Provider/Concessionaire will not shuttle client(s) who refuse to comply with the complete minimum equipment/gear requirements (Carr, 2024).

The current shuttle concessionaires will instruct paddlers to first attempt to get ahold of 911 or the sheriff's office if they are in need of major medical assistance. This can be a daunting task since there is no cell phone service on the river. Making contact with a landowner or paddling to the nearest State Natural Area to get cell phone service without trespassing would be the safest route. If the paddler is not accessible by vehicle, then a helicopter will be flown in to extract the paddler.

If there is no emergency but paddlers are lost on the river, concessionaires have used drones to fly the river to locate paddlers to help aid in getting them to an area for extraction.

Calls for Landowner Rescue

The other less seen misuse is the result of situations with human interaction with landowners due to paddlers not being prepared for the trip and unforeseen accidents (sprained ankles, heat exhaustion, extreme sunburns, etc.). The number of paddlers looking to be helped by private landowners increases every year. This situation is frustrating for landowners because there is a moral responsibility to do the right thing combined with the unwanted legal risk taken on as well as the time away from the landowner. However, since the introduction of better telecommunication access along the river, putting the DRAP system in place, and ongoing working relationships between landowners, Texas Parks and Wildlife personnel, and reputable outfitters, this situation has become less time consuming for landowners in recent years. Phone calls are made, and, in most cases, law enforcement or outfitters take over these situations. Unfortunately, this scenario is still an issue that lands at landowners' feet each year without warning (TPWD, 2013).

Human-Wildlife Interactions

Multiple anecdotes of raccoon incursions into riverside campsites to raid food stores have been reported by recreationists to recreation managers. This seems to be particularly apparent at stops that are designated stopover campsites and receive a higher level of paddler traffic. Most of these sites are either on public land or are publicly leased private land, and State Natural Area personnel are considering the provision of permanent bear canister installations (bear boxes) at the State Natural Area campgrounds and paddler camps, in addition to encouraging paddlers to bring their own smaller canisters to mitigate raccoon interactions and minimize negative impacts of wildlife habituation. At the time of this report's publication, no actions have yet been taken.

Public recreation managers have reported that recreationists ask about the presence of large carnivores and their risk to human safety, with references to specific species such as black bears and mountain lions. However, no reports of interactions between large carnivores and recreationists along the Devils River have been documented. That said, black bear and mountain lion populations are expected to continue expanding eastward from West Texas, and the likelihood of encounters along the Devils may also subsequently increase. Awareness of their presence in the region, in addition to mitigation strategies such as limiting access to potential introduced food sources (i.e. via the use of bear boxes), will go a long way to minimizing the likelihood of these kinds of interactions.

Perception of Migrant Presence

Recreationists do occasionally inquire about the likelihood of encountering undocumented migrants along the Devils River. However, there are no official reports by recreationists or public recreation managers of negative interactions with individuals or groups perceived as migrants, and the movements of migrants in the region are not considered a risk to visitor safety on the river at the time of this report's publication.

When asked about her perspective on perceived risk, Alli Hatten, Val Verde County game warden, suggested that the danger lays more in travel in and out of the region: "I would say our biggest safety concern with migrants, is getting to and from here, not even necessarily on the river, but people traveling in here and traveling out...I was just listening on the radio and there's pursuit going on...the majority of it is towards Eagle Pass, but it bleeds over here a lot. Like we had one at Rough Canyon the other day where they were trying to run from Border Patrol on us and they wrecked out and killed multiple people."

She said generally in her experience as a law enforcement officer on the border, migrants "keep such a low profile because they don't want to be caught...they know how much law enforcement is in the town of Del Rio. And that's another great thing about Del Rio. We have the Air Force base...and just on my street alone – seven or eight agencies. I feel safer there than I do when I visit my parents in Temple."

Regarding migrant interactions, she spoke of multiple incidents where people were found to have temporarily squatted in unoccupied homes in the region but concluded. "Even when people run into them -we'll hear them running into them all the time- they'll just go the other way. So, they're trying to get farther away from people."

Hunting and Fishing Violations

Hunting and fishing recreation in Texas is regulated by the State of Texas through Texas Parks and Wildlife, and regulations are enforced by game wardens and other law enforcement officers. Recreationists participating in these activities on public and private land are required to hold the appropriate license for the right year/season, with the exception of fishing from the banks of the State Natural Area, which visitors may do without a license through the Free Fishing in State Parks program. Catch, bag, and size limits remain in effect for all recreationists.

Alli Hatten, Val Verde County game warden, said that citations for not having a fishing license was one of the top four water body code violations she's cited over the past ten years. She also commented on incidents of hunting without a license, saying "It's definitely gone down over the last few years, but yeah, you still have people, especially out of state hunters who come in and don't have the right license. More than not having the right license, a lot of people don't have the Hunter Education course. I think that could possibly be our number one violation [related to hunting violations]: people actually have to have that in order to hunt."

> *"It's hard to convince people that don't live here, that don't have feet on the ground, how valuable – invaluable - this river really is...They just don't get it and for some reason when they get out in the country, they think, apparently, that the sky is the limit as to what they can do. And that's my backyard.*
>
> **- Dell Dickinson, 2024**

Other Illegal or Damaging Recreational Behaviors

There are other potential cases of misuse of recreational access to the Devils River natural areas which were not discussed in the previous sections. Due to the long stretch between river access points, emergency situations most often arise during periods of low flow, coupled with higher temperatures and the ingestion of alcohol. Often paddlers are without cell or 911 contact, requiring landowners to help. The introduction of the paddler camps has greatly reduced these issues, but the gap between River Mile 6 and River Mile 10 continues to have a relatively high rate of incidences for the river.

One landowner relayed a recent experience, saying "We had a rescue involving a helicopter and game wardens on our ranch in April of this year. Paddling down the Devils during low water drought conditions is uninformed as well as dangerous."

Noise pollution is another source of contention among landowners and recreationists. Music and other sounds generated by recreationists at campsites and while paddling may disturb landowners and other recreationists seeking ambient sounds of nature. While Texas Parks and Wildlife does not currently have sound regulations at the Devils River, several options are being discussed to provide equitable access to natural soundscapes for both landowners and visitors.

It is generally considered best practice to limit the volume of music to a level that cannot be heard distinctly beyond the area temporarily inhabited by the recreationist [group]. Additionally, when in sight of a landowner's home, recreationists are encouraged to keep the music down.

Communication of Misinformation Involving Misuse

A recurring issue regarding recreational misuse within the Devils River watershed is the communication of inaccurate information to and among recreationists that leads to, often unintentional but nonetheless problematic, misuse behaviors. When recreationists rely on unverified sources to plan their visit to the Devils River, they may be receiving poor advice and find themselves ill-prepared. This can lead to a negative, and even unsafe, experience for the recreationist, as well as increased risk of conflicts with landowners, greater pressure on recreation management personnel and outfitters to mitigate safety risks, and damage to ecological systems. Personal and commercial blogs, social media, YouTube videos, podcasts, radio shows, and newscasts and articles can contain helpful tips, but any guidance that violates either responsible use guidelines, public access regulations, general safety practices, or the Leave No Trace© ethic should be ignored. If a recreationist is unsure of the validity of a piece of information, it is recommended they contact a recreation manager, such as State Natural Area personnel, to confirm its accuracy before proceeding.

When asked about recreational safety issues she's observed, Alli Hatten, game warden, said, "On occasion we've had some river rescues, like when the river is at a high like this [referring to the July 2024 flooding event], people still try to put on the river...I think we've gotten better at telling people and especially working with our concessionaires...They, in past years, let people put on the river and then they didn't make it 100 yards down the river and flip their kayaks and [we] had to go rescue them. She goes on to add, "as far as those safety concerns, it's gotten less and less over the years. We had a few right at first, and growing pains...you know, with a lot of people comes a lot more of that stuff... - same with me, I didn't know about the flooding going on. If you're outside of this country, you don't know the dangers, but I feel like the concessionaire service does a good job and hopefully, when the new State [Natural Area unit] opens up, it will also do a good job of letting people know."

Instances of digital content creators and influencers of relative stature posting images or content endorsing misuse behaviors, knowingly or unknowingly, have been noted with relative frequency by stakeholders. These behaviors have been exhibited through images, video content, and written content such as blog posts and shortform posts alike. Stakeholders often attempt to provide correction to posts endorsing misuse as they encounter them via comment and personal communications, though there is no systematic framework for finding or enforcing misuse regulations through social media posting. Though law enforcement may choose to pursue action based on posted evidence, the nature of web-based posting leaves much to chance, including the spread of misinformation to other recreationists.

Public Agencies

To navigate the complicated and delicate relationships among stakeholders since paddlers discovered the pristine waters of the Devils River, Texas Parks and Wildlife has worked with a diverse range of organizations and individuals within the watershed to maintain an amicable relationship for public paddlers. The Devils River Conservancy, the Devils River Association, The Nature Conservancy, the National Park Service at Amistad National Recreation Area, and the Shumla Archeological Research and Education Center are a few notable groups.

Beginning at Bakers Crossing, the historical Devis River paddle trip starts at a Texas Department of Transportation easement access point and courses over 47 miles to Rough Canyon Marina on Lake Amistad. Paddlers will pass from the Texas Department of Transportation easement, through private ranches, by the State Natural Area-Del Norte Unit, Dolan Falls Preserve of The Nature Conservancy, through the Blue Sage subdivision, past the State Natural Area's DAH Unit, and onto the Devils River arm of the Amistad National Recreation Area.

Through Leased Concessions contracts, Texas Parks and Wildlife is able to provide shuttle services, guided fishing, flyfishing, and paddling trips for the public.

Outfitters

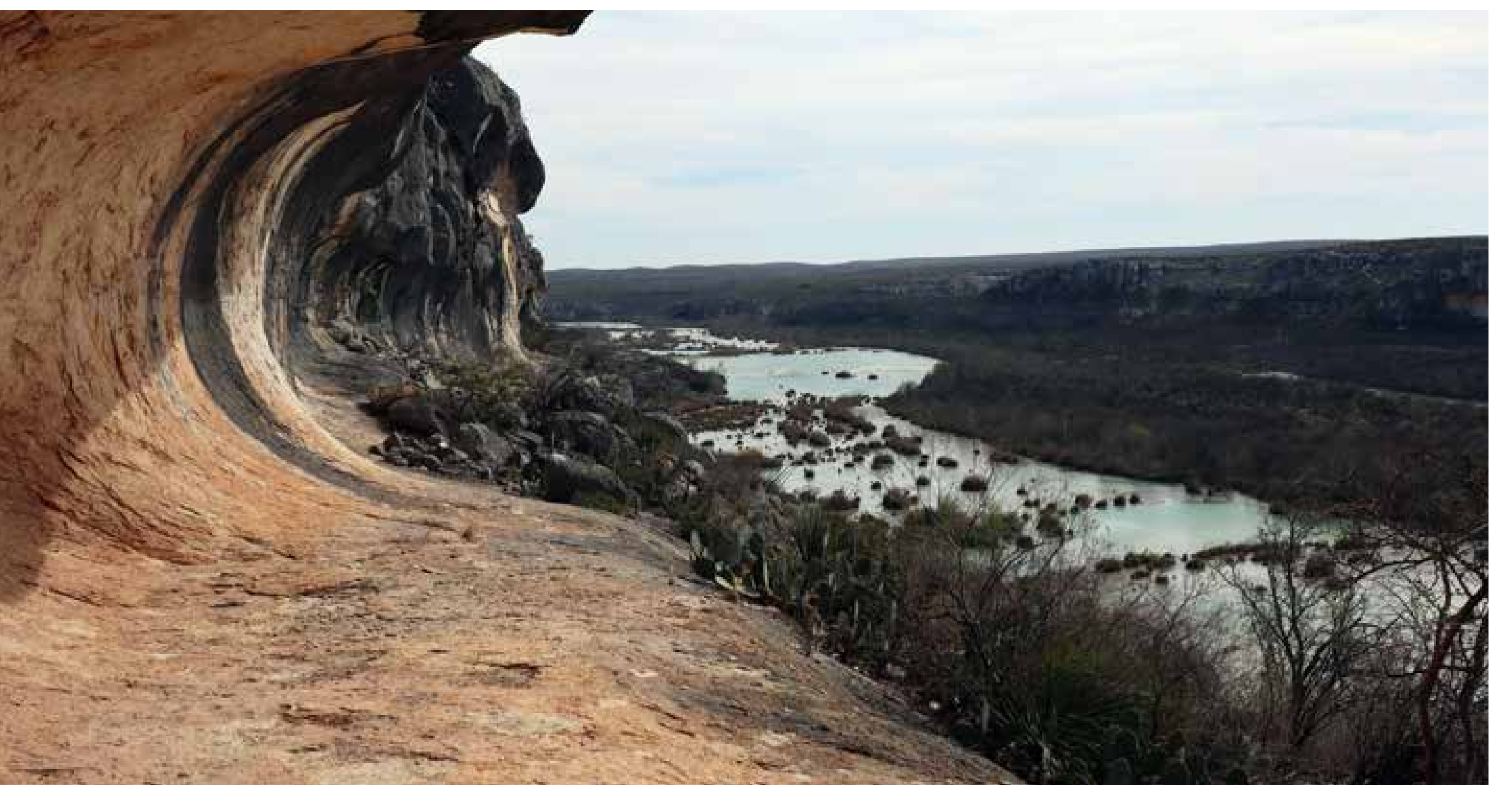
There are two types of outfitters on the river: those that are Texas Parks and Wildlife-approved and those that are not. Texas Parks and Wildlife-approved outfitters, or concessionaires, became recognized as stewards of the river among recreationists, landowners, and governing agencies over time largely because of the contractual requirements to incorporate good river and business ethics. Those outfitters that are not Texas Parks and Wildlife approved may not have paddler admittance limitation requirements and are not obligated to educate their clients on river ethics and sustainable recreation practices. Additionally, they are not required to pay state fees or secure specific insurance coverages that Texas Parks and Wildlife-approved outfitters are. Recreationists will often choose non-Texas Parks and Wildlife approved outfitters because there are fewer obstacles to river access and because these outfitters can provide services at costs lower than Texas Parks and Wildlife-approved outfitters. These leniencies cause frustration among landowners and other stakeholders in the Devils River watershed.

Texas Parks and Wildlife-approved outfitters often find their relationship with governing agencies like Texas Parks and Wildlife challenging because of the ever-changing rules, requirements, fees, and obligations that are implemented, sometimes without advanced notice. These changes are occasionally made even without dialogue or input from concessionaires and can highly effect how their business operates and persists.

Anecdotally, some recreationists have expressed concerns that concessionaires may effectively decrease accessibility of DRAP permits to independent recreationists through bulk permit orders in the reservation system. While this practice has been noted occasionally, it has not yet become a common occurrence. However, State Natural Area personnel are hoping to address this gray area as they review processes in preparation for the opening of the DAH Unit.

Landowners

Ever since recreational paddlers discovered the Devils River in the 1970s, there have been incidences of contentious relations between guarded ranchers and honest paddlers struggling to understand the nuances of riparian trespass within the context of Gradient Boundary law. Tales of rifle stand-offs are legend. Around 2010, when Devils River Ranch (32 miles downstream of Bakers) was donated to Texas Parks and Wildlife, it was time for a Devils River management plan. Texas Parks and Wildlife implemented a group of stakeholders to fairly address the issues, which became the Devils River Working Group in 2011, an



advisory board of local landowners, ranchers, paddlers, anglers, outfitters, and other stakeholders. The Texas River Protection Association was well represented at the 2011 and 2013 sessions and on the paddle trips. The charge of the Devils River Working Group was to find common ground between landowners, paddlers, and anglers to protect the river corridor for the long term. The Devils River Working Group submitted its recommendations to Texas Parks and Wildlife Commissioners in January 2012, including a recommendation for river access permit system. The State Natural Area completed the pilot DRAP Program in 2013. The Devils River Working Group II met several times and completed the updated Devils River Working Group II Action Plan in July 2014, which included feedback on the concept of paddler camps to effectively limit trespass on private property. Later, two additional official paddler camps at M12 and M20 were announced.

The Paddler Camps on the Devils, leased through Texas Parks and Wildlife's River Access and Conservation Area program, are prominent examples of "focused acquisition of rights-of-way," which limit trespassing on adjacent private properties, protect sensitive habitat areas, and help to create a sense of place to further enhance the recreation experience while forging strategic partnerships that enhance community trust.

Threats to the Sustainability of Recreation

River Flow Level

The flow level of Devils River is crucial for maintaining the quality of recreational activities:

- **Flow Measurements:** Cfs is a critical measurement, with activities such as issuing DRAPs being contingent on these levels. Although data on water flow is available at various monitoring points along the river, there is limited guidance provided for recreationalists who seek to understand what conditions are required for access to the river.
- **Impact of Low Flow:** Decreased flow levels can alter the river's course, affecting both the ecological balance and the recreational quality. Low flow also impacts the difficulty recreationalists face in traversing specific rapids and challenging sections of the river. Furthermore, extended dragging of paddling vessels along the riverbed can introduce increased levels of microplastics into the system.
- **Monitoring Tools:** Tools like Riverapp provide real-time data on river levels, helping visitors and managers plan activities and conservation efforts accordingly. However, reliable information is not readily accessible for many stakeholders who wish to understand current conditions.
- **Closure Conditions:** Specific flow conditions, such as reaching flows of less than 85 cfs, can lead to the closure of access points like Pafford Crossing and camping sites such as Bakers Crossing to protect both the river ecosystem and visitor safety.

Changes In Landownership and Land Use

The fear of further fragmentation along the Devils River has been a concern for several decades. As large ranches along the Devils River get bought, sold, and often subdivided, often as a result of generational exchanges, individual property acreage continues to trend smaller. This results in an increase in the number of homes, roads, wells, and other infrastructure, the development of which ultimately puts more strain on the river resource overall. Some of this is unavoidable as a function of the changes wrought by time and population growth, but protections can and have been identified to limit the associated negative impacts. The Devils River Conservancy has worked in conjunction with the Devils River Association (a historical landowner group) to help provide guidance as much as it can with these changing dynamics. Hosting educational seminars on the role of conservation easements, sustainable water well development, and improved septic system rules and regulations is one example of the many efforts that have been made to unite landowners in working together to help ease the burden on the river and conserve its resources.

The Nature Conservancy has also taken several steps to contribute as conservation partner by purchasing land on the Devils River, now known as Dolan Falls Preserve, to mitigate future fragmentation. This, in conjunction with Texas Parks and Wildlife's 38,000 acres and numerous conservation easements voluntarily entered by private landowners, has contributed to Val Verde County's status as the county with the second highest amount of conserved acreage in the state. However, working lands (without conservation easements) in the county and the larger watershed are at serious risk for development and fragmentation.

One ongoing concern by conservation organizations and landowners in the region is the development of wind energy infrastructure, including one wind farm that is currently operational and at least one more that is in the planning stage.

When discussing threats to the dark skies of the Devils River, landowner Dell Dickinson expressed the effects of the installed windfarm on the viewscape: "The first night they turned those lights on I literally thought the Martians had…landed in Val Verde County. It looked exactly like a runway lighting system. If you could imagine 69 of these things along the 12-mile line viewed from 18 miles away. And those things are so big and tall that I can actually see [them] from the deck - the individual blades turning around. So…as the sun is peeking over the horizon, there are those turbines exactly in the in the way of the sun coming up. It takes away from watching a beautiful sunrise when you sit there and watch those industrial monsters turning." He also described a possible mitigation strategy, explaining "We have, on occasion, tried to get the operator to consider installing a radar-assisted program that would allow at least …the lights to be off when aircraft aren't around and then just turn on when the aircraft [are near]. We found out here, they would never [need to] be turned on at night because Laughlin doesn't do any low-level flying at night -to the best of my knowledge- and the only other aircraft at night would be commercial aircraft flying at 33-35,000 feet, so that wouldn't even affect the situation at all. But they, so far, haven't been open to doing anything like that. I think that would help a lot if they would agree to do that…"

Continuance/Increase/Expansion of Negative Impacts by Recreation

Economic viability of recreation and tourism operations can fluctuate depending on an array of external and internal factors. For paddling the Devils River, it depends on at least two major factors: Mother Nature and human limitations. Drought in the Devils River watershed often leads to low water levels and flows. The stretch of river between Bakers Crossing to Finegan Springs, around the Del

Norte Unit of the State Natural Area, includes numerous natural flowing springs but is also heavily dependent on seasonal rain. Finegan Springs, starting around River Mile 15, provides the remaining river with the majority of its water flow downstream. When the watershed has plenty of rain, the cfs is higher and is therefore more conducive to paddling. When the cfs drops, the river can become unnavigable, which deters visitors from planning paddling trips. The visitation data as seen in Figures 45 and 46 articulates this relationship. Looking at Figure 46, overnight DRAP visitation in 2021 and 2022 were 1,271 and 1,298 respectively, and a significant drop in visitation can be seen in 2023 with only 1,059 visitors. This decrease in visitation can be linked to Texas Parks and Wildlife's paddling restrictions at Bakers Crossing due to the low cfs levels. Additionally, the limited number of DRAPs sold by Texas Parks and Wildlife along with limited river access restricts immediate tourism operations. Though these limitations may seem to curb tourism in the present and near future, these lower visitation numbers may contribute to ecosystem preservation and resilience for future generations of tourists to enjoy in conjunction with community residents.

Opportunities

Despite these threats, there are numerous opportunities to bolster the sustainability of recreation on the Devils River. Recreation and tourism industries can be significant economic drivers for communities, including residents of Del Rio and those within the wider Devils River watershed. Local businesses can benefit directly from visitor patronage, and the increase in jobs and subsequent employee spending can further contribute to economic resiliency in the region as well as contribute to conservation funding.

One facet of collective efforts is effective communication among groups. For the purposes of recreation management, agency staff, concessionaires, landowners, and recreationists all play a role in ensuring negative impacts to the river basin and its inhabitants are minimized. When communication channels are maintained, it can uphold sustainable operations through improvements in education, safety, and enforcement.

Alli Hatten, Val Verde County game warden, stated, "One of my biggest advocates for patrolling the river are concessionaires telling me when people are on the river, so that's been a big help." Dell Dickinson, Devils River landowner, also spoke of the importance of communication, saying "when we first made the agreement with Texas Parks [and Wildlife], both sides communicated very, very well. As a matter of fact, I could remember on random occasions that's how it always was. I would meet the Superintendent of the Del Norte unit there at the Dolan Falls and we can sit there and have a sandwich and talk about how things were going, and he would let me know what he had been doing in terms of maintaining the camps... I was provided with data on a monthly basis such that I knew how many people were coming ..and this and that and the other. Also, I had full warning of people coming in case someone got in trouble or something like that. We're always ready to help if we know someone's in trouble." It is also the recreationist's responsibility to have some form of reliable communication device on their person or in their group to call emergency services for help when cell service is not available.

