PEDERNALES WATERSHED
STRATEGIC CONSERVATION PRIORITIZATION

The Meadows Center for Water and the Environment, Texas State University | *Hill Country Alliance*

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Cover Image. The Pedernales River. Courtesy of The Hill Country Alliance, www.hillcountryalliance.org

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PROJECT GOALS

1. Use the best data and analysis methods available to inform good decision making, for the efficient use of hydrological, cultural, and ecological resources associated with conservation in the Pedernales Watershed.

2. Conduct an overall characterization of land use and natural resources in the Watershed to inform conservation efforts.

3. Create an informative, compelling tool that identifies areas of highest conservation value in the watershed, and supports and catalyzes action by stakeholders, decision makers, and conservation practitioners.

4. Document terrestrial conservation opportunities in the watershed to help protect the water supply for downstream communities.

Image 1. Hamilton Pool. Picture courtesy of KUT.org

SUMMARY

The Pedernales River watershed is a critical refuge for life in the Texas Hill Country. The watershed provides water, agricultural resources, and tourist attractions to millions of people, while simultaneously protecting the unique flora and fauna of the region. Large, undeveloped, open lands within the watershed protect the quality and flow of the river, which in turn contributes 23% of base flow to Lake Travis, and by extension the water for the Austin metropolitan area (Meadows 2016).

While the watershed is a haven, it also sits at the edge of a rapidly expanding metropolitan area. Stretching from San Antonio and Austin to the south and east, and along the Highway 71 and Interstate 10 corridors to the north and west, this area is home to more than 4.2 million people. People choose the Hill Country as their home for the beauty and the equally stunning quality of life. Unfortunately, the form of development that accommodates new residents is threatening the very amenities they desire. Between 1997 and 2012, Texas added an average 500,000 residents each year (Texas Land Trends 2014). This trend greatly impacted Bell, Williamson, Travis, Hays, Comal and Bexar counties, which border the Pedernales Watershed on its eastern edge. All six ranked among the top 25 highest population growth counties and saw a 25%-100% decrease in working lands over the 15- year period (Texas Land Trends 2014).

Over the next 50 years, the population of this area is expected to double (TWDB 2016). The impending fragmentation and development that will likely accompany this growth will impact the nature of the watershed and the critical ecosystem services it provides. Areas within the watershed, including the rolling Hill County landscape, iconic Texas towns, and functioning watersheds (Figures 3-4), are already experiencing pressure from ex-urban large-lots and suburbs (Figure 6). Between 2001 and 2011, high intensity development within the watershed expanded by 20 percent, to cover 8,100 acres (land use data, Texas State University Geography 2014). If current development patterns (Figure 6, 9) continue, the expansion will fundamentally alter the character of the watershed and impact its ability to provide critical resources to existing and future Hill Country communities.

While these challenges are substantial, conservation and the wise use of our resources can help ensure that fundamental environmental services will continue in perpetuity. Models of successful conservation initiatives already exist at the regional (e.g., San Antonio Edwards Aquifer Protection Program, Texas Playa Conservation Initiative), state (e.g., Texas Living Waters Project), national (e.g., Network for Landscape Conservation), and international level (e.g., Yellowstone to Yukon Conservation Initiative). These programs employ a multi-pronged approach of education, policy, and public-private partnerships—which facilitate stewardship and the purchase of conservation easements—to have large-scale, quantifiable impacts. In Texas alone, conservation easements over the past four decades have been used to protect over 1 million acres through the support of willing, private land owners (TLTC, Siglo Group). In the coming decades this powerful tool—which allows the land owner to maintain ownership and continue traditional agricultural practices while preserving open space—will likely surpass publicly owned land in both quantity and importance. Where it is feasible, conservation easements can also be supplemented by purchases of key conservation lands, cost-sharing for environmental management, and other voluntary incentives. Together, these tools are one piece of a comprehensive strategy that requires public investment and regulatory programs to advance multi-benefit conservation.

Building on these already effective strategies, the Pedernales Watershed's Strategic Conservation Prioritization identities lands that will maximize the efficiency and success of conservation investments within the study area

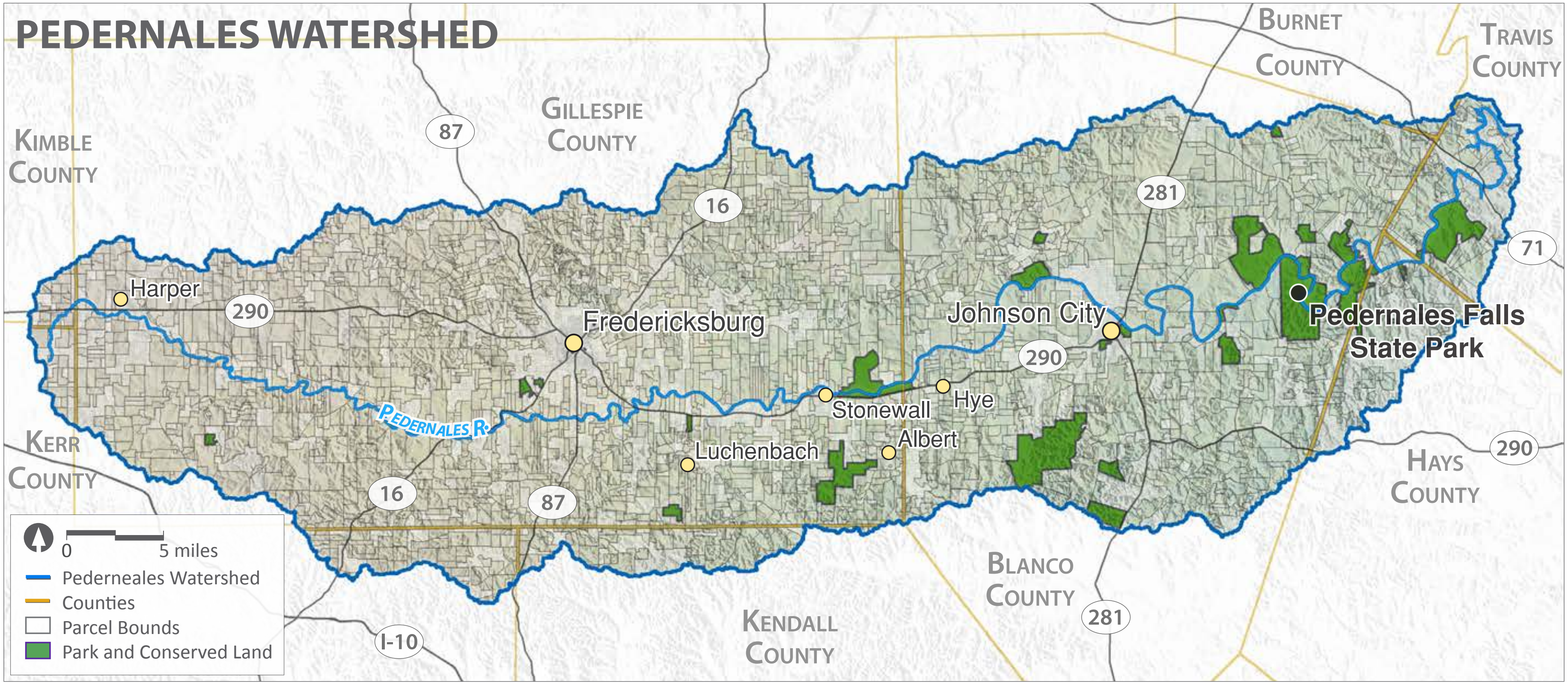


Figure 1. The Pedernales River Watershed Study Area, including parcels, conservation lands, major roads, and county lines.

(results can be seen in Figure 2, the extent of the study area is in Figure 1). The prioritization uses a repeatable, procedural model within a geographic information system (GIS) framework to delineate the geographic distribution of conservation resources and their significance. The result is a set of prioritized areas that are suitable for immediate conservation action. These targets are time-sensitive, as some areas will likely be negatively impacted by ongoing development, rises in property costs, and degradation of natural resources. Fortunately, if more narrowly targeted evaluations are needed in the future, this prioritization can also be aggregated to specific parcels (see Figure 17 for an example of aggregation).

Overall, this strategic prioritization evaluated 819,370 acres of the Pedernales Watershed (Figure 2) for hydrological, ecological and cultural significance. Our findings isolate 160,420 acres (20%, Figure 16) that were deemed to be of the highest conservation value. Of these, 125,050 acres are in areas available for conservation and promise the greatest acre-for-acre impact. Four clusters—near Pedernales Falls State Park, the eastern section of the basin, along the Pedernales River, and among tributary streams— stand out as focus areas for concerted conservation action:

1. **Pedernales Falls State Park Conservation Cluster.** Several conservation properties form a cluster around and east of Pedernales Falls State Park and could be linked and expanded for significant conservation benefits. The cluster could serve as an important regional model of successful public-private conservation partnership. Within this area, the Ellenburger-San Saba Aquifer, between Pedernales Fall State Park and Johnson City, is an especially important contributor to stream flow.

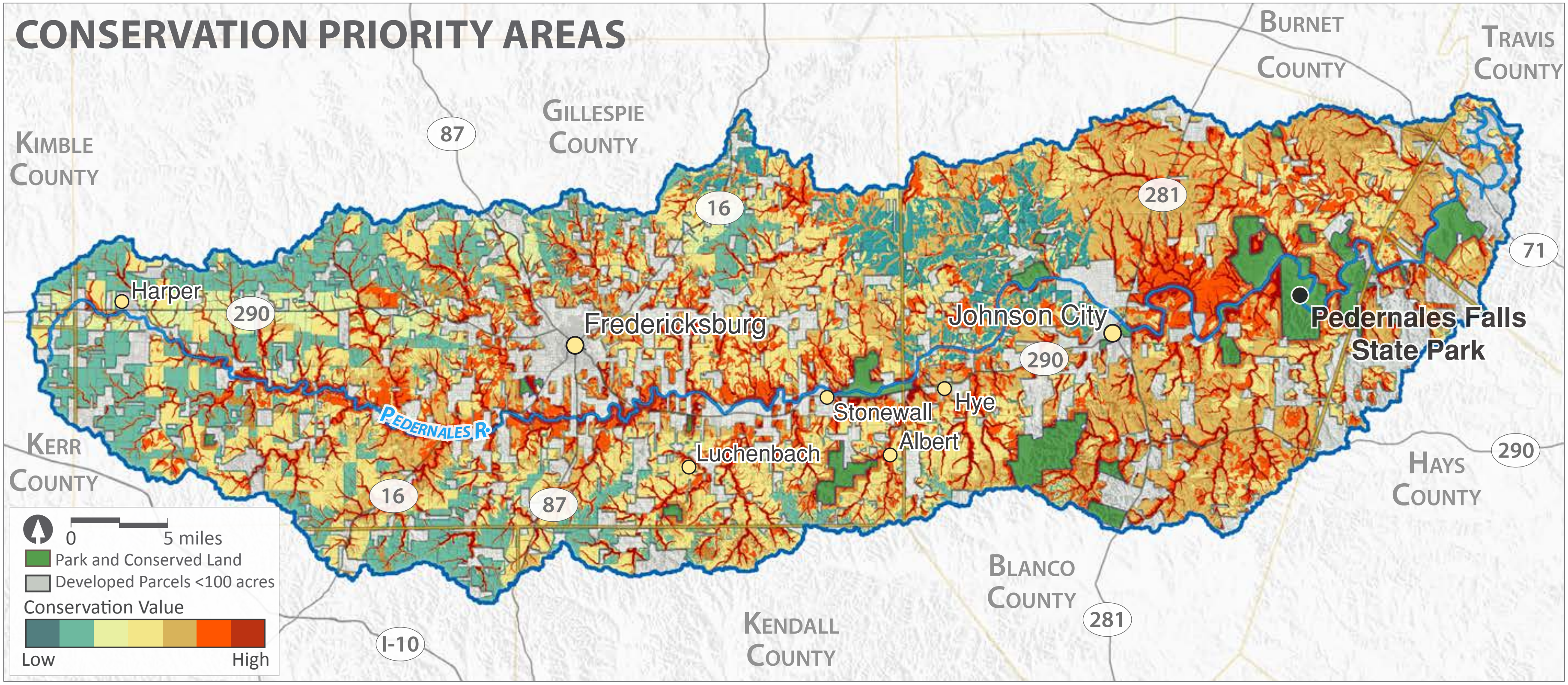


Figure 2. Conservation values across the Pedernales River Watershed. High-priority conservation areas shown in red; callouts indicate the 4 priority conservation clusters.

2. **Eastern Watershed Growth Opportunity Corridor.** Development in this area closely follows highways 281 and 290 (Figure 6). Within the eastern-downstream portion of the watershed, areas adjoining these roadways are under substantial development pressure. Several large properties, an aquifer recharge zone, and multiple tributary streams—including the 20-mile-long Cypress Creek—also overlap in this area. Because of its proximity to the Austin Metropolitan area, conservation efforts in this sub-region are highly time-sensitive and are expected to have greater direct impacts.

3. **Pedernales River Corridor.** Lands, especially riparian zones, along the main channel of the Pedernales meet many overlapping water protection conservation priorities. They also align with water quality buffers and the highway 290 development opportunity corridor, and their linear form offers potential for greater watershed-wide habitat connectivity.

4. **Tributary Streams Corridors**. In addition to Cypress Creek, noted above, several major streams flow into the Pedernales River. These areas serve as important buffers for the protection of riparian habitat, potential areas of archeological significance, and water quality.

