UNIVERSITY OF CALIFORNIA

Santa Barbara

# A WATER BUDGET ANALYSIS TO SUPPORT SUSTAINABLE WATER MANAGEMENT IN THE BLACK RIVER BASIN, NEW MEXICO

A Group Project submitted in partial satisfaction of the requirements for the degree of Master's in Environmental Science and Management for the Bren School of Environmental Science & Management

by

*JESSICA ARM*

*TODD CARLIN*

*NICOLE KAHAL*

*HANNAH RISELEY-WHITE*

*ELIZABETH ROSS*

Advisor:

*ARTURO KELLER*

Client:

*THE NEW MEXICO INTERSTATE STREAM COMMISSION*

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Bren School of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

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[redacted]
Jessica Arm

[redacted]
Todd Carlin

[redacted]
Nicole Kahal

[redacted]
Hannah Riseley-White

[redacted]
Elizabeth Ross

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Arturo Keller, Advisor

# Executive Summary

Water resources management in the Black River Basin in southeastern New Mexico is called upon to meet both human and ecological needs. This stream system is increasingly becoming the only regional refuge for a number of threatened and sensitive species. In addition to providing this important habitat, the Black River supports New Mexico's compliance with the Pecos River Compact as the last significant tributary before the Texas state line. Basin managers face mounting pressure on water resources that are increasingly limited by competing uses, including expanding regional oil and gas development, and the potential impacts of climate change. This Bren School Group Project provides state agencies and local stakeholders with initial data collection and analyses necessary to support sustainable water management within the basin.

Located in the arid Southwest the Black River drains approximately 390 square miles. From the upper reaches of the basin in the Guadalupe Mountains to its confluence with the Pecos River, the Black River is characterized primarily by ephemeral reaches with seasonal and punctuated flows. In the middle basin spatially intermittent perennial reaches become more common and result from spring discharges. The principal shallow aquifer exhibits karst properties and is composed of alluvial deposits and limestone conglomerate that contribute to dynamic subsurface flows in the basin.

By the end of 2015 the federal candidate and state-listed endangered Texas hornshell (*Popenaias popeii),* a freshwater mussel, is expected to be listed under the Federal Endangered Species Act (ESA). The hornshell previously occupied hundreds of miles of the Pecos and Rio Grande Rivers and their tributaries from Roswell, New Mexico to the Gulf of Mexico, but it is currently found only in a few select reaches including a nine-mile stretch of the Black River. Limited information is available about the hornshell's hydrologic needs, however, biologists from the New Mexico Department of Game and Fish estimate that a minimum flow of approximately three cubic feet per second (cfs) is required to support this sensitive species. It is important that state agencies implement management strategies to protect species habitat and prepare for the implications of the possible ESA listing.

The first phase of this project focused on data collection and basin characterization. A thorough understanding of the physical, ecological, and social conditions, including New Mexico's water law and administrative framework and an accounting of current water use in the basin, was required to evaluate possible solutions to support effective water management. Knowledge from this first phase supported analyses including: 1) the development of a hydrologic forecasting tool using the Water Evaluation and Planning (WEAP) model, 2) an evaluation of possible minimum streamflow thresholds required to support species and the associated costs of water acquisitions to meet those thresholds, 3) an assessment of trends in water use and administrative mechanisms responding to increasing demand from the oil and gas industry, 4) an evaluation of the possible impacts to water availability, including landscape responses, associated with climate change, and 5) an extensive review of possible management strategies.

Once calibrated, the WEAP model was intended to assess the potential impacts to the basin's water resources resulting from changes in both climate and water use. These impacts are especially relevant for critical habitat reaches and flows contributing to Pecos River Compact deliveries. Challenges encountered during the parameterization and calibration of the WEAP model limited its ultimate utility, but also revealed the importance of certain hydrologic processes. Based on the model's response to calibrated input parameters, it is clear that the karst nature of the local geology plays a significant role in conveying subsurface flows within the basin. The success of any future modeling efforts will require both additional data collection and a model platform that is better able to capture subsurface flows and groundwater-surface water interactions in this complex system.

In addition to model development, over sixty years of gaged streamflow data from the US Geological Survey provided an opportunity to assess hydrologic variability in the Black River reaches that provide critical habitat for the Texas hornshell and other species. Because of uncertainty around the minimum streamflow required to support the hornshell, a range of thresholds from two to four cfs was evaluated based on the frequency that average monthly flows have dropped below these flow rates, possibly putting the species in jeopardy. Average annual shortfalls for each threshold were used to estimate both the volume in acre-feet, and the possible costs of water acquisitions, necessary to ensure each minimum flow rate.

Streamflow responds to changes in climate and shifts in land and water use. An analysis of recent trends in water use, largely based on permit applications for temporary uses and changes in purpose of use, revealed the influence of regional oil and gas development on local water demand. Simultaneously, climate change presents a unique set of management challenges. Increasing temperatures and lower and more variable precipitation are likely to alter both seasonal and total water availability, as well as result in increased disturbance regimes such as fire frequency and ecosystem vulnerability to pests and invasive species.

In response to the management challenges presented, over twenty policy and market-based strategies were evaluated based on a literature review and consultations with state and local experts. Each strategy was given an initial ranking based on its ability to increase streamflow in the basin as well as the level of political and economic effort involved in implementation. Each of these rankings also acknowledged the underlying assumptions and degree of uncertainty involved in the evaluation process. Based on the information collected, a more detailed study of a select subset of management options was pursued.

Project recommendations include suggestions for both additional data collection and immediate management actions. Data needs were prioritized based on information needed to better understand species needs, current water use, basin hydrology and the impacts of climate change. In addition, the group recommends implementation of the following management strategies:

- Increased purchases and leases of water for environmental flows through New Mexico's Strategic Water Reserve, and the strengthening of the right of instream flow as a beneficial use through shifts in administrative practices at the Office of the State Engineer and/or through the New Mexico State Legislature.
- Adjustments to Office of the State Engineer administrative practices to better understand water use in the basin and respond appropriately to shifts in demand.

- Formation of a local water users district to plan for possible implementation of shortage sharing and/or rotational use agreements, and to empower locals to participate in management decisions.
- Support and incentivize increased recycling of produced water in the oil and gas industry to reduce regional demands on fresh water resources.

Adaptive management refers to an iterative process in which management actions are conducted in tandem with monitoring, using data collection to continually inform and adjust actions in order to meet overarching goals and reduce uncertainty. With this in mind, the research involved in this project revealed data gaps that present management challenges, as well as important management strategies that could be taken immediately to support adequate streamflow for local ecosystems and human needs.

The group hopes that this project will spur local agencies to coordinate management actions and the collection of data necessary to inform ongoing and effective basin management. Increasing demand on water supplies, especially from regional oil and gas development, and the uncertainties of climate change present challenges that, although difficult, can be met though coordination between state agencies and local stakeholders. This project is intended to serve as an important step toward guiding effective, equitable, and environmentally sound water resources management in the Black River Basin.

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# INTRODUCTION

Ensuring sustainable water use that meets social *and* biological needs will require collection and analysis of data and the generation of tools and recommendations to support effective, equitable and environmentally sound water resources management. This Bren School Group Project is intended to support state agencies and local stakeholders engaged in management of the Black River Section of the Carlsbad Administrative Basin, hereafter referred to as the Black River Basin.

## Project Significance

Western water planners face mounting pressure on resources that are increasingly limited by competing use priorities, drought, inter and intra-state legal constraints, and the uncertainties of climate change. Working to balance the range of demands represented in the Black River Basin of southeastern New Mexico presents a challenge to state water planners. Located primarily in Eddy County and draining approximately 390 square miles, this basin plays a key role in water delivery for local agriculture, regional oil and gas industry uses, and flow deliveries to Texas via the Pecos River Compact, all while supporting one of New Mexico's most important regional ecosystems (Figure 1). These challenges place increased importance on improving the understanding of local hydrology and the development of tools to support adaptive basin management.

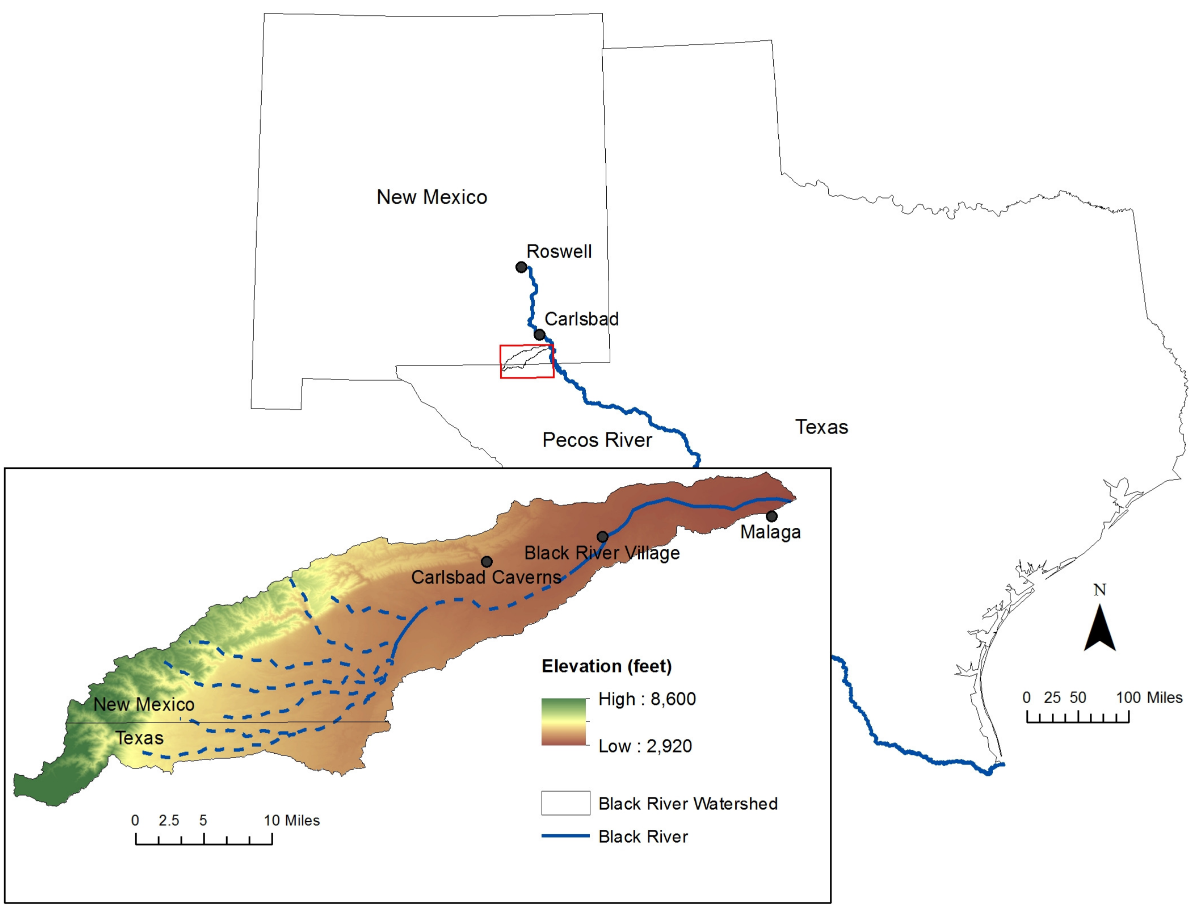
As the last significant tributary to the Pecos River before the Texas state line, the Black River plays an important role in ensuring that New Mexico meets compact delivery requirements. Decades of interstate conflicts over the Pecos River resulted in the designation of a federally appointed River Master who determines New Mexico's annual delivery obligations in order to avoid significant penalties and/or continued and costly legal battles. Additionally, local agriculture and livestock grazing, several small villages, and Carlsbad Caverns National Park all depend on basin surface and groundwater supplies. Within the last decade oil and gas production in the region has experienced significant growth, changing the character of local demand and increasing pressure on basin supplies already stressed by years of drought.

Beyond these human demands, the Black River Basin supports the highest diversity of native aquatic fauna among second order perennial streams statewide. It has become critical habitat for several species extirpated from the Pecos River due to diminished habitat quality and therefore is the only remaining intact regional aquatic faunal assemblage (Lang 2008). It is home to 44 of New Mexico's designated species of "Greatest Conservation Need" and in 2015 the federal candidate and state-listed endangered species, the Texas hornshell (*Popenaias popeii),* a freshwater mollusk, is likely to be listed under the Federal Endangered Species Act.

In order to continually support both the human and ecological needs of the Black River Basin, management must be flexible and able to adapt to possible changes in availability and demand. Adaptive management is defined as "a systematic process for improving management policies and practices by learning from the outcomes of implemented management strategies" (Pahl-Wostl 2007).

Given these challenges, state water agencies must work to protect this critical habitat and engage stakeholders in efforts towards species preservation including preparation for a possible candidate conservation agreement for the Texas hornshell. Candidate conservation agreements between the U.S. Fish and Wildlife Service and various public and private parties work to ensure species survival while addressing stakeholder concerns. These processes will be supported by improved understanding of current trends in water use and basin hydrogeology, including the potential implications to a basin water budget under a range of changing water demand and climate conditions.  Characterization and analysis of basin wide water use and potential impacts on streamflow is limited. A careful water budget that considers current basin conditions and likely ongoing changes in both use and climate will support important decisions to be made in the near future by state water management agencies.

**Figure 1: Map of the Black River Basin**




## Relevance to Other Regional Stream Systems

This study and others of its kind are increasingly important resources for western water planners who are working to balance the needs of changing demands with uncertainties in water supplies resulting from changes in climate.  Basin-scale water budget analyses that include consideration of a range of climate and demand projections are timely and necessary to avoid possible economic and environmental hardships.

The Black River Basin offers an interesting case study due to the range of stakeholders involved and the importance of the local aquatic ecosystems. Adaptive basin management will benefit local stakeholders by supporting effective resource allocation and provides an educational opportunity for state and regional resource management agencies. The scale of the Black River Basin is large enough that management options can have an impact on the stream ecosystem, but is not so large that strategy implementation is overly cumbersome. This scale provides an opportunity for effective stakeholder involvement and for New Mexico's water resources agencies to implement potentially innovative management strategies.

It is important to note that the southeastern portion of New Mexico is characterized by complex hydrogeological systems including karst aquifers and extensive networks of underground tunnels and caves. Due to this distinction some lessons learned on the Black River may be less applicable to other western regions.

## Client Description

The New Mexico Interstate Stream Commission (NMISC) was established by the state legislature in 1935 to investigate, protect, conserve and develop New Mexico's waters including both interstate and intrastate stream systems. As a sister agency to the New Mexico Office of the State Engineer (NMOSE), staff members from both entities work closely together to manage the state's surface and groundwater resources.

There are nine sitting Commission members. NMISC staff is assigned to five bureaus dedicated to oversight of various stream systems. The eight unsalaried Commissioners are appointed by the Governor and represent all regions of the state; the ninth member is the New Mexico State Engineer who serves as secretary.

The NMISC's authority under state law includes negotiating with other states to settle interstate stream disputes. New Mexico is a party to eight interstate stream agreements. This includes the Pecos River to which the Black River is a tributary. To ensure compact compliance, NMISC staff analyzes, reviews, and implements projects in New Mexico, and evaluates stream flow, reservoir, and other data on all interstate stream systems. The NMISC is authorized by statute to investigate and develop the water supplies of the state and institute legal proceedings in the name of the state for the purposes of planning, conservation, protection and development of public waters.

Expected outcomes for the NMISC from this project include an analysis of current water use in the Black River Basin, data collection used in the construction of a basin-wide hydrologic model, materials designed to support stakeholder engagement and the modeling tool itself for their future adaptation and use.

## APPROACH

A three-phase approach was designed to support effective water resources management and address the challenges presented in the Black River Basin (Figure 2). The organization of this report reflects the methodology chosen and implemented by this group project team.

### Phase 1: Develop a Conceptual Understanding of the Basin

Phase 1 involved gaining a well-grounded understanding of the physical and human environments within the basin, as well as the nature and extent of the problems facing water managers. All further analysis and the applicability of project outcomes depended on a thorough characterization of the following elements:

- *Physical Environment* - Characterization of basin geology and hydrology through the creation of maps, literature review, meetings with experts, a basin-wide water budget accounting, cumulative departure curves for precipitation, and generation of depth to water hydrographs provided important information. The group sought to understand the extent, seasonality and vulnerability of water resources.
- *Ecology and Habitat Quality* - Through an analysis of available ecological data the group looked to develop an understanding of which species, including the Texas hornshell, are of greatest concern, what defines adequate habitat and what factors have the greatest impact on the quality of that habitat. The ultimate goal was to characterize the ecohydrology of the basin, defined as the relationship between hydrology and ecosystem health.
- *Human Water Use and Trends in Use* - Data collection from the NMOSE enabled the creation of a water rights catalog specific to the Black River Basin as well as an analysis of trends in use. Through this process the group gained a comprehension of current administrative processes, opportunities and limitations, and the influence of those processes on water use trends. Changes in water use over time could then also be compared to fluctuations in oil and gas development.
- *Legal and Management Framework* - An understanding of New Mexico water law and administrative practices, especially as related to water rights administration, interstate compacts, and Endangered Species Act compliance, enabled an informed analysis of possible management strategies. Recommendations for effective water resources management required knowledge of the framework within which those efforts would operate allowed for discussion of both constraints and opportunities for action.

### Phase 2: Data and Research Analysis

Once the management challenges and the framework within which they exist were characterized the group used the data and research collected to implement Phase 2 action steps. The following two actions occurred in tandem:

- *Water Budget Forecasting Model* - Using the Water Evaluation and Planning (WEAP) software from the Stockholm Environment Institute a water budget forecasting tool was generated. Data from Phase 1 was used to calibrate the model to represent, as closely as possible, current basin conditions. Once calibrated, scenarios were developed to represent likely future changes in both use and climate.

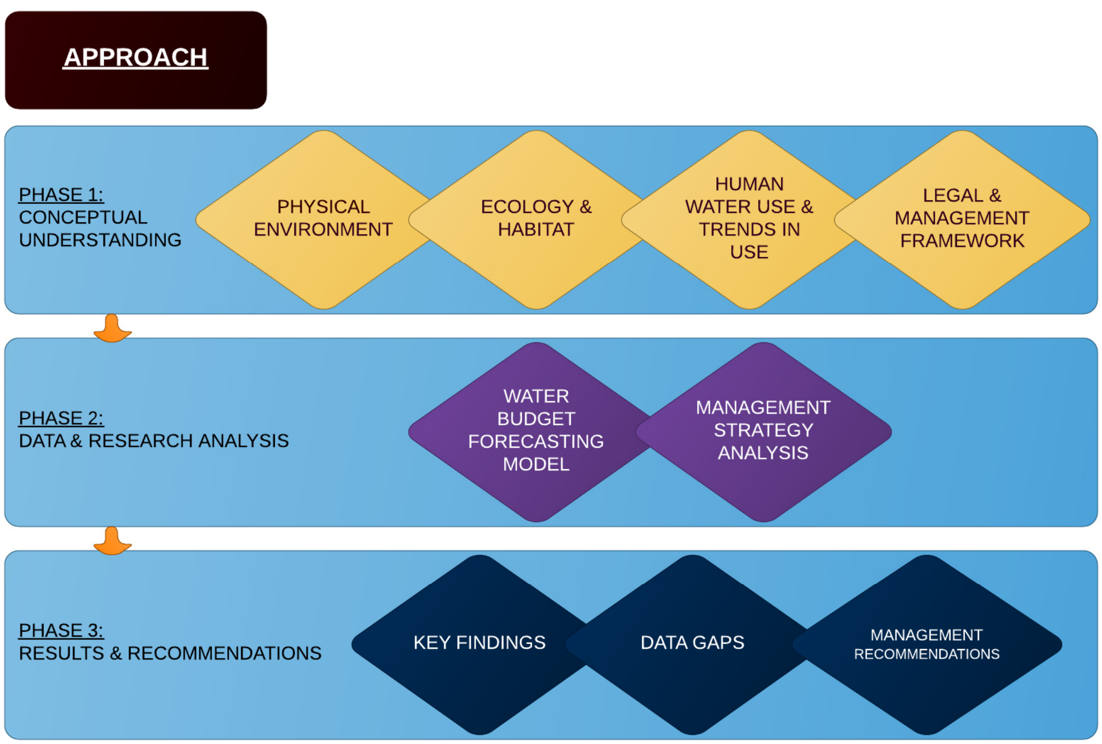
- *Management Strategy Analysis* - Using information and analysis from Phase 1, a wide range of management strategies were evaluated and ranked based on the amount of water they might provide and the level of effort involved in implementation. Each ranking also included an evaluation of the assumptions involved and the degree of uncertainty in the ranking process.

### Phase 3: Results and Recommendations

Based on findings from Phases 1 and 2, this project provides discussion of key results. Final recommendations were based on the management strategies that are most likely to address the challenges as characterized by this project.

Perhaps most importantly, this project also identified important data gaps that must be addressed in order to implement truly resilient and effective management of local water resources.

**Figure 2: Approach Flow Chart**



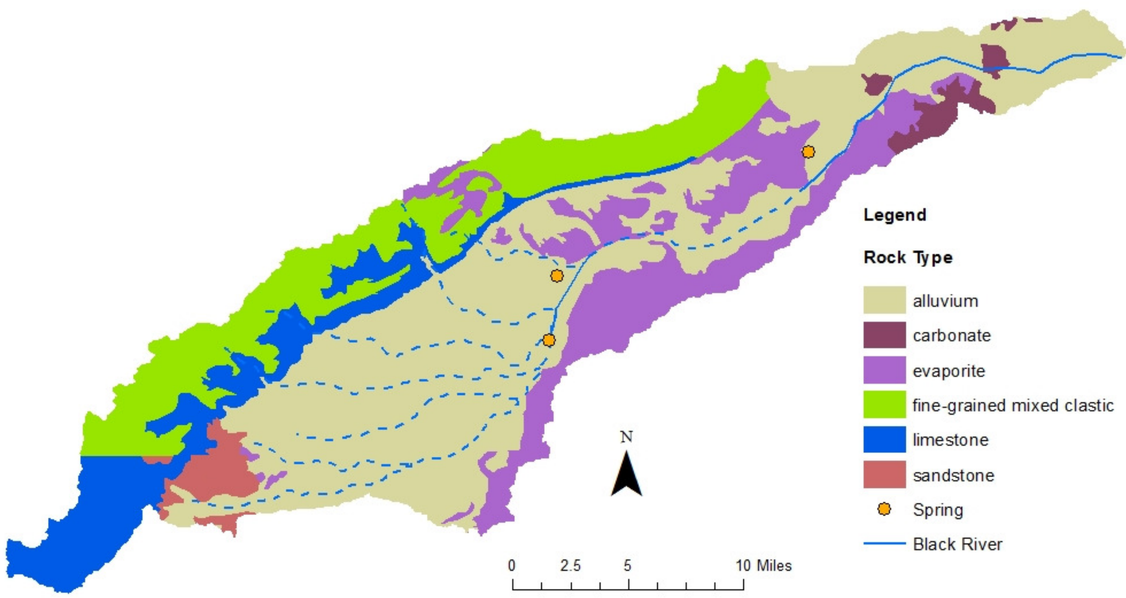
# BASIN CHARACTERIZATION

The first phase of this project aimed to develop a solid conceptual understanding of the Black River Basin, including: 1) the physical properties described by the geology, hydrology and climate of the basin, 2) the ecosystem with particular focus on sensitive and threatened species, and 3) the legal framework relevant to the basin, including land and water use. This compiled knowledge allowed an evaluation of basin water needs to aid the process of forming effective recommendations.

## Physical Environment

### *Geology*

**Figure 3: Map of Black River Basin Geology**




From its southernmost point and headwaters, the Black River Basin is bounded to the west and north by the Guadalupe Mountains and Capitan Reef Formation and to the south and east by the Yeso Hills and outcrops of the Castile Formation. Figure 3 shows the limestone and fine-grained mixed clastic deposits of which the Guadalupe Mountains are composed as well as the Castile Formation labeled as evaporite. The Capitan Reef escarpment along the Guadalupe Mountains was formed as a result of the deposition of stromatolites and calcareous sponges during the Permian age when a large body of water covered the area (Hayes 1964). During the late Cretaceous or early Tertiary period, the Guadalupe Mountains underwent significant uplift and the region tilted to the northeast, setting the stage for the northeast flowing Black River as it is today (Hayes 1964).

Dissolution of the limestone by groundwater moving along fractures in the permeable regions of the Capitan Reef has resulted in the formation of several large caverns, including Carlsbad Caverns.

However, overall bulk porosity of the Capitan Formation is thought to be relatively small (Hale 1955). The Yeso Hills and outcrops of gypsiferous Castile Formation bound the basin along the south and east. These low relief hills are composed of fine-grained white gypsum, and are underlain by layers of interbedded gypsum and fine-grained limestone (Hayes 1964). These outcrops can be seen mid-basin, and the deeper layers of varved gypsum can be seen in the road cuts along Highway 62 just north of the Texas state line. The impermeable beds of evaporitic gypsum and anhydrite found in the Castile Formation of Permian age extend in rough cross-section from the Yeso Hills, where the formation is relatively thick, to the toe of the Guadalupe Mountains, where it progressively thins and becomes thickly overlain by alluvium (Bjorklund 1958).

Underlying the Castile formation along the toe of the Guadalupe Mountains, the Capitan Reef gradually thins and interbeds with the Bell Canyon Formation of Permian age that extends past the eastward extent of the Black River Basin. Subsurface connectivity between the Castile formation and the Capitan limestone of the Guadalupe margins is not well understood, though it is assumed that there is little hydrologic connection due to low permeability of the Castile Formation. The valley fill is comprised of Quaternary age unconsolidated alluvium and karstic limestone conglomerate (Figure 4) that is bedded with boulders, cobble, caliche, gravel, sand, and silt that eroded from the Guadalupe and Delaware mountain ranges following regional uplift (Bjorklund 1958).

**Figure 4: Limestone Conglomerate along a Bank of the Black River**

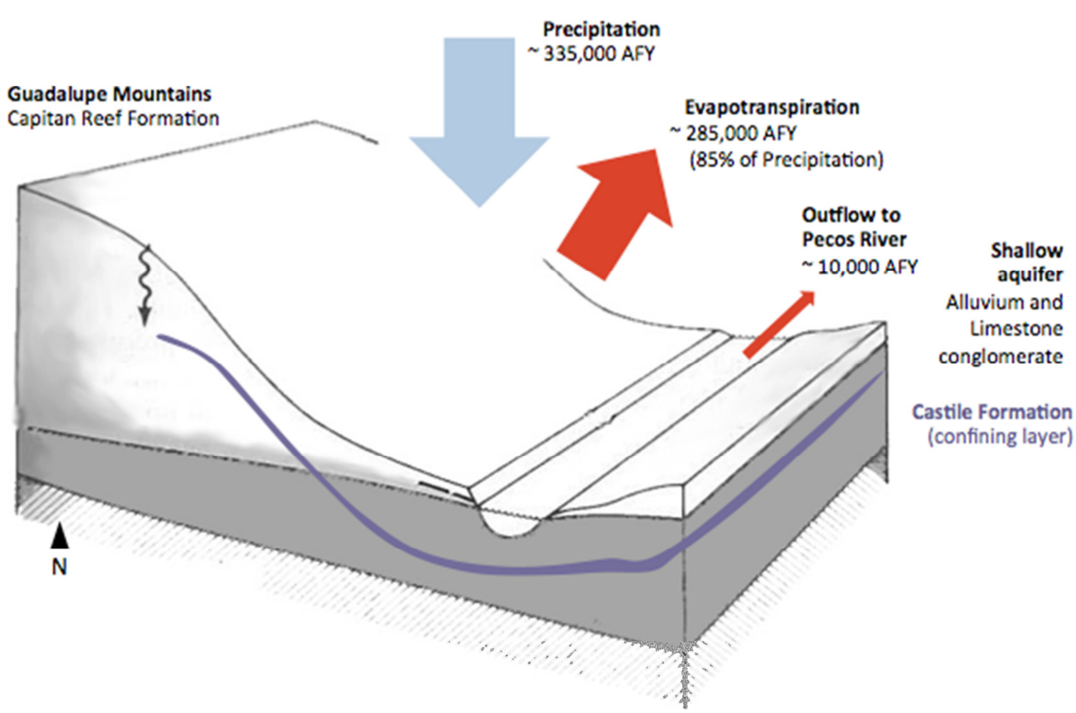
The alluvium extends from the fans of the canyon washes to the east of the Black River where it progressively thins until it abuts the Yeso Hills and Castile outcroppings. Alluvial material abutting the Yeso Hills is often comprised of finely weathered gypsum (Hayes 1964). Within the alluvial material consolidated limestone conglomerate underlies the unconsolidated deposits and outcrops throughout the basin where it is typically slumped and greatly fractured (Conover 1952). This well-cemented layer is a mixture of cobble-sized alluvial material and silt to pebble-sized limestone that was weathered and eroded from parent material in the Guadalupe range and the Capitan Reef Formation (Hayes 1964).

## *Hydrology*

### Flux Diagram

The flux diagram shown in Figure 5 provides an important snapshot of total estimated water volumes in the basin and was used to evaluate model performance.

**Figure 5: Initial Flux Diagram**




### Water Bearing Formations

The main water bearing formations in the Black River Basin are located in the unconsolidated alluvium and limestone conglomerate found in the valley fill and depositional floodplain areas (Hale 1955). In these regions of the basin where water is primarily extracted, it is estimated that the alluvium ranges in thickness from zero to 200 feet in the valley fill and reaches much greater thicknesses in alluvial fans and washes at the toe of the Guadalupe Mountains ( (Hale 1955) (Hayes 1964) ). Over geologic time periods, tectonic movement and Pleistocene uplift of the Guadalupe Mountains along with downcutting of the

Pecos River through the region have influenced groundwater flow in the local aquifers (Hiss 1980). The general movement of groundwater within the basin follows the topographic gradient and slopes from the Guadalupe Mountains eastward toward the Black River and to the northeast along the valley floor. Although the alluvium is the most productive material in the basin, there are a few deep wells that reportedly draw their water from the underlying gypsum formations, though it is estimated that yields are minimal (Conover 1952). Several productive springs, such as Headwater, Rattlesnake, Castle, and Blue Springs, exist throughout the mid and lower basin and provide surface flows to the Black River's perennial reaches through seeps and outcrops in the limestone conglomerate (Conover 1952).

### Groundwater Pumping

Water levels in wells throughout the Black River valley follow a seasonal pattern that is influenced mainly by groundwater pumping for irrigation, and are generally highest in late fall and winter and lowest in summer (Cox 1963). Likewise, both Rattlesnake and Blue Springs tend to have discharges of greater volumes in winter and lowest volumes in summer, suggesting that the alluvial aquifer is likely to be the principal source of water for the springs (Cox 1963). According to Hale (1955), irrigation from wells in the in the basin first began in 1946 around Rattlesnake Springs. Over the decades, wells have increased dramatically in number and draw predominately from the unconsolidated alluvial material and underlying limestone conglomerate.

Concern over the impact of groundwater pumping on the production of Rattlesnake Springs and the base flow of the Black River was first realized in 1952 with a State Engineer investigation into the groundwater conditions of the upper basin and the Rattlesnake Springs area. An initial assessment at that time indicated that groundwater pumping in the vicinity of the springs was likely to contribute to diminished flows and that continued monitoring of water levels and discharge measurements would allow for more detailed analyses of the effects of pumping on the Black River (Conover 1952).

Further investigations by Cox (1963) examined the impact of three groundwater wells on the water level of the Rattlesnake Springs holding pond over a one-year period. This study also evaluated water levels in a monitoring well near the springs that was thought to represent water levels in the principal shallow aquifer over a one-month period. The findings indicated that after pumping at the two wells within one mile of the springs, the water level of the holding pond and monitoring well fluctuated markedly and dropped in unison. This offered evidence that the springs' discharge may be in part determined by nearby pumping levels. Although water levels in the monitoring well were affected more than the holding pond, the prevailing gradient towards the springs was reduced in both cases and drawdown impacts were generally noticed within two hours (Cox 1963). Surface diversions from the holding pond occurred historically by the National Park Service (NPS) for Carlsbad Caverns with no impact on the springs' discharge. A dispute between the NPS and the landowners over proper allocation of the holding pond's water led the NPS to drill a well just to the northwest of the springs to supplement the surface rights. Generally speaking these studies and others have attempted to understand the complex movement of groundwater throughout the basin.

## Recharge

There are a myriad of canyons along the western and northern boundaries of the watershed that extend from the Guadalupe Mountains down to the Black River floodplain through which storm runoff infiltrates (Hale 1955). Recharge from incident precipitation on the valley floor and irrigation return flows also contribute to recharge of the alluvial aquifer. The sands and gravels found in the canyon washes are typically coarse, and although poorly sorted, have high rates of permeability leading to rapid infiltration whereas the broad fans in the lower valley consist of finer sediments and clays and generally have lower permeability leading to lower recharge rates. (Hale 1955).

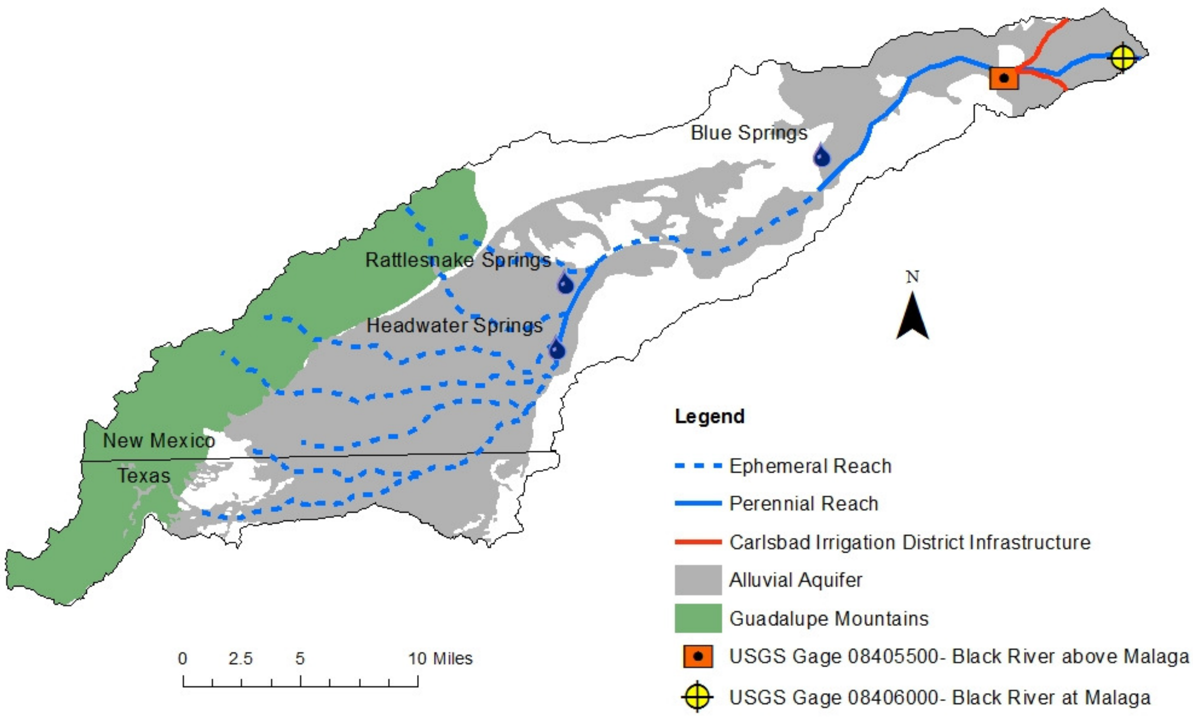
Given the spatial variation of precipitation in the basin, with a larger proportion falling over the Guadalupe Mountains, recharge in these canyon washes is likely to play a very significant role in recharge of the principal alluvial aquifer. Cox (1963) posited that while the majority of recharge to the alluvium occurs as a result of precipitation over the Guadalupes, the Castile Formation may be locally recharged by precipitation on the outcrop and where the overlying alluvium is thin. Furthermore, due to its small recharge area along the southern edge of the basin and its hydrologic characteristics, it is estimated that the amount of water moving through the Castile Formation into the alluvium is very small in comparison to the amount moving through the unconsolidated alluvium and limestone conglomerate (Hale 1955). Areas of the Black River Basin also recharge the Capitan aquifer through solution channels in the reef escarpment and follow a general northeastward flow path towards Carlsbad (Hiss 1980).

Return flows from irritation are also a contributor to recharge in the basin. Hale (1955) estimated return flows of irrigation water to be about 30 percent. There is at least one dispute between landowners within the basin based on the claim that local groundwater supply for wells comes in part from the irrigation return flow of an upgradient parcel (see “Legal Framework” section).

## Surface Water

The principal watercourse in the basin, the Black River, originates in the southern Guadalupe Mountains in Texas and flows in a general northeastward direction into New Mexico towards the Pecos River. The prevailing gradient of the valley and stream channel is approximately 25 feet per mile (Hale 1955). The current hydrography in the Black River Basin is the result of the ancestral drainage system that once covered the landscape. It is suspected that the Black River originated in the Tertiary period and developed its relatively current course as a result of regional uplift and tilt to the northeast (Hayes 1964). Following more recent uplift of the Guadalupe Mountains around the early Pleistocene, erosion from streams flowing parallel to the Capitan Reef Formation to the northeast, such as Walnut Creek, began to cut down the hillsides to the southeast to form many drainages such as Slaughter and Rattlesnake Canyons (Hayes, 1964).

**Figure 6: Black River Basin Hydrology**




The Black River has both perennial and ephemeral reaches, as shown in Figure 6. The ephemeral upper reaches and canyon washes that drain the Guadalupe Mountains only flow during concentrated storm events. Flows quickly infiltrate into the alluvium, sometimes even before reaching the valley floor. There are a number of small perennial springs mid-basin, referred to as the Headwater Springs, which discharge from the alluvium to create a series of pools connected by shallow channels (Cox 1963). These springs contribute to the flow of the upstream perennial reach of the Black River, which extends roughly four miles downstream of Rattlesnake Springs below which only large storm events produce flow in the channel (Hale 1955).

Rattlesnake Springs lies on the west side of the Black River and discharges water from the limestone conglomerate and overlying unconsolidated alluvium into a constructed spring pool (Hale 1955). Bowen (1999) hypothesized that a significant cause of groundwater discharge in the Rattlesnake Springs area is the near surface and outcropped Castile Formation just downstream of the springs. Bowen argues that water flowing in the northeastward direction is to some extent forced to the surface and confined by outcrops on either side of the Black River. Flumes on the Rattlesnake Springs pool funnel water to either nearby farms for irrigation purposes or through the "natural drainage" to the Black River. The natural discharge of Rattlesnake Springs contributes perennial flows to the Black River for a short ways downstream of its confluence with the Black River and then again the reaches become intermittent (Hale 1955).

Blue Springs (shown in Figure 7), which is about 11 miles northeast of Rattlesnake Springs, discharges from the limestone conglomerate that exists at or near the surface and is suspected to be the main contributor to perennial flows on the Black River (Cox 1963).

**Figure 7: One of Several Blue Springs Discharge Points**

The magnitude of the discharge at Blue Springs indicates that recharge to the principal aquifer must come from the upper Black River Valley and areas within the canyon washes and alluvial fans (Hale 1955). It is presumed that the outflow at Blue Springs does not affect the hydrologic conditions of the upstream Rattlesnake Springs, and that at least some volume of water flows past the upstream springs to comprise the discharge at Blue Springs (Cox 1963).

## Ecosystems

The Black River Basin supports a diverse ecosystem home to a wide range of fish, reptiles, amphibians, mammals and birds. This important habitat depends on sufficient water supplies and appropriate natural flow regimes. Because riparian areas are extremely important to many endemic species, New Mexico Department of Game and Fish (NMDGF) released a series of studies in 2008 urging state agencies to pay attention to the impacts that current water management has on biodiversity (Lang

2008). Many sensitive species seek refuge in the Black River Basin, including the Texas hornshell, a Candidate Species that will likely be listed as threatened or endangered under the Endangered Species Act (ESA) by 2015. Accordingly, local management agencies must be prepared to implement any changes the listing may warrant.

Balancing the competing water needs of irrigators and private industry with the natural environment is a challenging task, and a full analysis of the ecosystem and habitat requirements is necessary in order to inform sustainable management practices. The following subsections describe the ecosystem characteristics as well as state and federally listed species to aid in water management decisions.

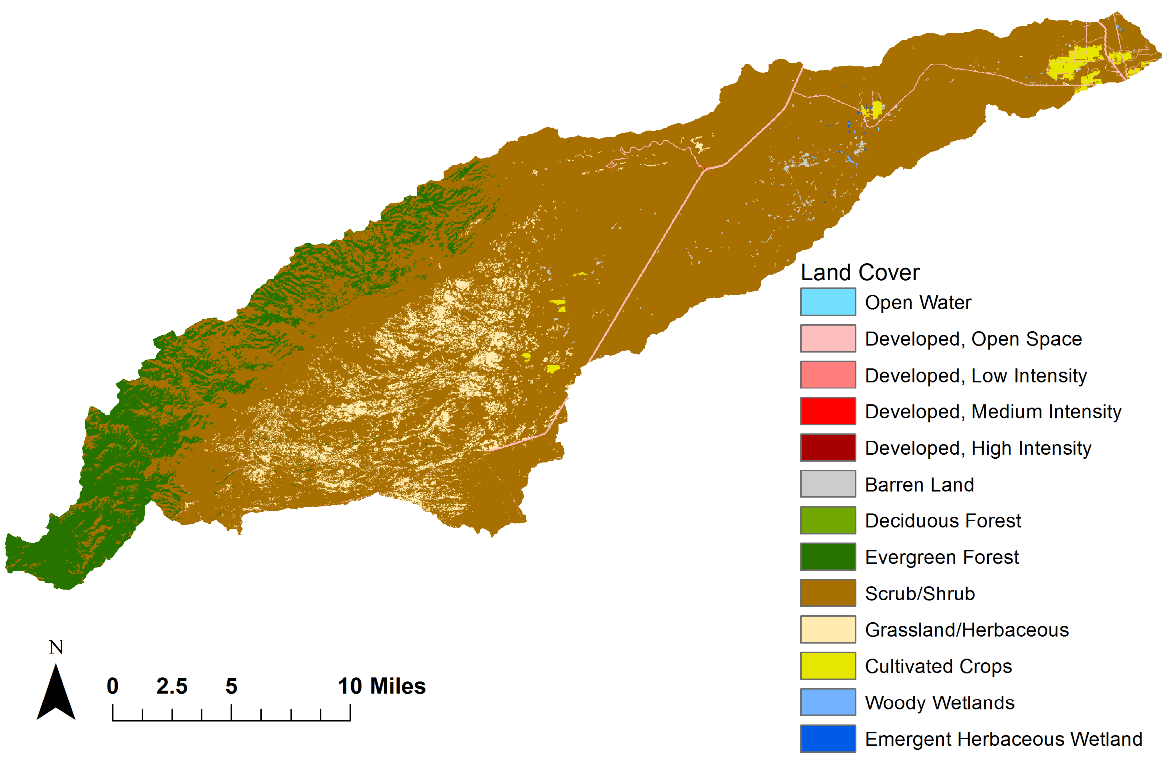
## *Vegetation and Land Cover*

Southeastern New Mexico is primarily Chihuahuan Desert, an ecoregion in which vital riparian areas surrounded by expansive desert landscapes support a diverse range of plants and animals (New Mexico Department of Game and Fish 2006). Two key terrestrial habitat types dominate the Chihuahuan Desert: grasslands and scrub environments as exemplified in Figure 8. Defining species of the Chihuahuan include creosote, mesquite, tarbush as well as cacti and agave (Dinerstein, et al. 2000).

**Figure 8: Typical Vegetation within the Basin with Precipitation Clouds Forming over the Guadalupe Mountains**

The Black River contains semi-desert grasslands, a habitat type that constitutes just a small portion of the Chihuahuan desert but is critical to the biodiversity of the ecoregion. The 2006 National Land Cover Dataset (Figure 9) shows predominately scrub vegetation with some intermingled grassland and herbaceous cover. In general, shrub lands in the Chihuahuan Desert, such as creosote and fluffgrass, are further expanding due to land use degradation from overgrazing (Dinerstein, et al. 2000). Common native species of the area include grasses such as black grama, hairy grama, rothrock grama, sideoat grama, blue grama, tobosagrass and alkali sacaton, as well as succulents such as dasylirion, agave and yucca (New Mexico Department of Game and Fish 2006).

**Figure 9: Black River Basin Land Cover Map**




## *Riparian Systems*

The rivers and streams in the Chihuahuan Desert provide a rich riparian habitat, characterized by the narrow belt of vegetation along all reaches of the Black River. Although riparian areas provide a valuable source of biodiversity in semi-arid regions, they comprise less than one percent of the total area of New Mexico (New Mexico Department of Game and Fish 2006). Riparian areas provide habitat to the most diverse range of wildlife and vegetation in the state, and it has been estimated that 80 percent of its total wildlife has spent at least a portion of its lifecycle in riparian areas (New Mexico Department of Game and Fish 2006).

Many bird species, including waterfowl, shorebirds and songbirds, are found along the Black River. Green-backed herons, orchard orioles, roadrunners and yellow-billed cuckoos are common to the area (Bureau of Land Management 2009). Rattlesnake Springs, in particular, provides important summer residence and breeding habitat for birds (Dinerstein, et al. 2000). Amphibians and reptiles of the Black River include the Barking frog, the New Mexico State Threatened Western River Cooter, Western Ribbon Snake and Rio Grande Leopard Frog and the New Mexico State Endangered Plain-bellied water snake (New Mexico Department of Game and Fish and United States Fish and Wildlife Service 2008).

