Upper Llano River Watershed Protection Plan

Developed by the Upper Llano Watershed Coordination Committee

May 2016

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In addition, we are grateful for cooperation and participation from representatives of key local groups who will play a vital role in protecting the health of the Upper Llano River watershed:

- The City of Junction and City of Rocksprings
- County Judges of Edwards, Kimble and Sutton counties
- Edwards Plateau, Upper Nueces-Frio and Upper Llanos Soil and Water Conservation Districts
- Real-Edwards Conservation and Reclamation District, Kimble County Groundwater Conservation District and Sutton County Underground Water Conservation District
- Texas Parks and Wildlife Department
- Llano River Watershed Alliance (formerly South Llano Watershed Alliance)
- South Llano River State Park
- Edwards Plateau and Upper Llanos Prescribed Burn Associations
- USDA-Natural Resources Conservation Service
- Texas Wildlife Association
- Landowners of the Upper Llano River watershed

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Photo Credits

- Llano River Field Station - Texas Tech University
- Texas Parks and Wildlife Department
- Llano River Watershed Alliance

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List of Acronyms

1.00E+6	Scientific Notation = 1 times 106 or 1,000,000
ac-ft	acre-feet (325,851 gallons)
AgriLife Extension	Texas A&M AgriLife Extension Service
ANOSIM	Analysis of similarities
ALU	aquatic life use
BMP	best management practice
BST	bacterial source tracking
CFDA	Catalog of Federal Domestic Assistance
CADDIS	Causal Analysis/Diagnosis Decision Information System
cfu	colony forming units
cfs	cubic feet per second (7.48 gallons per second)
CRP	Clean Rivers Program
CDA	Conservation Demonstration Area
CSP	Conservation Stewardship Program
CPOM	coarse particulate organic matter
DPT	Discovery Point Trail
D.O.	dissolved oxygen
EDYS	Ecological DYnamics Simulation
EPT	Ephemeroptera, Plecoptera, and Trichoptera
E. coli	*Escherichia coli*
ET	evapotranspiration
EQIP	Environmental Quality Incentive Program
FPOM	fine particulate organic matter
gpd	gallons per person per day
gal/min	gallons per minute
ft	feet
HUC	hydrologic unit code
kg/yr	kilograms per year
JTTB	Junction Texas Tourism Board
LULC	Land Use/Land Cover
LDC	load duration curve
LIP	landowner incentive program
LRFS	Llano River Field Station
LSHS	Lone Star Healthy Streams
LCRA	Lower Colorado River Authority
MSL	mean sea level
NAIP	National Agriculture Imagery Program
NASS	National Agricultural Statistics Service
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NRCS	National Resource Conservation Service
NPS	nonpoint source
NMDS	nonmetric multidimensional scaling
NDVI	normalized difference vegetation index
OSSF	on-site sewage facility
PEC	Pedernales Electric Cooperative
RCPP	Regional Conservation Partnership Program
RMU	resource management unit
SWCD	soil and water conservation district
TCEQ	Texas Commission on Environmental Quality
TDA	Texas Department of Agriculture
TFS	Texas A&M Forest Service
TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
TWA	Texas Wildlife Association
TDS	total dissolved solids
SLWA	South Llano Watershed Alliance
SEP	Supplemental Environmental Program
ULRW	Upper Llano River watershed
ULRWPP	Upper Llano River Watershed Protection Plan
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WBD	water boundary dataset
WPP	watershed protection plan
WQMP	water quality management plan
WSEP	Water Supply Enhancement Program
WWTF	wastewater treatment facility(ies)
yr	year

Executive Summary

The Llano River, a clear, spring-fed perennial river and major tributary of the Colorado River, is a true gem of the Texas Hill Country. The Upper Llano River, which includes the North and South Llano rivers and the springs that feed them, supports several unique plant and animal communities and provides constant flows downstream to the Llano and Colorado rivers, Lake Lyndon B. Johnson (LBJ) and other Highland Lakes, which are especially critical during times of drought. It is one of the few major watersheds containing a genetically pure population of Guadalupe bass, the Texas state fish. It is recognized by the Texas Parks and Wildlife Department as an Ecologically Significant Stream, having high water quality, exceptional aquatic life, high aesthetic value, and diverse benthic macroinvertebrate and fish communities.

Due to the pristine nature and relatively constant flow of the springs, the Upper Llano River is currently a healthy ecosystem supporting a variety of aquatic and terrestrial ecosystems and numerous recreational opportunities. However, decreased spring flow due to aquifer withdrawals and drought, subtle changes from land fragmentation, loss of riparian habitat, spread of invasive species and encroachment of juniper species on upland habitats threaten this system, impacting stream health, water quality and flows.

Upper Llano River Watershed Overview

The Upper Llano River watershed has seen pronounced growth in the number of small ranches subdivided from historically large ranches. This fragmentation has resulted in an increase in the absentee landowner population and an increase in the number of wells and septic systems; over the last 25 years, nearly 800 wells have been drilled in the watershed. The increase in the number of smaller properties has also brought about changes to land management practices where fewer acres are managed for livestock and more acres are managed for wildlife viewing and hunting.

The watershed has also seen an increase in the number of terrestrial exotic and invasive species, especially axis deer and feral hogs. Portions of the watershed are also affected by an overpopulation of white-tailed deer. The impacts from these population pressures are greatest in the riparian zones of the rivers, resulting in streambank erosion, periodic bacterial exceedances and lack of streamside forest canopy regeneration. These riparian zones also are impacted by invasive riparian species (giant cane, elephant ear and chinaberry), which can consume large amounts of water and out-compete native riparian species.

Historically, the North and South Llano rivers have had few water quality standard exceedances, indicating the Upper Llano River is a healthy ecosystem that supports high to exceptional aquatic life use. However, more recent data, collected through the development of the watershed protection plan (WPP), indicate sporadic exceedances of water quality standards for *E. coli* in surface water of the North Llano and in private drinking water wells throughout the watershed. In the Upper Llano Watershed, the sources of pollution are diffuse, making them difficult to identify. This type of diffuse pollution is defined as nonpoint source (NPS) pollution and is described as the collective runoff from the landscape. Nonpoint sources in the Upper Llano Watershed include wildlife, invasive species, livestock and septic systems. These sources may also contribute to the presence of nitrates in local private wells.

Problem/Action Taken

To proactively address these threats and improve the sustainability of the Upper Llano, development of a WPP was initiated on the Upper Llano River watershed above the confluence in Junction. Since watersheds cross jurisdictional/political boundaries, a watershed approach incorporates the entire landscape instead of management through predetermined boundaries.

The WPP was developed through a locally led process in which local stakeholders, represented by the Coordination Committee, develop a holistic strategy to restore and/or protect the quantity and quality of surface water and groundwater resources through voluntary, non-regulatory watershed management strategies.

Addressing Issues of Concern

Potential issues of watershed concerns in the Upper Llano were identified through stakeholder input, local project partner experience, land use classification, modeling and water quality monitoring and observations during the development of the WPP. Identified issues of concern include: 1) bacteria, 2) nutrients, 3) sediments, 4) contaminant runoff from impervious surfaces and 5) causes of streamflow reduction.

Recommended Actions

The Coordinating Committee selected a collection of management measures and goals to address sources of concern in a holistic manner to improve both the quality and quantity of flows in the watershed. These measures are directed primarily at improved grazing, wildlife, septic systems and invasive species management as well as implementation of sound upland and riparian management measures and other water quality protection measures.

Septic Systems (OSSF)

Septic systems can have a direct impact on bacteria contamination in rivers, streams and groundwater. The goal is to repair or replace at least 10 failing on-site sewage facilities (OSSF) per year or 100 over a 10-year period, focusing on systems posing the greatest threat to surface water (i.e. those nearest the rivers, streams and springs) and groundwater resources (i.e. those near wells found to contain elevated levels of *E. coli*).

Feral Hogs

Feral hogs are known to contribute *E. coli* to surface water bodies as well as damage streambanks and riparian areas. The formation of a Feral Hog Task Force will be a critical first step in implementing feral hog management efforts. The goal is to stabilize the hog population by harvesting 66% of the population (26,000) over a 10-year period.

White-Tailed Deer and Exotics (Non-native)

In many areas of the state, wildlife has been identified as a significant source of bacteria. Further, in the Upper Llano Watershed, wildlife has been shown to impact riparian vegetation in some areas. A coordinated effort to managing white-tailed deer and non-native, exotic populations (primarily axis deer) will be implemented through increased landowner participation in wildlife management plans, landowner incentive program or wildlife management associations. The goal is to increase the number of active wildlife management plans in the watershed by two plans per year.

Grazing Management and Complementary Practices

Increasing the number of landowners with a National Resource Conservation Service (NRCS) conservation plan or Texas State Soil and Water Conservation Board (TSSWCB) water quality management plan is a key management measure for the watershed. Key practices in these plans include grazing management and upland wildlife habitat management. The goal is to have a minimum annual average of 10,000 acres in improved upland wildlife habitat management (for a total of 100,000 over 10 years) and 25,000 acres of additional prescribed grazing annually (for a total of 250,000 acres planned over 10 years) implemented through these plans. In addition, Texas Parks and Wildlife Department (TPWD), through landowner consultations, will develop wildlife habitat management plans on an additional 10,000 acres annually. Thus, wildlife habitat plans are expected to be developed on a total of 20,000 acres per year or 200,000 acres over the 10-year implementation horizon through the joint efforts of NRCS, TPWD, soil and water conservation districts and TSSWCB.

Brush Control for Range Improvement and Water Supply Enhancement

Brush control, in conjunction with follow-up prescribed burns, is a key management measure to improve upland rangeland and enhance water supplies. Exceedances of water quality standards are often associated with occurrences of low flow. Thus, the goal is to treat a minimum of 9,000 acres annually (for a period of 10 years) of medium to heavy brush on slopes less than 12%. Areas shown by the Ecological DYnamics Simulation (EDYS) model to have

the greatest benefit to water supply from brush control will receive the highest priority; however, other areas with medium to high brush will not be excluded. Follow-up treatment using prescribed burns and other methods will be conducted on a six- to seven-year cycle or as mandated by agency program requirements.

Prescribed burns (in addition to those used in conjunction with brush control) are a key management measure to improve upland range conditions. The goal is to treat 5,400 to 7,700 acres of low-density brush annually over a 10-year period.

Streambank and Riparian Buffer Restoration

In order to improve and sustain streambank stability and stream health, implementation of riparian management measures including bank stabilization, recruitment of woody riparian vegetation and control of exotic invasives (giant cane and elephant ear) is recommended. The goal is to begin restoration on 10% of the riparian buffer annually (about 1.4 miles) over a 10-year period and implement one demonstration project of streambank restoration. An additional goal is to treat 100% of the riverbanks infested with giant cane (*Arundo donax*) and elephant ear (*Colocasia esculenta*).

Water Conservation

As previously noted, exceedances of water quality standards are often associated with occurrences of low flow. Implementing water conservation practices such as leak detection, installation of low-flow toilets and shower heads, and providing real-time irrigation water need information can help reduce these occurrences. The Coordination Committee established a goal of decreasing per capita water use in the watershed by 1% per year over the next 10 years. Per capita water use in Junction and Rocksprings will be used as a metric to identify measures of success.

Urban Stormwater Management

Stormwater runoff associated with impervious cover and contaminant runoff from the I-10 intersection to the North Llano in Junction is an identified water quality concern. The goal of the Coordination Committee is to obtain funding to study the implementation and location of best management practices (BMPs) to reduce runoff from 1% of the total urban land use in the watershed (i.e. 79 acres).

Education and Outreach

The development and implementation of this WPP depends on effective education, outreach and engagement efforts that inform landowners of activities, practices and programs associated with the WPP, as well as identify partnerships to assist with the WPP implementation. The Coordination Committee recommends using a variety of media to enhance outreach, including the project website and social media, newsletters, outreach at local events, BMPs and stewardship workshops, seminars, videos, river rangers, outreach to new and absentee landowners, brochures, visitor guides and the Llano River Field Station K-12 Outdoor School.

Measures of Success and Adaptive Implementation

The healthy watershed approach of the Upper Llano River WPP relies on multifaceted management measures that not only preserve and improve the water quality of the rivers and streams but also improve water quantity and the health and resilience of riparian and upland conditions in the watershed. Given such an approach, it is important to measure both changes in water quality as well as implementation of practices and resulting changes in water quantity and watershed conditions as measures of success.

Measures of successful WPP implementation will focus on achieving the water quality goals and ensuring the watershed remains in a healthy condition, with water quality parameters that do not exceed state standards.

The implementation of the recommended management measures are expected to achieve the following results at the end of 10 years:

- a reduction in *E. coli* loadings by 3.38+15 cfu
- a reduction in sediment loading by 15,700 tons
- a reduction in nitrogen and phosphorus loading by 650 tons and 110 tons, respectively
- an increase in water availability of 75,000 acre-feet per year (10-12 years after implementation)

As the recommended management measures of the Upper Llano WPP are put into action, it will be essential to monitor water quality and quantity and other measures of success to make needed adjustments to the implementation strategy. Routine water quantity and quality monitoring will continue at targeted locations along the North and South Llano rivers during the implementation phase. To provide flexibility and enable adjustments to monitoring and implementation activities, adaptive implementation will be used throughout the process. This on-going, cyclic implementation and evaluation process serves to focus restoration efforts and maximize impacts.

While water quantity and quality, as well as riparian and range conditions, will likely change and may not exactly follow projections indicated by the EDYS model and other estimates in the WPP, these estimates serve as a tool to better inform stakeholder evaluation and decision making associated with adaptive implementation.

It is the goal of the Upper Llano WPP to ensure that the long-term integrity and sustainability of the watershed, springs and rivers are preserved and that water quality standards and flows are maintained for present and future generations.

1. Introduction

A watershed is an area of land that drains to a common body of water such as a stream, river or even a spring. Some watersheds can be very small, draining a few square miles, while others, such as the Mississippi River watershed, drain more than 40% of the contiguous United States. The Upper Llano Watershed consists of the North and South Llano river watersheds, part of the larger Llano River watershed and even larger Colorado River watershed.

1.1 Watersheds and Water Quality and Quantity

John Wesley Powell once described a watershed as "that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community."

All activities, both human and natural, that occur within the boundaries of a watershed have the potential to influence both water quality and quantity of the receiving water body. As a result, an effective management strategy that addresses water quality and quantity issues in a watershed's receiving water body must examine all human activities and natural processes within that watershed.

1.2 The Watershed Approach

The Watershed Approach is "a flexible framework for managing water resource quality and quantity within a specified drainage area or watershed. This approach includes engaging stakeholders to make management decisions supported by sound science and appropriate technology" (USEPA, 2008). The Watershed Approach is based on the following principles:

- geographic focus based on hydrology rather than political boundaries;
- water quality objectives based on scientific data;
- coordinated priorities and integrated solutions; and,
- diverse, well-integrated partnerships.

A watershed's boundaries often cross municipal, county and state boundaries because they are determined by the landscape. Using the Watershed Approach, all potential impacts to the water quality and quantity of a waterway can be addressed through the process by all potential watershed stakeholders.

A stakeholder is anyone who lives, works or has an interest within the watershed or may be affected by decisions; stakeholders can include individuals, groups, organizations or agencies. Stakeholder involvement is critical for effectively employing a holistic approach to watershed management that adequately addresses all watershed concerns.

1.3 Watershed Protection Plan

Watershed protection plans (WPP) are locally driven mechanisms for voluntarily addressing complex water quality and quantity problems that cross jurisdictional boundaries. Through the development of the plan, stakeholders can holistically identify and address, through prioritized management measures, all of the sources and causes of impairments and threats to both surface water and groundwater resources within a watershed.

A WPP serves as a framework to better leverage and coordinate the resources of local governments, state and federal agencies, and non-governmental organizations. WPPs promote a unified approach to seeking funding for implementation and create a coordinated public communication and education program.

1.4 Watershed Protection Plan for the Upper Llano Watershed

The Llano River is a critical asset to Central Texas, providing legendary outdoor recreational opportunities, supporting unique aquatic ecosystems and providing critical downstream water supplies, especially during drought.

The headwaters of the Llano River consist of the North and South Llano rivers, clear, spring-fed rivers that discharge from the edge of the Edwards Plateau, one of the most biologically diverse regions in the nation (The Nature Conservancy, 2008).

The Llano River, just below the confluence of the North and South Llano rivers in Junction, Texas, has never ceased flowing in recorded history (USGS, 2012). Because of these continuous flows, high water quality and diverse benthic macroinvertebrate and fish communities, the South Llano River is considered by the Texas Parks and Wildlife Department (TPWD) as an ecologically significant stream segment (El-Hage and Moulton, 2001). Although the North Llano does not flow continuously during periods of drought, springs in the upper portions of the North Llano still provide critical habitat for aquatic species, as well as water supply for domestic users, livestock and wildlife (Broad, 2012).

The watershed of the North and South Llano rivers is currently considered a healthy ecosystem (Broad, 2012). The greatest threats to these rivers that comprise the Upper Llano include:

- loss of spring flow due to drought and aquifer withdrawals
- nonpoint source (NPS) pollution
- land fragmentation
- encroachment of invasive species
- encroachment of woody species on upland habitats
- loss of riparian habitat

To proactively address these threats and improve the sustainability of the Upper Llano, development of a WPP was initiated on the Upper Llano River watershed above the confluence in Junction.

The Coordination Committee recognizes that the Upper Llano WPP addresses a watershed that is larger than most other approved WPP watersheds in Texas. As there are currently no impairments in the watershed, the intent of this effort is to incorporate and protect as many good quality waters as possible. It is also necessary to engage as many landowners as possible to implement best management practices, and the relatively large size of many properties in this watershed requires planning on a larger scale. We believe this targeted, proactive approach will save time, effort, and funding, as opposed to attempting future restoration of water bodies not protected under this WPP. The largest percentage (77%) of land use in this WPP is undeveloped brush; if unforeseeable changes in land use patterns develop, this WPP can be amended.

The creation of a WPP follows nine fundamental elements that provide a template for the creation, implementation and review of watershed protection efforts (USEPA, 2008). While WPPs vary in composition and strategy, the fundamental elements of any WPP include (see Appendix J – Elements of a Successful Watershed Protection Plan):

1. Identification of causes and sources of impairment
2. Expected load reductions from management strategies
3. Proposed management measures
4. Technical and financial assistance needed to implement management measures
5. Information, education and public participation needed to support implementation
6. Schedule for implementing management measures
7. Milestones for progress of WPP implementation
8. Criteria for determining successes of WPP implementation
9. Water quality monitoring

Currently, the Upper Llano Watershed does not have any water quality impairments; therefore, this WPP is a proactive approach to watershed management, and as such, the Upper Llano River WPP follows the Healthy Watershed Approach. The Healthy Watershed Approach to watershed planning focuses on conserving and protecting healthy components of watersheds in an effort to preserve or enhance the ecosystem services provided and to prevent future impairments from land use changes or other perturbations. A healthy watershed provides a number of ecosystem services including:

- lowered cost of drinking water treatment
- avoidance of expensive restoration activities
- sustained recreational and tourism opportunities
- minimized vulnerability to disturbances (e.g., flooding, land fragmentation, invasive species colonization, etc.)
- critical ecosystem services at a fraction of the cost of engineered services
- increased property values
- fish and wildlife habitat

Historically, restoration was the solution to repairing damaged ecosystems. However, restoration is costly and often has a low success rate (Dlugolecki, 2012). Protecting highly functional aquatic ecosystems and their supporting landscapes is a cost-effective way to provide critical ecosystem services. The long-term economic benefits of natural, intact ecosystems far exceed the short-term economic gains from land conversion.

This document serves as the framework to focus preservation and restoration efforts, and to enable financial and technical assistance to implement improvements in the Upper Llano River watershed. The WPP is intended to be a living document that will evolve as circumstances change and will be guided by the stakeholders as they undertake active watershed stewardship.

Developed and implemented through diverse, well-integrated partnerships, this WPP aims to protect and preserve the water quality and flow within the Upper Llano River watershed using solutions that are economically and ecologically feasible and, at the same time, respect private property rights. The plan and its components address potential threats arising from the spread of noxious woody vegetation, terrestrial and aquatic invasive species, loss of riparian habitat, and contamination from septic systems and urban stormwater runoff. The WPP includes an assessment of water quality, flow and biological monitoring.

2. Upper Llano River Watershed Protection Planning Efforts

2.1 Stakeholder Involvement

WPPs are developed and implemented through local stakeholder involvement. To facilitate stakeholder involvement, an intensive outreach program was initiated to inform and educate stakeholders throughout the watershed about the planning process. Press releases and meeting invitations were developed and delivered in the watershed through media outlets such as the local newspapers, social media and listservs. More than 500 notifications were sent by direct mail to known potential stakeholders throughout the watershed. In addition, presentations were made at a number of local meetings including:

- Commissioners Courts of Edwards, Kimble and Sutton counties
- Upper Llanos, Upper Nueces-Frio and Edwards Plateau Soil and Water Conservation Districts
- South Llano Watershed Alliance
- Texas Water Symposium: Healthy Watersheds
- Junction Rotary Club

Following these efforts, two public meetings were held to disseminate information regarding conditions of the Upper Llano River watershed and the proposed development of the Upper Llano River WPP. Nearly 100 participants attended these meetings. Participants were invited to be involved in the WPP process and share the information that should be part of the process with other potential stakeholders.

2.2 Stakeholder Structure: Coordination Committee and Working Groups

To guide the overall WPP development and implementation, the Upper Llano River stakeholders voted to adopt a Coordination Committee and Working Groups.

2.2.1 Coordination Committee

At the second WPP meeting, stakeholders voted to establish a Coordination Committee to represent the key stakeholder interests in the watershed and be the decision-making body. Various stakeholder groups created the committee through self-nomination and requests. Eighteen members representing the majority of key interests in the watershed served as official members of the WPP Coordination Committee (see Appendix A) and were involved throughout the process.

The Coordination Committee followed a set of Ground Rules (Appendix B) developed, approved and signed by the Coordination Committee as its first order of business. The Committee met as needed during the development of the WPP. The primary goals of the Committee were to:

- identify and prioritize key issues in the Upper Llano River watershed;
- identify and prioritize management measures included in the development of the Upper Llano River WPP; and
- aid in the development and implementation of the WPP.

The Llano River Field Station (LRFS) of Texas Tech University, Texas Water Resources Institute (TWRI) and Texas State Soil and Water Conservation Board (TSSWCB) facilitated this process.

2.2.2 Working Groups

Working groups were created by the Coordination Committee to focus on specific issues and facilitate the development of the WPP. Working groups were composed of members of the Coordination Committee in addition to others invited by the committee with expertise or a vested interest in the particular topic. Working groups met as needed to identify and make recommendations on implementation strategies and support development of the WPP. Approximately 30 members were active in the various working groups (Appendix C).

Working group topics included:

1. Invasive Species: Aquatic and Terrestrial
2. Riparian Protection and Management
3. Water Quality, Conservation and Flow
4. Upland Management
5. Water Supply Enhancement

3. Characterization of Upper Llano River Watershed

The Upper Llano River watershed (1,890 square miles or approximately 1.2 million acres) is located in west-central Texas (Figure 1) and begins in the heart of the Edwards Plateau. Elevation ranges from 2,487 feet (758 m) above mean sea level (MSL) in the upper reaches of the watershed to 1,637 feet (499 m) above MSL near the watershed outlet. Figure 2 depicts the elevation of the watershed derived from 10-m national elevation dataset (NED) images.

The Edwards Plateau is capped with thick limestone that has been dissolved over time by water to form the largest continuous karst region in the United States (Anaya, 2004). The water stored in the karst emerges as springs along the canyon walls. The springs originate near an elevation of 1,900 feet and supply constant flow to the lower 20 miles of the South Llano and intermittent flow for the lower 27 miles of the North Llano. The two rivers join in the City of Junction, becoming the Llano River, which travels 100 miles before it terminates in Lake Lyndon B. Johnson (LBJ).

The watershed encompasses portions of Edwards, Kerr, Kimble, Menard, Real and Sutton counties with the majority of the watershed lying within the boundaries of Edwards, Kimble and Sutton counties Additional information about the watershed can be found in [Headwaters of the Llano River](http://llanoriver.org/) on the Llano River Watershed Alliance (LRWA) website: http://llanoriver.org/.

The North and South Llano rivers and their tributaries and springs support a diverse, vibrant terrestrial and aquatic ecosystem as well as provide municipal water supply, recreational opportunity and historic and cultural value. However, their flows and health are increasingly imperiled due to land use/cover/ownership changes, regional water demands, invasive species, drought and local-

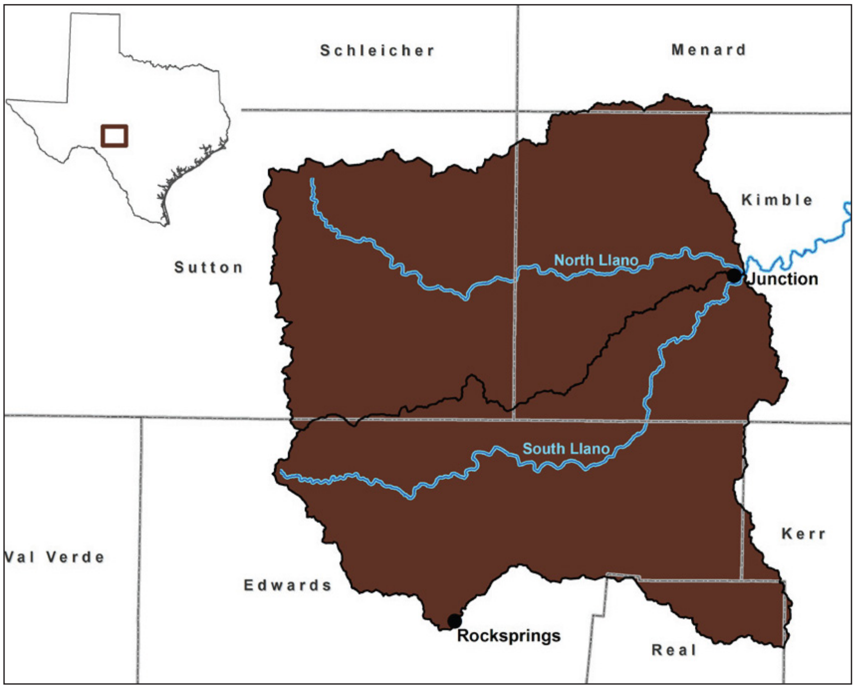


Figure 1. The North and South Llano rivers, comprising the Upper Llano River watershed form the Llano River in Junction. The Upper Llano Watershed is part of the Colorado River Basin.

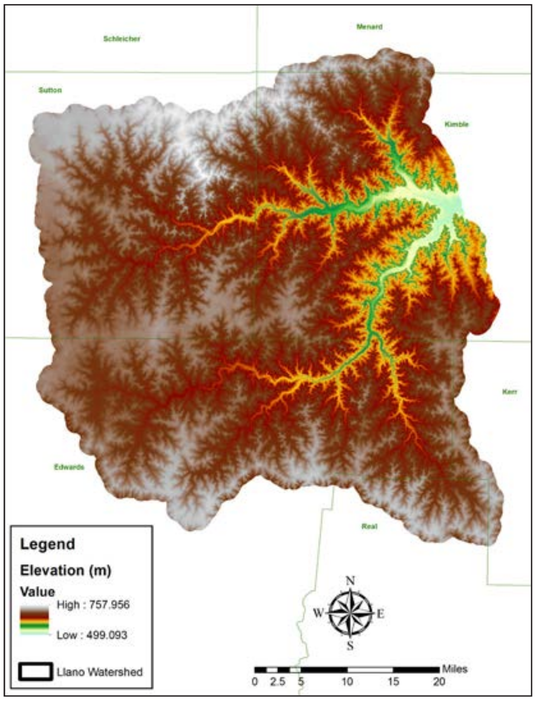


Figure 2. Elevation of Upper Llano Watershed.
Source: Mosaic of U.S. Geologic Survey (USGS) 10-m NED images.

ized impacts from wildfire (Broad, 2012). The magnitude of these individual threats largely remains undocumented in this watershed. This section reviews the demographics, land use, water quality, precipitation, flow and biological conditions in the watershed.

3.1 Soils

Soils in this region are mostly Mollisols, with shallow and moderately deep soils on plateaus and hills and deeper soils on plains and valley floors. The watershed is divided into six soil associations as seen in Figure 3 with Tarrant series dominating the watershed with the exception of creek bottoms and the northwest fringe of the watershed. The Tarrant series consists of soils that are very shallow and shallow to indurated limestone bedrock, interbedded with marl and chalk. These well-drained soils formed in residuum derived from limestone of Cretaceous age. These nearly-level to very-steep soils are on summits, shoulders and backslopes of ridges on dissected plateaus. Slopes are 1–50%. The predominant use associated with this soil series is rangeland and wildlife habitat. The climax plant community is a tall grass savannah with motts of live oak throughout the landscape. The dominant grasses are little bluestem and sideoats grama.

The Nuvalde-Dev-Frio series are deep, nearly-level to gently-sloping loamy and very gravelly soils found on upland outwash plains and bottomlands in valleys between limestone hills. Slopes range from 0–3%. These soils are used mainly as rangeland and wildlife habitat as well; however, some larger areas of Nuvalde and Frio soils are well suited to cultivation. These soils produce large amounts of forage and receive runoff from higher soils. Native range plants consist of short and mid grasses on the more upland sites and tall grasses on the bottomlands.

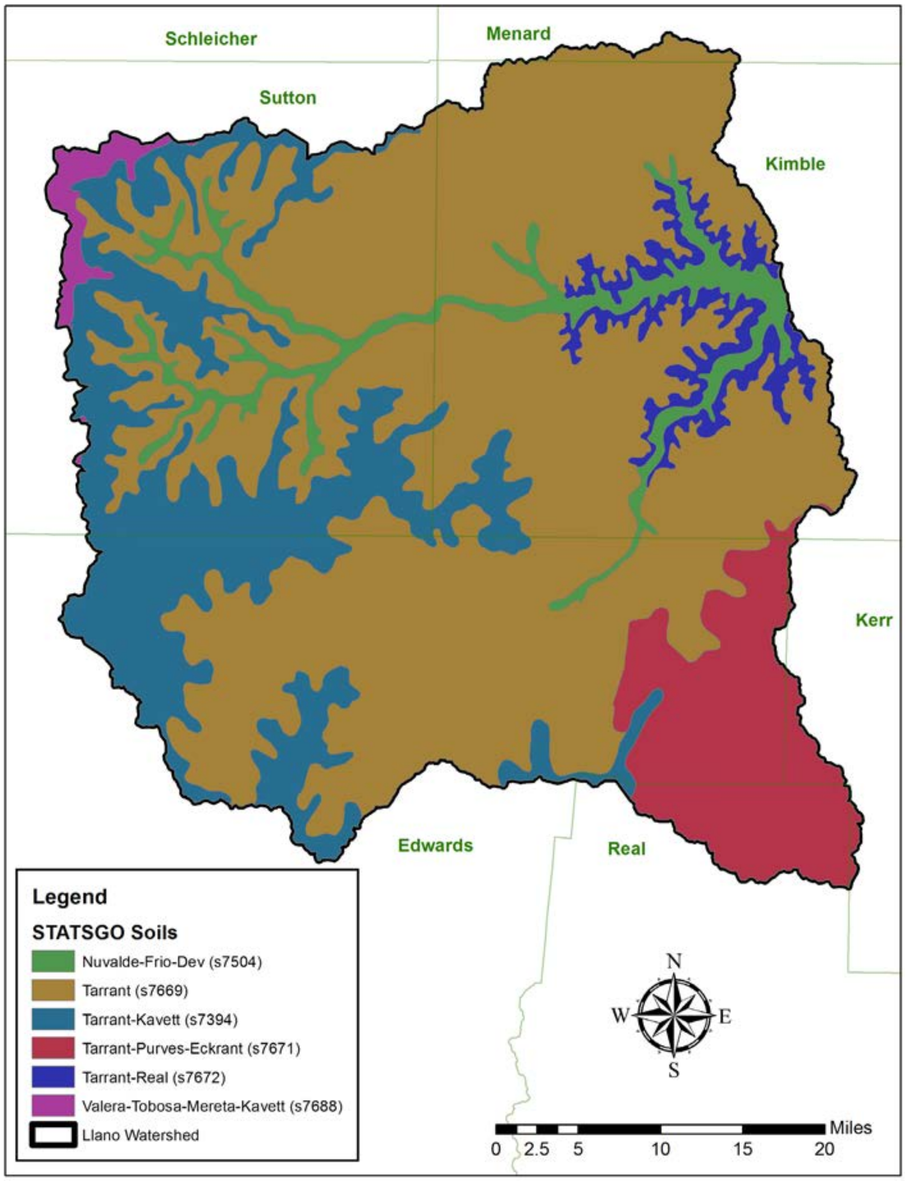


Figure 3. Soil associations within the Upper Llano Watershed.
Source: USGS State Soil Survey Geographic (STATSGO) Soils.

3.2 Demographics

The Upper Llano River watershed has between 4,555 and 5,026 people (U.S. Census, 2010). The U.S. Census data are grouped into county blocks that are not coincident with the watershed boundaries; therefore, ranges of population are reported[1]. The majority of the watershed's population is within Kimble County (3,135 to 3,279 population estimate) with 2,574 people living within the City of Junction. The remainder of the population within the watershed in ranked order is Edwards County (1,237 to 1,358); Sutton County (138 and 246); Menard County (up to 68); Real County (45 to 67); and Kerr County (up to 8) (U.S. Census, 2010).

[1]The low population estimate is determined using only U.S. Census data blocks with the centroid within the watershed; high population estimate includes all data blocks within watershed. The low estimate is likely underestimating population and the higher overestimating population.

The majority of people in the watershed have a high school education and about one-quarter of the population has a college degree (Table 1). The majority of residents in the watershed speak English as their primary language; however, for a large proportion of the population, English is spoken as a second language. An understanding of these varying audiences, their perspectives and ways to engage them is critical for successful implementation of the WPP. Implementation will be a collective effort of all to take ownership of the water resources and actively participate in stewardship of the watershed.

Table 1. Educational attainment (residents 25 years or older having completed high school or received a college level or higher degree) and primary language by county in the Upper Llano River watershed in 2010 (U.S. Census, 2010).

County	High School Diploma (%)	College Degree (%)	English Primary (%)	Non-English Primary (%)
Edwards	44.6	28.4	51.6	48.4
Kimble	53	24.7	75.7	24.3
Sutton	54.4	16.5	51.9	48.1
Texas Average	**48**	**32.4**	**65.6**	**34.4**

3.2.1 Population Projections

Population projections were determined using the Texas Water Development Board (TWDB) population data between 2010 and 2060 (Texas State Data Center and Office of the State Demographer, 2012). These projection data include projections based on historical growth rates, survival rates and net migration rates to individual cohorts (age, sex, race and ethnic groups). Over the next 50 years, Kimble County is expected to increase by 0.9%; Sutton County is expected to increase by 5.5%; and Edwards County is expected to decrease by 6.6%.