Armed with this strategic tool, conservation practitioners can focus their efforts to maximize their impact. The Pedernales watershed is a major lifeforce for the citizens of Fredericksburg, Johnson City, and beyond, and acts as a key contributor to Lake Travis, the main drinking water source for the city of Austin. As a result, any conservation investments will affect hundreds of thousands of downstream residents. By strategically assessing areas for conservation, this prioritization provides a path forward for philanthropists, land trusts, municipalities, river authorities, and others, so that they may efficiently and effectively invest in the Hill Country's successful future.

Figure 3. Photos from the Pedernales River Watershed. Clockwise from top left: "The Old Fredericksburg Bank", Chris Litherland, commons.wikimedia.org; "Texas Wine Grapes", Texas A&M AgriLife Extension Service, today.agrilife.org; "Lavender east of Fredericksburg", Sage to Meadow, swamericana.wordpress.com; "Is That a Welcome Sign?", D.J.Z., geographicallyyourswelcome.blogspot.com

INTRODUCTION

A well-functioning environment provides the numerous services upon which community health are built. In the case of the Pedernales, the watershed provides clean air and water, flood control, species habitat, recreational opportunities, and natural beauty. Currently, the Pedernales is a healthy water body, fully capable of providing these services. However, recent work by the Meadows Center for Water and the Environment showed that the steady growth of cities in the watershed, the increasing number of small ranches, expansion of tourism, and thriving agricultural industry are expected to increase the water demands by approximately 30% over the next 50 years (Meadows 2015, 2017). Additionally, imminent growth from highways 290, 281 and 71 promises to substantially degrade the watershed, limiting its ability to provide clean water and mitigate the effects of large rainfall events.

Now, residents must adjust course to plan for the future and build systems that enhance health and livability. This will require concerted and persistent strategy. Action-oriented conservation initiatives must remember that long term growth and development require a balance between cultural, ecological, and water resources, and economic opportunity. Studies have shown that the conservation of natural systems is both a necessary and cost-effective way to meet a variety of societal needs. For instance, in the 1800s, emerging cities across the U.S. made substantial investments to protect the lands at the source of their water supplies. Because of this, watersheds in the Catskills, Sierras, Cascades, and their foothills continue to provide safe drinking water to millions of Americans. More recently, smaller communities, from North Carolina to Ohio to Oregon, have used a variety of tools and partnerships to mitigate specific threats and ensure the long-term quality of their water (TPL 2004). One important collateral benefit of this action is that once protected, these lands can be preserved or managed to also enhance recreation, carbon sequestration, and the proactive mitigation of flood (Figure 5) and wildfire events.

Regionally, San Antonio provides a powerful model for conservation opportunities. After a successful municipal referendum in 2000, the city and its partners worked with local land owners to protect over 200,000 acres to maintain water supply and quality. This acquisition is estimated to benefit 1 to 5 million downstream residents at a fraction of the cost of finding and treating new water supplies (Siglo Group 2017, TNC 2017).

Following the best practices established by the San Antonio Edwards Aquifer Protection Program, this project will assist the Meadows Center for Water and the Environment in taking a strategic, proactive approach to conserving watershed resources. The prioritization presented here utilized numerous professionals and stakeholder groups to refine the process, guide calibration, and translate conservation goals into discrete data (Figure 8, 12). This data was then integrated into a procedural model within a geographic framework. This allows for repeat evaluations as new information comes to light or conservation opportunities and priorities change. The model follows two methodologies—one developed by the San Antonio Edwards Aquifer Protection Program to determine water resource conservation areas in the Edwards Aquifer (Siglo Group 2014), and another employed to prioritize lands in the Blanco and Upper San Marcos Watersheds for the Meadows Center at Texas State University (Siglo Group 2017).

The conservation priorities determined through this project support land conservation efforts within the Pedernales Watershed by identifying those areas that most efficiently meet multiple conservation objectives. This information should be useful to a cross section of stakeholders involved in conservation at the local, regional, and state level. However, it is only one phase in the process. This prioritization should be used as a catalyst and guide for additional action. Notable subsequent steps include the development of educational and policy-based stewardship programs, the identification of conservation funding mechanisms, the cultivation of relationships with willing land owners, the evaluation of particular properties, and the purchase and acquisition of conservation easements and assets.

Figure 4. The Pedernales River at Pedernales Falls State Park. Picture courtesy of www.wikimedia.org

STUDY AREA

This study area is defined by the flow of water in the Pedernales Watershed. It covers 819,370 acres across the Hill Country's iconic topography, communities, and agricultural lands. The area includes portions of Mason, Llano, Burnet, Travis, Hays, Blanco, Kendall, Gillespie, Kerr, and Kimble Counties, as well as Johnson City, the city of Fredericksburg, and extra territorial jurisdictions (Figure 1).

Growing Population

Fredericksburg is the largest population center within the study area with a reported population of 11,380 in 2016; an 8% increase since 2010. Unincorporated portions of Blanco and Gillespie Counties comprise another sizeable part of the watershed. While their populations are small—11,400 and 26,500, respectively—they are expected to nearly double in size over the next 50 years (US Census 2017, Meadows Center 2015). This growth will likely affect rates of groundwater pumping, particularly across the largely rural watershed. Increased pressure on the watershed will also trickle down through the communities beyond Fredericksburg and Johnson City—including Stonewall, Hye, Harper, Albert and others. While these areas are largely unincorporated and host smaller populations (Harper's reached 1,192 people in 2010), they still serve as key contributors to the economy and culture of the region.

The large tourist population centered on Fredericksburg, and rapid population growth and development pressures nearby, are expected to add to these future water demands. Five counties at the center of this development—Bexar, Comal, Hays, Travis, and Williamson—are projected to experience a 100% population increase, exceeding 8 million, by 2070. Areas from Marble Falls to San Antonio, and from Austin to Dripping Springs and through to Fredericksburg, have already experienced unprecedented land use change in recent years. This development closely follows highways 290 and 281 (see Figures 1, 6, 14), which together transect the watershed and cross the river and its tributaries numerous times. As can be seen in Figure 1, highway 281 traverses the watershed from north to south and intersects Highway 290, which parallels the river for much of the study area.

While highways 281 and 290, and the smaller highways 71, 16, and 87, undoubtedly service the 4.2 million residents of Austin and San Antonio's growing metro areas (TWDB 2016), they have also opened the door to development that largely degrades the services these communities need. Linear infrastructure—including highways and pipelines—and its ensuing development are known to negatively impact watershed quality and function (Fredriksen 1970, Hobbs & Ledger 1986, Trombulak 2000, Geneletti 2004, Cott et al. 2015,). Their straight lines fragment habitat (Vos & Chardon 1998, Keller & Largiader 2003), damage streams through crossings and disrupt natural drainage systems (Jones et al. 2000, Trombulak 2000), increase soil erosion (Forman & Alexander 1998) and noise pollution (Kight & Swaddle 2011, Francis & Barber 2013), and introduce invasive species (Christian & Matlack 2009, Barbosa et al. 2010). In the study area, Siglo's calculations estimate that 30% of land (246,667 acres) has already been developed. This number includes parcels under 100 acres, as well as portions of larger parcels characterized as urban or suburban development by the 2011 National Land Cover Dataset or the TPWD Ecological Systems Classification (2014). Much of this conversion is due to expanding populations and follows traffic arteries. To date, the growth has largely encroached into the open space surrounding these hubs, including aquifer recharge zones and areas traditionally used for ranching and agricultural production (Texas Land Trends 2014).

Unless we make a concerted intervention to protect the Pedernales watershed, our quality of life, ecological systems, and health will remain at-risk.

Current land development patterns indicate that rural parts of the study area will experience sprawling suburban development along with further reductions in ranching, agricultural, and natural lands in the near future. Common trends of low-density, high-impact development are also cause for concern. These subdivisions, roadways, and infrastructure come right up against the urban-wildland interface, degrading wildlife habitat and increasing the likelihood of flood and wildfire events. This development also has the potential to impact water resources through ground water pumping (Hunt 1999), the expansion of impermeable surfaces (Konrad 2003), and increased water nitrification and sedimentation (Nassauer et al. 2004, Dietz & Clausen 2008).

While these events may come to pass, they are not inevitable. As was mentioned above, the Pedernales River is currently in relatively good condition (Meadows 2015). While growth and development are already impacting the watershed, its form remains to be determined. The motivation behind this prioritization is to highlight the key areas where resources should be invested to ensure that the health of this watershed continues to be preserved.

Conservation Lands

The study area includes 31,809 acres of conservation and park land, which represent 3.9% of the study area. These areas include 22 public parcels, totaling 11,790 acres, and 25 private parcels, totaling 20,019 acres. The most notable public protected lands include the 1,500-acre Lyndon B. Johnson State Park & National Historic Site and the 5,400-acre Pedernales Falls State Park. More than 9,000 additional acres of privately conserved ranches surround the latter, forming a connected ecological system that can help mitigate the effects of rapid suburban development along the Highway 71 and Highway 281 corridors.

Nearby, the 3500-acre Bamberger Ranch Preserve also holds a long tradition of stewardship and conservation. Located in Blanco County, the ranch preserve was bought by J. David Bamberger in 1969 for the specific purpose of restoring it back to functional health. In the nearly 50 years since, the preserve has become one of the largest habitat restoration projects in the state, winning numerous awards. These awards include recognition from the Texas Forest Service, Nature Conservancy of Texas, and the Texas Wildlife Association. After the large removal of Ashe juniper trees and the replanting of native grasses, water on the property is once again flowing, with the major spring producing more than 4,000 gallons per day on average (Bamberger). These springs provide all the water for the ranch, including three households and agricultural use, before seeping into the headwaters for Miller Creek and thus the Pedernales and Colorado Rivers farther downstream. While the ranch preserve has experienced a long history of conservation and stewardship, establishing a plan for its protection in perpetuity will be a critical step in solidifying the success of conservation initiatives in this area (Bamberger website, May 2018).

Flooding in the Basin

The Pedernales is one of several Texas Hill Country river systems characterized by intense rainfall events, steep slopes, and sparse ground cover,

Table 1. Conservation acreage by category (public/private) across the Pedernales River Watershed (Data from Texas Land Trust Council and Siglo Group).

	Private Conservation Acres	Public Conservation Acres	Total Conservation Acres	Total Acres
Pedernales River Basin	20,019	11,790	31,809	**819,370**

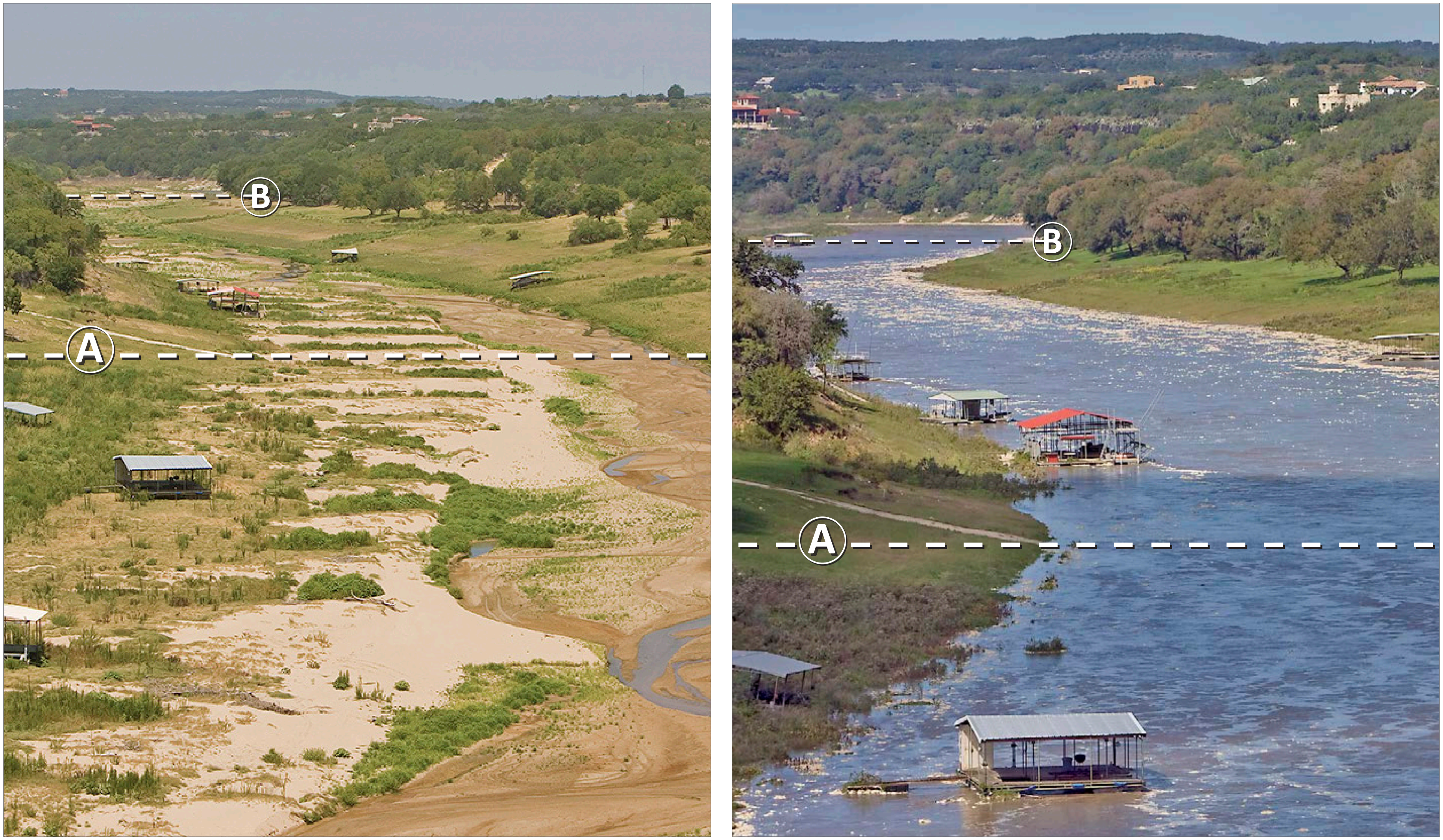


Figure 5. The lower Pedernales River during drought (left) and flood (right). Pictures courtesy of statesman.com and ralphbarrera.files.wordpress.com

which lead to rapid runoff and the potential for devastating and deadly flooding. Nineteen significant flood events have occurred in the watershed since the 1940s. In September of 1952, the largest flood on record resulted in the river cresting to 42.5 feet. Between 2000 and 2017, the river went into flood stage six out of seventeen years. This includes the fifth highest recorded flood event in 2002, when the river in Johnson City reached 26ft (USGS 2003, National Weather Service 2017).