Aside from providing wildlife habitat to several state and federal protected species, ecological functions of riparian areas include preventing erosion and protecting aquatic systems from excessive sedimentation. Riparian zones are extremely important for water quality because they act as a buffer for surface runoff and reduce the amount of excess nutrients entering the water supply from runoff. Riparian habitat is vulnerable to agricultural and industrial runoff, groundwater and surface water depletion, overgrazing and invasive species (New Mexico Department of Game and Fish 2006).

Figure 10 shows Headwater Springs, one of the uppermost perennial waterways of the Black River Basin. These springs provide habitat for numerous species and are essentially an oasis within vast expanses of desert scrublands.

**Figure 10: Headwater Springs**

## *Aquatic Systems*

Supporting the highest diversity of native aquatic fauna among second order perennial streams in the state, the Black River hosts 44 species of “Greatest Conservation Need” (SGCN) identified by the New Mexico State Department of Game and Fish (New Mexico Department of Fish and Game 2006). In areas of perennial flow, aquatic habitats of the Black River include cobbled riffles, undercut-bank pools, and shallow runs (Carman, Texas hornshell Popenaias popeii Recovery Plan 2007). Stream flow is perennial for approximately four miles upstream of Rattlesnake Springs where the river becomes ephemeral again until inflows from Blue Springs. From Blue Springs flow is perennial until the confluence with the Pecos River.

The outstanding water quality of the river supports many endemic species including the New Mexico State Endangered Texas hornshell, a freshwater mussel (Carman, Texas hornshell Popenaias popeii Recovery Plan 2007). Fish species found in the river include largemouth bass, killifish and catfish, the state threatened grey redhorse and Mexican tetra, the federally threatened Rio Grande shiner and Pecos gambusia, among many others (New Mexico Department of Game and Fish and United States Fish and Wildlife Service 2008). Introduced fish species include rainbow trout, spotted bass and white bass (New Mexico Department of Game and Fish and United States Fish and Wildlife Service 2008).

Interconnected with the riparian habitat, the aquatic ecosystems of the Black River rely on natural flow regimes. Sufficient stream flow is necessary to support nutrient cycling, seed dispersal, plant establishment and sediment balance, among other important processes (New Mexico Department of Game and Fish 2006). This makes the health of the aquatic system vulnerable to over pumping of groundwater, excessive surface water diversions, channel alteration and land management decisions. Land clearing has the potential to cause erosion, excessive sedimentation, and expansion of non-native plants, and ultimately alter natural channels and substrate composition (Dinerstein, et al. 2000). Increased agricultural and oil and gas industry runoff, as well as poorly designed road crossings, are other factors that have the potential to degrade water quality and overall health of the Black River ecosystem.

## *Sensitive Species of the Black River*

The Black River Basin is home to many sensitive species recognized and protected at both the state and federal level. The 44 New Mexico Species of Greatest Conservation Need (SGCN), 17 New Mexico Threatened or Endangered species (which can also be designated SGCN), two Federally Threatened or Endangered species and one Candidate Species for federal listing found in the Black River Basin are listed in Appendix B.

***New Mexico State Threatened or Endangered***
Species native to New Mexico are listed as state endangered if they are found to be at-risk of extinction or extirpation from the state and listed as state threatened if endangerment is likely in the foreseeable future. The New Mexico Wildlife Conservation Act (WCA) gives the NMDGF the responsibility to develop recovery plans for state listed species [17-2-40.1 NMSA 1978] aimed at restoring and maintaining viable populations and habitat, mitigating economic impacts of recovery, identifying economic benefits of recovery and utilizing existing resources and funding to carry out the plan (New Mexico Department of Game and Fish 2006).

***New Mexico Species of Greatest Conservation Need***
New Mexico is required by the federal government to identify SGCN in the Comprehensive Wildlife Conservation Strategy. These species are identified by their importance for adding to diversity, recreational, economic or charismatic value, as well as low or declining populations (New Mexico Department of Game and Fish 2006). Creation of the list facilitates the identification of conservation, research, surveying and monitoring needs of species and habitats, but does not require implementation of conservation actions.

***United States Threatened or Endangered Species***
The ESA allows the United States Fish and Wildlife Service (USFWS), under the Department of Interior, to evaluate species for federal listing as Endangered or Threatened. Species can be listed if they meet one of the following factors: 1) present or threatened destruction, modification, or curtailment of its habitat or range, 2) overutilization for commercial, recreational, scientific, or educational purposes, 3) disease or predation, 4) inadequacy of existing regulatory mechanisms, 5) or other natural or manmade factors affecting their survival (U.S. Fish and Wildlife Service 2013). Species are considered for evaluation by USFWS through petition by an interested party or through the candidate assessment process. Once a species is listed, designated critical habitat is determined and a recovery plan is created to act as a road map for the species' recovery.

Actions taken to address a species status vary by its legal protection as well as the amount of funding available to implement conservation actions. For example, the federally endangered Pecos gambusia (*Gambusia nobilis*) was listed in 1970, however no critical habitat has been designated and although federal projects must consider potential harm to the fish, most actions outlined in the recovery plan have not yet been implemented. The Pecos Gambusia Recovery Plan was published in 1983 and outlined recommended actions such as ecological studies, habitat restoration, reintroduction and non-native fish removal. One of the few initiated projects involving the conservation of the species was population monitoring to better understand the status of the Pecos gambusia in the ciénegas of Balmorhea State Park, Texas, which began in 2009. In addition, ongoing habitat enhancement was initiated prior to 1995 (United States Fish and Wildlife Service n.d.). No known projects are occurring in the Black River Basin.

The Southwestern Willow Flycatcher (*Empidonax traillii extimus)* was listed as federally endangered in 1995 under ESA and is found in Arizona, California, Colorado, Nevada, New Mexico, Texas and Utah. Critical habitat for this bird includes areas of Catron, Grant, Hidalgo, Mora, Rio Arriba, Socorro, Taos, and Valencia Counties in New Mexico. Funded projects to protect the Southwestern Willow Flycatcher have been implemented in many areas and include development of regional management plans, restoration and invasive species eradication, and feasibility studies of flood flow use to increase viable marsh habitat. Organizations like the World Wildlife Fund and the Walton Foundation have contributed funds and effort to complete surveys and implement restoration projects. Although the Black River Basin lies in the range of the Southwestern Willow Flycatcher, no USFWS projects specific to the Black River were found.

The ovate vertigo snail (*Vertigo ovate*) is a SGCN in New Mexico and known in just two locations of the Black River. Listed as state threatened in New Mexico in 1991, a stable population has been surveyed at Blue Springs showing signs of successful reproduction and recruitment. However, its historic range has been severely limited and changes in land use risk species extirpation. No protected critical habitat exists and no recovery actions have been implemented to regain its historical range.

### *Habitat Threats*

Many species in the Black River Basin are found, or have historically been found, on the Pecos River. However, viable riparian and aquatic habitat on the Pecos River has been fragmented or lost as a result of the manipulation of the water supply due to competing demands and regulation (Dinerstein, et al. 2000). Demand from public and private uses prompted construction of major dams between Artesia and Carlsbad in the 1890s. Today, the Pecos River flow is restricted and regulated by many dams including Brantley, Avalon, Santa Rosa, Sumner, Avalon, Upper and Lower Tansill, 6 Mile, and 10 Mile until it meets the Texas border (Carman 2007). Habitats are flooded above dams; below dams, the river is channelized or concrete-lined and aquatic species are unable to move past impoundments, fragmenting their natural range. Alteration of the natural hydrologic regime resulted in days of zero flow, as well as frequent block releases (U.S. Fish and Wildlife Service 2006). Excess sedimentation and water pollution from agriculture and industry, particularly oil and gas, pollute the river, further challenging the survival of many sensitive species (New Mexico Department of Game and Fish 2006).

The 1948 Pecos River Compact also played a role in the alteration of the Pecos because it specified the amount of water New Mexico is required to deliver to Texas, prompting further storage and manipulated releases of water from reservoirs. In addition, unregulated groundwater pumping in the early 20$^{th}$ century depleted the water table leading to a loss of surface flow along portions of the Pecos River and its tributaries (Carman 2007). This led to additional stress on the water resources upon which many sensitive species depend.

As in the larger Pecos Basin, development within the Black River Basin would likely put important habitat at risk. Significant increases in consumptive water demand could reduce groundwater and surface water to levels potentially unsuitable for aquatic species. Increased erosion and sedimentation from land uses that involve clearing native vegetation also put the sensitive aquatic habitat at risk. Oil and gas industry operations in particular have the potential to degrade water quality from spills, leaks or seepage.  Groundwater contamination from petroleum-derived hydrocarbons and sulfides has been recorded in the Black River, as well as contamination from tebuthiuron, an herbicide used to control woody plants (New Mexico Department of Game and Fish and United States Fish and Wildlife Service - Region 2 2008).  Tebuthiuron is toxic to aquatic life at varying degrees.  Long distance transport of water in the karst environment poses further concern in the area as contamination has the potential to spread across greater distances.

Potential blooms of toxic golden algae (*Prymnesium parvum*) in the lower Pecos River are also a concern to habitat range.  Toxins produced by the algae are especially deadly to aquatic, gill-breathing organisms, such as fish, bivalves, crayfish, gilled amphibians, and some species of plankton.  Golden algae was first reported in New Mexico in 1980, and between 2002 and 2007, blooms triggered extensive fish kills in the lower Pecos River, specifically Brantley, Bataan, and Carlsbad Municipal Reservoirs (Sallenave 2010).  Although exact conditions causing golden algal blooms are unknown, most fish kills have occurred in spring and winter when other algal species are unable to persist in the cooler temperatures and limited nutrient availability (Sallenave 2010).  Although it has not been seen in the Black River, toxic golden algae has caused mass fish kills in the Pecos River within close proximity to the Black River confluence (Lang 2008).  The reduction or extirpation of many species' populations have prompted protection under New Mexico state and United States law.

Black River species of special status are discussed in the following subsections, under New Mexico threatened or endangered listings, New Mexico Species of Greatest Conservation Need (SGCN), and United States threatened or endangered listings.

### *Endangered Species Act on the Pecos River*

Pecos River water is designated to three primary uses: 1) agriculture (including multiple irrigation districts), 2) Texas delivery via the Pecos River Compact, and 3) for Endangered Species Act compliance to support the federally threatened and New Mexico endangered Pecos bluntnose shiner (United States Fish and Wildlife Service 1992).  The Pecos bluntnose shiner is a small minnow approximately three inches in length that historically occupied about 392 miles of the Pecos River from Santa Rosa downstream to the Texas-Mexico border (United States Fish and Wildlife Service 1992).  Now restricted to 200 miles of the Pecos near Fort Sumner to the inflow of Brantley Reservoir, Pecos bluntnose shiner habitat was diminished due to the construction of dams and manipulation of the water delivery system (United States Fish and Wildlife Service 1992).  Historically uncontrolled floods and large inputs as well as blockages of sediment occurred naturally on the Pecos River.  Block releases from water impoundments occur longer and more frequently and the now narrow and incised channels beyond the impoundments provide significantly reduced refuges of backwaters and low velocity habitat (United States Fish and Wildlife Service 1992).  This causes displacement of eggs, larvae and small juveniles to less suitable habitat areas, such as Brantley Reservoir, where the lack of water velocity causes eggs to sink and perish when covered by sediments (United States Fish and Wildlife Service 1992).

The Pecos bluntnose shiner was listed as federally threatened in 1987 (United States Fish and Wildlife Service 1992). In 1991, the USFWS received a biological opinion indicating that the operation of the Pecos River dams were a continuing threat to the existence of the Pecos bluntnose shiner (United States

Fish and Wildlife Service 1992). According to the ESA, all federal agencies must protect species listed as threatened or endangered and preserve their habitat (Sims and Smith n.d.). Accordingly, the USFWS is responsible for ensuring federal agency compliance with planning or modifying federal projects so that they do not adversely affect federally protected species. As the main federal stakeholder in the Pecos Basin, owning three of the major dams on the river, the Bureau of Reclamation (BOR) has the responsibility of consulting with USFWS over issues regarding the Pecos bluntnose shiner and federal projects (Sims and Smith n.d.).

In July 2006, BOR issued a Record of Decision for the Carlsbad Project Water Operations and Water Supply Conservation Final Environmental Impact Statement, a requirement resulting from a 2002 lawsuit filed by Forest Guardians. The BOR decision identified the preferred alternative of diverting water at the Taiban gage when flow is over 25,339 acre-feet per year (AFY), for storage. To meet the target flow of 25,339 AFY at the Taiban gage (Below Taiban Creek near Fort Sumner gage, USGS 08385522), available inflows would be bypassed through Santa Rosa and Fort Sumner Dams (Bureau of Reclamation 2005). The stored water, as well as other supplemental water, would then be used to prevent intermittency of flows to augment bluntnose shiner habitat. Water is also used to ensure delivery of Carlsbad Project water and to make up for depletions caused by Sumner Dam operational changes associated with bluntnose shiner conservation. Other criteria of the proposed changes include guidance for block releases, continued use of a fish conservation pool and implementation of a water acquisition program (Bureau of Reclamation 2005).

Currently, sources of supplemental water available to BOR include a well field managed by NMISC that has a design capacity of 15 cfs, or 10,840 AFY. The award winning Vaughan Conservation Pipeline has 1,583 AFY of consumptive use water rights purchased with funds appropriated by the New Mexico State Legislature as part of the implementation of the 2003 Pecos River Settlement. Presently, due to ongoing drought it provides about 8.5 cfs just upstream of the Taiban River confluence. In addition there is a 1,000 acre-foot fish conservation pool, bypass water and Pecos River pumper leases that augment flow for the Pecos bluntnose shiner quality habitat reach (U.S. Fish and Wildlife Service 2006). These sources of water were adequate to maintain a flowing river from 2005 to 2011, however, historic drought has caused increasing river intermittence and population declines for the Pecos bluntnose shiner (personal communication with Emile Sawyer, NMISC 2013).

In 2009 the Fort Sumner Irrigation District (FSID) entered into an agreement with the BOR to forbear an annual diversion of up to 2,500 acre-feet of water which the district held in storage with agreement between BOR and CID, as FSID does not have a storage right, to maintain flows necessary to support the Pecos bluntnose shiner (Fort Sumner Project Title Conveyance 2013). BOR pays FSID $60,000 each year plus $20 per acre-foot and stores the water in Sumner Lake reservoir from which it is delivered to the river to prevent intermittency of flows on the Pecos (Fort Sumner Project Title Conveyance 2013).

### *Summary*

The Black River Basin supports a lush riparian community - a rare refuge of biodiversity in the semi-arid Chihuahuan Desert. An ecosystem adapted to periods of drought and large pulses of flow in summer rain events, it is still a sensitive environment that can be heavily impacted by over pumping and diversion of water. Consequently, water resources in the basin should be managed not just to support human uses, but also to allow for the continuation of a healthy system capable of supporting a wide range of species.

Planning sustainable water management that considers the long-term health of the Black River ecosystem entails efficient control of invasive species, reduction of water and soil contamination from industry spills, and controlled development. The wildlife present in the basin includes many special-interest species recognized by state and federal agencies as species in need of protection. Understanding the conditions necessary to sustain special-interest species will help prepare for the potential changes needed to fulfill requirements of species protection laws and regulations, allowing for water conservation in ways that prevent conflict amongst stakeholders. However, implemented federal actions toward species conservation vary widely, making it difficult to predict exactly how a new ESA listing would impact water administration in the Black River Basin.

## History and Demographics

The Black River region was home to nomadic tribes for millennia and was later settled by Ancestral Puebloans starting in the 1300s (Eddy County 2007). Spanish explorers traversed the area in the 1500s while tracking the path of the Pecos River but the area did not become steadily populated until the 1860s when ranchers and cattlemen became attracted to the warm, sunny climate and established grazing operations in what is now the Carlsbad area (Eddy County 2007). By the 1890s a system of canals were built to divert Pecos River water to farms and ranches which brought more settlers to the area and it became a vibrant agricultural region that produced cotton, alfalfa, cattle, sheep and wool (Eddy County 2007).

Oil was discovered in Eddy County in 1909 near Artesia, the present location of a refinery that processes oil into gasoline, diesel jet fuel and asphalt (Eddy County 2007). Potash was also discovered east of Carlsbad in 1925 where several large potash producers still operate (Eddy County 2007). Nearby, a local cowhand stumbled upon an extensive system of underground cave formations in 1898, which later drew international interest due to their vastness, and large population of Mexican free-tailed bats (Eddy County 2007). Upon further exploration the caverns revealed over 300 limestone caves that are some of the deepest, largest and most ornate caverns in the world (National Geographic 2014). The Carlsbad Caverns became a national monument in 1923 and were later designated a national park in 1930 (National Park Service 2014). The park receives part of its water supply from the Black River at Rattlesnake Springs and from the underground aquifer. To support the millions of visitors each year, six miles of water pipe was laid from Carlsbad Caverns to Rattlesnake Springs in 1935 to replace Oak Springs as the park's water supply (National Park Service 2014).

Today, the Black River Basin region remains primarily rural: 80 percent of the land in Eddy County is public, administered by the federal or state government, while 20 percent is privately owned (Sites Southwest 2008). Half of the county's 52,000 people reside in Carlsbad, just outside of the Black River Basin. The smaller towns of Artesia and Loving are home to a combined 12,700 people and the remainder of the area's population, including that in the Black River Basin, resides in small rural communities (U.S. Census Bureau 2013).

Basin farming operations are mostly found around Malaga and east towards the confluence of the Black River and the Pecos River. However, there are operations south of Rattlesnake Springs and as far as the Texas state line. Both surface and groundwater are sourced for irrigation (Pecos Valley Water Users Organization 2001).

Further analysis of land use changes and human influences on water demand in the basin is discussed in the "Competing Water Demands" section of this report.

## Legal Framework

A comprehensive review of the current legal framework is necessary to understand opportunities and limitations for possible changes in future basin management. The following sections contain a brief overview of general western water management, State of New Mexico regulations and policies, and considerations specific to the Black River Basin.

### *Western Water Management*

Management of Western water resources has changed over time as population and water scarcity has increased. Initially, miners established the prior appropriation doctrine that most western states follow today. This rule is otherwise known as "first in time, first in right" and sets different priority levels for water rights holders based on seniority. Riparian rights, or water rights that are held conjunctively with ownership of land abutting a waterway, were brought over from the eastern states and are complexly coupled with prior appropriation rights in California, Oregon, Texas, and Washington. Adding to this complexity, groundwater resources follow a different set of standards and are often tied to the land in a fashion similar to riparian rights. While these two doctrines successfully managed water resources in the early days of western development, population growth has resulted in increasing management hardships and may cause major complications as water resources become scarcer.

### *New Mexico Water Management Framework*

#### State Water Law

Modern water management in New Mexico is governed by a patchwork of policies influenced by historical populations in the region. Indigenous tribes were the first inhabitants known to put water to beneficial use for irrigation by establishing run-off collection systems and gravity-fed irrigation ditches (Utton Transboundary Resource Center 2014). These practices "depended on centralized authority and mandatory community responsibility for the maintenance of the irrigation canals and ditches" (New Mexico Museum of Art 2010). Spanish colonial settlement in the 1600s brought a similar approach to water management for the region, whereby community-based systems called *acequias* embody public control of water and community participation in its management (Utton Transboundary Resource Center 2014).

## Prior Appropriation

Today, New Mexico State Constitution and statutes incorporate the "first in time, first in right" prior appropriation doctrine as the overarching administrative approach to water management. This doctrine states that, "when shortages occur, the right to use water is determined by the chronological order in which the water was put to beneficial use" (Utton Transboundary Resource Center 2014). Earlier priority dates are deemed more valuable because the owner is more likely to receive water during shortages (Utton Transboundary Resource Center 2014).

The New Mexico 1907 Water Code declared that all water resources in the state "belong to the public and are subject to appropriation" (Harris 1984). Appropriation water rights are considered the same as property in that they can be transferrable and separated from the land to another location with a conditional permit from the New Mexico Office of the State Engineer (NMOSE). However, the appropriator only owns the right to beneficially use the water and does not own the water itself (Harris 1984). At the time of enactment the Code applied only to surface waters. However, following extensive groundwater development in subsequent decades, a separate groundwater code was developed in 1927 to declare groundwater administration for the state (Harris 1984). Today water appropriation guidelines are outlined and continuously updated in the NMOSE's Surface and Groundwater Rules and Regulations.

## Beneficial Use

Unlike many other states in the West, the New Mexico Constitution does not define beneficial use. However, historical judicial decisions and statutes characterize it as including irrigation, domestic, commercial and industrial, game and fish, and endangered species uses (Utton Transboundary Resource Center 2014). Each type of use is treated equally regardless of economic value (Harris 1984).

In the case of instream flow, it is not recognized as a beneficial use in New Mexico statutes, and that recognition could be complicated by statutory water diversion requirements. Recently, however, the interpretation of the law has shifted to support it as a beneficial use under specified conditions (United States Fish and Wildlife Service n.d.). In 2013 the State Engineer issued a statement confirming that it is acceptable to lease an existing water right for "stream augmentation" as a beneficial use for wildlife habitat, maintenance, and/or restoration under the Water-Use Leasing Act of 1974; the NMOSE has also permitted permanent water transfers for these purposes.

## Interstate Compacts and Treaties

New Mexico is a party to eight interstate compacts that govern how shared surface and groundwater resources are managed between states: (Harris 1984).

1. Colorado River Compact
2. Upper Colorado River Basin Compact
3. La Plata River Compact
4. Animas-La Plata Project Compact
5. Rio Grande Compact
6. Amended Costilla Creek Compact
7. Pecos River Compact
8. Canadian River Compact

Compacts supersede state laws and are designed to ensure that each state receives its share of water according to the conditions outlined in the agreement (Harris 1984). The Pecos River and its collective tributaries, including the Black River, are subject to flow delivery requirements to Texas as decided upon in the Pecos River Compact of 1948, the U.S. Supreme Court Amended Decree of 1988, and a subsequent 2003 Settlement Agreement between major New Mexico water users and water management agencies (New Mexico Office of the State Engineer 2007).

## *Basic New Mexico Water Rights Administration*

### Application Process

Surface and groundwater rights, and changes to water rights, must be filed with and approved by the NMOSE. All surface waters in the state have been fully appropriated and therefore no new surface water rights may be issued. As for the 39 declared groundwater basins in the state, NMOSE has the discretion to approve new appropriations. Most new small volume uses are approved under New Mexico's current domestic well statutes (§72-12-1.1-2). (See the "Relevant Recent Court Decisions" section for more information.)

The application process for new permits, temporary permits and changes to existing permits requires a public statement of the amount of water used, place and purpose of use, as well as the location of the point of diversion (New Mexico Office of the State Engineer 2007). After filing, the applicant must publish a legal notice stating the application details in a local newspaper once a week for three consecutive weeks. The application is subject to protest up to 10 days after the last date of publication (Harris 1984). The NMOSE then examines the application to determine if there is available unappropriated water, if relevant, whether or not there is a possibility of impairment to other existing rights or public welfare, and whether the requested permit is contrary to conservation of water for the state, in which case the application could be denied (Harris 1984).

### Meter Reports

For groundwater rights, the well owner must initially submit any available well drilling records, including depth to water after well construction and proof of compliance with state drilling standards (Utton Transboundary Resource Center 2014). In many underground water basins in New Mexico, including the

Black River portion of the Carlsbad Underground Basin, all groundwater users must submit periodic water use totalizing meter readings to NMOSE, except where the designated use is for single-household domestic purposes or livestock watering (NMOSE 2014).

### Water Right Changes and Transfers

Water rights owners can apply for changes in ownership, purpose of use, amount allocated, or location of point of diversion as long as any proposed re-configuration of the right is confined to the existing source of surface or groundwater (Harris 1984). A water right can be sold separately from the land and transferred – temporarily or permanently -- for a new use in another area as long as the transaction is approved by the NMOSE and has been determined not to impair other water users or be contrary to the conservation of water within the state (Harris 1984). A public notice of the application for change must be published once a week for three weeks according to surface and groundwater Rules and Regulations. Today, most changes in purpose of use and location apply to groundwater rights (Harris 1984).

### Emergency Changes to Water Rights

A water right owner can apply for an emergency change in the point of diversion, storage, or use of surface water, and an emergency change in the point of diversion only for groundwater, if the right holder can show that "an emergency exists in which the delay caused by awaiting publication or hearing would result in crop loss or other serious economic loss." Upon review by the NMOSE to ensure that the emergency change does not impair existing water rights, the change may be granted immediately without the need for public notice up until 30 days after the date of application after which a notice must be filed.

### Leasing and Temporary Appropriations

According to the Water Use Leasing Act of 1974, all or part of an approved, *existing* water right can be leased to another party for up to 10 years without the threat of forfeiture of any of the leased water right due to nonuse. The implementation of the lease agreement does not allow for the amount of water "to cumulate from year to year or to substantially enlarge the use of water in such a manner that it would adversely impact other water rights holders" (Harris 1984). The statute also allows for lease agreements of up to 40 years in duration for select lessees defined as "municipalities, counties, and member-owned community water systems" involved in the development of a long term water supply under a 40-year plan.

Because all surface waters in New Mexico have been fully appropriated, *new* temporary appropriations only apply to declared groundwater basins. New Mexico Groundwater Regulations authorizes temporary new appropriations and limits them to three permits per well, in the amount of three acre-feet per year per permit. The current cost for temporary new appropriations is five dollars per permit and may be issued for the period of up to one year for prospecting, mining, construction of public works, highways and roads, and drilling operations designed to "discover or develop natural mineral resources".

### Return Flow

Water delivery rates for irrigation purposes are allocated based on a farm delivery requirement (FDR) that includes an assumption of the portion of water that is fully consumed by crops as well as the portion that returns to the surface or groundwater system as return flow. The portion of those rights that is consumed by crops is referred to as the consumptive irrigation requirement (CIR). In an application for a change in purpose of use, if the new use is consumptive only the CIR portion of the right can be transferred. This mechanism is intended to account for losses in return flow attributed to changes in purpose of use.

### Special Districts

To share costs and the right to use water, water rights owners can form special districts (Harris 1984). The Carlsbad Irrigation District (CID) and the Pecos Valley Artesian Conservancy District (PVACD) are two important districts associated with the Pecos River.

## *Administrative Bodies*

The following administrative bodies are relevant to management of the Black River Basin.

### Office of the State Engineer

The 1907 Water Code created the NMOSE, which has general supervision over the measurement, appropriation and distribution of New Mexico's water (New Mexico Office of the State Engineer 2007). Article 2 of Chapter 72 of the state statutes designates the NMOSE as primary water rights administration body for surface and groundwater resources. The NMOSE is led by the governor-appointed State Engineer and is responsible for general water management (Harris 1984).

One of the State Engineer's primary roles is to pursue water rights adjudications for all surface and groundwater rights under its jurisdiction (Utton Transboundary Resource Center 2014). The purpose of this role is to define and formally describe water rights through the court system to ensure that they are properly recognized (Harris 1984). The State Engineer also has the authority to declare groundwater basin boundaries, which cover approximately 90 percent of the state's surface area, as well as the authority to recognize the connection between surface and groundwater (Harris 1984). The NMOSE also has the authority to create water districts and appoint water masters to actively manage them (Utton Transboundary Resource Center 2014).

### New Mexico Interstate Stream Commission

The New Mexico Interstate Stream Commission (NMISC) "protects New Mexico's right to water under eight interstate compacts, ensures the state meets its obligations to its sister states, and makes certain that endangered species are afforded necessary water" (Utton Transboundary Resource Center 2014). The NMISC is also the lead oversight agency for the State Water Plan (Utton Transboundary Resource

Center 2014). As authorized by the state legislature, the NMISC also purchases and leases water rights, such as groundwater rights in the Pecos River Basin, so that it can meet delivery obligations under interstate compacts and ensure flows for endangered species (Utton Transboundary Resource Center 2014).

In 2005 the NMISC was authorized to dedicate water to preserve instream flow for the benefit of endangered species via the Strategic Water Reserve (Utton Transboundary Resource Center 2014). It functions as a pool of publicly held water rights with the primary goal of maintaining flow requirements for species, as well as meeting compact delivery requirements (Utton Transboundary Resource Center 2014).

#### Carlsbad Irrigation District (CID)

Initially founded in the late 1800s and formalized through BOR participation starting in 1905, CID provides water to approximately 25,000 acres through 151 miles of laterals, 37 miles of canals and 24 miles of drains associated with storage in four reservoirs, Santa Rosa, Sumner, Brantley and Avalon. BOR's Carlsbad Project that supports CID was one of the earliest reclamation projects and is remarkable because it is a surviving example of mixed technologies from the late 1800s and 1900s, many features of which are listed on the National Register of Historic Places (Bureau of Reclamation 2013).

CID holds senior rights on the Pecos River through the Hope Decree of 1933, which established priority dates of 1887-1888 (T. Davis 1989). Most CID water users are small-scale family-owned farming operations.

## *Relevant Recent Court Decisions*

### Water Rights Administration: Active Water Resources Management (AWRM), 2012

After seven years of litigation the New Mexico Supreme Court ruled on the "Tri-State" case in November of 2012 upholding NMOSE's authority to promulgate a set of regulations called Active Water Resources Management (AWRM). Until AWRM, the NMOSE's ability to administer water rights in times of drought depended on the adjudication process in which water right priorities are established by the courts. In New Mexico and elsewhere that process has proven to be lengthy and cumbersome. For example, there are five stream systems for which adjudication proceedings began in the 1950s and 1960s that are still in process today (Utton Center Press 2013). And, there are numerous stream systems, including the middle Rio Grande where most New Mexico water users are concentrated, which have not yet begun an adjudication process. In response to perceived limitations on effective water rights administration the state legislature passed §72-2-9.1 in 2003 enabling the NMOSE to generate the AWRM rules.

After two rounds of public hearings in 2004 AWRM regulations were put in place. AWRM allows the NMOSE to broaden and formalize the use of water districts and water masters, appointed by the State Engineer, for water rights administration even where adjudications have not been completed. Districts, which are based on stream system hydrology, are to develop district specific rules to administer and protect water rights, including increased use of metering and installation of head gates and more detailed analysis of available water and current use rates. Each district and water master is charged with keeping records and regularly reporting on water use and compliance measures as well as monitoring and enforcement of district specific rules.

In times of shortage, AWRM's water districts are to determine an administration date which establishes a priority date cut off point. This cut off point could be used to remedy supply problems within the district or elsewhere on the stream system or to ensure New Mexico's delivery obligation through interstate compacts. A master list of water rights and their associated priority dates, although not yet confirmed by the courts, would enable each district to determine which users' priority dates fall after the determined cut-off date. Those water rights owners who are cut off can request a hearing or obtain a temporary "replacement plan" in which they form an agreement with a senior water right owner who may not be using their full allocation, in order to use their water for a maximum of two years, as long as that use does not impair any other users.

Under AWRM, communities can also work together to develop shortage-sharing agreements. The rules encourage water user groups to communicate with each other and work out alternatives to strict priority administration. These agreements are dependent on approval by the NMOSE and can then be incorporated into a district's rules for ongoing implementation.

Although AWRM appears to be a solution to New Mexico's adjudication woes, a number of significant objections have been raised and led to the 2005 lawsuit filed by Tri-State Generation and Transmission Association and the New Mexico Mining Association. The plaintiffs claimed that AWRM was unconstitutional. Principally the concern is that excessive power is being placed in the hands of the State Engineer, a political appointee. For many New Mexicans, AWRM appears to be substituting NMOSE's authority and judgment for that of the courts to conduct water rights adjudications. Rather than using a fair, yet lengthy, process to determine priority, now NMOSE water masters would take over that role. Also, concerns have been raised that the NMOSE hearing process may be inadequate for a water user who has been cut off, and that replacement plans could become permanent transfers of water rights without the procedural protections provided under current law (Utton Center Press 2013).

Since the New Mexico Supreme Court 2012 ruling that supported the constitutionality of AWRM, the NMOSE Water Rights Division has moved forward with implementation including a focus on getting the necessary tools in place, such as meter installation; inventorying water rights; developing GIS-based databases; and abstracting, imaging and posting water rights files online so that they can be instantly available for use. NMOSE has identified seven priority basins for the development of district-specific rules, including the Lower Pecos River.

### Domestic Well Statutes: New Mexico Supreme Court Bounds Decision, 2013

Although most surface and groundwater resources in New Mexico have been fully appropriated for almost a century, the cumulative impacts of increasing numbers of small volume groundwater wells, which continue to be permitted by the NMOSE are of concern to many. In July of 2013, the New Mexico Supreme Court ruled on Bounds v. State of New Mexico and determined that the current domestic well statutes (§72-12-1.1 through §72-12-1.3), which allow for continued permitting of these wells, do not violate the prior appropriation doctrine or the due process clause of the New Mexico constitution (Richardson 2013). The current domestic well statues passed by the state legislature in 1953 direct that the State Engineer "shall" issue a permit for certain types of temporary or low volume wells, including wells for domestic use, stock watering and temporary use for mining and prospecting. Since their passage these statutes have remained essentially the same and have been interpreted by the NMOSE to mean that such permits are granted with no evaluation, public notice or hearing even in basins that are fully appropriated (Utton Center Press 2013).

Before 1953 the NMOSE administered groundwater basins in accordance with the state's first groundwater statute enacted in 1927, which called for administration of groundwater under the prior appropriation system, and included a requisite evaluation of each well application based on possible impairment to other users, the publication of a notice of application, and hearings when called for by other users. However, by the 1950s, groundwater use had grown to account for approximately half of water use in the state and had become a significant administrative burden for NMOSE. The 1953 domestic well statutes aimed to streamline the NMOSE process for wells drawing relatively small amounts of water, up to three AFY or less (Utton Center Press 2013).

In 2006, Horace Bounds Jr. and the New Mexico Farm and Livestock Bureau filed suit against the state of New Mexico claiming that the domestic well statutes violate the prior appropriation doctrine by requiring that the State Engineer issue permits for new groundwater wells in fully appropriated, and in their case, adjudicated basins. Among other concerns they also claimed that the statutes violate due process by failing to provide notice to, and the opportunity to be heard, to other users prior to the issuance of well permits (Richardson 2013). The case was granted certiorari on these two issues in January 2011.The New Mexico Supreme Court 2013 ruling in favor of the State of New Mexico is significant because it upholds the current domestic well statutes. Because the claim that the statutes violate the prior appropriation doctrine is a "facial" challenge, meaning the law itself is claimed to be unconstitutional, rather than its application in a particular case, the court would have to determine that there are no circumstances under which the law could be constitutionally applied. The court found that the State Legislature "codified this simpler permitting process as a policy choice, something that the New Mexico Constitution generally empowers our Legislature to do" (Robinson 2013).

The court found that the statutes themselves do not violate the prior appropriation doctrine because the State Engineer still has the authority to enforce priority, dependent upon an adjudication process, and water users have the right to issue a priority call. The court also referred to a number of recent measures including AWRM and other new regulations that enable NMOSE to reduce permit allocations to one acre-foot per well in critical basins and declare critical groundwater management basins where monitoring and enforcement measures can be more strict (Utton Center Press 2013). To date, NMOSE has not declared any critical groundwater basins for special management.

On the issue of violation of due process, the court ruled that because Bound could not prove impairment to his own water rights, he had no grounds to this claim (Richardson 2013). If the Bounds water rights were impaired by any single domestic well of the 45 that have been drilled since their basin was closed, this claim could be brought as an "as applied" challenge to the statues.

In October 2012, it was estimated that over 160,000 domestic wells exist in New Mexico, and currently thousands of new domestic well permits are filed with the NMOSE each year (Utton Center Press 2013). The courts, by means of *Bounds v. State of New Mexico*, were considered a possible mechanism to address the growing challenges associated with the cumulative impacts of thousands of low volume wells. Ultimately this ruling has shifted that burden to the New Mexico State Legislature and the State Engineer. The ruling specifically urged:

> "…our Legislature to be diligent in the exercise of its constitutional authority over - and responsibility for - the appropriation process. We equally urge the State Engineer to fulfill its superintending responsibility by applying priority administration for the protection of senior water users" (Robinson 2013).

### *Water Rights Administration Specific to the Black River*

The NMOSE administration of water rights in the Black River Basin is consistent with administrative practices elsewhere in the state. However, the "duty of water" determined by the NMOSE varies throughout the regional districts depending on location, crop types and the amount of water that has been determined as necessary to produce a given crop type in that area. Duty of water refers to the total volume of irrigation water required to mature a particular crop, including consumptive use, evaporation and seepage from ditches and canals, and the water eventually returned to streams by percolation and surface runoff.

The duty of water in the Black River Basin for all types of irrigated agriculture has been set at three acre-feet per irrigated acre per year. This duty of water is also known as the farm delivery requirement (FDR). Most crops grown in the Black River Basin can be produced given the application of 3 acre-feet per acre per year. However, other crops grown regionally, such as pecans, often require an additional application of water, necessitating the "stacking" of water rights, where right owners transfer valid water rights from other farm locations to the fields with the neediest crops, thereby increasing the maximum amount of water that can be utilized per acre (NMOSE 2014).

The NMOSE has determined that the return flow portion of the FDR in the Black River section of the Carlsbad Administrative Basin is thirty percent. Therefore, the consumptive irrigation requirement (CIR) in the Black River Basin has been set at 2.1 acre-feet per acre per year (NMOSE 2014).

The uppermost portion of the Black River Basin is located across the Texas state-line. Texas statues governing water rights administration differ significantly from those in New Mexico. However, because no surface water diversions occur within the Texas portion of the basin, only regulations related to groundwater apply. The groundwater wells within the Texas portion of the basin are primarily used for ranching operations. As a "right of capture" state, landowners are allowed to pump whatever groundwater they can access from wells drilled on their properties. This could have a significant impact on the basin water budget if irrigated agriculture dominated the region, which it does not, or if well owners are pumping significant volumes of groundwater for sales to the oil and gas industry.

### Return Flow: Hood v Bounds Court Ruling, 2002

In August of 1993 the Bounds family, owners of the largest privately held surface water rights in the Black River Basin, entered into a multi-year lease agreement with the New Mexico Interstate Stream Commission (NMISC). The terms included the lease of 2,729 acre-feet per year (AFY) to NMISC, while withholding their remaining 500 AFY for private use. By the end of 1994 their neighbors, Eugene and Alice Hood, claimed that water levels in their wells had dropped because they were dependent on return flows from the Bounds irrigation. Legal action was eventually initiated against the Bounds and NMISC, which resulted in the termination of the leasing agreement in July of 1997.

In May of 2002, the Fifth Judicial District Court in Eddy County ruled that the Bounds were:

> "…required to continue to apply their water to beneficial use in their normal farming practices which will have the beneficial effect of recharging the plaintiff's wells, thereby allowing them to apply their appropriated ground water to beneficial use. This should be interpreted as a covenant running with the land" (Shuler 2002).

This court-imposed injunction remains in place today, even though New Mexico statute §72-5-27 states that irrigation return flows may be appropriated for beneficial use, but the junior user who makes such an appropriation cannot compel the senior user to continue to provide that return flow should they decide to change their water use (New Mexico State Legislature 1978). In addition, hydrologic analysis conducted by NMOSE concluded that the Hood wells did not depend on irrigation on the Bound's property for their supply and that the most likely cause of insufficient well production was related to chemical incrustation (Morrison 1994).

This ruling presents a challenge to NMISC efforts to purchase and lease water rights in the Black River Basin to ensure sufficient flows for threatened and endangered species, regional users and deliveries to Texas under the Pecos River Compact. However, perhaps most importantly, it also could present a challenge to the designation of instream flow as a beneficial use throughout the State of New Mexico

## *Federal influence*

### Pecos River Management Overview

#### *Pecos River Compact of 1949 and Amended Decree of 1988*

Conflicts over the Pecos River and its apportionment between New Mexico and Texas date back to the 1880s. The middle basin, defined as the portion between Santa Rosa Reservoir and the state line is the most heavily populated and irrigated. Farmers in the Roswell and Carlsbad areas began supplementing surface flows with groundwater development in the late 1800s. By the turn of the century appropriation of water on both sides of the state line had already begun to create a significant imbalance in the hydrology of the stream system. Between 1888 and 1895 Texas irrigators claimed that New Mexico used all of the water and left none in the river for them. They proposed a dam at the state line that would ensure a more dependable supply (O'Leary 1980).

Part of the challenge of sharing the Pecos River is that stream flow is extremely variable and dominated by flood inflows. Over 75 percent of the mean annual precipitation occurs from May through October and flood events often carry extensive sediment making it difficult to maintain water storage capacity in reservoirs (O'Leary 1980).

Multiple attempts to share the river came and went during the first half of the 1900s. The Compact of 1925 and the Alamogordo Agreement both resulted from many years of negotiation and yet never resolved the dispute between the two states. Finally in 1942, each state designated a representative to a new compact commission with instructions to negotiate a workable and binding agreement (O'Leary 1980). In December of 1948 an agreement was reached that was eventually ratified by both states and signed into law by President Truman in 1949 (Hall 2002).

The purpose of the compact is to provide for equitable division of the river's waters, remove causes of controversy, protect present development with the states, and facilitate the construction of works for water storage, more efficient use of water and flood protection. However, the execution of the compact depends heavily on the collection of data used to replicate the so-called "1947 condition". Essentially, the sharing agreement contained within the compact relies on a complex set of engineering equations that inform New Mexico what portion of river flows must be provided to Texas in any given year in order to replicate the portion of total flows that was delivered to Texas in 1947 (Hall 2002). Although tens of variables are included, the delivery calculations for Texas are approximately equal to fifty percent of dam releases from Fort Sumner and fifty percent of flood inflows in the lower Pecos between Fort Sumner and the state line within each calendar year (Hall 2002, Lewis 2012).

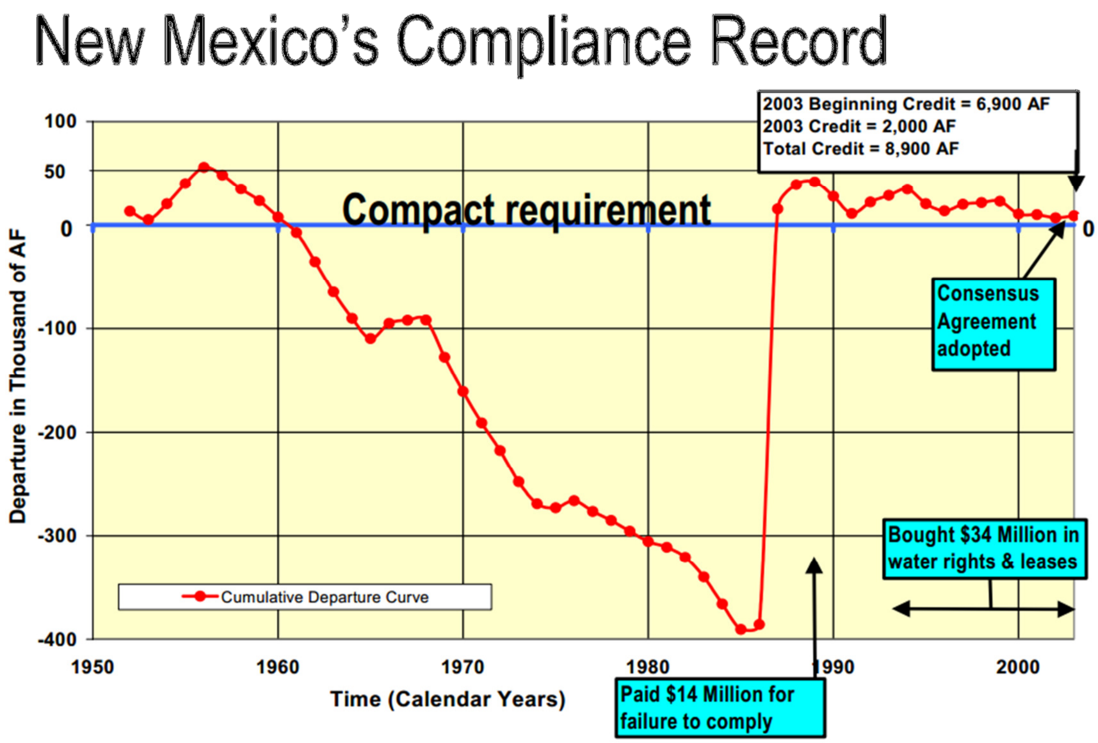
Unfortunately, the wet 1940s were followed by extreme drought in the 1950s, and New Mexico was quickly unable to meet compact delivery requirements. In the 1950s and 1960s, New Mexico under delivered approximately 10,000 acre-feet each year, and by the early 1970s, the deficit had reached more than 200,000 acre-feet (Lewis 2012).

In 1975, Texas sued New Mexico in the United States Supreme Court and a special river master was appointed to hear the dispute. For twelve years the litigation continued as both sides presented increasingly complex expert testimony from hydrogeologists and engineers. In 1988, the court finally issued an amended decree in which New Mexico was required to compensate Texas for economic losses resulting from under deliveries in the amount of $14 million. The 1988 Amended Decree also required the implementation of a federal River Master to calculate and oversee all annual deliveries to Texas. No net shortfall is allowed, meaning that rapid repayment must occur by New Mexico (Lewis 2012).

*Pecos River Settlement 2003*

Since 1988 New Mexico has remained in compliance with the Pecos River Compact (Figure 11), but not without internal disputes about how to accomplish that goal. If New Mexico, and specifically water users on the Pecos River, cannot successfully plan for compact compliance the state risks losing control of its water resources to the federal government. Each year the federal River Master evaluates data inputs to the "1947 condition" equations, which were adjusted somewhat by the 1988 Amended Decree, and then presents an estimated total delivery requirement for that calendar year. Each state can make objections or suggestions for improvements to the calculations and the River Master considers that input before issuing a final judgment. New Mexico currently is carrying a surplus delivery to Texas of over 100,000 acre-feet.

**Figure 11: New Mexico Pecos River Compact Compliance Record: 1950 – 2000**




However, making that surplus possible required New Mexico to both purchase and retire water rights on the stream system and work with water users to plan for reduced water use. Between 1992 and 2008 the state spent $88 million on water right purchases and leases on in the lower Pecos (Lewis 2012). Several years of negotiations amongst stakeholders resulted in the Pecos River Settlement signed in March of 2003 by the State Engineer, NMISC, the U.S. Bureau of Reclamation (BOR), which owns and operates reservoirs on the Pecos, the Carlsbad Irrigation District (CID) and the Pecos Valley Artesian Conservancy District (PVACD), the largest irrigation district on the Pecos River.