3.2.2 Issues related to Demographics

Population figures alone do not provide a clear picture of the demographics in the watershed. For example, of the 9,000 parcels in Kimble County, non-Kimble County residents own 55%, and non-Texas residents own an additional 5% (Broad, 2012). This high percentage of absentee landowners in the Upper Llano brings challenges to land stewardship. Many landowners are not presently living in the watershed and infrequently visit their properties. Education of absentee and new landowners is imperative to preserving the health of the watershed.

The large number of absentee landowners also reflects a growing problem with land fragmentation where larger ranches are sold and subdivided into smaller parcels to meet the demand of a growing urban population (Table 2). Urbanites and suburbanites purchase these smaller parcels as a weekend retreat. The increased infrastructure (roads, wells, septic systems) adds increased pressure on water resources and wildlife habitats, increases land prices and reduces available grazing acreage (Broad, 2012).

Table 2. Changes in ranch size in the Upper Llano River watershed (Texas A&M Institute of Renewable Natural Resources, 2014).

County	# of Acres in Ranches >2,000 acres (in 1,000 acres)		Market Value ($/acre)	
	1997	**2012**	**1997**	**2012**
Edwards	1,069	864	$253	$1,010
Kimble	580	384	$407	$2,150
Sutton	877	832	$200	$640

3.3 Water Quality

Water quantity and quality are closely related in the Upper Llano River watershed. Spring flow provides constant critical flows in the rivers especially during times of drought. Because of these continuous flows, high water quality and diverse benthic macroinvertebrate and fish communities, TPWD considers the South Llano River as an ecologically significant stream segment (El-Hage and Moulton, 2001). Although the North Llano does not flow continuously during periods of drought, springs in the upper portions of the North Llano still provide critical habitat for aquatic species, as well as water supply for domestic users, livestock and wildlife (Broad, 2012).

3.3.1 Surface Water Quality

The Texas Commission on Environmental Quality (TCEQ) and the Lower Colorado River Authority (LCRA) administer surface water quality and biological monitoring efforts in the Upper Llano River watershed. Historically, there have been eight surface water-monitoring sites within the watershed (Table 3; Figure 4). The period of record is variable with site and analyte.

Table 3. Water quality monitoring sites for the Llano River (Segment 1415).

Site #	Site Description	Monitoring Record
12212	North Llano at Bear Creek	1991
12391	South Llano River at US 377 crossing northeast of Rocksprings In Edwards County	1994-1999
14233	North Llano River on Kimble CR 274, 11 miles west of Junction off of US 290	1994-1997
16701	South Llano River on Edwards CR408 off of US 377 in Edwards County	1999-2012
17008	North Llano River at the confluence with Spring Hollow, 2.6 mi West and 1.0 mi North of the intersection of I-10 and West Loop 291 in Roosevelt	2000
17009	South Llano River at South Llano State Park immediately downstream of low water crossing, 250 yards south of US 377 and Crisp Hollow Creek	2000-2008
17425	North Llano River 570 feet upstream from confluence of the Llano/South Llano River confluence in Junction	2001-present
18197	South Llano River approximately 10 miles upstream of South Llano River State Park, 204 yards upstream of second US 377 crossing	2004-2005; 2011

In the development of the Upper Llano River WPP, 20 sites were sampled quarterly (10 samples each) between September 2012 and February 2015 (Table 4 and Figure 5). Routine ambient water quality monitoring was conducted at 14 main stem sites and tributaries and six spring sites throughout the Upper Llano Watershed on a quarterly basis. Monitoring included collection of field parameters—pH, temperature, conductivity and dissolved oxygen—and conventional parameters—total suspended solids, turbidity, sulfate, chloride, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, chlorophyll a, pheophytin, total hardness, total phosphorus and *E. coli*. Since water quality and water quantity are closely related, flow was also measured quarterly.

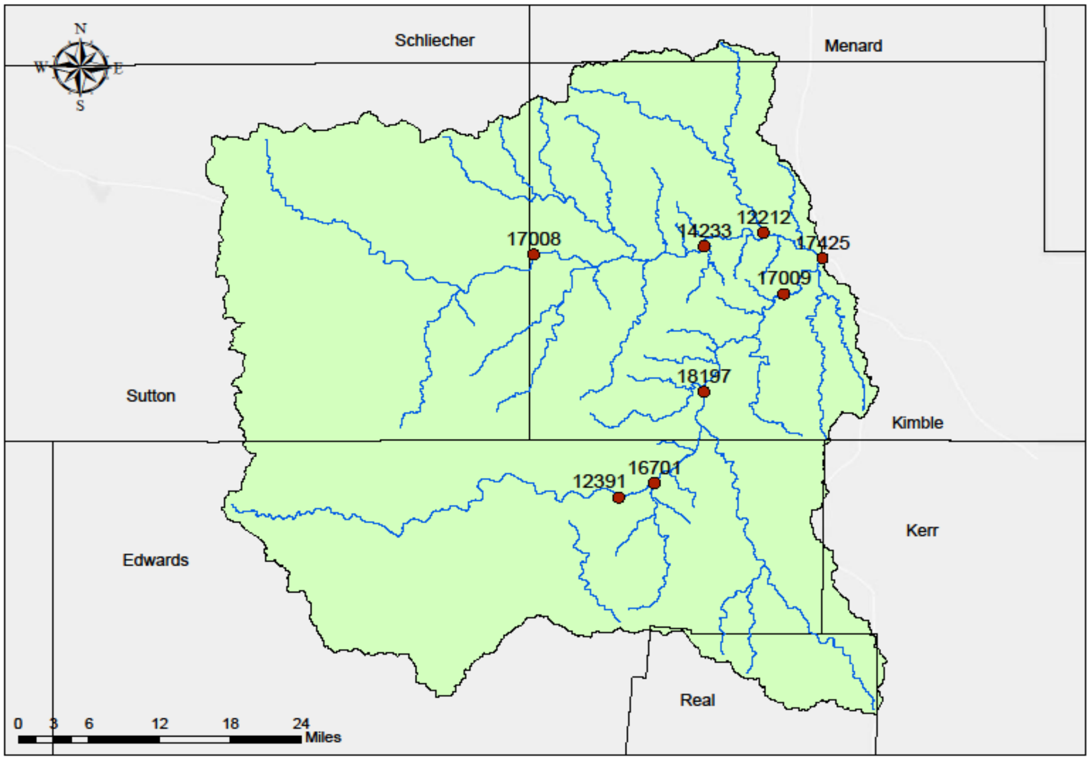


Figure 4. Historic surface water quality monitoring sites within the Upper Llano Watershed (see Table 6 for site names and locations).

Table 4. Water quality monitoring sites for ULRWPP 2012-2015.

Station ID	Site Description
21489	Llano below Confluence of N. Llano and S. Llano rivers
12212	Bear Creek @ 1674 Bridge
21263	N. Llano @ CR 274
21264	N. Llano @ CR 275
21283	N. Llano @ CR271
21266	N. Llano @ CR 260
21267	N. Llano @ Richardson Ranch
21268	N. Llano @ River Road below Fort Terrett Reservoir
21270	S. Llano @ State Park
21269	S. Llano @ CR 150/Hwy 377
21271	S. Llano @ 1st Crossing/Hwy 377
21272	S. Llano @ Telegraph
16701	S. Llano @ CR408
21273	Big Paint Creek
21274	Bois d'Arc Springs
21275	Christmas Spring
21276	Seven Hundred Springs
21277	Tanner Springs
21278	Deats Spring
21279	Llano Springs/Contrary Creek

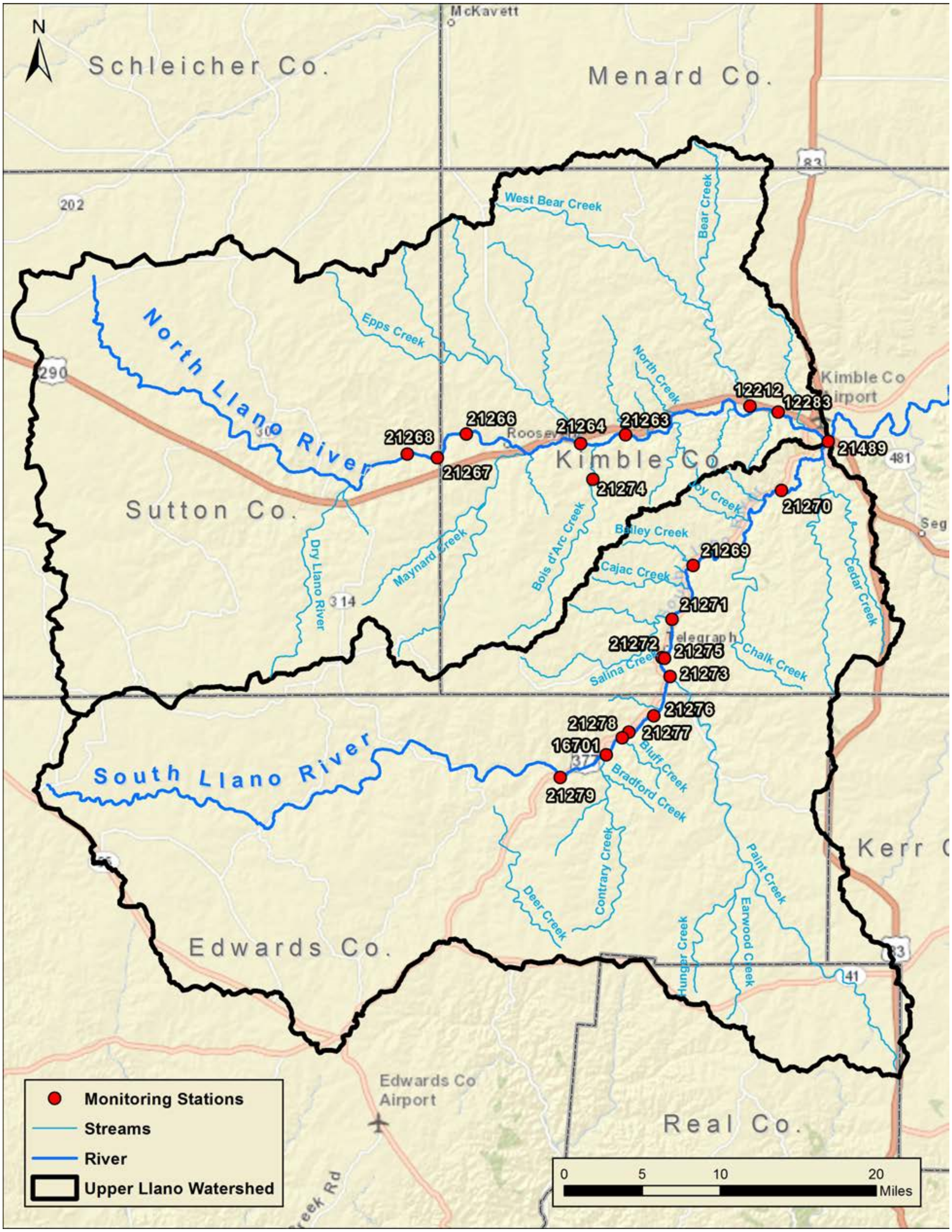


Figure 5. Water quality monitoring sites for the Upper Llano River WPP 2012-2015.

Water quality in the Upper Llano River watershed is protected for primary contact recreation (wading, swimming), high quality aquatic life, fish consumption and public water supply use. The 2012 Texas Integrated Report reported the aquatic life, contact recreation, public water supply and general uses were fully supported (TCEQ, 2012). In previous assessments, as well as sampling conducted 2012–2015, pH, chloride, sulfate, total dissolved solids (TDS), nutrients and temperature at all sites were compliant with state water quality standards. Only sporadic exceedances of dissolved oxygen (D.O.) and *Escherichia coli* (*E. coli*) were observed.

Dissolved Oxygen

D.O., a measure of the level of oxygen in the water, is essential for aquatic life. D.O. levels naturally exhibit diel (24-hour) patterns with levels increasing during the day as plants photosynthesize and decreasing at night as plants and other organisms respire. Extreme spikes and drops in D.O. concentrations may be an indicator of excessive nutrients or organic carbon loading. Extreme drops in oxygen levels are the most hazardous because levels <2 mg/L can cause death of fish and other aquatic organisms. In Hill Country streams, the level of D.O. necessary for exceptional aquatic life should typically remain above 5.0 mg/L over a 24-hour period. Except for four samples, D.O. at all sites would support exceptional aquatic life (>5 mg/L). As part of the historic water quality monitoring, the North Llano River, just a few feet upstream from its confluence with the South Llano (Site 17425), recorded a D.O. of 4.7 mg/L in August of 2008. Sampling for the WPP (Table 5) observed three samples below 5.0 mg/L on the North Llano at CR 274 and CR 275; both locations were below 5.0 mg/L in June of 2013 (4.29 and 4.83 mg/L respectively) and CR 274 was at 4.25 mg/L in September of 2014. These infrequent occurrences of lower D.O. in the North Llano were likely caused by low flows and higher water temperatures, resulting in increased algae production.

Table 5. Dissolved Oxygen readings for water quality monitoring sites for ULRWPP 2012-2015.

Highlighted results show exceedances.

Name	Site #	Sep-12	12-Dec	Feb-13	Jun-13	13-Sep	Dec-13	Mar-14	Jun-14	Sep-14
Confluence	1	7.19	9.84	7.28	7.85	5.89	10.78	9.55	8.46	7.47
Bear Crk	2	5.58	6.75	10.32	7.78	7.73	12.22	10.72	9.1	10.03
CR 274	3	6.29	8.47	9.68	4.29	7.03	12.45	9.85	8.3	4.25
CR 275	4	6.58	8.2	7.7	4.83	6.02	12.37	9.2	8.28	7.16
Copperas/CR 171	5	13.19	5.22	9.2	8.74	6.59	13.15	9.77	8.06	7.2
CR 260	6	7.8	8.58	8.18	4.23	5.26	13.04	9.9	8.35	7.75
Brady	7	6.57	8.48	8.08	5.57	7.73	13.7	10.5	8.2	8.01
Daryl	8	9.61	9.44	8.97	5.39	6.69	13.8	9.86	8	8.06
State Park	9	9.81	9.38	7.42	7.71	7.27	11.5	8.31	9.43	7.8
CR 150	10	7.36	7.68	6.95	6.72	7.52	12.8	9.6	9.32	6.52
1st xing	11	8.66	8.15	7.14	7.51	8.16	13	8.21	9.36	7.24
Coke Stevenson	12	8.03	9.48	7.54	8.16	8.76	15.45	9.57	8.37	8.73
Paint Creek	13	9.41	8.59	8.9	6.82	8.76	12.83	10.11	9.23	8.4
CR 408	14	8.41	9.48	9.4	6.98	8.06	9.46	8.43	9.06	7.58
Bois Darc	15	2.06	6.68	7.97	6.19	5.12	8.42	5.18	8.13	8.09
Xmas Sp	16	no data	7.83	7.72	9.73	9.26	7.71	6.9	9.56	7.86
700	17	10.91	7.67	8.18	9.28	6.78	11.03	9.94	6.45	5.22
Tanner	18	7.84	6.63	9.16	8.46	9.03	11.35	9.47	8.75	7.95
Deats	19	7.73	7.28	7.76	7.55	6.45	10.2	8.29	8.06	8.15
Contrary	20	no data	7.48	7.96	6.64	9.45	7.79	9.3	9.25	7.8

Escherichia coli

Escherichia coli (*E. coli*) are an indicator of fecal pollution and the potential threat of harmful bacteria, viruses and protozoans. All warm-blooded animals are sources of *E. coli*. Commonly cited sources include septic systems, wastewater treatment facilities (WWTFs), livestock and wildlife. In the North and South Llano rivers, the allowable limit for *E. coli* bacteria is a geometric mean of 126 colony forming units (cfu) per 100 ml. In the North and South Rivers, historically *E. coli* geometric mean values have met these criteria, which are established to protect swimming (i.e. primary contact recreation use). However, WPP sampling found geometric mean values to exceed these criteria in the North Llano at County Road 275 (21274), Richardson Ranch (Site 21267) and Bois d'Arc Springs (Site 21274)[2] , which flows into the North Llano (Table 6). Field observations at these sites note visible presence of hogs and deer.

Table 6. *E. coli* readings for water quality monitoring sites for ULRWPP 2012-2015.

Highlighted results show exceedances.

Station-ID	Sep-12	12-Dec	Feb-13	13-Jun	13-Sep	13-Dec	14-Mar	14-Jun	14-Sep	15-Feb	GeoMean
Confluence	2	14	24	63	51	38	13	12	4	31	17
Bear Crk	19	1986	179	117	30	9	33	38	<1	10	52
CR 274	49	33	11	20	38	144.5	34	17	15	23	29
CR 275	192	291	69	34	214	91	51	27	411	1733	138
Copperas/CR 171	2	no data	20	19	16	165.2	15	7	17	19	16
CR 260	10	39	6	25	22	65	55	23	17	21	23
Brady	157	276	196	517	59	65	727	1203	42	28	167
Daryl	158	58	33	26	28	67	25	147	111	27	53
State Park	32	26	20	28	42	37	38	27	40	11	28
CR 150	72	43	43	44	18	15	44	39	24	37	35
1st xing	9	20	4	44	10	16	3	20	6	21	11
Coke Stevenson	19	31	28	14	28	83	23	26	47	46	30
Paint Creek	2	31	10	1	3	6	no data	6	326	15	9
CR 408	3	2	<1	3	49	1	4	<1	16	no data	5
Bois Darc	866	118	15	365	73	93	140	192	921	19	133
Xmas Sp	12	12	9	129	77	61	55	248	50	26	41
700	26	28	63	35	7	54	40	11	29	68	30
Tanner	150	2	58	980	6	<1	272	461	133	24	70
Deats	<1	<1	<1	8	2	<1	21	23	55	921	27
Contrary	8	7	26	3	90	15	8	31	no data	9	13

Load Duration Curve

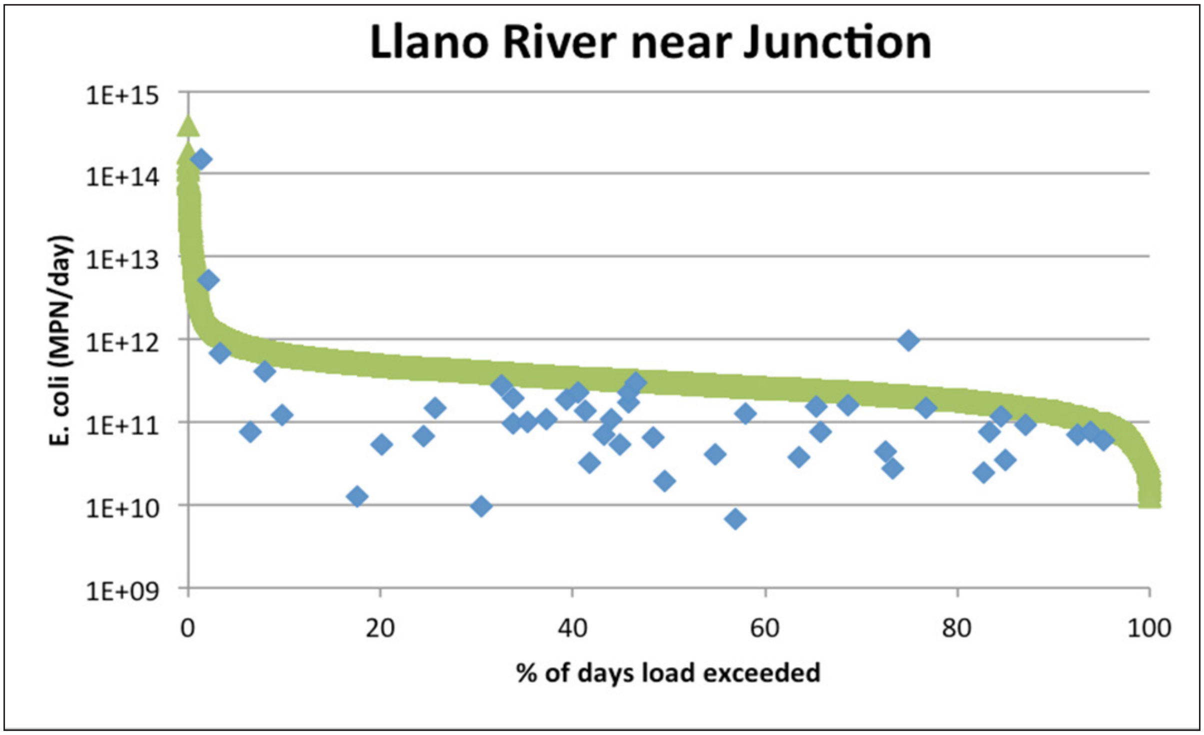
Watershed loading is commonly assessed using a load duration curve (LDC) analysis. A LDC enables determination and visual representation of pollutant loadings under different flow conditions. A flow duration curve is the first step in developing a LDC. Flow data for a particular location are sorted in order from highest to lowest to determine the frequency of a particular flow, or discharge, for a river. For the development of this WPP, flow duration curves were generated for the Llano River near Junction and the North Llano River near Junction where long-term flow and concentration exist.

Water quality data for a pollutant (*E. coli*) are then plotted on the curve to show the frequency and magnitude of exceedances. LDCs generated for the Llano River near Junction and the North Llano River near Junction were generated using historical river flow data from U.S. Geological Survey (USGS) gages at these sites (Figure 6). Individual water quality monitoring results (e.g. *E. coli* values) are superimposed on the flow-weighted curve. The resulting LDC shows the maximum load a river can carry without exceeding regulatory criteria or screening criteria across the range of flow conditions (low to high flow). Water quality monitoring data that fall above the curve indicates that the pollutant load has exceeded the regulatory limit and a violation of the criterion has occurred. Data falling below the line indicates a healthy water body.

It is possible to link pollutant concentrations with potential sources (point or NPS) by considering the processes at work during high, mid-range, and low flows. Exceedances that occur during high flows typically indicate NPS

[2] Water quality samples taken at spring sites in the Upper Llano Watershed are subject to contamination. The physical nature of these springs prevents sample bottles from being fully submerged, as required by sampling protocol.

pollution. High flows are generally correlated with significant rainfall events that generate runoff. Runoff transports sediment, bacteria and nutrients to the stream that would otherwise not reach the stream under drier conditions. In contrast, exceedances that occur during low flows typically indicate point source pollution, such as WWTFs, or direct deposition of fecal matter into a water body. There are no point source pollution locations in the Upper Llano Watershed; the City of Junction Wastewater Treatment Plant is located below the confluence of the North and South Llano rivers, just outside the boundary of this plan. All water quality samples were taken upstream of the plant. Thus, the sporadic low flow exceedances observed likely indicate direct deposition by wildlife and livestock. Although the separation of the timing of exceedances can be useful in predicting the pollutant source, LDCs cannot determine the exact sources and locations of the pollutant.



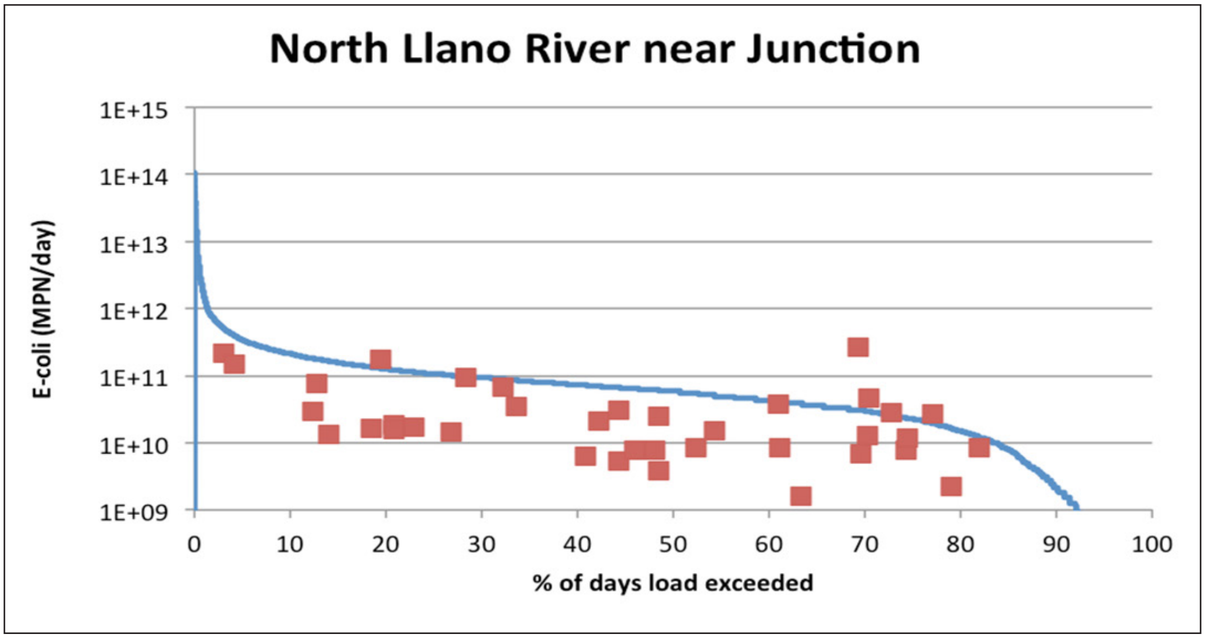


Figure 6. Load Duration Curves for *E. coli* for Llano River near Junction and North Llano River near Junction.

3.3.2 Groundwater Quality

Groundwater quality is monitored in accordance with TWDB procedures through the Submitted Driller's Reports generated for all new wells. Water quality parameters for new wells include the following: silica, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, pH, TDS, specific conductance and occasionally metals. Primary drinking water standards are those that, if exceeded, may pose a threat to human health. *E. coli* and nitrate are the primary standards (Table 7); however, *E. coli* data are not available via the Driller's Reports. Nitrate levels must be less than 10 mg/L. Levels greater than this may cause shortness of breath and blue-baby syndrome in infants (USEPA, 2009). There are natural nitrate sources (e.g., precipitation, bedrock, nitrogen-fixing bacteria and nitrogen-laden geological deposits), and anthropogenic sources of nitrate from faulty septic systems, livestock manure or fertilizers. The source of nitrate in wells in the Upper Llano River watershed is undetermined.

Table 7. National Drinking Water standards established through the Safe Drinking Water Act.

Parameter	Standard
E. coli ^{P}	0
Nitrate (mg/L)^{P}	10
pH (SU)^{S}	6.5-8.5
Chloride (mg/L)^{S}	250
Sulfate (mg/L)^{S}	250
Total Dissolved Solids (mg/L)^{S}	500

P-Primary drinking water standards

S-Secondary drinking water standards

For the portion of Edwards County in the Upper Llano Watershed (Figure 10), groundwater quality reports are available for 16 wells. Of these, five wells have nitrate levels that exceed the standard, and all are located in the Edwards-Trinity Aquifer (TWDB, 2013a/b).

For the portion of Kimble County in the Upper Llano Watershed, groundwater quality reports are available for 51 wells. Of these, 26 wells have one or more parameters that exceed the standard (Figure 7): 16 wells for nitrate, six for chloride, two for sulfate, and 14 for TDS (TWDB, 2013b). Except for three wells drilled in the alluvium, all wells that exceeded standards are located in the Edwards-Trinity Aquifer.

For the portion of Sutton County in the Upper Llano Watershed, groundwater quality reports are available for 100 wells. Of these, 14 wells have one or more parameters that exceed the standard: 13 wells for nitrate and one for pH (TWDB, 2013a/b). Except for one well drilled in the alluvium, all wells that exceeded standards are located in the Edwards-Trinity Aquifer.

In June of 2013, 46 wells were screened as part of the Texas Well Owner Network seminar and water screening. Of these wells, 63% tested positive for total coliform and 13% tested positive for *E. coli*. Similar screenings by the local groundwater district in 2014 showed 23% (of 35 wells) testing positive for *E. coli* and 14% for nitrates. In 2015, 15% (of 34 wells) tested positive for *E. coli* and 9% for nitrates. These positive tests potentially indicate inadequate waste disposal or contamination of the sample.

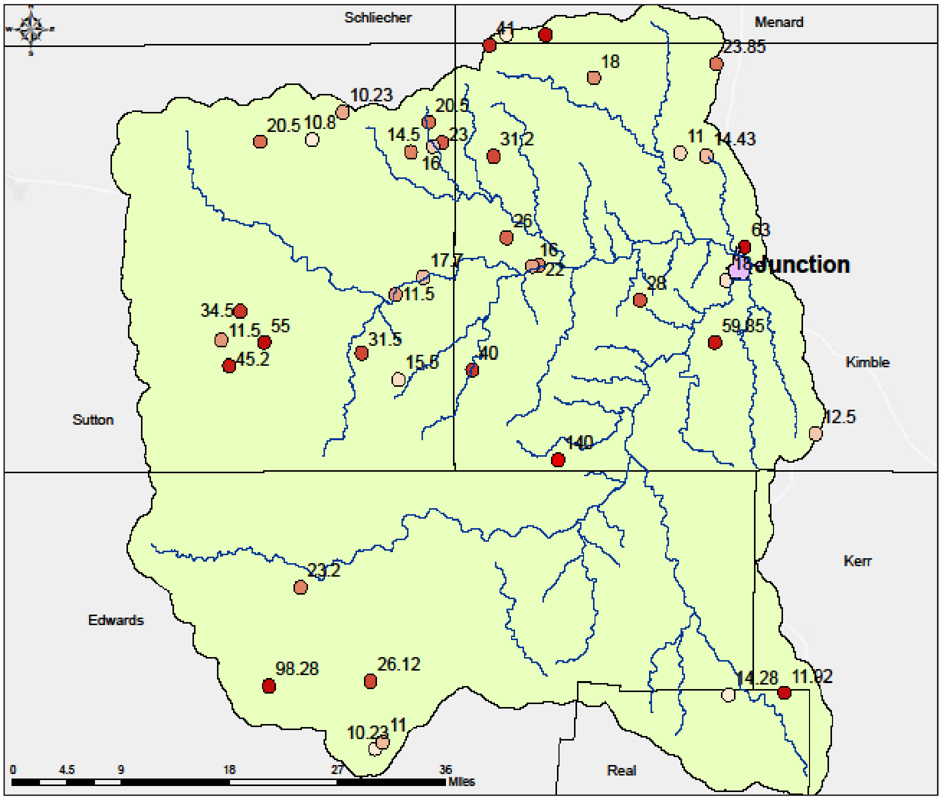


Figure 7. Spatial distribution of groundwater wells contaminated with nitrate (levels above the primary standard of 10 mg/L).

3.3.3 Summary of issues related to water quality

The Upper Llano River watershed is not an impaired water body. However, there have been three locations where surface water samples have exceeded *E. coli* bacteria standards and four locations where selected water samples fell below the D.O. standard. The majority of these exceedances have occurred during extreme low-flow events on the North Llano watershed and indicate the need for targeting efforts, especially those that address bacteria and nutrient loading, to that watershed. Further, during the last three years, about 15% of groundwater wells sampled in the watershed have tested positive for *E. coli* and 9 to 14% have exceeded drinking water criteria for nitrates. These concentrations are a concern and indicate the need for wellhead protection and assessment of septic system functionality throughout the watershed.

Monitoring efforts aid in gaging the health of the Upper Llano Watershed; however, the monitoring data provide only a snap shot in time and space of the health of the watershed. Watersheds are very dynamic and conditions change seasonally, annually, and on larger time scales from anthropogenic influences, animal disturbances, and other factors. The dynamic nature of watershed health, past and current data, and stakeholder input were collectively used for analysis of the current and future projections on health of the Upper Llano Watershed.

3.4 Water Supply and Use

The South Llano River is unique from other West Texas rivers because it has never ceased flowing in recorded history, largely because of the steady spring sources, such as Seven Hundred and Tanner Springs (Table 8). The North Llano River, which has less prolific springs than the South Llano, yields about one-fourth of the flow of the South Llano and is dry 6% of the time (Broad, 2012).

Table 8. U.S. Geological Survey flow statistics in cubic feet per second (cfs) for springs and North and South Llano rivers of the Upper Llano Watershed

Site Name	Lowest Flow (year)	Median Flow	Highest Flow (year)
Seven Hundred Springs	8.4 (1980)	19.5	42.5 (1973)
Tanner Spring	2.1 (2015)	12	17.7 (1997)
North Llano near Junction	0 (multiple)	22	102,000 (1936)
Llano River near Junction	3.7 (1956)	109	319,000 (1935)

As part of the development of the WPP, a water budget was calculated for the Upper Llano River watershed using the Ecological DYnamics Simulation (EDYS) model. This model is a general ecosystem dynamics model that can provide estimates of evapotranspiration and groundwater uptake and recharge under natural and anthropogenic-induced changes in watershed components (e.g., hydrology, soil, plant, and/or animals) at spatial scales from less than 1 m^2 to landscape levels (Coldren et al., 2011). The model can also be used to simulate water yields and water quality under a variety of brush removal scenarios. Based on model simulations using average conditions over a 25-year period (represented by the years 1958–1982), about 86% of the precipitation that falls is lost to evapotranspiration on an annual basis, while 3.6% goes to runoff and about 10% seeps into the ground.

3.4.1 Surface Water

Evaluation of mean annual discharge of the Llano River at Junction (just below the confluence of the North and South) from 1916–2014 (Figure 8) shows a cyclical trend in flows in the Upper Llano River, with generally declining flows observed from the beginning of the period of record through the drought of the 1950s, increasing flows from the end of the 1950s drought through the mid-1980s and declining flows again since the late-1980s to the present-day drought.

The primary springs of the South Llano include Llano, Big Paint, Seven Hundred, Tanner and Deats springs. Big Paint proportionally contributes the greatest flow to the South Llano, but these springs have the fewest flow measurements (Brune, 1981; Heitmuller and Reece, 2003; Broad, 2012). The largest of contributing springs on the North Llano are Adams and Fort Terrett Springs (Brune, 1981).