Over the years, Dickinson began to notice that "a lot of changes, personnel changes, were happening within Texas Parks [and Wildlife]... and so there was that loss of communication that we saw... And that, to me, was contributing to the increase in trespass, trash, [and] fire issues." He mentioned hearing about a recent meeting between several groups in the watershed and Parks and Wildlife. Dickinson noted "I think it was a very good meeting and I believe that they under-

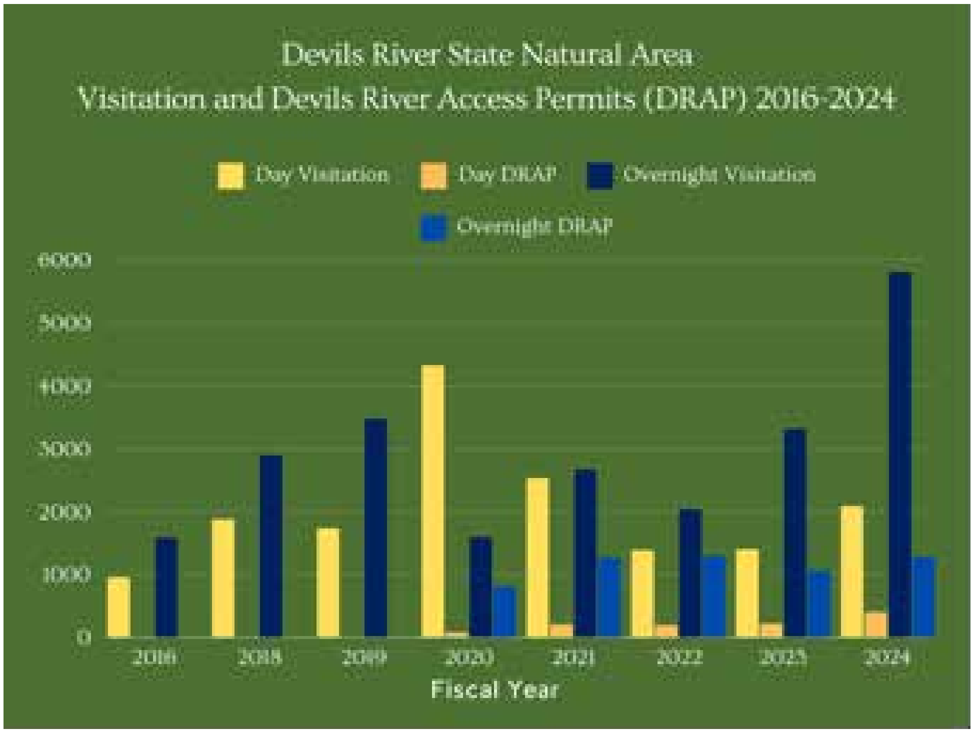


Figure 41. State Natural Area Visitation and DRAPs in 2016-2024

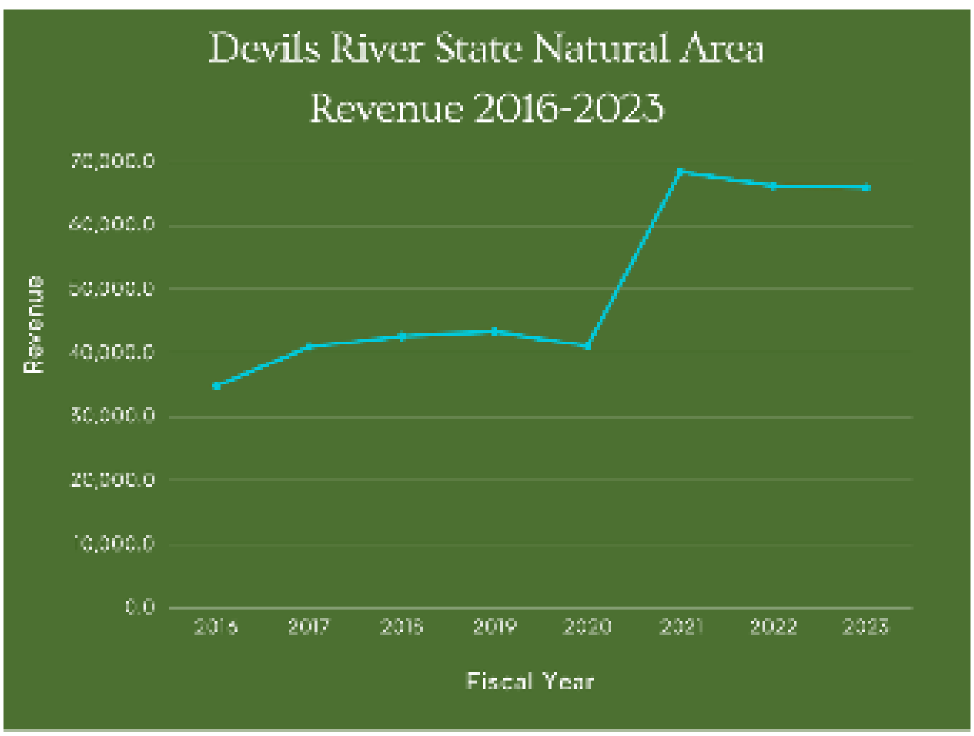


Figure 42. State Natural Area Visitation and DRAPs in 2016-2024

stand that it takes feet on the ground to make this thing work." The sustainability of future operations will, at least in part, rely on all stakeholder groups upholding a responsive communication network.

In addition to these considerations, outdoor recreation, particularly out in nature, has been shown to significantly improve human health and wellbeing across a range of metrics. Access to recreation is vital for the wellbeing of all Texans, and remote wilderness settings are becoming less and less available. The Devils River offers important experiential opportunities for adults and children, and if managed sustainably, can continue to provide soul-deep benefits for current and future generations.

Management of Recreation

Public Lands

Texas Parks and Wildlife manages the State Natural Area Complex, as well as the DRAP system for access to the river and down the Devils River Arm of Amistad National Recreational Area. With 5 miles of shared boundary, State Natural Area DAH Unit State Park Rangers and Amistad NRA National Park Rangers work together to manage invasive species, monitor spring flows, and monitor endangered or protected species.

Private Lands

Although many private landowners relish the limited public access to the river, some private landowners along the Devils River choose to offer recreation opportunities to the public. These activities include native and exotic hunting, rock art viewing, rock climbing, and river access for water recreation including paddling.

Recreation Outfitters

Texas Parks and Wildlife contracts with private outfitters to help provide recreation opportunities along the Devils River. These are the only outfitters allowed to do business inside Texas Parks and Wildlife land. Because there is only a limited amount of people permitted to launch for river trips each day, the number of outfitters is also limited. Outfitters must submit written proposals and undergo an interview process to even be considered for Texas Parks and Wildlife Devils River concessionaire status. Most outfitters provide fully guided fishing and/or paddling trips down the river. Some only offer shuttle and kayak rentals. Each concessionaire is provided with a set of rules and regulations regarding safety and respectfully paddling the Devils River that they are required to pass along to their clients. It is this education that helps sustain the recreation aspect of the river.

Areas of Conflicting Opinion

Perceptions vary among the diverse Devils River watershed stakeholders of recreation's impact in the region, even internally within associated landowner, agency, and recreationist groups. Some perceptions that have been identified are (1) that recreation, unmanaged, may lead to lasting damage to the watershed, (2) that recreation, when guided and well-managed, can lead to increased awareness and appreciation for conserving the natural environment of the watershed, and (3) that recreation is a vital economic driver in the area. While each of these perceptions are generally regarded as legitimate, stakeholders may assign them varying degrees of priority.

One example of differing perceptions of recreation impacts is the community's discussion around the recent adjustment of the river access gate in the Del Norte Unit of the State Natural Area from approximately one mile away from the surface water down to one-third of a mile away from the surface water. Some stakeholders viewed this as a necessary safety measure for recreationists who previously would have had to park at the gate and walk the remaining distance across unshaded, difficult terrain, possibly carrying heavy equipment in the elements. Others have expressed views that this change may encourage visitation at unsustainable levels, particularly in regard to unregulated paddler access, and this will result in an erosion of protections for the river. The gate was previously stationed at approximately two miles from the surface water and has been shifted closer over time as site managers determined that exposure continued to be a safety risk for recreationists and adjusted the distance incrementally to assess resulting shifts in incidence rates. Access for paddling put-ins and pull-outs is still regulated under the DRAP system within the State Natural Area complex. Stakeholders continue to monitor this change to observe any discernible outcomes as recreationists adapt to the improved access.

The Devils River Working Groups (convened by Texas Parks and Wildlife) have brought stakeholders together in the past to resolve and find balance between valid tensions and the outcomes that may be produced by such varying viewpoints (Andy Iverson, Personal Communication 2024). One such collaborative outcome is the DRAP system, which has allowed many stakeholders to feel both more comfortable with a reduced, regulated number of paddlers traveling through and more confident that these permitted recreationists have received responsible use education and likely have more experience and reverence for the Devils River. This system has also allowed other stakeholders to continue providing access to recreationists in a more sustainable manner.

Sustainable Recreation Data Gaps and Research Needs

Even as many aspects have been discussed in this report, knowledge gaps remain. Recreation impact assessments, particularly when tied to watersheds, can be difficult to complete due to the complexity and intricacies in its connection to the region. Other impediments include: data accessibility, unstaffed data collection / archiving, privacy or sensitivity concerns, and lack of consensus among experts.

Some of the knowledge gaps at the time of this report include but are not limited to:

- True ecological impact of human recreational activities on species and habitats
- Effectiveness of responsible use and conservation messaging in relation to recreationist behavior
- Identifying paratextual messaging channels and first point of entry for recreationists
- Visitor safety and incident data
- Education and outreach initiatives and activities
- Potential barriers to recreation access
- Impacts of recreation in the confines of responsible use parameters
- An economic impact analysis of recreation in the area and its relationship to conservation
- Data accessibility impediments
- Data collection or archiving is minimal or unsupported
- Privacy or sensitivity concerns
- Lack of consensus among experts

The sensitive nature of this region, coupled with the increased popularity and access to outdoor and natural recreation, creates increasingly new and complex questions regarding the relationship and balance between conservation and recreation. Some questions determined during the development of this report include:

- How will recreation use/access change when the DAH Unit of the State Natural Area opens?

- How will projected land use and land ownership changes affect recreation use/access?
- What are the current relationships between human recreational activities and species and habitats?
- How will future changes in recreation use/access affect the environment and economy of the region?

Comprehensive assessments of how recreation affects the environmental, economic, and social pillars of sustainable development are needed. These would be most informative if conducted repeatedly through time, to reveal any patterns that can contribute to informed decision-making by stakeholders.

Understanding how information is communicated and perceived is also essential. This includes examining the role of social media, determining which sources of information are reputable, and combating misinformation through education and outreach efforts.

Compiling data centrally on the types and associated frequencies of recreation-based incidents occurring annually along the river would allow both public and private recreation managers to better anticipate and mitigate risks and improve safety and emergency response measures.

Current demographic data is not detailed or accurate enough to provide a comprehensive understanding of who Devils River recreationists are. We need better information on who is visiting and their perceptions of their experiences, to provide recreation managers additional information to enhance current delivery of services as well as a baseline for comparison with future trends. Current understanding of demographics, visitation, and use are determined by surveys and DRAP issuance statistics and may not be tracked by private landowners or concessionaires. The available data is somewhat vague in an effort to protect recreationist privacy and because post-visit surveys are often overlooked, incomplete, or only filled out by those who typically have strong feelings about the visit. The nature of post-visit surveys is subjective and therefore difficult to measure in certain terms. The demographic data collected by the State Natural Area is linked to demographic data associated with visitors' home zip codes and only categorizes demographics as White, Hispanic/Lantinx, or Black, excluding all other races as well as age or gender information. These data conditions yield inconsistent, incomplete, or nonspecific results.

Several important questions need to be addressed to ensure the sustainable future of recreation in the Devils River watershed:

- How should sustainable recreation be evaluated in the Devils River watershed using practical metrics? Developing benchmarks that provide indications of trends to and by recreation activities can serve as a tool for adaptive management and long-term sustainability. The team acknowledges this is a difficult process, but even incremental progress would support current and future recreation and conservation resiliency. One important evaluation in support of this goal would be to understand the current economic impact of recreation and tourism on the region. Identifying direct, indirect, and induced effects of these industries better informs decision-making in terms of sustainability for investments not only in business but in the care of the environment itself.
- How will future changes in recreation use affect the environment, economy, and culture? Anticipating these changes allows us to develop proactive management strategies.

- How will anticipated trends in recreation in the area impact local ecosystems?
- How will changes in recreation patterns affect local businesses and job markets?
- How will shifts in recreational use influence the cultural landscape and community values?
- And referring back to changes in land ownership and land use, how will these changes affect recreation use, access, and associated management?

One change of interest to the community is the upcoming opening of the DAH Unit of the State Natural Area. Recreation managers anticipate this will support the sustainability of recreation along the river, but concerns of increased use are a continued concern. Adaptive management and collaboration with community partners will be important components of upholding sustainability metrics and navigating this change, but outcomes will remain unknown until after the unit opens.

- How are visitors and community members exposed to information and education about the region?
- What is needed in this area?
- How can we appropriately manage communications and education about the region?
- What information are we currently tracking, what can feasibly be tracked, and what should be tracked?What are the environmental impacts of visitors, and how can we measure this?
- Live Webcams for monitoring conditions
- Flows information (i.e. readily accessible links or regular reporting)
- More accurate and real-time resources overall
- How does the revenue from recreation impact conservation?
- How does recreation impact economy in the region?
- How can we continue and sustain this work for the benefit of the watershed and community members?

Recommendations for Sustainable Recreation Research, Monitoring, and Collaboration

The purpose of this report is to identify what is known about recreation on the Devils River and develop a framework for defining sustainable recreation in the context of the region. Due to current gaps in information, this secondary goal remains partially incomplete. To further develop this framework and support the development of recreation management best practices, more information is needed. Therefore, the authors of this report recommend several studies be conducted to fill in these gaps described below. Cooperation with private properties should occur on a strictly voluntary basis ensuring full transparency of methods and data use are conveyed to the property owner.

- **Ecological Impact Study** to understand the direct and indirect impacts of recreation on species and habitats. Current related research has so far focused on identifying local native, and invasive species and understanding their natural histories. This is an important baseline to establish for understanding changes to populations in the future, but due to the ongoing status of this initial work, little research has been focused on investigating the relationship between recreational activity and impacts on the local ecological systems. Studying the relationship between recreational activity and the Devils River environment could inform environmental protections and future regulatory practices.
- **Visitation studies** could provide a more in-depth understanding of the demographics within the recreationist population, which could also support communications strategies. Visitation information coupled with ecological impact research could potentially reveal important information about best practices for managing access and communicating a stewardship mindset to visitors. Current visitation metrics are determined by information collected when issuing DRAP permits. This data may not be reflective of recreation occurring outside the DRAP system. A study to gather data outside the DRAP permitting system may provide a more comprehensive understanding of recreation in the region.
- **Study of communication pathways** within Devils River stakeholder communities, to understand how past and present communication strategies have impacted recreation perspectives and outcomes. This could better inform future community dialogue, education, and reporting, both within and beyond associated stakeholder groups, and improve decision-making processes to protect the Devils River. Examples may include the Devils River Working Groups and other such productive, collaborative efforts between community members and public agencies.
- **Study of communication and education platforms** covering the region to further understand messaging and education about recreation in the area. There is limited understanding of how recreationists receive messaging about the region and what messaging they are able to access. It is anecdotally understood that messaging consumed by recreationists may come from social media platforms or even outdated blog posts in addition to the agencies' and outfitters' official channels. Across the globe, environmental groups and recreation managers have developed effective strategies to communicate stewardship best practices to various audiences. Thought-

ful review and adaptation of these strategies, tailored for the Devils River, could similarly improve the effectiveness of stewardship-oriented messaging for this region. Such a study would shed light on current messaging and could shape educational strategies in the future.

- **Investment in Planning Infrastructure for Recreationists.** There are currently limited ways for recreationists to adequately plan for their trip. Namely, no way to predict or understand flows beyond a single gauge at one point along the river. Increasing the planning infrastructure for recreationists such as live webcams, or image galleries with visual context for flows levels, could help recreationists understand practical conditions before their trip. Proper planning with the aid of tools such as this could likely reduce the number of health and safety or even trespassing incidents.
- An **Economic Impact study** may be helpful for understanding more fully the contributions of recreation to the regional economy as it stands and as projections may show. This type of study could shed light on the relationship between recreation-driven revenue, conservation funding, and the general financial health of the community. Developing a more detailed understanding of the economic impact of recreation on the region could support conscientious, best-practices planning.

Key Takeaways – Sustainable Recreation

These recommendations are based on a comprehensive literature review and reflect the collective expertise of a technical team from 2023-2024.

- → The pursuit of sustainable recreation is an ongoing and adaptive process that seeks to balance and ensure environmental, economic, and social resiliency within the region where recreation occurs while connecting community members to their natural and cultural heritage.
- → The public areas that offer recreation access in the Devils River watershed include the State Natural Area, managed by Texas Parks and Wildlife, and the Amistad National Recreation Area, managed by the National Park Service.
- → The DRAP system allows Texas Parks and Wildlife to manage public access to the Devils River through state property, including access regulations, reporting, and law enforcement.
- → Private outfitters who work with Texas Parks and Wildlife to provide access are required to secure DRAP permits for their recreationists.
- → Individuals may access the river outside the DRAP system by putting in at Bakers Crossing or via private property with landowner permission. For takeout, these recreationists would be limited to exiting on private property with landowner permission, or at Rough Canyon Marina on National Park Service property 47 river miles south of Bakers Crossing.
- → The history of conflict between private landowners and recreationists on the river has included trespassing, littering, unauthorized fire, noise, and emergency support, among other instances.
- → Devils River Working Groups convened in 2011 and 2013 to address various issues within the watershed. They recommended the initial development of the DRAP system and defined a gradient boundary to delineate where public land ends and private land begins along the river. The "Seven-Inch Rule" was adopted as the accepted regional rule to determine jurisdiction at any given point along the river.
- → The second Working Group also resulted in a cooperative lease agreement between a private landowner and Texas Parks and Wildlife to ensure safe and legal rest areas for recreationists at two critical points (River Mile 12 and River Mile 20) along the river by establishing campsites through the RACA program.
- → Once the RACA program, gradient boundary, and DRAP systems were established, instances of trespassing and other prohibited behaviors decreased, as noted by stakeholders and law enforcement, but these behaviors continue to persist with reduced instances.
- → Activities enjoyed by recreationists along the river include but are not limited to paddling, fishing, hunting, wildlife watching, camping, hiking, cultural site visitation, and stargazing.
- → At times of low flows, measured in cfs, public access to certain sites may be closed for paddling. This is both for environmental protection and human safety. Recreationists should refer to the Texas Parks and Wildlife website to monitor closures.
- → Extreme and unpredictable conditions at the Devils River can pose health and safety risks to even the most experienced recreationists. Monitoring conditions and packing appropriate gear, including emergency supplies, are necessary to mitigate risk.

Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report.* The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

- The remote location of the Devils River imposes hurdles for emergency services to access the area and assist recreationists in distress.
- The most frequent violations incurred from recreation along the river have been noted by law enforcement as trespass, insufficient personal floatation devices, lack of fishing license, and littering, though the total list of violations is more extensive. Recreationists are encouraged to review regulations related to their activities of choice.
- Changes in land use have sparked concern about environmental impacts, which could also impact the appeal to recreationists if the remote wilderness experience of the Devils River is compromised. Increases in access have also posed concerns for stakeholders about environmental impacts that may be caused by increased traffic.
- Regular communication among stakeholders in the Devils River watershed has been noted by private landowners, outfitters, public agency personnel, and law enforcement to benefit the collective management of sustainable recreation in the area.

- **Research priorities are:**
    - An ecological impact study in the area to understand the direct and indirect impacts of recreation on species and habitats.
    - Visitation studies to provide a more in-depth understanding of the demographics within the recreationist population and support communications strategies.
    - Study of communication pathways within Devils River stakeholder communities to understand how past and present communication strategies have impacted recreation perspectives and outcomes to better inform future community dialogue, education, and reporting within and beyond associated stakeholder groups and improve decision-making processes to protect the Devils River.
    - Investment in planning infrastructure for recreationists, such as live webcams or image galleries with visual context for flow levels, to help recreationists understand practical conditions before their trip and properly plan to prevent health and safety or trespassing incidents.
    - An economic impact study to understand more fully the contributions of recreation to the regional economy and shed light on the relationship between recreation-driven revenue, conservation funding, and the general financial health of the community. Developing a more detailed understanding of the economic impact of recreation on the region could support conscientious, best-practices planning.

Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK.

STAKEHOLDER JURY

STAKEHOLDER SOCIAL IN SONORA, TEXAS.

This chapter is the product of the Devils River Watershed Project's Stakeholder Jury and is an effort to reflect the interests, goals, needs, and challenges stakeholders are facing in the region as well as the opportunities this community has to work together to secure a sustainable future for the Devils River.

Foreward

The Devils River Watershed Project Stakeholder Jury

The Devils River Watershed Project incorporated a public participation mechanism to ensure that diverse stakeholder voices were represented and vetted the report's content through the formation of a Stakeholder Jury. The jurors include people randomly selected by lottery from a pool of nominated stakeholders to deliberate on important questions and collaboratively develop recommendations.

Between June and July 2024, the Meadows Center conducted an open call for volunteers and nominations to participate in the Stakeholder Jury. This open call was advertised via mass communication email to the stakeholder contact list, the project website, and via press releases in local newspapers (e.g., The Ozona Stockman). The open call included Frequently Asked Questions and additional information about the Jury along with the role of a juror. Representation targets were established for the jury (5 seats for land managers to include representation from the Devils River Association, Devils River Conservancy, National Park Service, Texas Parks and Wildlife, and The Nature Conservancy; 1 seat for a stakeholder from the upper watershed (Crockett, Sutton, or Schleicher Counties); 1 seat for a local government official; 1 seat for a county government official; and 3 seats held as wildcard seats (e.g., recreationist). The final seat was reserved for the project's sponsor (DRC) to serve as the non-voting foreman. The Jury Foreman acts as the leader and spokesperson for the Jury and is responsible for ensuring the process is fair, encouraging all members to voice their opinions, and to provide continuity for any future collaboration in the region related to identified action.

The Meadows Center conducted a random drawing (live via Zoom on July 24, 2024) using an online randomizer tool to draw names until the 11 seats were filled – redrawing names for each category until there were no more volunteers that fit a specific category (e.g., local government) (Table 12).

The Jury was not intended to have superior status to other stakeholders, but rather to ensure a diverse feedback mechanism. In addition to providing direct feedback, all stakeholders not participating in the jury process were invited to express their feedback or even join Jury proceedings. Jurors confirmed that stakeholder feedback has been adequately and respectively incorporated and ensured that the final version of The State of the Devils River Report reflected community perspectives.

Jurors served voluntarily and participated in monthly meetings in the final stages of the project based on specific project milestones.

Table 12. List of Stakeholder Jurors as of December 2024.

Name	Affiliation
Romey Swanson (Foreman)	DRC, Project Sponsor
Thad Jarrett	Land Manager, Devils River Association (DRA)
Merily Keller	Land Manager, DRA
Dell Dickinson	Land Manager, DRA
Tino Pruneda	Land Manager, DRC
Ruthie Russell	Land Manager, DRC
Jim Norman	Land Manager, DRC
Frank Tambunga	Upper Watershed (Schleicher, Crockett, Sutton)
Beau Nettleton	County Government
Amanda Evridge	Wildcard Seat
Philip Walker	Wildcard Seat
Randy Nunns	Wildcard Seat

**Seats were initially held for state and federal land managers, an NGO land manager, and local government. When no nominations were received in those categories, the seats were divided amongst nominated DRA/DRC-identified land managers.*

Findings on the Devils River Watershed Project and State of the Devils River Report

The intent of the State of the Devils River Report was to gather academic and local expertise to identify what is known about the watershed, highlight additional data needs, and recommend pathways to meeting those information needs. The Stakeholder Jury was asked to make requests and recommendations to the facilitation and technical teams to adjust the report as necessary to satisfy the desired final findings below.

The Jury unanimously found that:

1. Stakeholder comments were adequately addressed in the Second Draft of The State of the Devils River Report (Jury Charge I)
2. The approach and subject matter of the Report's five primary chapters (Introduction, Groundwater Science, Water Quality, Species and Flows, and Sustainable Recreation) was complete (to the extent possible) and areas of uncertainty were adequately addressed throughout. (Jury Charge II)
3. A watershed Vision Statement should be included to guide continued collaborative work in the watershed (see below). (Jury Charge III)
4. Opportunities for future collaboration in the watershed should be included in the Stakeholder Jury Chapter (see below) (Jury Charge IV)
5. Additional recommendations should be included in the Stakeholder Jury Chapter (see below) (Jury Charge V)

To our knowledge, the report compiled information on groundwater resources, water quality, species and their flow needs, and sustainable recreation, and (to our knowledge) did no knowingly exclude any information provided to the project or technical teams. (Jury Charge VI.i.)

1. The process was respectful to stakeholders' diverse needs and perspectives and the report reflects the project team's responsiveness to feedback. (Jury Charge VI.ii.)
2. We have reviewed the report's recommendations and find that they reflect scientific and or information needs only, and do not endorse any specific management outcomes. (Jury Charge VI.iii.)
3. We have reviewed the report and find that this report did not make recommendation for further federal investment in the region (Jury Charge VI.iv.)
4. The Devils River Stakeholder Jury finds that the State of the Devils River Report and process are complete. (Jury Charge VI.v.)