While the extremity of these two record-level floods is somewhat rare, significant floods still occur regularly. In Johnson City, where flood stage is reached at 14 feet, most of the floods on record have exceeded 20 feet. Fortunately, conservation and land management efforts on public and private lands have demonstrated an ability to mitigate the worst of these effects; reducing the number of people and structures in harm's way, increasing water infiltration, stabilizing soils, and filtering runoff. These ecosystem benefits result in reduced peak flows during rain events, reduced sedimentation in Lake Travis—a critical, regional water supply reservoir—and reduced water treatment costs.

Water Supply

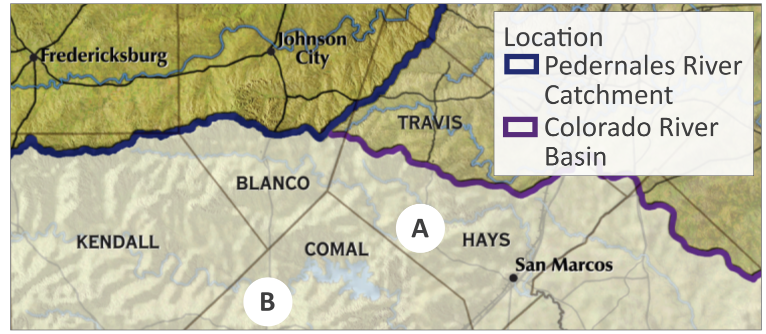
In years to come, the quality and quantity of our water supply will be the limiting factor for the development and long-term economic prosperity of central Texas. The Pedernales watershed is a key component in this equation. As a significant contributor to Lake Travis, the main source of drinking water for the city of Austin, the watershed contributes 30% of inflows and provides a source of sustainable water when other sources run dry (Meadows 2015). However, over the next 50 years, water demands for the Pedernales watershed are expected to increase by 30% (Meadows 2015). As they do, the watersheds that the Pedernales supplements—such as the lower Colorado—will experience reduced inflow, often while water demand increases. According to current projections, the lower Colorado watershed will experience a 23% water demand increase over the next 50 years (Meadows 2016). This is a demand that the Colorado is unlikely to meet without the continued health of the Pedernales.

Like many Texas watersheds, the Pedernales is a complex system of surface and ground water. The river itself alternates between gaining and losing stretches as is passes through layers of the Trinity, Edwards-Trinity and Ellenburger-San Saba aquifers. These aquifers reach the surface in more than 1,200 springs across the watershed, providing habitat for numerous native species and six endemic species of salamander (HCA 2015). They also reach the surface through numerous public and private water wells. There, these waters are pumped, used, and—in the case of the cities of Fredericksburg and Johnson City—returned as surface effluent into the Pedernales. Both Fredericksburg and Johnson City are permitted by the TCEQ to discharge up to 2.5 million and 0.303 million gallons per day, respectively. At times, these numbers comprise a significant volume of the river's water flow (LCRA 2017).

Yet, despite the importance of the Pedernales for the area's water supply, the watershed is increasingly imperiled by land use change. In 2015, 54 permits for withdrawing surface water were active, totaling over 5,000 acre-feet of water (Meadows 2015). These permits are likely to increase as population grows, and farmlands are fragmented and sold off for further development. Downstream, the effects of this siphoning can be seen in Austin, Burnet, Lampasas, and Llano—where the remaining water surfaces in the form of springs, Lake Travis, and the Colorado River (Meadows Center 2015). As the Colorado River meanders towards Matagorda and the bay, this water passes through numerous communities, continuing to impact the water resources for a large swath of central Texas.

In its 2015 study—How Much Water is in the Pedernales? Conservation Strategies, Management Approaches, and Action Plan—the Meadows Center identified that consumptive development, improper management, and incomplete knowledge were key threats to the river's continued prosperity. With these threats in mind, this prioritization should be utilized for proactive and preventative conservation. The most far-reaching successes will be achieved through actions that consider the connections between regional growth patterns, transportation, land use, water quality, and watershed planning. By targeting public information and education initiatives, additional research and analysis, and the promotion of state and local level policies, stakeholders across the watershed can ensure that stream and conservation buffers are incorporated into land development requirements for the years to come.

Figure 6. In recent years, areas surrounding the watershed have undergone increasing land use change, often occurring rapidly. Between 2015 and 2017, an open lot of land was converted to the Arrowhead Ranch community shown below in Figure 6A. Arrowhead Ranch is a master planned community of luxury homes, and will likely include, and attract, future development of restaurant and shopping centers. Similar developments, such as the conversion of highway-adjacent open lands to commercial and large lots, are also occurryng throughout the area. Figure 6B shows a large lot development near the intersection of highways 281 and 46, looking west. If left unchecked, these patterns are likely to continue into the watershed, impacting water supply, quality, and recharge capacity. Images from Google Earth.



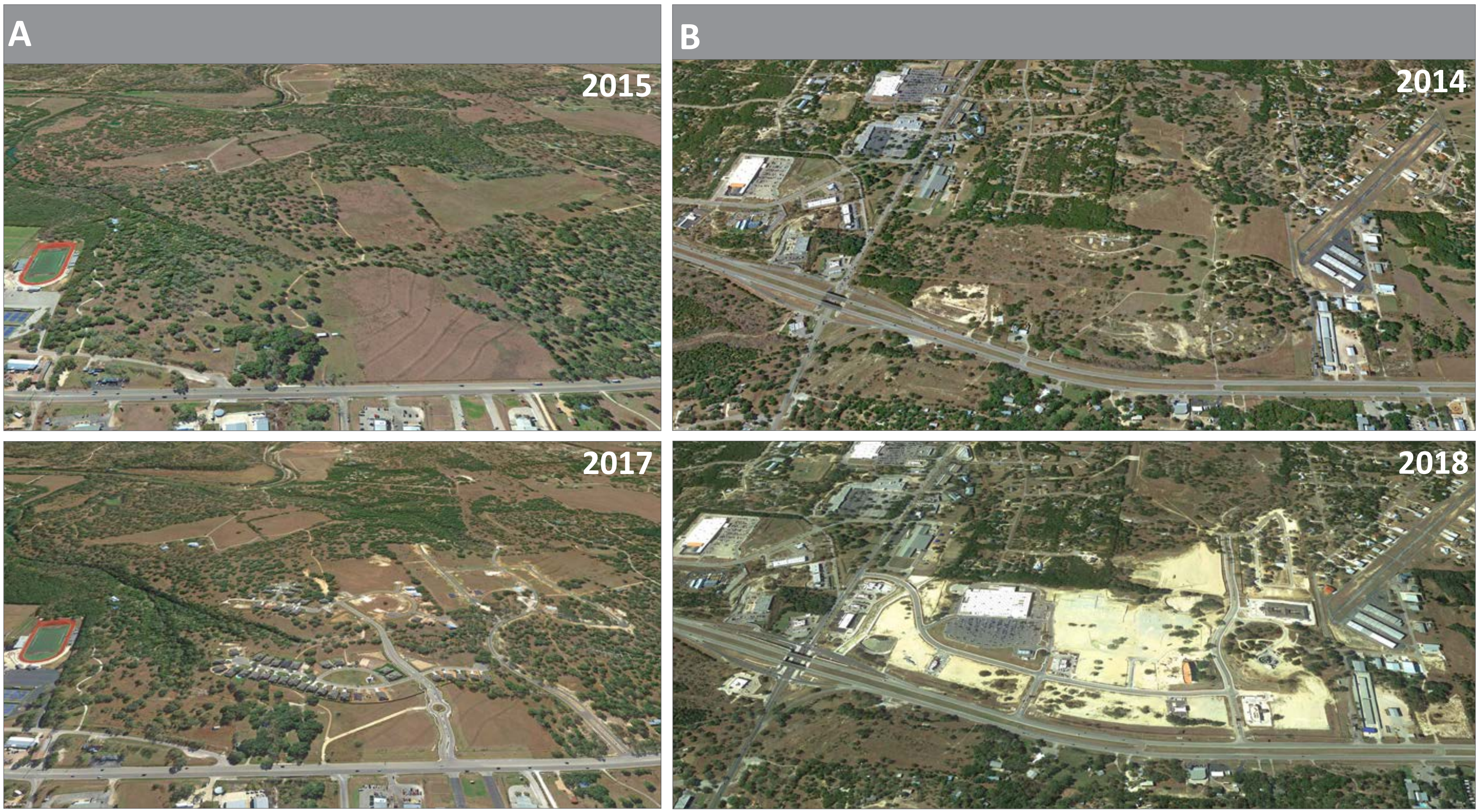


Figure 7. Vineyards like the one pictured here are becoming a more common land use in the Pedernales River Watershed. Picture courtesy of agrilife.org.

METHODS

This project determines conservation priorities for the Pedernales Watershed using a geographic procedural model. Model inputs include variables associated with water, culture, and ecology, which are used to identify and rank potential conservation areas. Areas with the highest rank reflect the confluence of multiple conservation resources with high value, and therefore represent areas to effectively and efficiently use conservation dollars. Figure 12 outlines the major steps of the modeling process, which include: collecting and evaluating available and usable data, refining the approach to meet study area needs and data availability, generating preliminary results, using stakeholder feedback to further refine the approach and results, and creating the final deliverables.

For its stakeholder process (Figure 8), the Pedernales Strategic Conservation Prioritization used Meadows Center staff and fellows to determine the initial set of conservation resources and values. This work built off of recently completed projects in the Blanco and Upper San Marcos water-

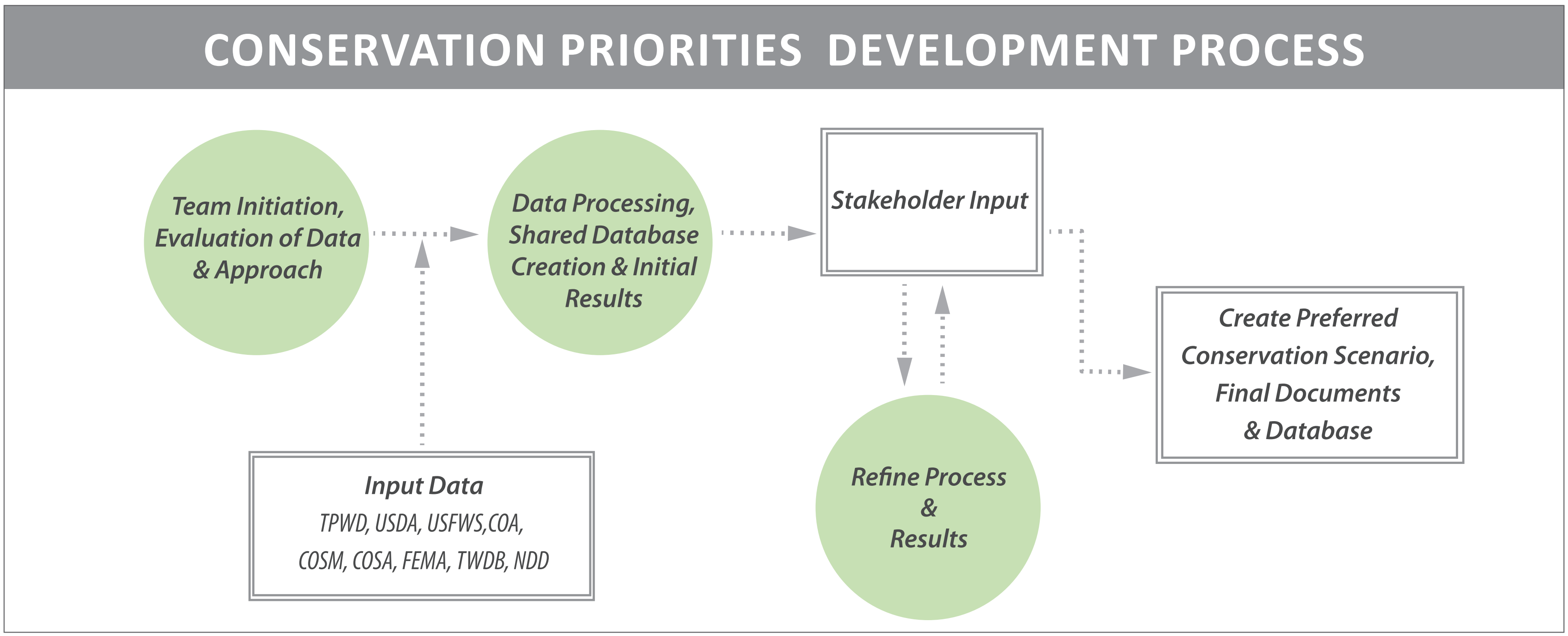


Figure 8. The general steps and process applied to determine conservation priorities in the Pedernales Watershed.

sheds. The draft and final results were then presented to the Hill Country Conservation Network, a group that includes Hill Country Alliance, Hill Country Conservancy, The Nature Conservancy, and other conservation-focused organizations. As the City of Austin depends on the watershed for up to a quarter of its water supply, results were also presented to members of the Watershed Protection Department and Austin Water Utility. In addition, a general presentation of the results was given to the larger Hill Country land trust community.