The goals of the Pecos River Settlement are to enable permanent compliance with the Pecos River Compact and Amended Decree, provide an increased and more stable water supply for CID, reduce the likelihood of a priority call affecting the ground water users in the Roswell Artesian Basin and bring the Pecos River back into hydrologic balance (Lewis 2012). To accomplish these goals the parties agreed to retire between 4,500 and 6,000 acres of irrigation rights within CID and between 7,500 and 11,000 acres within PVACD. In addition, the state agreed to construct well fields, operated by NMISC, for augmentation pumping up to 35,000 acre-feet annually.

Since 2003 the Pecos River Settlement has enabled New Mexico to remain in compliance with the compact. However, recent drought conditions have caused intense conflict among in-state water users over the distribution of Pecos River flows. Water year 2012 (November 1, 2011 through October 31, 2012) was the driest and hottest year in 117 years of recorded history on the Pecos River, and water year 2011 was the second driest and hottest (Lewis 2012). Runoff was essentially non-existent at three percent of average into Santa Rosa Reservoir. Pumping at the NMISC augmentation well fields was not intended to replace natural stream flows. At the beginning of 2013 CID issued a priority call on the Pecos River, which remained in place until mid-September of 2013 when torrential rains refilled reservoir storage and reduced, for the time being, pressure on NMOSE to resolve conflicts between water users on the Pecos.

Depending on climate conditions in the years to come New Mexico will likely continue to struggle to satisfy both inter and intra-state conflicts on the Pecos River. Planning for the settlement did not take into consideration drought conditions that since 2000 have been far worse than those during the 1950s drought. As the last significant tributary to the Pecos River, flows from the Black River Basin will continue to play a small but perhaps increasingly important role in New Mexico’s Pecos River management strategy.

# ANALYSIS

Basin characterization, including the physical and ecological environments as well as the existing legal and management frameworks, was essential to support further analysis. The likely upcoming Endangered Species Act (ESA) listing of the Texas hornshell has raised concern over how to best ensure species survival; necessary management actions could affect how water is used in the basin. Analyzing the quantity and potential cost of water needed to maintain sufficient flows aids in preparation for species management. In addition, an analysis of potential changes in water availability due to both climate change and regional oil and gas development, as well as the construction of a water budget-forecasting tool using the Water Evaluation and Planning (WEAP) model, assisted in defining more clearly the management challenges and identifying short and long-term recommendations for management actions.

## TEXAS HORNSHELL

The Texas hornshell (*Popenaias popeii*), a freshwater bivalve mollusk (Figure 12), will be considered for listing as threatened or endangered under the Endangered Species Act (ESA) in fiscal year (FY) 2015 as required in a settlement agreement between conservation organizations and the United States Department of Fish and Wildlife (USFWS) (United States Fish and Wildlife Service 2013). Changes in land use and increased water demand threaten the survival of this mussel as it is dependent on natural stream flows and high water quality. In preparation for the potential ESA listing, water management strategies must consider the ecological needs of the Texas hornshell, as well as other sensitive species dependent on natural flow regimes and water quality. The following sections discuss the current status and dependence on stream flow of the Texas hornshell, an analysis of potential minimum flow costs, as well as information needed to make informed management decisions regarding Texas hornshell habitat.

**Figure 12: Texas Hornshell**

## Methodology

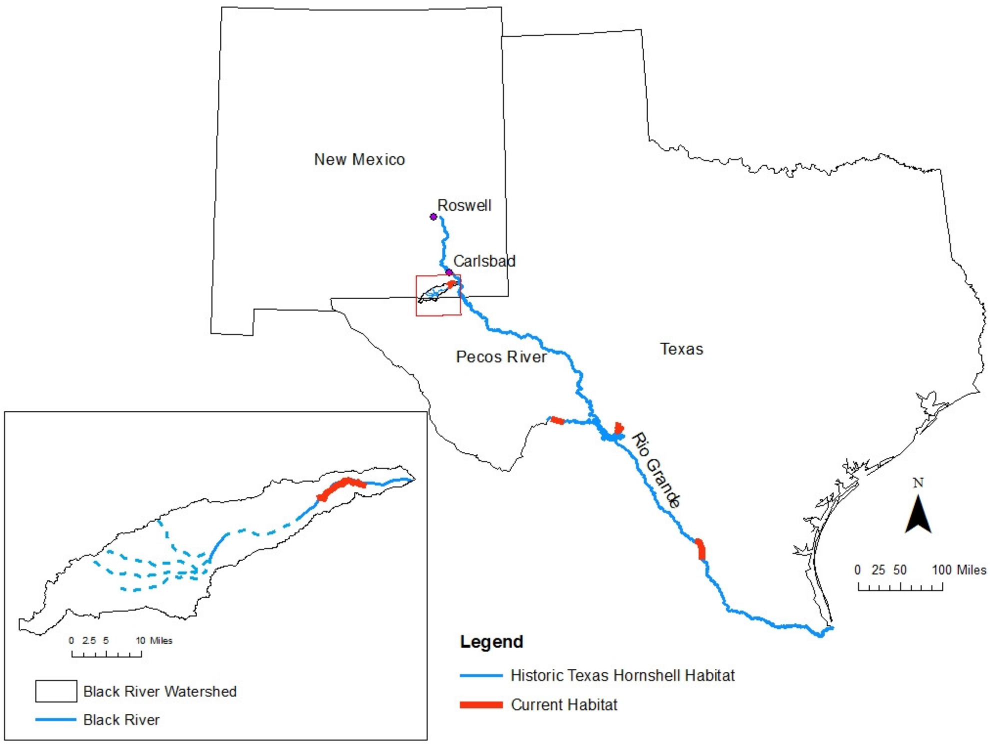
In order to assess the status of the Texas hornshell, existing reports such as the New Mexico Department of Game and Fish (NMDGF) Texas Hornshell Recovery Plan and research such as a mark and recapture study and studies investigating ecological host species were utilized to gain an understanding of the species' biological needs ( (Carman, Texas hornshell Popenaias popeii Recovery Plan 2007) (T. Levine 2004) (Levine, Lang and Berg 2012)). Through this process, a general understanding of habitat limitations was generated, however much is still unknown about specific factors causing the species' extirpation from historical reaches and influencing stable populations in current habitat. This led to the identification of critical information needed to further assess the species status and needed management.

Historical stream gage data and estimated purchase and lease water prices were used to analyze the amount of effort needed to maintain certain stream flow levels in support of the Texas hornshell. Cost data from purchases and leases of water in the Pecos River Basin from 2002 to 2012 was obtained from the New Mexico Interstate Stream Commission (NMISC) and stream gage data was obtained from the United States Geological Survey (USGS).

## Species Status

A freshwater bivalve mollusk, the Texas hornshell was historically found in the Pecos River and Rio Grande drainages in Texas, New Mexico and Mexico. Now confined to a fraction of its historical reaches, the only known populations of the Texas hornshell exist in the New Mexican Black River and the Texan Rio Grande River, below Big Bend National Park and near Laredo, Texas (Figure 13). The Texas hornshell population in Laredo, Texas is an estimated 8,000 individuals, making it by far the largest population recorded (Burlakova and Karatayev 2011). It is the only endemic mussel present in the Black River, occupying a nine mile reach from Black River Village downstream to the Carlsbad Irrigation District (CID) dam (Carman, Texas hornshell Popenaias popeii Recovery Plan 2007). Although this area currently provides sufficient habitat quality to support the population, the extremely restricted habitat range throughout New Mexico and Texas puts the persistence of the Texas hornshell in a vulnerable position.

**Figure 13: Historic and Current Distribution of the Texas Hornshell**




## Host Species Requirements

Texas hornshell larvae, called glochidia, must attach to fish hosts to complete its life cycle into adult mussels. Therefore, if water quantity or quality is not sufficient to support host species or if movement of host species is restricted by impoundments, the reproductive capacity of the Texas hornshell is greatly reduced.

## Habitat Threats

As filter feeders, freshwater mussels are extremely sensitive to water quality. Salinity, removal of aquatic vegetation, excess siltation, dissolved oxygen (DO) levels and common pollutants such as chlorine and metals are known to limit the survival of freshwater mussels and may be contributing factors to the Texas hornshell's extirpation from historical locations. For example, studies have shown that a salinity of around seven parts per thousand (ppt) causes physiological stress leading to death in the Texas hornshell (Burlakova and Karatayev 2011). The water above the CID dam, where the hornshell currently exists, has a salinity of around 0.9 ppt and an average temperature of 22.6 degrees Celsius ( (Burlakova and Karatayev 2011) (Carman, Texas hornshell Popenaias popeii Recovery Plan 2007) ). Downstream of the CID dam the salinity and temperature is slightly higher at 2.8 ppt and 25.9 degrees. The salinity gradient is caused by the input of the highly saline (around 6 – 7 ppt) Pecos River water via the CID supply ditch and may be a contributing factor limiting the Texas hornshell's colonization of downstream areas of the Black River as well as the Pecos.

The Texas hornshell attaches to substrate in crevices, undercut riverbanks and under boulders that have sufficient small grained substrate to attach to in order to remain secure during naturally occurring large inflows from sudden summer rain events. However, frequent block releases typical of impoundments often release larger quantities of water than what would naturally occur and for longer periods of time (T. Levine 2004). The currently occupied reach of the Black River is thought to be limited by two low-flow dams and the construction of impoundments such as Lake MacMillan, Brantley and Avalon reservoirs was a major factor in the elimination of the species from the Pecos River, as they disrupted the natural flowing hydrologic regime. Dams release stored water based on irrigation and interstate compact needs and any increase in water demand, or additional development of larger dams or impoundments, would adversely affect the Texas hornshell (Carman, Texas hornshell Popenaias popeii Recovery Plan 2007).

The dependence of the Texas hornshell on natural flow regimes is not yet fully understood, however sufficient pulses of surface flow is known to prevent excess sedimentation which can smother mussel habitat (Carman 2007).

## State and Federal Legal Status

The Texas hornshell is currently listed as state endangered in New Mexico. NMDGF has published a recovery plan outlining the management goals and objective of the Texas hornshell recovery. Goals include protecting the current hornshell population and habitat through monitoring, controlled propagation including a captive rearing management plan, securing host fish populations by removing impoundment barriers, encouraging private participation in candidate conservation agreements and investigating the potential to include adequate Texas hornshell water quantity as a beneficial use in meeting the Pecos River Compact (Carman, Texas hornshell Popenaias popeii Recovery Plan 2007). Larger goals include protecting and restoring historic hornshell habitat and further research of the Black River hydrologic regime to better understand factors influencing hornshell habitat, as well as the groundwater and surface water connectivity.

Considered a Candidate Species under the federal Endangered Species Act (ESA) since 2001, the Texas hornshell receives no federal regulatory protection and no current designated critical habitat exists. Originally designated a priority number of two, the highest ranking that can assigned to a Candidate Species, the Texas hornshell was revised to a priority number of eight in 2008, dropping it from the “Top 40” list, a subset of the nation’s most at-risk candidate species (Rosmarino 2009). USFWS found that the petition for listing contained enough information showing the vulnerability of the Texas hornshell to warrant a proposal for a listing as endangered or threatened, but has not yet published a decision due to the hornshell being “precluded by higher-priority listing.” Despite its long life on the candidacy list, litigation brought on by environmental groups, the Multi-District Litigation (MDL) settlement has ensured the Texas hornshell will be evaluated for federal listing under ESA by FY 2015 (United States Fish and Wildlife Service 2013).

### *Multi-District Litigation Settlement*

WildEarth Guardians, an environmental activist group, sued the United States Fish and Wildlife Service (USFWS) for failure to comply with deadlines associated with species’ federal listing decisions as prescribed by ESA (WildEarth Guardians v. Salazar, Nos. 10-cv-0048; 10-cv-0421; 10-cv-1043; 10-cv-1045; 10-cv-1048; 10-cv-1049; 10-cv-1050; 10-cv-1051; 10-cv-1068; 10-cv-2299; 10-cv-2595; and 10-cv-3366). The complaints filed included the failure of USFWS to make an initial 90-day finding evaluating if a petition contains enough substantial evidence to warrant an action, failure to declare if a petition is warranted, not warranted or precluded by higher priority actions within 12 months of receiving the initial petition, and length of time many species have been left on the candidacy list without protection.

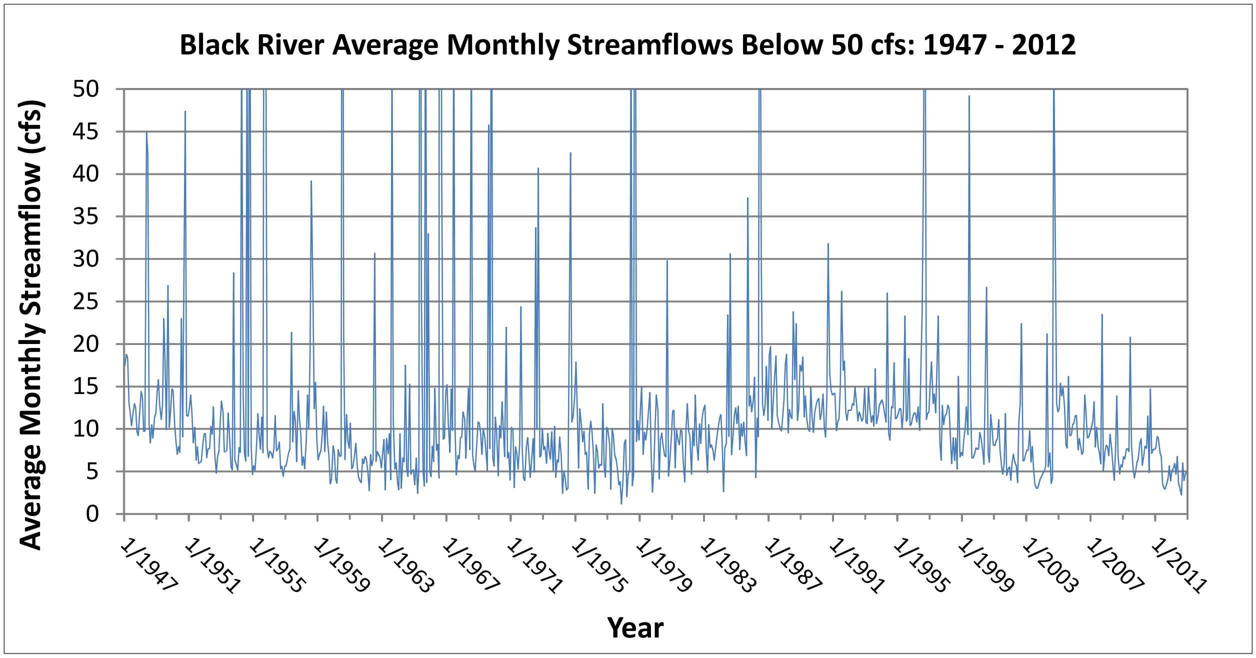
The MDL settlement was agreed upon through the development of a work plan requiring USFWS to publish a Proposed Rule or not-warranted finding on over 250 species on the 2010 Candidate Notice of Review by September 30, 2016. In addition, USFWS was required to publish a decision on individual species and critical habitats, many by sooner dates, including the "Mexican Wolf by FY 2012, New Mexico meadow jumping mouse by FY 2013, Pacific fisher by FY 2014, and greater sage-grouse, including any Distinct Population Segments, by FY 2015" (Stipulated Settlement Agreement 2011). The settlement included an agreement by WildEarth Guardians to refrain from filing any further lawsuits related to ESA deadlines or from challenging listing decisions made by USFWS until March of 2017. In 2011 the Center for Biological Diversity, a plaintiff, and USFWS reached a separate agreement reinforcing the work plan resulting from the MDL, including additional USFWS scheduling requirements (U.S. Fish and Wildlife Service 2013).

## Streamflow Analysis

Some amount of perennial streamflow is necessary to support Texas hornshell survival in its remaining habitat. Drought or prolonged low flows can contribute to population declines of freshwater mussels. Low flows may also restrict movement of necessary host fishes, while on the other hand high flows have the potential to wash out populations. Biologists studying species in southeastern New Mexico estimate that a largely consistent minimum flow of 3 cubic feet per second (cfs) is required for Texas hornshell survival, however no documented studies confirming this minimum flow threshold were found during the research for this report.

Streamflow fluctuates significantly across time in the Black River. The impact on the mussel of the frequency and duration of flows that fall short of minimum thresholds is uncertain. The USGS gage on the Black River above Malaga (#08405500) is located just downstream from the perennial reaches that are home to the Texas hornshell. This gage provided monthly streamflow data from January 1947 to December 2012. The record of streamflow indicates monthly flows have dropped below the recommended 3 cfs threshold a total of 16 times (Figure 14). Although further knowledge of the Texas hornshell's relationship with minimum flow is needed, potential thresholds of 2, 3, and 4 cfs were chosen to evaluate the total quantity of water needed to support the mussel's ecological needs as well as the costs of acquiring water for environmental flows.

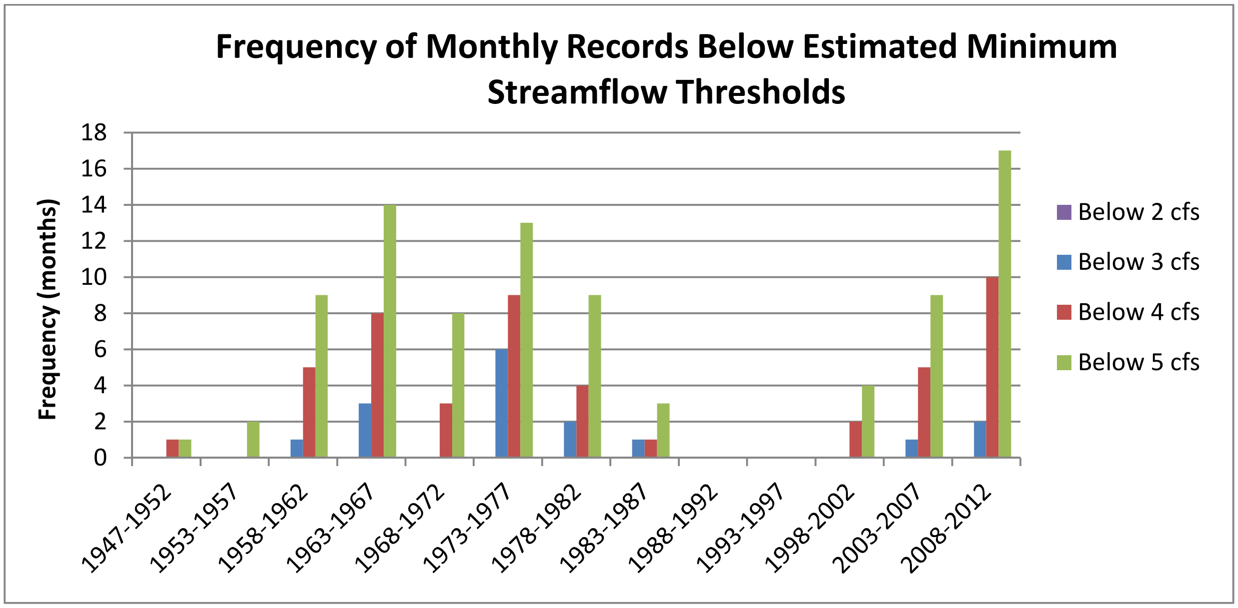
**Figure 14: Monthly Streamflow (January 1947 to December 2012) from USGS Gage 08405500**




To assess whether streamflow dropped below the minimum flow thresholds more frequently in recent decades, the frequency of months containing average streamflow below 2, 3, 4 and 5 cfs within five-year periods was quantified over the entire period of record (Figure 15). Although average monthly streamflow at this gage station has never dropped below 2 cfs, the period between 1973 and 1977 experienced the highest frequency of occurrences below the recommended threshold of three 3 cfs (six months in total). As seen in Figure 15, the gage data also seem to indicate an increase in low flow events since 2000.

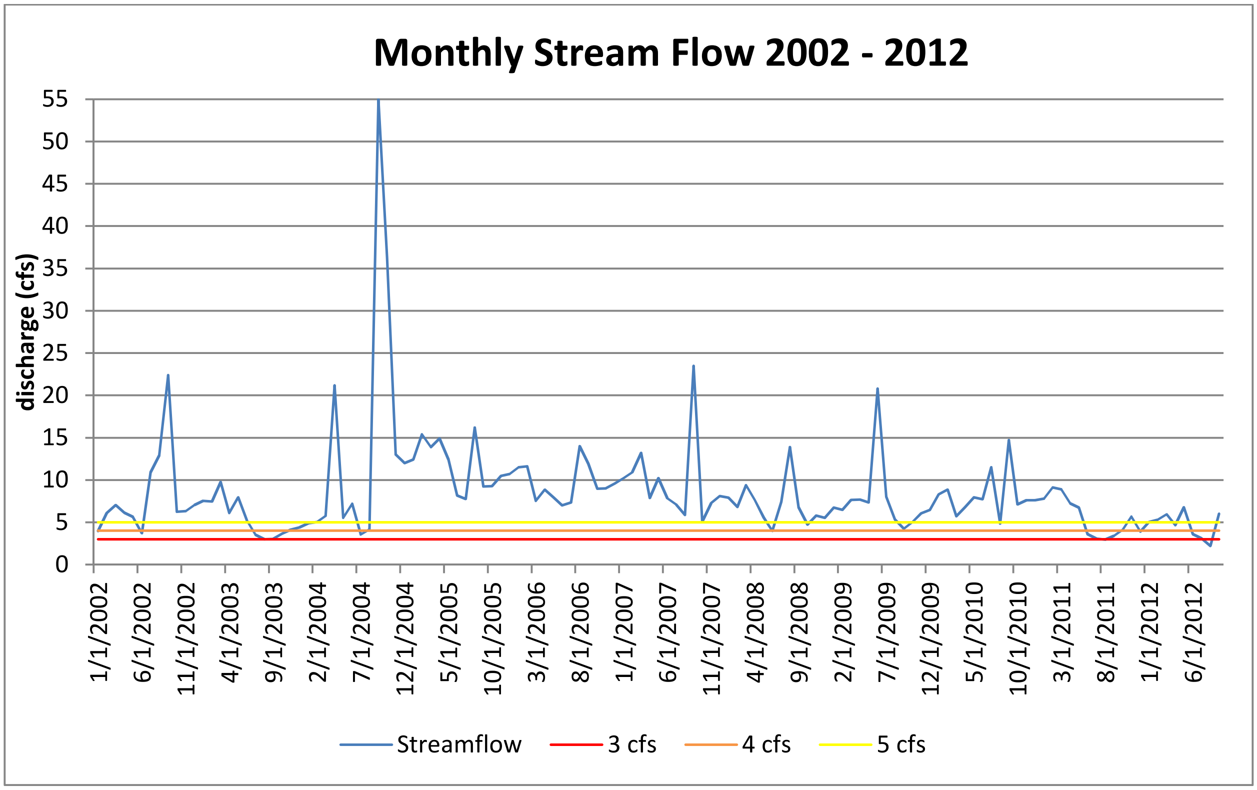
The analysis and data presented in Figure 15 corresponds to the cumulative departure curve of precipitation (Figure 40), which is based on seventy years of data from the Carlsbad Caverns meteorological station as shown in the "Climate" section of this report. For example, the decade between 1988 and 1997 had no streamflow occurrences below 5 cfs and corresponds to precipitation levels significantly above average in 1984 through 1988. However, 2010 experienced 179% of average precipitation based on the entire period of record and yet in years 2010 through 2012 the frequency of months in which streamflow dropped below all three thresholds steadily increased. Although this trend has not surpassed that of prior time frames, the discrepancy in these data sets implies a delay in water reaching the stream system and/or an increase in basin water use, rather than simply wet and dry decadal cycles.

**Figure 15: Frequency of Minimum Monthly Streamflow from USGS Gage 08405500**




Reviewing Black River streamflow data over a more recent 11-year period (2002 to 2012) provides critical information about the average annual volume of water required to meet the proposed minimum streamflow thresholds. Figure 16 shows the hydrograph from this 11-year period, with red, orange and yellow lines representing the threshold flow levels of 3, 4, and 5 cfs, respectively. Average monthly streamflow between January 2002 and December 2012 ranged from 2.2 to 55 cfs, with an average of 8.4 cfs. Flows dipped below 3 cfs three times, 4 cfs 16 times, and 5 cfs 25 times. Large deficits were seen in the summer of 2003, but monthly streamflow measurements below the thresholds have occurred most frequently since 2010. From the spring of 2011 to the summer of 2012, measured discharge fluctuated between 2 and 7 cfs, possibly due to increases in human use coupled with a state of exceptional drought beginning in June of 2011 (New Mexico Governor's Drought Task Force 2011).

**Figure 16: Monthly Streamflow in cubic feet per second (cfs) during 2002 to 2012 from USGS Gage 08405500**




The average annual water needed to meet each threshold was determined based on comparisons of actual streamflow data from 2002 to 2012 to the potential thresholds of 2, 3, and 4 cfs. By determining the difference in streamflow (cfs) between the proposed minimum flow thresholds and gaged monthly average flows, monthly deficit values were determined for each scenario. These values were converted from cfs to acre-feet per day (1 cfs over 24 hours = 1.98 AF per day) and multiplied by the average number of days per month, or 30.4. Monthly values were summed for each year to find the annual minimum volume of water (AFY) needed to meet the threshold scenarios for the years evaluated. Finally, the average of the 11 annual values was calculated to estimate an average volume of water needed meet each threshold. Based on these calculations, an estimated minimum streamflow requirement closer to a 2 cfs threshold would require additional water acquisitions.

The average annual volumes of water needed to meet a 3 and 4 cfs threshold from 2002 to 2012 were calculated and found to be 4.7 and 54.3 AFY, respectively. However, it is important to note that these values average a wide range of streamflow across the years studied, from 0 to 47.6 AFY needed to meet 3 cfs and from 0 to 192.6 AFY needed to meet 4 cfs. The difference between the average AFY values reflects the significant number of months in which average streamflow is between 3 and 4 cfs, just above the necessary threshold estimated by biologists at NMDGF.

A safety margin of 25 percent was added to all estimates of minimum water volumes needed to meet the potential thresholds (Table 1). Obtaining this additional water, or more, would be necessary as a precautionary measure. Amongst many concerns, it is possible that streamflow may drop further below any average deficits calculated here. The specific timing of low flows is uncertain and threats to habitat will be better addressed if water is obtained early enough to mitigate possible impacts to streamflow levels from changing water use and/or climate.

Alternatively, an estimation of required water was generated based on the lowest streamflow recorded in the 11-year period. Average monthly streamflow in 2012 would have required the highest volume of water acquisitions to meet potential thresholds of 3 and 4 cfs, 47.6 and 192.6 AF respectively. Again, a 25 percent safety margin was added to these values (Table 1). The lowest average monthly streamflow over the 11-year period occurred in August of 2012 (2.2 cfs).

**Table 1: Annual Volume of Water Needed to Meet Minimum Streamflow Thresholds based on Years 2002 -2012**

| **Minimum Flow Thresholds:** | **2 cfs** | **3 cfs** | **4 cfs** |
|---|---|---|---|
| *Average Annual Volume 2002-2012 (AFY)* | 0 | 5.8 | 67.9 |
| *Lowest Flow Year - 2012 (AF)* | 0 | 59.4 | 240.7 |

Overall, the last decade was a period of declining streamflows with more frequent low-flow events. This may be due to a slight decline in average annual precipitation, apart from the above average rainfall in 2010, and/or increases in basin water use. If this trend continues -- as a result of changes in climate and/or increases in human use -- the need to buy supplemental water for environmental flows may increase over time. As uncertainty around water availability increases, it is likely that the costs to lease and purchase water rights will increase.

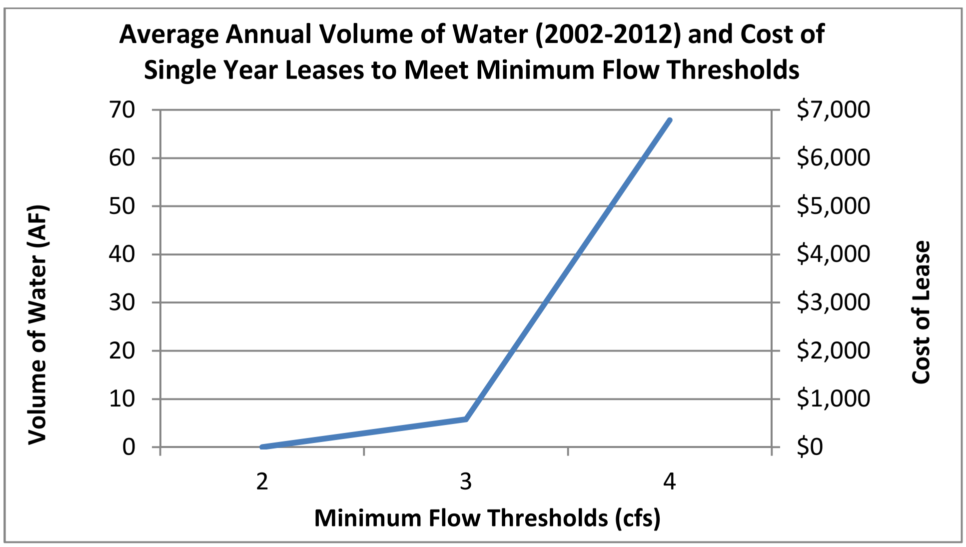
The total volumes of water needed to meet minimum flow thresholds, as discussed here, refer to the volumes needed in critical habitat reaches of the river. The ability of purchased or leased water rights to produce the needed increases in streamflow will depend on the type (surface or groundwater) and location of those rights in the basin. Unless they are adjacent to critical habitat reaches, it is likely that the amounts of water needed to be purchased or leased will be significantly higher in order to effectively ensure any minimum threshold.

## Cost Analysis

Water acquisitions for environmental flows can either be purchased or leased over single-year or multi-year time periods. Purchases provide long-term security but are more expensive and hold greater transaction costs, making them more difficult to obtain (Scarborough and Lund 2007 ). Leases provide flexibility to water rights holders; a farmer can fallow their farm while leasing water rights in one year, but use their full water right the next year. Single-year leases require less expenditure and may be acquired only during times of drought when water is needed most. While leases can provide a more flexible source of water when considering inter-annual variations, leases also present some measure of uncertainty as to whether water will actually be available to lease when required. The New Mexico Interstate Stream Commission (NMISC) has historically acquired the majority of publically-held environmental flows through purchases, although single-year leases have also been pursued.

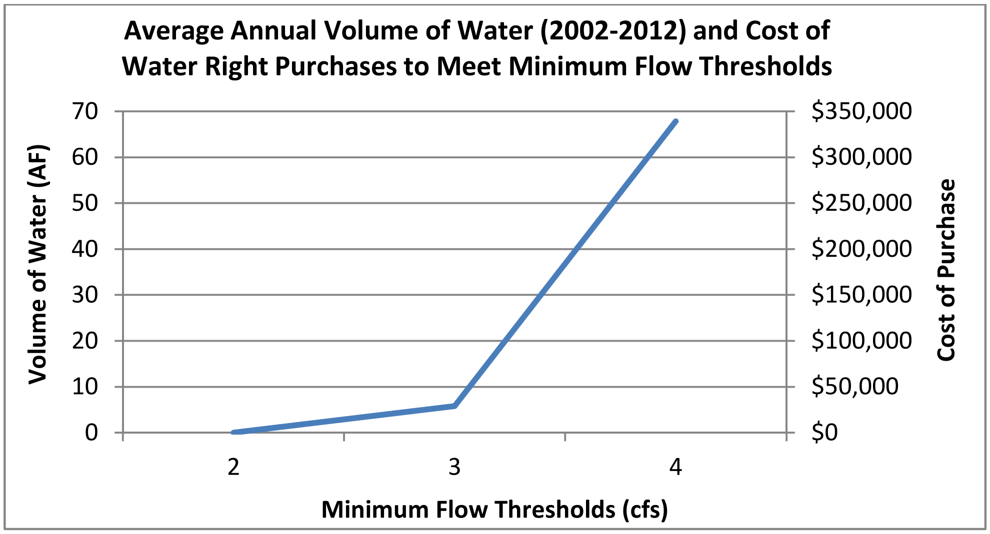
The range of minimum flow thresholds was analyzed to estimate the average annual costs for leasing or purchasing water to meet minimum flow goals. Generally, the current maximum price paid by the NMISC to acquire water leases in the Pecos River Basin is $100/AFY (Sawyer 2014). Multiplying this value by the average annual volume of water required to meet the estimated thresholds (calculated above) yields the total average annual lease cost to obtain water needed to meet the minimum flow thresholds, including the 25% safety margin (Figure 17). Minimum thresholds of 3 and 4 cfs would require $580 and $6,790 per year in lease costs, respectively. However, as discussed above depending on the type and location of the water rights, larger volumes may be necessary. As both demand for water and water scarcity increase, it can be expected that the market price of water will rise. This analysis applies a non-changing rate of $100/AFY for each threshold scenario, which does not capture market dynamics in response to changes in demand. Therefore, calculated lease costs should be viewed as a current total cost estimate subject to change.

**Figure 17: Costs of Water Leases to Reach Potential Minimum Flows During 2002 to 2012 based on a Lease Price Estimate of $100/AFY**




Purchasing costs to acquire water rights were also calculated. In 2006, the NMISC increased their offering price for senior, shallow groundwater rights in the Pecos River Basin from a range of $3,000 to $3,500 up to $4,500 to $5,500 per acre-foot (New Mexico Interstate Stream Commission 2006). However, even with this increase they also recognized that transaction prices at that time were likely much higher. If a water rights purchase price of $5,000/AF is assumed, volumes of water required to meet minimum flow thresholds of 3 and 4 cfs yield total purchase amounts of $29,100 or $339,300, respectively (Figure 18 and Table 2). If current actual purchase prices are much higher, $10,000/AF for example, these amounts could be significantly higher.

**Figure 18: Costs of Water Right Purchases to Reach Potential Minimum Flows during 2002 to 2012 based on Price Estimates for that Time Period of $5,000/AF**




Alternatively, the cost to acquire water to meet streamflow thresholds for the year with the lowest flows in the 11-year period studied (2012) would be much higher. Multiplying a $100/AFY lease amount by the calculated volumes of water required to meet either a 3 or 4 cfs threshold in 2012 (59.4 and 240.8 AF) yields annual lease costs of $5,940 and $24,080, respectively (Figure 19 and Table 2). Similarly, a $5,000/AF purchase amount is multiplied by the needed volume of water in 2012 to obtain purchase costs of $297,200 and $1,203,840 (Figure 20 and Table 2).

**Figure 19: Lease Costs During Year of Lowest Flow: 2012 based on Lease Price Estimates of $100/AFY**

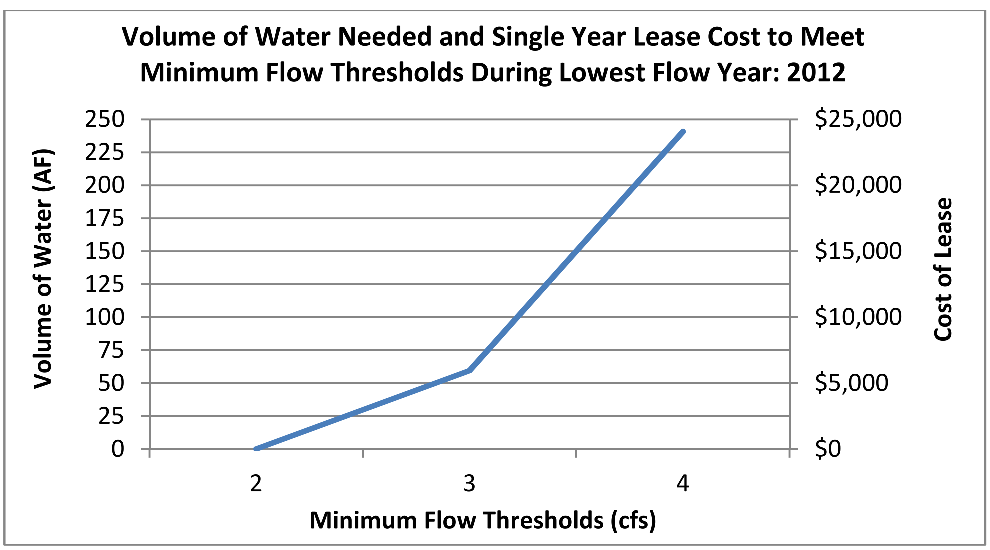
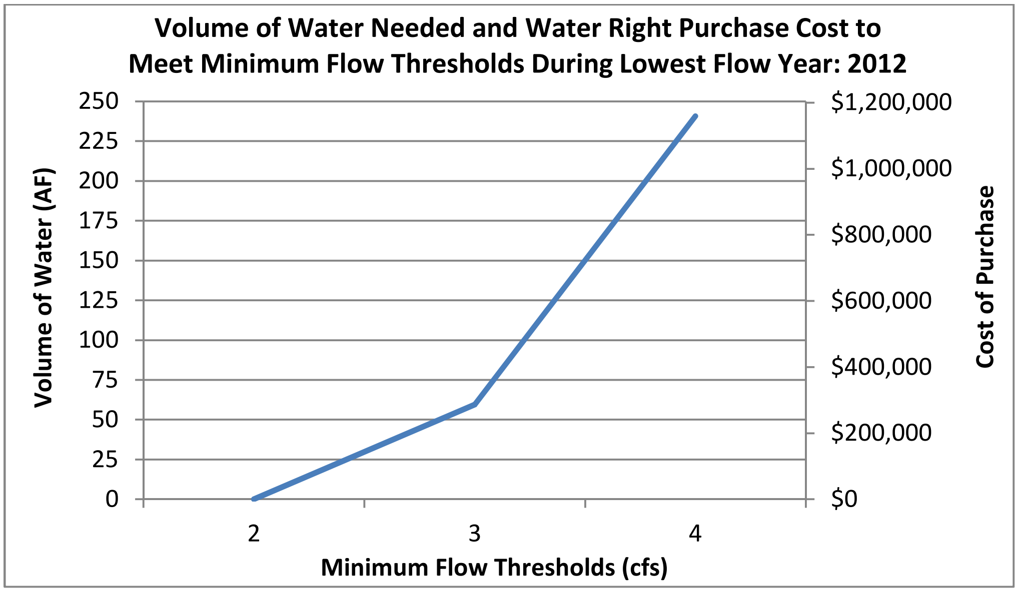


**Figure 20: Purchase Costs Under Year of Lowest Flow: 2012 based on Purchase Prices Estimates of $5,000/AF**




Lease and purchase price estimates needed to address 2012 streamflow levels could be seen as high-end estimates. However, if current trends in streamflow continue to decline, resulting from some combination of declining precipitation and increasing water use in the basin, this analysis could reflect a new normal. In addition, the price estimates used in this analysis are not current and do not reflect the marginal costs of leases and purchases. It should be assumed that current rates may be significantly higher. In addition, as the state and other buyers pursue purchases and leases of water rights in the basin, especially as regional oil and gas development expands, prices are expected to increase.

**Table 2: Costs to Acquire Water to Meet 3 and 4 cfs Thresholds in 2012 based on Water Right Lease and Purchase Cost Estimates of $100/AFY and $5,000/AF Respectively**

| **Minimum Flow Thresholds:** | **3 cfs** | **4 cfs** |
|---|---|---|
| *Average annual cost for 11-year study period* | | |
| Lease | $ 580 | $ 6,780 |
| Purchase | $ 29,070 | $ 339,260 |
| *Cost for lowest flow year, 2012* | | |
| Lease | $ 5,940 | $ 24,080 |
| Purchase | $ 297,200 | $ 1,203,840 |

## Uncertainty

This streamflow and cost analysis provides a simple and brief approach to assess the implications of the range of possible minimum flow thresholds needed to support Texas hornshell survival. However, it also includes multiple dimensions of uncertainty and is entirely dependent on the accuracy of the USGS gage data used. As mentioned, any water rights purchases or leases to support environmental flows in the basin will have to consider the location of the associated point of diversion, meaning the location of the water right and its relationship to the stream system.  Purchases or leases far away from viable habitat reaches may have a reduced or delayed beneficial impact on streamflow. Also, whether or not the water right is accessible for placement into the stream will be of large importance and may be determined by whether the water right for sale or lease comes from a surface water diversion or a groundwater right.

Other associated factors of uncertainty arise from market fluxes. Once a minimum flow threshold is determined, the cost of meeting that flow will vary depending on demand in the basin. As water scarcity and/or demand increase, the price of the water could rise and could influence the ability of the state to acquire environmental water at a cost within their budget.  The current size of the market is unknown; an estimate of the proportion of the total environmental transactions by the NMISC compared to total basin water transactions would provide a better measure of instream water acquisitions and where an appropriate equilibrium of price and quantity might exist.

Finally, these cost estimates do not take into account the uncertainties associated with future events that may influence climate or water use. If the drought of 2011 to 2012 ends and heavy precipitation ensues, water prices may drop.  Likewise, as temperatures continue to increase in the Southwest, the Black River Basin's water supplies will become further stressed and long-term water market trends could show gradual increases in prices that reflect scarcity.  Similarly, continued regional oil and gas development may alter the market, whereby the users willing to purchase or lease water at higher costs may outcompete state efforts to pursue environmental water acquisitions.

# COMPETING WATER DEMANDS

Effective and equitable water management depends on a comprehensive understanding of current use, trends in use, and correlations to land use practices.  To-date, such a comprehensive water demand profile specific to the Black River Basin has not been conducted. This analysis also helps anticipate management decisions associated with possible future changes in demand.

## Methodology

This comprehensive water demand profile consists of three components: 1) a water rights catalog, 2) analysis of administrative mechanisms that reflect shifts in water demand, and 3) land use analysis.

The water rights catalog details how water is appropriated to water rights holders in the basin. It includes the quantity of water permitted, allocations according to each type of use, and how much water is actually used according to metering reports. Catalog data is composed of points of diversion (POD) numbers, permitted or claimed water use, location and water use type collected from NMOSE GIS spatial and attribute data tables, which utilize information from the NMOSE Water Rights Reporting System (NMWRRS) and the New Mexico Water Administration Technical Engineering Resource System (WATERS) online databases. Additional information from original paper files at NMOSE offices in Roswell and Albuquerque were used to verify the most up-to-date status for these water rights. Finally, well records provided by the Texas Water Development Board were added to reflect the 12 PODs located in the Texas portion of the Black River Basin.

Analysis of the administrative mechanisms that reflect water demand shifts was examined to determine how water demand has changed and may continue to change over time. These mechanisms are important to consider given that surface and groundwater is fully appropriated in the Black River Basin, meaning that new appropriations for water are not authorized except for new domestic, livestock and temporary groundwater appropriations. The two administrative mechanisms that reflect changes in water demand are: 1) changes in purpose of use permits and 2) new temporary permits. The analysis quantified these permits by number that have been issued to-date within the basin, as well as the temporal trends and water use allotments associated with these permits.

Finally, land use analysis was conducted to examine changes in water demand associated with agricultural shifts and oil and gas development. . The information gathered from this analysis was used to assess possible trends of overall water use.

## *Water Rights Catalog*

Both surface and groundwater rights in New Mexico, as well as changes to water rights, must be filed with and approved by the NMOSE. All water rights for surface and groundwater sources are assigned a total annual diversion amount. In the case of groundwater rights, multiple PODs can be permitted per water right and likewise, multiple water rights can be drawn from the same POD. Each POD is issued a letter, representing the type of surface diversion or administrative groundwater basin, and a number. Those digits are specific to that geographically located POD. Water rights are also given a number, which is often - but not always - the same as the POD number.

## *Data sources:*

1. NMOSE Geographic Information System (GIS) shapefiles and attribute tables

   The NMISC Pecos Bureau provided a GIS layer created by NMOSE in early 2013 that included the following attributes for each POD:
   - POD number and suffix
   - Water source (surface sources are either “SD” for surface diversions, or “SP” for surface permits, and groundwater sources are listed as “C” for NMOSE declared Carlsbad Basin)
   - Location including northing and easting, and township range
   - Permitted purpose of use
   - Total permitted annual diversion
   - Owner name and mailing address
   - For groundwater rights:
     - Well drilling start date, finish data and if relevant plug date (where available)
     - Well depth and depth to water (where available)

   This GIS layer directly reflects data from the WATERS online database at the time it was generated and was clipped to include only the data points specific to the Black River Basin. The attribute table was then used to create an Excel file, which served as our working water rights catalog for comparison to NMOSE paper files.

Because multiple PODs can be permitted for water use under a single water right, the GIS layer displayed each of those PODs as permitted for the total allowed diversion for the associated water right. This resulted in duplicate listings for the total permitted diversion for several PODs. By cross checking all PODs listed with the same total diversion amount we were able to eliminate duplicate total diversion listings.

Based on the water rights catalog generated, total permitted demand in the basin is 14,874 AFY.

2. NMOSE Roswell and Albuquerque paper files

Although the region including the Black River Basin has been almost entirely uploaded to WATERS, performing a comparison with NMOSE paper files ensured greater accuracy in order to capture updates that have yet to be uploaded, or were inaccurately uploaded, to WATERS. The Pecos Bureau of the NMISC provided scanned documents for 38 PODs that had not been fully uploaded to WATERS. First, these files were compared for accuracy with the working water rights catalog. Any recent changes, including change in purpose of use permits and/or temporary permits issued by NMOSE, were recorded. Next, all PODs over 40 AFY were crosschecked with NMOSE's paper files located at the Roswell and Albuquerque offices.

Many of the paper files were difficult to follow and seemed to be missing important information. However, they also included important updates to the catalog, leading to significant reductions and increases in total permitted diversions, as well as the elimination of a small number of water rights. This research also assisted with capturing the extent of change in purpose of use permits in the basin (see "Administrative Mechanisms" section).