Framework for Continued Collaboration in the Devils River Watershed

The Devils River Stakeholder Jury crafted the following Vision Statement and Core Principles to guide future collaboration in the watershed:

VISION STATEMENT

The Devils River Watershed is sustainably managed in a way that honors its unique ecological and cultural heritage as well as the rights of landowner and local communities, leverages collaborative science, and embraces stakeholder input to ensure the river's pristine conditions continue for generations to come. An informal coalition focuses on shared values (with reoccurring opportunities to learn about ongoing and new challenges facing the watershed and needed research) and provides the opportunity for stakeholders to build community and consider coordinated education regarding projects affecting the watershed.

CORE PRINCIPLES FOR SUSTAINABLE MANAGEMENT OF THE DEVILS RIVER WATERSHED

Maintained Wild Texas Character: *informs the direction and delivery of collaborative actions in the watershed.*

Continued Watershed-wide Collaboration: *among all stakeholders and stakeholder groups; engaging and enlisting "newcomers"; emphasizing relationships between landowners, local organizations, environmental groups, and governmental agencies across the counties of Schleicher, Crockett, Sutton, Edwards, and Val Verde; harnessing the collective expertise, shared values, and resources of this unique region to tackle the watershed's challenges.*

Communication of Challenges and Research Needs: *advocate for comprehensive research* to address knowledge gaps; enhance understanding and support best management practices, borrowing from successful examples like the Don't Blow It campaign and the Hill Country Alliance; to an ever-growing contact list.*

Honoring Landowner Role and Rights: *in the stewardship of the river, respecting and integrating their insights and rights into the watershed's management plans, in emphasizing and enabling voluntary cooperation.*

Science-Based Decision-Making: *guided by rigorous scientific research; ensuring that management practices are effective, sustainable, and adaptable to new findings; incorporating local expertise and lived experience alongside traditional scientific research.*

Leverage Partnerships with Like-Minded Groups: *to glean resources and expertise of other organized efforts across the state addressing similar challenges (examples: Texas Land Trust Council, Pristine Streams Initiative, Dark Skies TX, DRA, DRC, and Edwards Plateau Association).*

Leverage Private and State Funding: *for implementation of voluntary efforts supporting these core principles; emphasizing initiatives that partner state and local shareholders and neighbors to the river.*

Education of Policymakers and Surrounding Communities (City, County, Agency, Legislative): *Communicate the importance and uniqueness of the Devils River watershed and the science needed to foster a better understanding of the watershed and its challenges.*

Recommended Priority Actions and Next Steps

The Stakeholder Jury refined the list of challenges affecting the sustainability of the Devils River originally identified by the project's Technical Teams, as outlined on pages 43-44, and proposed the following ideas for potential collaboration and future action. While the jury unanimously recognized land fragmentation as the greatest threat, other challenges varied in priority depending on individual stakeholder perspectives.

1. LAND AND HABITAT FRAGMENTATION ACTION IDEAS

a. Encourage conservation easements and update or develop a map of conservation easements to help track protected lands.

b. Examine cooperative land management models from other regions, using case studies to identify practices that could be adopted or improved locally.

c. Coordinate with the Edwards Plateau Alliance to expand the census map of landowners opposed to wind turbines and incorporate Val Verde County.

d. Explore the benefits of expanding the boundaries of the Amistad Land Use and Zoning Order granted to Val Verde County to encompass the Devils River and other areas necessary to enhance watershed protection, including the possible implementation of aerobic treatment systems, which is a form of on-site wastewater treatment that is used to augment a traditional septic system in areas of groundwater sensitivity. These systems mix air and bacteria with the wastewater to break down pollutants.

e. Investigate zoning and regulatory models, like those utilized by the Highland Lakes, to manage wastewater beneficial reuse for developments.

2. WATER SUPPLY ACTION IDEAS

a. Implement a well measurement program to monitor groundwater levels, with accessible and easy-to-understand reporting for stakeholders.

b. Develop a hog trapping monitoring program to track hog movements along the river, referencing similar programs and encouraging community participation (e.g., sign-up for association). Include resources for participants and establish a county-wide bag/tag system with guidance from a Texas A&M University hog eradication expert. This program should engage state landowners who own large properties in the region.

c. Install fencing panels around feeders to keep hogs out; though costly, this can prevent water contamination.

d. Regularly measure and monitor springflow to track groundwater levels.

e. Investigate river flow standards (e.g., environmental flow targets) for the Devils River.

f. Explore ways to enhance groundwater recharge throughout the watershed.

3. LANDSCAPE, ENVIRONMENTAL, AND INDUSTRIAL IMPACTS ACTION IDEAS

a. Explore opportunities to purchase avigational and wind rights by creating a TIRZ (Tax Increment Reinvestment Zone), which involves reinvesting tax revenue in local priorities. This setup would extend the distribution line to a mile wide on either side, facilitating the purchase of navigational zones where wind development is undesirable and directing it to designated "acceptable" areas. This would create a revenue stream for purchases.

b. Investigate opportunities to maximize groundwater recharge by examining differences in management needs across various recharge sites and zones, focusing on key areas.

c. Identify opportunities to expand recharge projects to boost aquifer recharge (e.g., dykes, dams, cedar, and mesquite control), taking inspiration from successful initiatives like San Angelo's salt cedar eradication. Consider offering tax exemptions to landowners and developers engaged in recharge efforts that meet or exceed the discharge rates of their activities. Strengthen regulations for development over recharge areas, especially in smaller subdivisions (e.g., large tracts subdivided into 100-acre parcels). Explore zoning legislation and potential amendments to adjust boundaries as needed, focusing on enhancing recharge efforts in upper watershed counties.

d. Explore land practices that enhance groundwater recharge by identifying resources and partners beyond governmental entities. This approach aims to encourage broader participation among landowners, meeting them where they are.

   i. Seek alternatives to Natural Resources Conservation Service-like programs that are more effective for the Devils region.

   ii. Provide a broader suite of tools and partners available to landowners, addressing costs related to money, time, and labor.

   iii. Consider a non-profit organization or trusted state or local entity to take on regulatory burdens, ensuring that landowners can participate without undo regulatory requirements/exposure.

e. Educate land managers on the role of fire (prescribed burning, increasing fuel load resulting from decreasing grazing, increased fire risk with climatic changes and ongoing drought).

4. "THE HUMAN FACTOR" ACTION IDEAS

a. Investigate special wastewater discharge regulations around Amistad as a potential model for upstream stakeholders to minimize potential water quality impacts.

b. Review current county wastewater discharge regulations and identify any gaps or inconsistencies (e.g., ranchettes are often regulated similarly regardless of their proximity to streams).

c. Set up a private system to monitor river access at Bakers Crossing to accurately quantify and manage the impact of recreational activities.

d. Research successful recreation management strategies employed by mountain states to limit river visitors.

e. Explore an education program for paddlers and others launching at Bakers Crossing and exiting at Blue Sage to minimize environmental impact.

f. Ensure Texas Parks and Wildlife commits to ongoing and stronger law enforcement, including the need for two dedicated game wardens/park police.

g. Revise water flow and level thresholds to discourage paddling during low-flow periods, possibly by using endangered mussels as a factor.

h. Explore mechanisms to track paddlers outside of the permitting system and assess the costs to the state for rescues, aiming to minimize private property damage and loss of life.

i. Investigate a standardized tracking program for recreationalists accessing the river.

j. Ensure Texas Parks and Wildlife provides supporting data to back up claims regarding the low number of paddlers outside the DRAP system.

k. Require outfitters to furnish guides for paddlers and distinguish authorized outfitters from unauthorized ones.

l. ncrease communication efforts with recreational users about the potential dangers of fires.

5. COMMUNITY EDUCATION AND AWARENESS ACTION IDEAS

a. Explore marketing and public relations strategies to educate stakeholders, including newsletter and email campaigns with watershed news, education, and awareness. There are more interested stakeholders than we realize who require outreach on various watershed issues.

b. Explore ways to share the legacy of landowner stewardship with new residents in the watershed. There is currently no shared stewardship or management culture among these newcomers, such as those in hunting camps and ranchettes.

c. Strengthen education and relationship-building with policymakers (city, county, agency, legislative) to enhance understanding and support for the challenges facing the Devils River watershed.

6. INVASIVE SPECIES MANAGEMENT & INTERSECTION OF PRIVATE LANDS AND NATIVE PREDATOR SPECIES ACTION IDEAS

a. Enhance brush management to address the decline in regional migratory pathways for species, such as monarchs and doves, focusing on removing invasive species to improve habitat quality and support migration routes.

b. In addition to being important for water supply, developing a hog trapping monitoring program will also support management of this invasive species. See 1(b) above for more information.

c. Conduct studies to determine the extent of predation on livestock, such as sheep and goats.

d. Address the increasing population of black bears, which will impact feeders and cabins along the river, and prepare strategies for coexistence and conflict mitigation.

e. Find a balance between utilizing aoudad as a revenue source for landowners and understanding its potential impacts by reviewing recent research on aoudad movements, life cycles, and their effects on the watershed.

f. Explore management strategies to address the imbalance between mountain lions and coyotes, as both adversely affect ranches and livestock.

g. Address invasive vegetation (e.g., chinaberry, fan palms, King Ranch bluestem, Malta star thistle, etc.) throughout the watershed.

h. Educate and implement prescribed fire techniques to manage vegetation, reduce wildfire risks, and maintain ecological balance.

Recommendations for Continued Coordinated Watershed Action

There was unanimous agreement amongst the members of the Stakeholder Jury that watershed-wide collaboration should continue through a representative coalition, hereafter called "Devils River Watershed Group." There is also a desire to keep the larger stakeholder community active to guide the implementation of the recommendations contained in the State of the Devils Report. With these aims in mind, the Jury recommended:

1. FORM A WATERSHED GROUP:

Continuation of the current 12-member structure (borrowed from the Jury format) as the core Watershed Group

- This recommendation for the continuance of a deliberative and voting body aims to build on the established rapport, productive dialogue, and diverse representation in the existing Stakeholder Jury. Additional considerations regarding representation of other landowner types should be discussed as the Watershed Group takes shape.
- The Watershed Group should invite scientific and policy experts as needed to aid the deliberations of the group.
- A chairperson should be elected each year. Romey Swanson (DRC) agreed to serve as the first chairperson to provide continuity from this Watershed Project to the new Watershed Group.
- The Watershed Group should meet at least quarterly, beginning in March 2025 after the Report is finalized and distributed to review and work from the action items identified in this chapter.
- The Devils River Watershed Group will aim to moving the needle on watershed issues. The first agenda is to include review of the Amistad Land Use and Zoning Order, opportunities associated with TIRZ's (Tax Increment Reinvestment Zones), learning from other regional examples like

Highland Lakes protections from the Hill Country Alliance, and concerns related to a new statewide trail proposal.

- The Technical Teams developed for State of the River Report should continue to be engaged with the Watershed Group and stakeholder community events (e.g., check in with them prior to the Watershed Group quarterly meetings to find out of there's anything to share for group's awareness).

2. CONVENE A DEVILS RIVER ANNUAL ALL-STAKEHOLDER MEETING:

An annual, in-person meeting should be held to focus on continued relationship building and discussion of potential responses to challenges facing the watershed. The Jury recommended a format that followed the examples os the meetings hosted by the Texas Sheep and Goat Raisers and Texas Cattlemen groups, featuring both educational and decision-making components. The meeting should be easy for people to attend (be held in Del Rio and not all day). The meeting could be a complement to other events already being considered in the region for 2025 (e.g., Community BBQ, Land and Wildlife Symposium) or with partners like the Witte Museum/Shumla Center or Texas Wildlife Association.

3. SHARE COMMUNICATIONS THROUGHOUT THE YEAR

The Jury recommended that stakeholders be kept apprised of developments related to the Devils River watershed, with the goal of supporting timely responses to challenges

4. ENGAGE IN AND ENDORSE RECOMMENDED RESEARCH:

The Watershed Group could serve as a forum for support of the research recommendations in the State of the Devils River Report. Ongoing interactions with researchers working on the Devils River will help to keep the stakeholders apprised of research initiatives, provide feedback to researchers on how to best engage with local landowners, and improve the likelihood that recommended research is funded by providing endorsement from the Devils River Watershed Group.

Reiterating Research Recommendations

The Stakeholder Jury wishes to include the comprehensive list of research recommendations from the State of the Devils River Report. These recommendations are based on a comprehensive literature review and reflect the collective expertise of four volunteer technical teams who worked to identify and prioritize research needs realted to the Devils River watershed. (Source: Meadows Center Report #24-003: State of the Devils River Watershed Report. The Meadows Center for Water and the Environment at Texas State University)

GROUNDWATER SCIENCE RESEARCH AND MONITORING RECOMMENDATIONS

1. General Recommended Research

   a. Refine the Geologic Framework:

      i. Expand geologic mapping of bedrock and surficial deposits for key areas, including faults, fractures, and karst in the mapping.

         - Define the role of the geologic framework regarding the water budget and outline characteristics of the hydro stratigraphy and diagenetic history that influence the permeability structure of the aquifer.

      ii. Use geophysical logs, outcrops, publications, and drillers logs to create and refine the structure contours of the aquifer system.

   c. Understand Recharge:

      i. Examine rainfall-runoff relationships using current IBWC stations and instrument small tributaries within the Dolan Creek watershed (near TxMesonet sites) to characterize runoff, and place instrument and focus in area(s) of the dry reaches in the upper watershed.

      ii. Complete additional gain-loss studies building upon the recent Texas Parks and Wildlife gain-loss data and other flow gauging sites and refine and quantify the gains and losses for the Devils River.

      iii. Create additional surficial and karst maps using remote sensing and GIS to map closed depressions and karst features in key parts of the watershed.

      iv. Assess historic long-term climatic changes and potential effects on water levels and spring discharge for the area to refine our understanding of possible future effects of climate change on groundwater recharge in karst aquifers.

         - Additional research in this area should also include the downscaling of climate models for the region.

   e. Research to Better Characterize Groundwater Flow:

      i. Refine and augment the existing regional potentiometric map.

      ii. Localize potentiometric maps.

         - Perform detailed potentiometric mapping around the spring complex of Dolan Springs, -Finegan Springs, and Pecan Springs. Continue to instrument wells in the Dolan and Pecan Springs area (particularly the possible new well near Juno) to track groundwater response to recharge.

iii. Perform dye traces within the Dolan and -Finegan Springs complexes starting from the Jose Maria Spring (estavelle feature) within Dolan Creek to the spring complex. to expand the definition of springshed(s), flowpathways, and variable residence times.

iv. Sample select wells and springs for geochemical and isotopic data under both low-flow and high-flow, or post-storm, conditions to provide insight into the matrix-conduit interaction and other geochemical processes including groundwater-rock interactions to understand groundwater flow and recharge source areas.

v. To better understand the relationship between Amistad Reservoir levels and both surface and groundwater extraction and to better understand the capture area for this system, we recommend additional study of the San Felipe Springs system.

f. Research on Discharge (Springflow):

i. To further delineate and quantify springflow, continue and develop springflow measurements and rating curves for known and possibly new spring complexes.

- Explore tools like baseflow separation to better understand springflow.

ii. Utilize existing wells in the State Natural Area to refine the water level-springflow index relationship. In the headwaters area (Pecan Springs), install a new monitor well at the IBWC site.

- Instrument with telemetry and incorporate into the Texas Water Development Board recorder well program.

iii. Evaluate the region's historical pumping and water budgets to better assess the potential range of response of this system to pumping, especially during drought.

iv. Create and maintain a map of monitoring points that is available to stakeholders.

2. Expanded Monitoring of Aquifer Conditions, Springs/Tributaries, and the Devils River

a. Expand the well-monitoring network throughout the Devils River watershed farther upgradient of the perennial springs to further understand spring discharge trends, recharge, aquifer storage, and source area delineation, including wells in the Dry Devils River watershed, which flows infrequently but may have important groundwater flows paralleling the ephemeral stream channel (Green et al., 2014).

b. A new well (est. 3-400 feet deep) north of Pecan Springs in the Juno area, perhaps within the IBWC easement at Cauthorn's Crossing, would provide key hydrogeologic data (e.g., Fort Terrett vs. Segovia) for regional structure contour mapping and key surface-groundwater interaction.

i. A rating curve could be developed for the Pecan Springs complex.

b. Establish real-time springflow and river data where key data gaps exist.

iii. Instrument select stream and spring sites intended to be permanent monitor locations moving forward.

iv. Maintain and improve the Dolan Crossing site with telemetry for real-time data.

v. Conduct bi-annual visits to various spring reaches and well sites for manual measurements, and to maintain and download probes. Maintain stream and springflow gaging stations at the State Natural Area for the Finegan-Blue Hole spring complex.

vi. Further explore the connection between spring flows and levels in Lake Amistad pathways.

WATER QUALITY RESEARCH RECOMMENDATIONS

1. Land Use Changes: Assess impacts from new septic systems and other introduced contaminants.
2. Climate Change: Evaluate changes in precipitation and runoff patterns.
3. Riparian Health: Monitor the condition of riparian vegetation and its role in river stability.
4. Increased Recreational Use: Investigate the effects of growing recreational activities on water quality.
5. Water Quality of Permitted Wastewater Discharges: Review water quality from facilities such as the Crockett County WCID and the City of Sonora. Explore opportunities to convert discharge permits into land application permits.
6. River Education and Stewardship: Foster stronger connections between local communities and the broader region to promote river care and stewardship and increase awareness around impacts to water quality.
7. Oil and Gas Disposal Wells: Study the potential impact of disposal wells on groundwater and surface water.
8. Invasive Species and Sedimentation: Address the rise of invasive species, such as feral hogs among others, and their contribution to sedimentation.

SPECIES AND FLOWS RESEARCH RECOMMENDATIONS

1. Biological inventories of taxa groups should be repeated at least every ten years.
   a. Include inventories of fish, aquatic and terrestrial invertebrates, plants, birds, mammals, reptiles, and amphibians across riverine, spring, riparian, karst, and upland habitats.
   b. Sites from the upper, middle, and lower watershed should be included to capture the climatic gradient and diversity of habitats throughout the watershed.
   c. Surveys at public lands (Devils River SNA and Amistad NRA) should be prioritized due to repeatability of surveys; however, private properties should also be surveyed on a strictly voluntary basis.

d. Physical and photo vouchers should be collected and georeferenced and any physical vouchers should be deposited in an accredited museum for research.

e. With landowner permission, species inventories should be quality-checked and deposited in the Devils River Digital Repository in perpetuity. Specific location data can be obscured to address any data privacy concerns by landowners.

2. Population tracking and habitat assessments for species vulnerable to extirpation or extinction every one to five years.

   a. Depending on the species-specific lifespan and life history of rare taxa, targeted data collection efforts should be made on a shorter cycle to ensure populations are stable and habitats remain able to support them.

   b. For short-lived species, such as Devils River minnow, or those that are more susceptible to rapid habitat degradation, such as Texas hornshell, it is recommended that targeted monitoring continue annually.

   c. For longer-lived or more adaptable species, monitoring could occur on a longer cycle. Data collection should include abundance or population estimates at multiple sites within the watershed, identification of recruitment and age class strength, and an assessment of habitat condition.

3. Population and harvest tracking for game and sport fish species.

   a. For species utilized for food or recreation purposes, including game species and sport fish, regular monitoring of populations and harvest helps landowners implement informed harvest practices and informs Texas Parks and Wildlife in setting regulations protective of stable populations.

   b. Voluntary creel surveys conducted through the DRAP survey for paddlers or conducted in-person at river access points should be continued to measure fishing pressure by species.

   c. Longitudinal angling surveys conducted by Texas Parks and Wildlife every two years should resume and be completed to complement creel surveys to assess adult sport fish populations along the river.

   d. Similar population estimates and creels should be done for target game species such as whitetail deer, turkey, etc.

4. Non-native species surveys, treatment, and monitoring.

   a. Any non-native species identified as part of the taxa inventories should be mapped for the location and full extent of the organisms.

   b. Non-native species should be prioritized based on potential impact on habitat, river function, and native species.

   c. A treatment plan should be developed for those considered at high risk for spread and ecosystem disruption.

   d. Follow-up surveys and re-treatment should be conducted to monitor effectiveness and mitigate spread.

   e. Non-native species considered a low risk in terms of environmental impacts should be monitored, and future taxa inventories should document any spread.

SUSTAINABLE RECREATION RESEARCH RECOMMENDATIONS

1. Ecological Impact Study to understand the direct and indirect impacts of recreation on species and habitats and to inform environmental protections and future regulatory practices.
2. Visitation studies to develop a deeper understanding of the demographics within the recreationist population and inform best practices for managing access and stewardship education strategies.
   a. A study to gather data outside the DRAP permitting system may provide a more comprehensive understanding of recreation in the region.
3. Study of communication pathways within Devils River stakeholder communities, to understand how past and present communication strategies have impacted recreation perspectives and outcomes to better inform future community dialogue, education, and reporting, both within and beyond associated stakeholder groups, and improve decision-making processes to protect the Devils River.
4. Study of communication and education platforms covering the region to further understand consumption of messaging and education about recreation in the area to ultimately shape and improve the effectiveness of stewardship-oriented messaging for this region.
5. Investment in Planning Infrastructure for Recreationists. Increasing the planning infrastructure for recreationists such as live webcams, or image galleries with visual context for flows levels, could help recreationists understand practical conditions before their trip which may prevent unfortunate health and safety and/or trespassing incidents.
6. An Economic Impact study should be conducted to understand more fully the contributions of recreation to the regional economy and to shed light on the relationship between recreation-driven revenue, conservation funding, and the general financial health of the community and supporting conscientious, best-practices planning.

ANNOTATED BIBLIOGRAPHIES BY TOPIC

This section provides a primer on the most important published literature related to each of our four topic areas: Groundwater Science, Water Quality, Species and Flows, and Sustainable Recreation. The project's Technical Teams selected and summarized these resources to further the shared understanding of the watershed.

Key Readings for Understanding Devils River Groundwater Science

1. Texas Aquifers Study
2. Groundwater Availability Models for the Edwards-Trinity and Pecos Valley Aquifers
3. Springs of Kinney and Val Verde Counties
4. Groundwater Data Acquisition in Edwards, Kinney, and Val Verde Counties, Texas
5. Estimates of Recharge and Surface Water–Groundwater Interactions for Aquifers in Central and West Texas
6. Spring Discharge and Thermal Regime of a Groundwater Dependent Ecosystem in an Arid Karst Environment
7. Distribution of Juniperus Woodlands in Central Texas in Relation to General Abiotic Site Type
8. Hydrogeological Study for Val Verde County and City of Del Rio, Texas
9. A Texas Ranching Family, the Story of E.K. Fawcett
10. Simulation of a Fire-sensitive Ecological Threshold: A Case Study of Ashe Juniper on the Edwards Plateau of Texas, USA
11. Focused Groundwater Flow in a Carbonate Aquifer in a Semi-Arid Environment
12. The Edwards Aquifer: The Past, Present, and Future of a Vital Water Resource
13. Geologic map of the Dolan Springs Quadrangle, Val Verde County, Texas
14. Airborne lidar bathymetry survey and aquatic habitat evaluation for Devils River minnow and Texas hornshell mussel in the Devils River of Val Verde County, Texas
15. Update of the Groundwater Availability Model for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers of Texas
16. Review of Water-Resource Management of the Devils River Watershed Report by Toll and others (2017)
17. Paleohydrology of southwestern Texas
18. Groundwater Use Planning Strategies and Best Management Practices for Drought Scenarios, Val Verde County Springs Assessment of the Dolan Falls Preserve and State Natural Area (Del Notre Unit)
19. Overview of Groundwater Conditions in Val Verde County, Texas
20. Subsurface stormflow is important in semiarid karst shrublands
21. Woody Plant Encroachment Paradox: Rivers Rebounds as Degraded Grasslands Convert to Woodlands
22. Streamflow Gain and Losses in the Devils River, Texas

1. **Anaya, Roberto et al. "Texas Aquifers Study." Texas Water Development Board, Texas, 31 Dec. 2016. https://www.twdb.texas.gov/groundwater/docs/studies/TexasAquifersStudy_2016.pdf.**

   Report by the Texas Water Development Board summarizing the quantity, quality, flow, and contributions to surface water and adjacent aquifers (inter-aquifer flow) from the major and minor aquifers of Texas. It provides a summary of the aquifers, including the Edwards-Trinity (Plateau) Aquifer, the source of baseflows of the Devils River. Some key points include groundwater levels in all major and minor aquifers have declined; aquifer interactions with surface water vary across the state, with an estimated 14 to 72 percent of streamflow over aquifer outcrop areas due to groundwater discharge. The largest groundwater contributions to surface water occur in East Texas, the Hill Country, and around major springs in West Texas. The average baseflow estimate for creeks and rivers within the outcrop of the Edwards Plateau Aquifer is 818,000 acre-feet per year, which is 55 percent of the total streamflow. This ranks third highest among the 30 major and minor aquifers in Texas.