The geographic procedural model used here follows the work of the San Antonio Edwards Aquifer Protection Program (Siglo Group 2014) and the Blanco and Upper San Marcos Watershed Strategic Conservation Prioritization (Siglo Group 2017), with modifications to suit the unique aspects of the study area and the interests of the stakeholders. The success of these previous modeling processes is grounded in their flexible and iterative nature. For example, the San Antonio model determines conservation priorities in the Edwards Aquifer Contributing and Recharge Zone associated with protecting the supply and quality of drinking water for San Antonio. The program has led to more than 200,000 acres being permanently conserved to date. Recently, voters renewed the program with an additional 90 million dollars allocated for conservation easements and fee simple acquisitions in the coming years. Within the Blanco and Upper San Marcos Watershed, stakeholders are using conservation prioritization to strategically assemble a network of conservation properties that will protect water quality, decrease flood damage, and provide contiguous habitat for a healthy ecological system.

In line with these past methods, the Pedernales model includes the input of conservation resources, the evaluation of priorities through a weighted sum, the display of results at 30-meter resolution, and the summation of those results to parcels. To deduce which data layers and variables were most significant, the project team evaluated each on their importance for conservation, the reliability of their source, their comprehensiveness throughout the study area, their resolution, and their temporal accuracy. Furthermore, because of the importance of water resources for the area and stakeholders, this prioritization placed an emphasis on those assets that will maintain water flows, reduce flooding, protect springs, and enhance water quality. The conservation resource data layers that were determined to be the most significant are listed in Table 2. Examples of individual conservation resources can be seen in Figures 9 and 10, and more information about these resources can be found in Table 3.

The model then used these weighted conservation resources to determine priority areas. This involved running several different preliminary prioritization scenarios, and incorporating stakeholder feedback to iteratively refine the effects of specific resources and weights on the resulting conservation priorities. Each time the model was run, it generated a study-wide map, or *Conservation Scenario*, consisting of a conservation value for each 30-meter by 30-meter area. Areas with the highest ranking were considered priorities. To understand how altering the values of conservation resources affected the resulting conservation scenario, the model was run numerous times. These iterative runs also provided a sensitivity analysis on the results, ensuring that no one variable overly impacted the findings. Evaluation of multiple conservation scenarios resulted in the creation of the *Preferred Conservation Scenario* described in greater detail in the Findings Section. The *Preferred Conservation Scenario* was determined to represent the best balance of important conservation resources within the study area.

Conservation Resources

This model uses data on conservation resources that are meant to represent influential factors for the physical and cultural environment of the Pedernales Watershed. For the purposes of the model, these resources were subdivided into three categories: water, cultural, and ecological. Unique conservation resources and their values in the prioritization can be found in Table 2. Table 3 describes why each conservation resource was used, and its source.

Water Resources

Water resources used in the model include: aquifer recharge zones, buffers around springs, buffers around public water supply wells, surface water quality buffers, wetlands, and designated significant streams. Two primary aquifer systems, the Trinity and the Edwards-Trinity, underlay much of the watershed (Figure 11). These aquifers are the primary water supply for Fredericksburg, Johnson City, and most of the study area's residential and agricultural activities. Between Johnson City and Pedernales Falls State Park, another aquifer—the Ellenburger-San Saba—is of special significance. Because of its disproportionate contribution to the flow of the Pedernales River below Johnson City (Meadows 2017), the Elllenburger-San Saba Aquifer has been included as a distinct layer in the model.

Within the Pedernales watershed, studies have shown significant interaction between surface and ground water (Smith et al. 2014, Hunt et al. 2017). In particular, dye tracing studies have revealed that the watershed's karstic aquifers are dynamic systems, rapidly conveying water, but with little ability to filter out dissolved pollutants. This interaction means that maintaining water quality and quantity requires the protection of both

	CONSERVATION RESOURCES	VALUE
WATER	Spring Buffers	High
	Trinity Aquifer Recharge Zones	Moderate
	Edwards-Trinity Aquifer Recharge Zones	Moderate
	Ellenburger Recharge Formations	Moderate
	Critical Waterquality Buffers	Moderate
	Public Water Supply Water Well Buffer	Moderate
	TPWD Designated Significant Streams	Moderate
CULTURAL	Conservation Land Buffers	Moderate/High
	Prime Farmland Soils	Moderate
	Parcel Size	Low-Moderate
	Opportunity Areas	Low
ECOLOGICAL	Golden Cheeked Warbler Habitat	Moderate
	TPWD Identified Riparian Areas	Moderate
	Steep Slopes	Low

Table 2. The fourteen conservation resources used in the prioritization process, by category: water (top; blue), cultural (middle; orange), ecological (bottom; green).

intake and outlet areas throughout the watershed. In the case of aquifers, these key zones often emerge in the form of seeps or springs, features that are hydrologically, ecologically, and culturally important, and thus are given wide conservation buffers within the model. This study used the USGS Heitmuller and Williams (2012) compilation that documented 64 springs within the study area. While this data is considered some of the most comprehensive associated with springs in the area, it is important to remember that there are numerous undocumented seeps and springs occurring within the watershed.

Beyond aquifers and springs, the areas around waterways and water bodies play important roles in water infiltration and filtration, flood and erosion control, habitat creation, flow sustenance, and bank stabilization. To represent these as conservation resources, this prioritization includes Texas Parks and Wildlife Department Designated Significant Streams and water quality buffers (TPWD 2002) based on the Regional Water Quality Protection Plan.

Cultural Resources

Cultural resources include elements associated with agriculture, areas close to existing conservation areas, corridors with a high probability of development, and parcels of considerable size. Ranching has long been an iconic regional cornerstone across the watershed, and Fredericksburg continues to be known for its peaches. In addition, wineries in and around Fredericksburg have grown popular in recent years (Figure 7). Activities such as these have a high cultural value, and a high economic impact. To protect the long-term success of these enterprises, the model includes prime farmland soils (Figure 10) as an explicit conservation resource (NRCS 2016).

The model also assigned additional value to areas adjacent to existing conservation land. One of the most efficient and effective ways to increase the impact of conservation lands is to create connections between protected areas across the landscape. This creates more robust habitat, increases connectivity, reduces management costs, and provides for greater recreational opportunities. To account for this in the prioritization, land within

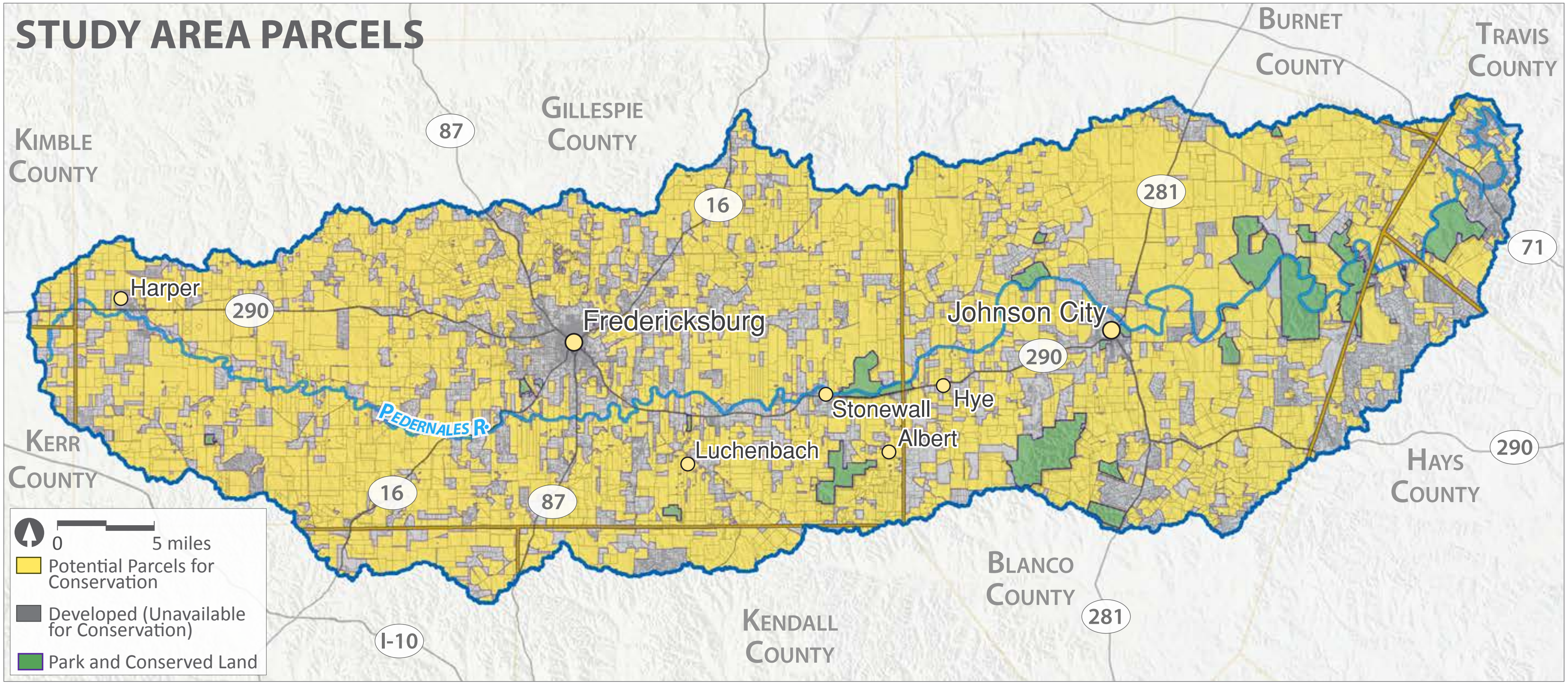


Figure 9. Potential parcels for conservation (shown in yellow) and those areas not available for conservation due to development and parcellation (gray).

1,200 feet of existing conservation areas was prioritized within the model. Given that development pressures within the watershed are already driving land use and land cover change and are projected to increase in speed and impact in the coming decades, this model also prioritizes those areas with a high probability of development. In the watershed, new land use and fragmentation are expected to continue existing patterns (Figure 6, 9) in which subdivisions and intense land uses radiate out from municipalities and road corridors. Recognizing this trend and the ability of conservation to shape land use in these areas, opportunity zones for potential conservation were defined as land within municipal extraterritorial jurisdictions or within 1 mile of highways 290, 281, 71, 16 and 87.

Finally, parcel size is a cultural attribute that has implications for both the process and impacts of conservation. Larger parcels tend to be more efficient to acquire and manage, and they can have a large impact on habitat and hydrology within the watershed. For this prioritization, parcels available for conservation were defined as those encompassing more than 100 acres. These parcels of interest were classified into three groups of increasing importance: (1) 100 to 640 acres, (2) 640 to 1,280 acres, and (3) greater than 1,280 acres. Within the study area these parameters selected 2,060 parcels within the first category, 151 parcels within the second, and 58 parcels within the third. Prioritizing larger parcels underscores the importance of reducing fragmentation, which is common after transfer of ownership. In addition to conservation benefits, prioritizing large parcels