3. Texas Water Development Board

The Texas area of the Black River Basin contributes minimally to total basin-wide water demand. Consultation with the Texas Water Development Board and the National Parks Service indicated that groundwater wells are owned by few users with stock watering and domestic use accounting for the primary uses. Because the soils are rocky and the land is sloped, agriculture is absent and does not have an effect on water demand.

As a "rule of capture" state, Texas allows groundwater rights holders to pump whatever volume they choose and extractions are not measured unless the area is regulated by a groundwater conservation district. The Texas portion of the basin lies in Culberson County but is not within the boundaries of the Culberson County Groundwater Conservation District. Because population is minimal within the Texas portion of the basin and the main water uses are for stock watering rather than irrigation, water shortages and drawdown levels have not been a concern. However, Culberson County's decision to refrain from regulating groundwater drawdown and extraction was made before the oil and gas boom in the Permian Basin (Hearst

2014). Better accounting of groundwater resources may be beneficial in assessing future impacts on the groundwater levels as demand changes occur.

Because the primary purpose is stock watering and metering reports are not available for the wells in Texas, it was assumed that each well within the basin is pumping approximately the annual volume of 3 AFY, as permitted by New Mexico statutes to support stock watering. Therefore, the total estimated water use in Texas accounts for 36 AFY attributed to 12 points of diversion. If this assumption is incorrect, which is likely given nearby oil and gas development, groundwater pumping may be having a significantly larger impact on the Black River Basin.

4. Actual use estimates

All groundwater wells within the Black River Basin - except for those low volume wells designated for domestic and livestock uses - are required to submit periodic meter reports to detail usage. After completing the water rights catalog, metering reports for groundwater wells were compared with permitted allotments in order to gain a more accurate perspective of how much permitted water is actually being used within the basin. Meter reports for a randomized sample of 38 percent of the 310 total PODs in the basin were sourced from WATERS. Research resulted in only 24 meter reports of the 118 PODs sampled or 20 percent of the PODs sampled within the basin (Table 3).

Based on this exercise, as well as anecdotal consultation with NMOSE staff, it is evident that a vast majority of water rights holders do not provide metering reports. Therefore, it is difficult to ascertain how much water is actually used in the basin.

**Table 3: Permitted vs. Actual Use Based on Randomized 20 Percent Meter Report Sample**

| Use Type | # PODs Sampled | # PODs with No Meter Reports | % Missing Meter Reports | Actual Use % of Permitted Use |
|---|---|---|---|---|
| Commercial | 3 | 1 | 33% | 335.6% |
| Domestic & Livestock | 10 | 10 | 100% | No Data Available |
| Domestic | 11 | 11 | 100% | No Data Available |
| Industrial | 3 | 3 | 100% | No Data Available |
| Irrigation | 32 | 23 | 72% | 30% |
| Multiple Households | 1 | 1 | 100% | No Data Available |
| Municipal | 1 | 0 | 0% | 21% |
| Domestic & Livestock (deeper than 2,500 feet) | 1 | 0 | 0% | 36% |

| | | | | |
|---|---|---|---|---|
| Prospecting/New Temporary | 34 | 24 | 71% | 254% |
| Public Use | 1 | 1 | 100% | No Data Available |
| Commercial Sanitary | 1 | 1 | 100% | No Data Available |
| Stock Watering | 20 | 19 | 95% | 5% |
| **Total** | **118** | **94** | **Average missing meter reports = 73%** | |

## *Administrative Mechanisms*

As previously stated, surface and groundwater resources have been fully appropriated in the Black River Basin. The two main administrative mechanisms that reflect changes in water demand are: 1) changes in use permits and 2) new temporary permits. The analysis looked at how many permits were issued to -date within the basin, as well as the temporal trends and water use allotments associated with these permits.

1. Change in purpose of use permits

   When the beneficial use of a water right changes, the switch must be approved and recorded by the NMOSE. For example, this would occur if a farmer changes their purpose of use from irrigation to commercial or industrial. Change in purpose of use permits, as well as permits for dual use, were researched in consultation with paper water rights and records filed with the NMOSE. The dates, allotments, and type of change were recorded in the water rights catalog for later analysis.

2. Temporary permits

   New temporary appropriations typically account for water needs associated with mineral, and oil and gas exploration. New Mexico Groundwater Rules and Regulations authorize temporary new appropriations either to existing wells or for new well construction, and limits them to three permits per well per year, at three acre-feet per permit. The total maximum permitted amount is therefore nine acre-feet per well per year. The current cost for temporary new appropriations is five dollars per permit. If applied for at the same time, the permits are issued on a rolling basis to allow for uninterrupted use of nine acre-feet within one year of the permit issue date and they are not limited by location or groundwater basin. Additionally, while permit grantees are required to submit meter readings to the NMOSE many often do not.

   NMISC Pecos Bureau staff assisted with research of NMOSE issued temporary permits. The WATERS database was scanned to detect temporary permits associated with existing PODs (categorized under “PRO” for prospecting purposes). Additionally, each township, range, and section was entered into the WATERS system to determine additional new temporary permits that are not associated with existing PODs. The results from each query were crosschecked to compile a comprehensive list of all PRO permits to-date.

Despite widespread commentary about a growing number of NMOSE-issued temporary permits in recent years, analysis found that only six temporary permits were issued in 2013 in the Black River Basin, totaling 18 AF from two PODs.

## *Land Use Analysis*

Analysis of current land use and possible impacts to water demand due to changes in land use helped lend insight into what the basin may experience in the future.

### Agricultural Data

The land use analysis consists of a profile of land use types, crop cover and agricultural census data provided by the United States Department of Agriculture (USDA), as well as land ownership data to delineate public and private land boundaries.

### Oil and Gas Data

Given that the Black River Basin lies within the highly productive Permian Basin, the land use analysis also includes a quantification and spatial assessment of oil and gas well activity using data obtained from the Petroleum Recovery Research Center. The process entailed pulling raw data of historic oil and gas wells in New Mexico from the Center's GO-TECH online database. The following relevant information was captured for each well:

- Operator name
- Drill date
- Plug date (if applicable)
- Well type
- Current status
- Location (latitude and longitude coordinates)

The spatial data was then converted into a GIS layer and clipped to the Black River Basin where the attribute table was then exported for analysis. Each well was referenced using the New Mexico Oil Conservation well search tool to confirm or estimate well completion date, which then was used to assess the temporal and spatial trends of well development within the basin.

## Water Demand Characterization

A characterization of water demand supports increased understanding of possible human impacts to the basin. The results of this comprehensive water demand profile indicate that appropriated water is primarily utilized for irrigation purposes. However, future shifts in demand may include possible increases associated with temporary new appropriations, as well as changes in use from agriculture to commercial purposes as a result of oil and gas development in the region.

### *Current Water Use*

Surface and groundwater resources in the Black River Basin are fully appropriated. There are currently 310 points of diversion associated with those water rights, the majority of which are for surface water diversions (66 percent) and the remainder for groundwater use. These rights reflect 14,874 AFY of total permitted use, of which 89 percent (13,072 AFY) is used for irrigation and the remainder is used for commercial/prospecting, municipal/sanitation, domestic/stock, and industrial purposes. A breakdown of demand by use type can be found in Figure 21.

**Figure 21: Black River Demand by Use Type**

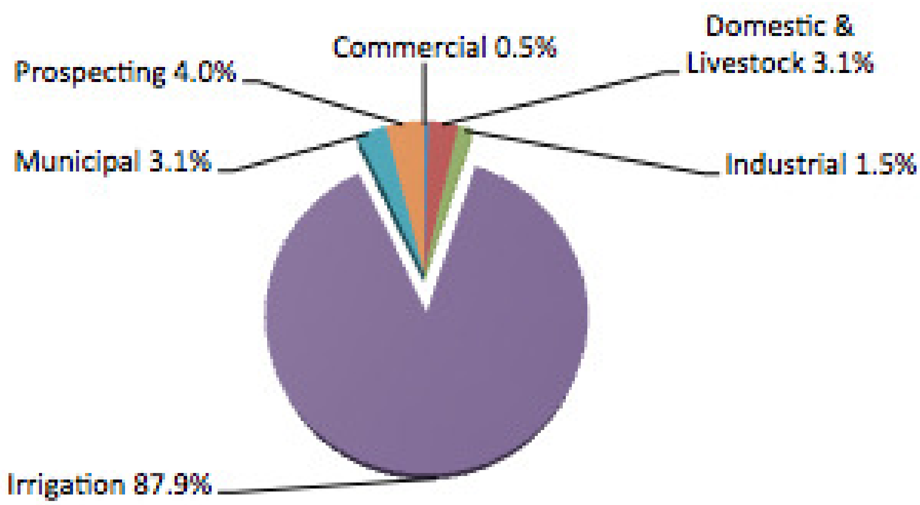
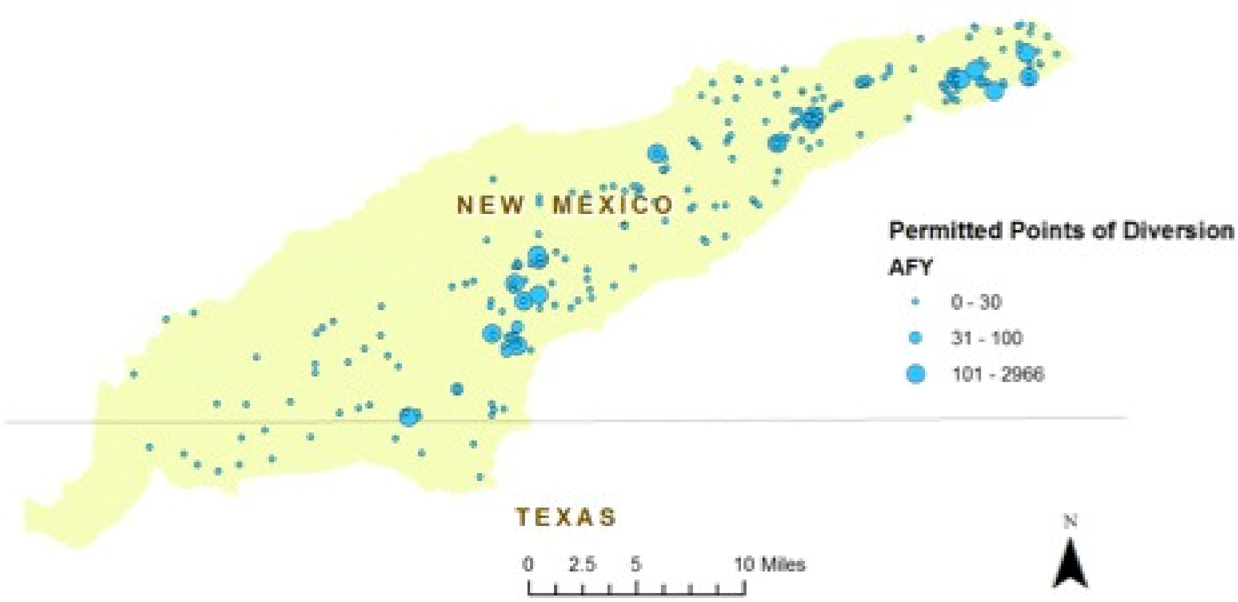



Figure 22 indicates the spatial locations of all PODs within the Black River Basin. The Carlsbad Irrigation District (CID) consists of the most senior surface water rights in the basin along with water rights owned by the Bounds Family Trust. Approximately 3%, 2,800 AFY, of CID water rights originate from surface waters of the Black River Basin.

**Figure 22: Black River Points of Diversion**




## Carlsbad Irrigation District

The privately managed Carlsbad Irrigation District (CID) holds some of the most senior water rights in the state of New Mexico. Originally developed by private investors, the project was one of the first in the west to receive the aid of the Bureau of Reclamation in the 1900s. At a time when the project's investors were going into debt, the Bureau purchased the lower Pecos irrigation system to make operational repairs, including lining the Black River Canal in the 1910s and 1920s. Federal investment continued and in the 1930s the Carlsbad project was a major recipient of Franklin D. Roosevelt's New Deal expenditures. Project management was transferred to the Bureau of Reclamation after the initial purchase, but in 1949 full management responsibilities were shifted to the newly created Carlsbad Irrigation District, of which had been voted into formation in 1932 (Bogener, Carlsbad Project 1993). Water rights from the original project of the 19th century carried over and are still held by the CID, contributing to the strength and stability of the district's water supplies in terms of the Interstate Compact.

Many surface water users in the Black River Basin are members of the CID and either depend on imported Pecos River water or on a specified amount from Blue Springs. Pecos River water is permitted to users and transported via the project's Southern Main Canal to the Black River Supply Ditch (shown in Figure 23).

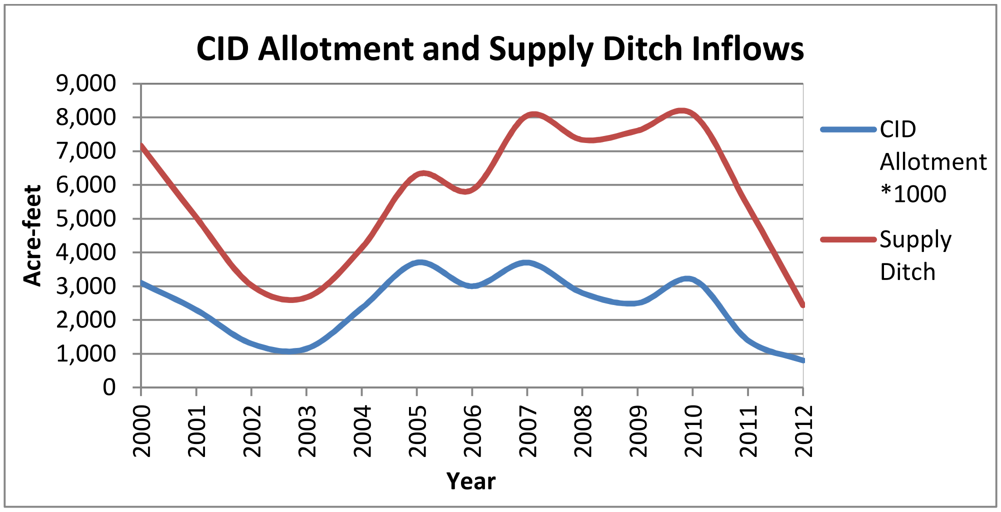
### Figure 23: Black River Supply Ditch

The Pecos water enters the Black River near Malaga before being diverted into the Black River Canal (Figure 24), where it is then allotted to individuals mainly for irrigation or stock use. Approximately 25 to 30 CID users are also permitted an amount of 2,800 acre-feet per year of water from the Blue Springs inflow to the Black River (District 2014).

**Figure 24: Black River Canal**

The volume of CID water allotted to users varies depending on water shortages and requirements to maintain compliance with the Interstate Compact. The maximum allotment per acre is set at 3.7 acre-feet and fluctuates significantly year to year (District 2014). The trend is generally correlated with the volume of inflow coming in through the supply ditch, as shown in Figure 25. As the annual allotment decreases or increases, so does the volume of Pecos water that is transported south to the Black River Canal.

**Figure 25: Carlsbad Irrigation District Allotment and Supply Ditch Inflows**




Rates of Blue Springs permitted water and imported CID Pecos water differ, although both rate structures are up for change when the annual budget is decided in October. The 2,800 acre-feet of Blue Springs water has been sold at a flat $19 per acre-foot for the past three years (2011-2014). Water from the supply ditch is not structured per acre-foot but instead, rates are based off of an assessment per acre. The rate has been $62 per acre for the past four years (2010-2014) and does not vary according to how much water is delivered. The fees per acre are directed towards maintenance and operation of the CID rather than a payment for water. Both Blue Springs and CID rates are not expected to decrease in subsequent budgets (District 2014).

Recommendations for management of the privately owned CID in order to promote water conservation may prove futile, but should still be noted in an all-encompassing water budget analysis. If oil and gas activity expands within the Black River Basin, surface water users of both Blue Springs and the Black River Canal may be enticed to change the use of their water rights from irrigation to commercial, thus enabling them to sell water. The existing flat rate structure for Blue Springs water does not promote conservation. Switching to a tiered rate structure will reward efficient agricultural practices, while minimizing the profitability of selling large volumes of water to oil and gas. Similarly, a reduced rate for landowners that irrigate with Pecos River water diverted through the Black River supply ditch would also promote efficiency and conservation.

## *Trends in Use*

The main shifts in use in the Black River Basin occur through temporary permits for changes in purpose of use or new prospecting (PRO) uses.

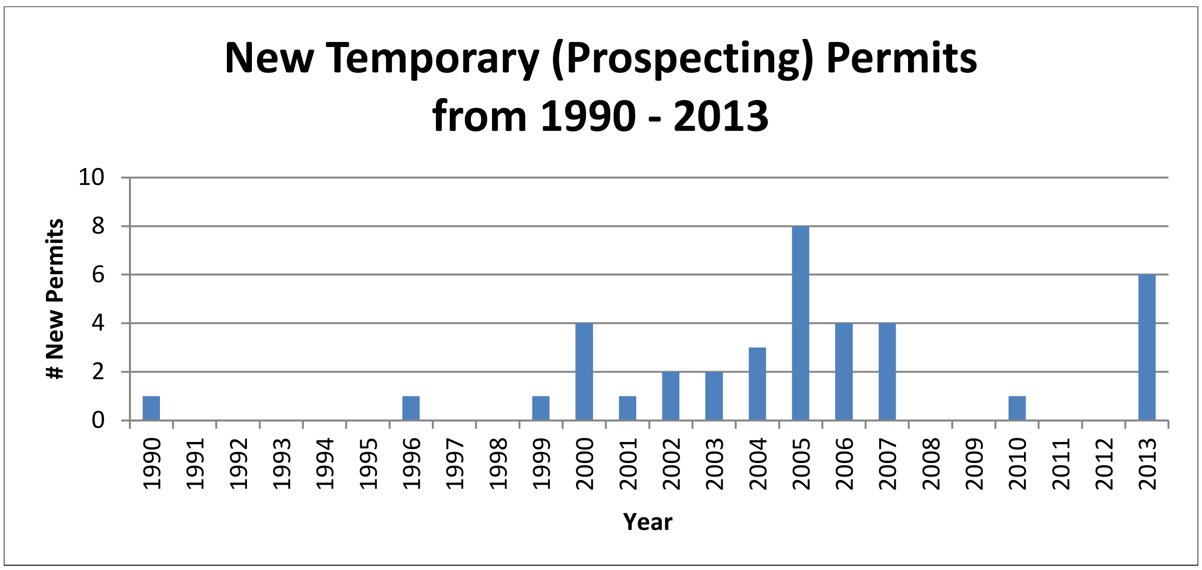
### Change in Use Permits

Significant water rights for irrigation purposes are undergoing temporary changes in purpose of use to commercial and/or industrial purposes. Approximately 12 percent of the total water allocated in the basin have recently had the purpose of use temporarily reconfigured or have had an additional purpose of use temporarily added. The bulk of these permit requests were filed during 2005-2006 and involved some or all of the permitted use for irrigation being temporarily converted into commercial use

### Temporary Permits

New temporary appropriations typically account for water needs associated with mineral and oil and gas exploration. From 1950 to 2013, 49 new temporary permits were filed in the Black River Basin. The average rate of new permits per year stayed relatively steady from 1950 through 2000. However, beginning in 2000 the application rate increased to 2.7 per year. The greatest number of new temporary permits filed in one year occurred in 2005 involving eight permits (Figure 26).

**Figure 26: Temporal Trends of Temporary and Prospecting Permits in the Black River Basin**




## Land Use Analysis

The Black River Basin is primarily rural. Eighty percent of the land in Eddy County is public, administered by the federal or state government, while 20 percent is privately owned (Sites Southwest 2008). Farming operations are concentrated around Malaga and the confluence of the Black River and the Pecos River, but also exist near Rattlesnake Springs and as far as the Texas state line. Both surface and groundwater is used for irrigation (Pecos Valley Water Users Organization 2001).

### *Agriculture*

Two percent of the total land area in the Black River Basin is used for. Alfalfa, hay and other feed crops are the primary agricultural products in the basin and in Eddy County generally; around 30,000 acres of land are used for forage, hay, grass silage and greenchop (U.S. Census of Agriculture, 2007). The map in Figure 27 shows the range of agricultural products produced in the basin.

The Census of Agriculture indicates that between 2002 and 2007 the number of farms in Eddy County decreased by six percent, however the total acreage of farmland increased by six percent most likely due to farm consolidation (Figure 28 and Figure 29) (United States Department of Agriculture 2007). Anecdotal references from conversations with local landowners in the basin point toward a possible reduction in agriculture as operating costs rise and the current drought makes farming more challenging.

### Figure 27: Crop Cover in the Black River Basin

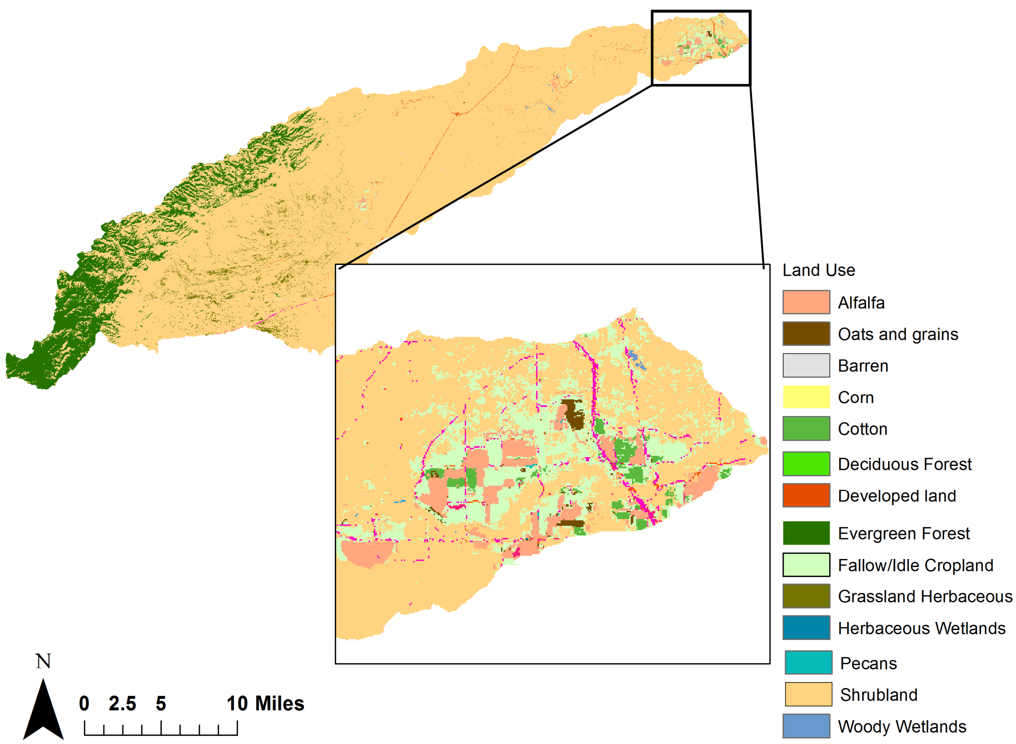


Figure 28: Distribution of Farm Size in Eddy County, New Mexico

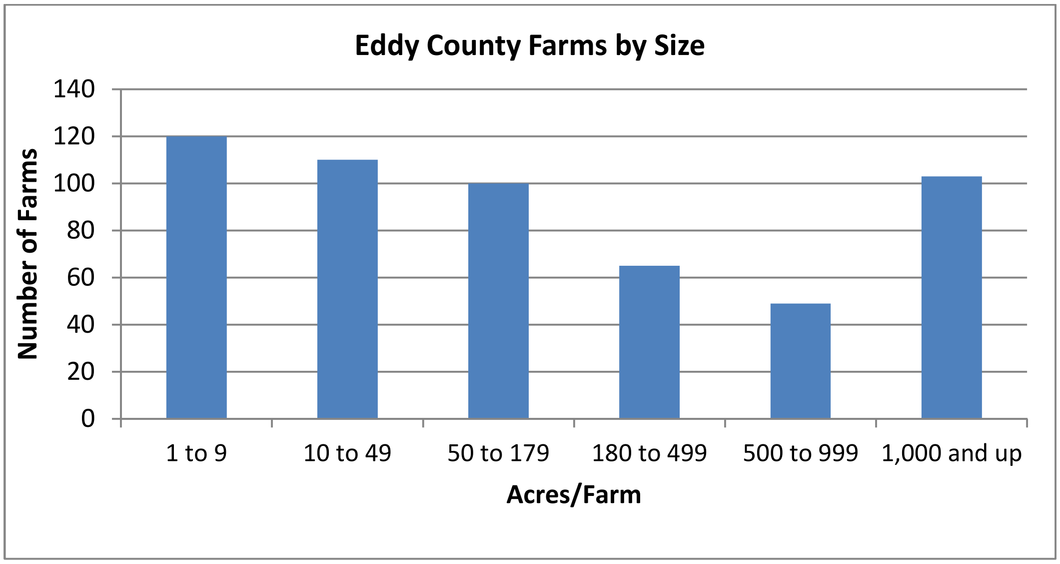
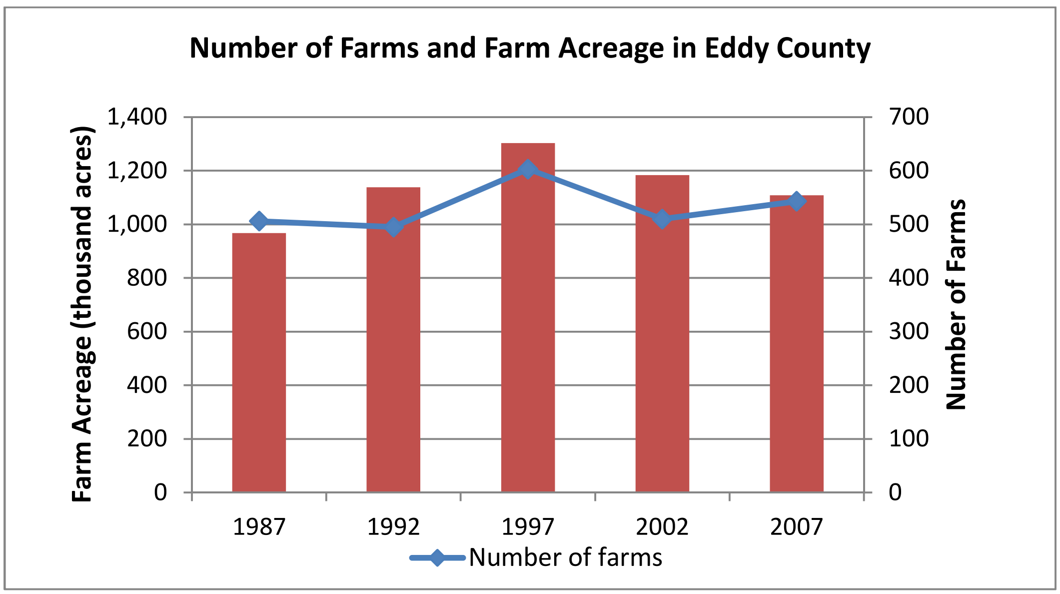


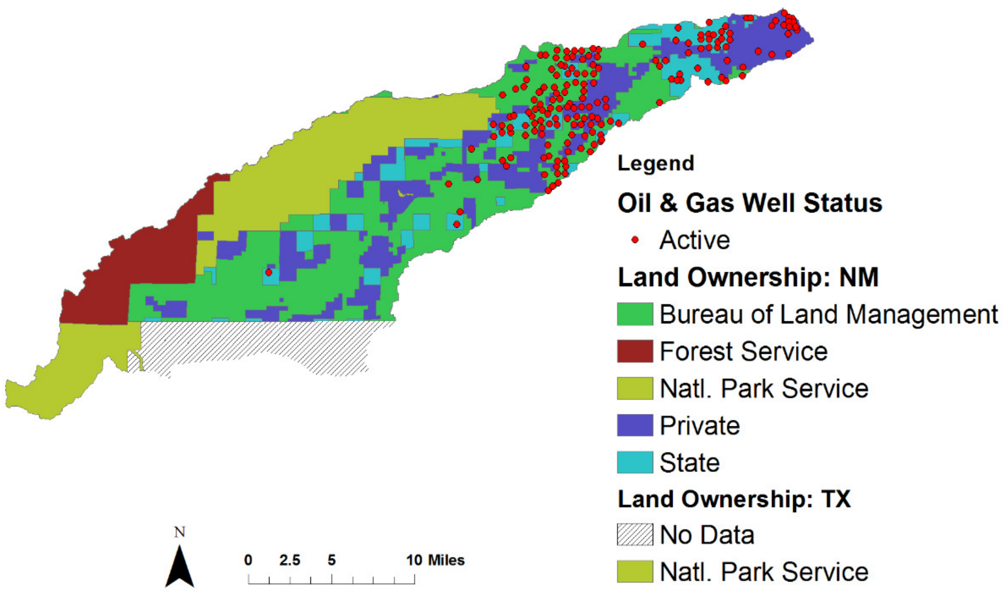

Figure 29: Farm Size and Number in Eddy County, New Mexico from 1987 to 2007




### *Land Ownership*

Aside from private land used for livestock grazing and agriculture, the Black River Basin is comprised of public land, both federal and state owned (Figure 30). The Bureau of Land Management manages approximately 31 percent of the basin, and the Forest Service manages another 21 percent. The majority of land in the Texas portion of the basin is privately owned. The National Park Service manages a portion of the Guadalupe Mountains on the Texas portion of the basin as well as Carlsbad Caverns National within the basin.

**Figure 30: Land Ownership in the Black River Basin**



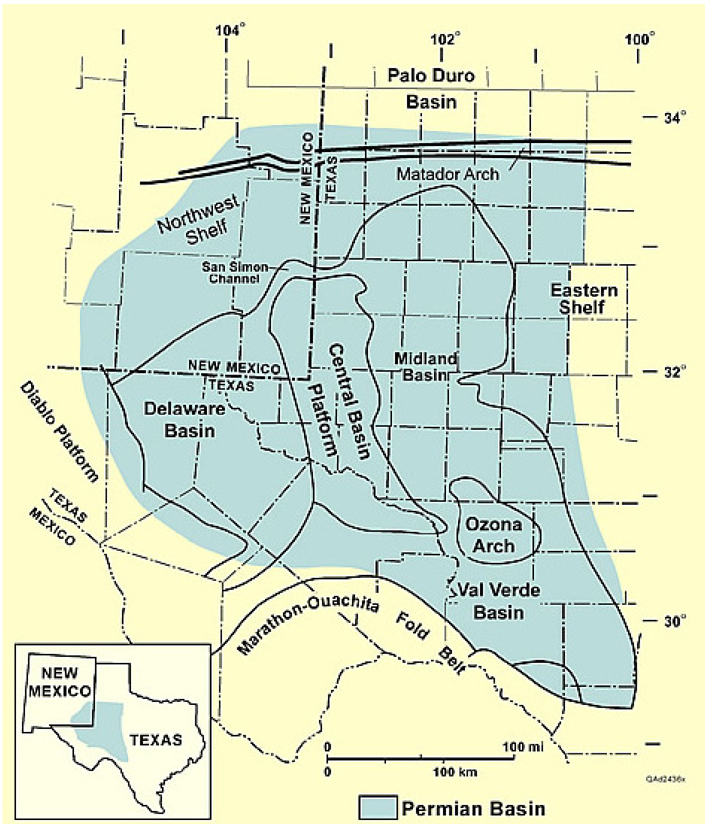

## *Oil and Gas*

Oil was discovered in Eddy County in 1909 near Artesia, which presently hosts a refinery that processes it into gasoline, diesel jet fuel and asphalt (Eddy County 2007). Potash was also discovered east of Carlsbad in 1925 where several large potash producers still operate (Eddy County 2007). Although representing just a small fraction of the total number of oil and gas wells in the New Mexican Permian Basin (Figure 30), water resources of the Black River Basin are subject to water demand by oil and gas operations.

### Sources and Types of Oil and Gas Production

Defined by sedimentary deposits, the Permian Basin spans 86,000 square miles across southeastern New Mexico and western Texas (Ball 1995). The Delaware Basin is a sub-unit of the Permian Basin that spans Chaves, Eddy, Lea, and Roosevelt counties. Even further segmented, the unconventional Avalon Shale Play produces both oil and gas and encompasses 1,313 square miles primarily in Eddy County (Figure 31).

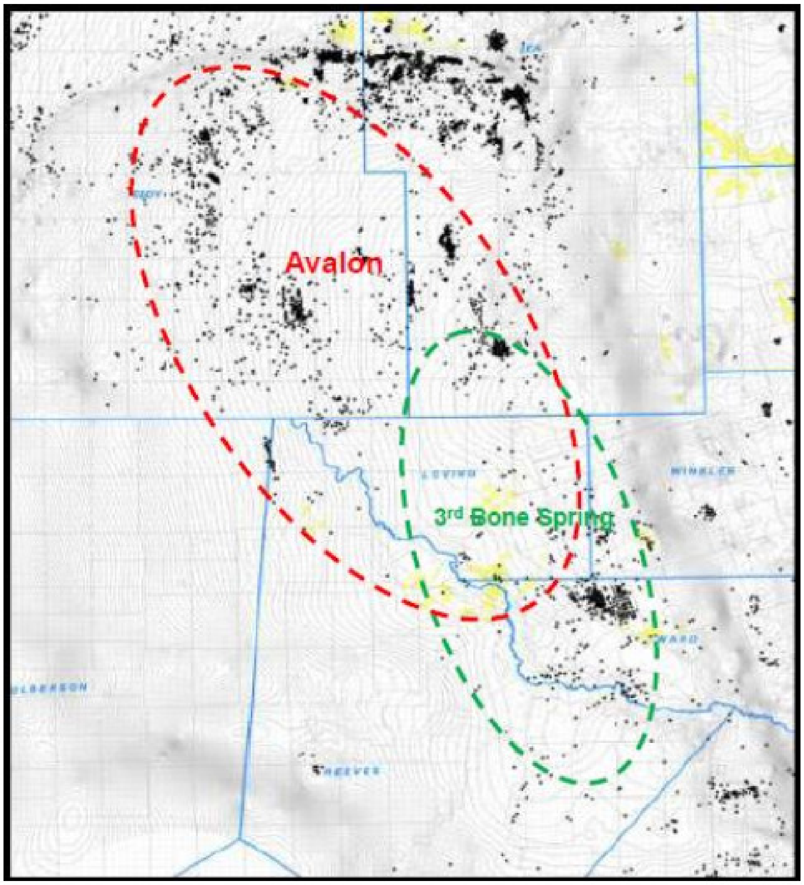
**Figure 31: Map of the Permian Basin**




The Avalon and Bone "shale plays" located in southeastern New Mexico differ from conventional oil extraction because the pore sizes are much smaller and impermeable to gas flows, requiring advanced hydraulic fracturing technology, or "fracking", to pump out oil and natural gas (Figure 32) (US Energy Information Administration 2011). In the Avalon and Bone Shale Plays conventional drilling is almost obsolete and most wells are drilled horizontally. Vertical wells can be re-entered and converted to horizontal wells, but experts at the New Mexico Oil and Gas Conservation Division claim that this is a rarity (VonGonten 2014).

Although hydraulic fracturing increases the rate of oil and gas production the process is more water intensive than traditional drilling practices (Montgomery and Smith 2010). Fracturing requires proppants (sand or ceramic material) and fluids, such as acid, water and brines. Initially, the fluids used were gels, but in 1953 water became the main fluid of proppants and gelling agents gained popularity as an additive to water to obtain greater viscosity to push the proppants through fractures (Montgomery and Smith 2010).

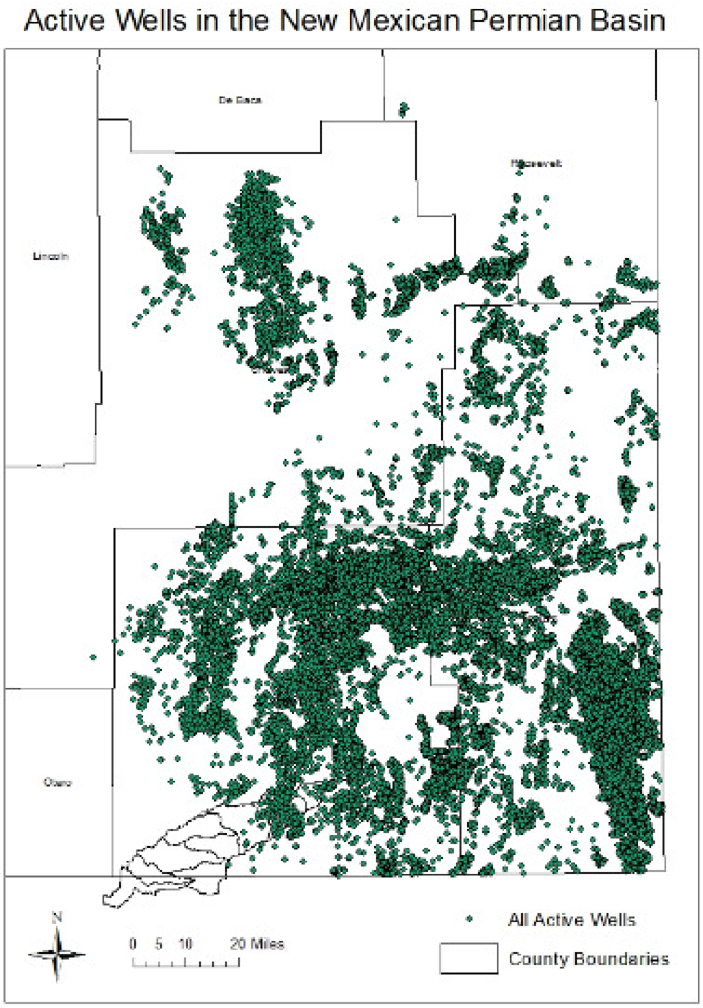
**Figure 32: Map of Avalon and Bone Springs Shale Plays**




## Regional Oil and Gas Production

Throughout New Mexico, there are 25,448 active oil and gas wells located in the Permian Basin. Eddy and Lea Counties rank highest of the four counties represented by the basin; 40 percent are within Eddy County and 47 percent are within Lea County. However, only one percent of the total active wells are within the boundaries of the Black River Basin (Figure 33) (Petroleum Recovery Research Center 2014).

**Figure 33: Active Oil and Gas Wells throughout Chaves, Eddy, Lea, and Roosevelt Counties**




## Black River Basin Production

In the Black River Basin 87 percent of the land is federally owned (mainly by the BLM) and oil and gas companies are highly concentrated in these areas. Therefore, the majority of current production activity within the Black River Basin is concentrated within the downstream areas near Malaga, consisting of 179 oil and gas wells (Figure 34). Of the 288 obtained Applications for Permit to Drill (APD) in the Black River Basin, 73 percent are actively producing or will produce in the future (Figure 35). A significant number of applications were cancelled before drilling began possibly because of time or financial constraints. Generally, applications are valid for two years before they expire and the high costs of obtaining an application on federal lands may restrict a second application from being filed (VonGonten 2014). However, this constraint does not apply to proposals on state lands because the State of New Mexico does not require an application fee.

**Figure 34: Spatial Distribution of Active Oil and Gas Wells in the Black River Basin**

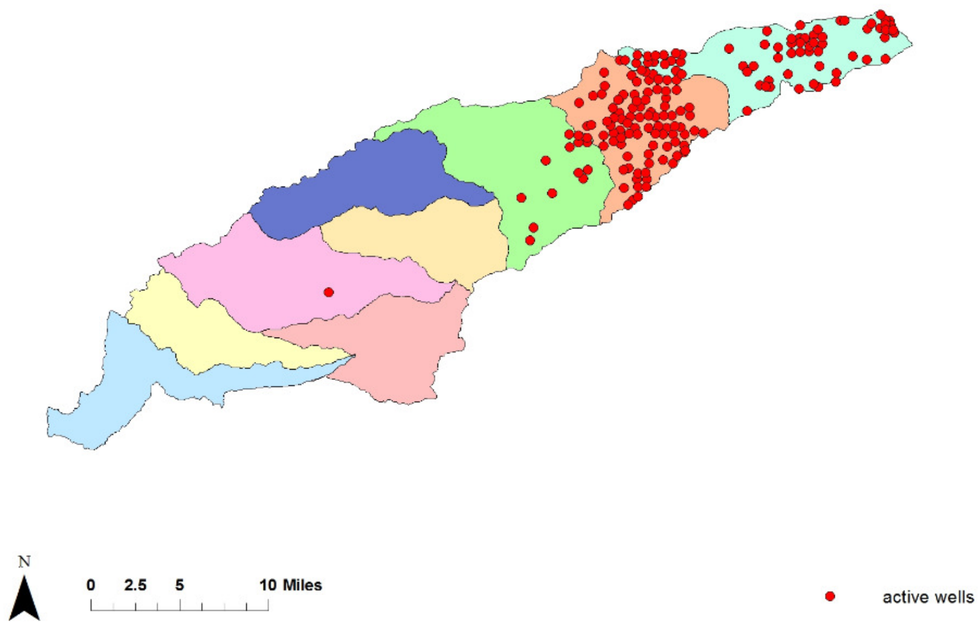
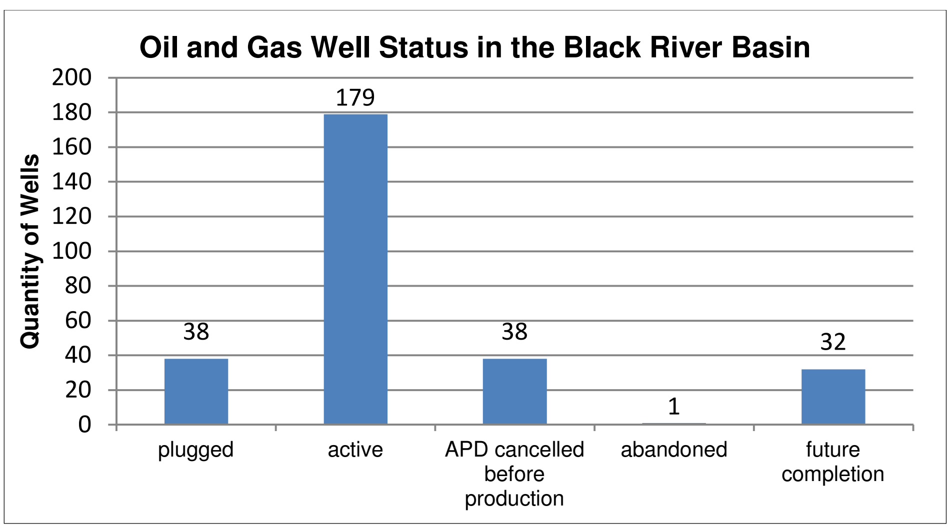



**Figure 35: Oil and Gas Well Status within the Black River Basin**

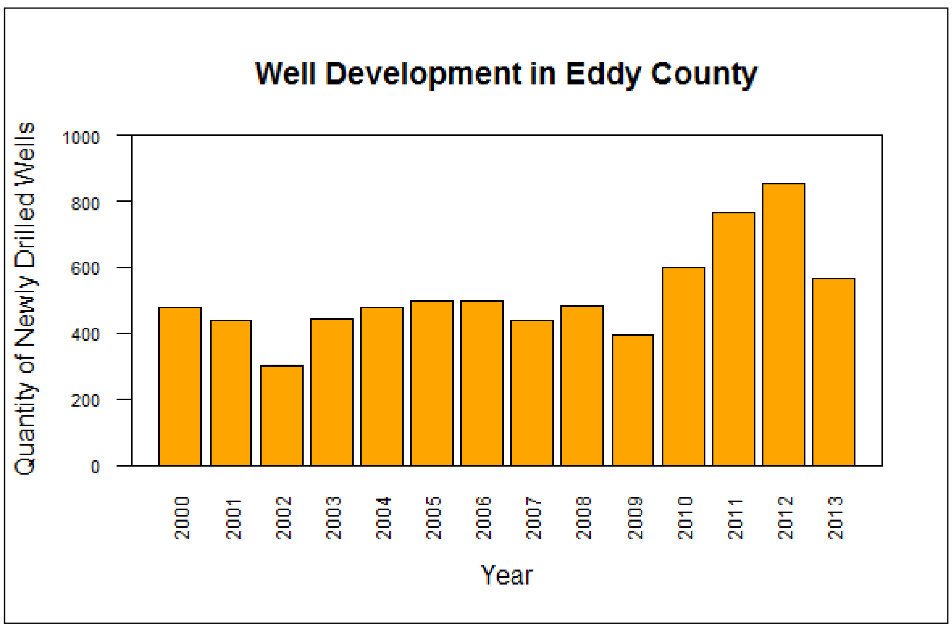


## Regional Trends

Although each well produces a unique range of both oil and gas, recent exploration in New Mexico has focused on oil extraction more than natural gas due to the current economic state. Throughout the 2000s drilling operations for natural gas were booming nationwide. However, due to the 2009 recession demand for both oil and gas dropped. Natural gas was over-supplied leading to a shift in prices and the dominance of oil sales. As of 2012, there were 1,414 rigs drilling for oil and just 565 rigs drilling for natural gas in the state of New Mexico (Headwaters Economics 2012). An initial production test specifies what the well is capable of producing once drilling operations begin, but a well can be re-classified if the ratio of oil to gas production shifts. Generally, as oil resources deplete over time there will be a greater yield of natural gas.

Figure 36 shows temporal trends in oil and gas drilling in Eddy County. The industry is prone to volatility as many factors affect "booms" and "busts", such as supply and demand, macroeconomics, regulatory constraints, cost, price and competitive behavior. Analysis of economic and policy trends that affect development are outside of the scope of this project.