2. **Anaya, R. & Jones, I. 2009. Groundwater Availability Models for the Edwards-Trinity and Pecos Valley Aquifers. Texas Water Development Board. https://www.twdb.texas.gov/groundwater/models/gam/eddt_p/ET-Plateau_Full.pdf?d=4025.600000023842.**

   In 2001, the Texas Legislature directed the Texas Water Development Board to obtain or develop groundwater availability models for all major and minor aquifers in coordination with groundwater conservation districts and regional water planning groups. In 2004, the Texas Water Development Board released the first groundwater availability model for the Edwards-Trinity (Plateau) and Pecos Valley aquifers and published the model report in 2009.

   This report describes the study area and hydrogeologic setting of the aquifers, model input and parameters assigned during model construction, calibration and sensitivity analysis of the model for steady state and transient conditions, limitations of the model, and suggestions for future model improvements.

   The two-layer model is based on an upper layer representing the Pecos Valley Aquifer and Edwards hydrostratigraphic unit and a lower layer modeling the Trinity hydrostratigraphic unit. The groundwater availability model was calibrated to steady-state conditions for 1980 and historical transient conditions for 1980 through 2000. Calibration of the steady state and transient models resulted in recharge rates ranging from one to eight percent of mean annual precipitation, specific yields of 0.003 to 0.2, and specific storage of 10-6 to 2 X 10-4 per foot.

   Results of the model under steady state conditions indicate that approximately 60 percent of the groundwater flows through the unconfined Edwards hydrostratigraphic unit and Pecos Valley Aquifer. Discharge to streams, springs, and reservoirs accounts for approximately 60 percent of discharge from the aquifers and pumping (primarily from irrigation) accounts for approximately 25 percent of discharge from the aquifers. The remaining 15 percent is discharged mostly to the Edwards (Balcones Fault Zone) Aquifer.

   The U.S. Geological Survey modeling software, MODFLOW-96, and associated model packages were used. The model should be used only for assessing groundwater availability on a regional scale. The Edwards-Trinity and Pecos Valley aquifers cover approximately 44,000 square miles of West Central Texas. Future improvements to the model should include a collection of additional data to reduce uncertainties in hydraulic properties, groundwater and surface water interactions, and recharge.

3. **Ashworth, J.B. & Stein, W.G. 2005. Springs of Kinney and Val Verde Counties. LBG-Guyton Associates report prepared for Region J Plateau Regional Water Planning Group, 36 p. http://ugra.org/assets/pdfs/SpringsKinneyValVerde2005.pdf.**

   The report, "Springs of Kinney and Val Verde Counties," prepared by LBG-Guyton Associates for the Plateau Regional Water Planning Group, is a short synopsis of some of the major springs in these two counties. The document includes some basic information on the importance of spring systems for ecology, culture, and

water resources. The purpose is to produce a hydrogeologic-spring database for the two counties to improve understanding of how the springs relate to the aquifers and rivers. The report provides brief sections on the following topics:

- Climate Impact on Springflow
- Groundwater Occurrence and Recharge
- Groundwater Movement
- Inventory of selected springs
- 28 springs in Kinney County (Las Moras, Mud, Pinto Creek, Pecan, etc.)
- 45 springs in Val Verde County (San Felipe, Goodenough, Dolan, Finegan, Cantu, etc.)
- Springflow record graphs are shown for a few of the major springs with available data.
- Potential Impact on Springs Due to Pumping

The report includes some photos of major springs but does not go into detail on any of the springs, providing a general description of some and a list of the major springs.

4. **Ashworth, J.B. & Stein, W.G. 2009. Groundwater Data Acquisition in Edwards, Kinney, and Val Verde Counties, Texas. LBG-Guyton Associates report prepared for Region J Plateau Regional Water Planning Group, 104 p. https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/0704830695_RegionJ/study1_GW-Data-Acquisition.pdf.**

The report, "Groundwater Data Acquisition in Edwards, Kinney, and Val Verde Counties, Texas," prepared by LBG-Guyton and Associates in 2009 (revised in 2010), is a broad document reviewing existing data and reporting on several dye tracer experiments in Kinney and Val Verde counties. The dye tracer tests were run in the Pinto Creek Valley of Kinney County and in the City of Del Rio to San Felipe and Cantu Springs. No specific investigations were performed in the Devils River area.

5. **Sen, A., et al. 2022. Estimates of Recharge and Surface Water – Groundwater Interactions for Aquifers in Central and West Texas. Texas Water Development Board Contract #2048302455. https://www.twdb.texas.gov/groundwater/models/research/recharge/recharge.asp.**

This report provides key findings and recommendations for estimating groundwater recharge in Central and West Texas. The modeling tools discussed include: 1) the Soil Water Balance model (SCS); 2) Soil & Water Assessment Tool model (SWAT), distributed water-balance models; and 3) U.S. Geological Survey Groundwater Toolbox, which amalgamates six hydrograph-separation methods to estimate groundwater discharge or baseflow analysis and groundwater recharge components of the streamflow data. Overall, the report emphasizes the importance of data quality and using multiple approaches to estimate and refine recharge values for future water resource management.

Key findings from the report include:

- **Most impactful factors:** Total precipitation and evapotranspiration are the most important factors for estimating recharge.
- **Precipitation data:** PRISM is the best currently available source for precipitation data.
- **Evapotranspiration data:** While MODIS data is a potential source, the project recommends using calculations based on established equations for better reliability.

- **Model comparison:** Different models provided similar recharge estimates when averaged across large areas (aquifers) but not at smaller scales (watersheds). Choosing the "best" model is not conclusive based on their performance.
- **Single model use:** The Soil Conservation Service method can provide a good initial estimate of recharge in other regions if precipitation and evapotranspiration data are available. However, using a second model is recommended to assess variability.

The report outlines the following recommendations for using the results from the study:

- **Improve data quality:** Efforts should be made to refine the available data for precipitation and evapotranspiration, both in terms of detail and processing methods.
- **Use all models for large-scale applications:** When working with large areas like entire aquifers, consider using recharge estimates from all the models in future groundwater availability models.
- **Soil Conservation Service method for initial estimates:** This method can be used for an initial estimate in new regions with available precipitation and evapotranspiration data. It is important to use a second model for comparison.
- **Alternative approach:** Consider using the Soil & Water Assessment Tool model on a watershed level for recharge estimates and additional information like baseflow.
- **Data aggregation:** Aggregate recharge estimates to a monthly or annual basis and use both the lowest and highest values from each area to calibrate future models.
- **Baseflow calibration:** Use baseflow estimates from the Soil & Water Assessment Tool model to calibrate the surface water components of future groundwater availability models.

6. Caldwell, T.G., et al. 2020. Spring Discharge and Thermal Regime of a Groundwater Dependent Ecosystem in an Arid Karst Environment. Journal of Hydrology, vol. 587, pp. 124947. https://doi.org/10.1016/j.jhydrol.2020.124947.

This article highlights the critical role of spring discharge in regulating temperature within a karstic, groundwater-dependent river ecosystem. The study focuses on the Devils River in Val Verde County, Texas, where springs like Finegan and Dolan contribute 40 percent of the river's flow and act as a natural thermal buffer. This buffering effect helps to mitigate extreme temperatures, keeping the water cooler in the summer and warmer in the winter. Notably, spring temperatures remain consistently around 22.6 degrees Celsius ± 0.3 degrees Celsius (~72-73 degrees Fahrenheit), providing thermal refuges for aquatic life within a 200-meter stretch of the river.

The analysis of temperature data reveals that springs significantly reduce the duration of extreme temperature events by 50 to 70 percent. These findings emphasize the crucial role of springs in maintaining thermal stability within rivers, especially in arid environments. Consequently, spring discharge is critical for preserving the health of the river ecosystem and its dependent aquatic habitats.

7. Diamond, D.D. & True, C.D. 2008. Distribution of Juniperus woodlands in Central Texas in relation to general abiotic site type. Ecological Studies, Vol. 196, pp. 48-57. https://doi.org/10.1007/978-0-387-34003-6_3.

The findings from this report indicate that woodland cover has seen gains (1992 to 2004), and there has been a loss of grassland in the Hill Country; however, the overall changes to land cover have not been dramatic since European settlement. The transition back to grassland is not likely without repeated clearing by land managers and is best suited for wildlife habitat rather than grazing for domestic livestock.

8. **EcoKai Environmental, Inc. & Hutchison, W.R., 2014. Hydrogeological Study for Val Verde County and City of Del Rio, Texas. Final Draft Report, 152p. https://digitalcommons.usf.edu/kip_articles/5448/.**

   The City of Del Rio and the County of Val Verde, Texas formed a partnership in 2013 to complete a hydrogeologic study of the groundwater conditions in Val Verde County. The study's overall objective was to evaluate the potential impacts of increased groundwater pumping for export on local spring flows, Lake Amistad elevations, and groundwater levels. As part of this study, a groundwater flow model of the area was developed and calibrated with a particular focus on San Felipe Springs flow.

   Data analyses in support of model development included correlating Lake Amistad water surface elevation and San Felipe Spring flow. In the early 1970s, when Lake Amistad began to fill, San Felipe Springs flow increased from about 40 million gallons per day to over 90 million gallons per day. During lower lake elevations in the 1990s and early 2000s, San Felipe Springs flow decreased to below 60 million gallons per day. This analysis suggested that Lake Amistad is a source of recharge to the groundwater system, and some recharge eventually discharges at San Felipe Springs.

   Data correlations also included an analysis of regional precipitation and San Felipe Springs flow. The analysis showed that spring flow was better correlated with 18-month and 24-month cumulative precipitation than with six-month or nine-month cumulative precipitation. The better correlation of spring flow with the longer cumulative precipitation data suggests that the regional groundwater flow system retains a "memory" lasting several months.

   The final correlation analysis evaluated groundwater elevations in wells several miles from Lake Amistad. Among the conclusions of the analysis was that the variations in Lake Amistad elevation correlate well with variations in groundwater levels, highlighting the interconnectedness of the groundwater flow system with surface water.

   The groundwater model developed for this study was calibrated using groundwater elevation data and spring flow data from 1968 to 2013. Calibration was considered sufficient to advance the objectives of providing technical information that could be used in developing groundwater management guidelines if Val Verde County formed a groundwater conservation district.

   Once calibrated, the model was used to 1) estimate the effect of Lake Amistad on groundwater elevations in the area, 2) provide information for management zone delineation, and 3) simulate the effects of 18 hypothetical large-scale pumping scenarios on spring flow, river baseflow, aquifer drawdown, and other changes to the groundwater flow system. For context, historic groundwater pumping from 1969 to 2012 averaged less than 3,000 acre-feet per year, and the simulated large-scale pumping scenarios ranged from 25,000 to 150,000 acre-feet per year.

   The hypothetical large-scale pumping scenarios characterized and quantified the source of the pumped groundwater. Less than one percent of the pumping would be sourced from groundwater storage decline. About half of the pumping would be sourced from induced inflow from surrounding counties and from Lake Amistad. The other half of the pumping would be sourced from reductions in natural outflow, mostly spring flow reduction and reduction in baseflow to the Rio Grande.

9. **Finegan, J.K., 2007. A Texas Ranching Family, the Story of E.K. Fawcett. AuthorHouse, pp. 43-44.**

   The excerpt from "Copy of Letter Sent to Texas Development Bureau as an Answer to Their Inquiry to E. K. Fawcett about Early Days History of Del Rio and Val Verde County 1893" provides an alternative view to the one used by Toll, et al. (2017) to validate their groundwater/surface level model of the Devils River, namely that the "decrease in or cessation of spring flow in the Devils River upstream of Pecan or Hudspeth springs is attributed to pumping in the upper Devils River watershed," is an early settler's recollection that "Wilkins Bros. came from the New England States, first settled about where the town of Juno now stands, about the latter part of the seventies. (1870s) They stayed there a while and the spring and the Devil's River went dry at that point."

10. Fuhlendorf, S.D., et al., 1996. Simulation of a Fire-sensitive Ecological Threshold: A Case Study of Ashe Juniper on the Edwards Plateau of Texas, USA. Ecological Modelling. https://doi.org/10.1016/0304-3800(95)00151-4.

The paper indicates that fire-sensitive woodlands dominated by Ashe juniper persist and expand exponentially if fires have been suppressed or the fire regime is altered from the landscape for at least 75 years. Fires with a return period of 25 years allow the grass to dominate the slopes. Ecological thresholds governed by fires determine the bistable savanna regime, which had been the case before European settlement. After long periods of fire suppression, simulations showed that herbaceous production ceased, and woodlands took over the landscape.

11. Green, R.T., Bertetti, F.P. & Miller, M.S. 2014. Focused Groundwater Flow in a Carbonate Aquifer in a Semi-Arid Environment. *Journal of Hydrology*. 517:284–297. https://doi.org/10.1016/j.jhydrol.2014.05.015.

The Devils River watershed was used as the study site to evaluate focused groundwater flow in a carbonate aquifer in a semi-arid environment. The research revealed that an efficient conveyance system for groundwater had formed in the carbonate Edwards-Trinity Aquifer despite its location in a semi-arid environment. This conveyance system comprises preferential flow pathways that developed coincident with river channels. A strong correlation between high-capacity wells and proximity to higher-order river channels (e.g., within 2.5 kilometers) is used as evidence of preferential flow pathways (Figure 43). Factors that contributed to the development of the preferential flow pathways: 1) karst development in carbonate rocks, 2) structural exhumation of a carbonate plateau, and 3) the requirement that the groundwater regime of the watershed has adequate capacity to convey sufficient quantities of water at the required rates across the full extent of the watershed. Once the topography is sufficiently developed after exhumation of the Edwards Plateau, focused recharge into stream depressions enhances karst development in the carbonate rocks in the river channels. Recognition of these preferential pathways near river channels provides a basis for locating where high-capacity wells are likely (and unlikely). It indicates that groundwater flow within the watershed is relatively rapid, consistent with flow rates representative of karstic aquifers. This understanding provides a basis for better-informed decisions regarding the water-resource management of a carbonate aquifer in a semi-arid environment.

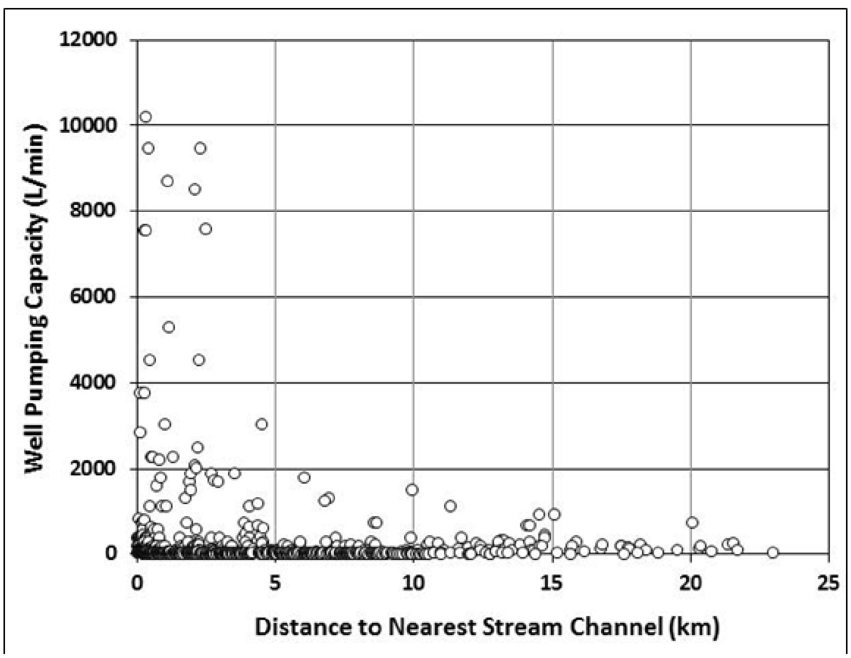


Figure 44. Graph of well capacity versus distance to the nearest third-order or greater stream channel. The data suggest a strong correlation between distance and well pumping capacity, especially for higher-capacity wells (> 2,000 L/min).

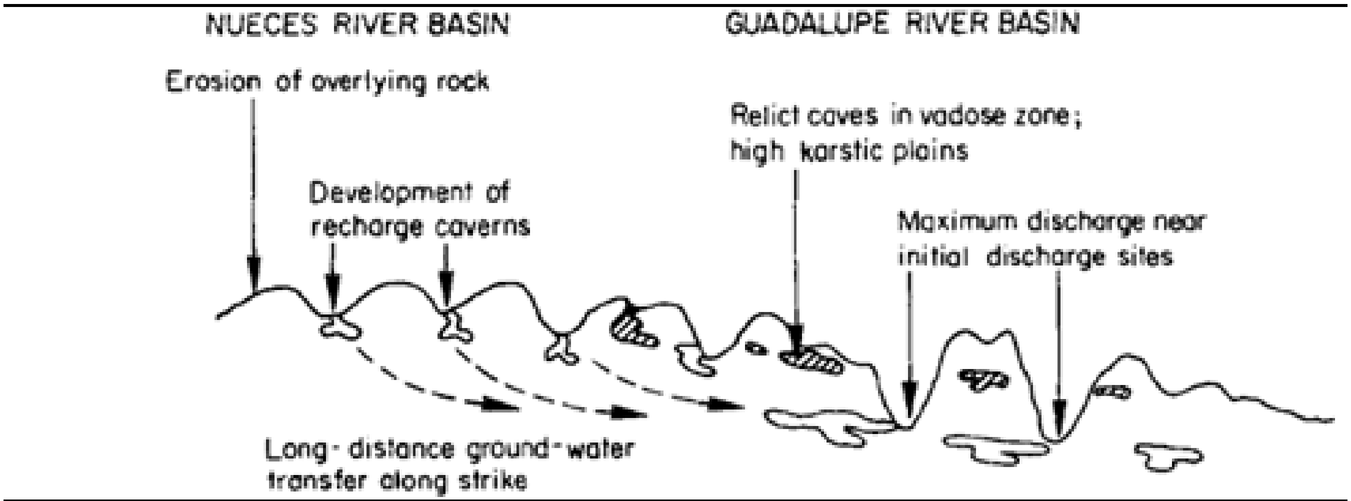
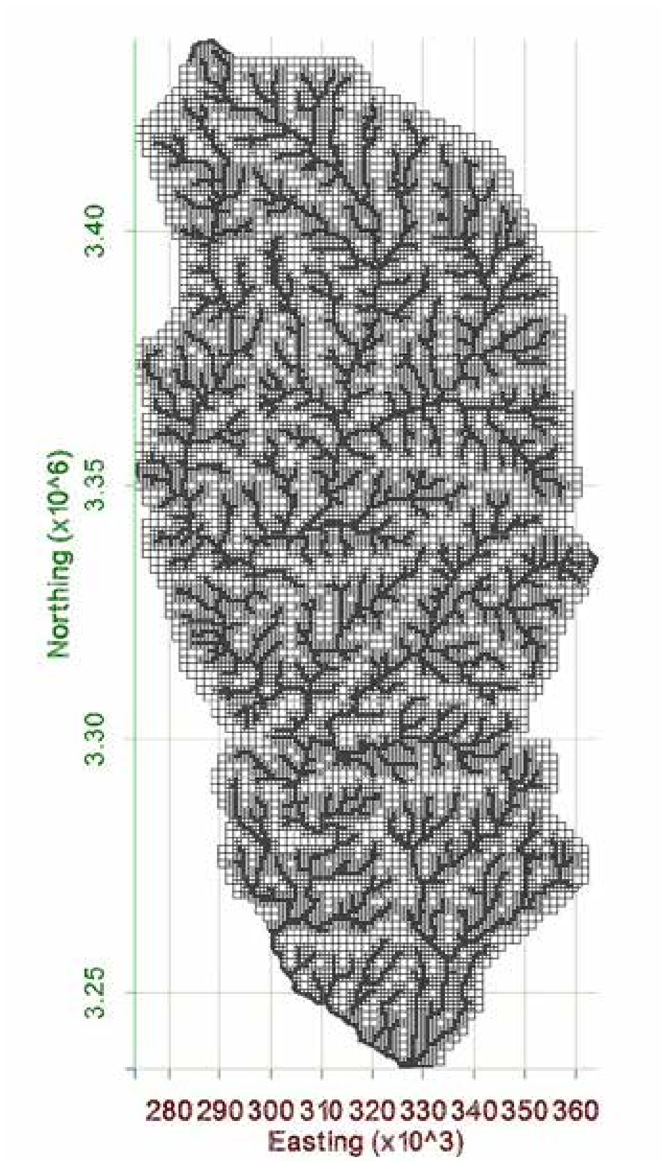


Figure 45. Schematic cross section of the development of recharge caverns coincident with incised river channels in the western Edwards Aquifer (taken from Woodruff and Abbott, 1979, 1986).



12. Green, R.T., Fratesi, S. E., Toll, N., Bertetti, F. P., & Nunu, R. 2019. Devils River Watershed. In Sharp, J.M., Jr., Green, R.T., & Schindel, G.M., eds., The Edwards Aquifer: The Past, Present, and Future of a Vital Water Resource: Geological Society of America Memoir. 215, p. 101–118, https://doi.org/10.1130/2019.1215(08).

The importance of the Devils River is noted as being one of the remaining pristine rivers in the state and as a key tributary to the Rio Grande, providing essential freshwater flows to south Texas and the Rio Grande Valley. An efficient conveyance system for groundwater is shown to have formed in the karst carbonate Devils River watershed, located in a semiarid environment with modest distributed recharge, often less than one to two centimeters per year. This conveyance system comprises preferential flow pathways that developed coincident with river channels. A strong correlation between wells with high-yield wells and proximity to higher-order river channels (e.g., within 2.5 kilometers) was used as evidence of the presence of preferential flow pathways. An important observation is that groundwater flow in the Devils River watershed appears to be controlled by the morphology of the area more than the bulk hydraulic properties of the rocks. Flow measurements in the Devils River measured under relatively high- and low-flow conditions support the hypothesis that the river is gaining in downstream reaches. This characteristic leads to perennial river flow being restricted to only the lower reach of the river. Last, essentially all of the recharge to Amistad Reservoir that is derived from the Devils River watershed is contributed as surface flow from the river, and there is minimal underflow or cross-formational flow from the watershed at the point where the watershed abuts Amistad Reservoir.

13. Hunt, B. B., Andrews, J. R., & Paine, J. G. 2023. Geologic map of the Dolan Springs Quadrangle, Val Verde County, Texas [Open-File Map No. 272]. The University of Texas at Austin, Bureau of Economic Geology. (Scale 1:24,000)

A new geologic map and digital map database provide detailed information about the geology of a portion of the Edwards-Trinity Plateau Aquifer and the Devil's River. This area, located within the Edwards Plateau region of Val Verde County, Texas, encompasses most of the State Natural Area managed by Texas Parks and Wildlife.

The bedrock geology primarily consists of the Fort Terrett and Fort Lancaster formations of the Edwards Group, as documented in previous studies (Waechter et al., 1977; Smith, 1964; Smith et al., 2000). Additionally, the map identifies Quaternary surficial deposits along the deeply carved Devils River and its tributaries, including various terrace formations. Other notable features mapped include fractures, faults, significant springs, and karst features.