CONSERVATION RESOURCE EXAMPLES

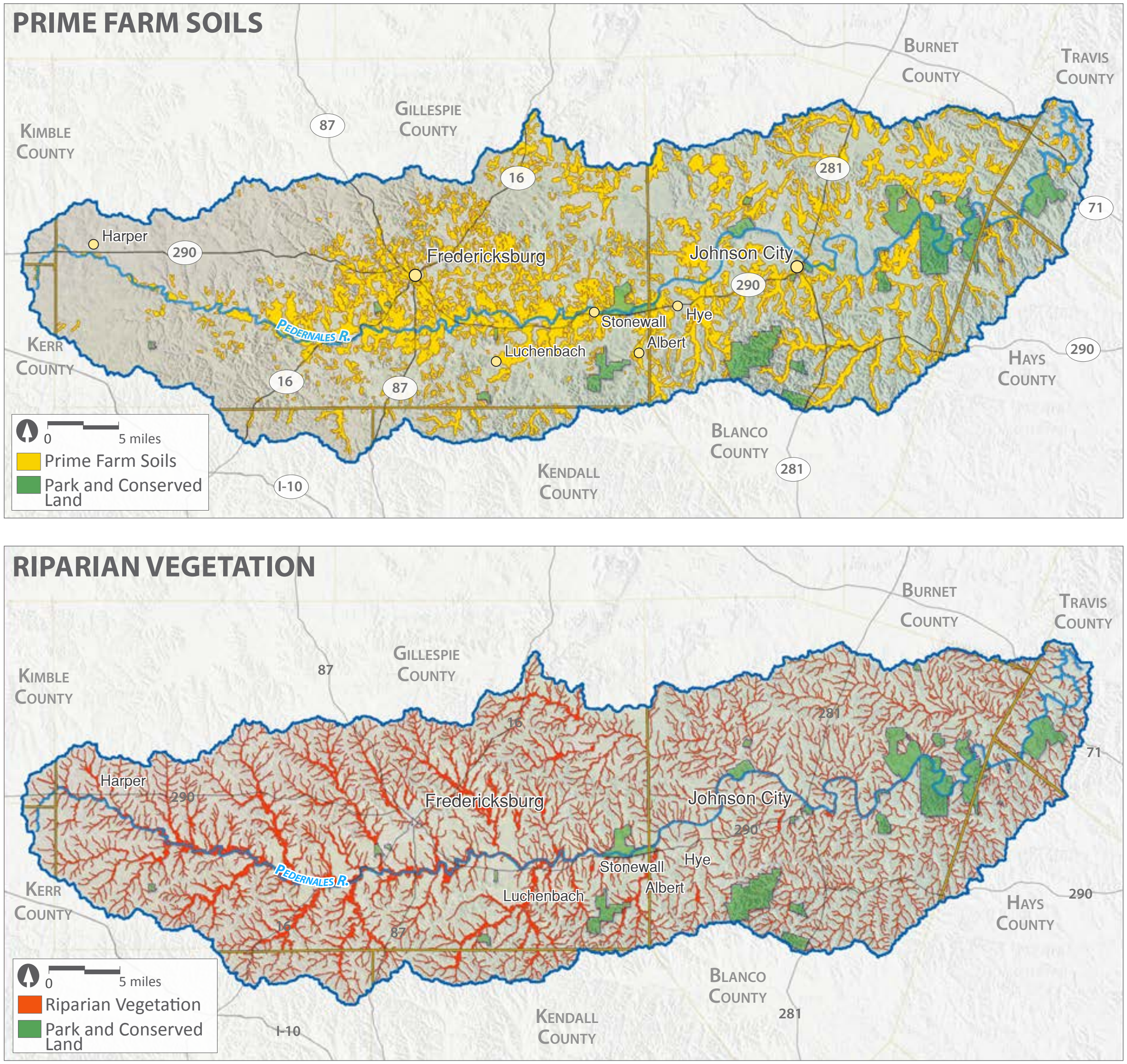


Figure 10. Areas of prime farm soils (top; yellow) and riparian vegetation (bottom, red) across the study area.

also allows land owners and their families to continue living and working on the land (Texas Land Trends 2014).

Ecological resources

Ecological resources for this study include Golden-Cheeked Warbler habitat, TPWD-identified riparian zones, and areas with substantial topographic relief.

Golden-Cheeked Warbler habitat supports a federally listed endangered species and is a unique ecological environment endemic to the Hill Country. Preservation of this species of concern is also a cornerstone of the Hays County Habitat Conservation Plans (Hays County Habitat Conservation Plan 2010). For the model, data on the Golden-Cheeked Warbler habitat is based on recent work (Aurora 2016) that identifies high potential, quality habitat by its presence in at least two of three habitat models used—models a, c, and l.

Riparian vegetation zones were incorporated into the model to protect water quality, water quantity, flood damage mitigation, and critical habitat and foraging grounds for both aquatic and terrestrial species. To account for this, the Texas Parks and Wildlife Department Ecological Systems Clas-

CONSERVATION RESOURCE EXAMPLES

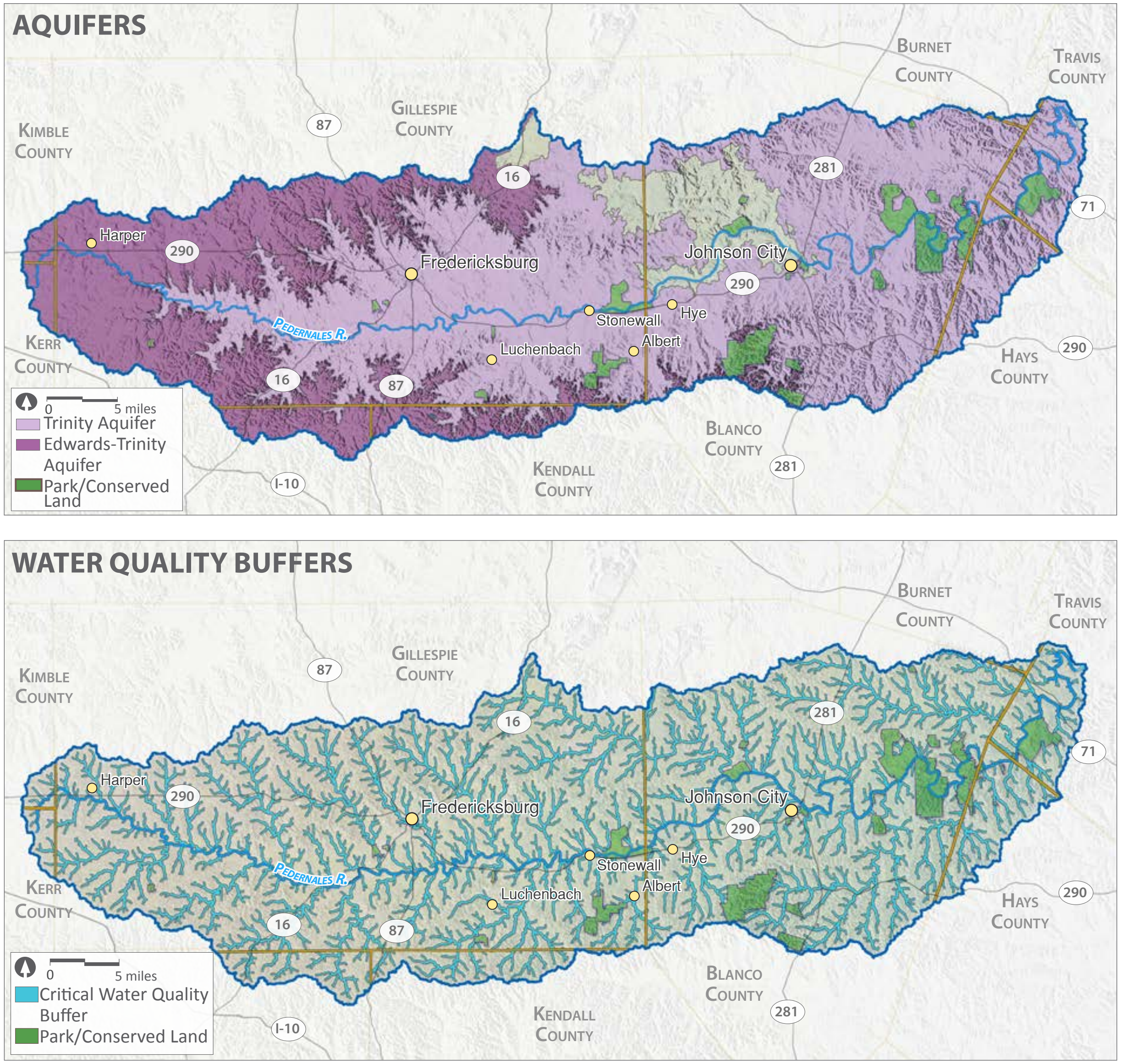


Figure 11. The location of the Trinity (light purple) and Edwards-Trinity (dark purple) Aquifers within the Pedernales River Watershed (top), and the critical water quality buffers throughout the zone (bottom; blue).

sification (2014) was used to define areas of riparian and floodplain vegetation, which were incorporated as a conservation resource in the model (Figure 10).

Steep slopes were also included as an ecological resource in the model, as they are prone to erosion, are less practical for development, and can serve as important habitat for plant and animal species that have been driven from more accessible parts of the landscape. Slopes were derived based upon the national elevation dataset at 30-meter resolution. All areas that had greater than 15% slope were incorporated as a conservation resource and slopes greater than 60% were given additional weight.

Table 3. The purpose, use, criteria, and source for each of the fourteen conservation resources used in the study.

WATER RESOURCES	PURPOSE, USE AND CRITERIA	SOURCE
Spring Buffers	Buffers were placed around springs to promote the conservation of groundwater and maintain spring flows. Mapping Criteria: 350ft Buffers were placed around known springs.	Heitmuller, Franklin T. and Iona P. Williams. Compilation of Historical Water-Quality Data for Selected Springs in Texas, by Ecoregion. 2006; U.S. Geological Survey and Texas Parks & Wildlife Department. Data requested and provided 2012. refined based upon Doug Wierman Personal Correspondence
Trinity Aquifer Recharge	High probability recharge/karst features. Preservation of these lands helps protect the water quality and quantity recharge of connected aquifers and springs. Mapping Criteria: Defined for this study as the area where the Lower Glen Rose is exposed at the surface.	Barnes, V.E. 1981. Geologic Atlas of Texas. The University of Texas at Austin, Bureau of Economic Geology, Austin, Texas. USGS. 2016. Geologic Atlas of Texas (GAT). Viewed and downloaded: https://tnris.org/data-catalog/entry/geologic-database-of-texas/
Edwards-Trinity Aquifer Recharge	High probability recharge/karst features. Preservation of these lands helps protect the water quality and quantity recharge of connected aquifers and springs. Mapping Criteria: Defined for this study in the Texas Administrative Code 30 TAC 213.	Texas Commission on Environmental Quality. 2016. Edwards Aquifer Regulatory Boundary (TSMS Version). Viewed and downloaded 2016: https://www.tceq.texas.gov/gis/download-tceq-gis-data/
Ellenburger Recharge Formations	These geologic formations are known to make significant contributions to stream flow downstream of Johnson City and above Pedernales Falls State Park and associated conservation lands.	Doug Wierman Personal Correspondence
Water Quality Buffers	These are critical for water filtration, erosion control, and bank stability. Mapping Criteria: Buffers based on National Hydrography Dataset Plus flow accumulation to define catchment areas in the following size classes with associated buffers: 32 to 120 acres buffer 100' from center line; 120 to 300 acres buffer 150' from center line; 300 to 640 acres buffer 200' from center line; greater than 640 acres; buffer 300' from center line.	Barton Springs Edwards Aquifer Conservation District. 2013. An Overview of the Regional Water Quality Protection Plan. Viewed 2016: http://bseacd.org/uploads/01_NextWave_Update-2013-04-26.pdf, National Hydrography Dataset Plus. 2006. Environmental Protection Agency. Viewed and downloaded 2009: https://www.epa.gov/waterdata/nhdplus-national-hydrography-dataset-plus.
Public Water Supply Well Buffers	Buffers help maintain and improve public water supply critical to long term community health and development. Mapping Criteria: 1000 foot radius around municipal wells	Texas Center on Environmental Quality. 2016. Public Water System Wells & Surface Water Intakes. Viewed 2016: https://www.tceq.texas.gov/gis/download-tceq-gis-data/.
TPWD Significant Streams	Areas determined by TPWD to be significant for habitat and/or water quality. Can have as buffer around streams. These are critical for water filtration, erosion control, and bank stability. Mapping Criteria: Buffers based on National Hydrography Dataset Plus flow accumulation to define catchment areas in the following size classes with associated buffers: 32 to 120 acres buffer 100' from center line, 120 to 300 acres buffer 150' from center line, 300 to 640 acres buffer 200' from center line, greater than 640 acres, buffer 300' from center line.	Barton Springs Edwards Aquifer Conservation District. 2013. An Overview of the Regional Water Quality Protection Plan. Viewed 2016: http://bseacd.org/uploads/01_NextWave_Update-2013-04-26.pdf, National Hydrography Dataset Plus. 2006. Environmental Protection Agency. Viewed and downloaded 2009: https://www.epa.gov/waterdata/nhdplus-national-hydrography-dataset-plus.
CULTURAL RESOURCES	**PURPOSE, USE AND CRITERIA**	**SOURCE**
Conservation Land Buffers	Incorporated to create larger nodes of conservation that are more effective in protecting resources, supplying environmental services, and creating corridors of open space. Mapping Criteria: Parcels adjacent to conservation lands	Texas Parks and Wildlife Department Land and Water Resources Conservation Program Open lands database, http://tpwd.texas.gov/gis/; Texas Parks & Wildlife Department. Conservation lands inventory, http://tpwd.texas.gov/gis/; Texas Land Trust Council
Prime Farmland Soils	Prime farmland soils play a crucial role in a robust agricultural system and are an indicator of areas more likely to qualify for state and federal protection programs. Mapping Criteria: Areas considered significant for agricultural production as defined as prime agricultural soil	Natural Resource Conservation Systems. 2016. Prime Farmland Soils. SSURGO- NRCS-USDA. Viewed and downloaded 2016: https://tnris.org/data-catalog/entry/soils/
Parcel Size	Larger sized parcels create valuable contiguous habitat that is required by many species. Mapping Criteria: Parcels available for conservation were defined as those greater than 100 acres. These parcels of interest were classified into three groups of increasing importance, 100 to 640 acres, 640 to 1,280 acres, and greater than 1,280 acres.	Blanco (2016), Comal (2015), Hays (2016), and Kendall (2013) county appraisal districts shapefiles and tax roll.
Opportunity Areas	Defining areas that will be impacted in coming decades by continued urban and suburban land use. Mapping Criteria: Extra territorial jurisdictions and 1 mile around major road corridors (I-35 & 281).	Major roads and extra territorial jurisdictions; Viewed and downloaded 2016: City of Austin, ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html; City of San Marcos, http://www.ci.san-marcos.tx.us/index.aspx?page=281; and Texas Department of Transportation, http://gis-txdot.opendata.arcgis.com/.
ECOLOGICAL RESOURCES	**PURPOSE, USE AND CRITERIA**	**SOURCE**
Golden Cheeked Warbler Habitat	Prioritize protection high probability habitat for endangered Golden Cheeked Warbler. Mapping Criteria: Areas with attributes likely to be high quality habitat based on at least two of the three habitat models used—models l, a, and c.	Aurora, A. 2014. Personal Correspondence and Data Delivery.
Riparian and Floodplain Vegetation	Riparian plant communities offer important water quality benefits, high-quality habitat and forage. Mapping Criteria: Areas defined as riparian or floodplain in the Texas Ecological Mapping Systems.	TPWD and Missouri Resource Assessment Partnership. 2014. Texas Ecological Mapping Systems of Texas. Viewed and Downloaded 2016: http://tpwd.texas.gov/landwater/land /programs/landscape-ecology/ems/
Steep Slopes	Serve as surrogates for areas with endemic species and areas more susceptible to erosion and increased stormwater velocities. Mapping Criteria: Slopes 15 to 60% and Slopes over 60%.	U.S. Geological Survey. National Elevation Dataset, 30 Meter. Viewed and Downloaded 2016: https://nationalmap.gov/elevation.html

Image 2. Pedernales Falls State Park. Picture courtesy of wikimedia.org.