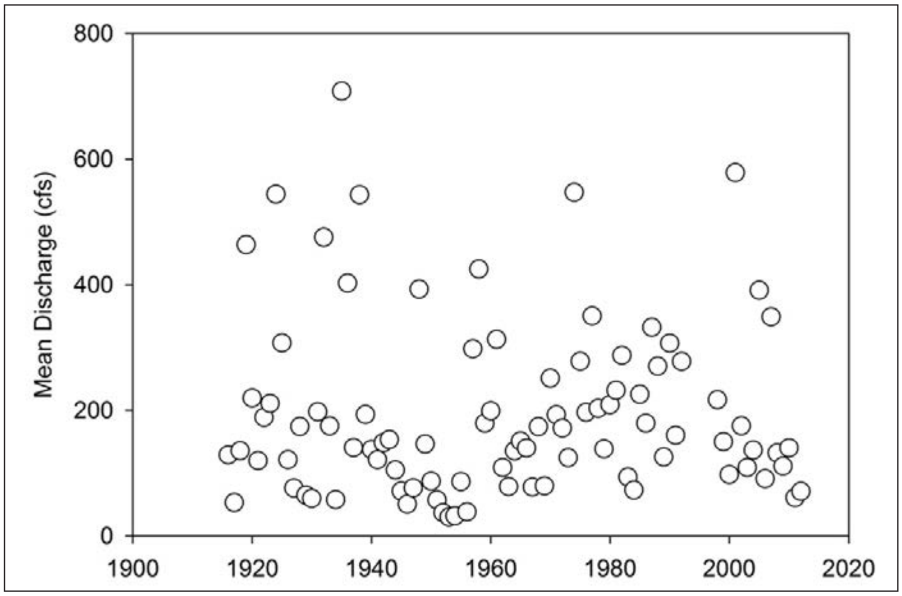


Figure 8. Mean annual discharge in cubic feet per second (cfs) for the Llano River near Junction (USGS 8150000) from 1916-2014.

To pump water from the river for purposes other than domestic or livestock use, a water right from TCEQ is required. Water rights in the Upper Llano were issued as early as 1883 (TCEQ, 2013). The issued water rights total 5,220 acre-feet per year (about 7 cubic feet per second (cfs)). With the exception of the City of Junction's water rights for 1,000 acre-feet per year, most of these water rights are for irrigation. The City of Junction currently uses about 66% of its water right, and many of the irrigation rights are unused or not fully used.

3.4.2 Groundwater

Groundwater conservation districts in Sutton, Real-Edwards, Kerr, Kimble and Menard counties manage ground-water used for municipal, industrial and irrigation purposes. Groundwater use for domestic and livestock purposes is not regulated. The City of Rocksprings is the largest single groundwater user in the watershed, pumping about 200 acre-feet per year from wells yielding greater than 500 gallons per minute (gal/min) from the Edwards-Trinity (Plateau) aquifer. Most wells pumping from this same aquifer generally yield less than 30 gal/min.

Groundwater data are collected by TCEQ, TWDB and the USGS. In the Upper Llano Watershed, the majority of data is collected through water well drilling reports. Accordingly, there are 828 wells in the Upper Llano Watershed: 170 well records in Edwards County; 2 in Kerr County; 410 in Kimble County; 23 in Menard County; 8 in Real County; and 216 in Sutton County (Figure 9; TWDB, 2013b). Wells drilled prior to 2002 tend not to be in the database.

3.4.3 Issues related to Water Supply and Use

During the 1950s, the flow of the Llano River at Junction fell to 3 cfs. While this volume of water could likely meet the City of Junction's water demands, it would not meet the demands of other users. During the drought of 2011, all surface water irrigation was suspended when the City of Llano, a senior downstream water rights holder, made a priority call on its water right. Such low flows in the river also exacerbate treatment costs due to decreases in water quality.

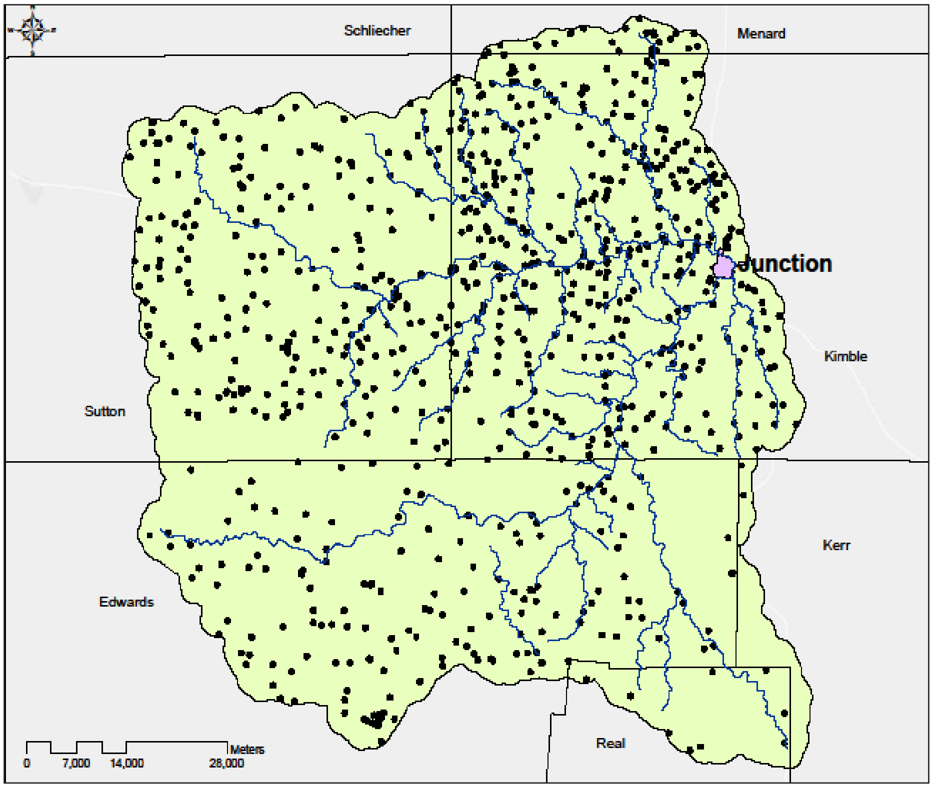


Figure 9. Geographic extent of water wells in the Upper Llano Watershed.

The drought also impacted groundwater levels and spring flows. Figure 10 shows declining water levels in a monitoring well northeast of Rocksprings and decreasing spring flow in the headwaters of the South Llano. While water levels only declined about two feet, Tanner Springs fell below 5 cfs and registered its lowest recorded flow of 2 cfs in January of 2015. Spring flow at Seven Hundred Springs declined to about 12 cfs and then maintained a fairly continual flow; these springs reacted in the same manner during the drought of the 1950s.

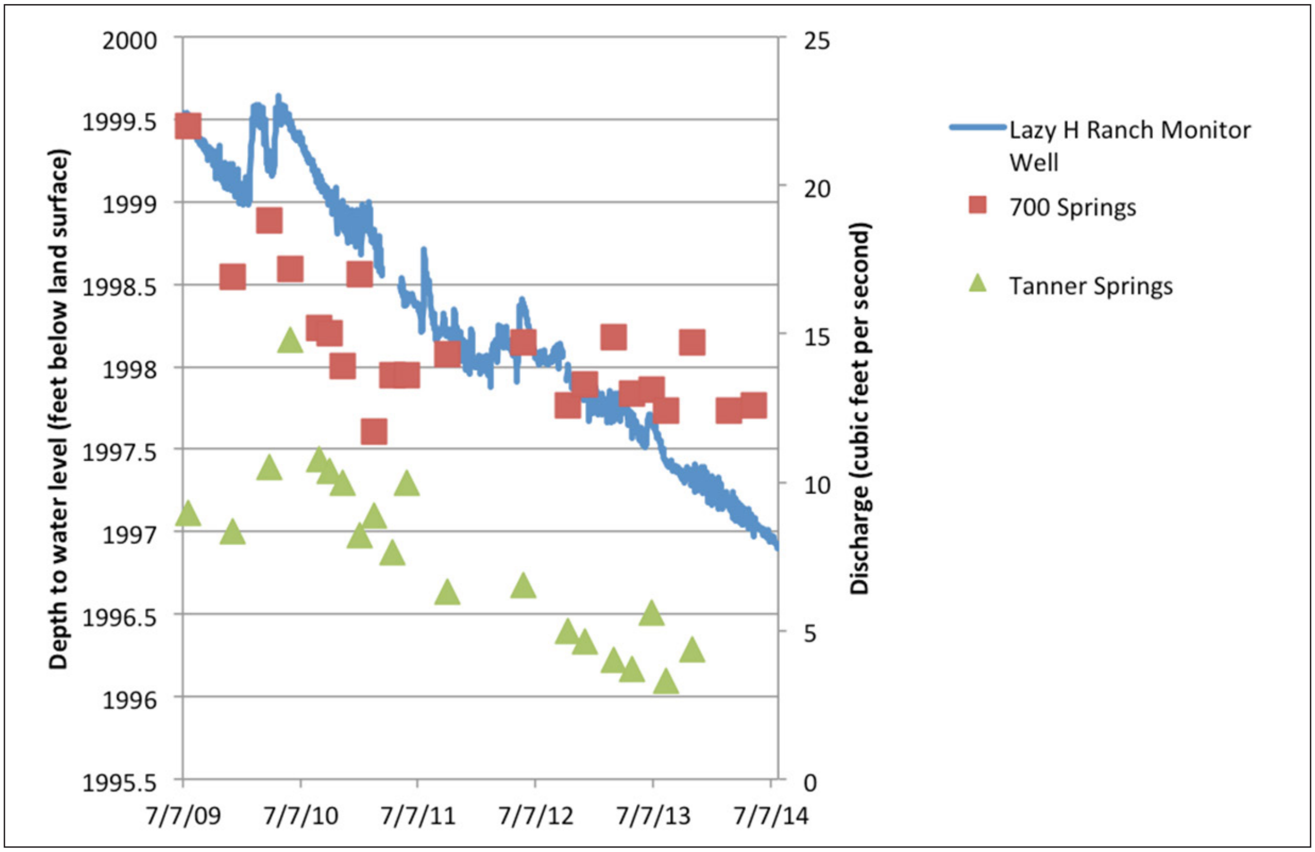


Figure 10. Groundwater levels measured at the Lazy H Ranch in Edwards County and Seven Hundred springs and Tanner Springs in Edwards County from 2009-2014.

Junction and Rocksprings have comparatively high per capita usage as demonstrated during 2011, when both communities used more than 200 gallons per person per day (gpd), exceeding the target of 140 gpd established by the Texas Water Conservation Implementation Task Force (TWDB, 2004).

Stakeholders have identified the installation of 'vanity ponds' on rural residential properties as one issue of concern. During droughts, many of these vanity ponds are supplemented with groundwater in order to keep them full, adding pressure on groundwater resources. Further information and education regarding 'vanity ponds' will be needed in the future.

Additionally, portions of the Upper Llano River watershed lie within the Barnett-Woodford Shale play. To date, more than 10,000 natural gas wells have been drilled in Sutton and Edwards counties, with a small number drilled in Kimble County. The majority of these wells are not located in the watershed. However, several hundred wells in the watershed are classified as "High Cost Tight Sands," meaning that they require some stimulation (such as hydraulic fracturing, or 'fracking') to produce at profitable rates. Fracked wells generally require a minimum of one million gallons of water, but the amount of water actually used is not well documented. In addition, there are about 75 active oil wells just north of the North Llano River in eastern Sutton County. More information is needed to assess impacts and needed management to minimize these potential impacts; additional TDS data from water well samples may be useful in assessing these impacts.

3.5 Biological Assessments

Biological surveys complement water quality monitoring by directly assessing the response of biotic communities in the field (USEPA, 1991). Surveys, which include the riparian and river habitat and fish and macroinvertebrate populations, effectively evaluate the health of the river. Faunal surveys increase the likelihood of detecting the effects of pollution on aquatic communities (such as episodic events, cumulative pollution or other impacts that chemical tests do not detect). In general, the presence of a variety of in-stream and riparian habitat types, as well as organisms intolerant to pollution indicates a healthy river. Previously, biological data has been collected at only a single site, 17009 near the Llano River State Park on the South Llano River (Table 9). Assessments from 2003–2008 suggest the available habitat is of High to Exceptional quality. Macroinvertebrate assessments from 2001–2008 suggest aquatic life use is of High to Exceptional quality. Fish surveys from 2005–2008 suggest aquatic life use is of High quality as well. Fish survey data from 2001–2005 were not used for this report because the data are incomplete to evaluate aquatic life use criteria (TCEQ, 2007). There are no identified issues of concern related to the biological assessments.

Table 9. Biological data aquatic life use score[1] for site 17009, Llano River State Park, South Llano River.

Year	Habitat	Macroinvertebrates*	Fish
5/23/2001		E (39)*	
8/14/2001		H (33)	
3/19/2002		H (32)	
8/28/2002		H (31)	
4/29/2003	H (25)	H (35)	
3/15/2004		E (37)	
9/20/2004	H (25)	H (36)	
3/22/2005	H (23)	H (35)	
9/13/2005	H (25)	H (35)	H (51)
3/21/2006	E (26)	H (33)	E (61)
3/20/2007	H (24)	H (33)	E (57)
10/9/2007	E (26)	H (34)	E (63)
4/30/2008	E (26)	H (36)	E (59)
7/11/2008	H (24)	H (35)	E (57)

*E=exceptional; H=high

1-Scores determined following TCEQ Surface Water Quality Monitoring Procedures (2007); blanks indicate no or incomplete data were collected. Number in parentheses is the quantitative score. E = Exceptional/H = High/ I = Intermediate

To support WPP development, additional biological monitoring including fish, macroinvertebrate and habitat assessment was conducted at the 14 main stem sites on a semi-annual basis (Table 10). All monitoring efforts followed TCEQ Surface Water Quality Monitoring Procedures (2007). Multivariate analysis (non-metric multidimensional scaling (NMDS)) was conducted to examine the watershed and determine relationships to the invertebrate community and water quality. The Causal Analysis/Diagnosis Decision Information System (CADDIS) model, often used for these types of analyses, was unable to identify stressors to the invertebrate community due to the Upper Llano River watershed being a relatively unperturbed system (see Appendix D).

Table 10. Average and (range) of biological data aquatic life use score[1] for site selected sites in Upper Llano River watershed (see Figure 9 for location map). Sampling dates: September 2012; February 2013; September 2013; and March 2014.

Station	Habitat	Macroinvertebrates*	Fish
21489	**20.5 (20-22)**	**43 (41-45)**	**51.2 (50-53)**
12212	**18.25 (15-21)**	28.33 (21-37)	49.5 (48-50)
21263	19.75 (18-21)	39 (37-41)	45.5 (36-50)
21264	20.75 (20-21)	37 (31-43)	50 (50)
21283	18.75 (16-20)	29.66 (21-39)	48.5 (45-53)
21266	22 (21-23)	42 (39-45)	49 (49-50)
21267	21.75 (21-22)	35.6 (33-39)	47 (42-50)
21268	21 (20-22)	44.5 (41-47)	48.8 (44-52)
21270	20.5 (20-21)	44 (41-47)	48.5 (46-52)
21269	20.5 (19-22)	45.5 (41-49)	48.3 (47-50)
21271	21.25 (20-22)	45.5 (45-47)	45.8 (37-50)
21272	21.5 (20-23)	43.5 (37-47)	46 (43-50)
21273	20.5 (20-21)	34.5 (27-41)	50.5 (48-54)
21279	15.5 (12-22)		

1-Scores determined following TCEQ Surface Water Quality Monitoring Procedures (2007); blanks indicate no or incomplete data were collected. First number is average index score; number in parentheses is the range of scores. **Blue = Exceptional** /**Green = High** /**Orange = Intermediate**

3.5.1 Habitat Assessment

Habitat assessments for all 14 sites were in the Intermediate to High classification. Four stations had an average score that fell within the Intermediate ranking, although all of these stations did have individual scores in the High classification.

Station 21279 (Llano Springs) had the lowest average score, as this site had no flow and was a stagnant pool during three of the four sampling events. The other three sites with average Intermediate scores are on Bear Creek at 1674 (Station 12212), North Llano at CR 274 (Station 21263) and North Llano at CR 271 (Station 21283). Zero to very low-flows conditions during the September 2012 and March 2013 sampling events are likely responsible for these lower than average scores. This demonstrates the impacts of low flows on aquatic and stream health and the need for water conservation and water supply enhancement in the watershed.

All other locations had index scores in the High category, with the North Llano at CR 260 (21266) and South Llano at Telegraph having the highest individual ratings. No sampling exceedances related to D.O. coincided with the habitat sampling (Table 8).

3.5.2 Macroinvertebrates

Over 38,000 aquatic invertebrates were identified in the four sampling efforts. Within the taxa identified were many Hill Country endemic species (Appendix D). Aquatic life scores for the majority of the sites were in the High to Exceptional category. Only two locations along the North Llano (Bear Creek and North Llano at CR 271) had Intermediate averages. Low index scores were recorded during February of 2013, following a period during the fall of 2012 when flow at both of these sites was zero. Subsequent samplings in March 2014 resulted in index ratings of High for both sites. Again, this demonstrates the impacts of low flows on aquatic and stream health.

3.5.3 Fish

Site scores for fish assemblage collections ranged from good (equivalent to 'Intermediate' for habitat and macroinvertebrates) to Exceptional across all sites and seasons with average scores for all sites considered very good (equivalent to 'High' for habitat and macroinvertebrates) or Exceptional. Species collected were consistent with historical collections and species diversity (including a good diversity of feeding guilds and habitat specialists) was High for almost all of the sampling events. A total of 16,414 fish were collected and identified, representing 19 species in the North and South Llano rivers.

3.6 Land Use / Land Management

Prior to European settlement in the mid-1800s, the uplands of the Texas Hill Country were a grassland savannah that was maintained through grazing of bison, antelope and frequent fires (natural and man-made). This "land management" favored a variety of forbs and grasses. The 19th century brought fences, which restrict wildlife movement; fire suppression; and livestock, including cows, sheep and goats. In some areas, historical overgrazing and loss of soil, in combination with fire suppression, have changed the Edwards Plateau and the Upper Llano River watershed from grassland savannah to juniper woodland (Broad, 2008).

Riparian zones of streams and rivers are recognized critical zones for watershed health. In the Upper Llano, these critical transitional areas between the water and upland systems comprise 19,431 acres or 1.6% of the watershed area. Although riparian zones often do not have definitive boundaries, they generally include those areas adjacent to streams and rivers including streambanks, floodplains and associated wetlands. A properly managed and functioning riparian area will "dissipate stream energy associated with high water flows, thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid in floodplain development; improve flood-water retention and groundwater recharge; and develop root masses that stabilize streambanks against cutting action," (Prichard, 1998). Since upland and riparian areas are interrelated, they must be considered together for BMPs.

3.6.1 Upland Management

The transformation of land cover in the watershed from a grassland savannah to a landscape dominated by brush may have had significant impacts on the watershed's hydrology. Clearing and sculpting of brush species, primarily Ashe juniper, is a technique used to improve livestock grazing, wildlife habitat, and, in some cases, increase spring flows and water supplies. Model output from the State Water Supply Enhancement Plan suggests if brush control is fully implemented on 15.7 million acres in the state, the resulting increase in water yield is 2.27 million acre-feet (TSSWCB, 2014).

3.6.2 Riparian Management

Rivers are naturally dynamic ecosystems that are constantly balancing the movement of water and sediment through erosion and deposition. Rivers are in balance when degradation (i.e. channel down cutting or widening) and aggradation (i.e., building up the channel) are equal. The balance can be tipped naturally or through manmade modifications.

Rivers react to increased water flow by increased erosion of the banks and/or channel bottom (down cutting). Over time, the channel will adjust the channel geometry, slope and/or flow to achieve stability. Alternatively, when flow decreases (due to excessive withdrawals or reduced inflows), rivers react by aggrading (accumulating) the sediment that can no longer be moved. Healthy, vegetated riparian areas help keep the balance from tipping too far in either direction by absorbing the changes, which lessen the effects of erosion and deposition (Nueces River Authority, 2015).

3.6.3 Issues related to Land Management

Currently, brush dominates the landscape of the Upper Llano Watershed (Table 11, Figure 11) covering more than 77% of the watershed. As such, brush control is a major interest in the Upper Llano River watershed because of the extensive stands of Ashe juniper, mesquite and live oak (Appendix E).

Table 11. Land use/land cover classification of the Upper Llano Watershed.[3]

Classification	Total Acres	% of watershed
Rangeland grass	222,163	18.75
Brush- low density	269,914	22.78
Brush- medium density	472,646	39.89
Brush- high density	175,362	14.80
Urban	7,938	0.67
Near riparian forest	19,431	1.64
Crop	6,161	0.52
Barren	10,071	0.85
Open water	1,184	0.10
Total	1,184,870	100

The Upper Llano Watershed has 47 miles of river; the South Llano is about 20 miles from the springs to confluence with the North Llano in Junction, and the North Llano is about 27 miles from the springs to the confluence with the South Llano in Junction. The riparian habitat along these rivers is, in places, impacted by cutbanks, loss of woody riparian vegetation, and the spread of both terrestrial and aquatic invasive species.

[3] See Appendix E.

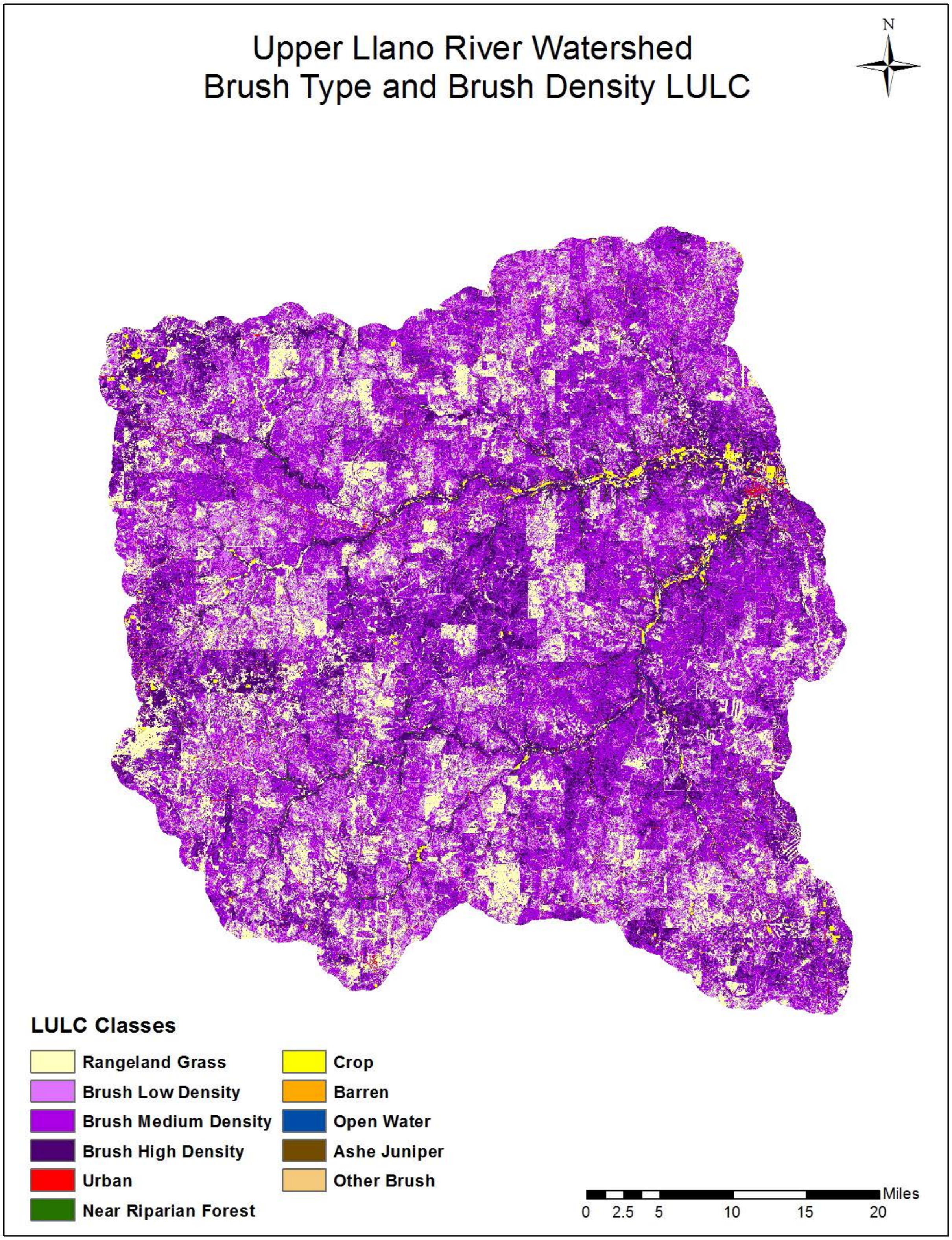


Figure 11. Land Use Land Classes within the Upper Llano Watershed.

3.6.3.1 Cutbanks

As part of the monitoring efforts, surveys of the distribution, abundance and severity of cut and eroding banks were conducted on the North and South Llano rivers from headwaters to Junction. There are 14.5 miles of the Upper Llano River affected by eroding banks (including both sides of riverbanks). The North Llano has around 7.1 miles of cutbanks while the South Llano has approximately 7.4 miles of cutbanks.

3.6.3.2 Loss of woody riparian vegetation

The riparian habitat in the lower portions of the watershed contains mature native pecans. These bottomlands provide bank stability and shade for aquatic habitat. However, because of intense browsing from deer populations, very few younger pecans are found along the riparian corridors (Jones, 2008), causing concern for the future stability of the riparian zone and streambanks as the older pecan trees die off.

3.6.3.3 Invasive Species

In addition to invasive feral hogs, (see 3.9), several aggressive invasive plant species are impacting the riparian corridors of the North and South Llano. These are elephant ear, *Arundo donax* (giant reed or Carrizo cane), and chinaberry. All of these species can use large amounts of water and dominate native riparian habitat (Broad, 2012). Surveys of the distribution and abundance of invasive emergent and aquatic plants (i.e. elephant ears and *Arundo*) were conducted on the North and South Llano rivers from headwaters to Junction.

Elephant Ears

Elephant ears are now found on the North and South Llano rivers. Nearly continuous patches of elephant ear were documented for approximately 1.1 miles on the North Llano beginning west of Roosevelt. Five sections of elephant ear covering about 2.5 miles were documented on the South Llano beginning near Telegraph. An additional six miles of river below the confluence of the two rivers are documented with elephant ears.

Arundo donax

On the North Llano River, there are two distinct stands of *Arundo*. Both are near Roosevelt and together have colonized about one mile of river. On the South Llano River, there are four patches of *Arundo*. All are located on the lower portion of the South Llano near the Llano River State Park. Together these stands affect less than one mile of river.

Chinaberry

Chinaberry, which is documented from above Roosevelt and Telegraph to below the confluence of the North and South Llano rivers, has invaded nearly the entire Upper Llano Watershed.

3.7 Summary of Identified Issues

The Upper Llano River watershed remains unimpaired; however, several concerns were identified including elevated nitrate and *E. coli* concentrations in some private groundwater wells. In the North and South Llano rivers, the following concerns were observed:

- episodic low D.O. concentrations
- episodic elevated *E. coli* concentrations
- flow reductions
- habitat alterations
- exotic species

The Upper Llano River watershed has seen pronounced growth in the number of small ranches subdivided from historically large ranches. This fragmentation has resulted in an increase in the absentee landowner population and an increase in the number of wells and septic systems; over the last 25 years, nearly 800 wells have been drilled in the watershed. The increase in the number of smaller properties has also brought about changes to land management practices where fewer acres are managed for livestock and more acres are managed for wildlife viewing and hunting. Further, noxious brush has invaded this historic live oak savannah ecosystem and now dominates the landscape of the Upper Llano Watershed covering more than 77% of the watershed, impacting not only range health/conditions, but also watershed hydrology.

Historically, the North and South Llano rivers have had few water quality standard exceedances, indicating the Upper Llano River is a healthy ecosystem that supports high to exceptional aquatic life use. However, sporadic exceedances of water quality standards for *E. coli* and D.O. in surface water of the North Llano and *E. coli* and nitrate in drinking water wells throughout the watershed are a concern. Low D.O. can be caused by increased algae production caused by nutrient loading, water stagnation and increasing water temperatures.

Habitat and benthic macroinvertebrate assessments demonstrated the impacts of low flows on aquatic and stream health in some areas and the need for water conservation and water supply enhancement in the watershed. The riparian habitat along the rivers is, in places, impacted by cutbanks, loss of woody riparian vegetation, and the spread of both terrestrial and aquatic invasive species. There are 14.5 miles of the Upper Llano River affected by eroding banks. Further, very few younger pecans are found along the riparian corridors, causing concern for the future stability of the riparian zone and streambanks as the older trees die off. Finally, the riparian zones have also been impacted by invasive aquatic species (giant cane, elephant ear and chinaberry). Elephant ears are now found along four miles of the North and South Llano rivers. Another two miles of these rivers is infested with stands of *Arundo*. Chinaberry trees are numerous along riverbanks; the total amount of chinaberry infestation has not been assessed.

Stakeholders participating in the WPP as part of the Coordination Committee developed targeted management measures goals to address issues of concern in the watershed related to septic systems, feral hogs, white-tailed deer and exotics, grazing management, brush control for range improvement and water supply enhancement, stream bank and riparian buffer restoration, water conservation, and urban stormwater management (see Chapter 5). Implementation of these management measures will improve and maintain streamflows and habitats as well as reduce potential impairments resulting from invasive species, sedimentation and loss of riparian habitat.

4. Potential Sources of Watershed Concerns

While there are several concerns related to the health of the Upper Llano River watershed, particularly related to *E. coli* in the North Llano Watershed, cutbanks and invasive species along both the North and South Llanos, hydrologic impacts from invasive brush throughout the watershed, and nitrate and *E. coli* in drinking water wells, there are currently no water quality impairments. Potential sources of the concerns identified in the Upper Llano Watershed include poor condition of rangeland in some areas due to current management, urban runoff, malfunctioning septic systems, flow modification due to brush infestation and withdrawals, overpopulation of wildlife (hogs, axis deer, etc.) in some areas, increasing groundwater withdrawals, drought, removal of riparian vegetation and streambank destabilization. These sources and their linkage to individual concerns are summarized in Table 12 below.

Table 12. Summary of watershed concerns and their potential sources.

CONCERNS	SOURCES (LINKED WITH CONCERNS)
Surface Water	
Bacteria (Pathogens)	Natural sources (wildlife)
	On-site Sewage Facility
	Urban runoff
	Range grazing – Riparian and/or Upland
Low D.O.	Natural sources (wildlife)
	On-site Sewage Facility
	Urban runoff
	Range grazing – Riparian and/or Upland
	Flow modification
Flow alterations	Flow modification
	Groundwater withdrawal
	Natural sources (drought)
Habitat alterations	Removal of riparian vegetation
	Bank modification/destabilization
	Range grazing – Riparian
	Natural sources (wildlife and drought)
Exotic species	Other
Groundwater	
Nutrients (Nitrate)	On-site Sewage Facility
	Natural sources (geologic formation)
Bacteria (Pathogens)	On-site Sewage Facility

4.1 Potential Sources Contributing to Watershed Concerns

Since the Upper Llano Watershed has no water quality impairments, the sources identified are potential sources based on stakeholder input and future water quality projections based on changing land use, and wildlife, invasive species, livestock and human populations. Because there are no wastewater treatment discharges in the Upper Llano Watershed, it can be deduced that all sources are NPS. Based on stakeholder input and supported by water quality monitoring data, *E. coli* exceedences are of greatest concern. Secondarily, stakeholders identified low D.O., flow and habitat alterations, exotic species and nitrate in groundwater as concerns for the future.

4.1.1 Sources of E. coli

Sources of *E. coli* include wildlife and invasive species, septic systems, urban runoff, and livestock/agriculture. Based on stakeholder input and field observations, the largest sources of *E. coli* in the watershed are believed to be from wildlife and invasive feral hogs.

4.1.1.1 Wildlife, Exotics and Invasive Species

E. coli and nutrient input from wildlife may contribute a large portion of the total stream bacteria load. This is particularly true where populations of riparian animals (deer, feral hogs, exotics) are high.

White-tailed deer

Populations of white-tailed deer are difficult to enumerate because populations are free ranging and can traverse several miles within a few days. However, TPWD conducts annual white-tailed deer population-density surveys. Large-scale estimates are made for each resource management unit (RMU). For the Upper Llano Watershed portion of the Edwards Plateau (RMU 5), deer densities range from 8.7-11.0 acres per deer. Based on an average deer density of 10.1 acres/deer, the white-tailed deer population in the watershed is estimated at 117,534.

White-tailed deer consume up to five pounds of forage per day (Perkins, 1991). In general, deer densities are higher close to urban centers, such as the City of Junction, and close to water sources, such as the riparian corridors of the North and South Llano rivers. Intensified browsing by deer in these riparian corridors impacts the growth of new woody vegetation, especially pecans (Jones, 2008). At the LRFS, deer densities are estimated to be one deer to 1.4 acres (Texas Tech University at Junction, 2011), compared to an average density of 8 to 10 acres per deer in riparian areas.

Exotic (Non-native) Wildlife

Non-native, or exotic, wildlife populations mainly include axis deer, but aoudad and black buck are also present in the watershed. Native to India, axis deer were introduced to Texas about 1932, and today are the most abundant exotic ungulate in Texas (Schmidly, 2004). With the growth of the hunting industry in the 1950s, the numbers of exotics increased rapidly. In the 1960s, there were 13 species of exotics and about 13,000 animals. By 1996, state-wide surveys found 76 species and 190,000 animals, and today estimates range from 275,000 to over one million exotics (Middleton, 2007).

Damage from axis deer includes competition with white-tailed deer and livestock (axis can shift their diet to grasses when food is scarce) as well as significant erosion from axis trailing behavior, especially in riparian areas (Global Invasive Species Database, 2015). The main problem with axis deer is the large population size; however, the exact populations of axis deer in the Upper Llano Watershed are unknown. Herds often consist of over 100 deer (Figure 12) and can contribute to bacteria and nutrient loading to streams.

Feral Hogs

Feral hogs are the species of greatest concern in the watershed and are considered an invasive species. Invasive species are defined as non-native (alien or non-indigenous) to the ecosystem under consideration and have the potential to cause economic or environmental harm or harm to human health.[4]

Hogs were introduced to the United States from Europe as a food source. The hogs were free range, which allowed for some of the animals to escape and become feral. Because of their size (up to 300 pounds) and their opportunistic omnivorous habits, feral hog numbers have soared to between 1.8 and 3.4 million statewide (Texas A&M AgriLife Extension, 2012). This equates to 1.33 to 2.45 hogs per square mile. Feral hog populations were estimated from the available literature (Tate, 1984; Hone, 1990; Hellgren, 1997), potential hog habitat and stakeholder input. Estimates of hog populations in the watershed are 39,496 based on estimates of 30 acres per hog or 21.3 hogs per square mile.

[4] See Executive Order 13112, Federal Register Feb 8, 1999 (Volume 64, Number 25)

Figure 12. Axis deer herd with more than 100 deer on the Llano River Field Station campus.

Feral hogs are highly destructive animals to riparian areas because they create wallows. (Feral hogs lack functional sweat glands and must wallow in water to keep cool.) As a result, feral hogs can contribute both bacteria and nutrients as a NPS and through direct deposition, depending on their location and stream conditions.

Annually, feral hogs cause about $54 million of damage to the agricultural industry of Texas (Texas A&M AgriLife, 2012). Other types of damage include consumption of native vegetation, destruction of riparian areas used as travel corridors, predation of wildlife, bacterial and nutrient pollution to the rivers, human health concerns from disease transmission, resource competition with native animals, and damage from vehicle collisions.