**Figure 36: Temporal Trends of Oil and Gas Well Drilling Dates in Eddy County**

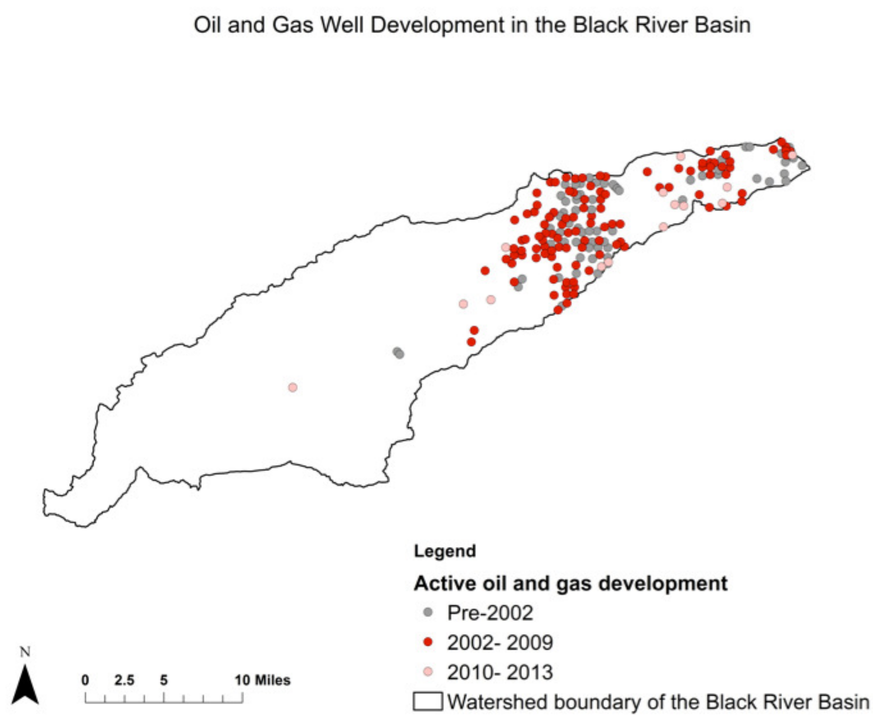



## Black River Basin Trends

Although only a small fraction of the total number of oil and gas wells in the New Mexican Permian Basin are within the Black River Basin, water resources there are subject to increasing demand if new activity expands within and adjacent to the delineation of the watershed. In addition to the 179 currently active wells mostly concentrated downstream, many APDs are categorized as new or not yet completed.

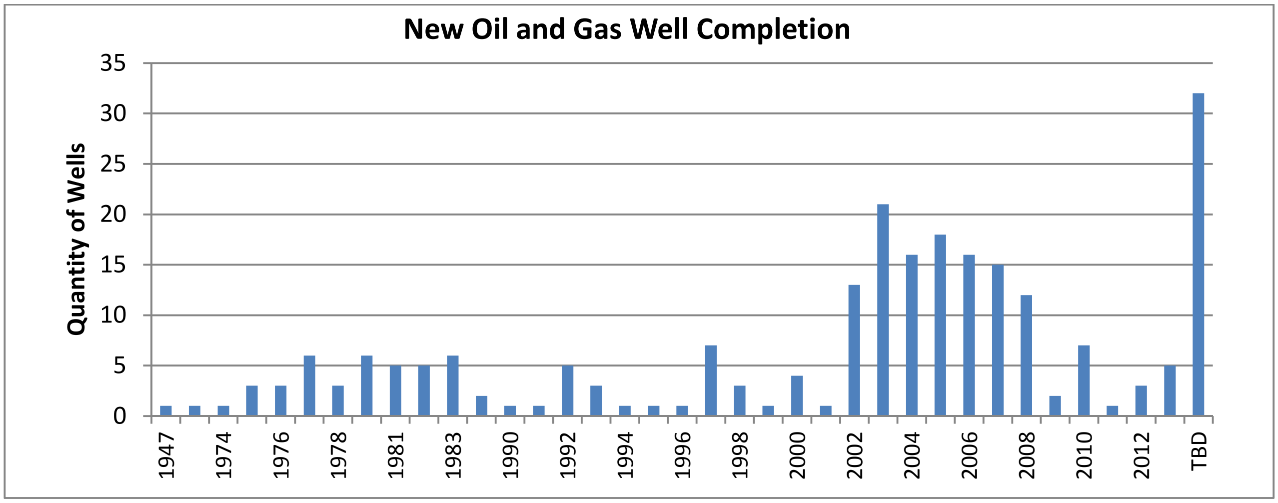
The average lifespan for wells that were plugged, given complete data for only 27 wells of 38 wells, is 13.2 years. In some cases, plugged wells may be re-entered because the economic benefits of drilling are again positive. The drill ("spud") date is an indicator of when the well was completed and the date of first extraction. Analyzing the Petroleum Recovery Research Center's GO-TECH online database does not clearly provide a spud date for every well because many records pre-date the Oil and Natural Gas Administration and Revenue Database (ONGARD), which is where the GO-TECH database retrieves information. Searches on New Mexico's Oil Conservation Division well search tool displayed the date that the APD was approved and this date was used as a proxy for a spud date. A revision of spud dates was applied to a clipped database for the Black River Basin to assess trends within the watershed. Spud date analysis suggests that recent development of oil and gas wells is still concentrated mostly within the downstream areas (Figure 37).

**Figure 37: Oil and Gas Well Development in the Black River Basin**




Out of the 250 oil and gas wells developed or proposed within the basin, the greatest concentration of development was seen between 2002 through 2008, with 44 percent of APDs showing a spud date across this period (Figure 38). This growth in oil and gas development slowed after the 2009 recession and since then there has been a slow rebound of development with 32 APDs yet to be completed. Many APDs often expire due to lack of funding or time constraints, therefore wells that have not yet been completed do not necessarily indicate actual future development (VonGonten 2014). Additionally, many wells with cancelled APDs were initially proposed in upstream areas. Overall, oil and gas development across the basin fluctuates greatly, making analysis of temporal trends uncertain.

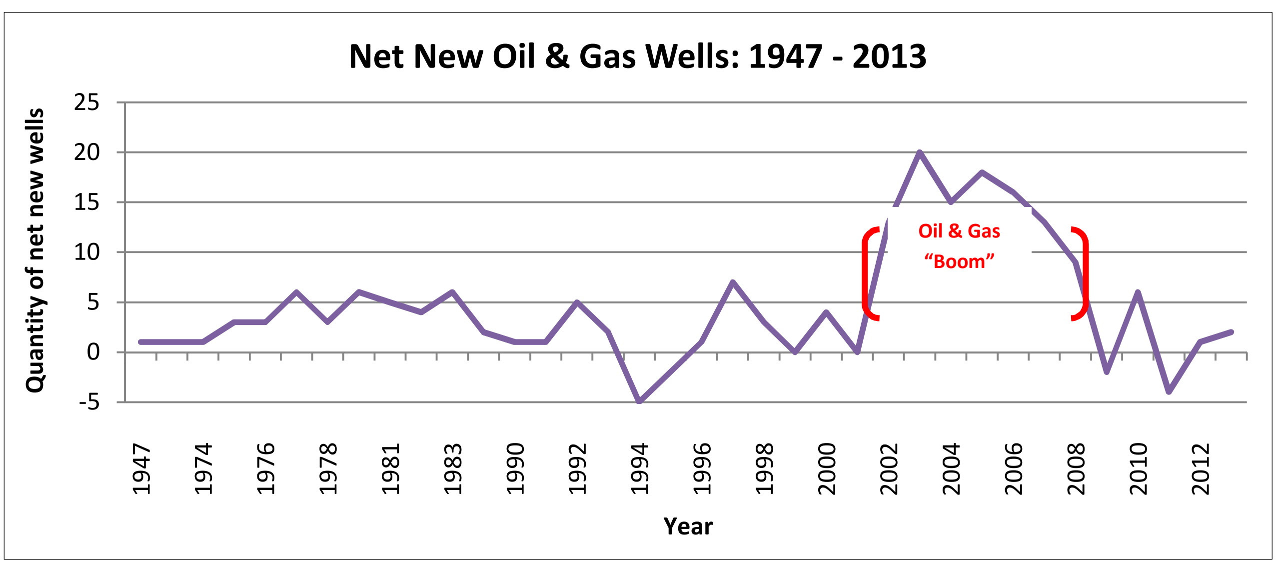
**Figure 38: New Oil and Gas Well Development within Black River Basin**




## Future Oil and Gas Development

Projecting how much new oil and gas production may occur in the Black River Basin - and thus the amount of water needed to meet demand - proves extremely difficult due to the highly volatile nature of the energy market. However, if the basin undergoes another growth cycle in oil and gas well development such as the natural gas "boom" experienced from 2002 to 2008, adaptive water resources management will be necessary in order to balance demands. The gas "boom" experienced in the Black River Basin during 2002 and 2008 resulted in ten times more new oil and gas wells in comparison to other years (Figure 39).

**Figure 39: Net New Oil and Gas Well Development in the Black River Basin**



### Estimated Oil and Gas-Related Water Demand

Estimates of the amount of water required to hydraulically fracture a well range greatly because each unique fracturing job is of different depth and geology. Conversations with consulting industries, federal agencies, the Congressional Research Service and New Mexico OCD reveal a wide range of estimated water use for new horizontal fracturing well (Table 4). These quotes reflect the water demanded by each "frack job", defined as the initial process in which water is injected into the ground to dislodge oil or gas. Over a well's lifetime, multiple "frack jobs" could occur. The average water use of each quote according to low and high estimates yields a range between 4.3 and 10.7 AF per well.

**Table 4: Estimates of Water Demand per Hydraulic Fracturing Job**

| Source: | Low Estimate (AF) | High Estimate (AF) |
|---|---|---|
| *ALL Consulting; Groundwater Protection Council; National Energy Technology Laboratory; Dept. of Energy* | 6 | 12 |
| *Congressional Research Service* | 4 | 11 |
| *New Mexico industry expert* | 3 | 9 |
| Average Estimated Use | 4.3 | 10.7 |

Total water demanded during the oil and gas development "boom" cycle, as experienced from 2002 to 2008, ranges from 451 AF to 1,109 AF (Table 5).

**Table 5: Estimates of Water Supply and Demand per Well**

| | | |
|---|---|---|
| **# Net New Wells (Oil & Gas "Boom" 2002 - 2008)** | 104 | |
| | | |
| Change of Use Appropriations | 1,204 AF | |
| New Temporary Permit Appropriations | 207 AF | |
| *Total Water Made Available During One "Boom"* | 1,411 AF | |
| **Water Demand** | **Low Estimate** | **High Estimate** |
| One "Boom" | 451 AF | 1,109 AF |
| **Total Surplus Supply** | 302 AF | 960 AF |

It is important to note that water right holders can sell water to oil and gas companies conducting operations outside of the basin. Many water hauling companies, such as Jim's Water Service of New Mexico, Inc., are based out of Artesia, which is a hub for local oil and gas refineries. These companies act as brokers between local water right holders and the industry to meet oil and gas water demand, securing a profit in the transfer. A comparison of the quantity of water demanded during an oil and gas "boom" cycle and the water made available by way of change in purpose of use and new temporary permits within the Black River Basin indicates a surplus ranging between 302 and 960 AF. This suggests that water is likely to have been transported out of the basin to meet water demands for oil and gas operations nearby.

## Data Gaps

Because of the lack of recorded meter reports there is not sufficient data to conduct a thorough analysis of seasonal or monthly trends in use. Because irrigation accounts for 88 percent of water allocations in the basin and results from randomized meter samples indicate that actual use may be significantly less than permitted use, it is possible that total water use in the basin is less than what is currently permitted or recorded by the NMOSE. However, permits currently in use for commercial purposes typically appear to utilize much more water than their permitted amounts, which may lead to a net balance in permitted versus actual use.

Additionally, the NMOSE applies a 30 percent reduction factor in authorized water diversion amounts to offset the losses in return flow to the aquifer resulting from temporary permits to change the purpose of use from irrigation to fully-consumptive commercial water sales. Assessing whether or not this reduction factor adequately accounts for return flow losses was outside of the scope of this project. However additional research could shed light on the accuracy of these calculations.

Changes in agricultural practices may also impact actual water use and the stream system, such as increased efficiency of irrigation through the use of pivots, and possible subsequent reductions in return flows. However, estimates of this kind are currently not available for the Black River Basin.

In terms of land use changes, while Census of Agriculture data indicates a decrease in the number of farms in Eddy County, data to support possible reductions in agriculture in the Black River Basin is currently unavailable. If this trend holds true, it may result in major changes for water rights transfers in the future (most likely from irrigation to commercial purposes).

Lastly, interviews with oil and gas industry experts yielded a wide range of water use estimates attributed to hydraulic fracturing operations. There is also uncertainty as to how many hydraulic fracturing jobs are performed per well during its lifetime. Although the NMOCD database shows a category for the volume of water injection per well, the data is largely unrecorded and only covers a three-year period. More detailed information regarding estimated water use per fracturing well by year would be useful in providing an accurate assessment of oil and gas-related water demand in the Black River Basin.

### Conclusion

Examining current water use and trends over time and comparing these trends with possible land use changes enables a more thorough understanding of the anthropogenic influences on water demand within the Black River Basin. The results of the water demand profile indicate that water is primarily utilized for irrigation purposes. Although agricultural operations are not projected to increase in the future, oil and gas development has undergone a series of growth stages that could impact the way that water is used within the basin. This change in demand could be met through change in purpose of use permits and new temporary permits, as indicated by the observed correlation in trends, or by over-pumping by users who are not in compliance with current permitting and/or metering standards. An increase in water demand outside of the basin due to increased regional oil and gas development will likely influence water demand.

## CLIMATE

Dry winter and spring conditions coupled with hot summer temperatures and reliance on summer monsoonal precipitation not only pose a unique set of challenges to the management of the Black River Basin's water supply, but also indicate potential vulnerability to a changing climate including increases in temperature and altered timing and volume of precipitation, and thus streamflow. Such unpredictable weather patterns are characteristic of the Chihuahuan Semi-Desert ecoregion, in which the basin is located. The Black River Basin occupies a high elevation desert that is bound to the west by the Guadalupe Mountains which produce an orographic effect by forcing air to rise, condense, and fall as precipitation (U.S. Environmental Protection Agency 2013) (Chihuahuan Desert Research Institute 2013). Precipitation and temperature vary across the region and are dependent on elevation, which ranges from about 2,920 to 8,600 feet, with a mean elevation of 5,110 feet. Late summer is marked by high temperatures and afternoon, monsoonal thunderstorms. In winter months, cold temperatures and dry air dominate weather patterns.

### Methodology

### Meteorological Stations

Characteristics of the basin climate are measured at three National Oceanic and Atmospheric Administration (NOAA) meteorological stations. For the purposes of this project, these data were compared to the PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Group's spatial dataset for general accuracy and to fill in any minor gaps in data. The PRISM dataset uses a digital elevation model (DEM) as the predictor grid to estimate spatial values for temperate and precipitation The NOAA stations are located at Carlsbad Caverns (4,435 feet), Carlsbad City Airport (3,232 feet), and Guadalupe Peak (7,755 feet). Although Carlsbad Caverns and Guadalupe Peak are the only stations within the basin, the nearby Carlsbad Airport station offers data to reflect the lower elevation areas within the basin and gives more representative coverage. Even with these three stations, accurately capturing the spatial variation of basin precipitation and temperature is challenging. At the

Carlsbad Airport and Carlsbad Caverns stations, measurements are available starting from 1931, however, for the analysis we used the period starting in 1950 because it offered the most complete dataset with no missing values. The earliest record for the Guadalupe Peak station is from 1985. Across the meteorological stations there were data gaps of unmeasured monthly values. To address these inconsistencies and fill in the gaps, PRISM data that reflect three decades of average monthly conditions from 1981 to 2010 were used. Both the NOAA and PRISM data generally fell within the same range for both precipitation and temperature, especially when considering that the PRISM data are long-term averages.

## Existing Conditions

### *Precipitation*

Over the 63-year period from 1950 to 2013, precipitation measurements indicate wide ranging year-to-year fluctuations that translate into a need for adaptive water management strategies. Over the same time frame, annual precipitation totals at the meteorological stations ranged from a low of 3.49 inches to a high of 33.03 inches in 2000 at the Carlsbad Airport and in 1986 at Carlsbad Caverns, respectively (Figure 40). Although precipitation in the upstream portions of the basin at the Guadalupe Peak station is the greatest, this rainfall does not immediately translate to increased surface water flows due to the ephemeral upstream nature of the Black River and high infiltrative capacity in the alluvial material and the Capitan Reef formation. Influenced largely by variation in elevation, the mean precipitation totals for Carlsbad Airport, Carlsbad Caverns and Guadalupe Peak over their respective periods of record were about 12, 14, and 19 inches per year and fit within the range estimated by the PRISM dataset. PRISM data across the Black River Basin show 30-year mean precipitation ranging from 12 inches to 26 inches (Figure 41)

**Figure 40: Total Annual Precipitation**

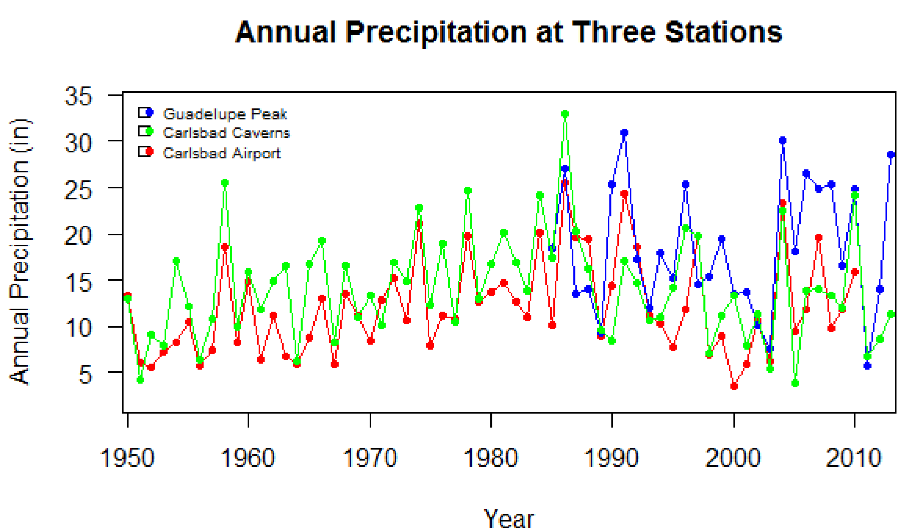
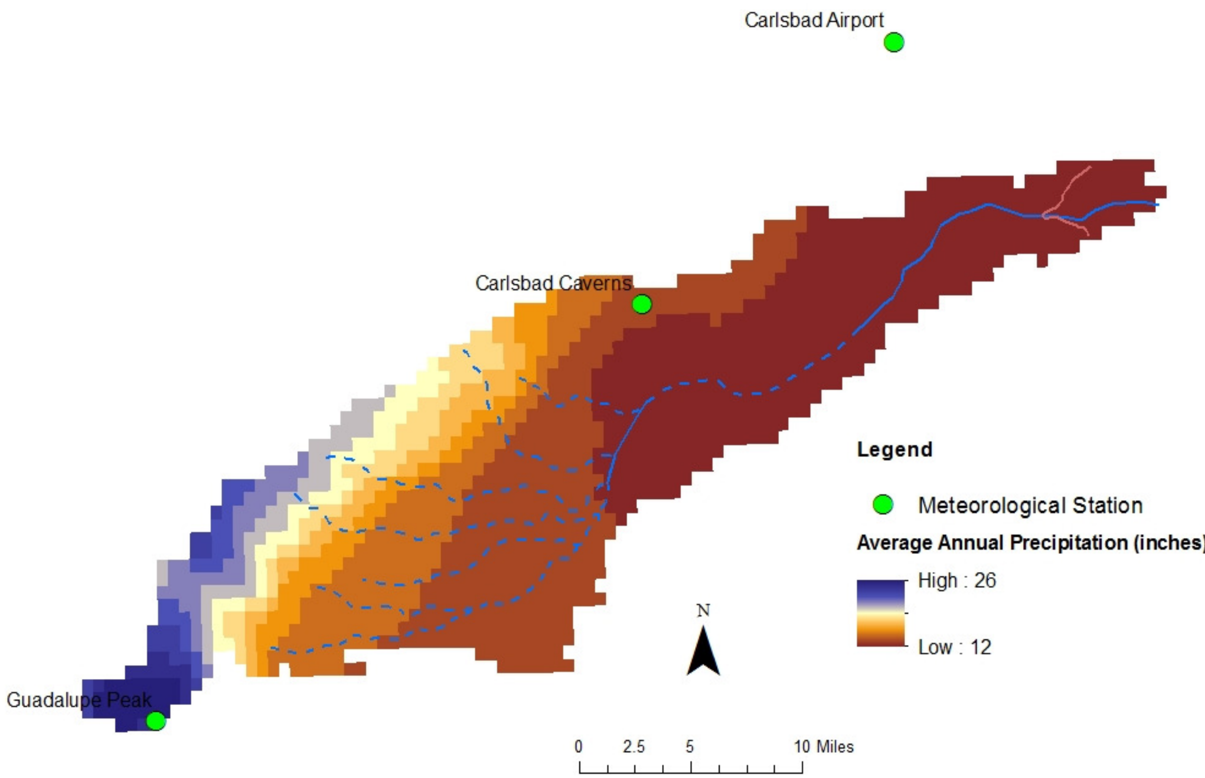
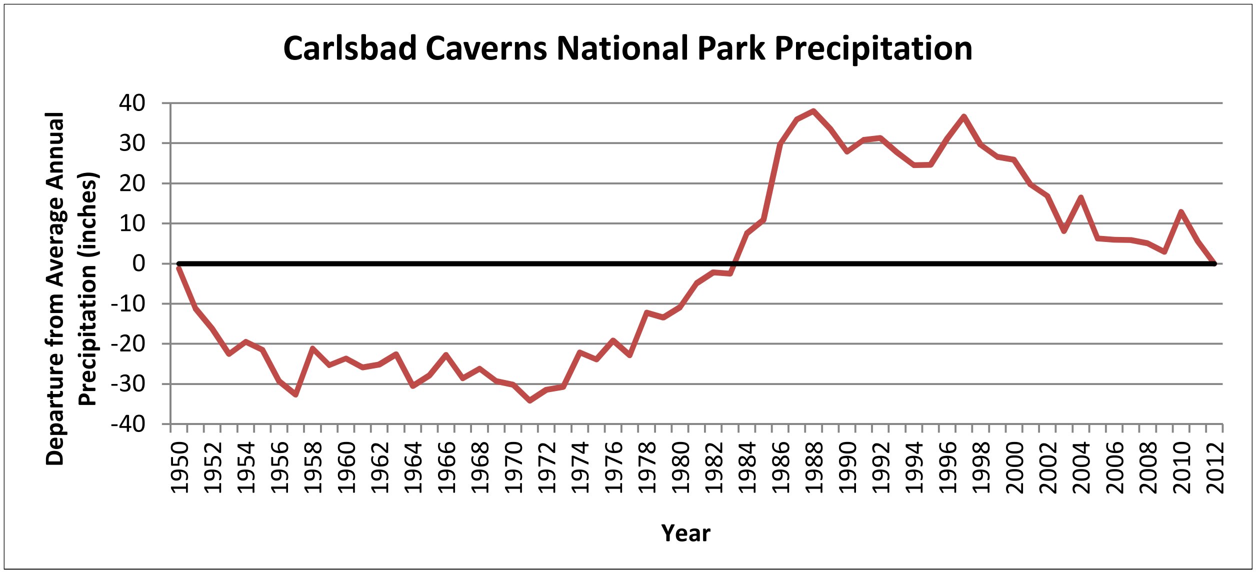


**Figure 41: Mean Annual Precipitation from 1981 to 2010 and Locations of the Three Meteorological Stations**




A cumulative rainfall departure (CRD) analysis can be a useful tool for establishing trends in precipitation and could be used as a tool to help inform the availability of surface water and groundwater resources (when compared to streamflow or water table elevations). The general idea is that with above average precipitation, surface and/or groundwater levels are also likely to increase depending on whether the system is dominated by subsurface processes. One of the other main reasons to conduct a CRD analysis is to identify a base hydrologic period, which is representative of mean precipitation. To construct a CRD, the average annual rainfall is subtracted from the precipitation average across all years, or the departure. The previous year's difference is then added to the value of each subsequent year. Because the Carlsbad Caverns weather station contained the most complete dataset from 1950 to 2012, it was the best candidate of the three stations to conduct a cumulative departure analysis (Figure 42). While precipitation records for the water year (October 1-September 30) are generally used in CRD analyses that are dominated by winter accumulation, the group used calendar year precipitation totals since the basin receives the majority of precipitation in the summer and fall monsoonal events. The data presented in the CRD indicate that generally speaking the period from 1971 to 1988 experienced above average annual precipitation, and a general decline has occurred since about 1997. Also, because the data does not encompass a wet-wet or dry-dry cycle, we cannot establish a base period for precipitation within the basin.

**Figure 42: Cumulative Rainfall Departure at Carlsbad Caverns, 1950-2012**




Precipitation patterns in the basin pose a challenge for management as water must be conserved throughout winter and spring until the late summer monsoon rainfall occurs over the region in punctuated events. Late summer months are wet and 90 percent of average annual rainfall occurs from July through October (Davey, Redmond and Simeral 2007). Over the available periods of record for each NOAA meteorological station, mean precipitation ranged from 4.7 inches to 11.3 inches throughout the summer months of June through August (Figure 43), and from 1.9 to 4.0 inches during July over the respective periods of record (National Oceanic and Atmospheric Administration 2014). Estimated PRISM data across the Black River Basin aligns with NOAA values and suggests a mean total July precipitation of approximately 1.8 to 4.2 inches (Figure 44).

**Figure 43: Mean Seasonal Precipitation**

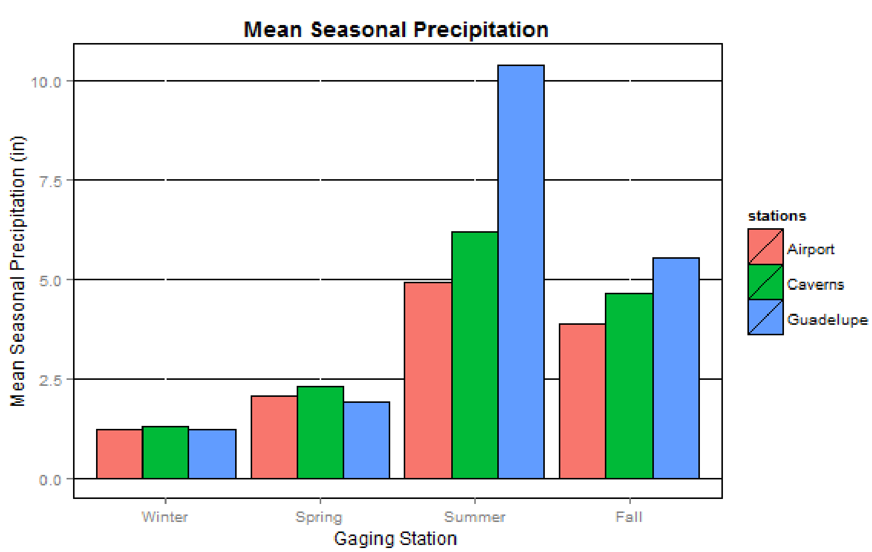
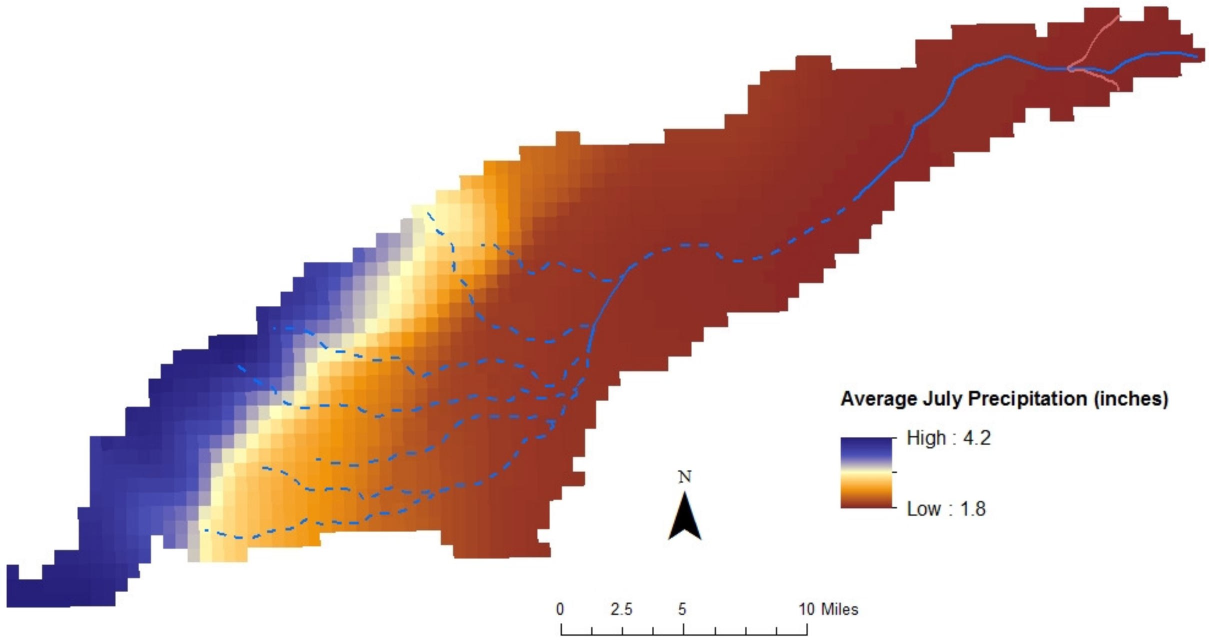


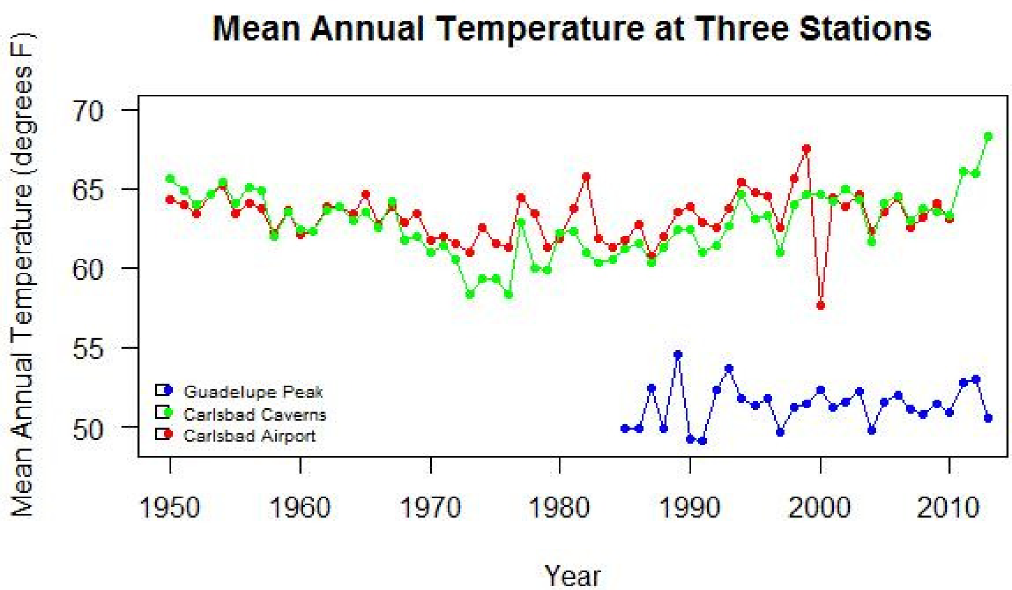
Figure 44: Average July Precipitation from 1981- 2010



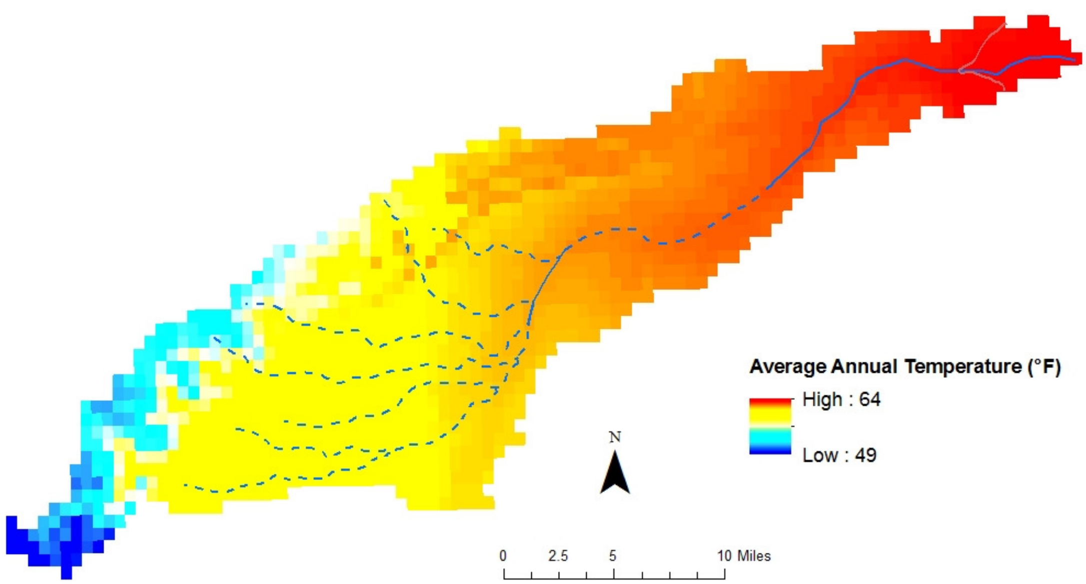

### *Temperature*

The arid climate in the Black River Basin contributes to high rates of evaporation from surface water and soil, and evapotranspiration from vegetation, all of which significantly affect local water availability. The mean annual temperature at all stations over their period of record ranged from 49.1 degrees Fahrenheit (1991 at Guadalupe Peak) to 68.3 degrees (2013 at Carlsbad Caverns) (Figure 45) (NOAA, 2014). However, these numbers likely contain errors due to multiple unreported monthly mean temperatures. PRISM data is used to compare temperature values and suggests basin temperatures within the range of 49 to 64 degrees based upon the 30-year normals (Figure 46).

### Figure 45: Mean Annual Temperatures from 1950 to 2010

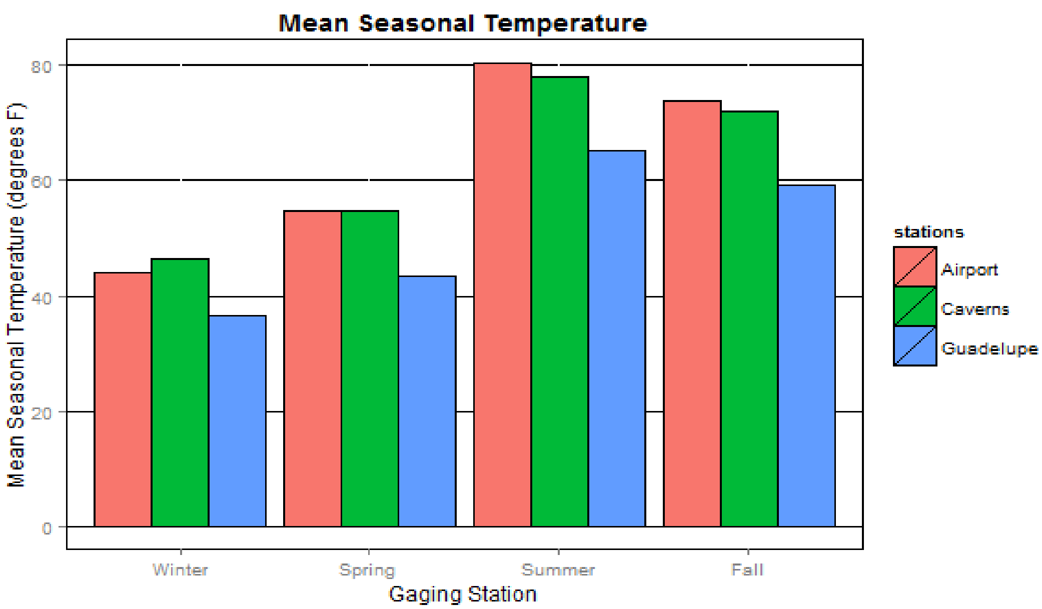



### Figure 46: Mean Annual Temperatures from 1981 to 2010



High summer temperatures coupled with summer storms increase evapotranspiration rates and intensify water loss from the system during the time when the majority of precipitation is received in the basin. Temperatures in the basin are highest in summer and fall; Figure 47 shows the variations of mean seasonal temperatures at all three stations. The maximum monthly average temperature recorded from 1950 to 2013 was 88.2 degrees for July of 1965 at the airport. The minimum monthly average temperature reported from 1950 to 2013 was 31.2 degrees for January of 1992 at Guadalupe Peak. The unique combination of dry, cold winters and hot, wet summers pose a challenge for sustaining year-round water supplies.

**Figure 47: Mean Seasonal Temperatures from 1950-2010 (Airport), 1985-2013 (Guadalupe), and 1950-2013 (Carlsbad Caverns)**




## Future Conditions

### *Literature*

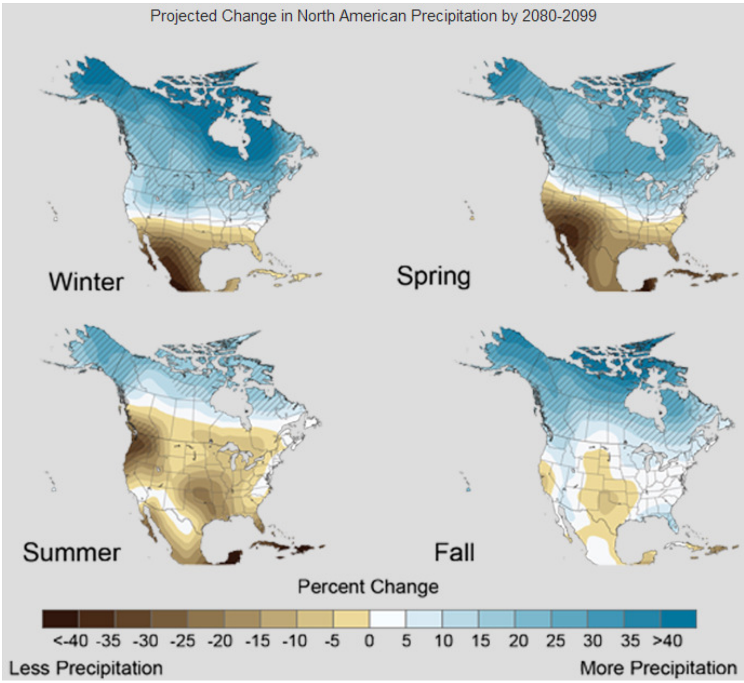
Many studies exist on highlighting past trends associated with climate change in the southwestern states but research specifically on New Mexico is limited. A report for the Colorado Water Conservation Board found that from 1977 to 2006 temperatures in Colorado increased two degrees (Colorado Water Conservation Board 2008). Relative to a 1950 to 1999 baseline, Colorado temperatures are likely to warm 2.5 degrees by 2025 and 4 degrees by 2050 (Colorado Water Conservation Board 2008). More extreme warm temperatures and less extreme cold temperatures are predicted in both summer and winter. The findings suggested that no long-term precipitation trends were detected and that variability is high, however the study proposed that more precipitation will fall as rain rather than snow. Although snowfall does not regularly take place in the Black River Basin the temperature trends may be applicable.

Another focused study was conducted by the U.S. Global Change Research Program (USGCRP) in 2009. Lower and higher emission scenarios predict a four to ten degree F increase in temperature by 2100 in the Southwest region of the United States. In terms of precipitation seasonality is important: winter and spring are predicted to be much drier and summer and fall are predicted to be slightly drier with smaller decreases in precipitation (U.S. Global Change Research Program 2009). The main effect of climate change on the southwest region is expected to be a northern extension of the dry belt, decreases in overall precipitation, and an increase in the amount of precipitation falling during the heaviest downpours (U.S. Global Change Research Program 2009).

### *Precipitation*

Spatial data from the USGCRP depicting nation-wide precipitation projections was used to establish a range of low change and high change scenarios for the Black River Basin. This data was the most specific source found for the area and includes uncertainty because of the nature of climate projection models and the spatially represented nature of the data (Figure 48). The USGCRP report shows seasonal precipitation projections by the year 2099 across the nation under a high emission scenario. An average annual precipitation change for a high emission scenario was achieved by estimating the Black River Basin's seasonal percent change. Although the low emission scenario data was not provided in the report, a comparison between springtime precipitation changes was depicted in the Southwest chapter of the report (Figure 49). Finding the ratio between the seasons under the high emission scenario and applying those percentages to the given springtime projection for the low emission scenario allowed an estimation to be made in regards to missing seasonal projections. Finally, the average annual precipitation change for the low emission scenario was found. Table 6 shows the final precipitation estimates for 2100.

### Figure 48: Projected Changes in North American Precipitation by 2099




### Figure 49: Southwestern Precipitation projections by 2099

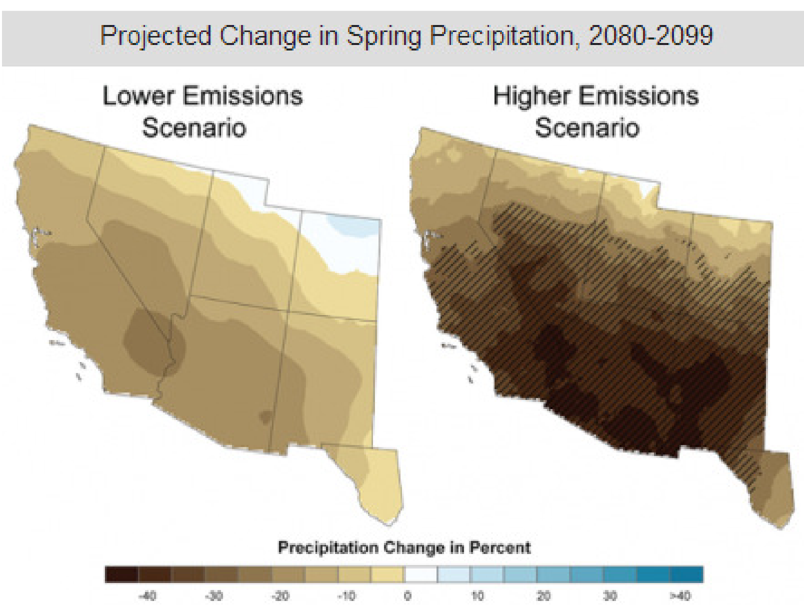


**Table 6: Calculated Projected Seasonal and Average Annual Precipitation Changes for the Black River Basin**

| **Season** | Low emission scenario | High emission scenario |
|---|---|---|
| Winter | -3.5 % | -17.5 % |
| Spring | -5 % | -25 % |
| Summer | -0.5 % | -2.5 % |
| Fall | -0.5 % | -2.5 % |
| **Average** | **-2.4** | **-11.9** |

Although researched literature did not imply that precipitation would increase as a result of climate change, the uncertainty of climate models with regards to precipitation allowed for a test scenario of a ten percent increase in precipitation to also be considered. This scenario, as well as the low emission and high emission precipitation projections, was applied linearly from 2010 to 2100.

### *Temperature*

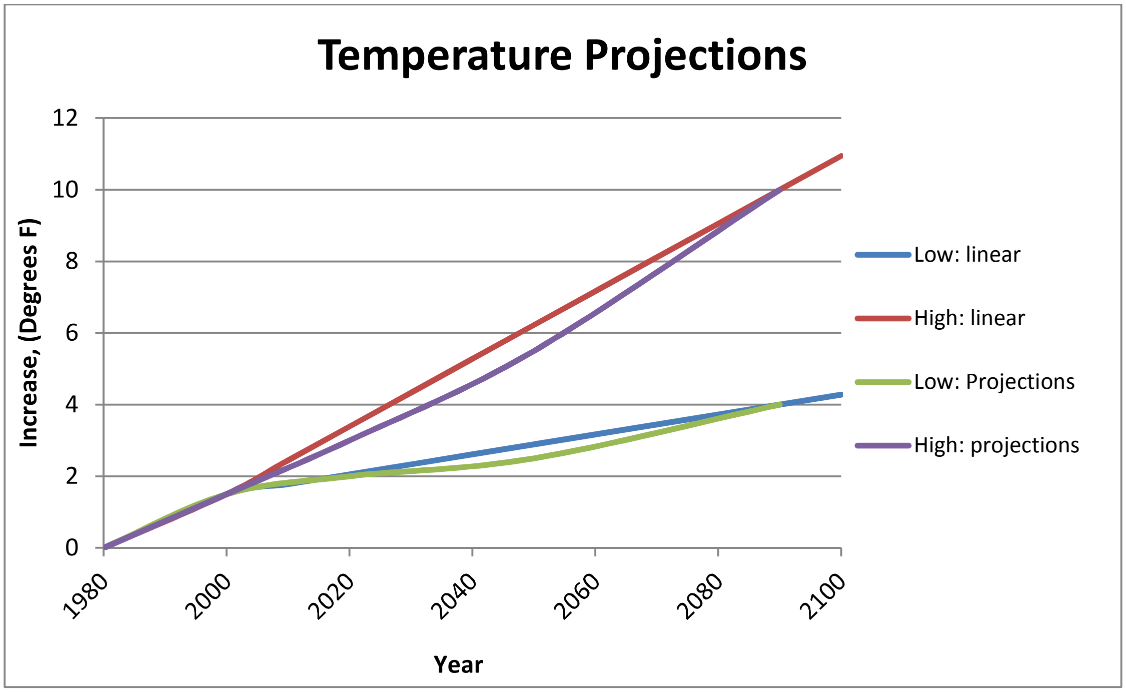
The USGCRP report projects temperature changes under a high emission scenario and a low emission scenario across the Southwest. The study uses a 1960 to 1979 baseline and denotes an observed 1.5 degree Fahrenheit increase by the year 2000. Projections for 2020, 2050, and 2090 are given for both scenarios and range from four to ten degrees above the baseline temperature by 2090. Table 7 displays the projected temperature change for each emission scenario. Although a range was provided for each scenario, the lowest value for the low emission scenario was chosen. Similarly, the highest value for the high emission scenario was also chosen to accurately represent the full range of possibilities.