This new map serves as a crucial foundation for understanding the structure of the aquifer and the interactions between surface and groundwater within the Edwards-Trinity Plateau Aquifer. The map area encompasses critical hydrologic features such as Dolan Creek, sections of the Dry Devils and Devils Rivers, and major springs like Finnegan Springs and Dolan Springs.

14. Hunt, B., Andrews, J., McKinney, T., Bongiovanni, T., Wolaver, B., Pierre, J. P., Caldwell, T., Saylam, K. & Costard, L. (2022). Airborne lidar bathymetry survey and aquatic habitat evaluation for Devils River minnow and Texas hornshell mussel in the Devils River of Val Verde County, Texas. The University of Texas at Austin, Bureau of Economic Geology, final contract report prepared for Texas State Wildlife Grant Program (TX T-174-R-1; F17AF01068), TPWD Contract No. 507663, 96 p. https://doi.org/10.18738/T8/JAY838.

The Devils River is a spring-fed river with a unique ecosystem and high biodiversity. The study aimed to address data gaps in understanding the river's hydrology and habitat characteristics. Overall, the study provides valuable data for future research and conservation efforts on the Devils River, particularly for endangered aquatic species.

Key Findings:

- **Task 1:** Created a detailed digital elevation and bathymetric model (DEM) from LiDAR and provided detailed aerial photography for a reach of ~43 miles (70 kilometers) of the perennial Devils River. Data was collected using airborne technology. Data provides a detailed DEM for further studies along the river corridor, including hydrologic modeling.
- **Task 2:** Monitored water temperature and depth at key locations for the endangered Texas hornshell mussel. Findings show that substrate temperature fluctuates with air temperature, and water depth varies significantly between locations.
- **Task 3:** Established and collected data from weather stations, stream gauges, and groundwater wells. Finegan-Blue Hole (FBH) spring complex is the largest quantified on the river (median 38 cfs), making up 23 to 71 percent of the total river flow at Dolan Crossing. Other springs upstream of the confluence of the Devils River and Dolan Creek were quantified in the study. Temperature and specific conductance (SC) were continuously measured at all the springs in this study and demonstrated a very good correlation of recharge. Groundwater levels correlate with spring flow, suggesting possible connections between specific wells and springs.

15. Hutchison et al. 2011. Update of the Groundwater Availability Model for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers of Texas. Texas Water Development Board (2011).

This report summarizes the updates to the groundwater flow model used in the groundwater availability model for the Edwards-Trinity (Plateau) and Pecos Vally Aquifers. The updated model (version 2.01) uses a one-layer model calibrated from 1930 through 2005.

The updates were completed with the overall objective of improving the calibration of the original model (version 1.01; Anaya & Jones, 2009).

A summary of adjustments made to the model include: 1) using a newer version of MODFLOW software (MODFLOW-2000) from the previous MODFLOW-96, 2) conversion from a two-layer to a one-layer model, 3) adjustments to Pecos Valley Aquifer boundaries to be more consistent with the aquifer boundary revisions of 2007 (Texas Water Development Board, 2007), 4) revisions to the western boundary of the model, including a general head boundary to simulate groundwater inflow from the west, 5) revision of the base elevation of the aquifer, 6) geographic extension of the model across the Rio Grande into Mexico, 7) revisions to the distribution of hydraulic parameters including recharge, hydraulic conductivity, anisotropy, and storage, and 8) updating the calibration period from 1980 through 2000 to 1930 through 2005.

16. Keester, M. R., & Furnans, J. 2018. "Review of Water-Resource Management of the Devils River Watershed Report by Toll and others (2017)." LRE Water, LLC Technical Memorandum to Ed McCarthy, Attorney for Val Verde County Landowner Interests.

Keester and Furnans conducted a preliminary review of Water Resource Management of the Devils River
Keester and Furnans conducted a preliminary review of Water Resource Management of the Devils River
Watershed Final Report (N. Toll, S. B. Fratesi, R. T. Green, F. P. Bertetti and R Nunu), Southwest Research Institute, August 11, 2017), which "provides detailed models linking groundwater in a Texas aquifer to the surface flows in one of the state's most pristine rivers" as well as stating the "Devils River watershed basin is being threatened by proposed large-scale groundwater export projects" by developing an integrated surface-water/groundwater model.

The review identified several flaws in the model, stating, "due to numerous apparent flaws, the reported simulation results are not credible and should not be used for planning or assessing impacts of proposed production." Further, the review recommends that the model be "re-conceptualized, re-parameterized, and re-calibrated..." incorporating "reasonable aquifer hydraulic parameters, aquifer structure, historical pumping, construction of Amistad Dam, and surface water interaction. The numerical model can then be developed to represent the conceptual model, taking into account and reporting all available data and model results so that stakeholders may better understand simulation results, limitations, and uncertainty."

17. **Kochel, R. C., Baker, V. R., & Patton, P. C. 1982. Paleohydrology of Southwestern Texas. *Water Resources Research*, 18(4), 1165-1183. https://doi.org/10.1029/WR018i004p01165.**

The Devils River is subject to extreme flash flood events, which this study quantifies while developing a methodology for studying high-water deposits of debris at the "slack water" perimeters in tributary mouths for both the Pecos and Devils rivers.

This paper introduces a methodology for estimating the occurrence intervals of rare, large-magnitude floods in the Pecos and Devils basins. The findings suggest that the most extreme floods on the Devils River may occur at intervals ranging from 1,000 to 4,000 years, with slightly lesser while still catastrophic floods occurring approximately every 700 years. For example, the rare 1954 flood caused by Hurricane Alice stalling over the Pecos and Devils watersheds appears to have a recurrence interval of "about 2,000 years."

Occurrence interval estimates for the four highest flood volumes at the mouth of the Devils (16,600 square meters per second to 15,400 square meters per second) range from 2,790 years to 700 years, respectively [Table 7b], while floods ranked in severity at the Jarrett Ranch range from 320 to 1,265 years for flood stages 8 to 11 meters, respectively [Table 5].

Although this study focuses on developing a methodology using the more abundant data available for the Pecos River, analysis of the Thompson and Jarrett (also known as Burnt Crossing) crossings contribute to flood interval and severity estimates for the Devils.

18. **Bradley and Ballew, 2023. Groundwater Use Planning Strategies and BMPs for Drought Scenarios, Val Verde County. Groundwater Management Report 23-01. Special Report to the Texas Legislature, Texas Water Development Board. https://www.twdb.texas.gov/groundwater/special_projects/valverde/index.asp.**

This report was generated in response to a 2021 Texas Legislature request whereby the Texas Water Development Board was tasked to identify possible groundwater planning strategies and best management practices for drought scenarios in Val Verde County. It summarizes and builds upon the 2018 Weinberg, et al. report, "Overview of Groundwater Conditions in Val Verde County, Texas," which provides an overview of the groundwater conditions in Val Verde County and discusses the feasibility of using hydrologic triggers to assist in groundwater management of the Edwards-Trinity (Plateau) Aquifer.

This report includes a summary of the groundwater conditions in Val Verde County and current data collection and modeling efforts.

Groundwater from the Edwards Trinity Plateau Aquifer is the major source of water supply for municipal, domestic, and livestock uses in the county. Val Verde County is an area of regional discharge with numerous springs that supply surface water for the City of Del Rio, sustain base flow for numerous creeks, including San Felipe and the Devils River, and support ecosystems for several threatened and endangered species.

The state's preferred method of groundwater management is by the direction of groundwater conservation districts. Currently, no groundwater conservation district(s) are present in Val Verde County and thus, groundwater planning and management in Val Verde County is limited to input from the Plateau Regional Water Planning Group and Groundwater Management Area 7, in which a desired future condition has been assigned for implementation in the State's Water Plan.

Recommendations from this report support future groundwater management and development, and center around educational and outreach opportunities, improving and enhancing data collection and research, and consideration of best management practices for drought conditions referencing examples of groundwater conservation districts with established index methods for drought and/or conservation stages. It suggests that Val Verde County, the City of Del Rio, and other interested parties would benefit from participating in Groundwater Management Area 7 activities to ensure that conditions adopted by the district members reflect groundwater concerns for Val Verde County.

19. U.S. Fish and Wildlife Service. 2017. Springs Assessment of the Dolan Falls Preserve and State Natural Area (Del Notre Unit). Final Report for the Nature Conservancy in Fulfillment of Dolan Springs Assessment.

This project mapped existing spring locations and gathered data on the aquatic communities and spring-adapted species present within the Dolan Falls Preserve and the State Natural Area. While the springs in this portion of the watershed had been generally mapped as spring complexes, there had not been a previous effort to map all individual springflow outlets in the complexes. This was a first step to detecting the best springs to monitor for flow, temperature, water quality, and biological communities.

In January 2016, the project mapped spring locations in three areas along and near the Devils River. Finegan Springs and Blue Hole Spring complexes are both on the Devils River proper, with the Dolan Spring complex feeding into Dolan Creek and finally the Devils River above Dolan Falls. Spring locations were collected and post-processed using a Trimble Nomad GPS unit and a Pro XT receiver. Following post-processing, 89.59 percent of the data was under a meter in accuracy. The remaining had 8.93 percent in the one to two-meter range and the remaining 1.48 percent in the two to five-meter range. The project collected elevation data using Topcon auto level and tied it into local benchmarks. The project documented spring locations (latitude and longitude) and elevation, defined the type of spring (e.g., orifice, upwelling, etc.), identified primary and secondary substrate (based on an expanded Wentworth scale), measured basic water chemistry (pH, dissolved oxygen, temperature, total dissolved solids, and conductivity), and flow which was quantified categorically (1 = seep through 5 = greatest flow). Overall, 102 spring openings were identified; Finegan Springs had 44, Dolan Springs 49, and nine were delineated within Blue Hole. The data collected from the mapping event was used to create a geodatabase and to design studies associated with this project. Sites were selected from the mapping data to provide either stratified or random sampling events over 2016.

This project also examined the aquatic invertebrate community structure of aquatic habitats within the study area, surveyed the springs and subterranean biota, and studied the distribution and habitat associations of Texas hornshell (*Popenaias popeii*) within the State Natural Area. The results of these tasks are not annotated in this report's Groundwater section.

This study also examined the contributions and types of contaminants present within the system. A semipermeable membrane device was used to determine contaminants within the water column, which collects the following fat-soluble, hydrophobic compounds: 31 organochlorines (OC), total polychlorinated biphenyls, five polybrominated diphenyl ethers (PBDE), and 34 polycyclic aromatic hydrocarbons (PAHs). Data collected was compared to a larger data set collected from other springs within the Edward Plateau.

20. Weinberg, A., French, L. N., & Perez, J. B. 2018. Overview of Groundwater Conditions in Val Verde County, Texas. Texas Water Development Board Special Report. https://www.twdb.texas.gov/groundwater/special_projects/valverde/docs/Groundwater-Resources-of-Val-Verde-County-86th-legislature.pdf.

This report compiles and analyzes scientific and technical data on the groundwater and related natural reThis report compiles and analyzes scientific and technical data on the groundwater and related natural resources of Val Verde County and considers the feasibility of potential hydrologic triggers as a groundwater management tool. It examines existing data on geography, geology, hydrogeology, pumping, water levels, and streamflow to determine if any current monitoring locations meet these criteria and to define the general types and locations of additional monitoring that might be required to meet potential groundwater management objectives.

Key findings of the report include:

- Maintaining streamflow and water quality are important components of wildlife management efforts for threatened and endangered species in Val Verde County.

- Worsening future droughts and the potential for increased groundwater withdrawals could exacerbate the loss of species habitat, increasing the rate of species decline and leading to critical groundwater problems in coming decades.
- Groundwater quality data suggest that most recharge supplying major springs occurs through large fractures and sinkholes, and discharges through a system of conduits with minimal interaction with the aquifer matrix under normal flow conditions.
- Available water level records do not demonstrate any widespread, long-term effects or recharge, streamflow, or groundwater-surface water interaction because of current pumping levels in Val Verde County.
- Several groundwater models cover Val Verde County, but targeted groundwater monitoring is needed to support refinements to the existing models. Data gaps exist concerning key factors such as groundwater-surface water interactions, aquifer storage, and recharge.
- Val Verde County does not have a groundwater shortage. Groundwater pumping in Val Verde County is less than 5,000 acre-feet per year, while the modeled available groundwater totals 50,000 acre-feet per year.
- The currently adopted desired future condition for the Edwards-Trinity (Plateau) Aquifer may not adequately address all potential groundwater management concerns in Val Verde County. Because there is no mechanism to enforce compliance with the desired future conditions, the rule of capture serves as the current groundwater management approach.
- Index wells and hydrological triggers would be feasible strategies for groundwater management in Val Verde County, but additional technical and stakeholder input is needed to develop management objectives before specific trigger values based on groundwater levels can be determined.

21. Wilcox, B.P., et al. 2008. Subsurface stormflow is important in semiarid karst shrublands, Geophysical Research Letters. https://doi.org/10.1029/2008GL033696.

This paper indicates that the removal of shrub cover had no appreciable changes to runoff generation in two river basins – Honey Creek in the Hill Country and Sonora River in the Edwards Plateau. Subsurface flow through the karst landscape remained the dominant runoff generation and recharge process even after vegetation removal. Overland flow does occur; however, it is not spatially or temporally uniform.

22. Wilcox, B.P. & Huang, Y. 2010. Woody plant encroachment paradox: rivers rebounds as degraded grasslands convert to woodlands. Geophysical Research Letters. https://doi.org/10.1029/2009GL041929.

This paper found that four major river basins (Llano, Nueces, Guadalupe, and Frio rivers) in the Edwards Plateau region experienced double the amount of baseflow even though the rainfall depths remained constant during the study period (1925 to 2008). It highlights that streamflow in these watersheds is fed by baseflow rather than stormflow. The research suggests that lower grazing pressure has promoted shrub encroachment, which has increased groundwater recharge and streamflow. The vegetation in this region has undergone grassland to shrubland/woodland conversion due to fire suppression and positive feedback between wind erosion and overgrazing. Contrary to some views that an increase in woody cover leads to a decline in runoff and recharge, this study's results indicate that the sequence of land cover transition and the karst landscapes are driving the increases in streamflow.

23. Young, D., Robertson, S. & Hunt, B. 2024. Streamflow gain and losses in the Devils River, Texas. (Work in Progress)

This work in progress describes a gain-loss study conducted along 42 miles of the spring-fed Devils River of the Edwards-Plateau Aquifer in Southwest Texas. The authors measured discharge at 19 sites across five sampling events in 2021 and 2022. Reach scale gains and losses were quantified as the difference between the upstream and downstream discharge measurement after accounting for quantifiable sources of input (tributaries, return flows) and output (withdrawals). Results indicate a spatially consistent pattern of gains and losses across the seasons and flow conditions observed during the study. Overall, the river is gaining across the study area except at two losing reaches that decrease streamflow by 17 percent and 39 percent on average. The higher sampling frequency and spatial resolution of the results improve existing knowledge. Significant gaining reaches are corroborated elsewhere, but details of the losing reaches were previously less refined. The author's purpose for this study was to support refinements to the conceptual model of the aquifer and allow for a better understanding of surface-groundwater interactions for the Devils River, something critical to understanding the relationship between environmental conditions and available habitat for imperiled species. The implications suggest that groundwater conservation management should focus on springs and spring habitats and include losing reaches, which are the habitats most susceptible to drying.

Key Readings for Understanding Devils River Water Quality

1. Spring Flow and Temperature Dynamics in an Arid Karst Environment - describes how springs stabilize water temperatures and reduce extremes, but a 30-year record shows gradual warming.
2. Assessment of Water Quality of Segment 2309 – highlights the Devils River's consistently excellent water quality and emphasizes the necessity for continued monitoring and conservation efforts.
3. Devils River at Pafford Crossing near Comstock – details historical water quality trends between 1978-1995 on the Devils River analyzing data from 104 water quality samples.
4. Final Report for the Nature Conservancy (Dolan Springs) – revealed higher levels of contaminants in the Devils River compared to Dolan, which is surprising given the low amount of impervious cover in both the Dolan and Devils catchments.
5. Goodenough Spring Discharge and Water Chemistry - highlights that water quality remains excellent for both human consumption and crop irrigation, with values largely unchanged from those reported 37 years ago.
6. Water Quality and the Types of Fish and Macroinvertebrates Living in the Devils and Pecos Rivers – describes how fish species in the Pecos were more tolerant of environmental stress, while the Devils River had a greater diversity of macroinvertebrate species.
7. Investigation of Water Resources of the Devils River Basin – describes how the groundwater drainage basin supporting the Devils River is much larger than the surface watershed, and surface water data show excellent water quality.
8. The Devils River Hydro Plants - details the history of hydropower plants on the Devils River, which were built to meet the growing demand for energy as people moved into southwest Texas.
9. Recommended Water Quality for Federally Listed Species in Texas - describes that contaminant and habitat threats to the Devils River minnow (Dionda diaboli) include ammonia, chlorine, effluent discharge, habitat dewatering, invasive species, oil spills, hazardous material releases, sediments, and stormwater runoff.

1. Caldwell, Todd G. et al. "Spring Discharge and Thermal Regime of a Groundwater Dependent Ecosystem in an Arid Karst Environment." Journal of Hydrology, vol. 587, no. 124947, 2020. https://doi.org/10.1016/j.jhydrol.2020.124947.

This study took place over three years, from January 2016 to December 2018, and assessed the impacts of spring discharge on instream temperatures in the Devils River. These impacts were assessed because groundwater discharge to streams generally stabilizes flows, mediates water temperatures, and supports riverine ecosystems. The Devils River was used as a case study for this research because it is a spring-fed river in a karst environment where climate change and groundwater development threaten to reduce spring flows and aquatic habitats of protected species.

The study site was a section of the perennial reach of the Devils River within the State Natural Area and The Nature Conservancy Dolan Falls Preserve in Val Verde County, Texas. The study site focused on the Finegan Springs complex and the confluence of the Devils River and Dolan Creek, approximately 37 miles north of the city of Del Rio.

Monitoring data revealed that springs contributed approximately 40 percent of total river discharge. Spring temperatures were consistently 22.6 ± 0.3 degrees Celsius (~72-73 degrees Fahrenheit) providing thermal buffering to aquatic habitats. Springs reduced temperature extremes by 50-70 percent, cooling the streamflow in summer and warming it in winter. By correlating short-term monitoring data with modeled long-term temperature data, the surface water temperature records were extended to 30 years, revealing a long-term warming trend with daily maximum water temperature increasing 0.16 degrees Celsius (~0.28 degrees Fahrenheit) per decade. This long-term air and water temperature evaluation suggests susceptibility to climate change; however, extreme drought and groundwater depletion represent more acute problems in the near-term for such karst environments.

2. **De La Cruz, Augustine. "An Assessment of Water Quality of Segment 2309 (Devils River)." No. AS-193, Texas Commission on Environmental Quality, 2004.**

The technical paper by De La Cruz et al., published in February 2004, evaluates the water quality of Devils River in Texas based on field studies conducted in September 1993 and July 1994. The study comprehensively assesses the river's environmental health by focusing on various parameters such as sediment quality, compliance with water quality standards, and evaluation of non-point source pollutants.

Spanning parts of Val Verde, Crockett, Sutton, and Schleicher counties, the study area features an arid landscape with intermittent stream flow within the upper basin and perennial flow within the lower basin sustained by springs. Despite occasional flooding and rough terrain, the river supports diverse aquatic life and recreational activities.

The findings reveal excellent water quality conditions except for naturally elevated nitrate levels. Dissolved oxygen levels and nutrient concentrations exceed water quality criteria. Sediment analyses indicate no significant accumulation of heavy metals or organic pollutants. However, a single instance of high fecal coliform concentration at one site prompted follow-up investigations.

Supported by historical data, the study underscores Devils River's consistently high-water quality, which complies with stringent standards established by the Texas Commission on Environmental Quality. Given the river's ecological significance, biological diversity, and recreational value, the paper emphasizes the necessity for continued monitoring and conservation efforts.

In conclusion, the technical paper is a crucial resource for policymakers and environmental agencies, providing valuable insights into Devils River's ecological health and guiding effective management strategies for its protection and preservation.

3. **"Devils River at Pafford Crossing near Comstock, Texas (Station 08449400)." Hydrologic Benchmark Network Stations in the Midwestern U.S. 1963-95, No. 1173-B, U.S. Geological Survey, 2000. https://pubs.usgs.gov/circ/circ1173/circ1173b/chapter12.htm.**

This report, published by the U.S. Geological Survey in 2000, details historical water quality trends between 1978-1995 on the Devils River at Pafford Crossin near Comstock (Station 08449400). This station is one of the approximately 50 stations in the Hydrologic Benchmark Network, a U.S. Geological Survey initiative to provide long-term monitoring data on waterways draining undeveloped lands.

The evaluated gauging station is located almost 11.5 miles east of Comstock, Texas. The 1.2-mile reach of the main channel upstream from the gaging station is in the boundaries of the Amistad National Recreation Area.

The analyzed data for this report includes 104 water quality samples collected from January 1978 through August 1995. Sampling frequency was monthly from 1978 through 1980, bimonthly from 1981 through 1986, and quarterly from 1987 through 1995.

The median discharge for the period of record was 8.7 cubic meters per second, or 307 cfs. Stream water in the Devils River is fairly ion concentrated and well buffered by its salt content; specific conductance ranged from 250 to 460 microsiemens per centimeter, and alkalinity was between 1,800 and 4,760 microequivalents per liter. Data suggests that salt content in the Devils River is derived from sources in the basin rather than atmospheric deposition, including dissolution of salts in the carbonate bedrock or perhaps oil field activities in the northern part of the basin.

4. **Diaz, Peter H. et al. "Final Report for the Nature Conservancy in Fulfillment of Dolan Springs Assessment." The Nature Conservancy, 2018.**

In 2016, The Nature Conservancy funded a collaborative project to map existing spring locations and gather data on the aquatic communities and spring adapted species present within the Dolan Falls Preserve and the State Natural Area.

Assessing the health of aquatic communities can indicate the quality of water in a water system as potential changes in water quality and quantity can threaten aquatic organisms. One hundred thirty-two aquatic invertebrate samples were collected from the aquifer, spring sites, transition area, Dolan Creek, and the upper and lower Devils River totaling 72,340 aquatic invertebrates. Based on this collected data, the health of the Devils River and Dolan Creek are in pristine condition. To maintain this pristine condition, the quality and quantity of water in the watershed (surface and subsurface) must be maintained.

Researchers also conducted a contaminant analysis on the Devils River and Dolan Creek, above and below the confluence. Contaminant results were examined in four ways: 1) the number of each type collected (count); 2) the amount of each type calculated (weight); 3) total summation of the overall sample; 4) a comparison to the larger Edwards Plateau spring data set.

Based on this type of analysis, both the contaminant count and weight collected on the Devils and Dolan sites fall between the second (median) and third (75th percentile) quartile of the larger Edwards Plateau spring data set. In other words, when compared to contaminant sampling of the larger Edwards Plateau, contaminants on the Devils and Dolan sites were above the median but less than the highest 25 percent of numbers.

The Devils River had more contaminates than Dolan in count and in weight. The Dolan Creek sample had more polycyclic aromatic hydrocarbon (PAH) detections in count and weight than the Devils River sample. No total polychlorinated biphenyls were detected at either site. The most common type of contaminant detected was organochlorines. The largest detection within the organochlorines was the pesticide Chlorpyrifos, accounting for 50 percent of the total weight of summed organochlorines within the Devils River sample.

Despite the weight of contaminants present being low for each type of contaminant, when compared to the larger Edwards Plateau spring data set, these results are surprising given the low amount of impervious cover in the Dolan and Devils catchments. As such, it is recommended to continue the work conducted within this document to allow for trends to be captured due to changes in spring flow or water quality overtime and determine responses of aquatic communities to these variables.

5. **Kamps, Ray H. et al. "Goodenough Spring, Texas, USA: Discharge and Water Chemistry of a Large Spring Deeply Submerged Under the Binational Amistad Reservoir." Hydrogeology Journal, vol. 17, 2008, pp. 891-899. https://link.springer.com/article/10.1007/s10040-008-0404-0**

Goodenough Spring is a large spring that discharges into the international Amistad Reservoir. Discharge was routinely measured from 1928 until 1968 but has subsequently been estimated indirectly by the IBWC.