4.1.1.2 Septic Systems

Rural areas across Texas rely on on-site sewage facilities (OSSFs), or septic systems, for disposal of household wastewater. In 1990, the last year for which statewide data on OSSFs were collected, 47% of the households in Kimble County relied on septic systems, 88% in Edwards and 28% in Sutton (NESCD, 2001). New systems are installed statewide each year when homes and businesses are constructed outside city limits or where centralized municipal sewer service is unavailable. While trained personnel must operate municipal wastewater facilities, septic systems are the responsibility of the homeowner. If regular and essential maintenance are not conducted, major problems can occur.

When septic systems fail, wastewater does not receive adequate treatment. This untreated sewage can be a source of bacteria, other pathogens and nutrients. While inadequate septic system maintenance is a factor in system failure, other concerns are system design, inappropriate soils and age. Systems installed before requirements issued in 1989 are often not as efficient as new systems and are more prone to failure. Degradation of construction materials can lead to a drop in performance and eventual failure. Alteration or compaction of the drainfield can also dramatically affect septic system function and may eliminate treatment in worst-case scenarios. Some soils also limit system function, because they inhibit leaching and increase the likelihood of surfacing. Selection of a system should be determined by soil type, a practice that has not always been followed. Additionally, a lack of enforcement of septic system regulations can contribute to system failure. In some cases, governing bodies do not have adequate resources to inspect and regulate septic systems throughout their jurisdictions. This allows potential problem systems to go undetected and unaddressed. A combination of these factors makes septic systems a potential major contributor of both bacteria and nutrients to the Upper Llano River. As with most types of NPS pollution, failing septic systems are found across the landscape. Those located nearest streams or drainage areas are most likely to impact water quality in the Upper Llano River.

4.1.1.3 Urban Runoff

Increased impervious cover (rooftops, roads and other hard surfaces) causes more surface runoff. This often leads to less water infiltration into the soil because of the fast-moving water unless the water is slowed or held in structures such as bioretention ponds. This greater runoff increases the potential for pollutants from household pets, leaky wastewater pipes, sanitary system overflows and urban wildlife to eventually reach the Upper Llano River. Identifying the original source of pollution is extremely difficult, since pollutants in runoff from urban areas may potentially come from any one source or a combination of several sources. The Upper Llano Watershed has less than 1% impervious surfaces (areas characterized by 30% or greater of constructed materials such as asphalt).

4.1.1.4 Livestock/Agriculture

Landowners in the Upper Llano River Watershed have historically relied on ranching as the primary source of income. Types of livestock within the Upper Llano Watershed include approximately 15,900 cattle (predominantly beef), 19,499 sheep, 36,318 goats and a small numbers of hogs, poultry and horses. Table 13 shows the majority of livestock within the three counties with the largest area in the watershed (USDA NASS, 2013).

Table 13. Livestock Populations by County in the Upper Llano Watershed as of September 2013.

County	% of County in Watershed	Livestock	Total Head	Estimated number in watershed
Edwards	29.7%	Cattle	17,000	5,049
		Goat	25,000	7,425
		Sheep	20,500	6,089
Kimble	48.6%	Cattle	11,000	5,346
		Goat	30,000	14,580
		Sheep	10,600	5,152
Sutton	36.7%	Cattle	15,000	5,505
		Goat	39,000	14,313
		Sheep	22,500	8,258

While overall numbers in the watershed are not large, goats and sheep are often found in high concentrations in areas where they are present. On average, there is a cow per every 77.6 acres, a goat per every 50.3 acres, and a sheep per every 89.7 acres (USDA NASS, 2013). The waste from these animals represents a source of both bacteria and nutrients. While stakeholders do not regard the impacts of livestock on water quality to be significant, there is recognition that proper grazing management is necessary to reduce the loss of plant cover, which can increase runoff and erosion of topsoil. In addition, direct access to riparian areas and streams increases potential contributions of both pollutants.

4.1.2. Sources of Low Dissolved Oxygen

Low D.O. is commonly caused by nutrient runoff (causing algae blooms) and/or organic loading. This becomes detrimental when the algae dies and it decomposes along with other organic matter in the water body. The decomposition process consumes oxygen; low oxygen levels can be lethal to aquatic organisms. Low oxygen levels can be exacerbated by low flows and water stagnation, thus preventing aeration, increasing water temperatures, and concentrating nutrients and organic matter.

Nutrient and *E. coli* runoff are closely related in many cases. Partially treated and untreated waste from humans, wildlife and livestock contribute nutrients at the same time as *E. coli*; therefore, the sources described in the previous section also apply to nutrients. In addition, soil erosion from both upland areas and streambanks can contribute nutrients to aquatic systems. Finally, inorganic fertilizer use and atmospheric deposition can also contribute nutrients; however, the Upper Llano Watershed only has a small proportion of cropland (0.52%), and urban land and fertilizer use in home application is expected to be small.

4.1.3. Causes of Streamflow Reduction

Water quality standard exceedances in the spring-fed streams of the Edwards Plateau often occur during low-flow conditions. Decreases in stream flow are primarily driven by drought but can be exacerbated by surface water and groundwater withdrawals, encroachment of woody upland species and loss of riparian habitat. Water withdrawals for domestic and agricultural purposes are usually greatest during periods of low flow, compounding water quality conditions also stressed by increased temperatures and low D.O. Upland woody species, especially Ashe juniper, can potentially reduce streamflows by increasing evapotranspiration and reducing the volume of water that recharges the aquifers that produce springflows in the Edwards Plateau. Conversely, deteriorating riparian habitat conditions increase runoff but reduce soil and streambank water storage potential. Water captured and stored in streambanks with healthy riparian habitat during periods of higher flow is released back to streams during low flow conditions. In addition, invasive riparian species can consume large amounts of water and out-compete native riparian species.

4.1.4. Habitat Alterations

Several causes of cutbanks in the Upper Llano River have been identified including drought-induced bank failure and creation of desert pavement (hardened soil created during times of drought), loss of woody riparian vegetation from overgrazing by wildlife and in some cases livestock, and mowing the riparian area. The rate of erosion from cutbanks is of concern because some landowners are losing land to the river at an alarming rate, and the sediment is either deposited in the channel or carried downstream, triggering a domino effect.

4.1.5. Exotic Species

Several aggressive invasive plant species (i.e. elephant ear, *Arundo donax*, and chinaberry) are impacting the riparian corridors of the North and South Llano.[5] Elephant ears were originally introduced from Asia in 1910 as a substitute crop for potatoes. Today these plants are commonly used for ornamental purposes in gardens and ponds. Elephant ears can easily spread through culm fragmentation and budding at the base of the plant, displacing native riparian vegetation and increasing water use from streamside vegetation. Disturbance encourages spreading of the plants.

Arundo donax (Giant reed) was introduced in the 1800s from western Asia, northern Africa and southern Europe for ornamental purposes and erosion control along ditches. Today, *Arundo* is found throughout the western United States. Little is known about the life history of *Arundo*, except that it can float miles downstream to take root. It grows rapidly and outcompetes native plants. Because of the dense growth and water use, *Arundo* chokes rivers, increases fire potential and reduces habitat for wildlife by completely suppressing native vegetation through formation of dense monotypic stands. Control of *Arundo* could represent an important water conservation method because it uses five to 10 times more water than mixed riparian vegetation (Johns, 1989; Giessow et al., 2011).

Chinaberry, a member of the Mahogany family, was originally introduced in the mid-1800s from Asia for ornamental purposes. It most commonly spreads through bird-dispersed seeds. Chinaberry is highly resistant to insects, pathogens and predation, outcompeting native riparian vegetation and altering the pH of the soil through its leaf litter (Reemts, 2009).

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[5] Other invasive species such as Malta Star Thistle (*Centaurea melitensis*), Mexican Feather Grass (*Nasella* or *Stipa tenuissima*), and Bermudagrass (*Cynodon dactlyon*) are found in riparian areas of the watershed but are not having as serious impact on the riparian corridor at this time.

5. Management Measures and Activities

The Coordination Committee selected a suite of management measures to address issues of concern in a holistic manner:

- Repair and replace 100 OSSFs
- Decrease feral hog population by 66%
- Increase number of ranches with wildlife management plans by at least two annually
- Enroll >250,000 acres of ranchlands in conservation plans
- Treat >144,000 acres of brush
- Implement streambank restoration/maintenance measures (i.e. bridge, exclosures, etc.)
- Treat 2 river miles for *Arundo donax* and 4 river miles for elephant ear
- Improve urban water management

Many of the management measures address multiple concerns simultaneously (Table 14). For example, septic system repair/replacement addresses bacteria and nitrate concerns in both surface water and groundwater throughout the watershed. Other management measures, such as brush control, streambank and riparian improvement, and grazing management, increase spring and streamflow and decrease sedimentation.

Table 14. Key concerns, sources, and management measures in the Upper Llano Watershed.

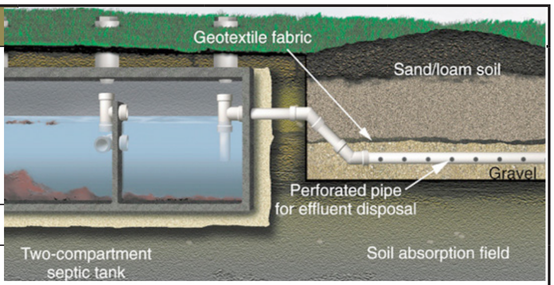
CONCERNS	SOURCES (LINKED WITH CONCERNS)	KEY MANAGEMENT MEASURES
Surface Water		
Low D.O.	Range grazing – Riparian and/or Upland	Enroll 250,000 acres of ranchlands in conservation plans
	Urban Runoff	Determine location and implementation of stormwater BMPs
	On-site Sewage Facility	Repair and replace 100 OSSFs
	Flow modification	Treat 144,000 – 167,000 acres of brush
		Water conservation
	Natural sources (wildlife)	Decrease feral hog population by 66%
		Increase number of ranches with wildlife management plans by 2 annually
Bacteria	Range grazing – Riparian and/or Upland	Enroll 250,000 acres of ranchlands in prescribed grazing plans
	Urban runoff	Determine location and implementation of stormwater BMPs
	On-site Sewage Facility	Repair and replace 100 OSSFs
	Natural sources (wildlife)	Decrease feral hog population by 66%
		Increase number of ranches with wildlife management plans by 2 annually
Flow alterations	Flow modification	Treat 144,000 – 167,000 acres of brush
		Water conservation
	Groundwater withdrawal	Water conservation
	Natural sources (drought)	Water conservation
Habitat alterations	Removal of riparian vegetation	Construction of temporary exclosures
	Bank modification/destabilization	Construct new bridge at South Llano River State Park
		Restore 2000’ of eroded streambank in South Llano River State Park
	Range grazing – Riparian	Enroll 250,000 acres of ranchlands in prescribed grazing plans
	Natural sources (wildlife)	Decrease feral hog population by 66%
		Increase number of ranches with wildlife management plans by 2 annually
Exotic species	Other	Treat of 4 river miles for elephant ear and 2 river miles for *Arundo donax*
Groundwater		
Nutrients (Nitrate)	On-site Sewage Facility	Repair and replace 100 OSSFs
	Natural sources (geologic formation)	N/A
Bacteria	On-site Sewage Facility	Repair and replace 100 OSSFs

5.1 Repair/Replace/Remove Septic Systems

The Coordination Committee identified septic systems (OSSFs) as a potential source of concern for both surface water and groundwater in the watershed. Data regarding the location and age of these systems is not well known. There are estimated to be 2,300 OSSFs in the watershed. This information is based on 1990 census data (indicating 1491 OSSFs in 1990) along with data regarding the number of wells drilled since 1990 (828 since 2002). Based on literature reviews, it is estimated that 12% of these septic systems (278) are likely to be failing (Reed, Stowe and Yanke, 2001).

The WPP will begin to address concerns regarding OSSFs by first verifying the numbers of OSSFs in the watershed and then identifying the location of septic systems located near streams or shallow groundwater sources. Once located, the goal of the WPP will be to replace at least ten of these failing systems annually. In areas near the Cities of Junction or Rocksprings, efforts will be made to identify septic systems that could be replaced by connecting to local WWTFs. Technical assistance and outreach efforts will also be employed to facilitate improvements in OSSF systems and wellhead protection in the watershed.

Management Recommendation 1

Repair/Replace/Remove Septic Systems (OSSF)	
Objectives: • Determine hot spots of failing OSSFs using GIS and inspections • Investigate reported OSSF failures • Prioritize OSSFs for repair/replacement • Repair/replace failing OSSFs or connect to municipal sewer system	 Image courtesy of Texas A&M AgriLife Extension Service
Location: All sub-watersheds	
Critical Areas: Target OSSFs within N. Llano riparian areas and flood plains and those near contaminated private wells	
Goal: Replace or repair a minimum of 100 failing OSSFs over 10-year period.	
Description: Reduce bacteria and nitrates through improved management of OSSFs	

Implementation Strategies			
Participation	**Recommended Strategies**	**Period**	**Capital Costs**
TWRI	Determine hot spots of failing OSSFs using GIS	2016-2018	$10,000
Kimble, Sutton, Edwards counties	Provide cost share using grant funds acquired to replace 100 failing septic systems at a cost of $5,000-$10,000/unit	2016–2025	$500,000 - $1,000,000
Cities	Junction and Rocksprings will be approached regarding connecting households in their jurisdiction to their centralized wastewater collection system (estimated cost of $2,000/connection)	2016-2025	N/A
TWRI, AgriLife Extension and TSSWCB	Provide Texas Well Owner Network and OSSFs Trainings	2016	N/A

Estimated Load Reduction	
It is estimated that each OSSF replaced will reduce annual *E. coli* loadings by 7.62E+11 cfu.	
Effectiveness:	High: New, repaired or eliminated OSSFs will remove bacteria or nutrient loads from human sources
Certainty:	Moderate: Replacing OSSFs is an expense not likely to be undertaking without supportive funding
Commitment:	Moderate: County designated representatives currently responsible for OSSF inspections; AgriLife Extension currently operates an OSSF education, outreach and training program.
Needs:	Moderate: Funding to support OSSF replacement in the watershed is needed.
Potential Funding Sources:	TCEQ CWA §319(h) grant program, SEP, local funds

5.2 Feral Hog Management

Based on field observations made at the LRFS and during water quality sampling, anecdotal information from stakeholders, Texas A&M AgriLife Extension Service information, and other WPPs developed across the state, feral hogs likely have the greatest impact on water quality in the watershed. Their impact is greatest in the riparian zones where their wallows and fecal deposition can readily impact nearby streams. However, because hogs tend to have a range of over 2 square miles, control measures should also be considered in the upland portions of the watershed.

The Coordination Committee recognizes that the best approach to reducing the feral hog population is through a coordinated landowner effort to facilitate the exchange of information, equipment and professional services. One solution is the development of a Feral Hog Task Force (such as was created in Caldwell County). A task force would help coordinate development of a management plan to reduce feral hog populations.

5.2.1 Feral Hog Education

AgriLife Extension, in conjunction with TSSWCB, hosts feral hog workshops for local landowners. Workshops will be implemented during the formative stages of the Feral Hog Task Force.

5.2.2 Feral Hog Reporting

One of the largest obstacles in controlling feral hogs is the lack of adequate population and distribution information. AgriLife Extension, through its Texas Wildlife Services division, maintains a feral hog reporting website, which will be used by the Feral Hog Task Force to monitor hog populations in the Upper Llano River watershed.

5.2.3 Feral Hog Bounties

Coordinated landowner efforts through the Feral Hog Task Force will help obtain funds to support a bounty program for feral hogs. Participants in the program will receive a monetary bounty for proof of harvest. Evidence of proof could be in the form of harvested feral hog tails presented in a sealed plastic bag.

5.2.4 Coordination of Feral Hog Hunting

The Upper Llano Feral Hog Task Force will facilitate hunting programs for feral hogs by putting potential hunters in touch with landowners. The Task Force will also help encourage youth or family hunts or contests and encourage donation of the feral hog meat to charity organizations, similar to what Texas Hunters for the Hungry does with venison. The Mill Creek Watershed Protection program is currently exploring the feasibility of changing regulations regarding the manner in which feral hogs can be processed for distribution in Texas. These more flexible regulations could help facilitate the harvesting of feral hogs for distribution to charities.

5.2.5 Sharing Resources

Feral hogs can become 'trap-wise' and learn to avoid conventional smaller hog traps. Using a variety of trap designs (especially corral traps) in different locations can help improve trapping success. Having the ability to share trapping resources (including remote sensing cameras and gate-triggering phone apps) amongst participating landowners in the task force improves the efficiency of trapping efforts. Aerial hunting could also be implemented across adjacent ranches participating in the Task Force, thus providing cost sharing.

5.2.6 Professional Trapping

There are professional trapping services that coordinate trapping with certified slaughtering facilities under U.S. Department of Agriculture inspection.

5.2.7 Supplemental Feeding

One cause of increasing hog populations is supplemental feeding of white-tailed deer by landowners. Outreach and management efforts related to feral hog reduction will address the need to construct exclosure fencing around feeders to allow access by deer, but exclude feral hogs. Most working ranches already use exclosure fencing to keep livestock away from the feeders; this effort will be especially focused on non-working ranches and absentee landowners.

5.2.8 Bacterial Source Tracking

Bacterial, or microbial source tracking, is a newer biological technique for determining the source of bacterial contamination. Using molecular biology based on genetic markers, bacteria-contaminated waters can be analyzed to determine the source of bacteria: human, livestock and wildlife. Use of bacterial source tracking (BST) in the Upper Llano Watershed can be used to identify bacteria contributions and help better focus BMPs.

Management Recommendation 2

Feral Hog Control

Objectives:
- Reduce hog numbers
- Reduce food supply for feral hogs
- Provide landowner education and outreach

Location: All sub-watersheds

Critical Areas: Riparian habitat throughout the watershed, particularly along the North Llano and areas with eroding streambanks

Goal: Decrease feral hog population by at least 66% (26,000) over 10-year period

Description: LRFS and county government officials collaborating with select state agencies to implement a variety of existing and new programs aimed at culling feral hogs to reduce population throughout the watershed by reducing food supplies, removing hogs as practical and educating landowners on BMPs for hog removal.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
Landowners, land managers, lessees	Voluntarily report feral hog activity to determine travel corridors using AgriLife feral hog reporting website	2016–2025	N/A
	Voluntarily construct fencing around deer feeders to prevent feral hog utilization ($200/feeder exclosure)	2016–2025	N/A
	Voluntarily participate in Task Force to coordinate hunting/trapping, sharing of equipment, donation of meat (via professional trapper)	2016-2025	N/A
AgriLife Extension and TSSWCB	Deliver Feral Hog Education workshop and help coordinate formation of Hog Task Force and Feral Hog reporting website	2016, 2019, 2025	N/A
Kimble, Sutton, Edwards, Real, Menard, Kerr counties agencies	Coordinate implementation and participation in the formation of Hog Task Force to serve the watershed.	2016-2018	N/A
Upper Llano Hog Task Force and Texas Department of Agriculture (TDA)	Feral Hog Bounties ($5/hog)	2016-2025	$130,000
	Purchase hog trapping equipment (3/county) for cooperative sharing ($3,000 / 30 ft' trap)	2016-2025	$27,000
	Aerial hunting ($700/hour)	2016-2025	$56,000

Estimated Load Reduction

Reducing the feral hog population will reduce bacteria loading to the watershed by 3.23E+14 annually. It will reduce sediment loading by 2.51 tons annually, or 0.6% (Appendix F).

Effectiveness:	High: Reduction in feral hog population will result in a direct decrease in bacteria and nutrient loading to the streams and decrease damage to riparian habitat.
Certainty:	Moderate: Feral hogs are transient, adapt to their environment and migrate due to hunting and trapping pressure; as such, the ability to remove sufficient numbers each year will be variable and is highly dependent upon the diligence of watershed landowners and outreach and technical assistance from the Feral Hog Task Force
Commitment:	Moderate: Landowners are actively battling feral hog populations and will continue to do so as long as resources remain available.
Needs:	Moderate: Additional funds are needed to provide an additional incentive to landowners to actively remove feral hogs. Hog trap material and automated trap doors need to be purchased for a trap-share program. Education and outreach delivery is needed to further inform landowners about feral hog management options, adverse economic impacts of feral hogs and what their options for dealing with feral hogs are.
Potential Funding Sources:	- Control: private funds, state-level feral hog control grants - Education: CWA §319(h) grant program (these monies cannot be used for control or removal but could be used for education and bacteria source tracking) - TDA Feral Hog Program - Local donations

5.3 Wildlife (and Exotics) Management

Deer populations in the watershed tend to exceed recommended carrying capacity (1 deer/12 acres) especially along the riparian corridors of the watershed. Since TPWD oversees management of white-tailed deer populations, no direct management measures were developed for this WPP.

Further, management of free-ranging exotic animals, primarily axis deer, is an issue of concern in the watershed. The Coordination Committee recognizes that hunting of axis deer generates revenue for many landowners in the watershed; therefore, the management measure for exotics focuses on only controlling the population of axis deer that are not behind high fences and are having impacts on riparian areas but only if there are minimal impacts on hunting revenue.

However, the Coordination Committee suggests expanding efforts to increase the number of properties with a TPWD Wildlife Management Plan by two per year, or 20 additional properties over 10 years. Participation in these programs provides landowners increased harvest rates (based on past and current deer census) through a Managed Lands Deer Permit. Additional measures include outreach regarding the proper siting and construction of deer feeders away from riparian areas and deter hog populations. Such coordinated landowner efforts, while primarily designed for white-tailed deer management, could also include management goals related to exotics.

5.3.1 Coordination of Exotic Hunting

Putting potential hunters in touch with landowners can facilitate managed exotic hunts. Such a program could also help encourage youth or family hunts or contests and encourage donation of the exotic meat to charity organizations, similar to what Texas Hunters for the Hungry does. Opportunities exist to highlight that exotic wildlife may be hunted year-round outside of the traditional hunting season as well as highlight this element of land stewardship through education and outreach.

5.3.2 Professional Harvesting

There is at least one Hill Country establishment that pays landowners to come on their ranch to harvest, inspect and process wild game for sale to restaurants. Landowners participating in watershed protection efforts to reduce exotic populations could coordinate harvests with such an establishment.

5.3.3 Outreach to New and Absentee Landowners

The majority (> 50%) of landowners in the Upper Llano Watershed do not live within the watershed full-time. Education of absentee landowners is a challenge to the successful management of wildlife and exotics. To overcome this obstacle, education brochures will be mailed to all absentee landowners.

In addition, a series of 'traveling' workshops will be developed for absentee landowners in the watershed in partnership with TPWD and Texas Wildlife Association (TWA). These workshops could be presented in urban areas where absentee landowners are concentrated—San Antonio, Midland, Dallas/Fort Worth and Houston—and focus on deer and exotic management as well as feral hog education, brush control and septic system upkeep and maintenance.

Management Recommendation 3

Wildlife (and Exotics) Management


Photo: Donn Edwards

Objectives:

- Reduce fecal contaminant loading from wildlife and exotics
- Reduce riparian damage from wildlife and exotics
- Provide landowner education and outreach

Location: All sub-watersheds

Critical Areas: Riparian habitat, particularly along the North Llano and areas with actively eroding streambanks

Goal: Increase number of “active” TPWD Wildlife Management Plans in watershed by 2/year to a total of 66 wildlife management plans in 10 years – i.e. increase acreage under wildlife management plan from 85,410 to 125,000

Description: This strategy focuses on the overpopulation of deer (native and exotic) throughout the watershed by promoting an increase in the acreage under wildlife management plans and wildlife management associations. Landowners can receive technical guidance from TPWD on matters pertaining to wildlife habitat management and deer population management. Landowners, with assistance from TPWD, can establish wildlife management associations or co-ops to create wildlife management plans for large contiguous areas. Landowners can also seek to acquire Managed Land Deer Permits from TPWD to allow hunting seasons to be extended. This management strategy requires ongoing commitment and collaboration by landowners in each county. Landowners and deer processing facilities can collaborate to evaluate possible incentives for culling the deer population.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
Landowners, land managers, lessees especially in sub-basins with riparian areas; TPWD	Evaluate formation of wildlife management association(s)	2016–2025	N/A
	Enroll and continue participation in and implementation of wildlife management plans	2016–2025	N/A
	Work with TPWD biologists to develop and implement plans via wildlife management or landowner incentive programs	2016–2025	N/A
	Voluntarily locate supplemental feeding locations away from riparian areas.	2016–2025	N/A
	Voluntarily participate with professional harvesting services to remove exotics	2016–2025	N/A
LRFS, AgriLife Extension and TPWD	Educate citizens, hunters and landowners on wildlife management and benefits of developing and implementing wildlife management plans, participating in landowner incentive program, and forming wildlife management association(s)	2016–2025	$5,000/each for events $10,000/each for 9 traveling outreach events
LRFS, Local Chambers of Commerce and TPWD	Outreach to coordinate and facilitate pairing of hunters seeking exotic hunts with landowners, highlighting the potential economic benefits of year-round hunting.	2016–2018	$2,500/yr

Estimated Load Reduction

There are no specific loading data for exotics. EDYS Model results however show decreasing deer population densities in the riparian zone from one deer per 2 acres to one deer per 10 acres results in nitrogen decreasing 36 kg/yr or 16%; phosphorus decreasing 41 kg/yr or 12%; and sediment decreasing 65 tons/yr or 12% (Appendix G).

Effectiveness:	Moderate: Exotic populations rely on ample water, food, and shelter found in riparian habitats. Effectiveness will require significant participation by landowners.
Certainty:	Moderate: Financial incentives exist through landowner participation in wildlife management plans and professional harvesting services. Potential means to address harvests on ranches with absentee landowners.
Commitment:	Moderate: Hunting leases are a large source of income to local ranches. Good landowner participation is likely in wildlife management programs that maximize both harvest and income.
Needs:	High: Outreach is lacking, especially on the large number of absentee-landowner properties.
Potential Funding Sources:	- Participation: Cost of landowner participation in these programs is minimal - TPWD

5.4 Develop and Implement Conservation Plans

With more than 98% of the watershed classified as rangeland, support for voluntary management strategies to improvement rangeland management and health are critical to successfully improving instream water quality, stream health, watershed hydrology and flow. Maintaining healthy vegetation coverage is essential to reducing runoff and soil erosion and maintaining good water quality. Proper stocking rates and rotational grazing, along with providing alternative water sources and cross fencing are recognized by the Coordination Committee as important management measures to achieve these goals.

The Coordination Committee recommended multiple agricultural BMPs be integrated, where appropriate, into local operations to address all potential agricultural-related sources of bacteria, nutrients and sediment. It further recommends this can best be done by developing voluntary, site-specific management plans for individual farms. The Natural Resources Conservation Service (NRCS) and TSSWCB offer agricultural producers technical guidance as well as financial incentives for implementation of BMPs. TPWD provides wildlife and habitat technical guidance to ranches involved in agricultural production or management of wildlife habitat. Others, such as Texas A&M Forest Service (TFS), offer agricultural producers technical guidance as well. To receive financial incentives from TSSWCB, the landowner must develop a water quality management plan (WQMP) that is customized to fit the needs of their operation with the local soil and water conservation district (SWCD). NRCS offers options for developing and implementing both individual practices and whole ranch conservation plans. Conservation plan development is done free of charge; however, there may be costs for implementing practices required in a conservation plan (i.e. cost share). Funding from NRCS, TSSWCB WQMP program, TSSWCB 319(h) grant program, TPWD Landowner Incentive Program (LIP) and others will be sought to support implementation of agricultural and conservation management measures in the watershed. To expand on existing/previous efforts within the watershed; the Committee supports continued or increased funding for these programs.

Some of the key BMPs from the Field Office Technical Guide (FOTG) that should be considered for incorporation into individual farm plans include:

- 314 Brush Management (discussed further in following section)
- 338 Prescribed Burning (discussed further in following section)
- 382 Fence
- 390 Riparian Herbaceous Cover
- 391 Riparian Forest Buffer
- 394 Firebreak
- 512 Forage and Biomass Planting
- 516 Livestock Pipeline
- 528 Prescribed Grazing
- 533 Pumping Plan
- 550 Range Planting
- 590 Nutrient Management
- 595 Integrated Pest Management (IPM)
- 614 Watering Facility
- 645 Upland Wildlife Habitat Management

The Coordination Committee placed highest priority on Prescribed Grazing (528) and Brush Management (314) for addressing watershed concerns. Brush management will be discussed in detail in the next section. The Coordination Committee established a goal of having a minimum annual average of 25,000 acres enrolled in prescribed grazing plans developed by NRCS, TSSWCB, and/or SWCDs for 250,000 acres over 10 years. With an average farm size of 2,921 acres in the watershed, this will equate to an estimated eight to nine WQMPs and/or conservation plans annually or approximately 86 over the implementation period.

Due to the importance of wildlife in the watershed, the Coordination Committee also recommends having a minimum of 20,000 acres annually receive technical and (or) financial assistance for developing and implementing wildlife habitat management practices. These wildlife habitat improvement practices are often developed in conjunction with, or may overlap, prescribed grazing plans. Technical assistance on wildlife habitat is provided by NRCS, SWCDs and TSSWCB; TPWD will provide significant technical assistance delivering wildlife habitat management planning for approximately 10,000 acres annually (of the 20,000 acres targeted). Additionally, the TFS provides planning assistance to landowners regarding forest habitat management as well.

Additionally, the Committee suggests the development of landowner outreach materials with stocking rate recommendations and rotational grazing practices as management measures for this WPP. AgriLife Extension's Lone Star Healthy Streams Program (LSHS) and other existing Extension programs are good sources of this information. The other key measure, brush control (and prescribed burning) is discussed in the following section.

Management Recommendation 4

Conservation Plan Development/Implementation

Objectives:
- Develop TSSWCB WQMPs
- Develop NRCS Conservation Plans
- Develop TPWD wildlife habitat plans
- Develop TFS plans
- Provide landowner education and outreach

Location: All sub-watersheds

Critical Areas: Riparian and Upland habitat, particularly in the North Llano watershed and in areas with active streambank erosion

Goals: Annually 25,000 acres of ranchlands are enrolled in prescribed grazing plans through NRCS and TSSWCB; Annually 20,000 acres of ranchland enrolled in wildlife habitat management plans through TPWD, NRCS and TSSWCB.

Description: The goal is to manage livestock and land cover over time to sustain herds while maintaining the land and watershed in a healthy condition. Local landowners participate in these programs share cost for improving grazing conditions and water quality in the watershed.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
SWCD, TSSWCB, NRCS	Work with landowners to implement 250,000 acres of prescribed grazing and complementary practices via an estimated 86 WQMPs and Conservation Plans. Cost basis: $15,000/plan for TSSWCB; $3.04/acre for NRCS; it should be recognized that costs will vary depending on practices.	2016–2025	Up to $1,290,000
SWCD, TSSWCB, NRCS	Work with landowners to implement 100,000 acres of Upland Wildlife Habitat Management and complementary practices via 34 WQMPs and Conservation Plans. Cost basis: $15,000/plan for TSSWCB; $3.94/acre for NRCS; it should be recognized that costs will vary depending on practices implemented and acreage covered in plan	2016–2025	Up to $510,000
SWCD, TSSWCB	Hire technician to support development of conservation plans and WQMPs	2016-2025	$500,000
TPWD	Work with landowners to develop and implement 100,000 acres of wildlife habitat management	2016–2025	N/A
Landowners	Voluntarily locate supplemental feeding and watering locations away from riparian areas.	2016-2025	N/A
LRFS, Coordination Committee	Work with County Assessor to ensure appropriate stocking rate requirements for agricultural valuations	2016	N/A
TFS	Provide technical assistance to landowners on land management practices.	2016-2025	N/A
NRCS, AgriLife Extension	Deliver grazing management workshop highlighting watershed specific opportunities.	2016	$7,500
AgriLife Extension, TSSWCB	Provide LSHS programming to watershed landowners	2016, 2018	N/A

Estimated Load Reduction

Improved grazing practices on 25% of the watershed will reduce *E. coli* loading by 1.44E+14 over the 10-year implementation period of the WPP. Model results show that improved grazing reduces runoff by 268 acre-feet (0.3%), sediment loading by 836 tons (2.2%), nitrogen by 3.5 tons (1.6%) and phosphorous by 0.6 tons (2.2%) across the watershed (Tables 7 and 8, Appendix H).

Effectiveness:	Moderate: Improving the upland conditions and providing alternative watering sources will decrease the amount of time livestock spend in the riparian areas. Improved vegetative cover will decrease upland runoff.
Certainty:	Moderate: Landowners acknowledge the importance of good land stewardship practices and are actively implementing these practices through NRCS, TSSWCB and TPWD cost-share programs.
Commitment:	Moderate: Landowners have demonstrated a willingness to implement grazing management practices. However, cost-share opportunities enhance the willingness of landowners
Needs:	High: Continued financial assistance will be necessary for these practices to be implemented.
Potential Funding Sources:	NRCS programs (EQIP, RCPP, CRP, CSP, others); TSSWCB WQMP Program; TSSWCB CWA §319(h) grant program; TPWD Landowner Incentive Program

5.5 Brush Control for Range Improvement and Water Supply Enhancement

The control of brush species (Ashe juniper and redberry juniper and mesquite) is a management measure designed to improve range conditions, water supplies and infiltration in the watershed and, in some cases, to increase spring flows, which can greatly improve water quality in the Edwards Plateau. Brush control measures include mechanical, chemical or biological (goats) removal of brush and prescribed burning. All implementation measures should consider minimizing soil erosion and any potential impacts on wildlife.

5.5.1 Mechanical and Chemical Control of Medium to Heavy Brush

The Coordination Committee has identified brush control as an important management measure for this plan, suggesting an annual goal of removing about 9,000 acres of medium to heavy brush on slopes less than 12%[6] and implementing follow-up treatments (on a 6- to 7-year cycle) using fire or livestock. Modeling brush control scenarios with the EDYS model suggests that over the course of 25 years, removing 9,000 acres of brush annually in the watershed decreases evapotranspiration by 75,000 acre-feet. However, the positive hydrologic response to removing brush in the watershed — i.e. increased water availability resulting from decreased evapotranspiration — has a lag time of approximately 11 years following brush removal. This positive response continues annually with proper brush maintenance and grazing practices. The EDYS model also identifies priority subwatersheds where positive hydrologic responses from brush removal are greatest.

This management measure provides opportunities to analyze water budget output from the EDYS model. The hydrogeology of the Upper Llano Watershed, with the porous Edwards Formation overlying a more impermeable Trinity Formation, offers a unique opportunity to compare hydrologic responses between subwatersheds where brush control measures have been implemented and where they have not. As part of the WPP, LRFS will determine potential sites and methodologies for developing and implementing paired watersheds studies that can be studied over the course of the plan. Such sites would examine hydrological responses of brush control at a subwatershed-scale using methods to measure changes in evapotranspiration, surface runoff, groundwater recharge and groundwater discharge through springs.