**Table 7: Temperature Projections under High and Low Emission Scenarios**

| **Source: UGCRP 2009 Report** | | | |
|---|---|---|---|
| *Temperature (degrees F)* | | | |
| Year | ΔT observed | ΔT projected (low emission scenario) | ΔT projected (high emission scenario) |
| 1960-1979 | 0 | 0 | 0 |
| 2000 | 1.5 | 1.5 | 1.5 |
| 2020 | | 2 | 3 |
| 2050 | | 2.5 | 5.5 |
| 2090 | | 4 | 10 |

The temperature projections of the USGCRP study are not linear, but transforming both scenarios into a linear trend allowed the projections to be carried out to 2100. A simple equation was fit to each scenario based off of the given projections to create the linear trends shown in Figure 50. Linear trends allowed for greater simplicity in applying changes to Black River climate data. Final temperature estimates incorporated a low increase of four degrees F and a high increase of 11 degrees by 2100.

Figure 50: Projected Temperature Trends




Expanding upon the USGCRP baseline of 1960 to 1979, a baseline of 1955 to 1985 was applied to the Black River Basin for both the Carlsbad Airport and Carlsbad Caverns temperature data. The Guadalupe Peak station began measuring climate data in 1985, and therefore a baseline of 1985 to 2000 was applied to that station, which contains some error as this time frame may already contain some temperature increases related to the climate change projections of the USGCRP. For all stations incremental temperature increases from 2010 to 2100 were added to the monthly averages of temperature developed in the baseline.

## Impacts on Future Water Supply

Changes in rainfall intensity and increasing temperatures may alter basin water supply. Prolonged droughts and high-intensity storms during the wet season will shift the timing of water availability because precipitation will be concentrated in a smaller time frame. Temperature changes, especially in higher elevations, will cause shifts in the vegetative cover, which will affect runoff rates and evapotranspiration. Greater risks of fire will also be seen in the forested areas upstream as well as the grasslands, further contributing to surface runoff.

### *Rainfall Intensity*

There is a lack of consensus on the impacts of climate change on summer monsoons. Generally, in the Southwest rainfall frequency is expected to decrease but storm events, including monsoons, may increase in magnitude (U.S. Global Change Research Program 2009).

Changes in rainfall intensity and seasonality of precipitation will affect water management decisions as well as mussel habitat. Increases of storm intensity may require efficient storage of water that can be released throughout the dry season. Intense rainstorms will increase the likelihood of floods, which could scour out Texas hornshell habitat in the Black River. Large floods have the capacity to disrupt and transform protective structures, such as undercut banks, boulders, or crevices, of where mussels find refuge and utilize accumulated sediment for anchoring. In 2000, flood events dislodged a mussel sub-population of the Black River and since 2002 mussel in that reach have not been recovered (U.S. Fish and Wildlife Service 2013). Additionally, flooding may carry sediment into the channel, which could suffocate mussel populations. The likelihood of more intense monsoonal seasons in the future may impact other currently stable populations of the mussel along the Black River.

### *Vegetation Changes*

High temperatures and drought may shift vegetation in both the mountainous region of the watershed and the valley floor. As the higher elevations become slightly warmer, migration of heat-tolerant vegetation may occur and the mountainous tree cover may change. In the Four Corners region of the Southwest the dominant overstory woody plants (piñon pine trees) were found to die off after 15 months of depleted soil water content as a result of drought (David B. Breshears 2005). Vegetation that can withstand higher temperatures is able to move in where die-offs occur. On the desert valley, a similar trend will likely take place as vegetation found south of the Black River Basin will move north to areas with cooler temperatures. A comparable example is taking place in the Sonoran Desert where heat-tolerant red brome and buffle grasses from Africa and the Mediterranean are able to out-competing cacti (U.S. Global Change Research Program 2009).

Vegetation shifts may affect the water supply through alterations in surface runoff, evapotranspiration, interception of precipitation and unsaturated groundwater flow. Differences in the root depths of new vegetation may directly influence streamflow levels and the level of groundwater in the alluvial aquifer. Although conducting a thorough analysis of the effects of vegetation changes on the Black River Basin's water budget was outside the scope of this project it is important to note all aspects of climate change on long-term water availability.

### *Evapotranspiration*

Potential evapotranspiration (PET) represents the theoretical amount of water that will evaporate from the soil surface or transpire from plant stomata given full water availability. The Thornthwaite equation is a commonly used formula for estimating PET values and takes into account temperature, daylight hours based on latitude and number of days per month (Equation 1). Using past climate data from the Carlsbad Caverns meteorological station, annual estimates of PET (mm/month) can be derived for the watershed. A PET range of 800 to 1,100 mm per year was found from 1950 to 2011. Because PET is much higher than the average annual precipitation of 361 mm, the region is labeled as a "water limited" region.

$$\boldsymbol{PET = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10Ta}{I}\right)^{\alpha}} \qquad (1)$$

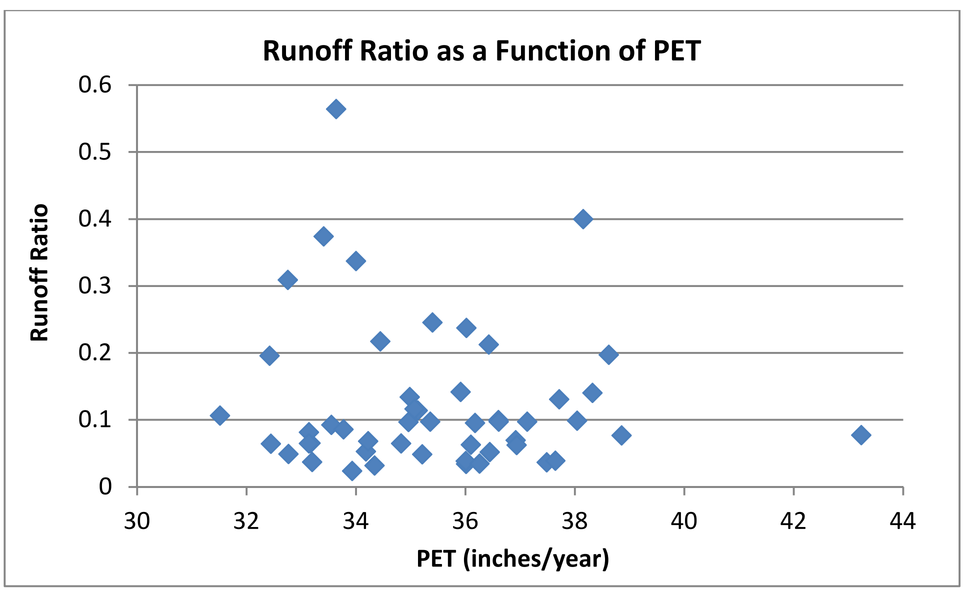
Where,

L= Average day length (hours) of month
N= Number of days in month
T$a$= Average daily temperature (Celsius)
α= $(6.75 * 10^{-7})I^3 - (7.71 * 10^{-5})I^2 + (1.792 * 10^{-2})I + 0.49239$
I= $\sum_{i=1}^{12} (\frac{Tai}{5})^{1.514}$ , heat index where i= January, February, etc.

Comparing the ratio of annual streamflow to precipitation, or the runoff ratio, to PET may show the effects of higher temperatures on actual evapotranspiration (AET) and therefore streamflow. The runoff ratio is calculated by converting USGS gaged streamflow data from cfs to cubic feet per month and dividing by precipitation data that has been converted to feet per month and multiplied by the area of the watershed.

The relationship between the runoff ratio and PET does not depict the expected decline of streamflow as temperatures increase. However, this analysis may be ineffective due to significant surface water diversions that occur upstream from the gaged streamflow data used in the calculations. Figure 51 presents the results from this exercise. As PET increases, correlated declines in the runoff ratio are not seen. Upstream water diversions from the river affect this relationship; in drier years more water may be diverted for agricultural uses. Additionally, this reference may require a longer time frame of data reflecting much higher increases in temperature, or in fact the system may already be sufficiently stressed by water availability that AET will not increase with increasing temperatures.

**Figure 51: Annual PET Plotted with Calculated Runoff Ratio**




Although higher temperatures may not affect streamflow directly through vegetative transpiration, AET rates may change as vegetation cover changes, plants adapt to increased temperatures, or disturbance regimes, such as fire, alters runoff. Further analysis of actual net evapotranspiration would relay a relationship between temperature and AET and can be calculated using the Penman-Monteith equation.

It is important to note that direct evaporation from surface water on the Black River will increase from higher temperatures.

### *Disturbance Regimes*

Disturbance regimes, such as fires and new vegetation diseases, may play a large role in altering the water fluxes as climate change occurs. Partly due to changes in vegetation, fire may pose a risk as temperatures increase. The migration of drought-tolerant grasses can provide fuel for fires that may have otherwise been restricted due to low fuel availability (U.S. Global Change Research Program 2009). A longer fire season also will develop as hot temperatures begin earlier in summer and last longer through autumn. Drier conditions in the mountains will increase fire risk, and the risk can be exacerbated by bark beetle infestations (National Wildlife Federation 2008). Finally, an increase in lightning-induced fires may develop as lightning in the Southwest is estimated to increase 12 to 30 percent by mid-century (National Wildlife Federation 2008). The aftermath of fires will result in an increase of surface runoff as the majority of flashy, summer monsoonal precipitation will run over the ground surface without being captured by vegetation and loss to evapotranspiration. New diseases may also likely arise as the vegetation cover shifts; as an example, bark beetle infestation of pine trees is currently altering southwestern forests.

## Conclusion

Water scarcity issues of the arid Black River Basin will be amplified as climate change affects the intensity of rainfall, vegetative cover, actual evapotranspiration, surface water evaporation and occurrence of fire. Monsoonal precipitation is likely to occur with greater intensity and prolonged droughts will reduce available annual water supply. Heat-tolerant vegetation could migrate to historically cooler areas and potentially alter evapotranspiration rates. Although there is uncertainty about changes in actual evapotranspiration, increases in temperature will influence surface water evaporation. Finally, changes in vegetation, frequency of lightning and longer fire seasons will increase the frequency of fire occurrences that result in the alteration of hydrologic processes.

# MODELING THE BASIN

## Introduction

A central component of this project was to understand the overall water budget within the Black River Basin and to evaluate how climate change and increased use could impact streamflow within the basin. The variability in water supply that could result from these scenarios are especially important for the management of critical habitat for the Texas hornshell which is being considered for Endangered Species Act listing by 2015. To investigate the components of the water budget and how streamflow could be affected in the important habitat reaches of the Black River, it was decided that a process-based, deterministic model would be useful to help confront the complexity of the physical environment being studied.

Although the group explored the potential of several models to characterize the basin, the Water Evaluation and Planning (WEAP) model was eventually selected. Developed by the Stockholm Environment Institute, the WEAP model serves as an integrated water resource planning and decision support tool designed to aid stakeholders in developing a quantitative understanding of the basin in study and assessing the potential efficacy of an assortment of user-defined resource management scenarios. It has been utilized by a variety of organizations such as the US Environmental Protection Agency, California Department of Water Resources, and the US Army Corps of Engineers to assess water use, model possible changes to water availability, and evaluate the effectiveness of an array of management solutions (SEI 2013). The group selected this model because of its ability to combine the physical parameters and processes of the watershed, especially groundwater-surface water interactions, with anthropogenic stressors such as surface water diversions and groundwater extraction, while also allowing for the analysis of projected scenarios such as temperature increases and shifts in water use within the basin. With the choice to use a software package to aid in the group's research, realistic funding constraints also had to be considered, and the WEAP model provided an affordable instrument with the desired scenario analysis capacity.

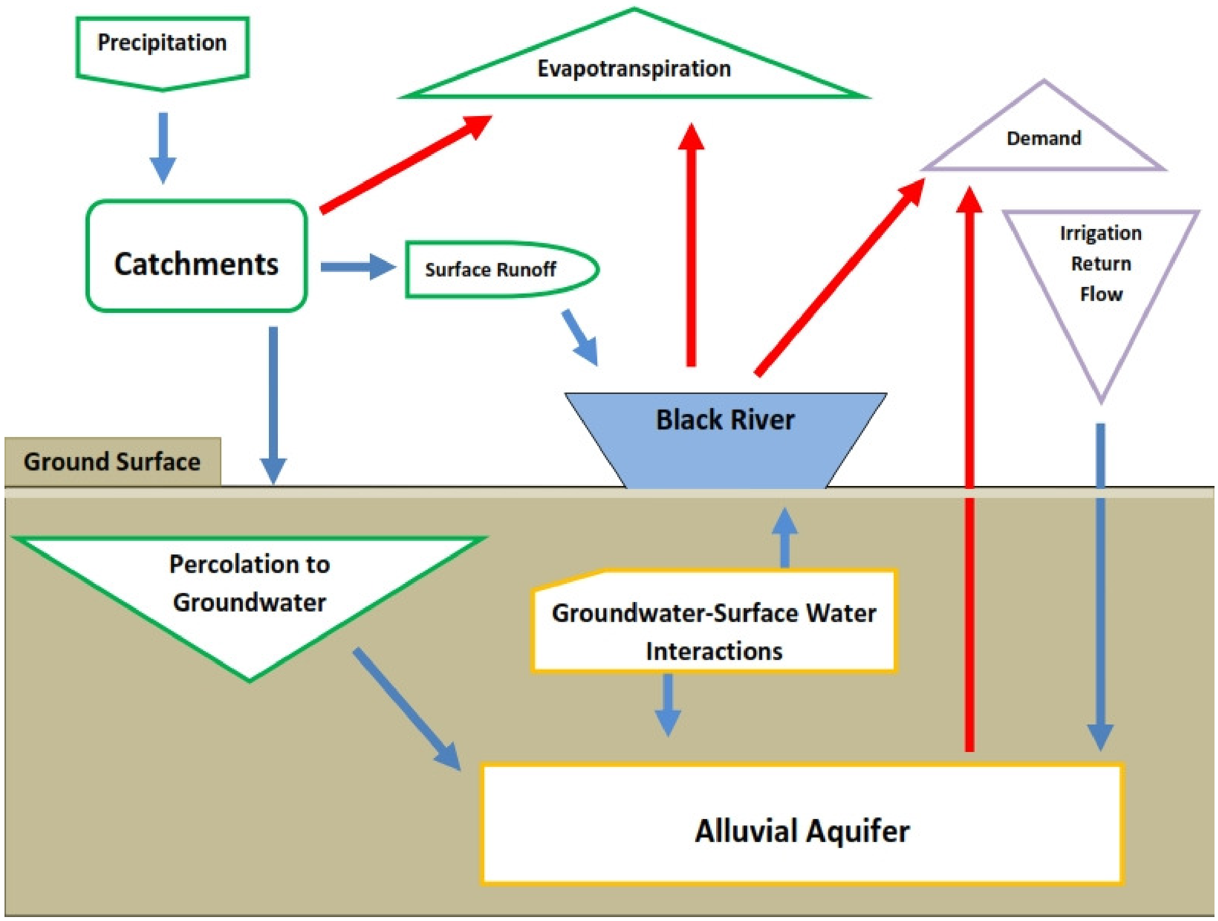
The WEAP model has been widely used to predict water supply scenarios, and is often coupled with a climate change analysis, and a variety of policy options aimed at increasing water reliability. For example, a study by Purkey et al. (2008) in the Sacramento River Valley, California used the WEAP model to combine downscaled general circulation models (GCM) with adaptation strategies to determine the impacts on water availability for agriculture uses and other important sectors. Another application of WEAP closer to the Black River study area was conducted in the Rio Grande Basin by the Center for Research in Water Resources (CRWR) at the University of Austin at Texas. This assessment established a WEAP model for the Rio Grande basin while also examining an array of water management opportunities with the engineered water supply in both the United States and Mexico (Center for Research in Water Resource 2006).

## Methodology

### *Model Development*

The WEAP model operates as a basic, precipitation-driven water accounting system that considers physical characteristic inputs, such as soil properties, climate, and various demand-side outputs such as groundwater pumping and surface diversions. Figure 52 shows a conceptual schematic of the major interactions and linkages between components within the model, where the blue and red arrows represent system inputs and outputs, respectively.

Figure 52: WEAP Conceptual Water Budget Diagram




WEAP is a process-based, lumped-variable catchment model that uses measured or estimated physical parameter inputs to predict the partitioning of water between system compartments and the resulting surface water flows at a given point along a watercourse. The model simulates the relevant interactions and processes within the water balance by transferring the parameter inputs into equations that capture the magnitude of the processes and produce the modeled output hydrograph. Because the model's water budget analysis is catchment-based, each of the parameter values were averaged and assigned to each of the nine identified catchments within the watershed, though in a few cases the same parameter value was used for multiple catchments.

Given the paucity of data from previous studies within the basin, the majority of parameters were first or second order approximations from available data, and therefore assumptions were utilized in their estimation. Available information for the parameter inputs came from the synthesis of data from numerous sources including the: NMISC, NMOSE, United States Geological Survey (USGS), Natural Resources Conservation Service (NRCS), New Mexico Department of Game and Fish (NMDGF), and National Park Service (NPS). In addition to consultations with state agencies and professionals in the field who provided a critical understanding of regional characteristics, background resources such as Hale (1955), Bjorklund (1959), the NMOSE's Carlsbad Area Groundwater Flow Model (2002), and Bowen's 1998 research on the 'Hydrogeology of Rattlesnake Springs' served as a basis for comparing the estimated parameters against field observed or estimated parameter values for the basin.

For the purposes of this analysis, a monthly model time step was chosen. While the resolution of the model may not capture processes such as rapid, localized monsoonal precipitation and evapotranspiration, the dataset required for the analysis and parameterization of a monthly model was much more manageable. Table 8 indicates a list of parameter inputs required for development of the WEAP model.

**Table 8: Parameter Inputs Required for WEAP Development**

**Catchments**

| LAND USE | |
|---|---|
| **Parameter** | **Description** |
| Area | Land surface area within catchment |
| Crop Coefficient ($K_C$) | Consumptive use metric relative to reference crop. Controls evapotranspiration. |
| Soil Water Capacity | Effective water holding capacity of the upper soil layer |
| Runoff Resistance Factor | Controls surface runoff responses. Runoff would increase with lower resistance factors |
| Root Zone Conductivity | Rate at which upper soil layer conducts water to lower soil layer and groundwater |
| Preferred Flow Direction | Apportions subsurface flow between interflow and percolation to lower soil layer and groundwater (1= 100% horizontal, 0= 100% vertical) |
| Initial Z1 | Relative soil moisture at start of simulation |
| Demand | Anthropogenic water demand from surface diversions and groundwater abstraction |
| Return Flow | Percentage of water demand returned to system through irrigation use and return flows |
| **CLIMATE** | |
| **Parameter** | **Description** |
| Precipitation | Total monthly rainfall |
| Temperature | Average monthly temperature |
| Humidity | Average relative humidity |
| Wind | Average wind speed |
| Cloudiness Fraction | Fraction of day without cloud cover (0-1, 1= no clouds) |
| Latitude | Midpoint latitude of catchment |

**Groundwater Nodes**

| Parameter | Description |
|---|---|
| Storage Capacity | Maximum theoretical capacity of the aquifer |
| Initial Storage | Amount of water stored in the aquifer at the beginning of the simulation |
| | and |
| Storage at River Level | Groundwater storage volume at which top of groundwater is level with river and where the river is neither gaining nor losing. Used to calculate head difference |
| Hydraulic Conductivity | Rate at which aquifer transmits water through its pore space |
| Specific Yield | Fractional volume of aquifer that would drain from pore space under gravity |
| Horizontal Distance | Distance from farthest edge of aquifer to river |
| Wetted Depth | Depth of river. Used to calculate the seepage through the river channel bottom |
| Reach length | Length of river reach in contact with the aquifer |
| | or |
| Natural Recharge | Estimated monthly inflow to groundwater |

**Watershed delineation**

The watershed boundary of the Black River was delineated from a 30-meter National Elevation Dataset digital elevation model (DEM) layer.

**Catchments**

The nine catchments within the Black River Basin were delineated using the USGS's 12-digit Hydrologic Unit Code (HUC 12) boundaries.

**Demand**

Demand inputs were estimated from a review of the existing groundwater and surface water diversion rights within the basin, and were spatially connected to each of the catchments. For this analysis, it was assumed that the entirety of the allocated water right is being utilized and exercised. (See analysis section on water use for more information).

**Supply**

Additional supply to the Black River comes from CID-imported water that is diverted from the Pecos River. This water flows into the system through the Black River Supply Ditch. The amount of water flowing through the ditch is monitored by the Pecos Valley Surface Water District (PVSWD), which provided metering data of the supply ditch inflows to the river. For the purposes of the model, it is assumed that all water being delivered through the CID system is consumed by irrigation uses within the basin, less return flow.

**Land Use**

*Crop coefficient*:

Crop coefficients applied in a previous WEAP study of the Rio Conchos, a tributary to the Rio Grande, were used to estimate this consumptive use metric within the Black River given the similarities in vegetation types and climate and the difficulty in assigning this metric to the predominantly native, desert-scrub vegetation.

*Soil water capacity*:

The available soil water capacity was determined from the NRCS's gSSURGO data (Gridded Soil Survey Geographic Database) for each of the represented soil types within each catchment and was reported as the average root zone available water storage capacity.

*Root zone conductivity:*

The root zone conductivities were estimated from the weighted areal coverage of alluvium and other formations within each of the catchments and derived from surficial lithology datasets from the New Mexico Bureau of Geology and Mineral Resources and the USGS.

*Preferred flow direction*:

The preferred flow direction parameter (between 0 and 1, with 0 being vertical and 1 horizontal) is a rough estimation of anisotropy amongst the geologic formations. Within the areas of little relief, the flow direction is assumed to be mainly in the horizontal direction along the bedding planes and fabric of the sedimentary material, leading to a significantly greater vertical component in the Guadalupe Mountains and canyon washes given the existence of folding, fracturing, and vertical dissolution channel formation in the karstic limestone.

*Runoff resistance factor:*

A proxy for this parameter was developed using scaled values of slope and vegetation cover percentage. The information on slope and vegetation cover percentages within each of the catchments came from the LANDFIRE dataset, and percentages were weighted by areal coverage within each of the catchments. It was assumed that areas with greater cover provided more resistance (from interception and dispersion), and that areas with lower slopes provided more resistance. For slope, it was assumed that with any value of 45 degrees or higher (100 percent), all water would runoff and there would be no functional resistance.

*Return flow*:

From NMOSE consumptive use calculations, return flow percentage from irrigation within the basin was assumed to be approximately 30 percent.

*Initial Z1*:

The initial soil saturation percentage was estimated at 10 percent given the simulation began in January, which on average is the month with the lowest rainfall amounts.  While this percentage was somewhat arbitrary, it was determined that the initial moisture only affects the first few months of the modeled output hydrograph.

**Climate**

*Latitude*:

The midpoint latitude for each of the catchments was identified in GIS.

*Temperature, Relative Humidity, Wind, and Precipitation:*

Data from 2000 to 2010 were obtained from the three nearest meteorological observation stations within and near the basin: 1) Guadalupe Peak, 2) Carlsbad Caverns, and 3) Carlsbad Municipal Airport. Input values were then assigned to each of the nine catchments according to the nearest meteorological station.

*Cloudiness fraction:*

The cloudiness fraction for all nine of the catchments was determined from hourly measurements taken at the Carlsbad Municipal Airport over the 2000 to 2010 time period. This was the only station out of the three that reported sky cover. The measurements were reported as the portion of total celestial dome covered by clouds, with a range of zero to four (with four being full coverage). Since WEAP required the parameter value to be a measure of sky cover with no clouds between zero and one, the following values were assigned to the reported measurements, and subtracted from one (Table 9).

**Table 9: Assigned Values for Cloudiness Fraction**

| Reported Sky Cover Value | Description | Coverage | Assigned Value |
|---|---|---|---|
| 0 | Clear | 0 | 0.00 |
| 1 | Few | 2/8 or less (exclusive of 0) | 0.125 |
| 2 | Scattered | 3/8-4/8 | 0.4375 |
| 3 | Broken | 5/8-7/8 | 0.75 |
| 4 | Overcast | 8/8 | 1.00 |

**Groundwater Nodes**

*Initial storage*:

The initial storage of the alluvial aquifer was calculated from estimates of the effective porosity and areal extent of the aquifer, as well as the average elevation of the lower confining layer/aquiclude (e.g. the Castile formation) and the average elevation of the water table within each catchment. The lower confining layer was determined from well drilling logs (where it was explicitly stated that a layer of gypsum or anhydrite was encountered) and the water table elevation came from depth-to-water measurements at well locations. In a couple of the catchments, for better coverage identifying the lower confining layer, if the drilling log did not explicitly note that gypsum or anhydrite was encountered, then 20 feet was added to the maximum drilling depth.

*Storage capacity*:

The maximum aquifer storage capacity for each of the catchments was calculated using the elevation of the lower confining layer and the average land surface elevation at each of the wells that had depth-to-water measurements, in addition to the averaged effective porosity and extent of the alluvial aquifer within each catchment.

*Hydraulic conductivity*:

The average hydraulic conductivity for each catchment was estimated from literature values for the rock types presented in the surficial lithology map. It was assumed that materials that exist at the surface also occur to depth at the base of the alluvial aquifer.

*Storage at river level*:

The storage capacity of the aquifer for each of the catchments was calculated from the average elevation of the lower confining layer and river channel (estimated at 15 feet below the land surface), and the averaged effective porosity and calculated surface area for the alluvial material within each catchment.

*Specific yield:*

Given that the aquifer in study is unconfined, the group used literature values of effective porosity as a measure of the specific yield.

*Horizontal distance*:

The horizontal distance was calculated as a straight-line distance from the farthest point of each catchment’s aquifer boundary to the river.

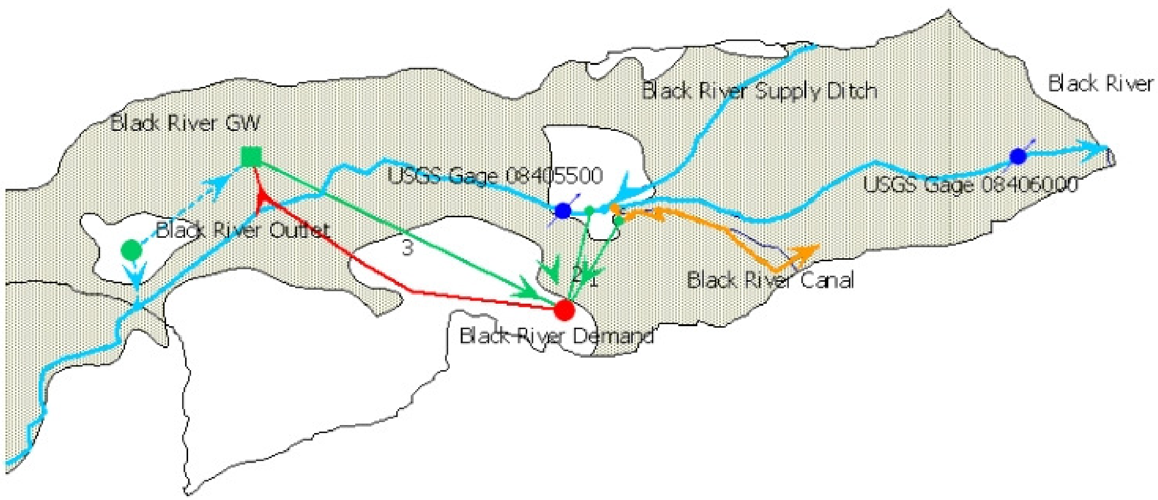
*Reach length:*

The reach length in contact with each catchment’s aquifer was roughly calculated using the distance measurement tool in GIS.

*Wetted depth*:

Because it was assumed that the average elevation of the river bottom was about 15 feet below the land surface elevation used in the aquifer storage calculations, a maximum theoretical wetted depth of 15 feet was also used.

**Figure 53: WEAP Model Schematic of a Catchment within the Black River Basin**




The last step in the model development process was to enter each of the parameters described above into the graphical user interface and to establish the link-node connections within each of the catchments that allow water to move between the various compartments of the system. The schematic in Figure 53 shows the user interface for one of the catchments within our study area, where the catchment and groundwater nodes are represented by the green circle and square, respectively, and the demand node is represented by the red circle. The green lines that lead to the demand node represent transmission links that carry water from the surface and groundwater nodes to the demand sites, while the red line represents a return flow link from the demand site to the groundwater aquifer. The other important linkages to mention are the dashed blue lines from the catchment node to the surface water and groundwater nodes, which represent the runoff and infiltration into each of the nodes, respectively.

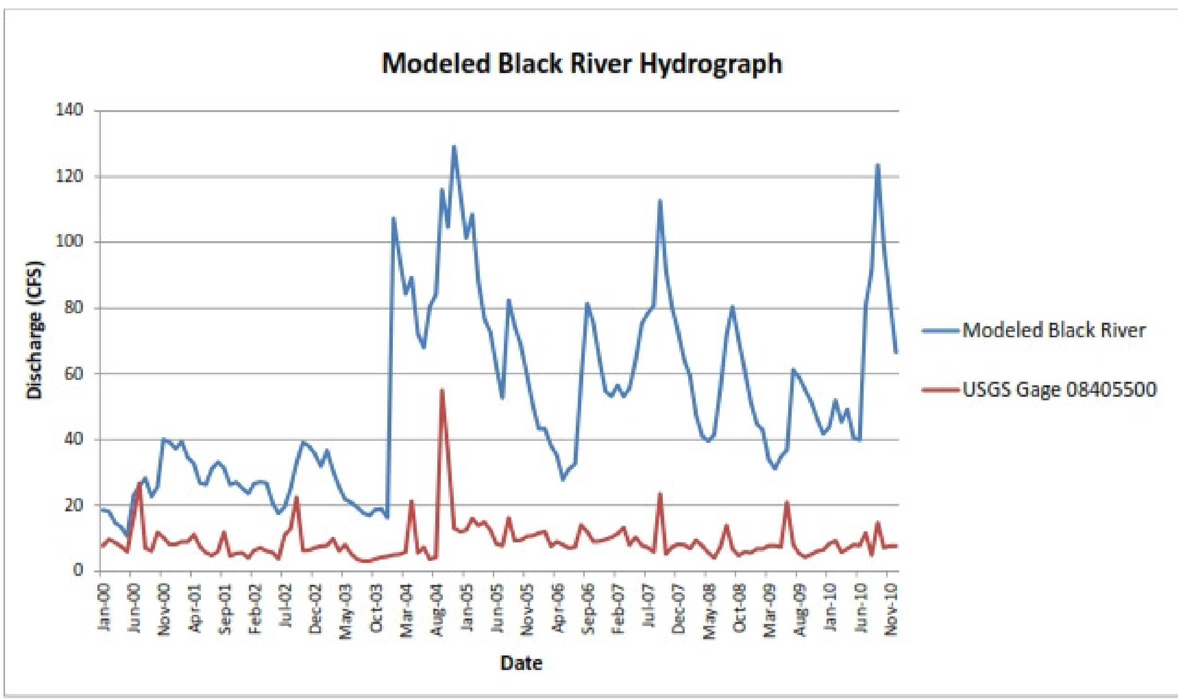
## *Calibration*

Once the WEAP model of the Black River Basin was parameterized and preliminary runs were implemented, the model required sensitivity analysis and calibration to promote the most accurate parameter inputs for the basin. The 10-year calibration period from January 1, 2000 to December 31, 2010 was used because it contained the most complete data records from: climate measured at the three representative weather stations, Rattlesnake and Blue Springs' discharge and diversion records, Black River Supply Ditch and Black River Canal measurements, and the USGS gage data from the river.

The modeled outputs of Black River streamflow were compared to and calibrated against USGS stream gages at Malaga, NM (Station 08406000), and just above the Black River Supply Ditch confluence with the river (Station 08405500). Measured inflows from the Black River Supply Ditch (which augments supply to the basin by diverting from the Pecos River) and diversions from the Black River Canal, both parts of the Carlsbad Irrigation District (CID) delivery system, also helped add to the accuracy of the supply and demand inputs. While the group hoped to use the modeled groundwater storage output to calibrate against available depth-to-water records collected within each of the catchments, limitations in the model prevented an accurate representation of this output, and therefore only the predicted streamflow was used to calibrate the model outputs to the two stream gages in the basin.

The calibration of the Black River WEAP model consisted of both individual and cumulative parameter sensitivity analysis and an analysis of their impact on the modeled output hydrograph by essentially conducting a trial-and-error type investigation. With each change in parameter input values, the group looked for changes in the timing and amplitude of minimum and peak flows in an attempt to best reflect the actual, gaged stream flow. While the group compared the model outputs to both stream gages on the river, it was decided to look specifically at the upstream gage since it is above the CID's Black River Supply Ditch and much of the demand and diversions within the basin. This stream gage is also located just downstream of the critical habitat reach of the Texas hornshell, which was valuable for investigating the scenario outputs as they related to one of the main motivations for the project. Figure 54 shows the initial model output hydrograph in relation to the actual flows at the upstream gaging station (USGS Station 08405500).

**Figure 54: Initial Model Hydrograph Using WEAP-Modeled Groundwater to Surface Water Interactions**

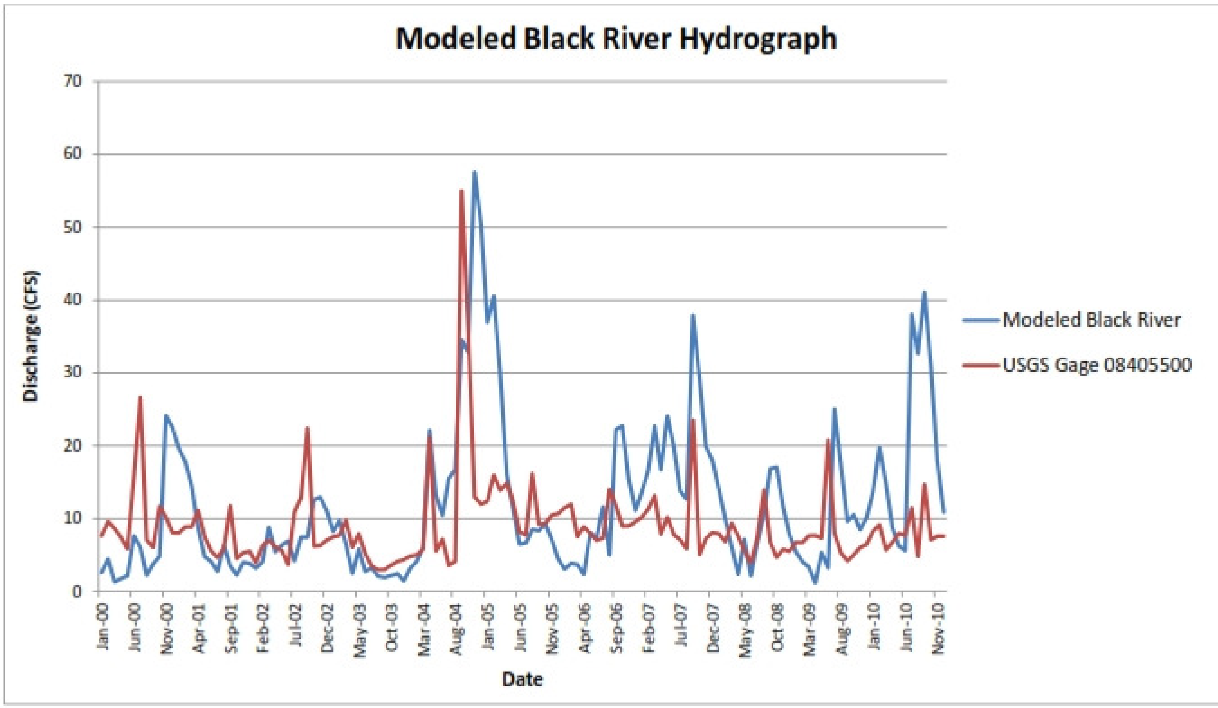



This hydrograph represents the group's first attempt to model the basin's streamflow. It is important to note that this output was derived through the WEAP model's estimate of the groundwater-surface water interactions and the partitioning of water between the two. The output shows that the model did a reasonable job estimating the timing of peak flow events; however, it did a relatively poor job at predicting the amplitude of the events especially within the latter years of the model run period. Given that, the group looked for parameter adjustments within the model that could be implemented to reduce overall streamflow, including: increasing the consumptive use of vegetation by increasing the crop coefficient ($K_C$), increasing the availability of water for evapotranspiration by decreasing the available soil water holding capacity and by adjusting root zone conductivity to allow water to remain in the upper soil layers longer, and by adjusting the parameters that controlled the flow of water between the river and the groundwater aquifer. While the ultimate model inputs encompassed a combination of all of these parameter adjustments, changing those that affect the groundwater-surface water interactions had the largest impact on the predicted streamflow. These parameters included the wetted depth, hydraulic conductivity, and most importantly, the initial storage of the aquifer in relation to the theoretical capacity of the aquifer at river level (dictating whether the stream reach is gaining or losing).

As a way to mitigate some of the difficulties faced with the groundwater-surface water interactions, the group chose to employ a different input method within the model. Instead of having WEAP estimate the recharge and flow between the major groundwater and surface compartments, recharge was estimated from literature values and entered directly into the model. Because the basin is located in an arid region, we suspected that the amount of water lost from the system through evapotranspiration would be relatively high. Research of similar systems in Arizona and the Sevilleta Long Term Ecological Research site in New Mexico estimated that evapotranspiration rates from Chihuahuan desert scrub communities could range from about 80-95% (Buoj 1964) (Cleverly 2006), although the higher estimates include riparian vegetation whose evapotranspiration rates are usually not water-limited. Given that range of estimates, the group decided to use an average evapotranspiration rate of 85%. To estimate recharge, the 85% evapotranspiration rate was applied to the monthly precipitation amounts from each of the meteorological stations.

Figure 55 shows the revised model calibration output hydrograph using this direct input method. The resulting model inputs captured the amplitude of flows much better. However, because the model is unable to represent subsurface flows between the catchments regardless of input method, significant uncertainty remains in terms of its ability to accurately capture the movement of water within the basin. That said, for the purposes of the scenario evaluation, this version of the WEAP model was used going forward.

**Figure 55: Revised Modeled Hydrograph Using Natural Recharge Estimates**




## Scenarios

Climate scenario model inputs for the Black River Basin were derived from projections made by the U.S. Global Change Research Program and covered a suite of possible changes including both small and moderate increases in temperature, slight increases in precipitation, and small and moderate decreases in precipitation. For an explanation of how the model scenario estimates were developed see the climate change projections discussed within the "Climate" section.

Based on analysis of past and current shifts in water use, especially to support regional oil and gas development, model scenarios to simulate future water demand were derived from estimates of the amount of water required to support an individual or multiple development booms by the year 2100. For further information on recent oil and gas expansion periods and the process by which the group estimated the amount of water required to satisfy this hypothetical demand, see the "Competing Water Demands" section.

Motivation for this project stemmed from concerns over Texas hornshell habitat within the river and contributions to interstate compact deliveries and therefore, the group evaluated the implications of model scenario output in a few select reaches of the river. The critical habitat reaches are located just upstream of the Black River Supply Ditch's confluence with the river and the upstream USGS gaging station. Reaches near the Black River's confluence with the Pecos River could be representative of the volume of water leaving the basin through surface flows, and thus contributing to Pecos River compact obligations. The results from scenario runs indicated that both scenarios, climate variation and changes in use, would have negative impacts on streamflow within the basin. The climate change scenarios, especially the combination of large projected increases in temperature with decreases in precipitation, had the most salient impacts in terms of flow reduction.

Modeled streamflow response in the critical habitat reaches of the Black River to climate change alone ranged from a 7% to 22% percent decrease in flows by the year 2100 (Figures 56). The smaller estimated decrease in streamflow is based on the lowest estimates of changes in climate, including a -2.5% change in precipitation and a 4° F increase in temperature by 2100. The larger estimated decrease in streamflow is based on the highest estimates of changes in climate including a -12% change in precipitation and an 11° F increases in temperature by 2100. Very similar trends were observed in the river reaches just upstream from the confluence with the Pecos River. These projections were independent of any changes in water use in response to increasing regional demands.

Modeled output was interpreted in relationship to output that assumed no change in climate, as shown with by the yellow line in Figure 57. This analysis is valuable because of the general trends that the model predicts rather than as a means to estimate exact rates of future streamflow. Generally speaking the model continues to overestimate even current streamflow levels as can be seen by a comparison of Figure 57 to the current gaged hydrograph in the "Texas Hornshell" section of this report (Figure 14). In the last decade, streamflow has frequently dropped below both 5 and 4 cubic feet per second (cfs).

If the trends seen in this model output are correct, it is likely that decreases in streamflow could significantly affect critical habitat and Pecos River deliveries, even if there are no changes in water use, in the coming 20 to 30 years.

**Figure 56: Modeled Percent Decrease in Streamflow within the Texas Hornshell Reaches of the Black River**

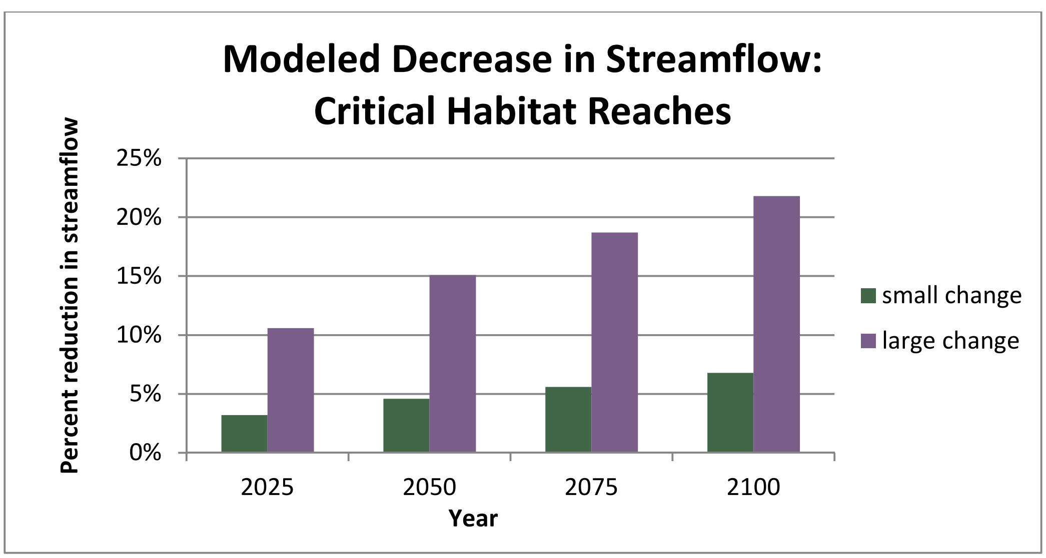
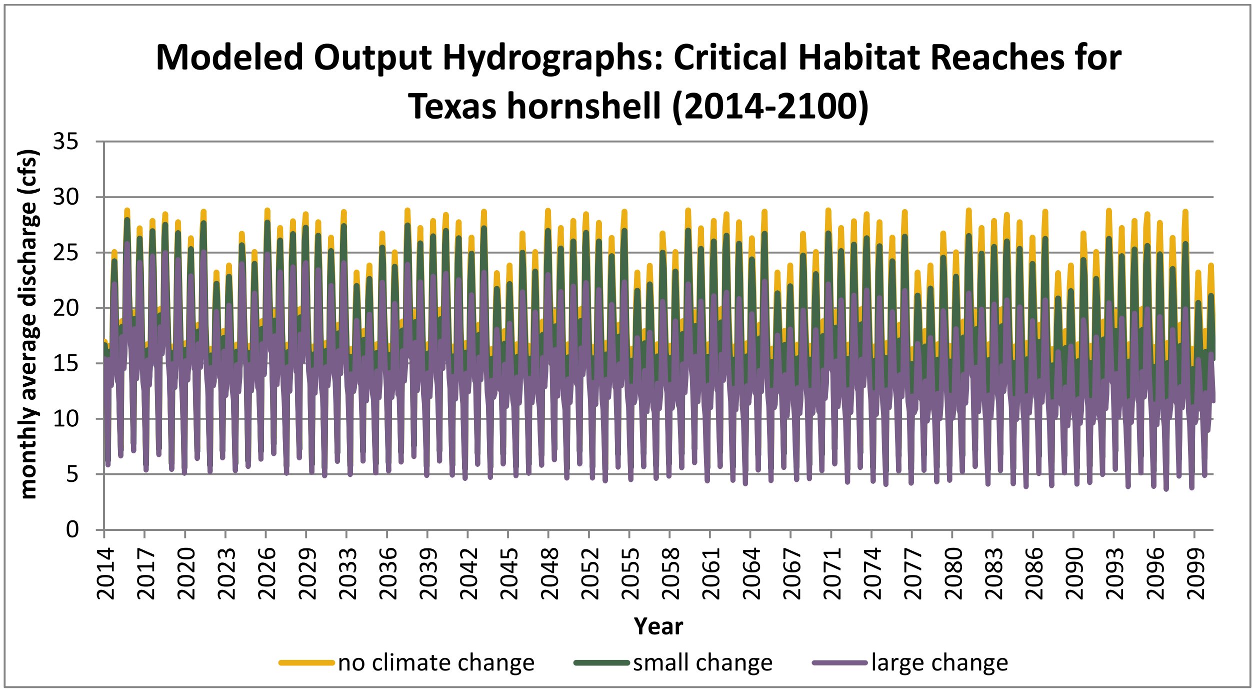


Figure 57: Modeled Hydrograph Estimates of Streamflow in Texas Hornshell Reaches from 2014-2100




However, given the modeling challenges and limitations (discussed below), the group decided that a detailed statistical analysis of these results was not warranted. This was due in part to the fact that the model response to input values and difficulty encountered during the calibration time period produced uncertainty that was likely to outweigh the observed systematic variation in the explored scenarios. Difficulties encountered in the calibration process both produced sufficient uncertainty about the model's ability to accurately reflect basin hydrologic responses to prevent further investigation, and revealed and confirmed key geophysical properties of the basin.