In the Summer of 2005, researchers took the first direct measurements of the Goodenough Spring in 37 years. These measurements included spring discharge as well as in situ and laboratory analyses of water samples for temperature, pH, dissolved oxygen, specific conductance, alkalinity, nitrate-nitrogen, dissolved solids, chloride, sulfate, fluoride, phosphorus, calcium, sodium, potassium, magnesium, and iron.

Spring discharge was calculated at 2.03 cubic meters per second (or 71.cfs), approximately one-half of the historical mean of 3.94 cubic meters per second (or 139.1 cfs). Water quality was shown to be very good for human consumption and crop irrigation, and these measurement values are relatively unchanged from those reported 37 years prior. One key conclusion is that the Devils River flow may be used as a general indicator of regional climatic conditions.

6. **Moring, J.B., "Water Quality and the Composition of Fish and Macroinvertebrate Communities in the Devils and Pecos Rivers in and Upstream from the Amistad National Recreation Area, Texas, 2005–7." U.S. Geological Survey Scientific Investigations Report 2012-5038, 70p., 2012, https://pubs.usgs.gov/sir/2012/5038/**

Over the course of three years, this study looked at various water quality parameters in the Devils and Pecos Rivers and the composition of fish and macroinvertebrate communities. Of particular note, concentrations of total dissolved solids, chloride, sulfate, and ammonia plus organic nitrogen, were higher within the Pecos River, frequently by more than an order of magnitude, however, levels were still below the proposed Texas Surface Water Quality Standards for the segment of river where samples were collected. Fish species more tolerant to environmental stressors were more abundant in the Pecos River, and the Devils River boasted a larger number of macroinvertebrate species. It was theorized that water chemistry, differences in zoogeographic history, lack of riverine connection between rivers due to impounded waters, and distance from Amistad Reservoir may account for differences in fish communities between rivers.

7. **"Reconnaissance Investigation of Groundwater and Surface Water Resources of Selected Portions of the Devils River Basin, Val Verde, Crockett, and Sutton Counties, Texas." United Research Services; The Nature Conservancy, 2004**

In 2004, The Nature Conservancy published this report detailing the preliminary research the Conservancy conducted regarding the water resources of the Devils River watershed to assess and potentially identify strategic locations for establishing conservation easements designed to maintain watershed health. Additional research objectives included assessing data needs (especially water quality) and making recommendations to improve the current state of science where there is insufficient information to make detailed scientific evaluations.

Regarding groundwater resources, the report found that the groundwater drainage basin is significantly larger than the surface watershed. Thus, to properly delineate the groundwater basin that supports the Devils River Watershed, a regularly monitored network of groundwater wells to monitor groundwater levels is required. The Nature Conservancy recommends a water budget approach is the best method of determining the amount of groundwater needed to support baseflow within the Devils River.

Regarding surface water resources, the only available long-term and consistent water quality data is for the Pafford Crossing gage. However, other data collected in both the main stem of the Devils River and on Dolan Creek support the conclusion of excellent water quality in the river. Also, the water quality in the Devils River can significantly impact the water quality in the Rio Grande. The development that has occurred in the watershed is almost entirely agricultural, but there is no evidence to suggest agricultural practices in the area are impairing water quality. Regarding applying for a new water right on the Devils River (e.g., agriculture, recreation and pleasure, public parks, and game preserves), the Nature Conservancy may wish to discuss the advantages, disadvantages, opportunities, and costs of securing a water right to support the organization's goals.

The report concludes with identified programs to help fund watershed research and management, as well as recommendations. Because hydrologic and hydrogeologic studies of the Devils River Watershed are severely limited, this report is important in furthering the knowledge related to water resources in the watershed.

8. **"The Devils River Hydro Plants." U.S. National Park Service, 2023. https://www.nps.gov/amis/learn/historyculture/devilslake.htm**

   This article, published by the National Park Service, details the history of hydropower plants on the Devils River. As people began to move into Texas lands, there was an ever-increasing demand for a steady supply of energy, particularly in southwest Texas. The Devils River became the ideal choice as an energy source for the Central Power & Light Company due to the geography of the area—it was near existing railway and highway corridors, it had a history of steady flow, and the topography would keep construction to a minimum.

   In 1928, the Central Power & Light Company, with the help of the L.E. Myers Construction Company, began constructing three hydropower plants on the Devils River. The first was named Devils Lake Hydro Plant and was located 16 miles northwest of Del Rio and 10 miles above the confluence of the Devils River and the Rio Grande. The second was named Lake Walk Hydro Plant and was the smallest and most technologically advanced of the three plants on the Devils River. The third was named Steam Plant and was located on the east side of the Devils River, about 10 miles outside Del Rio and just west of present-day Southwinds Marina.

   As a result, regional development in southwest Texas occurred for decades after the plants were constructed. The Central Power & Light Company, with the help of West Texas Utilities, also built over 200 miles of new transmission lines from the Devils plants to existing power grids about 70 miles east in Uvalde.

   The hydropower plants withstood several major floods that occurred in the area but were ultimately shut down after the construction of the Amistad Dam and power plant. The article includes 17 images of the hydropower plants on the Devils River.

9. **White, Allen J. et al. "Recommended Water Quality for Federally Listed Species in Texas." USFWS Technical Report, U.S. Department of the Interior; U.S. Fish and Wildlife Service, 2006.**

   This technical report assessed the water quality requirements for aquatic species and aquatic-dependent species that have been listed (or proposed for listing) in Texas as threatened or endangered. The purpose of the report is to provide this preliminary water quality information to agencies regarding the development of protective water quality criteria and standards.

   Waters in Texas serving as species habitat are grouped into four broadly defined water categories, with the Devils River falling into Category 3 – surface waters in spring runs, spring pools, or spring-dependent wetlands. The categories are used to make recommendations for conserving listed species regarding actions required under the Clean Water Act such as permits for discharge of wastewater.

   The U.S. Fish and Wildlife Service recommends that all Category 3 waters (excluding the Comal and San Marcos rivers) should not have wastewater discharges because those discharges would likely have an adverse effect threatened or endangered species along with their associated habitats. Additionally, it is recommended that wastewater discharge permits should not allow zones of initial dilution (ZIDs) in any waters where aquatic listed species occur.

   Contaminant habitat threats to the Devils River minnow (*Dionda diaboli*) include ammonia, chlorine, effluent discharge, habitat dewatering, invasive species, oil spills/hazmat releases, sediments, and stormwater runoff.

Key Readings for Understanding Devils River Species and Flows

1. A 2016 baseline assessment of bat occurrence within the State Natural Area's DAH Unit.

2. A 2003-2004 floral inventory at Amistad National Recreation Area in Val Verde County, Texas, comparing current plant communities with historical records.
3. A 2001 study of mammal surveys at the State Natural Area across varied habitats, providing detailed data on abundance, seasonal activity, and reproductive patterns.
4. A 1953-1954 inventory of fish populations and water quality of the Devils River up to its confluence with the Rio Grande before the construction of Amistad Reservoir.
5. A study that assessed springs and aquatic ecosystems in the Dolan Falls Preserve.
6. Results of breeding bird surveys (1997-2001) at Dolan Falls Preserve.
7. Relationship between stream discharge and habitat availability for the Devils River Minnow (*Dionda diaboli*) and other native fishes in the Devils River and Dolan Creek.
8. Habitat associations of a semi-arid fish community in the upper and middle Devils River from Juno to the Dolan Falls Preserve.
9. Water quality and composition of fish and macroinvertebrate communities in the Devils and Pecos rivers in and upstream of the Amistad National Recreation Area
10. Results of a two-year (2003–2004) reptile and amphibian inventory survey of six National Park Service sites, including a portion of the Amistad National Recreation Area.
11. Habitat associations from 2003 of fishes across two reaches in the middle Devils River.
12. An examination of conservation efforts for the Devils River that details its ecological significance, threats, and collaborative efforts to preserve its endemic aquatic species and habitats.
13. A preliminary survey from 1975 of the vertebrate fauna of the Dolan Falls Preserve.
14. A 2020 investigation of vegetation changes at Dolan Falls Preserve.
15. Nesting ecology and multi-scale habitat use of the black-capped vireo in the State Natural Area.
16. An overview of the Nature Conservancy's 2024 Conservation Area Plan for the Devils River

1. Allred, Fredric Grayson. Baseline Assessment of the Bats of State Natural Area, Dan A. Hughes Unit, Val Verde County, Texas. 2016. Angelo State University, M.S. Thesis. http://hdl.handle.net/2346.1/30568.

This thesis documented bat species occurrence within the DAH Unit to establish a baseline of bat diversity and determine seasonal fluctuations in bat taxa and activity at the site. Monthly monitoring efforts from July 2013 to December 2014 comprised ten nights of mist netting, 14 nights of stationary acoustic recordings, and 24 driven acoustic transects. Resulting capture and acoustic data revealed the occurrence of 13 bat species at the study site; stationary acoustic monitors detected all 13 species, while seven species were detected by acoustic monitors driven along transects, and only three species were captured by mist net. There was seasonal variation in diversity, with 12 bat taxa detected in spring 2014, and only five detected in summer 2014. Three species were detected year-round, and the other ten were detected only seasonally, though the activity of all species varied according to season. A discussion of management recommendations advised that wetlands and snags be maintained at the site. The results of this thesis may not accurately represent seasonal variation in bat taxa presence and activity at the site because survey methods were not always the same each month at each site. One method was used consistently (driving acoustic transects); however, only 6.5 percent of the resulting data from this method was of useable quality for analysis.

2. **Poole J.M. An Inventory of the Vascular Plants of Amistad National Recreation Area, Val Verde County, Texas. 2013. Lundellia, Vol. 16. http://hdl.handle.net/2152/32661.**

   As of 2013, the Amistad National Recreational Area spans approximately 23,000 hectares in Val Verde County, Texas. The plant community in the park has been shaped in part due to land use history, including grazing by cattle, sheep, and goats; fire suppression has led to an increase in woody vegetation, and vegetation restoration management such as bulldozing, root-plowing, chaining, and hand clearing was used to improve overall vegetation. A vegetation survey was conducted in 2003-2004, of which 61 sites were visited, which resulted in the observation of 699 taxa and 686 species. No federally or state-listed species were observed; however, 17 species of conservation concern were verified in the park. Primary plant compositions in the park include South Texas Plains mixed shrublands of blackbrush (*Acacia rigidula*), guajillo (*Acacia berlandieri*), and Texas barometer bush (*Leucophyllum frutescens*), and woodlands mixed of oak (*Quercus spp.*) and juniper (*Juniperus spp.*) of the Edwards plateau. The west part of the park is composed of primarily creosote bush (*Larrea tridentata*) and Lechuguilla (*Agave lechuguilla*), indicator species of the Chihuahuan desert. This landscape's semi-arid nature is somewhat mitigated by springs, rivers, and a human-created reservoir, which includes aquatic vegetation such as Hydrilla species. The Amistad National Recreational Area contains many rare and endemic plants, and the author discussed the need for continued plant surveys to further understand factors associated with the plant community in the area.

3. **Brant, J. G., & Dowler, R. C. 2001. 2000. The Mammals of State Natural Area, Texas. Occasional Papers, Museum of Texas Tech University, Lubbock, Texas. https://www.depts.ttu.edu/nsrl/publications/downloads/OP211.pdf.**

   The objectives of this study focused on updating previous mammal surveys of the State Natural Area, specifically: 1) occurrence of mammal species, 2) relative abundance estimates of small rodent species, 3) habitat associations for species, 4) seasonal patterns of abundance for species, and 5) seasonal reproductive patterns of species. The following representative vegetational communities were sampled: riparian, juniper-oak series shrubland, cenizo series shrubland, lechuguilla-sotol series desert shrubland, and curly mesquite-sideoats grama series grassland. Identifiable locations of sampling sites within these communities were: Jumper Slope, East Canyon Slope, Cenizo Slope, Grassland Plateau, Dolan Springs, the Headquarters Building, Fawcett Cave, Radio Towers, First Landing Strip, Second Landing Strip, and Jose Maria Springs. Sherman and Tomahawk live traps were employed for small to medium-sized mammals, whereas larger mammals were observed by spotlight, casual visual observation, or collection. Certain specimens were individually marked and released. Others were collected and prepared as museum voucher specimens and deposited at the Angelo State Natural History Collections in San Angelo, Texas. Mark-recapture data were sampled from 200 trap nights per season, totaling 800 trap nights per primary sampling site. Thirty-nine species (10 orders, 18 families) were collected, including three county records. The two most abundant rodents were Peromyscus pectoralis and Chaetodipus nelsoni, and the most abundant bat was the Mexican free-tailed bat (*Tadarida brasiliensis*). Val Verde County records included the evening bat (Nycticeius humeralis mexicanus, Davis 1944), desert shrew (*Notiosorex crawfordi crawfordi*, Cones, 1877), and plains harvest mouse (*Reithrodontomys montanus griseus*, Bailey 1905).

4. **Brown, W.H. 1954. "Inventory of species present and their distribution in those portions of the Devil's River, excluding Devil's Lake and Lake Walk which lie within Val Verde County, Texas." Texas Parks and Wildlife Department, Project No. F-9-R-1, pp. 1–3.**

   Fish collections were made at 12 reaches on the Devils River, spanning most of the perennial section of the river from Pecan Springs down to the confluence with the Rio Grande, in 1953 and 1954 using seines and a gill net. Water quality data was collected at seven sites, including temperature, pH, dissolved oxygen, alkalinity, and chlorides. Twenty-eight species were collected, two of which were new species. The most abundant fish species encountered were *Notropis venustus* (now *Cyprinella venusta*) and *Dionda episcopa* (now *Dionda argentosa*). Sportfish were found throughout the entire stream and were thought to provide excellent fishing opportunities. This report provides a valuable look at the fish community and water quality along the length of the river prior to the construction of Amistad Reservoir and includes historical photographs of the river.

5. **Diaz, P., Montagne, M., Norris, C., & Aziz, K. 2018. Final report for the Nature Conservancy in fulfillment of Dolan Springs Assessment. U.S. Fish and Wildlife Service and Texas Parks and Wildlife Department.**

   The Nature Conservancy funded a project to map and categorize the springs, collect spring community and water quality data (including contaminants), and conduct mussel surveys in and around the Dolan Falls Preserve. Data was collected on the community structure of the ecosystem components to better understand the complex interface of the region's surface and subterranean hydrology and identify any deleterious effects resulting from land or water use changes.

   There were five main goals of the project: mapping the springs, examining the community structure of aquatic habitats, examining spring-associated organisms' distribution and abundance to determine distribution and habitat associations of Popenaias popeii within the State Natural Area, and collecting and examining contaminants data from the springs.

   Results from this study show that the Devils River and Dolan Creek aquatic ecosystems and their associated springs are taxonomically diverse, well-balanced in community structure, and unique. This study highlights the importance of the ecosystem components and their associated taxa to the diversity within the study zone and regionally in some cases (*Typhloelmis finegan*, *Eurycea sp. 3*, *Bicornucandona fineganensis*, etc.). The data was collected during a year when the flow in Dolan Creek was slightly above-average.

6. **Farquhar, C. C. 2001. Results of breeding bird surveys (1997-2001) at Dolan Falls Preserve, Val Verde County, Texas. Unpublished data.**

   In 1997, a permanent Breeding Bird Survey route was established following standard procedures in riparian, canyon, and upland habitats at Dolan Falls Preserve in Val Verde County, Texas. All points were established along navigable roads to facilitate access and data collection in one morning. A metal T-post was driven into the ground at each point to serve as a permanent marker. Geographic coordinates for each point were logged into GPS units and entered into GIS files. Surveys were conducted from 30 minutes after sunrise until completion during mid-May each year. A total of 2,267 individuals from 87 species were recorded over the five-year period, with 53 to 61 species observed per year. The most frequently observed species (51 percent of total) included, in descending order, turkey vulture (*Cathartes aura*, 10 percent), northern cardinal (*Cardinalis cardinalis,* 7 percent), painted bunting (*Passerina ciris*, 6 percent), black-throated sparrow (*Amphispiza bilineata*, 5 percent), Bewick's wren (*Thryomanes bewickii*, 5 percent), rufous-crowned sparrow (*Aimophila ruficeps*, 5 percent), yellow-breasted chat (*Icteria virens*, 4 percent), canyon wren (*Catherpes mexicanus*, 4 percent), and Bell's vireo (*Vireo bellii*, 4 percent). Black-capped vireo (*V. Atricapilla*) was recorded 73 times (3 percent), mostly in riparian and canyon habitats.

7. **Hardy, T.B. 2014. Relationship between stream discharge and habitat availability for the Devils River Minnow (*Dionda diaboli*) and other native fishes in portions of the Devils River and Dolan Creek, Val Verde County, Texas. Texas Parks and Wildlife Department, pp. 1 – 28.**

   Two-dimensional hydraulic models were developed for two sites on the Devils River adjacent to the State Natural Area-Del Norte Unit and one site on Dolan Creek adjacent to the Dolan Falls Preserve. Three-dimensional bathymetric data, stream discharge and associated water surface elevations, mesohabitat, substrate, aquatic vegetation, and current velocities were provided by Texas Parks and Wildlife and used to construct and calibrate two-dimensional models (multi-dimensional surface water modeling system) at three study sites. Habitat suitability criteria for priority species were used to simulate the relationship between stream discharge and available physical habitat. During the data collection period, discharge was stable for Dolan Creek, leading to low stream flow variability, making model runs infeasible for Dolan Creek. Habitat remained consistent at the upper Devils River site and decreased with increasing flows at the lower site; however, it should be noted that the model was calibrated to a relatively narrow range of flows (30 to 75 cfs) so it had limited utility in predicting habitat changes at moderate to high flows. While not modeled, data indicates that declining flows below 35 cfs would reduce margin habitats exponentially. Overall, this study provides information connecting available fish habitat and stream discharge at lower flows in priority reaches of the Devils River. Water surface elevation data coupled with stream discharge at a wider range of flows would expand the capability of this modeling effort and allow greater inferences on the impact of changing flows on available habitat for fish species.

8. Kollaus, K. A., & Bonner, T. H. 2012. Habitat associations of a semi-arid fish community in a karst spring-fed stream. Journal of Arid Environments, vol. 76, pp. 72 – 79.

Six sites were assessed in the upper and middle Devils River from Juno to the Dolan Falls Preserve. Sites were selected to represent both spring and river-influenced habitats and were sampled every two months from September 2007 through October 2008. Fish, water quality, and instream habitat data were collected along transects. Twenty-seven fish species were collected across the sampling period, ***Dionda argentosa*** and ***Notropis amabilis*** being the most abundant species. The report details habitat associations for species collected, with current velocity, depth, and vegetation as the primary drivers for fish distribution and stream temperature as an important factor for spring-associated species. Thermally stable spring habitats serve as a refuge for spring associates in the winter and summer months. This study provides comprehensive fish assemblage data for the upper and middle Devils River that can be compared to historical data to assess changes in the fish assemblage. It also contains valuable habitat use data to develop habitat suitability criteria for species in this Devils River.

9. Moring, B. 2012. Water quality and composition of fish and macroinvertebrate communities in the Devils and Pecos Rivers in and upstream from the Amistad National Recreation Area, Texas, 2005-2007. U.S. Geological Survey. https://pubs.usgs.gov/sir/2012/5038/.

The project conducted a reconnaissance-level survey of the water quality and fish and macroinvertebrate communities in the Devils and Pecos Rivers in and upstream from the Amistad National Recreation Area in Southwest Texas during 2005 and 2007. Water quality conditions during the spring and summer months of 2005 in the Devils and Pecos rivers were assessed at locations just upstream from the Amistad National Recreation Area, and the composition of fish and macroinvertebrate communities were assessed during 2006 and 2007 in and upstream of the Amistad National Recreation Area and Amistad Reservoir. Water-quality samples were collected at one site on both the Devils and Pecos rivers.

A total of 29 fish species were collected from the four sites on the Pecos River in and upstream of Amistad National Recreation Area. The number of fish species decreased by about 42 percent between the site farthest upstream and the site farthest downstream on the Pecos River based on a comparison of 2006 sampling results. Totals of 100 and 80 unique macroinvertebrate taxa were collected in the Devils and Pecos River, respectively. No pattern in the number of unique macroinvertebrate taxa in relation to distance from Amistad Reservoir was observed.

The reconnaissance-level survey of selected water-quality constituents was done during the spring (March, April, and May) and summer (June and August) of 2005 at sampling sites on the Devils and Pecos rivers—U.S. Geological Survey stations 08449400 Devils River at Pafford Crossing near Comstock, Texas, and 08447410 Pecos River near Langtry, Texas (sites D2 and site P2, respectively). Water-quality data collected during 2005 were also compared with water quality data collected as part of the U.S. Geological Survey Hydrologic Benchmark Network program during 1978 and 1995 at site D2 and with water quality data collected as part of the U.S. Geological Survey National Stream Quality Accounting Network program during 1974 and 2007 at site P2.

10. **Prival, D., & Goode, M. 2011. Chihuahuan Desert National Parks Reptile and Amphibian Inventory. Natural Resource Technical Report NPS/CHDN/NRTR—2011/489, National Park Service, Fort Collins, Colorado.**

    This publication contains the results of a two-year (2003–2004) inventory survey of six National Park Service sites by the University of Arizona. A portion of one site, Amistad National Recreation Area, lies within the Devils River watershed. Survey methods included foot searches, road cruising, pitfall traps, and turtle traps; incidental observations were also recorded. Survey efforts ultimately recorded 45 native herptile species within the Amistad National Recreation Area, including nine frogs and toads, 15 lizards, 17 snakes, four turtles, and one non-native gecko. Four of these are state-threatened. No federally listed herptiles occur within the Amistad National Recreation Area. The authors suggest an additional 10 species (one lizard and nine snakes) inhabit the park but were not found as part of the inventory effort. The publication includes maps of survey locations, lists of each species found, and a discussion of survey methods and considerations for designing subsequent monitoring work.

    Note: Another publication by the same authors with a similar title, "A Herpetological Inventory of Chihuahuan Desert National Parks," is also available. This second publication is a conference proceeding published in 2014 but is associated with a presentation given in 2004. The publication reviewed here is a technical report published by the National Park Service and should be considered the more authoritative item.

11. **Robertson, M. S., & Winemiller, K. O. 2003. "Habitat associations of fishes in the Devils River, Texas." Journal of Freshwater Ecology, vol. 18, no. 1, pp. 115–127. https://doi.org/10.1080/02705060.2003.9663957.**

    Fish assemblage and physiochemical habitat data were collected across two reaches in the middle Devils River in 1997 and 1998, one adjacent to the State Natural Area (what is now the Del Norte Unit) and one adjacent to the Dolan Falls Preserve just upstream of Dolan Falls. Water temperature, dissolved oxygen, and pH varied seasonally and between reaches. Seventeen fish species were captured across the study, and distribution was stable seasonally. Physiochemistry varied more between reaches than within; however, the opposite was true for the fish assemblage, indicating that geomorphological variation (i.e., substrate, mesohabitat, cover, water velocity) may be a stronger driver of fish distribution than water chemistry and temperature. This study provides specific information about seasonal habitat associations of fish species in the Devils River and provides historical fish abundance information from two reaches along the middle Devils River.

12. **Robertson, S., Wolaver, B. D., Caldwell, T. G., Birdsong, T. W., Smith, R. K., Hardy, T., Lewey, J., & Joplin, J. 2019. Developing the Science and Public Support Needed to Preserve the Devils River: A Case Study in Collaborative Conservation. Multispecies and Watershed Approaches to Freshwater Fish Conservation, pp. 293-314. American Fisheries Society. Bethesda, MD. https://doi.org/10.47886/9781934874578.ch13.**

    Robertson et al. 2019 is a chapter in an American Fisheries Society book, "Multispecies and Watershed Approaches to Freshwater Fish Conservation," that presents several case studies of watershed-level conservation work addressing focal fishes and fish communities around the United States. This chapter gives background on the Devils River, its unique biological resources, and the threats and issues it faces. It then summarizes recent conservation partnerships and conservation initiatives seeking to address these threats. It includes sections on building partnerships, managing sustainable recreation, and science as the foundation for conservation.