In addition, brush control practices result in more immediate improvements in range conditions by changing a landscape dominated by brush to one of grasses and forbs and their associated ecosystem services. These services include wildlife habitat, recreation (including that associated with wildlife), carbon sequestration, biodiversity conservation and improved vegetative cover that protects soils, controls erosion, reduces sediment, improves water quality and enhances stream flow.

5.5.2 Prescribed Burning

Prescribed burning is an important component of maintaining range health and hydrology. While the Coordination Committee does not recommend prescribed burning in areas of heavy brush due to uncertainties related to potential erosion, it is recognized as an important maintenance treatment in areas previously cleared through mechanical or chemical means. The Coordination Committee identified prescribed burning as an important management measure for this plan, suggesting an annual goal of burning 2% of areas with low-density brush as well as follow up in areas previously cleared through brush control.

Modeling this level of prescribed burning suggests that over the course of 25 years, there will be minimal impacts on surface runoff (less than 1% increase overall) and decreased runoff response in some subwatersheds. Prescribed burning at this level only slightly increased storage and seepage (less than 1%) and had a negligible effect on sediment loading. Although prescribed burning measures do not appear to significantly increase water supply, they are an effective method for upland management, controlling woody invasives, stimulating new growth, improving range quality and restoring historical grassland conditions.

[6] In special cases, brush control on slopes greater than 12% may be warranted if adequate downslope erosion control mitigation measures are employed.

Prescribed burning requires trained personnel to light, maintain and control the fire. Having an available crew on-hand coincident with the right climatic, soil and fuel conditions for burning can often be problematic. Further, having the necessary liability insurance can often be expensive. To offset these hindrances, the Coordination Committee recommends working with the TFS, TPWD and NRCS to evaluate forming burn teams that can deployed when burn conditions are optimal. These burn teams, who would also carry liability insurance, could consist of military veterans trained through the Veterans Fire Corps.

Brush Control for Range Improvement and Water Supply Enhancement

Objectives:

- Develop and implement TSSWCB Water Supply Enhancement Program (WSEP) plans to control medium to high density brush
- Develop and implement NRCS Conservation Plans to control medium to high density brush
- Maintain areas with low density brush or those areas previously treated with prescribed burning

Location: All sub-watersheds

Critical Areas: Uplands as identified by subwatersheds in EDYS model scenario results, specifically Bell Hollow, Frog Creek, East Copperas Creek in the North Llano Watershed and Paint Creek and Joy Creek in the South Llano Watershed (Appendix H).

Goal: Annually remove 9,000 acres of heavy to medium density brush on slopes less than 12% with programs through NRCS, TSSWCB and TPWD. Annually treat between 5,400 and 7,700 acres of low-density brush with prescribed burning. Follow up treatment every six years on areas with brush control treatment.

Description: Local landowners participating in these programs share cost for removing brush and increasing grazing conditions and water infiltration in the watershed. Follow-up fire treatments are necessary to prevent regrowth of brush.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
NRCS, TSSWCB, TPWD	Work with landowners to implement 90,000 acres of mechanical and/or chemical brush control. Support brush control by providing cost-share or incentive funding through EQIP/WSEP/LIP (incentive or 50:50 to 70:30 cost share). $1.53 million to treat 9,000 acres/year	2016-2025	$15,300,000
NRCS, TSSWCB, SWCDs, TPWD, TFS	Work with landowners to provide appropriate follow-up brush-control treatment practices – i.e. reseeding, buffer strips, ‘trincheras’ and other BMPs	2016–2025	Capital Costs included in Conservation Plan Measure
Prescribed Burn Associations, NRCS, TPWD, TFS	Work with landowners to burn 5400 – 7700 acres annually of low density brush (follow up treatment and otherwise) at a cost of $6-20/acre.	2016-2025	$851,500
AgriLife Extension	Provide brush control education programs to watershed landowners.	2016	$7,500
Llano River Field Station	Paired watershed study – hydrologic response	2018-2025	$500,000

Estimated Load Reduction

Model results show that brush control and prescribed fire, coupled with improved grazing practices reduce sediment loading across the watershed by over 40%, from 37,940 tons to 22,273 tons; nitrogen is reduced by 30% (65 tons) and phosphorous is reduced by 40% (11 tons) (Appendix H).

Effectiveness: Moderate: Modeling of brush control efforts in the watershed shows a decrease in evapotranspiration and a corresponding increase in recharge of over 75,000 acre feet 11 years after brush removal and follow-up treatment. Prescribed burning is shown to be an effective method to increase forage yield and control regrowth of woody species

Certainty:	High: Landowners acknowledge the importance of good land stewardship practices and are already participating and showing interest in NRCS and TPWD cost-share programs for brush control. SWCDs want a TSSWCB WSEP Feasibility Study to accompany this WPP in order for the watershed to be eligible for WSEP funds.
Commitment:	High: Landowners have demonstrated a willingness to implement brush control practices. However, cost-share opportunities dictate the willingness of landowners to participate. Participation from absentee-landowners may present some challenges
Needs:	High: Continued financial assistance will be necessary for these practices to be implemented.
Potential Funding Sources:	NRCS EQIP program, TSSWCB WSEP and TPWD Landowner Incentive Program

5.6 Streambank/Riparian Restoration and Invasive Species Management

The Coordination Committee has identified streambank erosion, loss of woody riparian vegetation and aquatic invasive species as issues of concern within the watershed's riparian areas. The Committee has developed a holistic approach to riparian restoration by setting a goal of initiating restoration efforts on 10% of the riparian buffer zone every year for 10 years. Such an approach incorporates a wide range of management practices to address riparian issues.

Efforts to reduce streambank erosion are addressed through stabilization methods, while efforts to improve the recruitment of woody species in the riparian corridor will rely on the construction of exclosures. Chemical application and follow-up treatments are the recommended method for removing aquatic invasive species. As most of these management measures will be visible to recreational users of the river, outreach will be an integral component of these efforts to ensure maintenance, public understanding and support.

5.6.1 Stabilization of Eroding Banks

In areas of extensive erosion, bank-reshaping techniques may be necessary. There are numerous techniques, using natural materials such as woody debris and rocks that can be used to stabilize eroding banks. Many of these techniques have already been specifically recommended for locations along the South Llano River as part of the TPWD and LRFS Conservation Demonstration Area (CDA).

Structures using boulders, such as rock vanes and J-hooks (Figure 13a), can be constructed in the river's channel to deflect currents away from streambanks. Such techniques require an environmental permit from TPWD and have previously been employed just upstream of the Flat Rock Crossing of the South Llano River in Junction (Figure 13b).

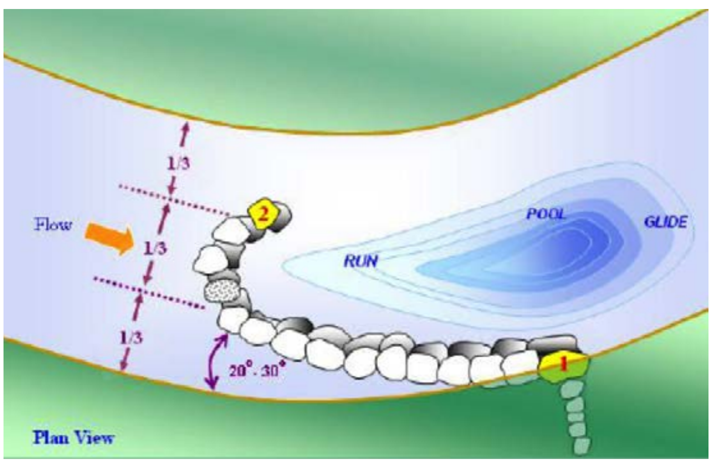


Figure 13a. Plan view of J-hook vane structure (TPWD Conservation Demonstration Area). Figure 13b. View of J-hook vane structure above Flat Rock Crossing, Junction, Texas.

5.6.2 Loss of Woody Riparian Vegetation

Native pecan trees provide much of the riparian habitat along the North and South Llano rivers. These pecans and other woody species provide bank stability and important shade for aquatic habitats. However, due to intensive browsing from deer and axis populations, few of the younger pecan trees or other woody species are surviving. The Coordination Committee recommends, as a strategy to address this lack of woody vegetation recruitment, the construction of temporary exclosures to allow saplings to become established and reach a growth stage resistant to browsing pressures.

Exclosures consist of an 8-foot game fence ranging in size from one-half acre to several acres. Exclosures can also be created with T-posts and net wire or livestock panels to protect individual or small groups of trees. Vegetation within these exclosures would be able to naturally regenerate or could be reseeded and replanted. One such exclosure on the LRFS campus has produced striking results (Figure 14).

Figure 14. Exclosure at Llano River Field Station.

5.6.3 Invasive Riparian Species

Arundo donax (giant cane) and elephant ear (*Colocasia esculenta*) are the two primary invasive riparian species along the rivers and streams of the Upper Llano Watershed. Another invasive riparian species is chinaberry (*Melia azedarach*).

BMPs to remove these species are through biological or chemical control. *Arundo* may be controlled biologically by using either scale bugs (*Rhizaspidiotus donacis*) or *Arundo* wasp (*Tetramesa romana*). These insects cause *Arundo* to produce smaller, less robust stands. Chemical controls for *Arundo* include Glyphosate, imazamox and imazapyr applied as a foliar spray directly on the leaves of the plant. These same chemicals are also used to control elephant ear. The Coordination Committee recommends that all stands of *Arundo* and elephant ear be removed.

Chinaberry may be treated by cutting and applying triclopyr to the stump. Information regarding the treatment of chinaberry will be provided to landowners as part of the WPP implementation, but because of its widespread nature across the watershed (on private lands), the Coordination Committee did not establish any specific goals for its removal and will rely predominately on education and outreach.

5.6.4 Recreational User Outreach

The South Llano River seasonally receives a high volume of paddling and tubing traffic. During the summer season, the river experiences higher than normal traffic because it is one of the few rivers in the Hill Country that, due to springflow, maintains adequate flows for recreational purposes. To protect and explain riparian restoration efforts along the South Llano, a river ranger will be hired seasonally to travel the river. During the course of restoration, many of the management measures, especially bank stabilization and invasive species control, will be in fragile and (or) unsightly conditions. The ranger's efforts will be focused on explaining the reason for these measures, ensuring their protection and working with outfitters and recreational users on litter pickup, an important component of water quality protection.

Management Recommendation 6

Streambank/Riparian Restoration and Invasive Species Management

Objectives:

- Decrease streambank erosion
- Improve recruitment of woody vegetation in riparian zone
- Eradicate selected invasive riparian species

Location: All sub-watersheds with riparian habitat

Critical Areas: Riparian habitat

Goal: Begin restoration on 14 miles of areas lacking riparian buffer and begin to improve vegetation conditions along 10% of riparian zone.

Description: A holistic riparian restoration approach that involves landowners, community members and agencies to address loss of streambanks, loss of riparian vegetation, and the impacts of invasive species.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
LRFS, TPWD, AgriLife Extension, Kimble County	Provide education and outreach regarding exclosures, treatment of invasive species, streambank restoration and riparian management as well as seasonal river ranger	2016–2025	$78,000
NRCS, TPWD	Provide cost-share funding to landowners for exclosure construction thru EQIP/ LIP (up to $2,000/exclosure)	2016-2025	Capital Costs included in Conservation Plan Measure
TPWD	Construct new bridge at State Park to prevent bank erosion	2017	N/A
	Restore 2000’ of eroded streambank in South Llano River State Park	2016-2023	TBD
LRFS, TPWD	Continue treatment of *Arundo donax* and elephant ear	2016-2025	$80,000
Master Naturalists, Boy Scouts, other service organizations	Provide volunteer hours to improve riparian habitat	2016-2025	N/A

Estimated Load Reduction

Modeling results show that removing *Arundo donax* will decrease sediment runoff by 35 tons (7.8%). While modeling results show that increasing the amount of woody vegetation in the riparian zone has no impact on sediment runoff, benefits to the watershed accrue through increased streambank stability and shading of aquatic habitat (Appendix I).

Effectiveness: Moderate: The benefits of this holistic approach will not be immediate; results will be realized toward the latter stages of the plan implementation (7-10 years).

Certainty:	Moderate: TPWD has funding to address riparian issues within the State Park.
Commitment:	Moderate: Landowners have previously demonstrated a willingness to participate in invasive species eradication efforts on the South Llano. The availability of service organizations may facilitate implementation, as increasing woody vegetation in the riparian zone makes for good service projects as well as public relations.
Needs:	High: Additional streambank restoration activities and construction of sufficient exclosures will necessitate additional funding.
Potential Funding Sources:	NRCS EQIP program/TPWD Landowner Incentive Program

5.7 Urban Water Management

Urban areas only comprise a small portion of the watershed; however, opportunities exist to improve watershed health through improved stormwater management and water conservation.

5.7.1 Urban Stormwater Management

Pollution of surface water (and potentially groundwater) from urban stormwater runoff is of concern to the Coordination Committee, especially in the City of Junction, where runoff can drain to nearby rivers, especially near the Interstate 10 interchange. Presently, few, if any, practices are being used to reduce runoff from the impervious surfaces.

This issue will be addressed by working with the City of Junction to establish funding to identify BMPs that may be implemented to reduce stormwater runoff. Such practices might include detention ponds, retention ponds or surface sand filters. The goal is to implement BMPs to address urban runoff from 79 acres of urban areas, or 1% of the total urban land use in the watershed. Funding will be secured to provide an engineering study for implementation of these BMPs. TCEQ 319(h) grant funds and TWDB's Rural Water Assistance Fund are potential sources to fund this effort.

5.7.2 Water Conservation

The conservation of water supports improvements in water quality, especially in the Upper Llano River watershed, where water quality exceedances are often associated with low flows in the rivers and streams. In addition, for the City of Junction, water quality downstream of the Upper Llano Watershed improves with decreased water use as the quality of water leaving the WWTF improves the longer it can remain being treated in the plant.

The Coordination Committee identified several practices for increasing water conservation. These include leak detection, the installation of water conservation fixtures such as toilets and showerheads and improved irrigation efficiencies resulting from the dissemination of timely information regarding irrigation water needs. Water conservation fixtures may be obtained at a better wholesale rate by partnering with existing water conservation programs; San Antonio Water System's Water Conservation Program offers such a partnership. Information regarding the proper timing and amount of irrigation may be disseminated by using information from the Mesonet weather station located at the LRFS in Junction. AgriLife Extension's Water My Yard program uses existing Mesonet stations to distribute email notifications to subscribers regarding the proper timing and amount necessary for adequate lawn irrigation. All of these practices will be implemented as part of the WPP.

Management Recommendation 7

Urban Water Management

Objectives:

- Identify stormwater BMPs, optimal siting, and associated costs and implement as funds allow
- Implement water conservation measures

Location: Cities of Junction and Rocksprings

Critical Areas: Riparian and Urban areas

Goal: Identify and implement BMPs to address urban runoff from 79 acres, or 1% of the urban area in the watershed. Improve water use efficiency by 10% through leak detection, installation of water conservation fixtures and dissemination of information regarding irrigation timing and needs.

Description: Improve water quality through improved management of urban stormwater runoff and water conservation measures.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
LRFS, City of Junction	Determine location, optimal siting, and costs to guide implementation of BMPs to reduce stormwater runoff	2018	$50,000 for study
Cities of Junction, Rocksprings	Purchase and distribute water conservation fixtures ($200/ toilet)	2016-2025	TBD
LRFS	Disseminate information regarding water application rates and timing through Mesonet Weather Station	2016	N/A
LRFS	Deliver water conservation education programs	2016-2025	N/A

Estimated Load Reduction

The amount of potential contaminant reduction is unknown until BMPs can be evaluated.

Effectiveness:	Moderate: Education is the most critical step to ensure effective water conservation. The potential exists for low-cost BMPs to be implemented to reduce urban stormwater runoff.
Certainty:	High: Drought conditions over the past five years have raised community awareness of the need for effective water conservation programs. There is a great deal of community concern within Junction regarding contamination from urban stormwater runoff to the North Llano River.
Commitment:	Moderate: Homeowners are largely willing to implement conservation practices if such practices can be shown to reduce monthly water bills.
Needs:	Moderate: Funding to deliver water conservation fixtures is needed.
Potential Funding Sources:	Community grant programs, local funds, State Water Implementation Fund of Texas

6. Outreach and Education

The development and implementation of this WPP depends on effective education, outreach and engagement efforts that inform landowners of activities, practices and programs associated with the WPP, as well as identify partnerships to assist with implementation.

6.1 Watershed Coordinator

The Watershed Coordinator plays an important role in outreach and education efforts associated with the WPP, serving as the point of contact. The Coordinator guides the development and implementation of the WPP through maintaining stakeholder support, identifying and securing funding sources to implement the WPP, organizing management strategies, tracking successes, and developing adaptive implementation strategies.

6.2 Initial Education and Outreach Strategies

A suite of strategies was used to initially engage stakeholders in support of the development of the Upper Llano WPP. Ongoing education and outreach efforts have maintained public involvement in the WPP development. Those activities include the following:

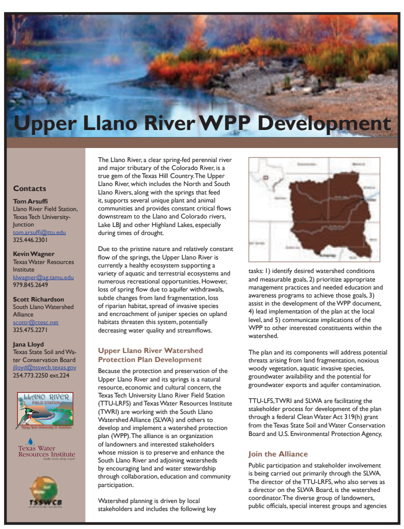
6.2.1 Project Website and Social Media

The South Llano Watershed Alliance, now LRWA, hosts the information and supporting documents for the Upper Llano WPP. LRFS staff creates and maintains website content. The site includes information on the watershed, project partners, newsletters, press releases, links to project partners, and meeting summaries and information presented at previous meetings.

In addition, project information was and continues to be disseminated through the Facebook pages of the Texas Tech University Center at Junction and the South Llano Watershed Alliance.

6.2.2 Fact Sheet

A fact sheet (Figure 15) was created on the development of the Upper Llano WPP as an outreach tool to gain support and facilitate participation in the WPP process. The fact sheet was distributed throughout the watershed prior to the first public meeting and is distributed at area events, stakeholder meetings, and other academic conferences. In addition, the fact sheet is available electronically on the South Llano Watershed Alliance (SLWA) website or in hard copy at the LRFS. Updated versions will continue to be created as needed to reflect project updates and/or accomplishments.



Upper Llano River WPP Development

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The Llano River, a clear spring-fed perennial river and major tributary of the Colorado River, is a true gem of the Texas Hill Country. The Upper Llano River, which includes the North and South Llano Rivers, along with the springs that feed it, supports several unique plant and animal communities and provides constant critical flows downstream to the Llano and Colorado rivers, Lake LBJ and other Highland Lakes, especially during times of drought.

Due to the pristine nature and relatively constant flow of the springs, the Upper Llano River is currently a healthy ecosystem supporting a variety of aquatic and terrestrial ecosystems and numerous recreational opportunities. However, loss of spring flow due to aquifer withdrawals, subtle changes from land fragmentation, loss of riparian habitat, spread of invasive species and encroachment of juniper species on upland habitats threaten this system, potentially decreasing water quality and streamflows.

Upper Llano River Watershed Protection Plan Development

Because the protection and preservation of the Upper Llano River and its springs is a natural resource, economic and cultural concern, the Texas Tech University Llano River Field Station (TTU-LRFS) and Texas Water Resources Institute (TWRI) are working with the South Llano Watershed Alliance (SLWA) and others to develop and implement a watershed protection plan (WPP). The alliance is an organization of landowners and interested stakeholders whose mission is to preserve and enhance the South Llano River and adjoining watersheds by encouraging land and water stewardship through collaboration, education and community participation.

Watershed planning is driven by local stakeholders and includes the following key tasks: 1) identify desired watershed conditions and measurable goals, 2) prioritize appropriate management practices and needed education and awareness programs to achieve those goals, 3) assist in the development of the WPP document, 4) lead implementation of the plan at the local level, and 5) communicate implications of the WPP to other interested constituents within the watershed.

The plan and its components will address potential threats arising from land fragmentation, noxious woody vegetation, aquatic invasive species, groundwater availability and the potential for groundwater exports and aquifer contamination.

TTU-LFS, TWRI and SLWA are facilitating the stakeholder process for development of the plan through a federal Clean Water Act 319(h) grant from the Texas State Soil and Water Conservation Board and U.S. Environmental Protection Agency.

Join the Alliance

Public participation and stakeholder involvement is being carried out primarily through the SLWA. The director of the TTU-LRFS, who also serves as a director on the SLWA Board, is the watershed coordinator. The diverse group of landowners, public officials, special interest groups and agencies

Figure 15. Upper Llano Watershed Protection Plan fact sheet.

6.2.3 News Releases and Radio

Together, LRFS, TWRI and TSSWCB personnel prepared numerous press releases that were submitted to a variety of media outlets during the WPP development. These media outlets included newspaper and radio outlets serving Junction, Sonora, Rocksprings and Menard. Additionally, news releases were also sent to stakeholders via email and the SLWA website. Other news associated with the WPP are magazines and website stories: USGS South Central Climate Science Center, Texas Tech University Media and Communications, Texas Tech Alumni Magazine, the Techsan, and Hill Country Magazine. LRFS also participated in a radio interview on healthy watershed approaches for the Texas Farm Bureau.

6.2.4 Newsletter Articles

The Upper Llano WPP Newsletter, written and disseminated by LRFS, contains informational articles regarding general watershed health issues and updates on the WPP process. The newsletter provides basic stewardship information to a broader audience. The newsletter was and continues to be distributed on a quarterly basis via e-mail and/or hard copy to all Upper Llano WPP stakeholders. In addition, all newsletters are posted on the SLWA website.

Since the beginning of 2015, the SLWA has disseminated a weekly newsletter to over 250 members on the Alliance's listserv. Articles in the newsletter contain information about the WPP as well as outreach efforts related to water well and septic testing, riparian habitat, feral hog education and invasive aquatic species.

6.2.5 Outreach at Local Events

Local events were used as a platform for disseminating project information. Presentations were made to the Junction Rotary Club on topics such as the Upper Llano WPP, the Texas Well Owner Network, invasive species and water conservation. In addition, presentations on water conservation and the Upper Llano WPP were made to the Leti Study Club and the Daedalian Society. Project updates were regularly communicated to the SLWA board members, and the local SWCDs. In addition, project information was provided as invited presentations to Hill Country Master Naturalists and annual meeting of Texas Sheep and Goat Raisers Association.

6.2.6 Texas Watershed Stewards

The Texas Watershed Stewards program, sponsored by AgriLife Extension and TSSWCB, is a free, science-based workshop that helps educate citizens to identify and take action to address local water quality impairments. Topics of the workshop include the nature and function of watersheds, potential impairments and strategies for watershed protection. The program is designed to engage citizens in water resource management and protection planning. A Texas Watershed Stewards workshop was held in Junction at LRFS on August 30, 2012. The workshop attracted 34 participants with a range of backgrounds. Additional workshops are held throughout the state. The workshop offered three general continuing education units for Texas Department of Agriculture (TDA) pesticide license holders, seven for certified landscape architects and three for certified floodplain managers. Recently, an online training course of the workshop was launched.

6.2.7 Texas Riparian and Stream Ecosystem Education Workshop

The Texas Riparian and Stream Ecosystem Education program, sponsored by TWRI and TSSWCB, is a free educational workshop on streams' function and the role of vegetation in properly functioning stream systems. A Riparian Education workshop was held in Junction at LRFS on October 16, 2013. The workshop attracted over 30 participants with a range of backgrounds. Additional workshops were held throughout the state. A variety of continuing education units were offered: two general and one integrated pest management — for TDA pesticide license holders, one unit from the TWRI, six hours for Texas Nutrient Management Planning specialists, six hours from the Texas Forestry Association, and 4.5 hours from the Society of American Foresters. In addition, the program was acceptable for health, safety and welfare credit from the Texas Board of Architectural Examiners and may be used for continuing education units for professional engineers.

6.3 Education Strategies Employed at the Llano River Field Station

6.3.1 Outdoor School

The LRFS Outdoor School (OS) is devoted to creating innovative educational experiences that immerse learners into authentic, real-world, hands-on activities that stimulate imagination and understanding of difficult abstract concepts. It is an extension of the classroom; all units align with the Texas Essential Knowledge and Skills (TEKS). Through the development of the WPP, the OS created and launched an Understanding Watersheds unit. The OS is internationally recognized for Human Diversity, as a Texas Exemplar Program using a STEM-TEKS, and Global Learning and Observations to Benefit the Environment (GLOBE) transdisciplinary, multiple best learning practices instruction for at-risk urban students linking innovative curriculum with nature and the outdoors. Since inception, OS has provided science/nature/water education to more than 65 independent school districts, 20,000 K-12 students and hundreds of teachers. In 2014, NASA selected OS to provide professional development on air quality and the hydrological cycle to teachers in Houston and the Hill Country.

LRFS was on the writing team and is on the implementation task for the Texas Natural Resource/Environmental Literacy Plan.

6.3.2 Conservation Demonstration Areas and Discovery Point Trail

The South Llano State Park, in conjunction with LRFS, is developing a CDA for the public to view BMPs appropriate for riparian protection and stream health. The Discovery Point Trail (DPT) is a component of the CDA at LRFS in Junction. The DPT is a self-guided nature trail developed in partnership with the National Park Service Rivers and Trails Conservation Assistance program and local stakeholders that highlights the mosaic of habitats and ecosystems of the Hill Country (these include the Upland Plateau, Upland Draw, mesquite thicket, pecan grove/riparian area, and oak and pecan savannas). Since over 95% of land in Texas is privately owned, the public DPT offers a unique opportunity for visitors (5,000/yr) to view the established BMPs including mesquite brush control, wildlife watering guzzlers, invasive-species control, riparian and stream restoration, and a renewable energy demonstration. Among notables is a one-half-acre herbivore exclosure established in 2011 that show the tremendous impact of exotics, hogs and white-tailed deer on riparian function—inside are massive increases in plant biomass, grass diversity and seedling established and growth, outside is bare ground and some unpalatable weeds.

6.3.3 Photo points

This strategy emphasizes the immediate and long-term changes in riparian management. Photo points will be placed on the LRFS campus in several locations in the CDA, and pictures posted on the project website. In addition, riparian landowners are encouraged to establish photo points and share photos. LRFS has given photo point instruction and handouts at an Oasis Fire Recovery Workshop.

6.3.4 Texas Water Symposium

The Texas Water Symposium is an innovative approach to educating the public about water in Texas. For the past nine years, LRFS, Texas Public Radio, Schreiner University and Hill Country Alliance have planned and presented four radio/face-to-face programs each year; audience feedback is used to structure topics for subsequent programs. Reaching tens of thousands of people, the series brings together policy makers, scientists, water resource experts and regional leaders to explore the challenges and complexities of managing water in Texas and increase public understanding. Examples: "Texas Springs: Making Connections between Groundwater, Surface Water, Science and Stewardship," "Healthy Watersheds," "Drought: What, Where, Why and When…will it end?" "The Insidious and Stealthy Water Thieves of Texas: Invasive species impacts on resources, economics and ecosystems."

6.4 Policy Maker Education and Engagement

LRFS provided project and project related information to policy makers at the state and national level. They include LRFS campus visits by U.S. Representative Mike Conaway. LRFS also conducted Congressional visits in Washington DC in 2012, 2014 and 2015 and met with Texas Senate or House staff. More recently, LRFS gave a Congressional Briefing to policy makers on field stations as partners for research, education and engagement at the invitation of American Institute of Biological Sciences/Organization of Biological Field Stations in Washington, DC on July 14, 2015. At the state level in 2015, LRFS provided testimony on behalf of the water supply enhancement program to the House Agricultural and Livestock Committee and watershed approaches and invasive species management as water conservation strategies to the executive directors of the Texas Water Development Board.

6.5 Science and Education Conferences

Attending professional science and educational organizations is another strategic outreach venue and important source for feedback on project research and engagement activities. Over the project's last three years, LRFS has given invited and contributed presentations to the Society for Freshwater Science, Southwestern Stream Restoration Conference, Joint Aquatic Sciences Meeting, Engagement Scholarship Consortium, George Wright Society, Universities Council on Water Resources, Texas Academy of Sciences, International Water Resources Association World Water Congress XV, American Fisheries Society and National Association of Environmental Education.

6.6 Oasis Pipeline Fire and other Agency Workshops and Training

In 2011, SLWA, TPWD, LRFS and other agencies developed a workshop addressing four years of recovery and restoration of the land impacted by drought and the 10,000-acre Oasis Pipeline Wildfire of 2011 in Kimble County. Other agency workshops and training at the LRFS campus include NRCS, TFS, TPWD, TCEQ, TSSWCB, Texas Comptroller Mussel Workshop and the Joint Meetings of the Society for Ecological Restoration and Texas Riparian Association (TRA). All such workshops included elements of the WPP.

6.7 Proposed Education Strategies

Since the Upper Llano Watershed has no water quality impairments and therefore the WPP is voluntary, the success of the WPP implementation is steeped in education and outreach to initiate behavior changes. The goal of the education and outreach strategies is to increase public awareness and participation, as well as encourage local stewardship. Each of the Working Groups (Water Supply Enhancement brush control, Invasive Species Management, Riparian Protection, Water Quality and Conservation and Upland Management) individually developed effective strategies for education and outreach. The suggestions are summarized in this chapter.

6.7.1 Seminars

A series of seminars and workshops will be developed for landowners and stakeholders to address proper management techniques. The development of these seminars will build upon existing programs and materials such as the TRA workshops and the TRA YouTube videos. Seminars will be offered by partnering agencies to include the greatest breadth of information per seminar. In addition, seminars will be held to address the management of public riparian areas and right-of-ways (e.g., establishing no mow zones) and identification workshops to help landowners identify native and invasive riparian vegetation. Offering Continuing Education Credits will encourage attendance. Seminars may also be offered in major urban areas such as San Antonio, Midland and Houston, where many of the absentee landowners in the watershed live.

6.7.2 Videos

The Department of Media and Communications of Texas Tech University (TTU) will create educational short videos (around 5 minutes or less) covering a variety of topics, such as water quality, riparian best management practices, etc. In addition, TPWD will create a video on the CDA of the South Llano State Park, the Discovery Point Trail of TTU-Junction, and the connecting South Llano Paddling Trail.

6.7.3 Watershed Protection Campaign Brochure

A brochure will be developed to educate about the impacts of individual activities on watershed health. These brochures will be located at businesses that sell hunting and fishing licenses, sporting goods stores, and the Rock Springs, Sonora and Junction Chambers of Commerce.

6.8 Outreach

6.8.1 River Rangers

The South Llano River seasonally receives a high volume of paddling and tubing traffic. In a proactive response, the SLWA and LRFS worked with TPWD to establish a Paddling Trail on the South Llano River in 2013. In drought years, the South Llano River experiences higher than normal traffic because the river is one of the few in the Hill Country that has never ceased flowing in recorded history. To build upon the Paddling Trail outreach and to further educate river users, a river ranger will be hired seasonally to travel the river, work with outfitters and educate users on litter pickup and etiquette of the paddling trail, in addition to the watershed protection efforts, especially related to riparian restoration efforts.

6.8.2 Outreach to New and Absentee Landowners

The majority (> 50%) of landowners in the Upper Llano Watershed do not live within the watershed full-time. Education of absentee landowners is a challenge to the successful implementation of the WPP. To overcome this obstacle, education brochures will be mailed to all absentee landowners. A mailing list of absentee landowners is accessible from the respective county tax offices.

In addition, a series of 'traveling' workshops will be developed for absentee landowners in the watershed in partnership with TPWD and TWA. These workshops could be presented in urban areas where absentee landowners are concentrated: San Antonio, Midland, Dallas/Fort Worth and Houston. Workshop topics could include deer and exotic management, feral hog education, brush control, and septic system upkeep and maintenance.

6.8.3 Annual Hunting and Fishing and Visitors Guides
TPWD publishes an Outdoor Annual Hunting and Fishing Regulations guide that is also has short articles. An article about proactive watershed planning will be submitted for the 2016–2017 guide. Articles will also be submitted about healthy watersheds in local visitor guides for Junction, Sonora, Rock Springs, Menard and Kerrville.

6.8.4 K-12 Education
To engage elementary school students and promote education of future generations, an annual Conservation Field Day will be developed and hosted by the LRFS campus in partnership with local SWCDs and other state and federal agencies (e.g., TPWD, NRCS, TSSWCB, TCEQ, etc.). The Conservation Field Day will be modeled after the Sutton County Field Day or the former TPWD Expo and include units such as plant identification, soils, wind/water erosion prevention, wildlife management, and natural resources conservation hands-on activities. The goal of the Conservation Field Day is to leave students and families with a better understanding of how to play a role in watershed preservation and their impacts on society.

6.8.5 Texas Stream Team
The Texas Stream Team is a volunteer water quality-monitoring program that trains citizens to be certified water quality monitors. Local entities, such as the Master Naturalist Program and LRWA, can partner with the Stream Team to train and equip citizens in the watershed. Through the Stream Team activities, volunteers develop a better understanding of water quality and its causes and impacts.

6.8.6 Roadway Signage
Roadway signage can be employed to develop a better understanding of the watershed as well as help deter illegal dumping. Having signage along Interstate 10, where it enters the North Llano Watershed, and along US 377, where it enters the South Llano Watershed, would increase awareness of the vast contributing areas of these two rivers. Having signage at low-water crossings and bridges, as part of TCEQ's "Don't Mess with Texas Water" program or LCRA's illegal dumping program, could continue to keep illegal dumping problems at a minimum.