## Discussion

Through the development and calibration of this resource forecasting model for the Black River Basin it became clear that there were key characteristics and interactions governing the fate and transport of water within the basin. In addition, further data collection could improve future modeling efforts and the general understanding of influential water budget components (see the "Recommendations" section for further data collection suggestions). The modeling effort was intended to both support an understanding of the overall water budget within the basin and predict how varying inputs such as demand and climate could impact the hydrograph in the future, especially in the critical habitat reaches for the Texas hornshell. While the group had uncertainty in the model's ability to predict streamflow to the point of accurately informing hornshell recovery, the group did identify several broad observations.

Variability in precipitation inputs to the model greatly impacted the output hydrograph. Not only was the spatial distribution of rainfall difficult to estimate, it was also challenging to estimate the partitioning of precipitation falling on the Guadalupe Mountains, where it may enter the Capitan Reef formation and move away from the basin towards Carlsbad Springs, or flow into the alluvial aquifer in the Black River Basin.

Perhaps the most important observation going forward is that the movement of groundwater within the basin plays a critical role in determining the timing and location of surface water availability and therefore the overall water budget. Any future efforts to model the basin should place focus on accurately capturing groundwater-surface water interactions and the movement of subsurface flows. This effort would be aided by further data collection related specifically to the groundwater basin including the subsurface characteristics that determine groundwater flow volumes and timing.

There were several challenges that the group faced in developing the WEAP model. Some of the challenges were inherent to the WEAP model, while others resulted from sparse coverage or limitations in data that made it difficult to estimate model input parameters. The following subsections describe the challenges faced during the parameterization and calibration in further detail.

### WEAP Model

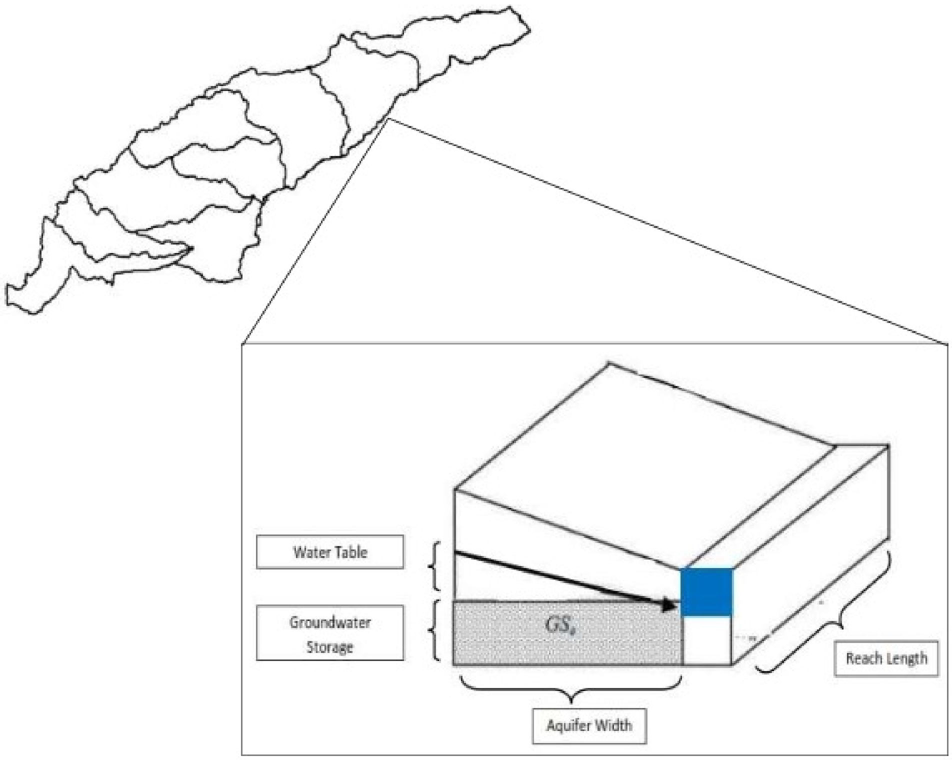
The main challenges that the group encountered in developing the WEAP model for the Black River Basin were accurately capturing:

- interactions between the groundwater and surface water,
- subsurface contributions to the spring sources throughout the basin, and
- subsurface flows between catchments.

Several of these challenges are due to the inability in WEAP (without linking to a more sophisticated groundwater model) to connect groundwater nodes except through surface water flows in the stream system. As a "lumping" model, separate aquifers are created as opposed to having one continuous aquifer body in the subsurface, and water cannot flow between these aquifers as subsurface flow. Similarly, because streamflow is evaluated in lumped reaches, the model has limitations in accurately reflecting surface flows at very specific locations, which could reduce its applicability in evaluating responses in critical habitat reaches.

Because the Black River flows predominantly over alluvial material, it was assumed that the aquifer is in hydrologic connection with the river. Therefore, the initial development of the WEAP model for the basin employed a method of calculating the groundwater and surface water interactions within WEAP. This method requires several additional parameters that characterize the aquifer in each of the catchments, including: the porosity and hydraulic conductivity of the subsurface material, as well as the aquifer dimensions, including the length of the river in contact with each catchment's aquifer and the storage level at which the aquifer would gain or discharge to water to the river. Figure 58 shows the nine modeled sub-catchments and basis for WEAP's calculations of groundwater-surface water interactions within each sub-catchment.

**Figure 58: Visual Representation of WEAP Groundwater to Surface Water Interactions Calculations**




The maximum theoretical and current volumes of water in the aquifer were calculated using these parameters. The linear program model that is embedded within WEAP then calculates the flow of water between the aquifer and river depending on whether the river is gaining or losing. If there is not enough water in the river to fill the available storage capacity within the aquifer, WEAP will attempt to reduce the percentage of water that should flow to the aquifer. Even after reducing this amount, if the river cannot meet the available storage capacity it will not partition any water to the aquifer leaving the full volume in the surface system.

The initial value estimates used for calculating aquifer storage came from actual depth-to-water measurements collected by the NMOSE and USGS, and with these parameter inputs, WEAP's linear program could not accurately simulate the flow between the river and aquifer and therefore no water flowed between the surface water and groundwater. With adjustment of the parameters to increase initial storage in the aquifer, we were able to capture these interactions, but the extent to which this had to be increased did not reflect our best estimate of the actual conditions of each sub-catchment's aquifer.

Direct input of natural recharge estimates for each sub-catchment's aquifer helped address some concerns regarding the model's ability to estimate surface water - groundwater interactions. However, it did not resolve concerns about the model's ability to represent subsurface flows between sub-catchments independent from the stream system. The majority of the Black River stream system is ephemeral (as seen in Figure 6 in the "Basin Characterization" section). These stream networks are characterized by short, punctuated surface flow events, usually in response to summer monsoons; however, those sub-catchments also contain subsurface flows that transport precipitation from the Guadalupe Mountains towards eventual discharge at the springs that feed the Black River and to the river itself.

The perennial Black River flows are largely associated with spring discharge. For those sub-catchments containing the most productive springs, Rattlesnake and Blue Springs, total annual gaged spring discharge is significantly larger than estimated total annual precipitation over those individual sub-catchments, revealing the extent and importance of subsurface flows within the basin. Given the karst nature of the local geology, these results are not surprising and confirm the geophysical properties of the basin that must be better simulated with modeling platforms more capable than WEAP of capturing groundwater movement.

To resolve these issues, the group recommends that any further modeling efforts of the basin using the WEAP model include a groundwater linkage with MODFLOW such that subsurface conveyance of water could be more accurately represented. MODFLOW is a three-dimensional groundwater modeling platform that was developed by the USGS, and provides a more sophisticated linkage between groundwater-surface water interactions. This linkage option could better represent how changes in groundwater levels affect streamflow in the Black River.

To meet the need for a decision support tool that could analyze anthropogenic impacts, the RiverWare model (designed by the Center for Advanced Decision Support for Water and Environmental Systems at the University of Colorado Boulder) offers another viable option. However, the model does not internally calculate the impact of various climate processes on the precipitation input like WEAP, and those calculations would have to be made outside of the model. RiverWare offers the ability to simulate subsurface flows between catchments within the groundwater aquifer.

### Data Limitations

As with many modeling processes, analysis was limited due to the lack of data representation and spatial coverage, and the inherent difficulty of estimating bulk averages of parameters across subsets of the study region. With only three meteorological stations from which to draw data for the climate inputs, our ability to capture the impact of topographic variation on the input parameters was limited. With the implementation of additional climate gathering efforts, this challenge could be better addressed.

Similarly, because physical, process-based models such as WEAP often require a single input value for parameters such as aquifer characteristics or vegetation cover, capturing heterogeneity across the units of study can prove difficult where the resolution of the model is coarse. For this reason, it is beneficial to have representative, field-measured estimates and accurate data sources from which to draw information for the parameterization of any lumped-variable model.

## Conclusion

The deterministic hydrologic model simulation of the Black River Basin using the WEAP software did not result in a reliable prediction of the water budget and streamflow over the ten-year calibration period from 2000-2010. Limitations in the model's ability to capture subsurface flows without linking to MODFLOW, and challenges simulating groundwater-surface water interactions and parameterizing the catchment-averaged inputs, made it difficult to replicate the current conditions in the basin. This was complicated by the fact that much of the basin is dominated by subsurface and ephemeral surface water flows. Throughout the model development and calibration process it became clear that given the basin's arid climate, highly variable precipitation, and complex hydrogeology, having sufficient data and a sound understanding of these influencing factors could greatly improve any future modeling efforts and recommended management actions for the basin.

Shifts in water use associated with hypothetical further oil and gas expansion appeared to reduce streamflow, but impacts were minimal given the relatively low amount of water required to support well development within the basin's mid-2000s expansion period. This could change depending on actual water demand in the decades ahead. In terms of the overall water budget, the timing of water use and the possible ecological impacts from the reduction in return flows from previously irrigated land may end up being more impactful. More salient, however, were the projected model output results from the 201-2100 time period using the 'best-effort' model calibration and the climate change scenarios. Streamflow was reduced throughout the basin, including in the critical habitat reaches to the Texas hornshell. Though it is clear that climate change (including both possible decreases in precipitation and increases in temperatures) will impact the already arid basin, with the lack of confidence in the model output and limitations in its ability to accurately reflect groundwater storage and subsurface flows, the group did not feel that the results presented from the scenario analysis could provide significant insight except for general trend observations.

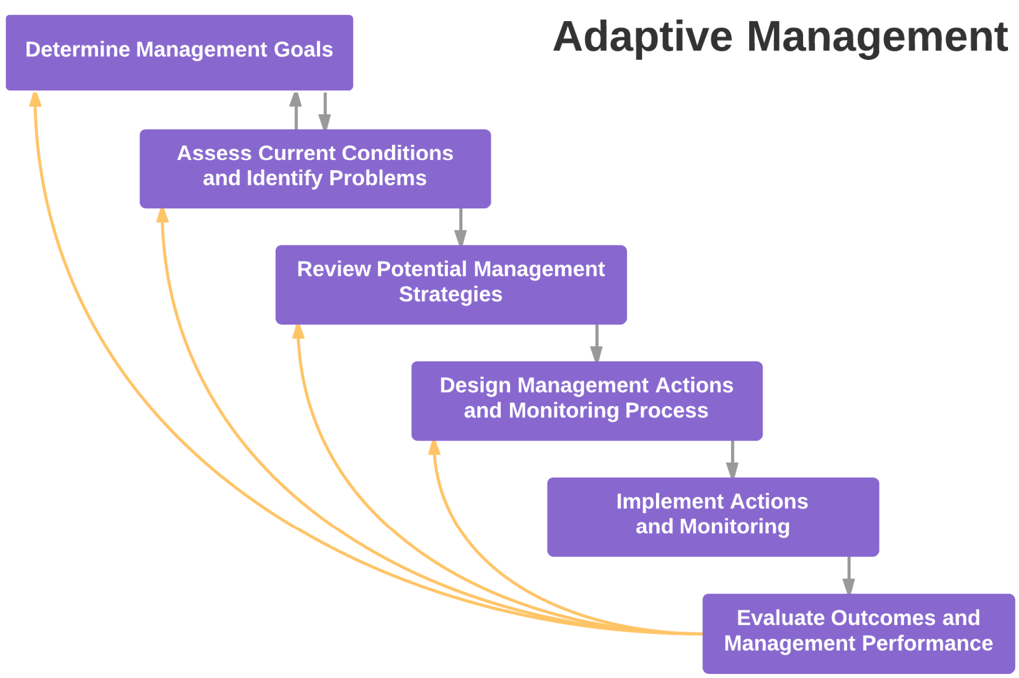
Regardless of which modeling tool(s) is utilized moving forward, better data collection and characterization of critical elements of the water budget could improve the accuracy of model inputs and lead to more representative outputs. The modeling process made it clear that better understanding the geophysical properties and response processes in the basin will be beneficial to any future studies of or subsequent modeling efforts.

# RECOMMENDATIONS

Based on the analysis conducted for this project, it is clear that successful basin management will require both prompt efforts to obtain additional data necessary to understand the Texas hornshell and its relationship to hydrologic processes, as well as implementation of management strategies likely to reduce stress on water supplies and increase understanding of human impacts within the basin.

This recommended approach is consistent with an adaptive management framework. Adaptive management is an iterative process in which management actions are conducted in tandem with monitoring and data collection to support those actions and meet overarching goals. Figure 59 shows a flow diagram representing this process. This project has identified management goals, assessed current conditions and identified problems, as well as reviewed many possible management strategies. State agencies and local stakeholders can now use this foundational work to design management actions and monitoring processes.

Figure 59: Adaptive Management Flow Chart

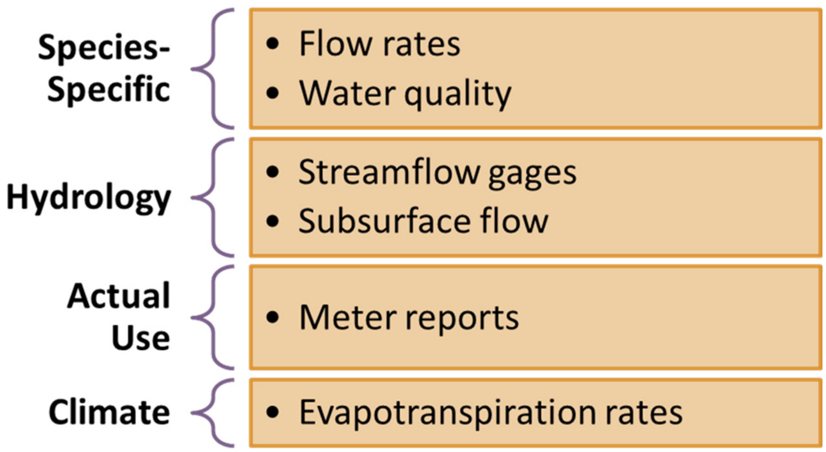



The following section discusses the top priorities for next steps. Given the impending timeline for possible Texas hornshell Endangered Species Act (ESA) listing, it is critical to begin the process by collecting data on its habitat needs. Further data is also necessary to better inform state agencies of actual water use within the basin. Concurrently, management strategies designed to support ecological and human needs within the basin should be implemented and monitored for efficacy.

## Data Collection to Support Further Analysis

The following data will support equitable water distribution for the Texas hornshell, local farmers, industry, and compact deliveries. Ideally, the New Mexico Interstate Stream Commission could work with and/or identify agency and other organizational partners for collaborative collection and review. Figure 60 identifies the data collection priorities identified by this project.

**Figure 60: Key Data Needs**




### *Species Data*

Populations of the Texas hornshell have been studied and threats to the mussel are well known but quantitative data relating population to streamflow conditions is not easily accessible. In addition to population studies undertaken by the New Mexico Department of Game and Fish (NMDGF), mark-and-recapture studies have continued since 1997 (U.S. Fish and Wildlife Service 2013). Known threats to the mussel include siltation and sediment, water quality contamination, low flows and inadequate pulse flows, as well as the possible consequences of increased water temperatures associated with long-term climatic temperature increases. Additional data in conjunction with existing species density information would allow for better correlation of habitat conditions to species survival rates.

#### Flow Rates

The minimum flow rate required for the Texas hornshell will determine how much water will be need during times of water stress. Currently, data was not accessible to this project to identify such correlations. Experts at NMDGF estimate a rate of 3 cfs; however, no published reference to this rate was found. Additional funding for species density monitoring at various flow rates is necessary. These relationships can then be applied to instream water acquisitions aimed at maintaining stable populations during low flows, especially as temperature increases will likely alter stream levels.

Additionally, it is important to understand the impact of low flows on host fish species required for glochidial attachment. Because the mussel plants its larva from May to June, low streamflows during this period caused by the monsoonal nature of the basin may affect the availability of host fish if changes in demand or climate trends exacerbate water scarcity. Research is essential to determine the habitat quality necessary for host fish during the glochidial attachment stage, as well as any mussel adaptations that may take place if the population of host fish changes.

## Water Quality

### Sediment and Siltation

Excessive sediment and siltation smothers mussel habitat and can be caused by removal of native vegetation, overgrazing and trucking operations. Native vegetation is removed by clearing land for agriculture, overgrazing and invasion of non-native vegetation. Under such conditions sediments that otherwise would have been trapped in the thicket of vegetation move at a greater rate into the stream channel. Truck crossings through the Black River and erosion of dirt roads associated with oil and gas operations contribute to sediment delivery to the channel. If oil and gas operations continue in the watershed without sediment monitoring, mussel populations maybe threatened. A sediment budget inclusive of sinks, sources and carriage of sediments should be conducted in areas with high rates of farming, ranching and oil and gas operations and compared to upstream reaches that are less impacted by human use. Reaches that are found to be at-risk in terms of sediment accretion will need to be placed at highest priority for species recovery. Special attention should also be paid to the carriage of sediment throughout the stream system and possible impacts to downstream mussel populations.

### Other Water Quality Concerns

The Texas hornshell requires water quality that is low in contaminants and salinity. Oil and gas development in the basin poses a risk for the mussel as contaminants, such as produced water, can enter the river via truck spills or on-site leaks. Although Black River flows are low in salinity, Pecos River water entering the Black River through the Supply Ditch transports higher saline water into the downstream reach.

Point and non-point discharges related to oil and gas operations and agriculture could impact mussel populations in the Black River. Juvenile mussels are most likely to intake contaminants such as ammonia and chlorine (U.S. Fish and Wildlife Service 2013). Larval attachment to host fish, or glochidial attachment, takes place annually from May to July and is inhibited by heavy metal contaminants (U.S. Fish and Wildlife Service 2013). Through the New Mexico Oil Conservation Division's website numerous examples of produced water spills are identified. For example, well number 310311 spilled 80 barrels (bbl) of produced water in 2013, of which 70 bbl were reportedly as recovered (New Mexico Oil Conservation Division 2014). Produced water can enter the stream directly as runoff or into groundwater through infiltration. Because of the spring-fed nature of the Black River both means of contamination pose significant risks to mussel populations. Water quality measurements of ammonia, chlorine, and heavy metals need to be taken at occupied habitat, especially at areas where surface runoff from oil and gas operations is most likely and at gaining reaches of the river downstream of active operations. Monitoring glochidial attachments along any contaminated reaches from May to July is recommended.

Salinity increases in the downstream reaches of the Black River where agricultural activity is greatest and where the Supply Ditch transports Pecos River water into the channel. Just past the Carlsbad Irrigation District's (CID) diversion dam salinity levels increase from 0.9 parts per thousand (ppt) to 2.8 ppt (Carman, Texas Hornshell Recovery Plan 2007). The mussel's sensitivity to saline water is shown at a maximum salinity concentration 0f 7.0 ppt, at which point the mussel experiences stress followed by death (Carman, Texas Hornshell Recovery Plan 2007). Although the mussel is not found downstream of the CID dam, data collection of trends in salinity levels could inform any future reintroduction measures in currently unoccupied reaches.

As climate change increases temperatures in southeastern New Mexico surface water temperatures will also increase. Research as to the Texas hornshell's relationship to water temperature could not be found. If this information does not exist, it should be collected to predict any future impacts to mussel habitat and ecosystem requirements. Additionally, temperature impacts on host fish that are necessary for glochidial attachment need to be identified. Temperature measurements could be taken during water quality sampling so that correlations between temperature and the mussel and host fish populations can be made.

## *Water Use*

### Metering

Metering of water use is underreported to the New Mexico Office of the State Engineer (NMOSE). The percentage of metered water use to permitted water use varies across sector and significant uncertainty exists as to the thoroughness and accuracy of reports available through the NMOSE online database. Although a random sample of metering reports showed actual use typically below permitted use, commercial and prospecting permits averaged over double their permitted amount. There are flaws in New Mexico's water reporting system and steps to represent actual water demand should be explored through appropriate administrative changes. Sound data reflecting water use will establish trends in use and identify possible overuse.

## *Hydrology*

Data describing the karst, spring-fed nature of the Black River alluvial aquifer and its subsurface flows is sparse and understudied. Further efforts to model a water budget for the system will be limited without more adequate data defining hydrogeologic conditions.

### Groundwater Flow

Data collection that reflects the timing and transit of subsurface flow is needed and can be obtained through groundwater tracers. Although depth-to-water measurements and drilling logs help estimate the storage capacity of the shallow aquifer, karst sinkholes may dramatically affect the vertical flow of the aquifer through leakage to deeper aquifers and variances between diffuse and conduit flow (Mull 1993). Dye tracers have been used in karstic regions to determine the direction of flow and the location of spring discharge and are the "most practical and satisfactory method" to provide insight of groundwater flow (Mull 1993). Other useful tracers include isotopes, such as tritium and/or water chemistry constituents such as sulfates or carbonates resulting from dissolution of native geologic deposits that can inform improved understanding of the direction and timing of subsurface flows.

Temperature sampling throughout the Black River may point to areas where cooler groundwater seeps up from the aquifer to enter the river. Measurements taken at these locations can provide information about water flows in the basin.

### Stream Flow

Stream gaging stations placed at additional locations beyond the current downstream locations will support a better understanding of natural hydrologic trends and changes related to water use. Although ephemeral reaches mainly transport water during heavy rainfall, year-long gaging of these reaches would inform better understanding of the hydrologic pulses of the basin. Gaging stations before and after springs, especially Rattlesnake and Blue Springs, would help quantify their contributions to total streamflow and the impacts of human use.

## *Climate*

An additional weather station(s) in the basin could support better understanding of climate influences on the water budget and climate change. However, the high heterogeneity in precipitation may make accurate estimates challenging even with additional weather stations.

### Evapotranspiration

Actual evapotranspiration (AET), the combined effect of evaporation from soil and water surfaces and transpiration from vegetation, accounts for the single largest output in the water budget. As changes in climate influence AET, this information may be crucial for adapting to associated water scarcity issues. Many methods for measuring evapotranspiration exist. Lysimeters measure the weight of soil and vegetation while also accounting for precipitation. Changes in weight quantify the losses of water through evapotranspiration (Shuttleworth 2008). Water vapor measurements can also be utilized and either the Bowen Ratio-Energy Budget or eddy covariance can measure the latent heat lost from vegetation.

## Steps to Implementation

Cooperation amongst various state and federal agencies as well as local stakeholder and legislative buy-in will be essential to support data collection efforts.

## *Stakeholders*

Essential participating agencies include the New Mexico Department of Game and Fish, the New Mexico Interstate Stream Commission, U.S. Fish and Wildlife Service, Bureau of Reclamation, National Parks Service, and New Mexico State Lands Office.

In addition, private landowners along the Black River need to be engaged and encouraged to participate. The benefits of participating in ecologic and hydrologic monitoring must be clearly communicated.

Since the opinion of the Black River community largely favors a 'hands off' approach to government, framing data collection to fit within this local mentality is crucial. Outreach campaigns should stress the importance of local decision-making rather than federally mandated regulations. Since the mussel has not yet been listed, cooperation amongst community members may ensure adequate habitat to prevent a listing, or facilitate a smooth process if a listing occurs. Candidate Conservation Programs can be a useful tool for landowners who do not want the imposition of federal ESA regulations on their property and who are willing to make efforts to promote stable habitat for the mussel. Outreach through local forums and distribution of literature will strengthen the landowners' understanding of the complex regulatory threats that may be associated with an ESA listing.

### *Legislation*

The current political climate in New Mexico is generally reluctant to allocate state funds for environmental purposes. Data collection will require legislative-approved funding. Without a federal mandate that would force state agencies into action, legislative approval may be the most daunting and challenging aspect in terms of acquiring the recommended data. In the case of the Pecos bluntnose shiner, data was acquired after the species was listed. Communicating to legislators the benefits of spending now on data collection in order to avoid potentially much larger expenses associated with an ESA listing in the coming years is critical.

# Management Strategies

A range of management strategies were explored and ranked based on their ability to increase water in the basin and their level of effort -- political and economic -- to implement. An assessment of the degree of uncertainty associated with each ranking was also completed. Of the options evaluated, four recommendations were chosen for further research. The following management recommendations are made to the New Mexico Interstate Stream Commission (NMISC) and all relevant state agencies and local stakeholders. (See Appendix C for the full list of management strategies assessed for the project.)

## Instream Flow Markets and the Strategic Water Reserve

### Context

The management of surface and groundwater resources for the purposes of maintaining instream flows has taken place in a disparate manner amongst the western United States. In each of the states, there exists some type of market where water rights, particularly those for instream environmental flows can be purchased or leased, though New Mexico is often regarded as the last western state to acknowledge and develop mechanisms through which transactions for these purposes could occur. The extent to which transactions have occurred for the purpose of maintaining instream flows has varied dramatically by state (Scarborough 2010). These differences can most likely be attributed to the varying regulations governing water rights, differing interpretations of beneficial use under the Appropriative Rights Doctrine, and also to respective market conditions such as the existence of transaction costs (from lack of adequate information) and barriers to entry.

While New Mexico has not formally recognized instream flow as a beneficial use through statute, there have been several actions highlighting the state's willingness to acknowledge the benefits of instream flows for both endangered species preservation and interstate compact deliveries. The state has also adopted a legislative mechanism through which the NMISC has been granted authority to purchase, lease, or accept donated water rights to maintain or augment stream flows for these purposes. Even with these mechanisms in place however, water rights transactions for instream flow benefits within the state have been limited. Administrative changes within the New Mexico Office of the State Engineer (NMOSE) or amendment to the state water code to formally designate instream flow a beneficial use could aid water managers meet demand from the competing uses in times of shortage. Within the Black River, this could be helpful as a mechanism to augment flow to allow for the maintenance of critical Texas Hornshell habitat, which is the only remaining habitat in New Mexico.

Until the late 1990s, state water law under the Appropriative Rights Doctrine was interpreted by the NMOSE to require a physical diversion for a beneficial use to be established and a water right permit to be approved (Fort 2000). Accordingly, the prevailing sentiments of the NMOSE and traditional consumptive users stymied the recognition of instream flow benefits, highlighted by the uncertain impacts to adjacent users and assigned seniority rights, as well as the complications associated with monitoring and enforcement (De Young 1992). Prompted by a request from state senators in 1997, Attorney General Tom Udall, in consultation with the NMOSE, issued Opinion No. 98-01 in 1998 which recognized that nothing in the New Mexico Constitution, statutes or case law should preclude the NMOSE from affording legal protection to instream flows or from approving a change in use of a water right to instream purposes, under the condition that a flow monitoring device be installed when/if the permit is administered (Udall 1998). Though this did open the discussion over instream flow benefits, because the opinion was not legally binding on the State Engineer and NMOSE, it did not immediately lead to the creation of instream flow markets within the state because of the remaining uncertainty associated with the water rights and possible confusion over the required metering measures mentioned in the opinion.

Following the Pecos River Settlement Agreement (2003) and associated litigation, which disputed New Mexico's delivery amounts under the compact, state agencies such as the NMISC and the think tank Think New Mexico began pushing for a legislative mechanism whereby instream flows could be increased and delivery requirements could be met. It was not until 2005 that the state passed legislation which recognized the potential benefit of instream flow markets as a tool to manage scarce water resources amongst competing uses with the development and funding of the Strategic Water Reserve (NMSA § 72-14-3.3).

The guiding vision behind the Strategic Water Reserve (SWR) was to create a pool of publicly held water rights that could be used to keep the state's rivers flowing for the benefit of endangered species and compact deliveries (Utton Transboundary Resource Center 2014). Under this framework, the NMISC was delegated authority to purchase and/or lease water or water rights, and was allocated 2-year funding from the state legislature totaling $4.6 million (MacDonnell 2009). One significant benefit to water rights holders or stakeholders looking to purchase or lease water for environmental flows is that the SWR does not require metering of flows that are currently a precondition to any permit issued by the State Engineer for this purpose. It should be noted however that as it was constructed, only the NMISC is able to purchase or lease rights to hold in the SWR, thus potentially limiting the number of entrants into the market. Another potential weakness of this framework is that funding for the SWR must be appropriated by the legislature unless the NMISC is able to lease water from the reserve as a means for agencies to mitigate their environmental impacts on aquatic and riparian habitat.

Even with these constraints, there have been several notable uses of the SWR for endangered species flows, including the Bureau of Reclamation's (BOR) current lease of water from the NMISC at the Vaughan Conservation Pipeline and associated well field. This project was intended to mitigate Pecos bluntnose shiner declines that have resulted from BOR storage and delivery operations on the Pecos River. Similarly, if the Texas Hornshell is listed under the Endangered Species Act and data becomes available clearly linking flow regimes with species abundance estimates within the Black River, the SWR could be used as a mechanism to aid water users and the NMISC in meeting the flow requirements that are set forth.

## Alternatives

The Pecos River, to which the Black River is a tributary, is one of the state's transboundary rivers that are required to meet delivery requirements under long-standing compacts. Further utilization of the SWR to preserve instream flows should be a target for water managers given that it provides dual benefits in many instances, allowing the state to meet delivery obligations and also providing water required for endangered species survival and critical habitat maintenance.

After conducting the review of current state water policy as it relates to the maintenance and provision of instream flows, there are several measures which could be adopted by the New Mexico Legislature, the NMISC, and the NMOSE to allow for a more robust market to capture instream flows benefits.

1. *Strengthening of the Strategic Water Reserve* -- To the extent that periods of nonuse are actually enforced (leading to forfeiture), as a low effort implementation strategy, the NMOSE could allow for water rights held under NMSA § 72-5-28(G) to be stored in the Strategic Water Reserve. This provision allows conserved, "non-use" water to be temporarily stored in a state engineer-approved conservation program without the threat of water right forfeiture. As mentioned previously, a formal recognition by the state legislature of instream flow as a beneficial use would reduce some of the uncertainty and risk associated with instream flow rights and the required monitoring actions (King 2004). Short of statutory designation, however, the State Engineer could more clearly instruct district NMOSE offices to acknowledge and inform stakeholders that water rights leasing for instream flow benefits is supported under the Water Leasing Act, and that several transactions, including ones with the NMISC, have already taken place under this direction.

2. *Metering Requirements* -- Along with this instruction to the district offices, the metering requirements that are prerequisite for instream flow uses must be more clearly defined. While the confusion surrounding metering requirements may currently deter permitted instream flow transactions, the NMOSE and NMISC could be endorsing the utilization of the use of the Strategic Water Reserve as an instrument to avoid this precondition.
3. *Funds Appropriation* -- As it is currently being implemented, without funding or donations of water rights, the long-term ability of the NMISC to administer the reserve as originally envisioned may be limited. As such, in order to maintain the effectiveness of the Strategic Water Reserve, appropriation of funds for future purchase and/or lease of rights will be necessary.
4. *Broader Stakeholder Engagement* -- Similar to frameworks established in other western states which seem to attract more actors into the market for instream flows, mechanisms that allow for broader stakeholder use of the Strategic Water Reserve, in addition to the NMISC, should be sought or implemented. Removing entry barriers and allowing for more widespread use could markedly increase the size of the instream flow portfolio, even if funding from the legislature to the NMISC falls short in future, water-scarce years.

### Potential Uncertainties

Efforts to statutorily recognize instream flows as a beneficial use have been largely unsuccessful, with the exception of Attorney General Opinion No. 98-01 and more recent acknowledgements from the State Engineer indicating the acceptable use of the Water Use Leasing Act (NMSA § 72-6-1 through 7) for the purpose of augmenting flows for instream environmental benefits or compact delivery requirements (provided procurement of a permit and the requisite monitoring).

Since 2005, the Strategic Water Reserve has served as a mechanism for the NMISC to purchase, lease, or accept donated rights for the purposes of maintaining instream flows to benefit the interests of the state, mainly endangered species preservation and compact deliveries. The current market is not perfect however, and in changing climate conditions where arid regions are likely to receive more variable precipitation, New Mexico should be looking for ways to strengthen the market for instream environmental flows.

## Changes in New Mexico Office of the State Engineer (NMOSE) Administration

As the state's primary water rights administrative body, the NMOSE yields significant authority over measurement, appropriation and distribution of surface and groundwater in New Mexico. Given this influence, shifts in administrative mechanisms offer an opportunity to gain additional information about how water is used, as well as enable closer regulation of how use responds to changing supplies and increasing demands.

The following proposed changes to NMOSE administration will allow for more effective management of surface and groundwater within the Black River Basin.

### *Strengthen/enforce metering requirements*

#### Context

All groundwater wells within the Carlsbad Administrative Basin, which includes the Black River Basin – except single household domestic and livestock uses – are required to submit periodic meter reports to detail water usage. However, careful analysis of groundwater meter reports for a 20 percent sample of PODs within the Black River Basin indicates that many of these water rights holders – 62 percent of the PODs sampled -- do not comply with meter report requirements. For those PODs for which data was available, and assuming that data is accurate, it was found that irrigation, municipal, domestic and stock watering uses are not fully exercising their total appropriated water rights. Use for those PODS ranged between 21 and 36 percent of the total allocated amount. In contrast, commercial water rights typically utilize more than three times the permitted amount, and prospecting (new temporary permits) use more than double the permitted amount.

Metering reports are an essential tool for the NMOSE. They enable better understanding of actual water use and are necessary to ensure compliance with water right allocations. Although it is difficult to ascertain the quantity of water affected by increased metering report compliance, it would provide valuable information to better inform possible policy adjustments that address gaps in permitted to actual water use.

#### Alternatives

To ensure better compliance with metering regulations, the NMOSE could consider the following initiatives:

- Increasing education for new and existing users about metering requirements;
- Increasing enforcement and monitoring to improve compliance and accuracy;
- Penalize rights holders who do not comply with metering requirements;
- Increase the lead-time for the temporary permit filing process to ensure meter installation for all new temporary permits;
- Increase application fees for temporary permits to generate funding for better meter reporting enforcement.

#### Potential Uncertainties

This analysis relied on meter report research from the WATERS database, as well as reports supplied directly from the NMOSE. It is possible that additional meter reports exist, but were inaccessible at the time of this research.

## *Adjustments in administration of change in purpose of use permits*

### Context

Water rights holders in the Black River Basin are frequently applying to the NMOSE for temporary change in purpose of use permits from irrigation to commercial use. These applications are driven in part by water demands from oil and gas development. In the Black River Basin, roughly 12 percent of total water allocated in the basin has undergone temporary reconfiguration to allow for commercial use, amounting to approximately 1,700 AFY. Although the NMOSE reduces the amount of transferable water by 30 percent to account for losses in return low, depending on the accuracy of this reduction it is possible that these change in use permits may be impacting local ecology as well as water users located adjacent to areas where change in use permits are highly concentrated.

Additionally, some water rights holders have been able to accelerate the rate of change in purpose of use permits by utilizing emergency requests. According to the New Mexico Surface Water Rules and Regulations, emergency consideration is available for existing water rights where serious economic loss could be incurred if there is a delay experienced by the application for a change in point of diversion, storage, or use. This mechanism allows for expedited approval however proof of economic loss is required. In the case of groundwater, however, there are no emergency regulations for these types of changes. For that reason, based on consultation with the NMOSE, some emergency requests to expedite changes in groundwater configurations for commercial sales have instead cited the Water Use Leasing Act to speed up the approval process. It is unknown at this time what proportion of active change in use permits have utilized this mechanism.

### Alternatives

To address these concerns, the NMOSE could impose restrictions or more closely monitor change in purpose of use permits to address possible implications within the basin. These adjustments could include:

- Limiting the total number of active permits at any given time within all or specific areas of the basin;
- Limiting the total volume of permitted water use attributed to active changes in beneficial use permits in all or specific areas of the basin;
- Increasing change in purpose of use application fees;
- Assessing and adjusting the 70 percent reduction in delivery rate for change in purpose of use permits to more accurately reflect impacts on return flows;
- For either/or permits, increasing monitoring for total combined use (irrigation and commercial).

Although these change in purpose of use permits account for only 12 percent of total water allocations in the basin, this trend appears to be increasing. Based on the volumes of water involved, it is likely that

Black River water is being transported out-of-basin to meet demand in the surrounding region for oil and gas purposes. As the likelihood of regional oil and gas development increases, the basin may undergo increased pressure to provide water to meet these needs, and change in purpose of use permits are the primary administrative mechanism by which this demand can be met. Limiting or improving monitoring of these permits may enable the NMOSE to better manage water withdrawals and possible out-of-basin transfers associated with land use changes.

Additionally, adjustments to change in purpose permits could address potential adverse impacts on return flow, and limit reactivation of unsubstantiated water rights claims or minimally active water rights for change in purpose of use permits. Imposing limits to the rate or amount of permits approved for a change in purpose of use may not prove significant in terms of total demand reduction, but it would address concerns about diminished return flows if that is determined to be a concern.

#### Potential Uncertainties

Limited information is available regarding whether current permit holders were actively using their rights for irrigation prior to applying for change in purpose of use permits. If they were not, or were only minimally using their rights, and change in use administration allows for the full use of those rights then increased water usage could be occurring. Additional analysis of this possibility is needed and could inform administration of change in use permits.

In addition, it is beyond the scope of this project to verify the accuracy of the water transfer conversion factor currently applied to change in purpose of use permits. To the extent that this conversion factor does not fully account for losses in return flows, impacts to the stream system could be occurring.

Administrative adjustments concerning change in purpose of use permits could include any or a combination of the suggested approaches listed above, and would be best informed by this additional analysis.

### *Adjustments in administration of temporary permits*

#### Context

Surface and groundwater are fully appropriated in the Black River Basin except for new appropriations for domestic and livestock wells (3 AFY) and for temporary new appropriations, categorized under prospecting (3 AFY). Because population growth within the basin is limited at this time, concerns over increases in demand from domestic and stock wells are minimal. However, new appropriations to meet mineral, and oil and gas demand in the region could be of greater concern.

Currently, New Mexico Groundwater Rules and Regulations authorize temporary new groundwater appropriations and limits them to three permits per well per permit. The cost is five dollars per permit. If applied for at the same time, the permits are issued to new or existing PODs on a rolling basis to allow for uninterrupted use of nine acre-feet within one year of the permit issue date. Additionally, while permit grantees are required to submit meter readings to the NMOSE, research conducted by this project indicates that many often do not.

### Alternatives

The NMOSE could adjust the administration of temporary permits in the following ways:

- Limiting the total number of permits issued in the Black River Basin each year;
- Increasing permit fees for new temporary permits;
- Actively enforcing three acre-feet per permit limit and/or three permit per year limits;
- Actively enforcing metering requirements and/or establishing penalties for permit grantees who do not comply;
- Allowing only one permit per year per POD (three acre-feet per year total);
- Prohibiting temporary permits in the Black River Basin.
- Requiring applicants to demonstrate that the water needed for prospecting cannot reasonable or practically be acquired from some other existing or recognized water source.

This recommendation offers the opportunity to quantify changes in water use associated with oil and gas development, as well as the opportunity to measure and monitor activity. Although only six active temporary new permits (18 AF total) are operating within the basin as of 2014, currently there are no limitations imposed. Consequently, increases in demand associated with increased oil and gas development are possible. Therefore, limitations and/or monitoring of new temporary permits would improve the accuracy and level of information available regarding the status of new water demand in the Black River.

From an administrative perspective, better enforcement of current temporary permit policy could be easily implemented by the NMOSE. Changes to current policy may be more challenging and would require additional effort and dedication of resources to implement.

### Potential Uncertainties

Assuming that temporary permits issued in the basin have been accurately recorded, the current rate of temporary permits has a minimal impact on total demand. However, possible increases in demand could result in greater impacts depending on the rate of issued permits, if left unchecked.  If additional permits have been issued for which information is not publicly available, this option could prove more impactful.

## Shortage Sharing Agreements and Collaborative Management Options

### Context

Just as New Mexico's history is full of stories of epic battles over water it also provides plenty of precedent for community water sharing agreements. Native American groups as well as early European settlers recognized the resilience offered by collaborative management systems. The Spanish brought to New Mexico the *acequia* system adapted from Arab and Persian traditions and established networks of community managed ditches and rotational water use agreements depending on available supply.

Priority administration as established by New Mexico state law functions in times of shortage so long as basins have been adjudicated and the NMOSE takes action to shut off junior water users. In 2004 NMOSE issued the Active Water Resource Management rules or AWRM (19.25.13) in response to §72-2-9.1 passed by the New Mexico State Legislature in 2003. AWRM has been criticized because of the power it places within the NMOSE to enforce prior appropriation without court completed adjudications. However, AWRM also encourages collaborative management by water user groups in districts to be created based on hydrologic boundaries.

> ***NM 19.25.13.38 FORMATION OF WATER RIGHT OWNER GROUPS****: Water right owners are encouraged to form water right owner groups for the purpose of discussion and negotiation among themselves, with other water right owners, or with the water master, regarding the possibility of shortage sharing agreements and other forms of alternative administration and joint application for replacement plans.**

These regulations are significant for the Black River Basin because they may, depending on how AWRM is applied, offer an opportunity for local water rights holders to control decisions impacting how water is used and distributed in the basin. Coordinated water use now could better support current users in their specific activities as well as help avert a U.S. Fish and Wildlife Endangered Species Act (ESA) listing of the Texas hornshell.

### Alternatives

In the case of an ESA listing of the Texas hornshell, or other species on the Black River, reductions in use may be required. These reductions may be enforced through prior appropriation administration, and therefore the curtailment of water use by junior users, or by some other arrangement agreed upon by rights holders in the basin. AWRM regulations allow for some degree of local control over water rights administration.

Water users in the Black River Basin have the opportunity to work together to determine solutions to water distribution in times of shortage. Options available to them include, but are not limited to, rotational use or shortage sharing agreements.

- *Rotational use agreements* - Water users agree to fallow their land, or temporarily cease other water uses, on a rotating basis. These agreements often include some form of compensation to users whose turn it is to curtail their water use.

- *Shortage sharing agreements* - All water users adjust their water use each season based on an assessment of available supplies.

### Potential Uncertainties

Alternative administration agreements must be deemed "acceptable to the state engineer". (NM 19.25.13.7(4)). However it is likely that they will be approved as long as they are well organized, implementation is feasible and they support NMOSE objectives, and compliance with interstate compacts and given a species listing, ESA regulations.

Given a species listing, the amount of water made available by such a strategy will be determined by the amount required by the state or U.S. Fish and Wildlife. This strategy is unlikely to provide any more environmental flows than the minimum required, or anticipated to support local ecosystems and prevent species listings.

The level of effort to implement will depend entirely on the willingness of local rights holders to work together towards collective resource management.

*Definitions:

Alternative administration - *Administration that is based on water sharing agreement amount affected water right owners, and that is acceptable to the state engineer. Such administration may include voluntary shortage sharing such as, but not limited to, percentage diversion or pro rata allocation, rotation of water use, and reduced diversions. (NM 19.25.13.7(4)).*

Replacement Plan - *A plan submitted by the owner(s) of administrable water rights, and approved by the state engineer for no more than two consecutive years, subject to renewal, for the purpose of offsetting depletions attributable to out-of-priority administrable water rights. (NM 19.25.13.7(3e)).*

## Produced Water Re-Use in the Oil and Gas Industry

### Context

Large amounts of water from subsurface formations are brought to the surface during oil and gas production. This formation water -- or produced water -- accounts for the largest waste stream volume associated with conventional oil and gas production. For every one barrel of oil produced, approximately ten barrels of produced water is generated (U.S. Environmental Protection Agency 2013).

In 2011 Eddy County alone generated over 21,000 AF (164 million barrels) of produced water (Lebas, et al. 2013).

Produced water often contains hydrocarbons, high levels of total dissolved solids (TDS) reflecting the depositional environmental of the reservoir, suspended solids and residual production chemicals. In addition, small concentrations of naturally occurring radioactive material (NORM) present in water can become concentrated in pipes and sludge from holding tanks. The produced water from the Delaware Basin is primarily contaminated with sodium chloride, and has TDS concentrations up to 285,000 ppm, a level too high for beneficial use without treatment (Halliburton).

Treated as a waste rather than a potential resource, common practices for the disposal of produced water include land application and subsurface injection. Land application is the least expensive method, however is not feasible for produced water of poor quality because of the likely environmental contamination. Because disposal into saltwater injection wells has low liability for producers, it is the industry preferred disposal practice. Approximately ninety eight percent of produced water in the United States is re-injected (Guerra, Dahn and Dundorf 2011). This is an expensive practice. Producers in Eddy County pay around $0.75 to $1.00 per barrel for the produced water to be disposed of in saltwater injection wells (Lebas, et al. 2013). In areas where on-site injection is not feasible due to insufficient capacity of the geologic formation, produced water is transported to offsite re-injection facilities, adding an additional cost of transportation and an increased risk of environmental contamination from truck spills or pipeline failures. Average transportation costs for fresh water are around $2.00 to $3.00 per barrel (Dan Girand, personal communication).