FINDINGS

The following section presents the results of the prioritization process and looks at how particular conservation resources are represented in the *Preferred Conservation Scenario*. Descriptions of some areas of particularly high value are provided, and the specific relevance of these findings for future conservation action is discussed. These findings are based on current conditions, available data, current best analysis practices, existing conservation lands, and stakeholder input.

Draft conservation scenarios (Figure 13) were run iteratively to consider the impact of various conservation resources and their values on final priority areas. Through this process, conservation resource values were adjusted to create additional scenarios, and to eventually generate the *Preferred Conservation Scenario* (Table 4, Figure 14). Within the preferred scenario, water resources contributed approximately 60% of the value in the model while cultural and ecological resources each contributed approximately 20% of the value. The resulting preferred scenario indicates 160,420 acres are high priority conservation areas—approximately 20% of the 819,370-acre study area (Figure 16). This total includes 125,050 acres (78%) that are available for conservation, and 35,370 acres (22%) that did not meet the criteria for conservation consideration because they were either in developed areas or under 100 acres in size. The high priority areas are characterized by the occurrence of multiple conservation resources in the same location. These areas represent strategic opportunities, where time and money can be put to maximum effect.

Table 3 lists conservation resources, their value in the model, and the total acres and percentage of each resource that are found within priority areas. Overall, water resources had the highest representation in the Preferred Conservation Scenario, ranging from 9 to 97

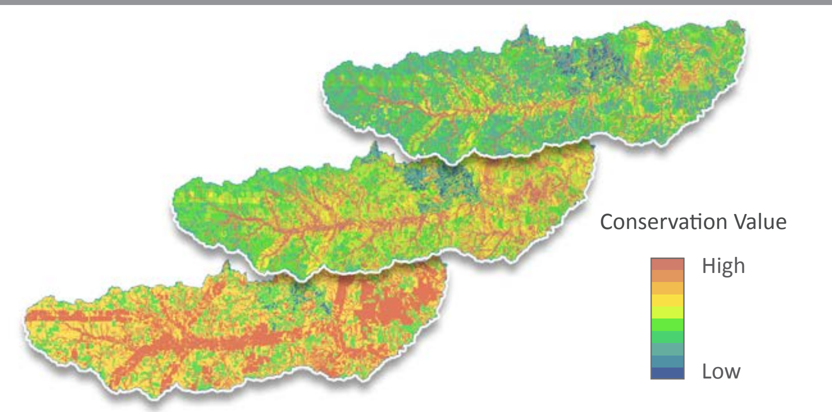
STEPS IN RUNNING THE MODEL

1. *Evaluate and adjust the existing conservation lands file as con ditions change;*
2. *Add or delete individual conservation resources;*
3. *Adjust the values/weights of conservation resources;*
4. *Run model;*
6. *Evaluate results and obtain stakeholder feedback;*
7. *Repeat as needed.*

Figure 12. (Above) The seven key steps involved in running the conservation prioritization model.

Figure 13. (Below) A comparison of example results from the conservation scenario iterations used in the study.

EXAMPLE CONSERVATION SCENARIO ITERATIONS



percent. Between 77% and 97% of spring buffer, the Ellenburger-San Saba Aquifer recharge formations, TPWD-designated significant streams, and critical water quality buffers were represented in the top priority areas. The Edwards-Trinity Aquifer Recharge Zones had the lowest level of representation—likely as a result of its size and its moderate value within the model. Cultural resources contained in the top priority areas ranged from 22% to 52%. Of these, prime farm soils had the highest level of representation—largely a result of its co-occurrence with other conservation resources, and the high value it was given in the model. Ecological resources ranged from 26% to 79% representation in the Preferred Conservation Scenario, with TPWD-identified riparian areas having by far the greatest representation. This is likely because riparian areas were frequently co-situated with other water-related resources. Nodes of conservation priorities are evident in some areas due to the overlap of numerous conservation resources (Figures 14). The four clusters displayed in Figures 14, 15, and 16, and described to the right should serve as focal points for priority conservation action.

Table 4. Results of the Preferred Conservation Scenario, including the acreage and percent of study area occupied by each resource, and the resource category: water (top, blue), cultural (middle, yellow), and ecological (bottom, green).

	CONSERVATION RESOURCES	VALUE	ACRES IN STUDY AREA	% IN PRIORITY AREA
WATER	Spring Buffers	High	541	97
	Trinity Aquifer Recharge Zones	Moderate	538,952	25
	Edwards-Trinity Aquifer Recharge Zones	Moderate	222,940	9
	Ellenburger Recharge Formations	Moderate	14,176	85
	Critical Water Quality Buffers	Moderate	110,375	77
	Public Water Supply Water Well Buffer	Moderate	5,126	60
	TPWD Designated Significant Streams	Moderate	32,191	77
CULTURAL	Conservation Land Buffers	Moderate/High	58,160	36
	Prime Farmland Soils	Moderate	120,221	52
	Parcel Size	Low-Moderate	N/A	N/A
	Opportunity Areas	Low	197,839	28
ECOLOGICAL	Golden-Cheeked Warbler Habitat	Moderate	44,179	45
	TPWD Identified Riparian Areas	Moderate	76,862	79
	Steep Slopes	Low	52,808	26

1. **Pedernales Falls State Park Conservation Cluster.** This area includes existing conservation land and key water quality elements. Several conservation properties form a cluster around Pedernales Falls State Park and could be linked and expanded for significant conservation benefits. The cluster is also well-situated to serve as an important regional model of successful public-private conservation partnership. Within this area, the Ellenburger-San Saba Aquifer, between Pedernales Falls State Park and Johnson City, is especially important because of its contributions to stream flow (Figure 15a).

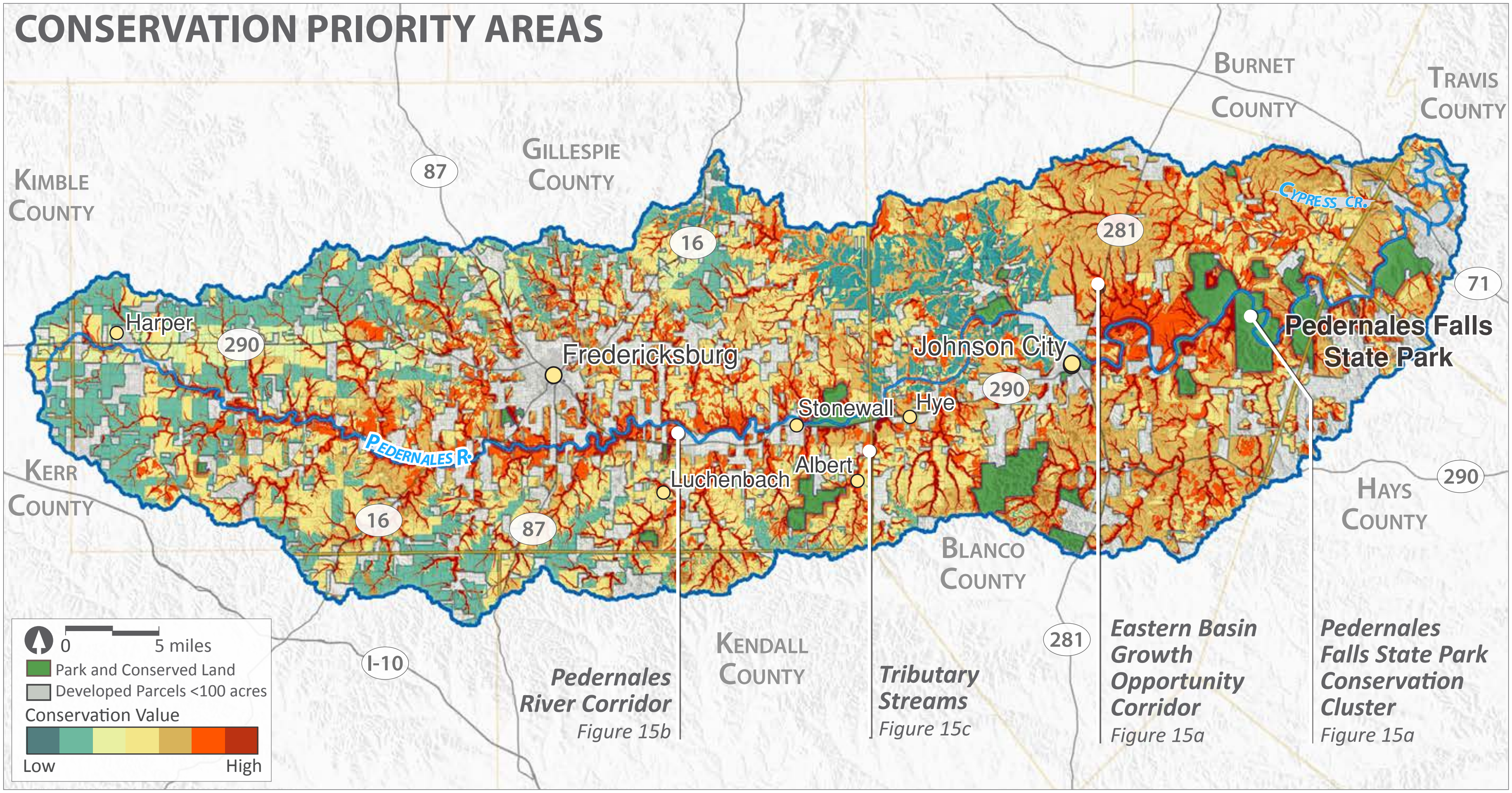
2. **Eastern Watershed Growth Opportunity Corridor.** Development in this area closely follows highways 281 and 290. Within the eastern-downstream portion of the watershed, the areas adjoining these roadways is already under substantial development pressure. Several large properties, an aquifer recharge zone, and multiple tributary streams—including Cypress Creek, an important 20-mile-long tributary—also overlap and intersect in this area. Because of its proximity to the Austin Metropolitan area, conservation efforts in this sub-region are highly time-sensitive and are expected to have greater direct impacts (Figure 15a).

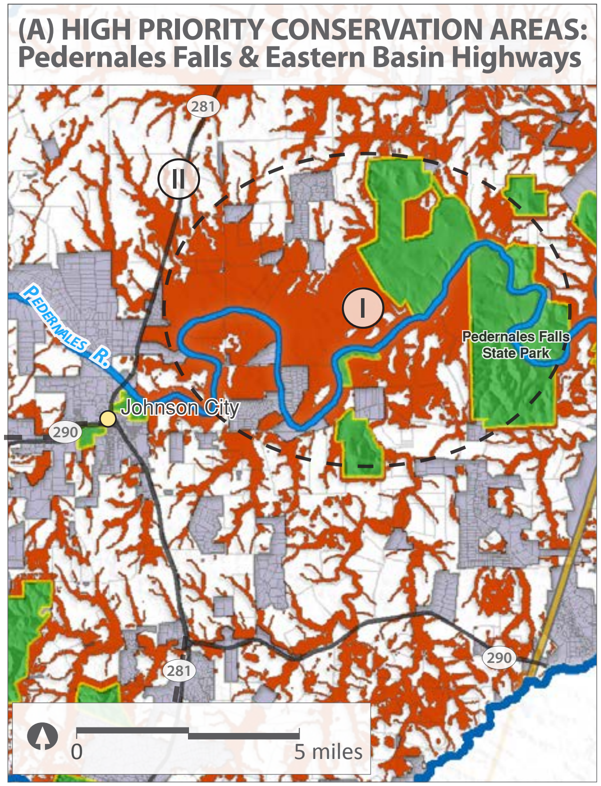
3. **Pedernales River Corridor.** Lands along the main channel of the Pedernales meet many overlapping water protection conservation priorities, and their linear form represents a potential for greater watershed-wide habitat connectivity. Despite the absence of large parcels, this area stands out in the model because of the alignment of riparian vegetation areas, water quality buffers, and the Highway 290 development opportunity corridor; all critical conservation areas (Figure 15b).