DANGER
CAVING BANKS

7. Estimated Load Reductions Achieved With Management Measures and Activities

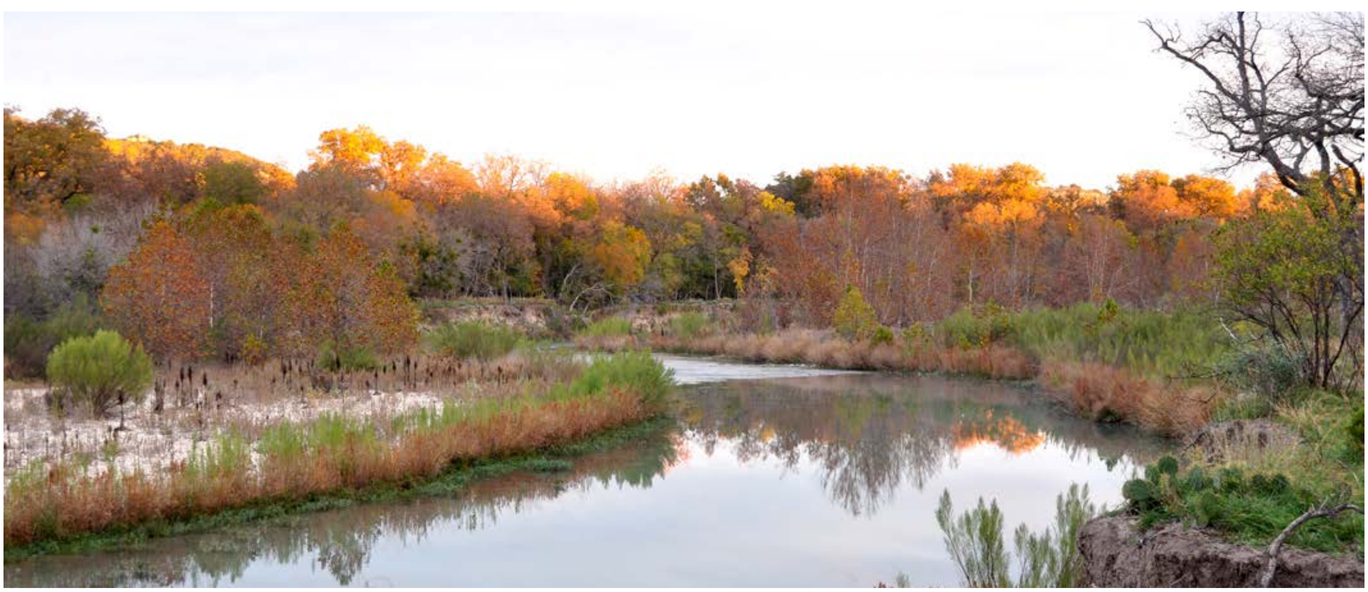
The Upper Llano River WPP is a holistic plan designed to maintain the overall healthy nature of the North and South Llano rivers watersheds. Areas along the North Llano River, where there are water quality issues related to *E. coli* and D.O., will be targeted for implementing certain measures, such as control of feral hogs. Load reductions in sediment and nutrients and increases in water budgets are available as EDYS models output for certain practices. Load reductions in *E. coli* are calculated from the literature. There are a few management measures for which no load reduction calculation is available.

7.1 OSSF Repair/Replacement

Based on the 1990 Census (the most recent information on septic systems) and data regarding the number of wells drilled since 1990, the total number of households with OSSFs in the watershed is estimated to be 2,300. Using an OSSF malfunctioning rate estimated for the region of 12% (Reed, Stowe and Yanke, 2001), 278 of these systems are estimated as potentially failing. To address failing OSSFs, stakeholders set a goal of bringing at least 10 OSSFs into compliance annually. OSSFs located near the North Llano and its tributaries and springs are of highest priority, followed by OSSFs near the South Llano and its springs and tributaries, followed by OSSFs near wells where *E. coli* has been detected. Potential loading from these failing OSSFs was estimated using the methodology presented in USEPA (2001) and used in many other watersheds in Texas as well as watershed-specific population estimates and other assumptions.

Assumptions:

- 10 failing OSSFs in the critical area of the watersheds may be replaced annually
- 106 cfu/100 mL fecal coliform concentration in OSSF effluent as reported by Metcalf and Eddy, 1991, Canter and Knox, 1985, Cogger and Carlile, 1984.
- 0.63 is the conversion factor to convert between fecal coliform and *E. coli* by dividing the current *E. coli* standard of 126 cfu/100 mL by the previously used fecal coliform standard of 200 cfu/100 mL
- 3785.2 mL/gallon = number of milliliters in a gallon
- 70 gpd is estimated discharge in OSSFs as reported by Horsley and Witten (1996)
- 2.50 persons per household in watershed
- 0.05 = Proximity factor is a percentage-based impact factor that accounts for an assumed stream impact based on the location of the OSSF (Larsen et al., 1994)



Potential Annual OSSF *E. coli* Load Reduction (Table 15):

10 failing OSSFs replaced annually * 10^6 fecal coliforms/100 mL * 0.63 * 70 gal./person/day * 3785.2 mL/gal. * 2.50 persons/household * .05 proximity factor * 365 days/year = **7.62+11 cfu**

Table 15. Potential Cumulative *E. coli* Load Reduction from OSSF replacement.

Year	OSSFs replaced	Annual reduction	Cumulative Reduction
1	10	7.62E+11	7.62E+11
2	10	7.62E+11	1.52E+12
3	10	7.62E+11	2.28E+12
4	10	7.62E+11	3.05E+12
5	10	7.62E+11	3.81E+12
6	10	7.62E+11	4.57E+12
7	10	7.62E+11	5.33E+12
8	10	7.62E+11	6.09E+12
9	10	7.62E+11	6.85E+12
10	10	7.62E+11	7.62E+12

Estimates of cumulative nitrogen and phosphorous reductions based on the implementation of this management measure are presented in Tables 16 and 17. Nitrogen reductions are based on Horsley and Whitten (1996); phosphorus reductions are based on Lusk, et al. (2014).

Table 16. Potential Cumulative Nitrogen Load Reduction from OSSF replacement.

Year	OSSFs replaced	Annual reduction (grams)	Cumulative Nitrogen Reduction (grams/yr)	Cumulative Nitrogen Reduction (kg/yr)
1	10	7.25E+03	7.25E+03	7
2	10	7.25E+03	1.45E+04	15
3	10	7.25E+03	2.18E+04	22
4	10	7.25E+03	2.90E+04	29
5	10	7.25E+03	3.63E+04	36
6	10	7.25E+03	4.35E+04	44
7	10	7.25E+03	5.08E+04	51
8	10	7.25E+03	5.80E+04	58
9	10	7.25E+03	6.53E+04	65
10	10	7.25E+03	7.25E+04	73

Table 17. Potential Cumulative Phosphorus Load Reduction from OSSF replacement.

Year	OSSFs replaced	Annual reduction (grams)	Cumulative Phosphorus Reduction (grams/yr)	Cumulative Phosphorus Reduction (kg/yr)
1	10	1.21E+03	1.21E+03	1
2	10	1.21E+03	2.42E+03	2
3	10	1.21E+03	3.63E+03	4
4	10	1.21E+03	4.84E+03	5
5	10	1.21E+03	6.04E+03	6
6	10	1.21E+03	7.25E+03	7
7	10	1.21E+03	8.46E+03	8
8	10	1.21E+03	9.67E+03	10
9	10	1.21E+03	1.09E+04	11
10	10	1.21E+03	1.21E+04	12

7.2 Feral Hog Management

The feral hog population is estimated to be 39,496 animals for the Upper Llano River watershed. This population estimate was derived using a density of 30 ac/hog.

Management reduction goals for feral hogs focus on removing animals from the watershed and keeping populations at a static level. The established goal is to remove, at a minimum, approximately 66% of the total hog population (26,000) over a 10-year period. This amount equates to removal of a minimum of 2,600 individual hogs from the watershed annually. By removing the hogs from the watershed, the potential *E. coli* load from feral hogs will be removed by an equal amount. The North Llano Watershed is of highest priority due to the elevated *E. coli* concentrations noted at main stem and tributary sites; however, feral hog control is needed throughout the watershed, particularly in riparian areas.

The potential annual *E. coli* load reductions from feral hogs were estimated using:

Annual Feral Hog Load Reduction = # hogs removed * 1.1E+10 cfu/day * 0.63 * .05 * 365
Where:

- 1.1E+10 = average daily cfu fecal coliform production rate per hog (USEPA, 2001)
- 0.63 = conversion factor for converting fecal coliform to *E. coli* (i.e. 126/200)
- 365 = days per year
- 0.05 = Proximity factor is a percentage-based impact factor that accounts for an assumed stream impact based on the location of the feral hogs

Potential Annual Feral Hog *E. coli* Load Reduction (Table 18):
2600 feral hogs removed annually * 1.1E+10 fecal coliform/100 mL * 0.63 * .05 * 365 days/year = 3.23E+15 cfu

Table 18. Potential Cumulative *E. coli* Load Reduction from feral hog management measures.

Year	Feral Hogs Removed	Annual Reduction	Cumulative Reduction
1	2600	3.23E+14	3.23E+14
2	2600	3.23E+14	6.46E+14
3	2600	3.23E+14	9.69E+14
4	2600	3.23E+14	1.29E+15
5	2600	3.23E+14	1.61E+15
6	2600	3.23E+14	1.94E+15
7	2600	3.23E+14	2.26E+15
8	2600	3.23E+14	2.58E+15
9	2600	3.23E+14	2.91E+15
10	2600	3.23E+14	3.23E+15

Estimates of cumulative nitrogen and phosphorous reductions based on implementing the feral hog reduction management measure are presented in Tables 19 and 20. Both nitrogen and phosphorus reductions are based on a 2005 report from the American Society of Agricultural Engineers (ASAE, 2005).

Table 19. Potential Cumulative Nitrogen Load Reduction from feral hog management measures.

Year	Feral hogs removed	Annual reduction	Cumulative Nitrogen Reduction (lbs/yr)	Cumulative Nitrogen Reduction (kg/yr)
1	2600	3.37E+03	3.37E+03	1.53E+03
2	2600	3.37E+03	6.74E+03	3.06E+03
3	2600	3.37E+03	1.01E+04	4.58E+03
4	2600	3.37E+03	1.35E+04	6.11E+03
5	2600	3.37E+03	1.68E+04	7.64E+03
6	2600	3.37E+03	2.02E+04	9.17E+03
7	2600	3.37E+03	2.36E+04	1.07E+04
8	2600	3.37E+03	2.70E+04	1.22E+04
9	2600	3.37E+03	3.03E+04	1.38E+04
10	2600	3.37E+03	3.37E+04	1.53E+04

Table 20. Potential Cumulative Nitrogen Load Reduction from feral hog management measures.

Year	Feral hogs removed	Annual reduction	Cumulative Phosphorus Reduction (lbs/yr)	Cumulative Phosphorus Reduction (kg/yr)
1	2600	9.49E+02	9.49E+02	4.30E+02
2	2600	9.49E+02	1.90E+03	8.61E+02
3	2600	9.49E+02	2.85E+03	1.29E+03
4	2600	9.49E+02	3.80E+03	1.72E+03
5	2600	9.49E+02	4.75E+03	2.15E+03
6	2600	9.49E+02	5.69E+03	2.58E+03
7	2600	9.49E+02	6.64E+03	3.01E+03
8	2600	9.49E+02	7.59E+03	3.44E+03
9	2600	9.49E+02	8.54E+03	3.87E+03
10	2600	9.49E+02	9.49E+03	4.30E+03

7.3 Wildlife (and Exotics) Management

White-tailed deer populations in the watershed are estimated to be 117,534. However, no estimate was available for exotics as they are managed on an individual ranch basis and population densities are not available. The focus of management measures for wildlife and exotics is in the riparian zone. EDYS model results show that reducing herbaceous and shrub biomass in the riparian area to 15% of normal, to reflect overgrazing in the riparian corridor, results in a 14% increase in sediment load (45 cubic meters per year), a 17% increase (336 kg) in nitrogen loading and a 14% increase (42 kg) in phosphorus. As there can be no specific reduction goal for deer[7], there are no load bacterial load reductions calculated for this management measure.

7.4 Conservation Plan Development and Implementation

Because an accurate estimation of conservation plan implementation cannot be clearly defined, calculating potential load reductions through plan implementation is computed through a generic equation. This equation uses the number of conservation plans implemented, average stocking rates, average fecal material production rates of cattle, the average *E. coli* content for cattle manure and the median *E. coli* effectiveness of the prescribed grazing BMP. This equation for daily potential load reductions is:

= number of conservation plans * number of cattle per conservation plan * *E. coli* production rate of cattle * BMP median *E. coli* effective rate* proximity factor

Where:

- 9 are the number of conservation plans to be implemented annually
- 37 is the number of cattle per conservation plan (based on an average ranch size of 2,781 acres and an average stocking rate of 75 acres per animal unit)
- 5.40E+09 = average daily cfu fecal coliform production rate per cow (Metcalf and Eddy, 1991)
- 0.63 = conversion factor for converting fecal coliform to *E. coli* (i.e. 126/200)
- 365 = days per year
- 0.05 = Proximity factor is a percentage-based impact factor that accounts for an assumed stream impact based on the location of livestock.

Annual potential *E. coli* load reduction is (Table 21):

9 * 33 * 5.40+E9 * 0.69*.05 * 365 = 1.44E+13 cfu

[7]White-tailed deer populations are regulated by TPWD statewide

Table 21. Potential Cumulative *E. coli* Load Reduction from conservation plan implementation.

Year	Conservation Plans Implemented	Annual Reduction	Cumulative Reduction
1	9	1.44E+13	1.44E+13
2	18	1.44E+13	2.87E+13
3	27	1.44E+13	4.31E+13
4	36	1.44E+13	5.75E+13
5	45	1.44E+13	7.19E+13
6	54	1.44E+13	8.62E+13
7	63	1.44E+13	1.01E+14
8	72	1.44E+13	1.15E+14
9	81	1.44E+13	1.29E+14
10	90	1.44E+13	1.44E+14

Similarly, the EDYS model predicts annual reductions in nitrogen and phosphorus loading over a 25-year period by an average of 3.5 tons for nitrogen (218.2 to 214.7 tons) and an average of 0.6 tons for phosphorous (27.2 tons to 26.6 tons).

7.5 Brush Control for Range Improvement and Water Supply Enhancement

Brush control management strategies (in conjunction with follow-up prescribed burning and grazing) were modeled with EDYS using a 25-year simulation period. Model output shows that these strategies increase water availability (through a decrease in evapotranspiration and an increase in recharge) by 75,000 acre-feet annually in years 11 through 25. EDYS model output for 25 years of simulation also shows a decrease in runoff across the watershed of 983 acre-feet (about 1%) and a decrease in sediment loading of 15,666 tons, or 41%. EDYS model output also predicts an annual decrease of 30% (from 218 tons to 153 tons) in nitrogen loading and a 40% decrease in phosphorus loading (27 to 16 tons) over 25 years of simulation utilizing this suite of management strategies.

Prescribed fire is an important method for follow-up treatment of brush removal as well a means for maintaining and improving range conditions. The simulated effect via EDYS of prescribed fire to maintain range conditions shows little impact on water yield and sediment loading. Total potential water yield across the watershed increased 1,734 acre-feet and only increased sediment loading by 75 tons or 52.7 m^3 per year. Future EDYS modeling efforts will target different scenarios and different benefits.

7.6 Streambank/Riparian Restoration and Invasive Species Management

Modeling efforts by TPWD show the importance of streambank restoration efforts in the South Llano River State Park. It is estimated that sediment loading from existing bank erosion in the park is 2,474 tons per year.

Controlling *Arundo donax* will be an important component of the WPP. EDYS model results show that if *Arundo* is not removed, sediment runoff will increase by 35 tons (7.8%). Research also indicates that water use by *Arundo* is 24 acre-feet/acre/year, six times that of native riparian species (Giessow, et al, 2011).

7.7 Urban Water Management

As the Upper Llano River watershed is primarily rural, the WPP has not developed estimates of load reductions associated with improvements in urban runoff, as specific BMPs and locations have not been identified. BMPs and associated load reductions will be assessed through a study to be funded during initial implementation of the WPP.

Water conservation efforts will reduce withdrawals from surface water and groundwater sources in the watershed. Surface water rights in the watershed have been granted for 5,220 acre-feet or about 7 cfs. Water conservation efforts designed to reduce consumption by up to 15% can reduce water use by 1 cfs, a small but critical volume during periods of low flow.

7.8 Summary of Load Reductions Resulting from Management Measures

The annual *E. coli* load, based on the mean of water quality and discharge measurements taken below the confluence of the North and South Llano rivers since 2001, is 3.63E+16 cfu; the annual *E. coli* load based on the geometric mean of these measurements is 7.14E+15. The mean annual nitrogen load, below the confluence, based on is 83,141 kg/yr (92 tons/year) while the median load is 61,767 kg/yr, or 68 tons/year. The mean annual phosphorous load (below the confluence) is 2,808 kg/yr (3 tons/year), and the median load is 1,716 kg/yr, or 2 tons/year.

Cumulative load reductions for *E. coli* will total 3.38E+15 cfu with the implementation of management measures in the WPP. Feral hog management measures will achieve the most significant portion of this reduction (95.5%), with conservation plans achieving 4.3% of the reduction and OSSF management measures achieving 0.2% of the reduction (see Table 22 and Figure 16). Cumulative 10-year load reductions for nutrients, based on an annual average reduction of 65 tons for nitrogen and 11 tons of phosphorus, is 768 tons or about 700,000 kg.

Table 22. Potential Cumulative *E. coli* Load Reduction.

Year	Feral Hogs	Conservation Plans	OSSFs	Total Reduction
1	3.23E+14	1.44E+13	7.62E+11	3.38E+14
2	6.46E+14	2.87E+13	1.52E+12	6.76E+14
3	9.69E+14	4.31E+13	2.28E+12	1.01E+15
4	1.29E+15	5.75E+13	3.05E+12	1.35E+15
5	1.61E+15	7.19E+13	3.81E+12	1.69E+15
6	1.94E+15	8.62E+13	4.57E+12	2.03E+15
7	2.26E+15	1.01E+14	5.33E+12	2.37E+15
8	2.58E+15	1.15E+14	6.09E+12	2.70E+15
9	2.91E+15	1.29E+14	6.85E+12	3.05E+15
10	3.23E+15	1.44E+14	7.62E+12	3.38E+15
	95.3%	**4.3%**	**0.2%**	

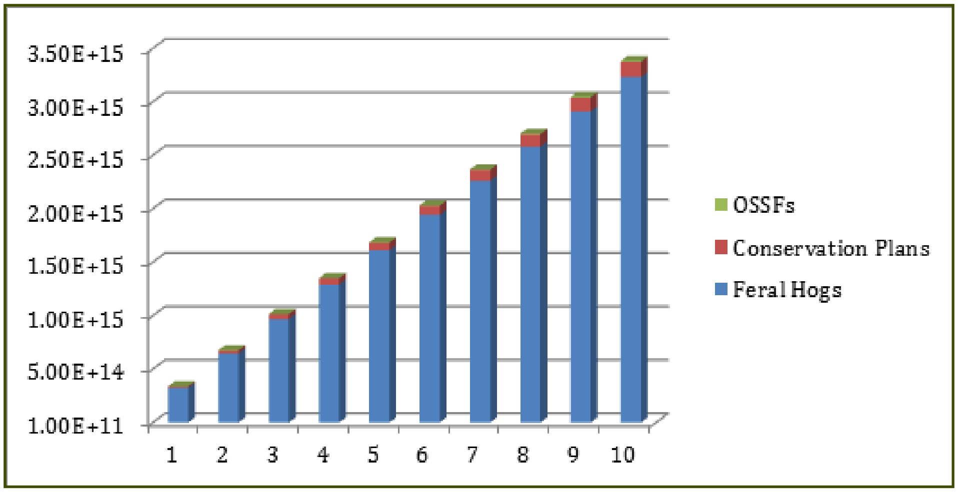


Figure 16. Potential Cumulative *E. coli* Load Reduction.

8. Technical and Financial Assistance

8.1 Technical Assistance Needs

8.1.1 Program Coordination

It is recommended that a full-time Program Coordinator be employed to facilitate continued progress. This position will oversee project activities, seek additional funding, organize and coordinate regular updates for the Partnership, maintain the website, and coordinate outreach and education efforts and workshops in the watershed. An estimated $95,000 per year including salary, benefits and travel expenses will be necessary for this position.

8.1.2 SWCD Technician

An SWCD Technician will be needed to assist with conservation planning, brush management and riparian restoration management measures through programs such as EQIP, WQMPs and WSEP. An estimated $50,000 per year is necessary for this position.

8.2 Sources of Financial Assistance

8.2.1 Local and Private Sources

Cynthia and George Mitchell Foundation

The Mitchell Foundation is a grant-making foundation that seeks innovative, sustainable solutions for human and environmental problems. The foundation deploys resources on several water issues including the protection of water resources in the Texas Hill Country through landowner engagement and a science-based identification of the most critical water resources. Foundation funding can be used to support water conservation and water supply enhancement studies.

Community Foundation of the Texas Hill Country

The foundation funds projects that have a significant and long-lasting impact on the community, or when the project tests a new approach to solve a community problem. Projects may cover the following topics: civic and cultural, family and wellness, community service, youth and education, or animal welfare. Foundation funding can be used to support local non-profit efforts to participate in the implementation of the WPP.

Dixon Water Foundation

The mission of The Dixon Water Foundation is education, outreach and research on water issues, with a particular focus on ecologically and financially sustainable land management that will enhance water retention and minimize erosion in watersheds. Grants are available for projects addressing the foundation's mission to nonprofit organizations.

Junction Texas Tourism Board (JTTB)

The JTTB was created to administer the revenue generated by Junction's hotel/motel occupancy tax, which is 7% of the cost of a motel room. The mission of the JTTB is to foster tourism-based economic development activities for the benefit of local businesses. Board funding can be used to advertise and sponsor events that bring visitors to learn about the Llano River.

Pedernales Electric Cooperative (PEC) Community Grant

Grants of up to $1,000 are available to non-profit organizations within the PEC territory. Emphasis is placed on awards that support life-saving, conservation and educational projects or equipment. Grants can be used for capital improvement projects, equipment needs, program implementation and other special projects.

Wells Fargo Environmental Solutions for Communities
In 2012, Wells Fargo and National Fish and Wildlife Foundation launched a five-year Environmental Solutions for Communities initiative to support projects that link economic development and community well-being to the stewardship and health of the environment. Funding from this program can be used to study BMPs related to urban-stormwater runoff.

8.2.2. State Sources

Texas State Soil and Water Conservation Board (TSSWCB)

Water Supply Enhancement Program (WSEP)
Administered through TSSWCB, this program is designed to increase available surface water and groundwater through the targeted control of brush species that are detrimental to water conservation. Through this voluntary program, landowners may contract with TSSWCB for cost-share assistance to implement brush control activities for water supply enhancement on eligible acres. A 10-year resource management plan is developed for each property enrolled in the WSEP, which describes the brush control activities to be implemented, follow-up treatment requirements, and supporting practices to be implemented, including livestock grazing management, wildlife habitat management, and erosion control measures (e.g., buffers, filter strips, reseeding).

Water Quality Management Plan Program (WQMP)
The TSSWCB administers the WQMP Program as a voluntary mechanism by which site-specific plans are developed and implemented on agricultural and silvicultural lands to prevent or reduce NPS pollution. Plans include appropriate treatment practices, production practices, management measures, technologies or combinations thereof. Plans are developed in cooperation with local SWCDs, cover an entire operating unit, and allow financial incentives to augment participation. Funding from the WQMP program will be sought to support implementation of agricultural management measures in the watershed.

Texas Nonpoint Source Management Program – 319(h) Grant Program
Established under Section 319(h) of the Clean Water Act, the Environmental Protection Agency provides funding through TSSWCB to abate agricultural NPS water pollution.

Texas Commission for Environmental Quality (TCEQ)

Supplemental Environmental Projects (SEP)
Administered through TCEQ, SEPs use monetary penalties or fines assessed when a plant or facility is found to be in violation of certain environmental regulations. Through the SEP program, violators can put their fine to work close to home and help improve the environmental quality of the nearby region. A SEP may include a variety of actions that protect or improve the quality of air, water and/or soil. In general, SEPs enhance the environment in communities affected by environmental violations.

Texas Nonpoint Source Management Program – 319(h) Grant Program
Established under Section 319(h) of the Clean Water Act, the Environmental Protection Agency provides funding through TCEQ to abate urban NPS water pollution through OSSF repair and replacement and educational workshops.

Texas Parks and Wildlife Department (TPWD)

Landowner Incentive Program
TPWD along with other partners provide support to private landowners and non-governmental agencies for conservation practices on private land that benefit the health of terrestrial and aquatic ecosystems. Support is provided as a cost-sharing program. The funding series includes a statewide program as well as watershed programs. Currently, the

watershed series targets the James and Llano rivers watersheds with the goal of improving water quality, increasing water quantity, restoring riparian areas, removing invasive species, and reducing stream system fragmentation.

Technical Guidance Program

Through the TPWD Private Lands Program, landowners are offered this advisory program without charge to develop sound wildlife management programs consistent with the landowner's goals and objectives.

Texas Department of Agriculture

Agricultural Loan Guarantee Program

This program provides a loan guarantee to a lender on behalf of a creditworthy agriculture producer or agriculture-related business. The loan may be used for any agriculture-related operating expense, the purchase or lease of land or a fixed-asset acquisition or improvement, or for any enterprise based on agriculture as identified in the application.

County Hog Abatement Matching Program

Under the Feral Hog Abatement Grant Program, the County Hog Abatement Matching Program is focused on implementing a long-term statewide feral hog abatement strategy. The program is designed to encourage counties across the state to create partnerships with other counties, local governments, businesses, landowners and associations to reduce the feral hog population and the damage caused by these animals in Texas. Only Texas counties with at least one partner may apply. Partners include other local governments, private or non-profit businesses, landowners, ranchers or entities that have an interest in feral hog abatement.

Renewable Energy Demonstration Pilot Program

This program provides assistance to incorporate renewable energy technologies to help rural communities reduce energy costs for their water and WWTFs. This fund competition rewards applicants proposing innovative technology solutions, long-term cost reductions and leveraging partnerships. Priority for awarding grants is given to projects that incorporate renewable energy technologies to help rural communities reduce energy costs for their water and WWTFs. Only nonentitlement general-purpose units of local government, including cities and counties, are eligible. The maximum award is $500,000.

Texas Water Development Board (TWDB)

Agricultural Water Conservation Grants Program

This grant program offers state agencies and political subdivisions funds for technical assistance, demonstration, technology transfer, education and metering projects that conserve water. Grant topics must address current issues and topics in agricultural water conservation with the goal of implementing agricultural irrigation projects designated in the State Water Plan and demonstrate BMPs that conserve water or improve water use efficiency. Grants are available for up to $600,000.

Clean Water State Revolving Fund

Authorized by the Clean Water Act, this loan program funds a variety of practices including wastewater treatment, nonpoint pollution control and watershed management. Examples of projects include upgrading WWTFs, collection systems, wastewater recycling and reuse improvements, stormwater pollution control, NPS pollution control, and eligible green project reserve components. Loans are offered to individual landowners to business and non-profit organizations at interest rates lower than the market. This program also includes Federal (Tier III) and Disadvantaged Communities to provide even lower interest rates for those meeting the respective criteria.

Drinking Water State Revolving Fund Loan Program

This loan program, authorized by the Safe Drinking Water Act (SDWA), provides low-interest loans for planning, design and construction of water infrastructure to both public and private water systems. Examples of projects include water treatment facilities, distribution systems, upgrade/replacement of water infrastructure, address standards from the SDWA, consolidation of systems, purchasing additional capacity, source water protection projects and eligible green project reserve components.

Rural Water Assistance Fund Program

This program provides low-cost financing for water and wastewater projects by small rural utilities (serving a population of 10,000 or less, and counties in which no urban area has a population exceeding 50,000). Those eligible may also partner with a federal agency, state agency or another rural political subdivision to apply for funding. Financial assistance may include planning, design and construction for water and water quality enhancements. Examples of water-related projects include acquisition of groundwater and surface water rights, water projects included in the State or a Regional Water Plan, and improvements of wells, among other projects. Examples of water quality enhancement projects include NPS pollution abatement, among others.

State Participation Program

This program enables TWDB to assume temporary ownership interest in a regional water, wastewater or flood control project when the local sponsors are unable to assume debt for the optimally sized facility. The goal of the program is to allow for the "right sizing" of projects in consideration of future growth. TWDB may acquire ownership interest in the water rights or a co-ownership interest of the property and treatment works. The loan repayments that would have been required, if the assistance had been from a loan, are deferred. Ultimately, however, the cost of the funding is repaid to TWDB based upon purchase payments, which allow TWDB to recover its principal and interest costs and issuance expenses. TWDB's participation from this program is limited to a maximum of 80% of costs for projects creating a new water supply and to 50% of costs for other types of projects. In both cases, state participation is limited to the portion of the project designated as excess capacity. At least 20% of the total capacity of the proposed project must serve existing needs.

Water Development Fund

The state funded (i.e., does not receive federal subsidies) State Loan Program Texas Water Development Fund II (DFund) allows TWDB to fund multiple eligible components in one loan to borrowers. Political subdivisions (cities, counties, districts, and river authorities) of the state and nonprofit water supply corporations are eligible to apply for assistance on a first-come, first-serve basis for water supply, wastewater and flood control projects.

8.2.3 Federal Sources

U.S. Department of Agriculture-Farm Service Agency

Conservation Reserve Program (CRP)

The CRP offers a yearly rental payment to farmers and ranchers in exchange the removal of environmentally sensitive land from agricultural production. Once lands are removed from production, CRP participants plant grasses and other cover crops to control erosion, improve water quality and develop wildlife habitat.

U.S. Department of Agriculture-Natural Resources Conservation Service (NRCS)

NRCS is a federal agency that works hand-in-hand with Texans to improve and protect their soil, water and other natural resources. For decades, private landowners have voluntarily worked with NRCS specialists to prevent erosion, improve water quality and promote sustainable agriculture. NRCS provides conservation planning and technical assistance to landowners, groups and units of government to develop and implement conservation plans that protect, conserve and enhance their natural resources. When providing assistance, NRCS focuses on the sound use and management of soil, water, air, plant and animal resources. NRCS ensures sustainability, allows for productivity and respects the customers' needs. Conservation planning can make improvements to livestock operations, crop production, soil quality, water quality, and pastureland, forestland, and wildlife habitats. NRCS also integrates ecological and economic considerations in order to address private and public concerns.

NRCS administers numerous Farm Bill Programs authorized by the U.S. Congress that provide financial assistance for many conservation activities:

- Conservation Innovation Grants (CIG)
- Conservation Stewardship Program (CSP)
- Environmental Quality Incentives Program (EQIP)
- Regional Conservation Partnership Program (RCPP)
- Agricultural Conservation Easement Program (ACEP)
- Conservation Reserve Program (CRP) administered by USDA Farm Service Agency

EQIP and other programs were reauthorized in the federal Agricultural Act of 2014 (Farm Bill) to provide a voluntary conservation program for farmers and ranchers that promotes agricultural production and environmental quality as compatible national goals. People who are engaged in livestock or agricultural production on eligible land may participate in EQIP. EQIP offers financial and technical assistance to eligible participants for installation or implementation of structural and management practices on eligible agricultural land.

NRCS also provides incentive and payments to implement conservation practices. NRCS activities are carried out according to a plan of operations developed in conjunction with the producer that identifies the appropriate conservation practice(s) to address resource concerns. All practices are subject to NRCS technical standards described in the FOTG and adapted for local conditions. The local SWCD approves the plan.

Local work groups provide recommendations to USDA-NRCS on allocating EQIP county base funds and on resource concerns for other USDA Farm Bill programs. Upper Llano River stakeholders are encouraged to participate in the Local Work Group in order to promote the goals of this Watershed Protection Plan as compatible with the resource concerns and conservation priorities for EQIP.

U.S. Department of the Interior

WaterSMART Grants

This cost-share program aims to increase future water supplies for farms, cities, people and the environment across the West. The Bureau of Reclamation administers the WaterSMART Grants, which is designed to contribute to this goal by providing 50% cost-shared funding for water and energy improvement projects that more efficiently use existing water supplies. Funding is used primarily to carry out water and energy efficiency improvements, including projects that save water, increase energy efficiency and the use of renewable energy in water management, address endangered species and other environmental issues, and facilitate transfers to new uses. Other projects may result in water delivery improvements that also facilitate future on-farm improvements that can be carried out with the assistance of NRCS to accomplish coordinated water conservation improvements.

U.S. Environmental Protection Agency

Environmental Education Grants

This program supports environmental education projects that increase the public's awareness about environmental issues and provides them with the skills to take responsible actions to protect the environment. Environmental education includes the range of activities from awareness to action with an ultimate goal of environmental stewardship. Environmental information and outreach are not eligible under this program.

Environmental Justice Small Grants Program

The Environmental Justice Small Grants Program supports and empowers communities working on solutions to local environmental and public health issues. The program assists recipients in building collaborative partnerships to help them understand and address environmental and public health issues in their communities. Successful collaborative partnerships involve not only well-designed strategic plans to build, maintain and sustain the partnerships, but also work toward addressing the local environmental and public health issues. Grant awards are $25,000.

Pollution Prevention Incentives for States

The U.S. Environmental Protection Agency (USEPA) Office of Pollution Prevention (P2) and Toxics is responsible for overseeing several grant programs for tribes and states that promote pollution prevention through source reduction and resource conservation. The Source Reduction Assistance Grant Program under Catalog of Federal Domestic Assistance (CFDA) 66.717 funds work plans that carry out or promote pollution prevention (P2)/source reduction, resource conservation projects relating to gathering or transferring in formation or advancing awareness. Proposals must present innovative project tools; forge creative partnerships that engage and educate communities P2 practices; or augment existing P2 practices by taking a business, community or locality into a new and resourceful direction to benefit human health and the environment.

In addition, the Pollution Prevention Grant Program under CFDA 66.708 gives states and tribes the capability to assist businesses and industries in identifying better environmental strategies and solutions for complying with federal and state environmental regulations. It also aims to improve business competitiveness without increasing environmental impacts. The majority of P2 Grants fund state-based projects for technical assistance, training, outreach, education, regulatory integration, data collection, research, demonstration projects and recognition programs.

Section 319(h) Clean Water Act

Clean Water Act Section 319(h) funds are provided only to designated states to implement their approved NPS management programs. State NPS programs include a variety of components, including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and regulatory programs. In Texas, both TSSWCB and TCEQ receive 319(h) funds to support NPS projects, with TSSWCB funds going to agricultural and silvicultural issues and TCEQ funds going to urban and other non-agricultural issues.

Targeted Watersheds Grant Program

The goal of this program is to encourage successful community-based approaches to protect and restore the nation's watersheds.

Water Pollution Control Program Grants (Section 106)

Section 106 of the Clean Water Act authorizes the EPA to provide federal assistance to states and interstate agencies to establish and implement ongoing water pollution control programs. Prevention and control measures supported by pollution control programs include permitting, development of water quality standards and total maximum daily loads, surveillance, ambient water quality monitoring, and enforcement; advice and assistance to local agencies; and the provision of training and public information. The Water Pollution Control Program is helping to foster a watershed protection approach at the state level by looking at states' water quality problems holistically, and targeting the use of limited finances available for effective program management.

U.S. Fish and Wildlife Service

Partners for Fish and Wildlife Program

Through voluntary agreements, the Partners program provides expert technical assistance and cost-share incentives directly to private landowners to restore fish and wildlife habitats. There is no formal application process; a phone call or letter initiates the process.

9. Project Implementation

The implementation of the Upper Llano WPP will be on a 10-year timeframe, focusing on eight different management measures. Each measure will have annual implementation milestones (defined by the stakeholder-driven Watershed Coordination Committee), expected funding needs and identified organizations that can guide the implementation of the desired practice (Tables 23-25).