Unconventional resources such as tight sands, oil shale and gas shale reservoirs generate less produced water (from formation water) than conventional oil and gas wells due to the tighter formations (Guerra, Dahn and Dundorf 2011). For these operations the largest waste stream is generated through the use of imported fresh water in initial drilling and fracturing. The fresh water used in fracturing is blended with additives such as gelling agents so that the fluid is viscous enough to transport the proppant and friction reducers so that it is slick enough to permeate the micro-fissures in the rock formation. It is then combined with the saline formation water in the subsurface resulting in an end waste product that is also referred to as produced water. This produced water is also disposed of in injection wells, often off-site.

## Alternatives

Treating produced water for re-use in hydraulic fracturing and other oil and gas operations could reduce environmental risks associated with the transportation and disposal of produced water, reduce costs to producers of obtaining fresh water and alleviate stress on the fresh water supply. Figure 61 shows water hauling trucks waiting for the next delivery, which often go to supply the hydraulic fracturing sites within the basin and surrounding areas.

**Figure 61: Water Hauling Trucks in the Basin**

Halliburton published a case study in the Permian Basin using new technology to clean and re-use produced water for use in hydraulic fracturing operations in 2013 (Halliburton 2013). The studies found that high concentration of total suspended solids (TSS), not high TDS, prevents produced water from being an efficient substitution for fresh water in fracturing fluid. Halliburton treated the produced water with an electrocoagulation process to remove suspended solids, hydrocarbons and heavy metals; however it is worth noting total dissolved solids were not greatly reduced. A cross-linked fracturing fluid was designed to be compatible with high TSS water, effectively allowing for the replacement of fresh water with produced water. Field tests conducted near Carlsbad confirmed the feasibility of the new treatment and fluid mixture technology for use in fracturing operations (Lebas, et al. 2013). The operator featured in the study reported to have saved a total of eight million gallons of fresh water, saving around $500,000 to $700,000 in fresh water purchases and transportation (Halliburton 2013).

This new technology offered by Halliburton presents a feasible and cost-effective way to treat and re-use produced water for fracturing operations. Water demand permitted for natural resource prospecting currently equals 588 acre-feet per year (AFY) in the Black River Basin. Well stimulation and enhanced recovery require the largest quantities of water. For example, hydraulic fracturing in the Delaware Basin (Eddy County) requires around five to eight acre feet (AF) (40,000 to 60,000 barrels) of fresh water for each well during well development (Lebas, et al. 2013). The Black River Basin alone observed a total 104 natural gas wells from 2002 to 2008, totaling an estimated 520 to 832 AF of fresh water required for the development of the wells during the six year time frame. This is a large quantity of fresh water demand that could be replaced with recycled produced water.

### Potential Uncertainties

It is uncertain if recycled produced water can completely replace fresh water in hydraulic fracturing, and the feasible proportion used may differ by operator and well. In addition, oil and gas operations will likely not be able to use recycled water for all of their activities, such as on-site sanitation. Nonetheless, eliminating a portion of the fresh water needed for hydraulic fracturing would reduce operation costs as well as reduce fresh water stress in arid environments. Although the incentive of cost reduction is apparent, mechanisms to further incentivize oil and gas operators to invest in the recycling of produced water may be necessary. This could be achieved by regulations requiring the use of reclaimed produced water or market based incentives such reduced taxes to those operators reclaiming their produced water. Although reducing TDS concentration to a level suitable for drinking water may currently pose high treatment costs, the produced water treatment has the potential to be applied to other beneficial uses, such as augmenting supplies for irrigation, New Mexico’s largest water use category.

# CONCLUSIONS

The Black River Basin presents a unique setting within which to study the management of water resources in New Mexico and the arid Southwest. From a biological standpoint, the river system has become an important regional refuge for numerous vulnerable species. It supports the only remaining habitat for the Texas hornshell mussel (*Popenaias popeii*) within the state of New Mexico, and one of only four such reaches within its historical habitat extent on the Pecos and Rio Grande Rivers (Texas Hornshell Recovery Plan 2007). The basin is located amidst expanding oil and gas development occurring within the Permian Basin in northwestern Texas and southeastern New Mexico. Water from the basin is used to support hydraulic fracturing operations, as evidenced by the many recent applications to change the purpose of water rights from irrigation to commercial use. The Black River also supports New Mexico's interstate compact compliance that requires annual water deliveries to Texas on the Pecos River. Cumulatively, these factors lead to a complex set of demand conditions that water managers must consider when meeting the potentially competing requirements of biological and human needs within the basin.

This project sought to identify how changes in land and water use, and the impacts of climate change, could affect water availability within the basin, and to asses a range of management strategies that could be implemented to mitigate the impacts of these potential changes on water availability. To develop an understanding of the Black River Basin's characteristics and to assess how these changes could impact the basin's water supply, a deterministic hydrologic model using the Water Evaluation and Planning (WEAP) tool was created. Challenges faced in the WEAP model's parameterization and the inherent limitations in the model's ability to capture the underlying aquifer's subsurface flows without linking to MODFLOW, prevented confident predictions of how possible changes in land and water use could impact the water budget and streamflow in the basin.

Defining representative climate inputs and accurately modeling the subsurface and groundwater-surface water interactions within the system will be crucial in developing any understanding of the overall water budget and predicting how external stressors to the system could impact the Texas hornshell. To support this understanding and future modeling efforts in the basin, further data will need to be collected including actual water use, measured evapotranspiration rates, aquifer properties including likely flow paths and timing, and correlations between hydrology and ecosystem health.

Disruption of flow regimes could put the Texas hornshell at risk. In order to support this and other vulnerable species, this project analyzed historic streamflow data and evaluated the costs associated with meeting minimum flow thresholds. However, in light of the possible Endangered Species Act (ESA) listing, it is critical that the relationship between hydrology and ecosystem health be better understood. Climate change and the impacts of increasing water demands could lead to significant costs associated with maintaining instream flows to meet habitat requirements. Although historically the state has primarily purchased water rights to augment streamflow, further consideration of water market participation could offer flexibility in the face of limited supply and competing uses.

Immediate consideration should be given to management strategies that support effective water distribution. Four recommendations were made based on their estimated ability to increase water availability in the basin and the associated level of effort to implement each. They include:

- Increase leases and purchases of water rights to support environmental flows, in part through New Mexico's Strategic Water Reserve, and by strengthening the recognition of instream flow as a beneficial use through shifts in administrative practices at the Office of the State Engineer (NMOSE) and/or through the New Mexico State Legislature.
- Conduct changes in the NMOSE administrative practices, including: 1) strengthening and enforcing metering requirements, 2) adjusting the administration of change in purpose of use permits, and 3) more closely regulating the administration of temporary permits.
- Promote shortage sharing and/or rotational use agreements between local stakeholders to allow for collaborative, multi-stakeholder solutions.
- Incentivize produced water recycling and re-use in the oil and gas industry to alleviate demand on freshwater resources.

Successful basin management requires both prompt efforts to obtain additional data as well as the implementation of management strategies that are likely to reduce stress on water supplies and increase understanding of human impacts within the basin. This Bren School Group Project is intended to support state agencies and local stakeholders in taking actions that will allow for long-term adaptability and resiliency in water resources management within the Black River Basin.

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## B. Sensitive Species of the Black River Basin

SGCN= species of greatest conservation need

| Fish | | |
|---|---|---|
| **Common Name** | **Scientific Name** | **Status** |
| Rio Grande shiner | *Notropis jemezanus* | SGCN |
| Blue sucker | *Cycleptus elongatus* | State Endangered, SGCN |
| Smallmouth buffalo | *Ictiobus bubalus* | SGCN |
| Gray redhorse | *Moxostoma congestum* | State Endangered, SGCN |
| Mexican tetra | *Astyanax mexicanus* | State Threatened, SGCN |
| Headwater catfish | *Ictalurus lupus* | SGCN |
| Rainwater killifish | *Lucania parva* | SGCN |
| Pecos gambusia | *Gambusia nobilis* | State and Federal Endangered, SGCN |
| Bigscale logperch | *Percina macrolepida* | State Threatened, SGCN |
| Greenthroat darter | *Etheostoma lepidum* | State Threatened, SGCN |
| **Amphibians** | | |
| **Common Name** | **Scientific Name** | **Status** |
| Barking Frog | *Eleutherodactylus augusti* | SGCN |
| Rio Grande Leopard Frog | *Rana berlandieri* | SGCN |
| Plains Leopard Frog | *Rana blairi* | SGCN |
| **Reptiles** | | |
| **Common Name** | **Scientific Name** | **Status** |
| Western River Cooter | *Pseudemys gorzugi* | State Threatened, SGCN |
| Collared Lizard | *Crotaphytus collaris* | SGCN |
| Plainbellied Watersnake | *Nerodia erythrogaster* | State Endangered, SGCN |
| Western Ribbon Snake | *Thamnophis proximus* | State Threatened, SGCN |
| **Birds** | | |

| Common Name | Scientific Name | Status |
|---|---|---|
| Painted Bunting | *Passerina ciris* | SGCN |
| Varied Bunting | *Passerina versicolor* | State Threatened , SGCN |
| Yellow-billed Cuckoo | *Coccyzus americanus* | SGCN |
| Northern Pintail | *Anas acuta* | SGCN |
| Golden Eagle | *Aquila chrysaetos* | SGCN |
| Olive-sided Flycatcher | *Contopus cooperi* | SGCN |
| Southwestern Willow Flycatcher | *Empidonax traillii extimus* | State & Federal Endangered, Critical Habitat Designated, SGCN |
| Northern Harrier | *Circus cyaneus* | SGCN |
| Osprey | *Pandion haliaetus* | SGCN |
| Scaled Quail | *Callipepla squamata* | SGCN |
| Loggerhead Shrike | *Lanius ludovicianus* | SGCN |
| Bank Swallow | *Riparia riparia* | SGCN |
| Sage Thrasher | *Oreoscoptes montanus* | SGCN |
| Juniper Titmouse | *Baeolophus ridgwayi* | SGCN |
| Bell's Vireo | *Vireo bellii* | State Threatened, SGCN |
| Gray Vireo | *Vireo vicinior* | State Threatened, SGCN |
| Black-throated Gray Warbler | *Dendroica nigrescens* | SGCN |
| Lucy's Warbler | *Vermivora luciae* | SGCN |
| Yellow Warbler | *Dendroica petechia* | SGCN |
| | **Mammals** | |
| **Common Name** | **Scientific Name** | **Status** |
| Black-tailed Prairie Dog | *Cynomys ludovicianus* | SGCN |
| Mule Deer | *Odocoileus hemionus* | SGCN |
| | **Invertebrates** | |
| **Common Name** | **Scientific Name** | **Status** |
| Sideswimmer | *Hyalella* sp. | SGCN |
| Long fingernailclam | *Musculium transversum* | State Threatened, SGCN |
| Texas hornshell | *Popenaias popeii* | State Endangered, SGCN, Federal Candidate Species |

| | | |
|---|---|---|
| Pecos springsnail | *Pyrgulopsis pecosensis* | State Threatened, SGCN, |
| Creeping limpet | *Ferrissia rivularis* | SGCN |
| Ovate vertigo snail | *Vertigo ovata* | State Threatened, SGCN |

Source: (New Mexico Department of Game and Fish and United States Fish and Wildlife Service - Region 2 2008)

## C. Management Strategy Analysis

### Management Strategy Analysis

| Strategy | Potential to increase water in system | Level of effort to implement |
|---|---|---|
| Public purchase and/or lease of water rights | 💧💧💧💧 | ●●● |
| Strengthen right of instream flow as a beneficial use through administrative practices / legislation | 💧💧💧💧 | ●/●●●●● |
| More efficient irrigation | 💧💧💧💧 | ●●● |
| Aquifer storage and recovery | 💧💧💧💧 | ●●●● |
| Administrative changes in water delivery rates | 💧💧💧💧 | ●●●●● |
| Expand the Strategic Water Reserve | 💧💧💧 | ● |
| Administrative changes in metering requirements | 💧💧💧 | ●● |
| Administrative changes to change in use permits | 💧💧💧 | ●●● |
| Rotational use or shortage sharing agreements | 💧💧💧 | ●●● |
| Mitigation tax on oil and gas industry | 💧💧💧 | ●●●● |
| Private purchase and/or lease of water rights | 💧💧💧 | ●●●● |
| Changes to existing conservation tax | 💧💧💧 | ●●●● |
| Administrative changes for new temporary permits | 💧💧 | ●● |
| Local groundwater districts | 💧💧 | ●●● |
| Mitigation banking | 💧💧 | ●●● |
| Increase recycling and/or reuse of produced water | 💧💧 | ●●● |
| Water purchasing clearinghouse for oil and gas | 💧💧 | ●●●●● |
| Outstanding National Resource Water designation | 💧 | ●●●●● |
| Set minimum flow requirement | N/A | ●● |
| Remove forfeiture doctrine | N/A | ●●●●● |
| Cap and trade | N/A | ●●●●● |

## Contents

## Private purchase or lease of water rights

| |
|---|
| Encouraging non-profits or foundations to purchase and/or lease, or provide funding to support purchases or leases, of water rights in the Black River Basin as a means to increase environmental flows. Groups like Bonneville Environmental Foundation (BEF) and The Nature Conservancy would be ideal examples. However, BEF has alluded to concerns of uncertain water right policies supporting instream flows in New Mexico. This strategy would be strengthened by shifts in state statue, policies or OSE administration that more clearly upheld instream flow as a beneficial use, and the administration of rights accordingly in the OSE district offices.<br><br>In addition, the NM Strategic Water Reserve, established in 2005, allows for donations of surface or groundwater rights. Steps could be taken to better facilitate and publicize that process for private groups committed to enhancing environmental flows in NM. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, **Low** | **Amount of water**<br>**High**, **Medium**, **Low** |
|---|---|
| **Medium** to **High**: Given current NM policy, especially as related to the rights of instream flow, private groups may or may not be willing to dedicate funds to water purchasing/leasing in the state.<br>The benefit of this strategy is that it does not depend on state allocated funding. | **Medium:** Private groups could potentially invest significant funds towards instream flows. However, this is dependent on water availability and outside competition, i.e. what prices are oil and gas paying vs. what prices private groups can pay? |
| **Level of uncertainty / Assumptions**<br>**High:** Requires more study/research about rights holders willingness to sell and non-profit/foundation interest.<br><br>Would third-party effects/injury be too great of a barrier?<br>* Specifically, what is the status of the Bounds/Hoods case in the Black River and what would be necessary to overturn that decision? | **Level of uncertainty / Assumptions**<br>**Medium:** More information is needed on the availability of water for purchase, pricing competition (within NM and amongst the states in which private groups are weighing options), and the amount of funding available from private groups.<br><br>Would some groups be willing to make purchases in NM with policy as is? What policy conditions would make them sufficiently comfortable to invest? |

## Public purchase or lease of water rights

| |
|---|
| Federal/State money could be granted to purchase and/or lease water rights from private landowners to increase environmental flows. This would require the state legislature to allocate funds for this purpose. State law authorizes the purchase of water for instream flows for compliance with the Endangered Species Act and water delivery requirements under various compacts that apportion the water in the state's interstate basins. Since its establishment in 2005, the Strategic Water Reserve has been used to hold rights for those purposes. In addition, the River Ecosystem Restoration Initiative, created in 2007, can use funds for water leases and purchases. The RERI is administered by the NM Environment Department but represents diverse public-private partnerships aimed at restoring NM's river ecosystems.<br><br>Changes in OSE administrative policy and/or statutory changes in support of instream flows would strengthen this option as well. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, **Low** | **Amount of water**<br>**High**, **Medium**, **Low** |
|---|---|
| **Medium** to **High:** Due to lack of funding availability at the state level, and lack of political will to work on environmental issues. However, the institutions already exist to facilitate these purchases/leases. | **Medium:** Given available funds, this is dependent the willingness of rights holders to sell/lease their rights, which may vary based on changes in the economy. |
| **Level of uncertainty / Assumptions**<br>**Medium:** It is not clear how much funding could be made available and/or what kinds of shifts could occur in public opinion and political will to address water issues in NM.<br><br>*Under what conditions would Federal funding for environmental flows be possible? | **Level of uncertainty / Assumptions**<br>**Medium:** Even if the legislature allocated funds, for example $10 million, for this purpose, it is uncertain how much water that could buy in the Black River Basin and/or if enough rights holders would be willing to sell. |

## Mitigation Banking

| |
|---|
| A requirement that all new applications to the OSE for temporary permits, and possibly changes of purpose of use permits, purchase mitigation credits to account for increased impacts to the stream system. Landowners who are able to conserve water easily could do so to generate the credits for purchase. In the Black River this would be an intra-basin program. However, there could be further consideration given to establishing this as a regional or state-wide program. Credits could be 1:1 based off of consumptive use, or 2:1 conserved water to new consumptive use. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **Medium:** This strategy would require sufficient research to determine the hydrologic equality of mitigation credits and conserved water, as well as the work necessary to implement and administer the program. Implementation and administration would require state involvement, but could possibly be run as a public-private partnership.<br><br>This strategy avoids the political controversy of a tax, benefits landowners, and allows for continued oil and gas development. | **Medium** to Low: If applied only to temporary permits this would generate only enough water to balance, or double, temporary permits (1:1 vs. 2:1). (In 2013 there are only 6 active permit, totaling 18 AF.) But if applications for temporary permits increase significantly and/or this program was applied to other change in use permits, the effects on water in the basin could be more significant. |
| **Level of uncertainty / Assumptions**<br>**Medium** to **High:** Although there are successful examples of this strategy elsewhere (Deschutes Groundwater Mitigation Program in OR) it is unclear how it would work within current NM state policy as well as on the ground implementation. | **Level of uncertainty / Assumptions**<br>Low: Assuming that temporary permits issued in the basin have been accurately recorded on WATERS, this has minimal impact. If additional permits have been issued for which information is not publicly available, this option could provide more water.<br><br>* How would this type of program deal with rights holders who want to sell conservation credits who are not actively using their water rights? (In other words, there is no actual added water conservation. That said it could be a means of locking-in that non-use.) |

## Rotational Use Agreements

| |
|---|
| Establishing a framework for rotational use by water rights holders could address shortages in times of drought. Annual assessments could be made as to the availability of water and in drier years a system would be in place to limit use on a rotating basis amongst rights holders. Some form of compensation to rights holders who are not allowed water access that year would be likely. This type of framework could be established by the state, or initiated and implemented by local right holders independently of the state as a means to prevent a species listing and/or to more equitably distribute water in dry years. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **Medium** to **High:** Given significant water stress experienced by water users, and/or the possibility of a species listing and the associated implications of reductions in use, there would be more motivation to make this happen.<br><br>Given water stress not experienced by users, or the possibility of a species listing and its implications being perceived as low, motivation to participate will be minimal.<br><br>Coordination amongst rights holders may be challenging.<br>*Is there a track record in the basin for coordinated efforts? | Low to **Medium:** This depends on the specifics of the agreement, but is unlikely to provide much water for environmental flows beyond what is desired by users.<br><br>A high amount of water might be possible through threatened federal ESA listing or some other mechanism. |
| **Level of uncertainty / Assumptions**<br>Low: More information is needed on what would motivate rights holders to participate. | **Level of uncertainty / Assumptions**<br>**Medium:** This strategy has been successful elsewhere (ex. San Luis, CO), but given the hydrological heterogeneity of the Black River Basin it is somewhat unclear how it effective it could be. |

## Expand Strategic Water Reserve

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|---|
| The Strategic Water Reserve (SWR) is a pool of publicly held water rights established by the state legislature in 2005 to maintain stream flows necessary for endangered species as well as fulfillment of water delivery obligations to neighboring states through interstate compacts. Expanding this could mean increasing the amount of purchased rights transferred into the pool. Additional state purchases would require funding from the state legislature. The SWR allows for donation (by individuals, non-profits or foundations) of surface or groundwater rights. Although several public and private entities have expressed interest in placing rights in the SWR, no donations have been publicized thus far.<br><br>Adjustments could be made to the SWR to accommodate temporary placement of rights, as for rights holders avoiding forfeiture or participating in some form of conservation program, within the SWR. Temporary placement within the SWR would depend on specific terms to be determined by the ISC (at this point they have determined that the term of such a temporary transfer would need to be at least five years), and in addition it could be incentivized in some way. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| Low: Because the SWR already exists it is an easy solution as long as there are funds (private or public) for water rights purchasing. Level of effort becomes directly related to securing funds for purchases. | **Medium:** This depends on how much money is available for purchases and how much water is on the market. This could also be affected by outside competition, i.e. current water rights pricing. |
| **Level of uncertainty / Assumptions**<br>**Medium:** There is significant uncertainty for both:<br>• The state's ability to designate funds for purchases<br>• Private groups' willingness to purchase rights for donation to the SWR<br>* What conditions, or possible changes to the SWR, would make private donations more likely? | **Level of uncertainty / Assumptions**<br>**Medium:** More information on water rights availability for purchase is needed. |

## Water Purchasing Clearinghouse

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| Increase market efficiency by replacing informal water brokers with a more formal fresh water (not water rights) purchasing exchange that would connect buyers to sellers - especially for oil and gas industry uses. Profits currently earned by brokers could go to buyers, sellers and to supporting environmental flows. Buyers and sellers would have less uncertainty and the oil and gas industry could promote their environmentally friendly practices.<br>Ideally, the clearinghouse would be efficient enough that buyers and sellers would opt in on their own once it was established through public or private efforts. (This would be a major change in the way water is currently exchanged.)<br>Alternately, the state would have to require participation. This could include a range of options, the simplest of which would be requiring current brokers to participate in some form certification and compliance with reporting standards. A portion of their profits (through the certification process) or a fee to the industry could be used to support environmental flows. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **High:** Water has been sold in the same way for a long time in southeastern NM, essentially 'under the radar'. This would be hard to shift, but could potentially be pushed forward by the oil and gas industry if the terms sufficiently addressed their interests. | **Medium** to Low: This would depend on how the market was set up and how active it is. However, for participants to opt in, it would likely produce minimal funds for environmental flows. More funds could be generated if participation was required. (Although that may be a less politically viable option.) |
| **Level of uncertainty / Assumptions**<br>**Medium** to Low: Without industry leadership, or at least buy-in, in the formation of this type of clearinghouse its success would be unlikely. | **Level of uncertainty / Assumptions**<br>Low: We assume that it would be hard to generate enough funds through this strategy to make a significant impact on the Black River. |

## Set minimum flow requirement

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| The State of New Mexico could conduct credible hydrology/ecology research to establish a minimum required flow for the mussel (including pulses, seasonal flows, etc.) and designate this flow as an instream right. The required flow would be relevant only to a particular reach.<br><br>This was tried in 1989 with the Instream Flow Protection Act. (Did this pass?) However, rather than changing law with respect to instream flows as a beneficial use, this act aimed to identify where instream flows could be protected, recommend reaches for designation, and then work with NM DGF to identify preservation flows. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| Low: This strategy would require funding for research and could ultimately be motivated, or required, by an ESA listing. An ESA listing could force local communities to accept the use of instream flow designation as a right. | This would depend on what the ecohydrology findings conclude about how much water is needed - they could conclude that no additional water is currently needed.<br><br>If water is needed, this strategy also depends on the ability of the state to ensure that water is in the designated reach. As a junior right, the probability of this in dry years is likely to be Low. |
| **Level of uncertainty / Assumptions**<br>**Medium:** Uncertainty exists as to whether or not the mussel will be listed by USFW, and if it is listed whether or not action will be forced. Without an ESA listing, there is not sufficient precedent in NM for the use of minimum flow requirements, and local opposition would be significant. | **Level of uncertainty / Assumptions**<br>**High:** The ability to secure flows in a certain reach is uncertain, especially as a junior right.<br><br>Climate change adds additional uncertainty. |

## Adjustments in administration of change in purpose of use permits

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| The OSE could impose restrictions or more closely monitor change in purpose of use permits to address potential adverse impacts on return flow and/or overall increases in withdrawals. Adjustments could include:<br>• Limit the total number of active permits at any given time<br>• Limit the total volume of water rights in the basin that have currently active permits<br>• Increase application fees<br>• Adjust the delivery rate (CIR) for change in purpose of use permits only so as to more accurately reflect impacts on return flow and/or proximity to the stream system<br>• For dual use permits, the OSE could more carefully monitor total combined use (IRR and COM)<br>• Require and enforce appropriate metering of use |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| Low to **Medium:** This would require some changes in policy and additional resources to conduct monitoring, but could be accomplished within the OSE. | **Medium:** = Currently 12% of water rights in the basin have active permits for change in purpose of use and/or dual use permits (IRR and COM). Potential changes in administration of these policies could have a real impact. |
| **Level of uncertainty / Assumptions**<br>**Medium:** More information is need as to whether or not OSE has the authority to make some or all of these potential adjustments in administration. | **Level of uncertainty / Assumptions**<br>**Medium:** More information on trends in water use is needed, as well as the implication of current conversion rates.<br><br>If the oil and gas 'boom' continues, OSE may see increasing application rates for change in purpose of use permits.<br><br>* Does the 30% reduction from FDR (IRR use) to CIR (COM use) fully account for reduction in return flows to the system? (In other words, does the reduction in the Black River Basin from 3AF/acre to 2.1AF/acre required for temporary permits for change in purpose of use fully account for the loss of return flows to the system? And/or is current consumptive use higher than 2.1 AF/acre given high water use crops and/or high efficiency irrigation technologies?)<br><br>*Questions exist as to whether current permit holders were actively using their rights for irrigation prior to applying for |

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| | change in purpose of use permits. If they were not, and these permits allow for the use of rights that were not actively being used, this is more significant in terms of increased water use in the basin. |

## Adjustments in administration of temporary permits

Currently applicants can apply for up to 3 temporary use permits per year for 3 AF each. If applied for at the same time, the permits are issued on a rolling basis to allow for uninterrupted use of 9 AF within one year of the permit issue date. Fees for temporary permits are minimal. Permit grantees are required to submit meter readings to the OSE, but often do not. The OSE could adjust the administration of temporary permits in one of the following ways:

- Limit total number of permits issued in the Black River Basin each year
- Increase permit fees
- Enforce 3 AF/permit limit and/or 3 permit/year limit
- Enforce metering requirements and/or establish penalties for those that do not comply
- Allow only 1 permit per year per applicant (3 AF total)
- Not allow any temporary permits in the Black River basin
- Apply climatic criteria to permit granting, such as drought threshold values that trigger reductions or elimination of temporary permitting

### Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| Low to **Medium:** Better enforcement of current policy would be relatively easy to implement with some additional resources at OSE. Changes to current policy would require additional effort. Either scenario requires additional monitoring by OSE staff. | Low to **Medium** = Quantifiable changes could be measured and monitored.<br><br>However, we have found only 6 active permits in the basin this year (18 AF total assuming they are not over-pumping). |
| **Level of uncertainty / Assumptions**<br>Low: Increased monitoring and enforcement would improve understanding water use in the basin.<br><br>Better understanding is needed on the process by which OSE makes changes policy changes. | **Level of uncertainty / Assumptions**<br>Low: Assuming that temporary permits issued in the basin have been accurately recorded on WATERS, this has minimal impact. If additional permits have been issued for which information is not publicly available, this option could provide more water. |

## Remove or revise the forfeiture doctrine

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| Use policy mechanisms to prevent the "use it or lose it" of the forfeiture doctrine from encouraging unnecessary water use. This could be accomplished by the OSE continuing to loosely enforce regulations, or creating a compensation scheme to incentivize users not to sell or lease. This already exists to some extent; NMSA § 72-5-28(G) allows conserved 'non-use' water to be temporarily stored without the threat of losing the right.<br><br>*OSE does not currently enforce "use it or lose it", except occasionally for rights with 4 consecutive years of non-use before 1965. Therefore, it is possible that rights holders who were not previously using their water are reactivating those rights for temporary permits of change in purpose of use for sales to the oil and gas industry. As long as the oil and gas 'boom' continues this effect may grow.<br><br>How OSE can address this issue without addressing the forfeiture doctrine could be complicated. This issue may therefore be better addressed through the temporary change in purpose of use permitting process. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, **Low** | **Amount of water**<br>**High**, **Medium**, **Low** |
|---|---|
| **High:** This would require a major policy/regulatory shift with potentially significant consequences in water use. | Unknown at this time. |
| **Level of uncertainty / Assumptions**<br>**Medium:** It is unclear what the process would be for this policy shift and/or what the possible consequences could be.<br><br>Also, more information is needed as to whether rights covered by NMSA § 72-5-28(G) could be placed in the SWR. | **Level of uncertainty / Assumptions**<br>**Medium:** Unknown if this would actually achieve quantifiable water conservation. |

## Strengthen/enforce metering requirements

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| To ensure better compliance with metering regulations, the OSE could consider the following initiatives:<br>• Increase education for new and existing users<br>• Increase enforcement and monitoring for accuracy<br>• Penalize rights holders who do not comply with metering requirements<br>• Increase the lead time for the temporary permit filing process to ensure meter installation for all new temporary permits |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| Low to **Medium:** This would require better administration of current OSE policy, and/or some changes in policy and additional OSE resources to conduct the changes. | **Medium** to **High:** This option could potentially capture major savings. |
| **Level of uncertainty / Assumptions**<br>Low: Conducting these changes should not be too complicated and would allow for better information collection and ultimately greater rights holder compliance with FDR and CIR use rates. | **Level of uncertainty / Assumptions**<br>**Medium:** This strategy assumes that users are regularly in non-compliance with both metering requirements and delivery rates. |

## Strengthen the right of instream flow as a beneficial use

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| The OSE could provide leadership in administration of current instream flow policy. This would address the apparent disconnect between state policy and lack of administration of that policy through the regional OSE offices. In addition, efforts could be made, likely outside of the OSE, to push for statutory confirmation of instream flow as a beneficial use through the NM State Legislature.<br><br>The 1989 Attorney General Opinion issued by Tom Udall confirmed instream flows as a beneficial use under NM law, and states that approval of such permits by the OSE may be conditioned on the use of some type of measuring device. 'Streamflow augmentation' does not require measuring after discharge to the receiving water and has therefore been more acceptable to OSE staff charged with administering NM water rights. Standardizing, clarifying or adjusting acceptable standards for instream flow measurements could be beneficial. And, those standards must account for gaining and losing stream reaches. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| Low: OSE leadership in administration of current policy could be accomplished relatively simply.<br>**High:** Statutory designation through the state legislature would be challenging. | **High** to **Medium:** Could significantly encourage private purchase of water rights for instream flow, and would clarify OSE and the state's position on this issue. |
| **Level of uncertainty / Assumptions**<br>Low = In terms of level of effort, actions from the OSE office could be fairly simple. We assume legislation would be more difficult.<br>*Because of challenges in enforcing instream flow, perhaps measuring requirements could be adjusted. What would that process entail? And to what extent would we want to diminish/remove measurement requirements? | **Level of uncertainty / Assumptions**<br>**Medium:** It is fairly unclear how much water this could produce, although it appears to be an obstacle. NM is behind other several other western states in its policies in support of instream flows. |

## Formation of a local groundwater management district

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| A local groundwater management district could be created to administer groundwater use in the basin, that is, local rights holders would be empowered to manage, within the limits of state law, decisions regarding basin administration. (Different from AWRM in that it would be administered locally rather than by a designated water master, in so far as certain criteria are met.) This type of district would be particularly useful in times of drought, and could have a taxing authority to create an earmarked fund for compensating farmers for fallowing in times of shortage, or for switching to more water-thrifty crops that may, at least initially, result in reduced profitability.<br><br>Formation of a groundwater district could be initiated by the OSE or by local rights holders themselves. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, **Low** | **Amount of water**<br>**High**, **Medium**, **Low** |
|---|---|
| **Medium:** Depends on 1) motivational factors for rights holders - they gain autonomy while agreeing to conditions that could include maintaining some designated minimum flow, and 2) legal authority from state for formation of this type of district (not unlike acequias).<br><br>What drives this, a potential species listing, concerns about water access? How likely are folks in that basin to organize and coordinate? | **Medium** or Low: This depends on how the district is administered. But it is likely that users will not offer up much more water than they have to for environmental flows. |
| **Level of uncertainty / Assumptions**<br>**High:** We are not sure whether or not the legal framework exists in NM to enable this type of district. (Again, could be not unlike acequia system.) If it does not exist, this might require state legislation. | **Level of uncertainty / Assumptions**<br>**Medium:** There are very good examples of local groups decreasing use through local administration (Kansas groundwater districts, PVACD's reductions in use in the Roswell area.) |

## Adjustments to delivery rates

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| Adjustments to delivery rates (FDR and CIR) for the Black River basin specifically or the administrative region, that could include:<br>• Decreasing the total delivery rates<br>• Adjusting delivery rates annually based on water availability (Essentially delivery rates per acre would be proportional to annual estimates of water availability, similar to CID's annual determination of water rates for members based on available storage in Brantley Reservoir.)<br>• Adjusting the 30% reduction in delivery rate between the FDR and CIR to more accurately reflect impacts on return flows - across the basin or based on proximity to the river |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **High:** There would be significant push back from water rights holders.<br><br>*Although there is a challenging disconnect for the state of NM between fixed delivery rates for rights holders and annual delivery requirements to Texas based in part on variation in climate. | **High**, **Medium**, or Low: Depends on the size of the delivery rate reduction. |
| **Level of uncertainty / Assumptions**<br>Low: We assume that this would be highly politically infeasible, but recognize that it may be something that the OSE will have to address in the long run. (Especially as increasing efficiency in irrigation technologies continues to generate more water availability for irrigators at the expense of river flows.)<br><br>Beyond political obstacles and public dissatisfaction, there would also be obstacles in enforcement for OSE. | **Level of uncertainty / Assumptions**<br>Low: See above. |

## Mitigation tax on oil and gas industry purchases of water from within the basin

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| Either reallocate a portion of the current tax revenues from oil and gas development to water conservation purposes, or implement a new excise tax/fee on water purchased from within the basin. It would have to be low enough that it would still be attractive to purchase from within the basin and not have to pay trucking expenses. Revenues could be used to purchase rights and place in the Strategic Water Reserve. Additionally, permitting for oil and gas could include conditions such as a minimum percentage of water used coming from recycled sources and/or requirements to recycle a minimum percentage of produced water from each operation. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **Medium** to **High:** Reallocating a portion of current taxes would require the least effort; there will be little political tractability to create any new tax. The oil and gas industry would be unhappy, but could be included in the development of regulations and offered an opportunity for positive PR on environmental issues.<br>Administrative/enforcement changes could be challenging, most particularly for any new tax on water sales. | **Medium:** This depends on the amount of money generated by existing taxes. A new tax could generate significant funds (to the extent that the state is able to implement and enforce the tax).<br><br>Tax generated funds for purchases/leases of water rights also depends on the availability of rights in the basin. |
| **Level of uncertainty / Assumptions**<br>**High:** We assume that decisions to redirect current tax funds would need approval from the state legislature. We also need more information on much revenue is generated by existing taxes.<br><br>That is certainly true for the implementation of any new tax. | **Level of uncertainty / Assumptions**<br>**High:** There is significant uncertainly about how much water this could purchase/lease because there are many variables involved. |

## Redirect revenues from and/or increase the existing conservation tax on oil and gas

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| Some portion of the current Oil and Gas Conservation Tax could be redirected to fund water rights purchases/leases. Currently, the tax is dedicated to plugging abandoned wells and educational initiatives. This existing tax could also be increased, dependent on a change in political climate. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **Medium** to **High:** Shifting the use of revenues from an existing tax could be less challenging than increasing the tax. However, plugging wells may be seen as a safety measure, whereas instream flows may seem unnecessary to those not interested in environmental issues. | **Medium** to **High:** The more oil and gas development, the more tax money there could be to purchase water. However, this depends on the size of the revenue generated by the current tax and what portion of that could be redirected and/or increased. |
| **Level of uncertainty / Assumptions**<br>**Medium:** More research needed on current tax. We assume redirecting funds from the current tax would require state legislature approval. | **Level of uncertainty / Assumptions**<br>**Medium:** More research needed on current tax and how much revenue it generates. |

## Increase recycling and re-use of produced water

A high volume of produced water is generated by the oil and gas industry. By increasing the recycling and re-use of produced water, demand for fresh water from the Black River Basin, and elsewhere, would be reduced. Mechanisms to increase re-use of produced water include:

- State requirements that a portion of water used/produced in oil and gas operations be recycled
- Provide incentives for operations that recycle water
- Encourage reuse by enabling the use of large scale portable pits for storage of produced water between operations (for some form of treatment before reuse)
- Provide incentives to support generation of new technologies that make reuse more possible
- Create a public-private task force, including oil and gas industry representatives, to advise the creation of policies that reduce fresh water use while meeting industry needs

*Some industry changes may occur without state involvement, for example, Halliburton is already working on a gel additive to enable reuse of produced water.

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **Medium:** Push back from industry could be significant, but would be reduced by inviting them to participate in the solution.<br><br>Current Halliburton R+D on reuse shows that industry is either looking for ways to reduce costs or avoid future regulation, or both. | **Medium** to Low: Depending on the portion of produced water that could be recycled. If all produced water was recycled this could be significant. |
| **Level of uncertainty / Assumptions**<br>**Medium:** We need to know more about why this is not already being done, i.e. regulatory framework, costs to industry especially trucking costs, political feasibility. | **Level of uncertainty / Assumptions**<br>**High:** We need more information on how what percentage of water in the Black River Basin actually goes to oil and gas use. Fewer temporary permits than we expected are listed on WATERS meaning that the portion of use for oil and gas may be smaller than we originally anticipated. |

## Aquifer storage and recovery

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| During wet years, water in excess of user, environmental and compact requirements could be captured and either allowed to infiltrate slowly or re-injected into the groundwater basin. Capture would involve construction of infrastructure to catch excess runoff safely. Infiltration basins could be constructed and located strategically where the most recharge into the groundwater basin is likely, i.e. maximizing natural heterogeneity to increase infiltration rates. Re-injection wells could also be constructed to move the water into the aquifer more quickly.<br><br>This strategy aims to take advantage of summer monsoons to reduce runoff and keep water in the system for a longer period of time. |

## Rankings:

| **Level of effort**<br>**High, Medium, Low** | **Amount of water**<br>**High, Medium, Low** |
|---|---|
| Medium to **High:** This strategy has high infrastructure costs, but lower political and regional opposition. It may be a solution that everyone can get on board with - holding water in the basin longer is good for users and the environment, but may have significant consequences for compact deliveries to Texas. | Medium to **High:** Depending on the infrastructure chosen, large volumes of water could be captured. (Peak flows last September in the Black River were over 2,000 cfs.)<br><br>Seasonal variation in climate as well as climate change must be considered. |
| **Level of uncertainty / Assumptions**<br>**High:** Although the state has granted significant funding toward managed aquifer recharge (MAR) project including Bear Canyon, incentives to dedicate funds to projects in the Black River Basin may be small - too few users.<br><br>Significant uncertainty exists as to whether the aquifer system in the basin is capable of supporting ASR. | **Level of uncertainty / Assumptions**<br>Low: We assume that large volumes of water could feasibly be captured and for aquifer storage as long as the infrastructure was in place. |

## Designation as an 'Outstanding National Resource Water' (ONRW)

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| Designation of the Black River as an Outstanding National Resource Water would establish criteria for designated stream uses, and establish provisions to preserve water quality. In the last decade work was begun to apply for ONRW designation, but political obstacles have stalled that process. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **High:** Given the current political climate this could require many levels of approval and significant resources to implement. | Low: This measure focuses on water quality rather than quantity. However, required higher quality may have implications for securing stream flow. |
| **Level of uncertainty / Assumptions**<br>**Medium:** We need more information on what would need to shift to make this designation possible. | **Level of uncertainty / Assumptions**<br>**High:** We would need more information on the relationship between water quality and quantity on the Black River specifically. |

## Incentives to switch to more efficient irrigation under condition of reduced water right

Conservation-use agreements would allow the state/private entities an opportunity to purchase or lease conserved water from agricultural efficiencies. Farmers reducing their water use could sell that portion of their water right and/or lease their conserved water to the state/private entity. Also, state/private entities could increase incentives to employ more efficient irrigation technologies by offering funding support.

### Rankings:

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|---|---|
| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
| **Medium:** Conserved irrigation is definitely the low hanging fruit, but funding for purchases may be limited. | **Medium** to **High:** Significant water can be gained through increased agricultural efficiencies. |
| **Level of uncertainty / Assumptions**<br>**Medium:** We need more information on rights holders' willingness to sell and how to accurately balance impacts of increased efficiencies on return flows. | **Level of uncertainty / Assumptions**<br>**High:** This is in large part dependent on current agricultural practices in the Black River Basin and how much room and incentive there is for improvement. |

## Cap and Trade Program

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| Implement a shift from appropriative rights management to a cap and trade scheme, wherein a cap would be set to the perennial yield of the basin and shares of the 'budget' would be allocated to current water rights holders. The cap could be adjusted annually according to estimated storage, the previous years' rainfall, or future projections. Water that is conserved or unused could be sold or leased, including to the Strategic Water Reserve. This would eliminate the perverse incentive to potentially waste water if it is not put to beneficial use. Although stakeholder buy-in could be difficult, a solution like this might be attractive if the ESA listing were to impose significant hardships on the CID and other users, since it could facilitate management and lay the framework for a market. To benefit the landowners in the cap and trade program, the current temporary permit scheme could be reworked to include only emergency permits, allowing for water transactions with the oil and gas industry and other temporary users. |

## Rankings:

| **Level of effort**<br>**High**, **Medium**, Low | **Amount of water**<br>**High**, **Medium**, Low |
|---|---|
| **High:** Unless a listing were imposed that would significantly curtail irrigation and use, or would create instability in administering appropriative rights. Little incentive to participate exists.<br><br>This would require administrative and/or legislative changes. And would require information and a background assessment to set cap, as well as ongoing monitoring after implementation. | Low, **Medium**, or **High:** Depends on what the current use is, in comparison to the availability or the estimated perennial yield (if use is high, then the return on effort could be high).<br><br>This would also depend on what required flows or storage were set forth in the recovery plan to support the listed species (if the required storage and/or flows are much higher than they currently are, return on effort could be high). |
| **Level of uncertainty / Assumptions**<br>**Medium:** We assume that unless there is enough of an impetus, from potential listing impacts, or an overdraft situation, no administration would likely implement this strategy.<br><br>*Questions exist as to how to allocate shares in a 'fair' way. Should it be based on previous, demonstrated use, or irrigated acreage? | **Level of uncertainty / Assumptions**<br>**High:** There is uncertainty in the level of difficulty in collecting information and accurately setting basin yield and monitoring standards.<br><br>Also, uncertainty exists in estimating what amount of storage/flows would be required for species recovery. |

## D. Map of Carlsbad Area Irrigated Lands and CID District

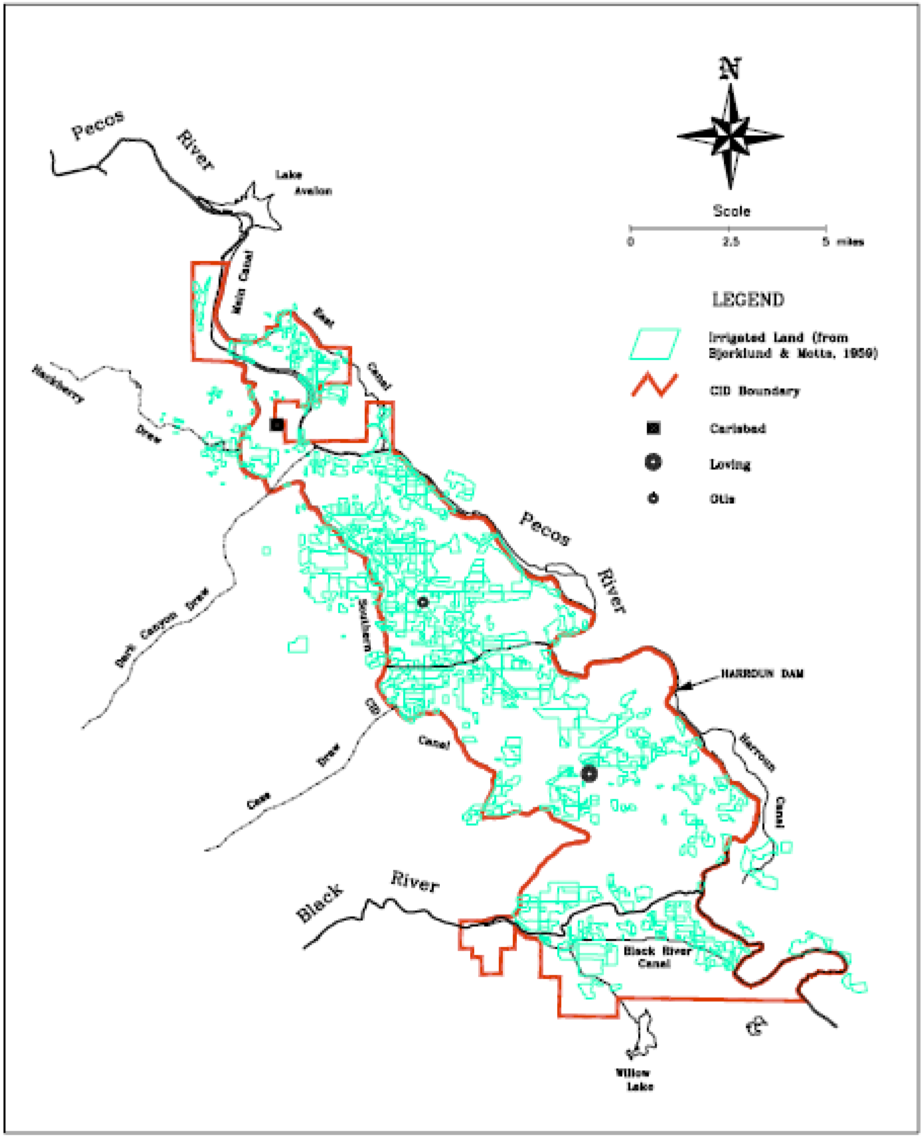


Figure 1-3. Carlsbad Area Irrigated Lands and CID Boundary.

Source: (Barrell, 2004)