    The chapter describes the Devils River as a groundwater-dominated, semi-arid river in Southwest Texas that is considered one of the most pristine rivers in the state, with one of the last strongholds for multiple species of regionally endemic freshwater fishes and mussels. However, groundwater pumping in the watershed was noted as a threat to the river and its fragile ecosystem, with reductions in groundwater availability having the potential to result in reductions in spring discharge and, thus, instream flows. It also indicates that baseflow reductions would negatively impact many imperiled aquatic species. The chapter supports the development of a comprehensive basin-wide fish and mussel conservation plan due to the relatively small size of the watershed. However, challenges include the isolated location of the river, and the low proportion of publicly held lands needed to implement on-the-ground conservation measures. It describes how the Texas Parks and Wildlife has partnered with governmental agencies, universities, non-profit organizations, and landowners interested in preserving this unique resource to best determine science needs, focus resources, and increase informed river stewardship. The chapter concludes with a discussion about the steps underway to preserve the aesthetic, ecological, and recreational values of the Devils River through collaborative research aimed at a better understanding of groundwater-surface water interactions and instream flow needs of endemic species and through building cooperative relationships with landowners and non-profit conservation organizations.

13. Scudday, J.F. & Hanselka, C.W. 1975. A Preliminary Survey of the Vertebrate Fauna of the Dolan Falls--Dolan Creek Area. Devils River: A Natural Area Survey, Part VI of VIII, pp. 58–75. Division of Natural Resources and Environment, University of Texas.

This publication reflects the synthesis between several existing taxa-specific inventories and an all-taxa survey performed by the authors over an eight-day period in July 1975. A short discussion of why the Dolan Falls–Dolan Creek area in Val Verde County is so species-rich is included. The inventory includes 29 fishes, eight amphibians (all anurans), 55 reptiles, 62 birds, and 39 mammals. A discussion of each taxa group focuses on microhabitats, survey methods, and comments on any trends. Due to its age and the significant changes to land, water use, and climate of the area in the last 50 years, this resource is likely most useful as a snapshot of the vertebrate ecology of the region because it likely also reflects the significant changes in fauna that already occurred following the establishment of European settlement in the area. Finally, the authors identify more intensive inventory efforts underway but not yet completed that may be a useful source for a more complete set of occurring species within the various taxonomic groups.

14. Reemts, C.M., et al. 2020. Semi-Arid Shrublands Require Little On-Going Management to Remain Suitable for Black-Capped Vireos. https://doi.org/10.1637/19-027.

This study conducted a vegetation survey in Dolan Falls Preserve, owned by the Nature Conservancy, in Val Verde County, Texas, primarily because there is no specific management of black-capped vireo habitat. This area spans three ecoregions: Edwards Plateau, South Texas Plains, and Chihuahuan Desert. Since a flooding event in the 1950s, vegetation has changed significantly. Habitat characteristics were examined in 2002 and 2017 at a mesic alluvial terrace and a semi-arid canyon. Generally, habitat varies by a precipitation gradient, where in arid parts of Southwest Texas, habitat consists of dense shrubland, whereas in more mesic areas there is generally less vegetation cover. The overall plant community consists of a mix of riparian vegetation, including sycamore, willow, and Plateau live oak, among others, upland species, including ashe juniper and various oak species, and grassland species of the curly mesquite-sideoats grama series. In addition, several chaparral shrubs and succulents, such as cenizo, guajillo, coyotillo, lechuguilla, and sotol, are mixed in. In alluvial and canyon sites, species composition changed from 2002 to 2017, although species composition, richness, and relative abundance in both alluvial and canyon habitats were similar. This relates to vireo detections such that detections declined significantly in alluvial sites but were stable in canyon sites, suggesting alluvial sites became less suitable.

15. Smith, K. N. 2011. Nesting ecology and multi-scale habitat use of the Black-capped vireo. M. S. Thesis. Texas A&M University, College Station, Texas. https://nri.tamu.edu/publications/theses-dissertations/2011/nesting-ecology-and-multi-scale-habitat-use-of-the-black-capped-vireo/.

This study, conducted at the State Natural Area from 2009 to 2010, examined various aspects of black-capped vireo (*Vireo atricapilla*) nesting ecology, including nest success, clutch size, breeding season duration, rates of brood parasitism by Brown-headed Cowbirds (*Molothrus ater*), habitat use at the landscape, territory, and nest-site scales, characteristics of habitat and potential influence on territory success and/or nest success, and management guidelines. This portion of the vireo's breeding range is more arid than those to the east and north and supports vegetation communities that are attractive to vireos for a greater span of time. Little is known about the ecological requirements for the black-capped vireo in this drier, more mature ecosystem. A total of 119 nest sites were visited and measured; 69 were monitored with cameras to assess nest depredation. Nest predators included brown-headed cowbirds, greater roadrunner (*Geococcyx californianus*), bobcat (*Lynx rufus*), common raccoon (*Procyon lotor*), and greater arid-land katydid (*Neobarrettia spinosa*). Thirteen species of woody shrubs were used as nest substrates led by mountain laurel (*Sophora secundiflora*), juniper sp., Texas persimmon (*Diospyros texana*), and vasey oak (*Quercus pungens var. vaseyana*). Nest success was heavily influenced by weather, chiefly precipitation during the breeding season; nest placement, largely on north-facing slopes, appears to be an adaptation to a drier climate. It indicates that black-capped vireo habitat management in this drier southwest portion of its range should not include maintenance of second growth, as is the case for wetter areas east and north of the Devils River watershed.

16. The Nature Conservancy. 2004. Conservation Area Plan for the Devils River.

In 2004, The Nature Conservancy led a planning process, which included representatives from six other organizations and many landowners, to create an overarching vision for conservation in the Devils River watershed. The steps of the planning process involved: 1) identifying focal conservation elements for which conservation actions are designed, 2) assessing the viability of and threats to the conservation elements, 3) setting goals for improved condition of the elements and/or reduction of threats, 4) designing conservation strategies to address those threats, and 5) developing measures of success to monitor conservation progress. Focal conservation elements of the plan are:

- Rivers and streams
- Springs
- Riparian gallery woodland
- Caves and cave biota
- Black-capped vireo
- Texas snowbells

The highest-ranked threats to the conservation elements identified by the plan were:

- Overbrowsing by wildlife
- Non-native aquatic species
- Excessive groundwater withdrawal
- Unsustainable grazing practices (historic)
- Nest predation (snakes, etc.)
- Cowbird parasitism

The conservation goals were:

- By 2020, female fecundity of black-capped vireos exceeds 1.00, and the combination of fecundity and bird numbers is such that the probability of metapopulation extinction is less than 0.04.
- By 2030, there are at least 1000 snowbell individuals in each of the 3 populations currently known in the conservation area.
- Between 2004 and 2020, there is no loss of Conchos pupfish, Devils River minnow, headwater catfish, proserpine shiner, Rio Grande darter, or Rio Grande cooter from rivers, streams or springs.
- By 2025, maintain, increase, or enhance riparian gallery woodlands and understory and arroyo shrub habitats so that they can support current or increased numbers of neotropical migrants, black-capped vireos, and Texas snowbells.

- With the exception of natural drought periods, water flows are sustained in the Devils River and from the major springs (Finegan, Dolan Springs Complex, Snake and Yellow Bluff) in perpetuity.
- Cave use is managed to ensure persistence of conditions that support native cave invertebrates, and so that Fern Cave summer bat populations reach 20 million by 2015.
- The Nature Conservancy helps other stakeholders successfully manage river recreation in balance with ecological integrity and local quality of life, and with respect for private property rights.

The plan contributors defined fifteen strategies to achieve these goals, including:

- Share fish and other aquatic species data among groups that are doing surveys and/or research (U.S. Geological Survey, Texas Parks and Wildlife, Texas Commission on Environmental Quality, The Nature Conservancy, etc.). Collaborate on identified management needs.
- On conservation buyer properties, use easement agreements to protect integrity of riparian gallery woodlands and understory and arroyo shrub habitats.
- Work with landowners to incentivize understory and midstory vegetation enhancement in riparian woodlands and understory and arroyo shrub habitats (e.g., via NRCS cost-share programs).
- Help fund and contract research on aquifer health and function, especially focusing on recharge processes and what sustainable pumping levels might be. Might be done in conjunction with Val Verde Groundwater Conservation District, if/when that is formed.
- With landowners, recreationists and land management agencies explore collaborative options to better balance maintenance of biological diversity, public use of river, and private property rights.

Key Readings for Understanding Devils River Sustainable Recreation

1. 2019 Forbes newsletter article announcing the designation of the State Natural Area as the 6th International Dark Sky Sanctuary in the world.
2. Texas Monthly article exploring the cultural significance of the Devils River watershed landscape and Indigenous rock art sites.
3. A 2017 blog post discussing the opening of two paddling campsites highlighting the need for managed recreation use and how supporting paddlers can promote stewardship of the river.
4. A historic account of a multi-day excursion along the Devils River prior to the development of the DRAP.
5. A 1993 document outlining state laws in regard to navigability, ownership, recreational usage, river gradient, and portaging.
6. A modern-day blog post providing guidance on preparation for a multi-day Devils River paddling trip with photos and anecdotes from a recent trip.

1. Carter, J. (2019, February 4). “Texas claims the third dark sky sanctuary in the U.S. as struggle against light pollution continues.” Forbes. https://www.forbes.com/sites/jamiecartereurope/2019/02/04/texas-claims-the-third-dark-sky-sanctuary-in-the-u-s-as-struggle-against-light-pollution-continues/?sh=5a1d1d393840.

This Forbes newsletter article announces State Natural Area as the sixth International Dark Sky Sanctuary in the world, a designation given by the International Dark-Sky Association or IDA. This designation is the rarest and most fragile of Dark-Sky Designations. A Dark Sky Sanctuary is defined as “public or private land that has an exceptional or distinguished quality of starry nights and a nocturnal environment that is protected for its scientific, natural, or educational value, its cultural heritage and/or public enjoyment".

2. Hodge, Roger D. "The Writing on the Wall." July 2012. Texas Monthly. https://www.texasmonthly.com/articles/the-writing-on-the-wall/. Accessed 19 January 2024.

The author is from a long-time ranching family that still lives and ranches near the Devils River, and his deep familiarity and love for the landscape and its history is apparent in his vibrant writing. He uses the transient and unsustainable ranching history of Val Verde County to introduce this beautiful but difficult environment, a place where change is constant and water is everything; he also uses it as a foil to introduce the some of the succession of Native American hunter-gatherer peoples who lived off the land here for millennia, and whose colorful paintings still adorn the walls of the region's rock shelters. Who were they? What were they trying to say? Hodge describes what he saw and learned about them during a week-long series of discussions and visits to sites across the region with rock art researcher Dr. Carolyn Boyd and other archeologists associated with the Shumla Archeological Research and Education Center. He tells of Dr. Boyd's introduction to the area's rock art and her decades of subsequent research, which weaves together clues from iconography, mythology, and linguistics, finding that the 4000-year-old Pecos River Style pictograph murals may well be North America's oldest surviving narrative texts. One of Boyd's most intriguing lines of research explores motifs in the rock art through the lens of the long-surviving beliefs of the Huichol people of Mexico, whose symbols and stories often bear an uncanny similarity to designs and compositions in the Pecos River Style pictographs.

3. Gill, John. "GILL: Safe ways to enjoy kayak trip down the Devils River." Go San Angelo, 18 Feb. 2017, https://www.gosanangelo.com/story/sports/columnists/john-gil/2017/02/18/gill-safe-ways-enjoy-kayak-trip-down-devils-river/98096942/. Accessed 18 Jan. 2024.

Outdoor columnist, John Gills, highlights recent rainfall and the opening of two new Texas Parks and Wildlife paddler camps along the Devils River in 2017 as prime opportunities for outdoor devotees wanting to paddle the Devils River. Texas Parks and Wildlife emphasizes the two new campsites as a way to alleviate the current long distances between usual paddler launch and extraction sites creating a safer and more enjoyable paddle. This material supports the need for managed recreation use on the river and how supporting paddlers can promote healthy stewardship of the river. It does not include exactly where the sites are located nor how they were acquired. This information needs elaboration.

4. Reid, J. (2021, November 5). "Sympathy for the Devils." Texas Monthly. https://www.texasmonthly.com/travel/sympathy-for-the-devils/.

Author Jan Reid joins a group of Texas Parks and Wildlife officials working with Devils River landowners to come to terms between the river and its controversial navigable waters. This 1994 multi day excursion is a glimpse into the past, before the DRAP system was in place and helps you to understand the state of the river and the attitudes and opinions of the landowners.

5. Riverside and Landowners Protection Coalition, Inc. "Recreational Use of Texas Rivers and Streams." Feb 1993. https://nativefishconservation.org/devils-river-digital-repository-search/?query=Recreational%20Use%20of%20Texas%20Rivers%20and%20Streams#TFKA6T4Z.

Using law reviews, court cases, Texas codes, and the opinion of the Texas Attorney General from the 1950s and 1960s, the Riverside & Landowners Protection Coalition, Inc. defines river laws in regard to navigability, ownership, recreational usage, river gradient, and portaging; laws stemming from an 1837 declaration by the Republic of Texas that the riverbeds of rivers deemed navigable were owned by Texas. These laws have been elaborated on and are still considered current.

For a river to be measured navigable, it must retain an average width of 30 feet across. If it is deemed navigable, the State of Texas owns the riverbed and can manage its recreational usage. River gradient boundary rules are established to differentiate the line between the publicly owned river and the privately owned property which abuts such river. This line is defined as where the river's original containing banks start. This generally coincides with the wordage used by Texas Parks and Wildlife concessionaires today of ten inches above the water line. If paddlers come out of river gradient, even to portage, they would be trespassing on private property.

Examples of Texas rivers regarded as navigable are included, but the Devils River is not.

The document, though it gives an accurate depiction of river laws and the history behind such laws, is influenced by landowners of rural properties in Texas.

6. Williams, Derrest. "Devils River – The Most Pristine Water in Texas". 3 June 2019. Treadwright, www.treadwright.com/blogs/treadwright-blog/devils-river-the-most-pristine-water-in-texas. Accessed 19 January 2024.

This 2019 blog post gives an overview of what to expect and how to prepare for a multi-day Devils River paddling trip, with photos and anecdotes from the author's recent trip. The first part of the post gives background on the river's location, characteristics, and difficulty, and discusses permits/shuttle, river access, and camping considerations. The second part of the post gives a recommended trip/route (four days, three nights starting at San Pedro Point), and describes the river hazards, campsites, and other salient information for each day's segment. The article closes with advice on fishing tackle selection, and a recommended gear list. The post is clear and concise, informative while approachable and fun, and provides helpful information from official sources and personal experience, with links that prepare the reader to have a safe and enjoyable trip while complying with permit requirements and regulations.

Comprehensive Devils River Literature List

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Appendix A: Historic Spring Conditions

The spring inventory below expands on the examination by Mace and Galaviz (Revisiting Gunnar Brune's "Major and Historical Springs of Texas" with an Analysis on the Fractal Character of Springflow – 2024), revisiting the seminal work of Gunnar Brune's 1975 report, "Major and Historical Springs of Texas," and his subsequent 1981 book, "The Springs of Texas, Volume 1." This additional review focuses specifically on the springs of the Devils River and provides historical data longitudinal by spring system, beginning with the headwater springs and traveling down-system to Lake Amistad. Spring and location names follow the conventions of the original sources.

Juno / Stein / San Pedro / Headwater Springs

Historically, perennial flow in the Devils River didn't start until Juno Springs (also referred to as Stein Springs,

Figure 49. Revisiting Gunnar Brune's Major and Historical Springs of Texas" for the Devils River Watershed. (Meadows Center, Work in Progress)

San Pedro Springs, and Headwater Springs) just north of the former village of Juno. Texas Water Development Board files report flows of 5.5 cfs in 1925, 0.03 cfs in 1939, and no flow in 1971. Brune (1981) reported 1 cfs in 1976. The springs issued from the river bottoms, and there used to be a lake here called Beaver Lake (George 1940). Brune (1981) reports beavers at the location in 1971, but that they were struggling with lower water flows. Recent satellite imagery from Google Earth and the Texas Water Development Board's Groundwater Data Viewer does not indicate flow from the springs. Dr. John T. Nagle may have been referring to Juno Springs when he referred to Pecan Springs[8] where he noted that it was "another sparkling spring of pure limpid water, and its taste is delicious" Hill and Vaughn (1898 p 268). George (1940) referred to this spring as Stein Springs and mentioned Beaver Lake Springs, 2.5 miles upstream of Stein Springs, as separate spring systems with Beaver Lake Springs feeding Beaver Lake at that time. As springs sequentially dried from upstream to downstream, the beavers moved their dams and thus Beaver Lake.

Pecan Springs

These days, the headwaters of perennial flow in the Devils River doesn't start until Pecan Springs located about 14 miles downstream of Juno Springs on the right bank. Brune (1981) reported flows of 0.8 cfs in 1892, 42 cfs in 1925, 7cfs in 1939, and 14 cfs in 1976. Texas Water Development Board files report flows of 4.5 cfs in 1939 and 16.4 cfs in 2022. Total dissolved solids for a sample collected on June 9, 2022, were 272 milligrams per liter.

Prosser's Spring

Brune (1975) stated that Pecan Springs had originally consisted of at least six springs with only the lowest spring still flowing. Based on his description (six miles north of Fort Hudson and slightly to the west), Dr. John T. Nagle referred to this spring as Prosser's Spring (Hill and Vaughn 1898 p 268). The springs near Juno and Pecan Springs allow an approximation of water-level declines that caused these spring systems to fail or, in the case of Pecan Springs, be failing. In the case of Beaver Lake Springs and Stein Springs, the elevation change from the uppermost spring to the lowermost spring is about 30 feet over about 1.3 miles. For Pecan Springs, the change in elevation from the uppermost spring to the lowermost (and still flowing) spring is about 25 feet over about 1.3 miles. This suggests that the water level declines causing spring failures were probably around 30 feet. Perhaps not coincidently, water levels in shallow wells near the river in the Juno area are about 30 feet below land surface. Brune (1981) suggested that these springs failed due to overgrazing and soil compaction from cattle; however, pumping of groundwater is a more likely cause. Recent research suggests changes in vegetation only minimally affects recharge and runoff once new vegetation is established (see, for example, Wilcox and Thurow 2006, Acharya and other 2018). With the advent of affordable downhole centripetal pumps, access to affordable energy, and the drought of the 1950s, groundwater production increased ten-fold between 1940 and 1955 (Mace 2021). An irrigation well close to Beaver Lake Springs was drilled in about 1946 (TWDB 2024a).

Hudspeth Springs

Three miles downstream of Pecan Springs are Hudspeth Springs. Issuing from a cliff on the west side of the valley, the springs flowed at 2.3 cfs in 1939, 3.5 cfs in 1969, 5.7 cfs in 1971, and 0.1 cfs in 1976 (Brune 1981). Texas Water Development Board files report flows of 3.6 cfs in 1939 and 5.7 cfs in 2022 (TWDB 2024a). Total dissolved solids were 268 milligrams per liter for a sample collected on June 14, 1939, and 319 milligrams per liter for a sample collected on June 9, 2022 (TWDB 2024a).

Phillips Springs

About three miles downstream of Hudspeth Springs is Phillips Spring about 0.4 miles upstream of the Devils off the right bank of a creek flowing out of Phillips Canyon. The springs flowed 0.6 cfs from an opening in a rock ledge in 1939 (George 1940) and 0.8 cfs in 1971 (Brune 1975). Water sampled by the Texas Water Development Board in 2006 had an apparent age of about 2,640 years before present[9] and total dissolved solids of 272 milligrams per liter. Satellite imagery suggests the spring still flows to the Devils (TWDB 2024a).

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8 *Nagle refers to this spring as two miles north and a half mile west of R.W. Prosser's ranch house, but the location of the Prosser ranch house at that time is unclear.*

Huffstutler Springs

Texas Water Development Board files show that Huffstutler Springs are located on the left bank of this tributary somewhat across from Phillips Springs. Brune (1975) reports two springs at this location, suggesting that Phillips Spring may be one of the Huffstutler Springs. Brune (1975) reports that the "east spring" was reported dry, as it appears today via satellite imagery. It's possible that Huffstutler Springs is misplaced in the Texas Water Development Board database since its inclusion is based on Heitmuller and Reece (2003), which is a compilation of springs and spring locations with no verification of data (Mace and Galaviz 2024). This part of the river has a rich history of being near the ford (Bakers Crossing) across the Devils for the San Antonio-El Paso Road and for hosting Camp (later Fort) Hudson, established in 1857, at the mouth of Hudson Canyon on the right bank of the Devils (USBTE 1857, Smith 1952, Brune 1975, 1981).

Jarrett Springs

About 8 miles downstream are Jarrett Springs. Surveyed and sampled by the U.S. Geological Survey in 1966, the springs flowed at that time at 0.01 cfs (5 gallons per minute) from the left bank of Devils with total dissolved solids of 255 milligrams per liter (TWDB 2024a).

Unnamed Springs

About a mile downstream of Jarrett Springs is Cedar Canyon off the left bank. About a mile and a quarter up this dry stream are unnamed springs identified on a U.S. Geological Survey topographical sheet (USGS 1979a).

Finegan Springs

About 4.5 miles downstream of Jarrett Springs are Finegan Springs. Brune (1981) reports that the springs issue from the base of a limestone bluff about 15 feet above the river. Flow from these springs has been 3.5 cfs in 1928, 27 cfs in 1939, 4 cfs in 1966, and 20 cfs in 1971 (Brune 1981). Notes in the Texas Water Development Board files indicate numerous springs as the Finegan Springs Complex with an upper, middle, and lower spring and with the lower spring about 1,000 feet downstream from the upper spring (Figure 1, TWDB 2024a). Total dissolved solids were 265 milligrams per liter for a sample collected on September 17, 1966, 274 milligrams per liter for a sample collected on February 9, 2019, and 279 milligrams per liter for a sample collected on May 25, 2023 (TWDB 2024a). A different spring in the complex had total dissolved solids of 307 milligrams per liter for a sample collected on January 30, 1966 (TWDB 2024a). Finegan Springs is a major contributor to flow in the Devils River, providing, on average, about 40 percent of total flow downstream of the springs complex with contributions ranging from 23 to 71 percent of flows in the river (Caldwell and others 2020). Discharge from the springs complex as measured between September 2015 and February 2019 ranged from 27 to 73 cfs with a median of 35 cfs (Caldwell and others 2020).

Blue (Hole) Spring

About 1,800 feet downstream from Lower Finegan Springs is Blue Hole Spring or Blue Spring (the latter according to U.S. Geological Survey 1979b. Located at the head of deep side channel from the main Devils, there are no flow measurements for this spring. Total dissolved solids were 271 milligrams per liter for a sample collected on February 9, 2019, and 280 milligrams per liter for a sample collected on May 25, 2023 (TWDB 2024a)

Dolan Springs Complex

About 2,400 feet downstream from Blue Hole Spring, Dolan Creek merges with the Devils. Several springs issue from the left bank of Dolan Creek upstream of this confluence and are called Dolan Springs or Snake Springs. This perennial part of the creek hosts many rock shelters with pictographs (Brune 1981). Spice (1954) noted that Dolan Springs, along with Finegan Springs, continued to flow during the drought of the 1950s (at least through 1953), a drought that dried up the Devils upstream of Finegan Springs. The Texas Water Development Board database includes four discrete springs as part of the Dolan Springs Complex, including Fig Tree

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9 *Apparent age means that the carbon-14 sample hasn't been corrected. It is also an average age of the water, meaning that the water could be (and probably is) a mixture of water of a variety of ages. Regardless of these caveats, the age suggests that there is, at a minimum, a component of old water issuing from this spring, suggesting a regional component of flow, which is consistent with the persistence of flow in the river in general.*

Spring, Rock Art Spring, an unnamed spring (Snake Springs according to U.S. Geological Survey topographic maps), and Dolan Spring, TWDB 2024a, Figure 2). Based on satellite imagery, the head of the springs may be 3,600 feet upstream from Dolan Spring at the base of limestone ledge (or spring deposits?) in the creek. Springflow from Dolan Springs has ranged from 1 cfs in 1969 to 18 cfs in 1977 with an average flow of 7 cfs (Brune 1981). Dolan Springs are a group of springs in an area of about 75 feet in diameter with an average discharge of 3.82 cfs according to the IBWC (as quoted in TWDB 2024a). According to TWDB files, total dissolved solids for Dolan Springs were 263 milligrams per liter on March 4, 1966, 246 milligrams per liter on May 20, 1966, 255 milligrams per liter on September 17, 1966, and 262 milligrams per liter on January 30, 1967 (TWDB 2024a).