9.1 Septic Systems

Costs to replace or repair septic systems can range from $5,000 to $10,000, so developing a process for prioritizing which systems should be replaced is an economically effective approach to strategy implementation. LRFS will identify OSSFs within 150 yards of waterways in the watershed. Once identified, LRFS and the local counties will work with landowners to facilitate replacement efforts, through the 319(h) grant program. LRFS will also coordinate with the City of Junction to identify OSSFs that could be deactivated through connection to the city sewer system. Funding for such efforts is available through TWDB's Clean Water State Revolving Fund or Rural Water Assistance Fund.

9.2 Feral Hogs

The formation of a Feral Hog Task Force (similar to the task force created in Caldwell County, TX) will be a critical first step in implementing feral hog management efforts. The Task Force will be responsible for coordinating the hog trap distribution program, paying bounties and coordinating feral hog hunting programs.

LRFS, working with local county governments, TDA, and Texas A&M AgriLife, will oversee the creation of the Task Force; LRFS will manage the initial activities of the task force until it is self-sustaining. Texas A&M AgriLife or LSHS can also provide technical assistance to watershed landowners through the presentation of feral hog workshops, educational outreach efforts regarding supplemental deer feeders to exclude hogs, and the creation of a feral hog reporting system. TSSWCB will assist with BST to identify pollution sources attributed to feral hogs (and other sources), if funds become available.

9.3 Wildlife (and Exotics) Management

A coordinated effort to managing wildlife and exotic populations will be implemented through increased landowner participation in wildlife management plans or wildlife management associations. The focus of these efforts will be for lands in or near riparian habitat. TPWD is the primary agency responsible for these programs. LRFS, along with LRWA, TRA and TWA can assist TPWD in increasing landowner participation through outreach efforts to members as well as create a 'traveling' outreach effort to absentee landowners.

Additional management efforts will include outreach activities from AgriLife Extension and LRFS regarding to site and design feeders that are away from riparian areas and exclude feral hogs. LRFS will work with local chambers of commerce to expand year-round hunting opportunities for exotic species, especially to youth or disadvantaged hunters.

9.4 Conservation Plans

Increasing the number of landowners participating in Grazing Management Programs is the key management measure for managing livestock in the watershed. NRCS and TPWD, through the EQIP and LIP programs, and TSSWCB through the WQMP Program, are the key agencies involved in these efforts. Texas A&M AgriLife and LSHS outreach efforts can be used to expand proper grazing management practices, while LRWA, LRFS, and TWA can assist in increasing landowner participation through outreach efforts to members.

9.5 Brush Control for Range Improvement and Water Supply Enhancement

Brush control in conjunction with prescribed burns are the key management measures to improve upland rangeland and enhance water supplies. Programs for both management practices are available through NRCS and TSSWCB. In addition, local SWCDs and prescribed burn associations play a critical role in implementing these practices at the local level. Programs to improve and restore wildlife habitat through brush control and prescribed burning are also available through TPWD. LRWA, LRFS and TWA can help expand landowner participation through outreach efforts to members.

9.6 Riparian Management

TPWD, NRCS and LRFS all have active roles to play in the implementation of the various riparian management measures. TPWD and NRCS can provide funding to landowners through their LIP and EQIP programs respectively. U.S. Fish and Wildlife's Partners for Wildlife Program also provides technical assistance and cost-share incentives to private landowners for fish and wildlife habitat restoration projects. Local service organizations such as Master Naturalist and Boy Scouts can provide local volunteer hours to help implement restoration efforts.

In addition, two major projects affecting riparian health at South Llano River State Park (bridge replacement and streambank restoration) will be implemented in the near future as part of the LRFS-Texas Parks and Wildlife Conservation Demonstration Area. LRFS and TPWD will also continue their cooperative effort on the treatment efforts on *Arundo donax* and elephant ear.

9.7 Urban Stormwater Runoff

Stormwater runoff, associated with impervious cover and contaminate runoff to the North Llano River from the Interstate 10 intersection in Junction, is of concern to area stakeholders. Methods of reducing runoff are varied and subject to political and economic feasibility. To initiate efforts to address this issue, the WPP will work with the city to obtain funding for a study of potential BMPs to reduce runoff from this area. Determining the next steps for addressing this issue as part of the WPP will occur during the adaptive implementation phase of the effort. Funding for these efforts is available through TWDB's Rural Water Assistance Fund and Section 319(h) funds.

9.8 Water Conservation

Water quality exceedances are often associated with occurrences of low flow. Implementing water conservation practices can help reduce these periods of low flow. The watershed coordinator and stakeholders will work with the City of Junction, the City of Rocksprings and LRFS to procure funding for BMPs that reduce pipeline leaks and reduce water use in homes and at commercial and institutional facilities. Additionally, LRFS will partner with AgriLife Extension's WaterMyYard program to afford real-time irrigation water needs in the area, using the Mesonet station located on campus.

Table 23. Management recommendations, implementation schedule, responsible party and cost estimates.

Management Measure	Responsible Party	Planned Implementation Goal	Unit Cost	Total Cost
Septic System (OSSF) Management Measures				
Replace failing OSSF	Landowners Lessees	10 systems/year	$7,500/ system	$750,000
Connect existing OSSF to WWTF	City of Junction	Number unknown-estimate 20 total	$2,000/ connection	$40,000
Feral Hog Management Measures				
Fencing Deer Feeders	Landowners Lessees	As many as possible	$200 ea.	N/A*
Feral Hog Removal	Landowners Lessees	2,600 hogs/yr	N/A*	N/A*
Feral Hog Bounties	Upper Llano Hog Task Force	2,600 hogs/yr	$13,000/yr	$131,000
Feral Hog Traps	Upper Llano Hog Task Force	10 traps catching 25 hogs/month	$5,000 ea-30 ft trap	$50,000
Aerial hunting	Upper Llano Hog Task Force	As possible	$700/hr	N/A*
Wildlife and Exotic Management Measures				
Develop and Implement wildlife management plans	Landowners Lessees TPWD	2 new wildlife plans per year or 20 over 10-year period	N/A*	N/A*
Voluntary relocate supplemental feeding locations	Landowners Lessees	As possible	N/A*	N/A*
Voluntary participate professional harvesting	Landowners Lessees	As possible	N/A*	N/A*
Conservation Planning Measures				
Implement ag BMPs (Prescribed Grazing, etc.) via enrollment in conservation programs	Landowners Lessees NRCS TSSWCB TPWD	35,000 acres annually-equivalent to approximately 12 WQMP/year	$180,000/ yr	$1.80 million

Table 23. Continued

Management Measure	Responsible Party	Planning Implementation Goal	Unit Costs	Total Costs
Brush Control for Range Improvement and Water Supply Enhancement				
Implement Brush Management	Landowners Lessees NRCS TPWD TSSWCB	9,000 acres/yr	$170/acre assuming equal combination of medium-heavy brush = $1.53 million/year	$15.3 million
Prescribed Burning as follow up to Brush Management	Landowners/ Lessees NRCS TPWD TSSWCB Prescribed Burn Associations	9,000 acres/year—assuming implementation on areas burned before beginning of program years 1-6	$13.00/acre = $117,000	$1.7 million
Prescribed Burning	Landowners/ Lessees NRCS TSSWCB TPWD Prescribed Burn Associations	5,400-7,700 acres/yr	$13.00 acre=$85,150	$851,000
Paired Watershed Study – Hydrologic response to brush control	LRFS	3-year study	$300,000 – year 1 $100,000 years 2-3	$500,000
Riparian Restoration				
Install Riparian Exclosures	Landowners/ Lessees NRCS TPWD	10 exclosures/yr	$2,000/ exclosure	$200,000
Eradicate *Arundo* & elephant ear	TPWD/LRFS	4 times/yr	$8,000/yr	$80,000
Restore streambank in Park	TPWD	Completed by 2023	TBD	TBD

Table 23. Continued

Management Measure	Responsible Party	Planning Implementation Goal	Unit Costs	Total Costs
Urban Stormwater Runoff				
Engineering Study to determine location and implementation of BMPs	City of Junction	Completed 2018	$50,000	$50,000
Water Conservation Measures				
Purchase and distribute water conservation fixtures	City of Junction, Rocksprings	50 fixtures/yr	$200/ toilet	$100,000
Total Management Recommendation Cost				**$21,022,000**

* Cost will be incurred by the landowner and will vary depending on specific methods implemented

Table 24. Education and outreach implementation schedule, responsible party and cost estimates.

Education & Outreach Activity	Responsible Party	Planned Delivery Goal			Unit Cost	Total Cost
		Year 0 – 3	Year 4 – 6	Year 7 – 10		
OSSF Education & Outreach						
Texas Well Owner Network	AgriLife Extension	1	1	1	N/A	N/A*
Feral Hog Education & Outreach						
LSHS Feral Hog Education	AgriLife Extension	1	1	1	N/A	N/A
Outreach via Feral Hog Task Force	AgriLife Extension SWCDs	ongoing			$15,000/yr	$150,000
Traveling outreach for absentee landowners on various topics	LRFS AgriLife Extension TWA	3	3	3	$10,000	$90,000

Table 24. Continued

Education & Outreach Activity	Responsible Party	Planned Delivery Goal			Unit Cost	Total Cost
		Year 0 – 3	Year 4 – 6	Year 7 – 10		
Exotic Wildlife Education & Outreach						
Wildlife & Habitat Management Workshops	TPWD AgriLife Extension	1	1	1	$5,000 ea	$15,000
Year-round hunting outreach	LRFS Chamber of Commerce Extension TPWD	ongoing			$2,500/yr	$25,000
White-tailed Deer Education & Outreach						
Wildlife & Habitat Management Workshops	TPWD AgriLife Extension	1	1	1	N/A With Exotic Wildlife	N/A*
Livestock Management Outreach						
Grazing Management Workshops	NRCS TPWD SWCD	1	1	1	$2,500	$7,500
LSHS Grazing Management	AgriLife Extension	1	1	1	N/A	N/A*
Brush Management Outreach						
Brush Control Education Programming	AgriLife Extension NRCS TSSWCB TPWD SWCD	1	1	1	$2,500	$7,500
Riparian Management Outreach						
Riparian Management Workshops	LRFS TWRI Texas Riparian Association SWCD	1	1	1	N/A	N/A*
General Education & Outreach						
Outreach for Stakeholder Meetings	LRFS	Semi-Annually or As Needed			$250 ea	$5,000
Watershed Protection Campaign Brochure	LRFS	Two Printings			$5,000/ea	$10,000
"Don't Mess with Texas Water" signs	Counties/ LRFS	---	5	---	TBD	TBD
Conservation Field Day	LRFS	Annually			TBD	TBD
River Ranger	TPWD Kimble Co.	30 days/year during summer			$160/day or $4,800	$48,000
Total Education and Outreach Programming Cost						**$358,000**

* Funding currently provided through existing programs.

Table 25. Coordination and monitoring implementation schedule, responsible party and cost estimates.

Education & Outreach Activity	Responsible Party	Planned Delivery Goal			Unit Cost	Total Cost
		Year 0 – 3	Year 4 – 6	Year 7 – 10		
Personnel and Travel						
Watershed Coordinator		ongoing			$95,000/yr	$950,000
Water Quality Monitoring						
Volunteer Monitoring and Training (TST)	LRFS	Monthly sampling			$5,000/yr	$50,000
Routine Water Quality Monitoring	LRFS	Sampling as needed to monitor BMP effectiveness			$20,000/yr	$200,000
Total Coordination and Monitoring Cost						**1,200,000**
Total Cost						**22,580,000**

10. Measures of Success

The healthy watershed approach of the Upper Llano River WPP relies on multifaceted management measures that not only preserve and improve the water quality of the rivers and streams but also improve water quantity and the health and resilience of riparian and upland conditions in the watershed. With such an approach, it is important to measure both changes in water quality as well as implementation of practices and resulting changes in water quantity and watershed conditions to determine success. Reviewing changes in both of these conditions is important to developing adaptive implementation measures during the decadal implementation of the WPP.

10.1 Water Quality Targets

The primary goal of the Upper Llano River WPP is to preserve the healthy watershed conditions found throughout most of the watershed. However, water quality data collection efforts for the WPP identified two locations on the North Llano River with geometric means for *E. coli* levels in slight excess of the water quality standard 126 cfu per 100 ml (Table 26).

Table 26. Identified locations with *E. coli* levels in excess of water quality standard.

Station ID	*E. coli* Geometric Mean
21264	138
21267	167

Although these two locations exceed the geometric mean for *E. coli*, the exceedances do not result in the water body being considered impaired as some of the samples were obtained during extreme low-flow events. However, these two locations will serve as focal points for BMPs with the goal of removing water quality exceedances related to *E. coli* bacteria. Additionally, water quality sampling will occur downstream of the US Highway 83 bridge over the North Llano in Junction to monitor potential impacts from urban stormwater runoff.

Monitoring of water quality at four other locations will provide a metric for verifying that the rest of the watershed remains in a healthy condition, with water quality parameters that do not exceed the state standards for impairment. These sites will include:

- Station #21489 at the confluence of the North and South Llano
- Station #21271 at South Llano River State Park
- Station #21272 South Llano at County Road 150
- Station #21270 South Llano at Telegraph

10.2 Additional Data Collection Needs

To date, water quality data has been generally been collected quarterly. Effectiveness of BMP implementation on water quality will be better evaluated by increasing the frequency of data collection through citizen science using the TST. Monthly sampling will illustrate water quality variations especially during low flow summer months and especially in the North Llano where flows tend to be the lowest. Increased frequency of data collection will also identify potential areas of concern to be addressed through the adaptive implementation process.

Gathering additional baseline data and targeted data collection efforts that evaluate the effectiveness of BMP implementation on a small scale are an important component of effective WPP implementation and adaptive implementation. LRFS will gather additional baseline data using data loggers to analyze diel shifts in D.O. and promote and coordinate efforts that scientifically evaluate the effectiveness of BMP implementation. Such data collection efforts should focus on BMP efforts to reduce sedimentation, improve D.O., reduce *E. coli* and increase water yield. The completion and publication of these efforts will be a measure of success, as will be improvements in water quality parameters.

10.3 Tracking of Management Measures

Many of the management measures in the Upper Llano River WPP focus on preserving or improving riparian and upland conditions, and consequently, improving both the water quality and quantity of the watershed's rivers and streams. The implementation of both short-term and long-term management measures is important for the overall health of the watershed. The cumulative and collective improvements resulting from the implementation of these measures are shown through the predictive capabilities of the EDYS model.

Each of the management measures defined in the WPP has specific milestones. An important metric of success will be implementing each of these measures in a timely manner. Additionally, as these tasks are completed, the impact of their implementation will be compared against the predicted impact from the EDYS model to assess necessary changes in program implementation and model refinement through an adaptive implementation process.

10.4 Increased Community Awareness

The North and South Llano rivers, which comprise the Upper Llano River watershed, are important agricultural, economic, biological and recreational resources to the local community and to downstream communities as well. Local stakeholders have identified the protection and preservation of the flow and quality of these rivers and their watersheds as an environmental, economic and cultural concern.

The implementation of the Upper Llano River WPP as part of the Healthy Watersheds Initiative provides a unique opportunity to increase both community and regional awareness of the watershed by affording local participants an opportunity to understand the role they can play in restoring and preserving the resource, while not affecting private property rights. Additionally, it provides local participants the opportunity tell others how they view their role in implementing the WPP and provides opportunities to document the success of the healthy watershed approach. Such opportunities should not be overlooked.

A measure of success for the WPP is an increased awareness of the watershed and the WPP across the region. While such metrics can be measured through website visits, Facebook likes, etc., a more meaningful metric is how well the river and the watershed become part of the everyday discussion. The measure of success for community awareness will be that at least once a month an article will be published in a local paper or statewide or local newsletter about the WPP implementation. Such articles might discuss the need for a particular practice, its implementation or the reason why a landowner decided to participate in the WPP. Moreover, community awareness can also be generated through the LRFS Outdoor School, landowner workshops and the LRFS/Llano River State Park demonstration project.

10.5 Technical Assistance

Successful implementation of the WPP will require technical assistance and support to landowners from a number of sources. Many of the management recommendations will require expertise in practice design and implementation, education and outreach, coordination of implementation efforts, and securing financial resources to carry out implementation measures.

While it is difficult to predict the necessary combination of landowner practices, funding sources and outreach efforts necessary to fully implement the WPP, it will be important to track these efforts on a quarterly basis to identify areas of success as well as areas needing additional assistance or re-evaluation through an adaptive implementation process.

10.6 Adaptive Implementation

This holistic, healthy WPP will be implemented over the course of a decade on an ever-changing landscape. Management measures developed at the beginning of the plan will require flexibility to adjust to these changes. To provide this flexibility, adaptive implementation will be used throughout the process.

Adaptive implementation is an iterative process whereby the information gained through data collection helps update assumptions about the behavior of the watershed and define or redefine new or existing management measures. For example, if the goal to reduce the feral hog population by 66% is not achievable, or is not achieving the desired reductions in bacteria counts, a new suite of management measures may need to be implemented through a stakeholder-driven adaptive implementation process. At a minimum, the process should occur within five years following the start of implementation measures.

10.7 Bacterial Source Tracking

The Coordination Committee has recommended the implementation of BST as an additional management strategy, if this strategy is deemed necessary and funding is available. Bacterial, or microbial source tracking, is a newer biological technique for determining the source of bacterial contamination. Using molecular biology based on genetic markers, bacteria-contaminated waters can be analyzed to determine the source of bacteria: human, livestock and wildlife. Recent work by TSSWCB in developing a BST library has reduced the cost of implementing this measure. The decision to use BST likely will be part of the adaptive implementation process.

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Appendix A: Upper Llano River Watershed Protection Plan Coordination Committee

List of Members of Upper Llano River Watershed Coordination Committee

- City of Junction – Raymond McDonald/succeeded by Russell Hammonds
- County Extension Agents – Sam Silvers/Marvin Ensor
- County Judges/Commissioners/Water Districts
    - Edwards – Souli Shanklin
    - Kimble – Andrew Murr /succeeded by Delbert Roberts
    - Real – Judge Garry Merritt
    - Sutton – John Wade and Carl Teaff
- Soil and Water Conservation Districts
    - Edwards Plateau – Bob Brockman
    - Upper Nueces-Frio – Marty Graham
    - Upper Llanos – Ward Whitworth
- Outfitters – Texas Parks and Wildlife Department Paddling Trail Rep – Melissa Parker
- South Llano Watershed Alliance – Znobia Wootan
- South Llano State Park – Fred Gregg/succeeded by Matt Shelley
- Edwards Plateau Prescribed Burn Association – Butch Taylor
- Natural Resources Conservation Service (NRCS) – Dandy Kothmann
- Landowners
    - Art & Debra Mudge
    - Tom Vandivier
    - Ruth Russell
    - Jerry Kirby
    - Brady Richardson/Daryl Stanley

Appendix B: Upper Llano River Watershed Protection Plan Coordination Committee Ground Rules

The following are the Ground Rules for the Upper Llano Watershed Coordination Committee (hereafter referred to as the Committee) as agreed upon by the members of the Committee.

1. PURPOSE

The purpose of the Committee is to provide local input into the Upper Llano Watershed Protection Plan (WPP). The watershed plan will be developed by the stakeholders through the Committee with support from the Texas Tech Llano River Field Station and the Texas Water Resources Institute (TWRI). The Director of the Texas Tech Llano River Field Station shall serve as the Watershed Coordinator.

2. GOALS

The overarching goal of the Committee is to develop a WPP for the Upper Llano to sustain water quality and flows in the North and South Llano rivers. Basic goals of this public input process include:

- ensuring that a local perspective is included in the development of the watershed plan;
- encouraging an open dialogue on water quality and supply issues; and
- pursuing the successful implementation of the watershed plan once developed.

3. POWERS

The Committee shall have the responsibility for providing input and information with respect to selecting, designing, and implementing water quality and water supply management measures. Foremost among those responsibilities shall be identification of areas and issues with the greatest concerns and selecting voluntary measures.

4. LIFE OF THE STEERING COMMITTEE

The Committee will continue until the watershed plan is completed (tentatively October 2014).

5. MEMBERSHIP

Representation: Members include both individuals and representatives of organizations. A variety of members serve on the Committee to reflect the diversity of interests within the Upper Llano watershed. A membership roster is provided as Exhibit A.

Selection: Members were selected by stakeholders in attendance at the Upper Llano Watershed Protection Plan Stakeholder Meeting on October 9, 2012.

Replacements and Additions: Committee members may replace members unable to continue serving or add members to increase the diversity of the group. A new member must be recommended by an existing Committee member and approved by consensus of existing members (RE: Rule 8).

Substitutes: Those unable to attend a meeting (an absentee) may send a substitute. An absentee can provide advance notification to the Watershed Coordinator at the Texas Tech Llano River Field Station of the desire to send a substitute. A substitute attending with prior notification from an absentee will serve as a proxy for that absent member. A substitute attending without advance notification is considered an observer (see definition of observer under Meetings). Absentees may also provide input via another Committee member or send input via the Watershed Coordinator. The Watershed Coordinator will present such information to the Committee but may not argue in its favor.

Absences: Three absences in a row of which the Watershed Coordinator was not informed of beforehand and without designation of a substitute constitute a resignation.

6. MEETINGS

Observers: Meetings are open and observers welcome. Observers will be recognized by the Watershed Coordinator prior to making comments during the meeting.

Open Discussion: Participants express their views candidly, but without personal attacks. Time is shared because all participants are of equal importance. Texas Tech Llano River Field Station personnel will take notes during the meetings and provide audio recording. Meeting summaries will be based on notes and recording. A Committee member can ask to go off record; an observer cannot go off record.

Location and Arrangements: The Watershed Coordinator is responsible for making meeting arrangements.

Timing: Meetings start and end on time. Meetings will generally be held quarterly but this schedule may be amended as needed based on watershed planning milestones. Meetings are scheduled to allow time for member input to be considered for incorporation into plans and reports. Meeting times will be set to permit as many as possible to attend. While evening meetings are preferred, the Committee can decide time and date of meetings.

Agenda: The Watershed Coordinator, TWRI, and TSSWCB project manager, in consultation with Committee members, develops the agenda. The anticipated topics are determined at the previous meeting. A draft agenda is sent to the Committee with the notice of the meeting. Agenda items may be added by members at the time of the draft agenda is provided. The draft agenda will provide an estimation of meeting duration. The Watershed Coordinator reviews the agenda at the start of each meeting and amends if the Committee agrees. The Committee then follows the approved agenda unless they agree to revise it.

Quorum: A quorum of the Coordination Committee shall be a simple majority of the Committee Membership or those represented by a proxy. At least a quorum shall be necessary to conduct any business of the Committee.

Meeting Notes: Texas Tech Llano River Field Station personnel draft meeting notes and distribute them to the Committee for their review. The Committee revises if needed and approves the notes at the next meeting.

Distribution of Materials: Texas Tech Llano River Field Station and TWRI personnel prepare and distribute the agenda and other items needed for mailings to members. To encourage equal sharing of information, materials made available to one Committee member will be made available to all. Those who wish to distribute materials to the Committee may ask the Watershed Coordinator to do so on their behalf.

7. ROLES

Members: Members identify and present insights, suggestions, and concerns from a community, environmental, or public interest perspective as they carry out the objectives of the Committee in the development of the Upper Llano Watershed Protection Plan. The members offer their advice to the Committee and Watershed Coordinator.

Watershed Coordinator: The Committee operates without a chair but with a Watershed Coordinator. The Watershed Coordinator serves to help the Committee organize its work, run meetings, draft notes and other materials if requested, and work to send notices and mailings. The Watershed Coordinator encourages dialogue and candid input and transfers Committee recommendations into the watershed plan.

Speaking in the Name of the Committee: Individuals do not speak for the Committee as a whole unless authorized by the Committee to do so. Members do not speak for the Watershed Coordinator, and the Watershed Coordinator does not speak for Committee members. If Committee spokespersons are needed, they are selected by Committee members. Plan materials are not released in the name of the Committee unless the Committee agrees to the release.

Draft Documents: Members will review draft watershed plan documents and respect the fact that they are in draft form. No watershed plan documents will be released to the public until final or unless okayed by the Committee.

8. DECISIONMAKING PROCESS

The Committee shall attempt to make decisions by consensus to the maximum extent possible. If consensus cannot be reached, then a two-thirds affirmative vote of Committee members present or represented by proxy will be required to make a decision, pass an action, etc.

9. DEVELOPMENT AND REVISION OF GROUNDRULES

The ground rules were drafted by the TWRI and Watershed Coordinator. This draft will be presented to the members for their review, possible revision, and adoption. Once adopted, ground rules may be changed by consensus among Committee members as long as a quorum of the Committee, Watershed Coordinator, and TSSWCB representative are present for the discussion (RE: Rule 8)

Appendix C: Working Groups-Upper Llano River Watershed Protection Plan

Invasive Species - Aquatic & Terrestrial

Melissa Parker/Megan Bean – Texas Parks and Wildlife Department
Bob Brockman – Edwards Plateau Soil and Water Conservation District
Fred Gregg/Matt Shelley – South Llano River State Park
Andrew Murr/Delbert Roberts – Kimble County Judge
Joel Pigg – Real Edwards Conservation & Reclamation District
Brady Richardson – North Llano River Landowner

Riparian Protection & Management

Art Mudge – Landowner
Melissa Parker/Megan Bean – Texas Parks & Wildlife Department
Ruthie Russell – Landowner
Matt Shelley – South Llano River State Park
Znobia Wootan – South Llano Watershed Alliance

Water Quality, Conservation, & Flow

Marty Graham – Texas State Soil and Water Conservation Board
Jerry Kirby – Kimble County Groundwater Conservation District
Raymond McDonald/Russell Hammonds – City of Junction
Melissa Parker/Megan Bean – Texas Parks and Wildlife Department
Joel Pigg – Read Edwards Conservation & Reclamation District
Znobia Wootan – South Llano Watershed Alliance

Upland Management

James Crockett – Texas A&M AgriLife Extension
Marty Graham – Texas State Soil and Water Conservation Board
Dandy Kothmann- NRCS Kimble County
Lori Hazel – Texas A&M Forest Service
Joel Pigg – Real Edwards Conservation & Reclamation District
Joe David Ross – Landowner, Sutton County
Souli Shanklin – County Judge Edwards County
Sam Silvers – Texas A&M AgriLife Extension
Roland Trees – Landowner, Real County

Water Supply Enhancement

James Crockett – Texas A&M AgriLife Extension
Marty Graham – Texas State Soil and Water Conservation Board
Lori Hazel – Texas A&M Forest Service
Joel Pigg – Real Edwards Conservation & Reclamation District
Brady Richardson – Landowner, Sutton County
Joe David Ross – Landowner, Sutton County

Water Supply Enhancement continued
Souli Shanklin – County Judge, Edwards County
Sam Silvers – Texas A&M AgriLife Extension
Butch Taylor – Texas A&M AgriLife Extension
Tom Vandivier – Landowner, Edwards County/TWA
Ward Whitworth – Landowner, Kimble County/Upper Llanos SWCD

Appendix D: Macroinvertebrate Sampling Analysis

Methods

Using the appropriate keys (Wiggins, 1996, Merritt and Cummins, 2008 and Weiderholm, 1983), aquatic invertebrates obtained from benthic samples were identified taxonomically. In most cases, individuals were identified to genus. Large samples, containing over 600 organisms, were subsampled. The total sample was homogenized within a sieve and then divided into quarters or halves. One section of the divided sample was chosen randomly and identified in completion, regardless of the number of individuals remaining in the subsample. Small samples, containing less than 600 individuals, were identified entirely.

Prior to calculating the metrics, the data was prepared for analysis and was analyzed as follows. All early instar Perlidae were counted as *Perlesta*, as it was the only Perlidae recorded during these surveys and therefore, treated as *Perlesta*. All other early instars, pupating Chironomidae or damaged specimens were not considered for the analysis. A Hess sampler is a quantitative method used to determine the structure of benthic aquatic invertebrate communities and can allow for a standardized comparison between each site, or replicate. At each site, three Hess samples were taken. All three Hess samples from each site were combined into a composite sample to represent that site for each analysis. Metrics and analyses were completed using the Hess composite samples. Therefore, the analysis for the Hess metrics is dependent upon combined results, counts and densities of the individuals and functional feeding groups within the aquatic community from each replicate (TCEQ, 2015). Composite Hess samples with a missing sample have been noted in Table 1 (e.g. only two replicates out of three). A total of 50 Hess samples from four seasons were analyzed.

Three 5-minute kick samples were taken at each site. Each kick sample was analyzed individually, not as a composite. Metrics were calculated according to the TCEQ Surface Water Quality Manual Vol. II (TCEQ, 2014). Kick samples that fluctuate from the 20% rule are noted in Table 2. A total of 105 kick samples were processed from four seasons. Many types of metrics may be used to determine the health of an aquatic system. Some metrics have been correlated to show either a positive or a negative relationship within the benthic aquatic community and some type of perturbation. One of the type of metrics examined included functional feeding groups. Functional feeding groups is a classification approach to analyzing the community data separate from the taxonomic designations (Merritt and Cummins, 2008). Functional feeding groups group benthic aquatic invertebrates according to their methods for gathering food. Functional feeding groups can be used to examine ecosystem health and predict community assemblages (Merritt et al., 2008).

Analysis of similarities (ANOSIM) was done to examine community structure between the North and South Llano rivers. Riverine Hess samples were divided between the North and South forks of the Llano River. There were 28 sites with 14 from the North and South Llano, encompassing three seasons. Analysis was done in R using the statistical package "vegan" and Bray-Curtis distance (Oksanen et al., 2011). To examine where differences within the community structure between the North and South Llano t-tests were conducted on metrics calculated from the Hess samples (N = 10; from 10 seasons).

Nonmetric multidimensional scaling (NMDS; Kruskal, 1964) was applied to the composite Hess data from all Hess samples (N = 50; four sampling events), and additionally a separate analysis was done to Hess data from 2013 and 2014 exclusively (N = 38; three sampling events), using R code "metaMDS" to examine spatial orientation of the study sites in relation to the aquatic invertebrate community. The calculated metric data was overlaid on the NMDS plot using the function "envfit." For the NMDS analysis, the statistical package "vegan" in R was used (Oksanen et al., 2011).

Water quality data collected was also analyzed using NMDS to examine associations among sites. Data used for the analysis was composed of averages from 20 sites over 19 occasions from September 2012 to 2014. There are five sites from the North Llano, five sites from South Llano, one from the confluence of the two forks and the remainder (9) from spring sites. Variables analyzed included: pH, D.O., conductivity, temperature, discharge, *E. coli*, nitrates, sulfate and chlorine.

Results

A total of 38,342 aquatic invertebrates were identified for the analysis associated with 23 Orders, 77 families and 163 genra. Non-insects contributed 8% of the total. The Orders Diptera (32%), Ephemeroptera (29%) and Trichoptera (14%) contributed 77% of the total. Within those Orders, Chironomidae in the tribe Tanytarsini (9%), *Fallceon quilleri* (8%), *Tricorythodes* sp. (6%), *Simulium* (6%), and *Hydroptila* sp (5%) were five most dominant taxa. Within the total taxa identified, many Hill Country endemics were present, such as *Baetodes bibranchus* (Ephemeroptera: Baetidae), *Neotrichia juani* (Trichoptera: Hydroptilidae), *Xiphocentron messapus* (Trichoptera: Xiphocentronidae), and *Zealuctra* sp. (Plecoptera: Leucridae) (Bowels and Arsuffi, 1993). In addition to the Hill Country endemics, a Hess sample from the 1st Crossing site contained one individual *Lateniousus cibola*, a species on the Texas Conservation Action Plan.

The most abundant taxa present in all of the samples were in the family Chironomidae under the tribe Tanytarsini (9%), two mayflies, *Fallceon quilleri* (8%) and *Tricorythodes* sp. (6%), and a Dipteran *Simulium* sp. (6%). In addition to being the most abundant taxa, the above mentioned taxa were present at over 70% of the sites. Other taxa present at more than 70% of the sites include the other subfamilies and tribes of Chironomidae including Tanypodinae, Chironomini, Orthocladiinae. *Hydroptila* sp. (5%), *Chimarra* sp. (3%) and *Smicricea fasciatella* (3%) were the most common Trichoptera. Two other rare taxa collected in respect to this data set were *Pseudocloeon* sp. and *Trianoides* sp.

Percent gatherers (37%) were the most common functional feeding group present throughout the data set, followed by filterers (28%), grazers (19%), predators (13%) and shredders (0.7%). The dominance of percent gatherers within the system is driven by the abundance of the top three taxa mentioned above as all have a part that has been designated as collector gatherers (Merritt and Cummins, 2008). A large percentage of the predators consisted of Tanypodinae, Turbellaria and *Argia* sp.

Composite Hess samples from 50 samples taken in September 2012, February 2013, September 2013 and March 2014, produced mainly aquatic life use (ALU) designations of Exceptional (29) and High (15), with a few Intermediates (6). Three river sites had intermediates, Bear Creek and CR 271 in February and September 2013, and Big Paint in February 2013. One spring site, 700 Springs in February 2013, scored intermediate. The State Park, CR 150 and 1st Crossing scored Exceptional for all four sampling events. The Confluence and River Road sites also scored Exceptional although they were only sampled once in March 2014.

Kick samples were more varied in their ALU designation for each site. A total of 105 kick samples were processed from September 2012, February 2013, September 2013 and March 2014. There were 16 Exceptional, 32 High, 40 Intermediate and 17 Limited designations. Out of the 105 samples, 78 samples fluctuated around the 20% TCEQ rule for 5-minute kick samples. Of those 78 deviations, 50 were for samples with lower than the 20% of 175 organism count.

Analysis of similarities of 14 sites from the North Llano and 14 sites from the South Llano from February 2013, September 2013 and March 2014 data showed a significant difference between the community structure of invertebrate communities within the North and South forks of the Llano River ($R = 0.107$; $p = 0.016$). Although the R value is low, there are significant differences between the community structure of invertebrates within the two forks. The low R value demonstrates there are similarities between the majority of the sites and taxa present. A box plot of the analysis is presented in Figure 1. Six significant relationships between the North and South Llano related to water quality from t-tests were shown to exist. These relationships were from specific conductance, discharge, *E. coli*, Nitrates, Sulfates and Chlorine (Table 3).

Nonmetric multidimensional scaling with all four seasons showed a distinct separation between data collected in September 2012 and the remainder of the data set (Figure 2). Due to this separation, the NMDS was done again using the Hess samples from the three remaining seasons (February 2013, September 2013 and March 2014).