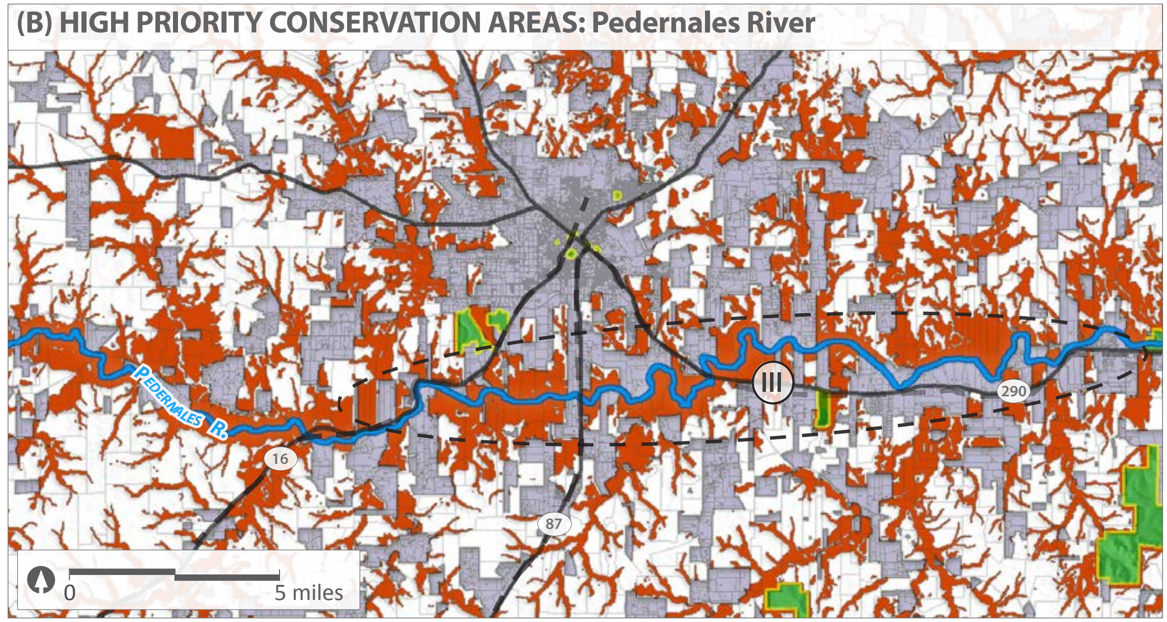
4. **Tributary Streams Corridors.** In addition to Cypress Creek, noted above, several major streams flow into the Pedernales River. These areas serve as important buffers for the protection of riparian habitat, potential areas of archeological significance, and water quality (Figure 15c).

While these results reflect current best analysis practices, they will evolve as new properties come under conservation, new information becomes available, and environmental conditions and priorities change. With this in mind, the areas in the Preferred Conservation Scenario are recommended for immediate conservation action. These actions can include conservation easement acquisition, land stewardship activities that protect, maintain, and enhance the conservation resources within the watersheds, or outright purchases from willing sellers.

Figure 14. Conservation priority areas (indicated with white callouts) across the study area. Already developed land (gray), park and other conserved lands (green), and conservation values also shown.







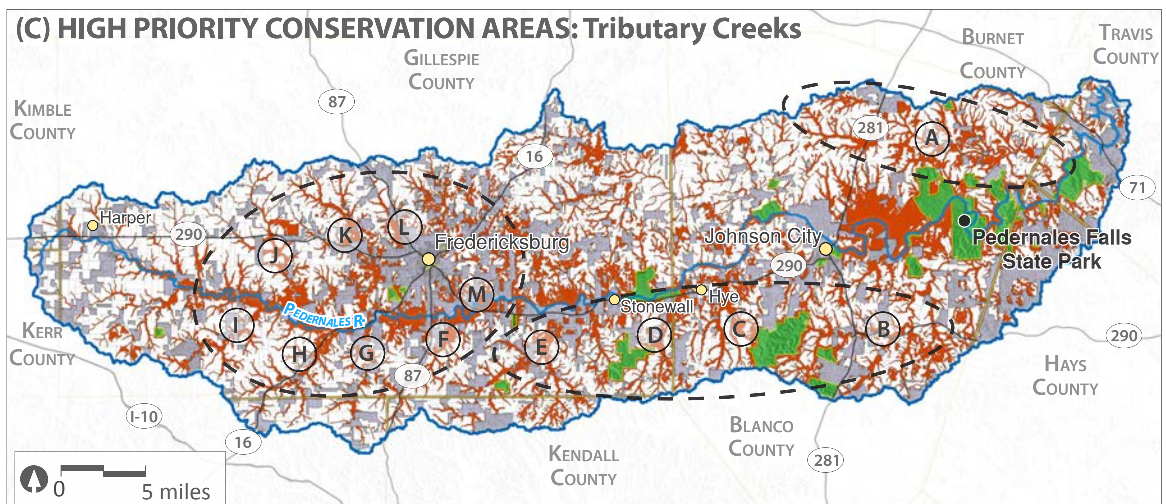


Figure 15. High priority conservation areas within the study area, with a focus on: (A) the eastern highway development corridor and the conservation cluster around Pedernales Falls State Park, (B) the main stream of the Pedernales River, and (C) the major tributary creeks throughout the basin.

Park and Conserved Land	(I) Pedernales Falls Conservation Cluster
Developed Parcels (Under 100 acres)	(II) Eastern Basin Growth Opportunity Corridor
High Priority Conservation Areas (Top 20%)	(III) Pedernales River Corridor

High Priority Tributary Creeks:

- (A) Cypress Creek
- (B) Miller Creek
- (C) Rocky Creek
- (D) Williams Creek
- (E) South Grape Creek
- (F) Muesebach Creek
- (G) Bear Creek
- (H) Wolf Creek
- (I) White Oak Creek
- (J) Spring Creek
- (K) Live Oak Creek
- (L) Barons Creek
- (M) Palo Alto Creek

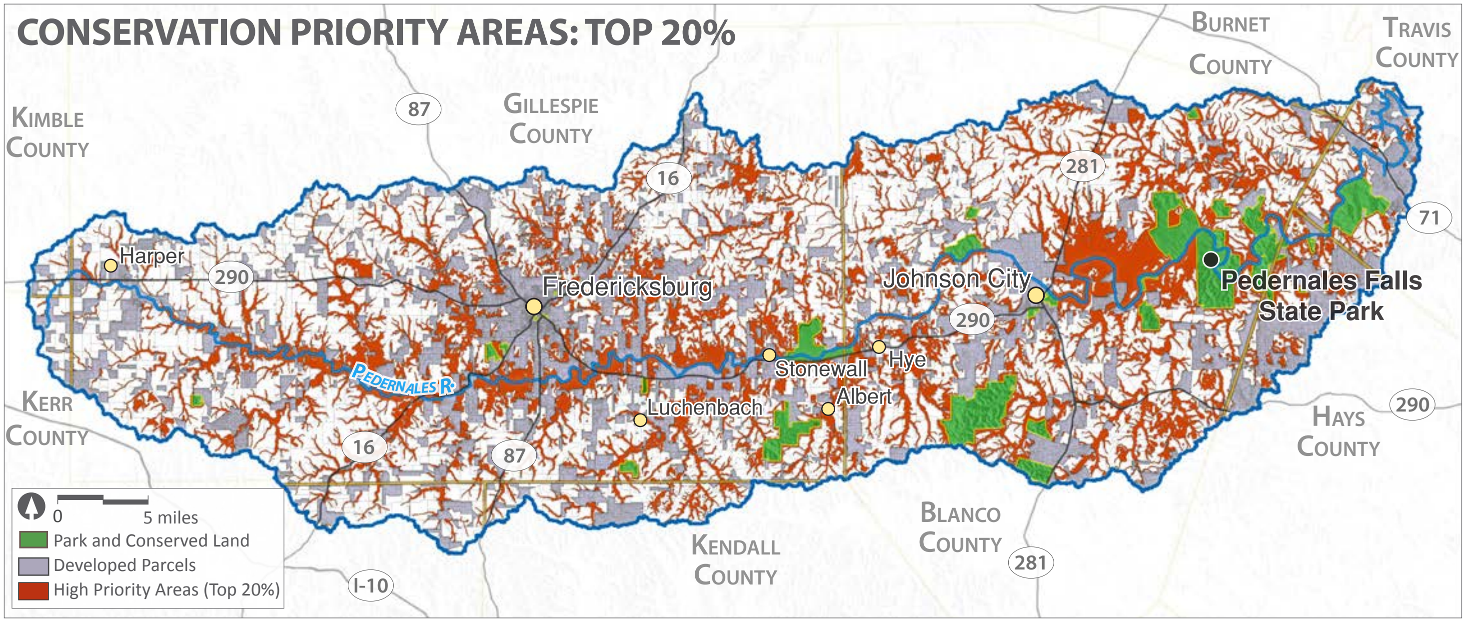


Figure 16. High priority conservation areas include areas with important cultural, ecological and water resources.

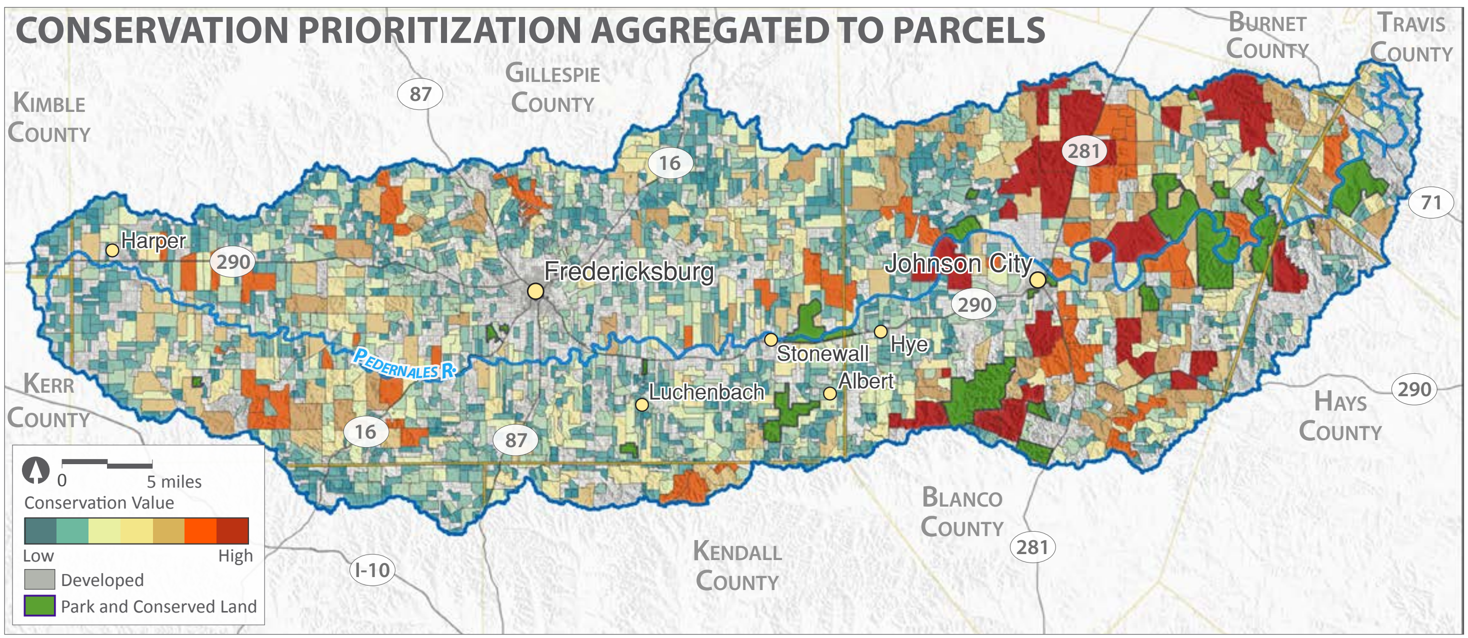


Figure 17. An example of conservation priority areas being aggregated to the parcel-level, based on the mean conservation value within the parcel.

Image 3. Fredericksburg's booming winery business has led highway 290 to be dubbed "wine road 290" by some. Photo by twitter.com/wineroad290

DISCUSSION & CONCLUSIONS

Though the Pedernales Watershed is currently in good condition, it will likely experience significant land use transformation in the coming decades. This development will take many forms, some of which will be detrimental to the area's water, cultural, and ecological resources. These resources are vital to the health and prosperity of communities and ecosystems within the watershed, as well as millions of downstream residents. Together, the watershed and its resources are foundational to the cultural heritage of the Hill Country. Not only does the watershed support the area's natural beauty and the well-being of our unique flora and fauna, it also provides high quality drinking water, mitigates flood damage, stabilizes soils, and irrigates land for agricultural production.

The transformation of this landscape and the potential degradation of our ecosystem services underscores the need for immediate action. While in the past, stewardship often fell to ranchers who had long histories in the area and understood best management practices, this knowledge is no longer being passed down. As more parcels develop and new owners step in, historic land management practices are being lost. The strategic prioritization presented here is meant to provide direction for current and new stakeholders in the area. By outlining the watershed's needs, key priority areas, and guidelines for continued conservation action, this report will support concerted stewardship for the future.