Rock Art Spring

According to Texas Water Development Board files, flow from Rock Art Spring was estimated at 2 to 5 cfs in 2019 with total dissolved solids of 246 milligrams per liter (TWDB 2024a). A subsequent sample of Rock Art Springs had a total dissolved solids of 273 milligrams per liter as measured on May 25, 2023 (TWDB 2024a).

Snake Springs

Flow from Snake Springs was estimated at 0.22 cfs in 1969 with a total dissolved solids of 266 milligrams per liter as measured on February 4, 1969 (TWDB 2024a).

Jose Maria Spring

About three miles upstream of Dolan Spring is Jose Maria Spring, which, based on its location in the Texas Water Development Board database and the topographic sheet (USGS 1979b), issues from the edge of canyon off the right bank of Dolan Creek. Based on satellite imagery, water commonly stands in Dolan Creek down the hill from this location. We were not able to discern the significance of the name.

Norris Springs

Brune (1981) reports the existence of Norris Springs eight miles north of Dolan Springs; however, these springs do not have entries in the Texas Water Development Board database. On Google maps, Little Norris Spring and Big Norris Spring appear, and these springs are named on a U.S. Geological Survey topographic sheet (USGS 1973). Satellite imagery suggests that these springs no longer flow. What appears to be an abandoned pool on satellite imagery is located near Big Norris Spring.

Leon Springs

Just downstream from Dolan Creek is Leon Spring Creek which hosts Leon Springs about a mile upstream from the creek's confluence with the Devils. This spring appears on a U.S. Geological Survey topographic sheet (USGS 1979b) and appears to still flow.

Grass Patch Springs

About half a mile downstream of the confluence of Dolan Creek with the Devils is Grass Patch Springs just on the left bank. The Texas Water Development Board recently surveyed this spring on May 9, 2024, and added it to its database. This spring also appears on a U.S. Geological Survey topographic map (USGS 1979c).

'Bjornson Springs'

About two miles downstream of Grass Patch Springs are several unnamed springs surveyed by the Texas Water Development Board on May 6, 2024 (TWDB 2024a). Since Cody Bjornson surveyed these springs while he was on vacation, let's name them Bjornson Springs. These springs issue from under a limestone shelf and are probably under the river outside of severe droughts (flow in the Devils at Bakers Crossing when Cody surveyed the springs was about 37 cfs).

Springs of the Dry Devils (Unnamed Spring, Carlos Camp Springs, Clark Waterhole, Gravel Waterhole, Unidentified Spring)

About 5.5 miles downstream of Bjornson Springs is the confluence of a second Dry Devils River with the Devils River. This Dry Devils River stretches to the very northwest corner of Edwards County. U.S. Geological Survey topographic sheets identify several springs along the Dry Devils (USGS 1979a, b, c), none of which provide enough flow to cause the Dry Devils to not be dry. These springs include an unnamed spring; dry according to recent satellite imagery), Carlos Camp Spring (still flowing), Clark Waterhole (still flowing), Gravel Waterhole, still flowing), and one unidentified spring (flowing).

Springs of the Tributaries to the Dry Devils

- Red Bluff Creek - Blocker Waterhole, Glen Waterhole (appears dry) and Glenn Waterhole (still flowing).
- Spotted Oak Canyon - Unnamed (flowing?) and Spotted Oak Spring (flowing?)
- Camp Spring Canyon's Camp Spring (flowing?)
- Springs of Cedar Spring Canyon, a tributary to the Devils River: Cedar Spring Canyon hosts three still-flowing unnamed springs, none of which provides enough flow to reach the river (USGS 1979c).

Gillis/Willow Spring

About 13 miles downstream of the confluence of Dolan Creek with the Devils is Gillis Spring which issues from the right bank of the Devils right at the river. Gillis Spring is sometimes referred to as Willow Spring on older maps (Brune 1981). Flow at Gillis Spring was reported in Texas Water Development Board files to be about 0.2 cfs in 1939 and nearly the same in 1967 with a total dissolved solids of 223 milligrams per liter as measured on July 18, 1939 (TWDB 2024a).

Dead Man's Hole

Brune (1981) refers to Dead Man's Hole on Dead Man's Creek, whose mouth is just upstream of Gillis Spring. Shafter (1877) shows the hole quite a bit upstream from the Devils, the exact location lost, although it was probably near where Dead Mans Creek crosses Highway 163 since Highway 163 follows the old Spanish trail. Brune (1981) reported the spring as dry. Given the location of Devil's Hole on the highlands between the Devils and Pecos rivers shown on Shafter's map and a depth to water more than 400 feet from the land surface, we suspect this was an ephemeral spring fed by a perched aquifer. There is a small dam and ephemeral pond in the area (that we suspect is the location of the spring.

Little Satan Creek

About 2 miles downstream from Gillis Spring is where Little Satan Creek empties into the Devils. About 0.5 miles upstream from the confluence is Little Satan Spring, #318 in George [1940]), reported to produce about three gallons a minute with a temperature of 72 degrees Fahrenheit as measured on July 19, 1939 (TWDB 2024a). Recent satellite imagery shows a consistent wet spot in the creek bottom at this location.

Goodenough Springs

The Lake Amistad Pool, at least when it is full, begins about a third of a mile downstream from the mouth of Little Satan Creek. Lake Amistad began impoundment on June 1, 1968, and was full for the first time on June 13, 1972 (TWDB 2024b).[10] The reservoir inundated a number of springs, including, most famously, Goodenough Springs, which is located farther upstream on the Rio Grande (Mace and Galaviz 2024). When the conservation pool is full, the lake elevation is at 1,117 feet above sea level and the top of the flood pool is at 1,140.4 feet above sea level (TWDB 2024c).

Big Satan Spring

About eight miles downstream of Gillis Spring and 1,800 feet upstream from Big Satan Creek's confluence with the Devils is Big Satan Spring, a collection of five to six springs (TWDB 2024a). Brune (1981) reported a flow at Big Satan Spring of 1 cfs at the lake level at an unspecified time. Total dissolved solids were 245 milligrams per liter on April 9, 2019 (TWDB 2024a).

Slaughter Bend Springs

About 4.5 miles downstream of Big Satan Creek's confluence with the Devils are Slaughter Bend Springs on the left bank of the river.

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10 *The start of impoundment here is based on the first date in the CSV period of record file and not the web page, which shows a date of January 1, 1969.*

Smith Springs and Swann-Shelter Springs

Brune (1981) noted that Smith Springs and Swann-Shelter Springs are also in the same general area, although only Slaughter Bend Springs is in the Texas Water Development Board database. George (1940) shows multiple springs (at least 12) on both sides of the river all along the bend between Big Satan Creek and the canyon that hosts Mountain Laural Road. There used to be a dam in the Devils just upstream from Rough Canyon forming Devils Lake (George 1940, USGS 1944). Brune (1981) identified these springs as the most downstream on the post-Amistad river. The discharge was 190 cfs in 1921, 340 cfs in 1925, 210 cfs in 1928, and 80 cfs in 1971 before being covered by the lake (Brune 1981). Recordable flow once the lake reached the springs was 30 cfs in 1976 (TWDB 2024a).

Lester Springs

Now beneath Lake Amistad (but potentially exposed when lake levels are low) are Lester Springs in Rough Canyon.

#448 (Spring, as numbered in George 1940[11])

This spring flowed about 1.5 cfs in 1928 (Brune 1981).

#458 (Spring, as numbered in George 1940)

Another dam near Baker Ranch formed Lake Walk (George 1940, USGS 1944). Between Highway 90 and Castle Canyon, George (1940) identified a spring on the left bank of the river (now inundated).

#443 San Pedro Creek (Spring, as numbered in George 1940)

George (1940) also identified a spring in San Pedro Creek, (#443 in George 1940) that is now inundated by Lake Amistad.

11 This is an approximate location for this spring based on the Brune (1981) description and this spring being proximate to that location.

Appendix B: Facilitation Process and Project Delivery

Appendix C: Jury Materials

Calendar

The Jury will be convened four times between September and December, with each session focusing on key aspects of the report:

September 20

Our first Jury meeting will review the stakeholder feedback received and dive into watershed threats and next steps. The Jury will also consider the development of a vision statement for future collaboration in the watershed.

October 15

A revised report draft will be presented virtually to all stakeholders, offering a chance for broader feedback.

October 21 (virtual)

The Jury will reconvene to ensure all stakeholder feedback is integrated into the second draft and to review the draft Stakeholder Chapter contents.

November 1

Final content will be submitted to the Meadows Center by all stakeholders for incorporation into the report.

November 12 (in-person)

Jury will reconvene in person at The Nature Conservancy offices in San Antonio to explore the potential content for a Stakeholder Chapter, including a vision statement and priorities for future watershed coordination. Should the Jury want to explore future watershed coordination, we will aim to create a draft chapter outline and ask volunteers begin drafting the contents.

December 2

Final draft release for 1-week final review.

December 10 (virtual)

Meeting for final findings and recommendations of Jury.

December 13

Release of Final Report.

Jury Charges

The Devils River Stakeholder Jury is charged with reviewing the successful implementation of the envisioned process as well as the accuracy and responsiveness of the State of the Devils River report.

Charge I (October Meeting): Review Stakeholder Comments and How They Were Addressed in Second Draft

Review second draft report and provide findings on how stakeholder comments and concerns were addressed; provide guidance if any subject needs further review from the Technical Team(s).

Charge II (October Meeting): Review Report Sections

Provide findings as to whether the approach and subject matter was completed to the extent possible and that areas of uncertainty were adequately addressed throughout. Review of the report's five sections:

i. Introduction to the Devils River
ii. Groundwater Science
iii. Water Quality
iv. Species and Flows
v. Sustainable Recreation

Charge III (Beginning at September Meeting): Watershed Collaboration Vision Statement

Consider a vision statement for future collaborative work in the watershed.

Charge IV (Beginning at September Meeting): Future Collaboration Opportunities

Consider the inclusion of opportunities/priorities for future watershed collaboration in the report.

Charge V (Beginning at September Meeting): Additional Recommendations

Consider any recommendations that the Jury would like to have accompany the report.

Charge VI (December Meeting): Final Jury Findings on the Final Report

The intent of the State of the Devils River report was to gather academic and local expertise to identify what is known about the watershed, highlight additional data needs, and recommend pathways to meeting those information needs. The Jury will make requests and recommendations to the facilitation and technical teams to adjust the State of the Devils River report, as necessary, to satisfy the desired final findings below:

i. To our knowledge, the report compiled information on groundwater resources, water quality, species and their flow needs, and sustainable recreation, and (to our knowledge) did not knowingly exclude any information provided to the project or technical teams.
ii. The process was respectful to stakeholders' diverse needs and perspectives and the report reflects the project team's responsiveness to feedback.
iii. We have reviewed the report's recommendations and find that they reflect scientific and or information needs only, and do not endorse any specific management outcomes.
iv. We have reviewed the report and find that this report did not make recommendations for further federal investment in the region.
v. With the inclusion of any edits or comments provided along with this vote, the Devils River Stakeholder Jury finds that the State of the Devils River Report and process are complete.

Revised October 21, 2024

Stakeholder Jury Guidelines

The members of the Devils River Watershed Project Stakeholder Jury agree to the following Guidelines:

1. Voting/Consensus

Members strive for "consensus" as the goal for decision-making. For the purposes of this jury, "consensus" will mean that no decision will go forward as having been endorsed by the Jury if any member of the jury "cannot live with" the outcome of a vote. Each juror has one vote, except the foreman, who will not vote. Jurors will strive for consensus, making adjustments to proposals to address everyone's concerns. If consensus cannot be reached, the outcome will be documented, specifying the number of jurors in favor of any given outcome. (Hypothetical example: "5 Jurors advocated for the creation of a watershed group, 4 were opposed, 2 took no position.")

2. Respectful Dialogue/Civility

Jurors agree to engage respectfully, valuing the perspectives and experiences that each member brings to the table. Listening is just as important as speaking, and jurors will approach discussions with an open mind. Differences of opinion are inevitable (– and welcome!) but will be expressed constructively. Jurors will approach disagreements with the intent to understand (not just to respond).

3. Active Participation

The jury's success depends on the active participation of all members. Jurors will come prepared, having reviewed the materials ahead of each meeting and thought critically about the issues at hand.

4. Representation of Other Stakeholder Feedback

To ensure a transparent process and that all voices in the watershed are represented, Jurors will actively seek and incorporate feedback from non-Jury stakeholders.

5. Facilitation and Support

The Meadows Center will facilitate all meetings to stay on course for each meeting's stated objective, providing structure to discussions with the goal of ensuring that all voices are heard.

6. Confidentiality

We encourage transparency and will work to foster an environment where everyone can speak freely. Any records of jury meetings and interactions will be generalized to describe the key points of jury discussion versus attributing quotes or sources of shared viewpoints (e.g., "the jury discussed changes in water quality, with a majority of jurors noting decreasing quality while several others disagreed"). Recordings will be destroyed after summaries are completed and approved by the Jury.

Revised September 27, 2024

Appendix D: Summarized Recommendations for Further Research, Monitoring, and Collaboration

These recommendations are based on a comprehensive literature review and reflect the collective expertise of a technical team from 2023-2024.

Source: *Meadows Center Report #24-003: State of the Devils River Watershed Report*. The Meadows Center for Water and the Environment at Texas State University; INSERT LINK

The purpose of this report was to identify what is known about the Devils River watershed, identify existing data gaps, and provide recommendations for addressing the identified data gaps. The following recommendations are outlined by the project's volunteer Technical Teams in greater detail in the body of the report and are summarized here to better support stakeholders in their continued stewardship of the Devils River and its surrounding ecosystem. Each of these recommendations is made with the embedding condition that cooperation with private properties should occur on a strictly voluntary basis ensuring full transparency of methods and data use are conveyed to the property owner.

Groundwater Research Recommendations

1. **General Recommended Research**
   a. Refine the Geologic Framework:
      i. Expand geologic mapping of bedrock and surficial deposits for key areas, including faults, fractures, and karst in the mapping.
         - Define the role of the geologic framework regarding the water budget and outline characteristics of the hydro stratigraphy and diagenetic history that influence the permeability structure of the aquifer.

      ii. Use geophysical logs, outcrops, publications, and drillers logs to create and refine the structure contours of the aquifer system.

   b. Understand Recharge:
      i. Examine rainfall-runoff relationships using current IBWC stations and instrument small tributaries within the Dolan Creek watershed (near TxMesonet sites) to characterize runoff, and place instrument and focus in area(s) of the dry reaches in the upper watershed.
      ii. Complete additional gain-loss studies building upon the recent Texas Parks and Wildlife gain-loss data and other flow gauging sites and refine and quantify the gains and losses for the Devils River.
      iii. Create additional surficial and karst maps using remote sensing and GIS to map closed depressions and karst features in key parts of the watershed.
      iv. Assess historic long-term climatic changes and potential effects on water levels and spring discharge for the area to refine our understanding of possible future effects of climate change on groundwater recharge in karst aquifers.
         - Additional research in this area should also include the downscaling of climate models for the region.

   c. Research to Better Characterize Groundwater Flow:
      i. Refine and augment the existing regional potentiometric map.
      ii. Localize potentiometric maps.
         - Perform detailed potentiometric mapping around the spring complex of Dolan Springs, Finegan

Springs, and Pecan Springs. Continue to instrument wells in the Dolan and Pecan Springs area (particularly the possible new well near Juno) to track groundwater response to recharge.

iii. Perform dye traces within the Dolan and Finegan Springs complexes starting from the Jose Maria Spring (estavelle feature) within Dolan Creek to the spring complex. to expand the definition of springshed(s), flowpathways, and variable residence times.

iv. Sample select wells and springs for geochemical and isotopic data under both low-flow and high-flow, or post-storm conditions to provide insight into the matrix-conduit interaction and other geochemical processes including groundwater-rock interactions to understand groundwater flow and recharge source areas.

v. To better understand the relationship between Amistad Reservoir levels and both surface and groundwater extraction and to better understand the capture area for this system, we recommend additional study of the San Felipe Springs system.

d. Research on Discharge (Springflow):

i. To further delineate and quantify springflow, continue and develop springflow measurements and rating curves for known and possibly new spring complexes.

- Explore tools like baseflow separation to better understand springflow.

ii. Utilize existing wells in the State Natural Area to refine the water level-springflow index relationship. In the headwaters area (Pecan Springs), install a new monitor well at the IBWC site.

- Instrument with telemetry and incorporate into the Texas Water Development Board recorder well program.

iii. Evaluate the region's historical pumping and water budgets to better assess the potential range of response of this system to pumping, especially during drought.

iv. Create and maintain a map of monitoring points that is available to stakeholders.

2. Expanded Monitoring of Aquifer Conditions, Springs/Tributaries, and the Devils River

a. Expand the well-monitoring network throughout the Devils River watershed farther upgradient of the perennial springs to further understand spring discharge trends, recharge, aquifer storage, and source area delineation, including wells in the Dry Devils River watershed, which flows infrequently but may have important groundwater flows paralleling the ephemeral stream channel (Green et al., 2014).

b. A new well (est. 3-400 feet deep) north of Pecan Springs in the Juno area, perhaps within the IBWC easement at Cauthorn's Crossing, would provide key hydrogeologic data (e.g., Fort Terrett vs. Segovia) for regional structure contour mapping and key surface-groundwater interaction.

i. A rating curve could be developed for the Pecan Springs complex.

c. Establish real-time springflow and river data where key data gaps exist.

i. Instrument select stream and spring sites intended to be permanent monitor locations moving forward.

d. Maintain and improve the Dolan Crossing site with telemetry for real-time data.

e. Conduct bi-annual visits to various spring reaches and well sites for manual measurements, and to maintain and download probes. Maintain stream and springflow gaging stations at the State Natural Area for the Finegan-Blue Hole spring complex.

f. Further explore the connection between spring flows and levels in Lake Amistad pathways.

Water Quality Research Recommendations

1. **Assess Land Use Changes:** Assess impacts from new septic systems and other introduced contaminants.
2. **Evaluate Climate Change:** Evaluate changes in precipitation and runoff patterns.
3. **Monitor Riparian Health:** Monitor the condition of riparian vegetation and its role in river stability.
4. **Investigate Increased Recreational Use:** Investigate the effects of growing recreational ac-tivities on water quality.
5. **Review Water Quality of Permitted Wastewater Discharges:** Review water quality from fa-cilities such as the Crockett County WCID and the City of Sonora. Explore opportunities to convert discharge permits into land application permits.
6. **Foster River Education and Stewardship:** Foster stronger connections between local communities and the broader region to promote river care and stewardship and increase awareness around impacts to water quality.
7. **Study Impacts of Oil and Gas Disposal Wells:** Study the potential impact of disposal wells on groundwater and surface water.
8. **Study Emerging Contaminant of Concern:** Study the potential impact of emerging contam-inants of concerns including pharmaceuticals and per- and polyfluoroalkyl substances (PFAS).
9. **Address Invasive Species and Sedimentation:** Address the rise of invasive species, such as feral hogs among others, and their contribution to sedimentation

ADDITIONAL RECOMMENDATIONS TO ADDRESS WATER QUALITY QUESTIONS FACING THE REGION

1. **What is the quantity of surface water in the Devils River watershed?** Further statistical analysis of the Devils River's daily average discharge and yearly volume is needed to identify trends, confirm whether there is a significant decline, and evaluate how these trends may be affecting water quality.
2. **How are feral hog populations impacting water quality in the Devils River?** More research is needed into the estimated feral hog population for the Devils River watershed, along with a greater understanding of their movements, how they are currently impacting water quality currently, how they could impact water quality, and a long-term management plan (Brown et al., 2012; Mersinger and Silvy, 2007).

Species and Flows Research Recommendations

1. **Biological inventories of taxa groups should be repeated at least every ten years.**
   a. Include inventories of fish, aquatic and terrestrial invertebrates, plants, birds, mammals, reptiles, and amphibians across riverine, spring, riparian, karst, and upland habitats.
   b. Sites from the upper, middle, and lower watershed should be included to capture the climatic gradient and diversity of habitats throughout the watershed.
   c. Surveys at public lands (Devils River SNA and Amistad NRA) should be prioritized due to repeatability of surveys; however, private properties should also be surveyed on a strictly voluntary basis.
   d. Physical and photo vouchers should be collected and georeferenced and any physical vouchers should be deposited in an accredited museum for research.
   e. With landowner permission, species inventories should be quality-checked and deposited in the Devils River Digital Repository in perpetuity. *Specific location data can be obscured to address any data privacy concerns by landowners.*
2. **Population tracking and habitat assessments for species vulnerable to extirpation or extinction every**

one to five years.

a. Depending on the species-specific lifespan and life history of rare taxa, targeted data collection efforts should be made on a shorter cycle to ensure populations are stable and habitats remain able to support them.

b. For short-lived species, such as Devils River minnow, or those that are more susceptible to rapid habitat degradation, such as Texas hornshell, it is recommended that targeted monitoring continue annually.

c. For longer-lived or more adaptable species, monitoring could occur on a longer cycle. Data collection should include abundance or population estimates at multiple sites within the watershed, identification of recruitment and age class strength, and an assessment of habitat condition.

3. **Population and harvest tracking for game and sport fish species.**

   a. For species utilized for food or recreation purposes, including game species and sport fish, regular monitoring of populations and harvest helps landowners implement informed harvest practices and informs Texas Parks and Wildlife in setting regulations protective of stable populations.

   b. Voluntary creel surveys conducted through the DRAP survey for paddlers or conducted in-person at river access points should be continued to measure fishing pressure by species.

   c. Longitudinal angling surveys conducted by Texas Parks and Wildlife every two years should resume and be completed to complement creel surveys to assess adult sport fish populations along the river.

   d. Similar population estimates and creels should be done for target game species such as whitetail deer, turkey, etc.

4. **Non-native species surveys, treatment, and monitoring.**

   a. Any non-native species identified as part of the taxa inventories should be mapped for the location and full extent of the organisms.

   b. Non-native species should be prioritized based on potential impact on habitat, river function, and native species.

   c. A treatment plan should be developed for those considered at high risk for spread and ecosystem disruption.

   d. Follow-up surveys and re-treatment should be conducted to monitor effectiveness and mitigate spread.

   e. Non-native species considered a low risk in terms of environmental impacts should be monitored, and future taxa inventories should document any spread.

Sustainable Recreation Research Recommendations

1. **Ecological Impact Study** to understand the direct and indirect impacts of recreation on species and habitats and to inform environmental protections and future regulatory practices.

2. **Visitation studies to develop a deeper understanding of the demographics within the recreationist population** and inform best practices for managing access and stewardship education strategies.

   a. A study to gather data outside the DRAP permitting system may provide a more comprehensive understanding of recreation in the region.

3. **Study of communication pathways within Devils River stakeholder communities**, to understand how past and present communication strategies have impacted recreation perspectives and outcomes to better inform future community dialogue, education, and reporting, both within and beyond associated stakeholder groups, and improve decision-making processes to protect the Devils River.

4. **Study of communication and education platforms** covering the region to further understand consumption of messaging and education about recreation in the area to ultimately shape and improve the effectiveness of stewardship-oriented messaging for this region.

5. **Investment in Planning Infrastructure for Recreationists.** Increasing the planning infrastructure for recreationists such as live webcams, or image galleries with visual context for flows levels, could help recreationists understand practical conditions before their trip which may prevent unfortunate health and safety and/or trespassing incidents.
6. **An Economic Impact study should be conducted** to understand more fully the contributions of recreation to the regional economy and to shed light on the relationship between recreation-driven revenue, conservation funding, and the general financial health of the community and supporting conscientious, best-practices planning.

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