As we strive to preserve a culture of stewardship in the Pedernales watershed, it is important to be creative. Conservation easements, fee simple purchases, and land owner engagement can support this effort. These methods have proven successful in other Texas communities, and some have already been favorably implemented within the watershed. The City of San Antonio's Edwards Aquifer Protection Program (http://www.sanantonio.gov/EdwardsAquifer) is one of the brightest lights for Texas conservation. There, rural land owners are working with urban communities to conserve the resources upon which they all depend. Through their collaboration, hundreds of thousands of acres of ranch and farmland, critical habitat, and aquifer recharge have been protected in perpetuity.

In the case of the Pedernales Watershed, protecting the four conservation clusters outlined above—the Pedernales Falls State Park, Eastern Watershed Growth Opportunity Corridor, Pedernales River Corridor, and Tributary Streams Corridor—would be a strong start for conservation. With the right funding and support, the current interests of land owners in the area—who are already self-organizing for watershed-level conservation—can be harnessed to dramatically change the fate of the area over the coming decades. This prioritization identifies target areas for that work to begin. Armed with this strategic tool, conservation advocates can focus their efforts to maximize their impact, as they form partnerships with land owners, municipalities, state and federal agencies, philanthropic conservation buyers, advocacy groups, and land trusts. In doing so, they will also support all the services the watershed has to offer; reducing impacts from future flooding events, and protecting rural aesthetics, water quality, spring flow, and working agricultural lands. While this conservation course may be long and marked by successes and setbacks, the result will be a landscape composed of working land, clean flowing rivers, and robust habitats that supports community success for generations to come.

SOURCES

Alan Plummer Associates, Inc. 2017. Upper San Marcos River, Flooding and Land Conservation.

Appleton, A. F. 2002. How New York City Used an Ecosystem Services Strategy Carried out Through an Urban-Rural Partnership to Preserve the Pristine Quality of Its Drinking Water and Save Billions of Dollars. Tokyo: Forest Trends.

Ashworth, J.B. and Hopkins, J. 1995. Major and Minor Aquifers of Texas. Austin: Texas Water Development Report No. 345.

Aurora, A. 2014. The Use of Golden Cheeked Warbler Data. Personal Correspondence.

Barber, J. R., Crooks, K. R., & Fristrup, K. M. (2010). The costs of chronic noise exposure for terrestrial organisms. Trends in ecology & evolution, 25(3), 180-189.

Barbosa, N. P., Fernandes, G. W., Carneiro, M. A., & Júnior, L. A. 2010. Distribution of non-native invasive species and soil properties in proximity to paved roads and unpaved roads in a quartzitic mountainous grassland of southeastern Brazil (rupestrian fields). Biological Invasions, 12(11), 3745-3755.

Barton Springs Edwards Aquifer Conservation District. 2013. An Overview of the Regional Water Quality Protection Plan. Viewed 2016. http://bseacd.org/uploads/01_NextWave_Update-2013-04-26.pdf.

Barton Springs Edwads Aquifer Conservation District. 2013. An Overview of the Regional Water Quality Protection Plan. Viewed 2016. http://bseacd.org/uploads/01_NextWave_Update-2013-04-26.pdf.

Bowden, M. 2000. The Cost of Community Services in Hays County, TX. American Farmland Trust. Viewed 2016. http://www.aquiferalliance.net/Library/LibraryFiles/Initiatives/Cost_of_Community_Services_Hays.pdf.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387 (6630):253-260.

Cott, P. A., Schein, A., Hanna, B. W., Johnston, T. A., MacDonald, D. D., & Gunn, J. M. 2015. Implications of linear developments on northern fishes. Environmental Reviews, 23(2), 177-190.

Christen, D. C., & Matlack, G. R. 2009. The habitat and conduit functions of roads in the spread of three invasive plant species. Biological Invasions, 11(2), 453-465.

Dietz, M. E., & Clausen, J. C. 2008. Stormwater runoff and export changes with development in a traditional and low impact subdivision. Journal of Environmental Management, 87(4), 560-566.

Ellis, G. 2016. San Antonio Support for San Marcos Conservation effort. Personal correspondence.

ESA. 2000. Ecosystem Services. Washington, DC: Ecological Society of America. ESRI. 2006. ArcGIS 9.1. Redding: ESRI.

Forman, R. T., & Alexander, L. E. 1998. Roads and their major ecological effects. Annual review of ecology and systematics, 29(1), 207-231.

Francis, C. D., Ortega, C. P., & Cruz, A. 2009. Noise pollution changes avian communities and species interactions. Current biology, 19(16), 1415-1419.

Francis, C. D., & Barber, J. R. 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. Frontiers in Ecology and the Environment, 11(6), 305-313.

Fredriksen, R. L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. Research Papers. Pacific Northwestern Forest and Range Experiment Station, (PNW-104).

Geneletti, D. 2004. Using spatial indicators and value functions to assess ecosystem fragmentation caused by linear infrastructures. International Journal of Applied Earth Observation and Geoinformation, 5(1), 1-15.

The Habitat Conservation Plan (HCP). 2012. Edwards Aquifer Recovery Implementation Program. Viewed 2016. http://eahcp.org/documents/Final%20HCP%20November%202012.pdf

Hays County. 2010. The Hays County Regional Habitat Conservation Plan. Viewed 2016. http://www.hayscountyhcp.com/docs/FINAL_Hays_County_HCP_20100621.pdf

Hegemier, Tom. 2017. Upper San Marcos River Watershed Flooding and Land Conservation Technical Memorandum. Meadows Center for Water and the Environment at Texas State University.

Hill Country Alliance (HCA). 2015. The State of the Pedernales: Threats, Opportunities and Research Needs. Viewed 2018. http://hillcountryalliance.org/wp-content/uploads/2015/01/Final_State-of-the-River_012015_PDF-reduced1.pdf

HOBBS, J. C., & LEDGER, J. A. 1986, June. The Environmental Impact of Linear Developments; Power lines and Avifauna. In Third International Conference on Environmental Quality and Ecosystem Stability. Israel.

Hunt, B. B., B. A. Smith, M.O. Gary, A. S. Braun, D. A. Wierman, J. Watson, D. Johns. 2017. Surface-water and Groundwater Interactions in the Blanco River and Onion Creek Watersheds: Implications for the Trinity and Edwards Aquifers of Central Texas. Bulletin of the South Texas Geological Society 57 (5):33-53.

Hunt, B. 1999. Unsteady stream depletion from ground water pumping. Groundwater, 37(1), 98-102.

Jones, J. A., Swanson, F. J., Wemple, B. C., & Snyder, K. U. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology, 14(1), 76-85.

Keller, I., & Largiader, C. R. 2003. Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. Proceedings of the Royal Society of London B: Biological Sciences, 270(1513), 417-423.

Kight, C. R., & Swaddle, J. P. 2011. How and why environmental noise impacts animals: an integrative, mechanistic review. Ecology letters, 14(10), 1052-1061.

Konrad, C.P. 2003. Effects of Urban Development on Floods. Viewed 2018. https://pubs.usgs.gov/fs/fs07603/

Lower Colorado River Authority (LCRA). 2017. Pedernales Watershed Posterhttps://maps.lcra.org/default.aspx?MapType=Watershed%20Posters. Last accessed 01/14/2018

Margules, C. R. 1989. Introduction to Some Australian Developments in Conservation Evaluation. Biological

Conservation 50:1-11.

Meadows Center for Water and the Environment. 2015. How much water is in the Pedernales? Conservation Strategies, Management Approaches, and Action Plan. Viewed 2018. http://gato-docs.its.txstate.edu/jcr:b86020ce-c1d8-4329-8577-5b59e9be09ba/How-MuchWaterisinthePedernales.pdf

Meadows Center for Water and the Environment. 2017. How much water is in the Pedernales? Occurrence of Flowing Water and Water Quality during Base Flow Conditions in the Pedernales River Basin. Viewed 2018. http://gato-docs.its.txstate.edu/jcr:1de06744-9500-41ad-b2a0-6d7e669f4e7e/Pedernales_Gain_Loss_Report_FINAL_20170307.pdf

Nassauer, J. I., Allan, J. D., Johengen, T., Kosek, S. E., & Infante, D. 2004. Exurban residential subdivision development: effects on water quality and public perception. Urban Ecosystems, 7(3), 267-281.

Nature Conservancy. 2017. Beyond the Source: The environmental, economic and community benefits of source water protection. Viewed 2017. https://global.nature.org/content/beyond-the-source.

National Weather Service. 2017. http://water.weather.gov/ahps2/hydrograph.php?wfo=EWX&gage=JOCT2. Last accessed 10/26/2017

Pressey, R. L. 1993. Ad Hoc Conservation: Forward or Backward Steps in Developing Representative Reserve Systems? Conservation Biology 8 (3):662-668.

Siglo Group. 2014. City of San Antonio Spatial Model to Identify High-Priority Properties for the Edwards Aquifer Protection Program Project Summary. City of San Antonio Edwards Aquifer Protection Program.

Siglo Group, 2017. City of San Antonio Edwards Aquifer Protection Program Spatial Model Scorecard. San Antonio Edwards Aquifer Protection Program. January 2017.

Solomon, D. 2014. The Fastest Growing City in the Country is Actually San Marcos. Texas Monthly. May 23, 2014. Viewed 2016. http://www.texasmonthly.com/the-daily-post/the-fastest-growing-city-in-the-country-is-actually-san-marcos/.

Smith, B. A., B. B. Hunt, A. G. Andrews, J. A. Watson, M. O. Gary, D. A. Wierman, and A. S. Broun. 2014. Hydrologic Influences of the Blanco River on the Trinity and Edwards Aquifers, Central Texas, USA, in Hydrogeological and Environmental Investigations in Karst Systems, Environmental Earth Sciences, Springer Berlin Heidelberg 1: 153-161.

San Marcos Watershed Initiative (SWMI). 2016. Upper San Marcos Watershed Protection Plan Draft. Viewed 2016. http://smwatershedinitiative.wp.txstate.edu/wpp-drafts/

Texas A&M University (TAMU) Natural Resources Institute. 2014. Texas Land Trends: Texas Landowner Changes and Trends. Viewed 2018. http://txlandtrends.org/media/1018/ltchanginglandownerfinal2.pdf.

Texas Department of Transportation (TxDOT). 2013. Rapid, Broad-Scale Modeling of Generalized Archeological Integrity Potential in Texas Using Extant GIS Data. A proposed methodology for supervised, semi-automated modeling of archeological potential, and a pilot study of its effectiveness. Viewed 2017. https://www.txdot.gov/inside-txdot/division/environmental/compliance-toolkits/toolkit/archeological-map.html.

Texas Parks and Wildlife (TPWD). 2016. Texas Natural Diversity Database (TXNDD). Data requested and received in 2016.

Texas Parks and Wildlife (TPWD). 2014. Ecological Mapping Systems of Texas: Summary Report. tpwd.texas.gov/gis/programs/landscape-ecology/supporting-documents/final-summary-report/view. Data available via tnris.org/data-catalog/entry/tpwd-texas-ecological-systems-data/

Texas State University Geography, Hill Country Associates GIS Consulting Project. 2014. An Analysis of Land Use/Land Cover Changes and Population Growth in the Pedernales River Basin. Viewed 2017. http://sites.geo.txstate.edu/g4427/S15/2Pedernales/docs.html. Last accessed 11/27/2017

Texas State University and National Environmental Resource Data Solutions. 2010. Analysis of Potential Scenic Sites for the Hill Country Conservancy and Hill Country Alliance. Viewed 2016. http://sites.geo.txstate.edu/g4427/F10/NERDS/index_files/Page392.htm.

Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1):32. Available from http://www.ecologyansociety.org/vol10/iss1/art32/

Trombulak, S. C., & Frissell, C. A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation biology, 14(1), 18-30.

Trust for Public Lands. 2004. Protecting the Source, Land Conservation and the Future of America's Drinking Water. Viewed 2017. https://www.tpl.org/sites/default/files/cloud.tpl.org/pubs/water-protecting_the_source_final.pdf.

TWDB. 2016. 2016 Regional Water Plan. Texas Water Development Board. Viewed 2017. http://www2.twdb.texas.gov/ReportServerExt/Pages/ReportViewer.aspx?%2fProjections%2fpop_county&rs:Command=Render

Ura, A. and L. Flannery. 2016. Suburban Population Continues to Surge in Texas. Texas Tribune. March 24, 2016. Viewed 2016. https://www.texastribune.org/2016/03/24/suburban-population-counties-surge-texas/.

Ura, A and J. McCullough. 2015. See How Each Texas City Grew From 2010 to 2014. The Texas Tribune. May 21, 2015. Viewed 2016. -https://www.texastribune.org/2015/05/21/interactive-texas-population-growth-2010-2014.

US Census. 2017. Viewed 2017. www.census.gov.

USGS. 2003. Major and Catastrophic Storms and Floods in Texas. Viewed 2017. https://pubs.usgs.gov/of/2003/ofr03-193/cd_files/USGS_Storms/patton.htm last accessed 10/26/2017.

Vos, C. C., & Chardon, J. P. 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog Rana arvalis. Journal of applied Ecology, 35(1), 44-56.

Wierman, D. A., A. S. Broun, and B. B. Hunt. 2010. Hydrogeologic Atlas of the Hill Country Aquifer, Blanco, Hays and Travis Counties, central Texas. Hays Trinity Groundwater Conservation District; Barton Springs/Edwards Aquifer Water Conservation District; Blanco-Pedernales Groundwater Conservation District.

Wierman, D. A., A. S. Broun, A. H. Backus, and L. Llano. 2008. Cypress Creek/Jacob's Well Hydrogeologic Report, Hays Trinity Groundwater Conservation District, 43 p. + tables + appendices.

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