The 3-season analysis with NMDS displayed sites with overlap between the samples by season (Figure 3A and B). Figure 3A shows the similarities of sites based upon the invertebrate community present at each sites and each season. Many sites showed high fidelity to specific sections of the graph throughout the seasons. For example, 1st Crossing, CR 150, CR 275 and Big Paint were all within tight clusters. On Figure 3B, NMDS axis I had major positive loadings in the vectors of percent gatherers, percent tolerant taxa and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa. The largest negative loadings for NMDS I were percent filterers, percent Chironomidae and intolerant taxa. Distribution of sites along NMDS II were driven by positive loadings of intolerant taxa, total taxa and Ephemeroptera taxa, and negative loadings of percent dominant taxa, percent Chironomidae and percent tolerant. Therefore, Bear Creek Feb 2013, CR 271 Feb and Sept 2013 and 700 Springs were comprised of a few number of taxa. Sites from the North Llano and the South Llano were segregated by NMDS II axis. Most of the South Llano sites are in the upper segment of the graph, while sites on the South Llano were mainly present in the lower portion of the graph. This separation of sites in multivariate space is not surprising given the significant analysis of similarities previously mentioned. Other sites within the analysis were mainly comprised of similar aquatic invertebrate communities, showing a rather central placement within multidimensional space.

Nonmetric multidimensional scaling with water quality data displayed similarities among the sites in relation to water quality (Figure 4). The analysis showed that the South Llano sites (red circles), the North Llano (orange circle) and spring sites (blue circle) showed more similarity with their group than among the other groups. However, the spring sites and the South Llano sites showed more variability as seen by their larger spread of their respective group within the graph compared to the tight grouping of South Llano sites in the red circle. Outliers of this grouping included Bois d'Arc and CR 408, with both being more similar to sites from the South Llano. Nonmetric multidimensional scaling axis I had the largest positive loadings from nitrate and discharge, with the largest negative loadings from *E. coli* and sulfate (Table 6). Axis II had the highest positive loadings from *E. coli* and nitrate with the highest negative loading from discharge. All of the other loadings on NMDS II were not situated far from the x-axis of the graph, indicating a low effect on the placement of sites within the graph. Many of the standard water quality parameters (D.O., pH, temperature, conductivity) are situated within the center of the graph showing less variability between the sites.

Discussion Points

- The Llano watershed has low pressures from urbanization at this time. Therefore, a recognizable urbanization gradient within the data set may be hard to determine. Sites with ALU designations of Limited or Intermediate, from kick samples, may be explained by low sample size or seasonality. February samples fall out of the index period according to TCEQ (TCEQ, 2015), and in this case, tended to have lower designations than September or March. In addition, the metrics used by TCEQ for this analysis may not be as suited for spring environments that have lower levels of fine particulate organic matter (FPOM) and coarse particulate organic matter (CPOM) within the Texas Hill Country, such as 700 Springs. A reference site approach may be more suited for the spring analysis. And finally, the periodic drying of streams within the Texas Hill Country could be another source for low scores at certain sites, such as Bear Creek and CR 408.
- The Hess samples taken from all of the sites throughout each season produced no limited designations, displaying the relatively pristine status of the system.
- The significant differences identified by the ANOSIM analysis between the North and South Llano were corroborated by the NMDS analysis. The NMDS analysis identified the actual sites driving the signifi-

cant differences between the systems in the ANOSIM analysis. For example, the Bear Creek and CR 271 (North Llano sites) are located in the lower portion of the NMDS graph and may explain the significant p-value and low correlation from the ANOSIM, based on their drastically different community structure in respect to the community structure of the Northern group, to drive the ANOSIM.

- CADDIS was going to be used initially for this analysis. However, due to the large number of exceptional sites within the analysis, the gradient needed by CADDIS to show perturbation and identify stressors may not be appropriate for this type of relatively unperturbed system. In partial fulfillment with the CADDIS type of analysis, multivariate analysis (NMDS) was conducted to examine the watershed and determine relationships to the invertebrate community and water quality.

Table 1. Hess Samples from the Llano watershed with associated aquatic life use score and designation from TCEQ analysis. All composite Hess samples that have incomplete data are designated with an asterisk (*).

Site	Date	Total Taxa	Diptera Taxa	Ephem-eroptera Taxa	Intol-erant	Percent EPT Taxa	Percent Chirono-midae	Percent Tolerant	Percent Grazers	Percent Gatherers	Percent Filterers	Percent Dominance	SUM	ALU
CR 274*	**13-Feb**	29	5	5	12	41.04	25.91	6.61	33.22	27.12	10.38	61.83	39	High
CR 274	**13-Sep**	26	7	7	9	26.63	40.76	1.90	11.01	42.80	14.95	64.67	37	High
CR 274	**14-Mar**	34	5	5	13	66.49	27.11	0.59	37.01	37.14	13.59	75.66	41	Exceptional
Bear Creek	**13-Feb**	14	1	1	3	41.98	31.28	0.53	0.94	12.43	30.75	93.32	21	Intermediate
Bear Creek*	**13-Sep**	4	1	1	0	81.82	0.00	9.09	40.91	40.91	9.09	90.91	27	Intermediate
Bear Creek	**14-Mar**	29	6	8	13	65.10	28.29	0.21	34.26	41.33	9.57	75.12	37	High
CR 271	**13-Feb**	8	3	3	4	0.96	5.21	0.00	0.53	2.27	94.61	98.83	21	Intermediate
CR 271*	**13-Sep**	3	2	2	0	66.67	0.00	0.00	16.67	83.33	0.00	100.00	29	Intermediate
CR 271	**14-Mar**	28	5	8	11	59.36	23.29	1.14	23.52	35.39	27.47	67.81	39	High
1st Crossing	**12-Sept**	33	2	12	18	62.90	7.74	0.00	20.97	23.23	45.48	48.06	45	Exceptional
1st Crossing	**13-Feb**	43	14	14	19	54.72	16.75	0.00	10.50	37.31	42.81	47.31	47	Exceptional
1st Crossing	**13-Sep**	29	6	6	15	44.24	8.76	0.00	21.20	41.40	26.11	34.10	45	Exceptional
1st Crossing	**14-Mar**	37	6	8	12	31.57	30.35	0.00	15.68	28.14	40.02	49.08	45	Exceptional
Big Paint	**12-Sept**	29	3	6	11	53.09	7.78	1.00	20.96	14.37	14.17	44.31	41	Exceptional
Big Paint*	**13-Feb**	17	4	4	4	16.96	20.80	0.59	2.36	26.33	54.57	68.58	27	Intermediate
Big Paint*	**13-Sep**	21	5	5	7	66.33	6.03	0.00	4.77	70.60	8.04	66.83	35	High
Big Paint	**14-Mar**	28	6	7	12	39.95	28.23	0.00	4.78	47.69	30.18	72.25	35	High
CR 260	**12-Sept**	27	2	8	14	51.00	3.59	0.00	29.08	34.26	23.90	35.06	43	Exceptional
CR 260*	**13-Feb**	32	8	8	15	16.97	39.85	0.00	16.24	33.95	23.55	59.78	39	High
CR 260	**13-Sep**	25	6	6	11	42.67	9.33	0.00	30.33	43.78	13.11	52.00	45	Exceptional
CR 260	**14-Mar**	31	3	11	17	57.95	19.39	0.00	12.85	37.84	33.22	50.33	41	Exceptional
CR 275	**12-Sept**	34	2	4	13	10.59	1.77	0.16	41.57	42.05	5.14	63.24	35	High
CR 275*	**13-Feb**	22	7	7	10	54.73	27.51	0.86	11.03	41.98	36.10	60.17	39	High
CR 275*	**13-Sep**	10	3	3	3	43.75	0.00	6.25	9.38	21.88	56.25	56.25	31	High

Table 1. Continued

Site	Date	Total Taxa	Diptera Taxa	Ephem-eroptera Taxa	Intol-erant Taxa	Percent EPT Taxa	Percent Chirono-midae	Percent Tolerant	Percent Grazers	Percent Gatherers	Percent Filterers	Percent Dominance	SUM	ALU
CR 275	**14-Mar**	32	4	9	12	50.16	30.25	0.48	24.28	40.34	19.96	53.66	43	Exceptional
Richardson*	**13-Feb**	24	4	4	13	13.68	16.04	0.00	34.20	45.20	8.33	73.58	33	High
Richardson	**14-Mar**	24	2	8	7	45.49	41.20	0.00	20.82	44.85	17.17	71.24	35	High
State Park	**12-Sept**	34	2	11	16	55.19	2.04	0.16	11.16	11.95	43.08	37.42	41	Exceptional
State Park*	**13-Feb**	30	8	8	16	50.62	28.02	0.00	9.70	49.51	25.59	58.19	41	Exceptional
State Park	**13-Sep**	40	13	13	20	37.79	2.29	0.38	14.31	27.10	46.09	39.69	47	Exceptional
State Park	**14-Mar**	37	4	11	20	50.25	13.49	0.00	26.79	36.47	27.39	44.01	47	Exceptional
CR 150	**12-Sept**	33	2	9	23	39.17	2.25	0.00	31.72	28.60	25.13	41.42	45	Exceptional
CR 150*	**13-Feb**	37	12	12	20	49.47	12.49	0.00	27.35	35.19	28.56	35.04	49	Exceptional
CR 150	**13-Sep**	30	8	8	14	39.12	4.41	0.00	27.27	44.31	13.36	49.31	47	Exceptional
CR 150	**14-Mar**	36	3	9	17	56.83	21.48	0.21	44.81	18.91	25.49	72.28	41	Exceptional
Telegraph Road*	**13-Sep**	32	9	9	13	73.13	4.65	0.00	15.12	35.27	44.44	51.94	47	Exceptional
Telegraph Road	**14-Mar**	29	3	8	13	37.62	30.39	0.16	9.08	28.22	47.27	59.49	37	High
Stanley*	**13-Feb**	31	6	6	13	20.20	21.67	0.00	24.75	38.26	17.82	59.61	41	Exceptional
700 Springs	**12-Sept**	28	3	4	11	45.55	1.57	0.00	11.26	37.43	17.54	46.86	39	High
700 Springs*	**13-Feb**	12	2	2	3	22.73	64.77	0.00	4.55	40.34	30.68	81.82	23	Intermediate
County Park	**12-Sept**	34	3	11	16	54.66	3.87	0.00	10.90	14.20	56.38	47.78	41	Exceptional
County Park*	**13-Feb**	27	8	8	13	42.67	31.54	0.00	16.16	25.36	45.97	52.49	45	Exceptional
MRVV	**12-Sept**	36	2	13	18	65.07	2.09	0.90	17.91	29.25	40.00	34.03	45	Exceptional
MRVV*	**13-Feb**	28	8	8	12	50.79	8.68	0.00	13.64	33.07	46.05	43.60	45	Exceptional
Daryl	**12-Sept**	22	2	5	11	47.27	0.91	0.00	25.45	41.82	15.45	48.18	43	Exceptional
Daryl	**13-Sep**	31	8	8	11	61.11	1.31	0.98	25.49	41.72	21.02	53.92	47	Exceptional
Confluence	**14-Mar**	32	3	8	13	82.05	10.67	0.00	32.83	32.33	28.67	49.43	43	Exceptional
River Road	**14-Mar**	35	4	10	14	65.81	14.27	0.31	16.58	45.67	27.96	47.54	47	Exceptional
Tanner Spring	**12-Sept**	34	2	8	16	28.72	3.81	0.00	40.14	33.22	17.30	58.13	41	Exceptional
Brady & Lynne	**12-Sept**	23	1	7	10	38.94	6.67	0.00	24.78	44.25	5.31	46.02	39	High

Table 2. Kick Samples from the Llano watershed with associated aquatic life use score and designation from TCEQ analysis. Kick samples that violate the ±20% rule are noted with an asterisk (*).

Site	Date	Taxa Richness	EPT	HBI	Percent Chironomidae	Percent Dominant	Percent Dom FFG	Percent Predators	Ratio Intol/Tol	Percent Hydropsyidae	Non insect Taxa	Percent CG	Percent Elmid	SUM	ALU
CR 274*	**13-Feb**	23	11	4.70	21.56	24.40	49.31	13.14	2.23	0.00	2	49.31	0.57	28	Intermediate
CR 274*	**13-Sep**	12	4	6.66	27.71	28.92	35.74	29.72	0.11	0.00	4	35.74	1.22	26	Intermediate
CR 274*	**13-Sep**	18	5	6.33	25.36	28.26	34.68	24.75	0.17	14.29	4	34.68	1.47	31	High
CR 274*	**14-Mar**	16	9	4.52	19.20	29.33	46.13	12.53	2.47	0.00	4	46.13	0.00	27	Intermediate
CR 274	**14-Mar**	17	8	4.98	38.76	38.76	40.11	17.15	0.93	0.00	4	40.11	0.00	25	Intermediate
CR 274*	**14-Mar**	17	10	4.19	14.84	29.95	43.47	8.49	4.05	0.00	2	43.47	0.26	30	High
Bear Creek	**12-Sept**	12	5	5.31	1.43	28.57	55.71	7.14	0.88	0.00	2	37.14	0.00	24	Intermediate
Bear Creek*	**13-Feb**	34	10	5.52	31.98	31.98	31.76	31.76	0.48	0.00	6	29.07	1.65	31	High
Bear Creek*	**13-Sep**	14	5	5.94	4.17	35.42	37.85	28.47	0.34	0.00	3	37.85	4.35	25	Intermediate
Bear Creek*	**13-Sep**	7	2	6.43	0.00	50.00	42.86	17.86	0.27	0.00	0	42.86	27.27	17	Limited
Bear Creek*	**13-Sep**	8	4	5.06	5.88	29.41	40.20	19.61	0.89	0.00	0	40.20	13.33	26	Intermediate
Bear Creek*	**14-Mar**	13	8	5.18	47.66	47.66	41.59	21.50	0.57	0.00	1	41.59	0.00	21	Limited
Bear Creek*	**14-Mar**	22	7	6.23	33.18	33.18	41.71	27.46	0.15	0.00	5	41.71	7.11	26	Intermediate
Bear Creek	**14-Mar**	10	5	5.90	65.07	65.07	36.76	32.65	0.11	0.00	1	36.76	0.00	18	Limited
CR 271	**12-Sept**	22	4	6.33	7.77	25.24	35.45	37.86	0.62	100.00	5	26.21	5.83	30	High
CR 271*	**13-Feb**	10	4	4.05	17.86	62.50	68.45	20.24	3.67	0.00	1	9.08	0.00	23	Intermediate
CR 271*	**13-Sep**	7	2	6.78	11.11	22.22	48.15	25.93	0.50	0.00	2	48.15	0.00	18	Limited
CR 271*	**13-Sep**	7	5	6.05	26.32	26.32	40.35	24.56	0.46	0.00	0	40.35	0.00	20	Limited
CR 271*	**14-Mar**	17	10	4.86	32.58	45.45	40.40	15.40	1.49	100.00	3	40.40	0.00	24	Intermediate
CR 271*	**14-Mar**	15	7	4.69	20.90	43.28	46.52	13.68	1.91	0.00	2	46.52	3.08	26	Intermediate
CR 271	**14-Mar**	12	5	5.38	45.95	45.95	44.23	20.99	0.65	0.00	1	44.23	2.21	21	Limited
1st Crossing	**12-Sept**	21	11	3.60	5.85	23.39	52.05	12.28	5.57	55.26	1	14.62	8.77	40	Exceptional
1st Crossing*	**13-Feb**	39	22	3.72	12.39	12.39	44.44	11.32	3.28	56.67	5	44.44	11.96	37	Exceptional

Table 2. Continued

Site	**Date**	Taxa Richness	EPT	HBI	Percent Chirono-midae	Percent Dominant	Percent Dom FFG	Percent Predators	Ratio Intol/Tol	Percent Hydrop-syidae	Non insect taxa	Percent CG	Percent Elmid	SUM	ALU
1st Crossing*	**13-Feb**	31	12	4.84	41.32	41.32	52.98	22.22	0.97	89.19	4	19.38	8.19	29	High
1st Crossing*	**13-Sep**	17	7	4.64	16.22	16.22	46.62	14.86	1.32	50.00	3	46.62	21.31	28	Intermediate
1st Crossing*	**13-Sep**	19	11	4.27	13.00	28.00	38.83	10.83	2.85	260.00	1	38.83	11.11	31	High
1st Crossing*	**14-Mar**	17	8	4.84	29.33	29.33	57.78	17.78	1.14	0.00	2	57.78	19.05	24	Intermediate
1st Crossing	**14-Mar**	22	9	5.34	35.56	35.56	50.46	22.41	0.50	0.00	6	50.46	7.78	27	Intermediate
1st Crossing*	**14-Mar**	21	9	5.19	54.68	54.68	47.36	20.38	0.61	12.50	5	47.36	5.30	28	Intermediate
Big Paint	**Sept 2012**	21	7	4.32	11.64	23.29	36.30	32.88	4.26	0.00	4	17.81	2.74	38	Exceptional
Big Paint*	**13-Feb**	33	17	5.18	31.46	31.46	40.26	24.39	0.90	95.65	6	27.90	0.28	29	High
Big Paint*	**13-Feb**	43	20	5.17	30.43	30.43	35.03	22.94	0.91	81.25	10	32.61	1.02	33	High
Big Paint*	**13-Sep**	23	10	3.59	4.64	20.89	54.35	17.79	9.31	38.46	5	54.35	2.38	38	Exceptional
Big Paint*	**13-Sep**	26	12	4.35	2.15	35.48	49.64	12.01	9.63	60.00	5	49.64	3.33	37	Exceptional
Big Paint*	**14-Mar**	17	8	5.45	25.58	37.21	46.90	11.43	0.38	0.00	4	30.62	1.18	27	Intermediate
Big Paint*	**14-Mar**	11	6	5.42	26.67	28.89	37.78	12.22	0.59	0.00	3	34.44	0.00	23	Intermediate
Big Paint*	**14-Mar**	14	6	5.66	51.46	51.46	35.60	23.95	0.24	0.00	3	34.14	0.98	24	Intermediate
CR 260	**12-Feb**	24	9	4.70	26.95	26.95	33.33	34.73	0.62	33.33	2	31.74	8.98	31	High
CR 260*	**13-Feb**	22	11	5.51	71.84	71.84	38.61	27.22	0.27	175.00	2	38.61	4.64	26	Intermediate
CR 260*	**13-Feb**	13	1	5.91	82.74	82.74	38.75	38.75	0.08	0.00	4	29.36	1.03	22	Intermediate
CR 260*	**13-Sep**	23	9	3.81	9.70	47.26	62.73	8.30	6.58	522.73	3	17.79	20.30	31	High
CR 260	**14-Mar**	16	6	5.67	59.26	59.26	45.06	27.78	0.33	0.00	6	45.06	1.89	24	Intermediate
CR 260	**14-Mar**	22	11	3.87	21.43	24.68	38.96	13.96	2.06	0.00	4	32.14	10.00	34	High
CR 260*	**14-Mar**	15	5	4.32	24.66	24.66	43.15	17.81	1.67	0.00	2	43.15	28.07	26	Intermediate
CR 275	**12-Sept**	25	7	2.74	0.50	44.50	40.50	6.00	8.79	50.00	4	40.00	73.00	33	High
CR 275*	**13-Feb**	25	10	4.98	58.31	58.31	34.22	24.67	0.65	0.00	2	34.22	9.65	29	High
CR 275*	**13-Sep**	13	7	4.50	6.25	12.50	52.08	2.08	1.40	33.33	3	23.96	6.67	34	High
CR 275*	**13-Sep**	14	3	5.47	6.25	12.50	45.83	14.58	1.14	0.00	5	45.83	14.29	26	Intermediate

Table 3. Significant relationships of t-tests between water quality data from 28 sites within the North and South Llano river watershed.

Abiotic Parameter	p-value
Specific Conductance	<0.0001
Discharge	<0.0001
E. coli	0.053
Nitrates	<0.0001
Sulfate	0.019
Chlorine	0.002

Table 4. Loadings of site scores from Hess samples taken on February 2013, September 2013 and March 2014.

Site	NMDS I	NMDS II
CR 274	-0.75	-0.13
Bear Creek	-0.78	-0.90
CR 271	-1.82	-1.04
Stanley	-0.22	0.53
1st Crossing	-0.11	0.45
Big Paint	0.36	-0.41
CR 260	0.04	0.30
CR 275	0.06	-0.32
700 Springs	0.12	-0.92
County Park	-0.04	0.15
Richardson	0.46	0.44
State Park	0.10	0.12
CR 150	-0.01	0.62
MRVV	0.21	0.37
CR 274	-0.40	-0.30
Bear Creek	2.11	-0.27
CR 271	1.32	-1.29
1st Crossing	0.12	0.57
Big Paint	0.33	-0.11
CR 260	0.22	0.24
CR 275	1.00	-0.33
State Park	0.11	0.33
CR 150	-0.06	0.54
Telegraph Road	-0.27	0.55
Daryl	0.32	0.16
CR 274	-0.46	-0.21
Bear Creek	-0.78	0.00
CR 271	-0.39	-0.02
1st Crossing	-0.11	0.27
Big Paint	0.17	-0.29
CR 260	0.09	0.43
CR 275	-0.19	-0.11
Richardson	-0.07	-0.36
State Park	-0.19	0.34
CR 150	-0.06	0.32
Telegraph Road	-0.13	0.05
Confluence	-0.25	0.22
River Road	-0.07	0.00

Table 5. Loading of vectors from metrics overlaid in nonmetric multidimensional scaling analysis from Hess samples taken on February 2013, September 2013 and March 2014.

Metric	NMDS I	NMDS II
Total Taxa	-0.27	0.81
Number Diptera Taxa	-0.09	0.58
Number Ehemeroptera Taxa	-0.17	0.71
Number Intolerant Taxa	-0.23	0.84
Percent EPT Taxa	0.31	0.16
Percent Chironomidae	-0.28	-0.27
Percent Tolerant	0.39	-0.24
Percent Grazers	0.12	0.42
Percent Gatherers	0.51	-0.07
Percent Filterers	-0.34	-0.13
Dominant Taxa	0.02	-0.81

Table 6. Loading of water quality parameters taken from the Llano River (2012–2014) analyzed using nonmetric multidimensional scaling.

Parameter	NMDS I	NMDS II
pH	-0.01	-0.01
D.O.	0.00	-0.02
Cond	-0.01	0.00
Temp	0.00	-0.01
Q	0.11	-0.24
E. coli	-0.13	0.22
nitrate	0.30	0.10
SO4	-0.13	-0.02
Cl	-0.06	-0.02

Table 7. Water quality means taken from 10 different events from September 2012 to September 2014 used for analysis with the North and South Llano analysis.

	pH	D.O.	Cond	Temp	Q	*E. coli*	nitrate	SO4	Cl
Bear Crk	8.085556	8.914444	537.9111	19.58444	4.049	242.1	0.043333	27.56	23.062
CR 274	7.925556	7.845556	499.7667	21.23222	15.62944	38.45	0.022222	9.592	15.151
CR 275	7.697778	7.815556	497.5	20.37444	10.18967	311.3	0.036667	8.645	15.164
Copperas/ CR 171	7.916667	8.49125	535.4	20.92444	17.77589	28.02	0.0125	12.43	15.42222
CR 260	7.891111	8.121111	489.1	20.16667	6.246111	28.3	0.27	6.612	12.922
State Park	7.843333	8.736667	447.2111	20.97667	42.64367	30.1	0.336667	6.025	11.648
CR 150	8.023333	8.274444	443.1778	20.29444	45.21967	37.9	0.458889	5.73	10.336
1st Crossing	8.007778	8.603333	445.5444	20.54667	46.97867	15.3	0.584444	5.834	11.392
Paint Creek	7.953333	9.227778	455.0111	20.10333	24.51056	40	0.5825	5.61625	10.94444
CR 408	7.914444	8.54	412.1778	18.39444	1.264444	7.8	0.01125	20.10778	20.31444
Confluence	7.901111	8.256667	457.1556	20.92111	80.57456	25.2	0.173333	6.539	11.924
Brady Springs	7.993333	8.537778	470.9333	20.13889	11.37689	327	0.394444	11.585	10.079
Daryl Spring	7.936667	8.868889	482.7333	20.93889	9.202	68	0.42	6.335	12.034
Coke Stevenson	8.266667	9.343333	439.6556	20.52222	49.903	34.5	0.628889	5.834	11.447
Bois d'Arc Spring	7.841111	6.426667	540.5222	20.61111	1.056286	280.2	0.042222	7.134	12.34
Christmas Springs	7.60875	8.32125	522.7375	21.5925	0.540222	67.9	1.016667	7.268	12.37
700 Springs	7.865556	8.384444	457.7556	20.52556	16.477	36.1	1.045556	6.029	11.02222
Tanner Spring	7.841111	8.737778	472.3556	20.27111	5.165333	208.6	1.3	5.905	10.105
Deats Spring	7.646667	7.941111	484.7222	21.72667	0.18325	103	1.328889	5.937	10.728
Contrary Spring	7.75125	8.20875	525.4625	18.96625	0	19.7	1.104444	5.882	14.495

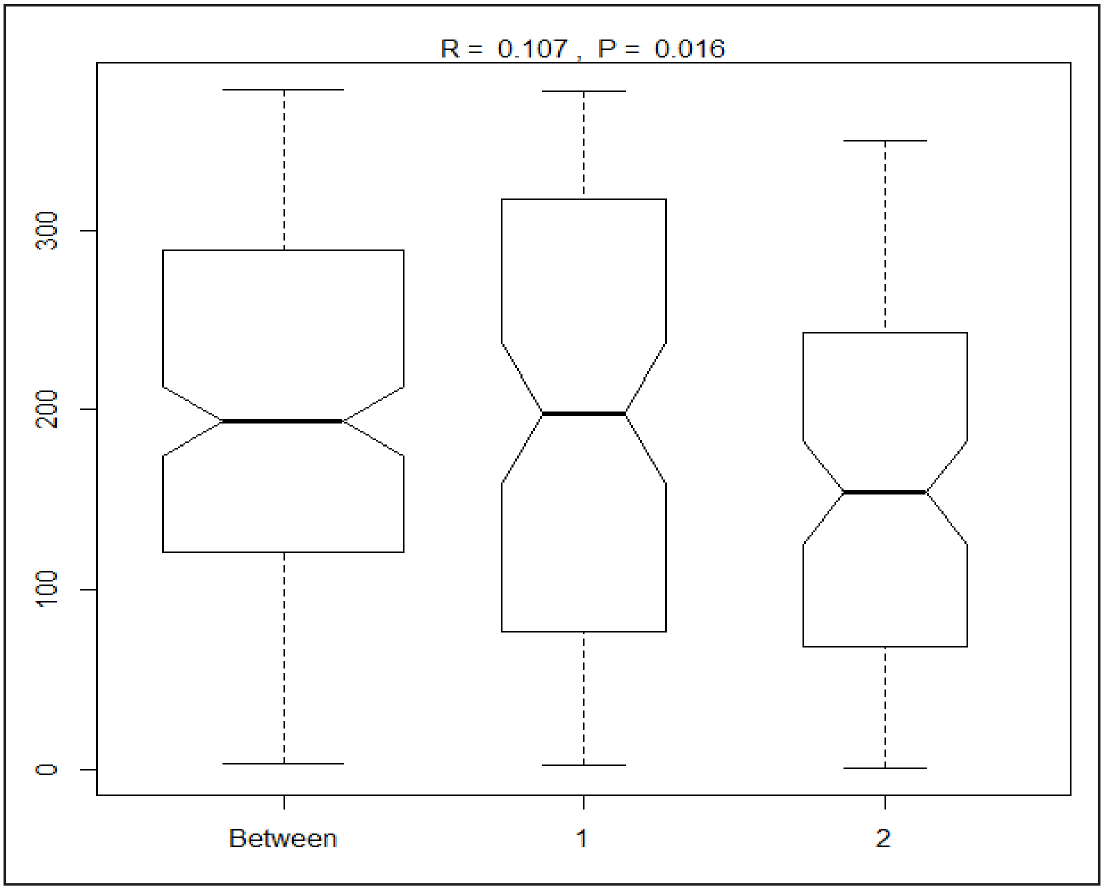

Figure 1. Box plot of analysis of similarities between the North (1) and the South (2) Llano River. Analysis was done on 28 sites with 14 from the North and 14 from the South Llano.

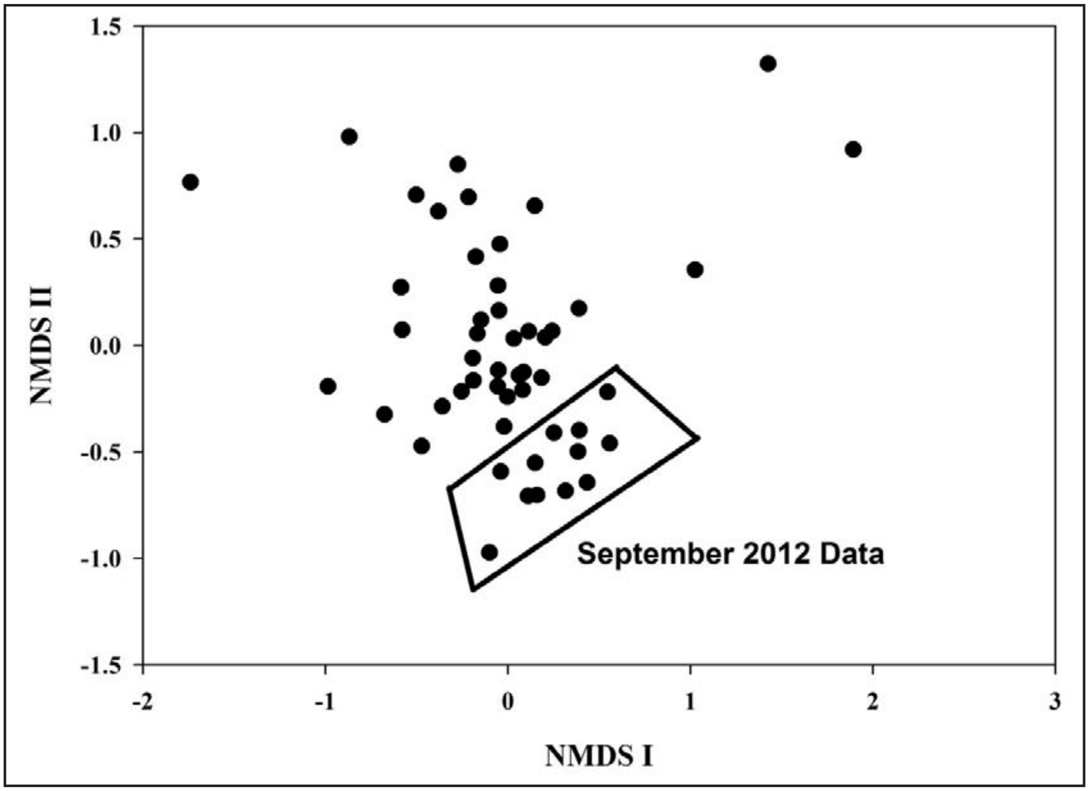

Figure 2. Nonmetric multidimensional scaling of benthic aquatic invertebrates sampled from the Llano River in September 2012, February 2013, September 2013 and March 2014. The data set from September 2012 is highlighted showing a distinct grouping of those sites.

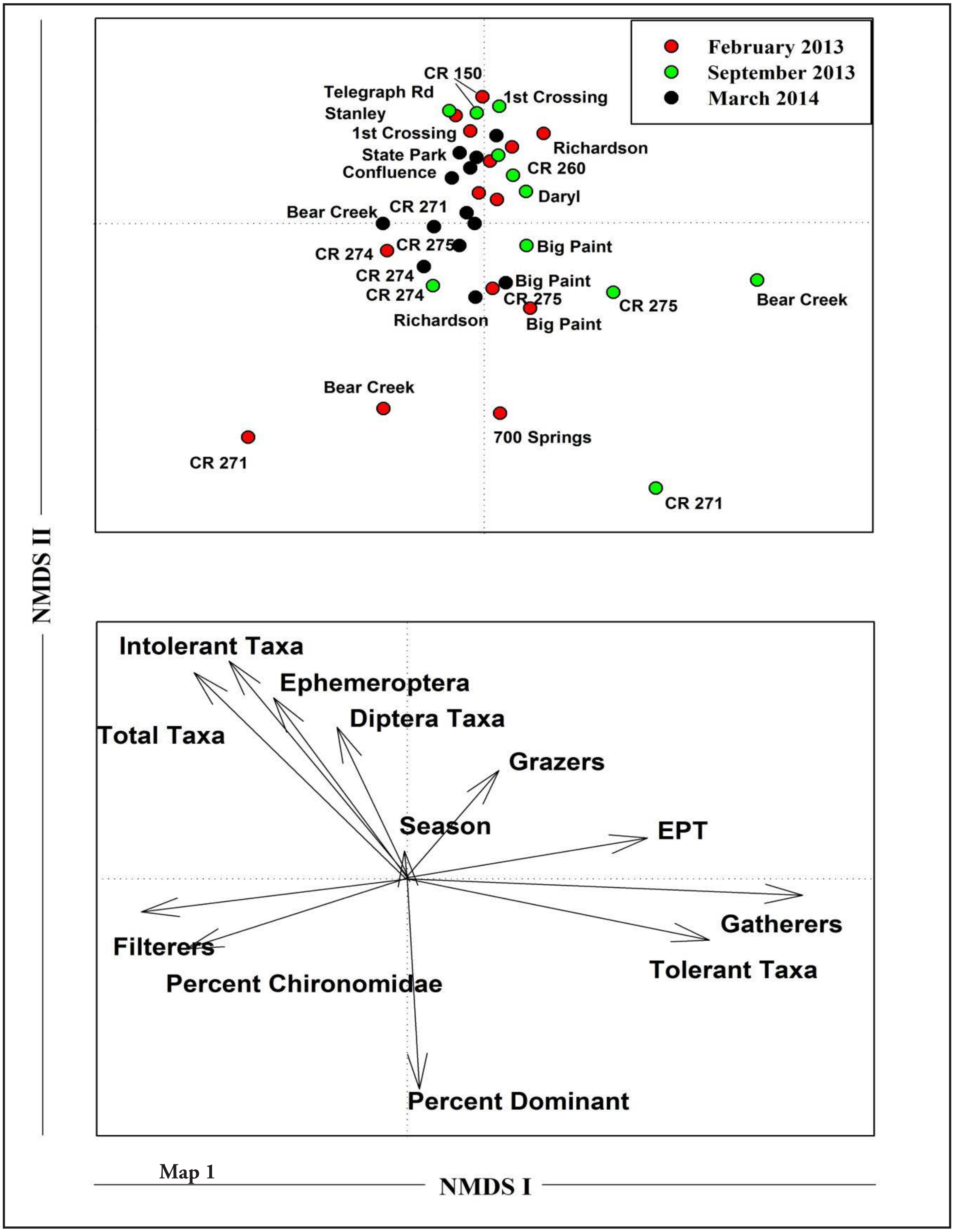

Figure 3. Nonmetric multidimensional scaling of sites from February 2013, September 2013 and March 2014 Hess samples. The top figure shows the distribution of sites within multivariate space coded by color to match sampling events. The lower graph shows the overlay of calculated metrics for the data set, describing the separation of sites within multivariate space.

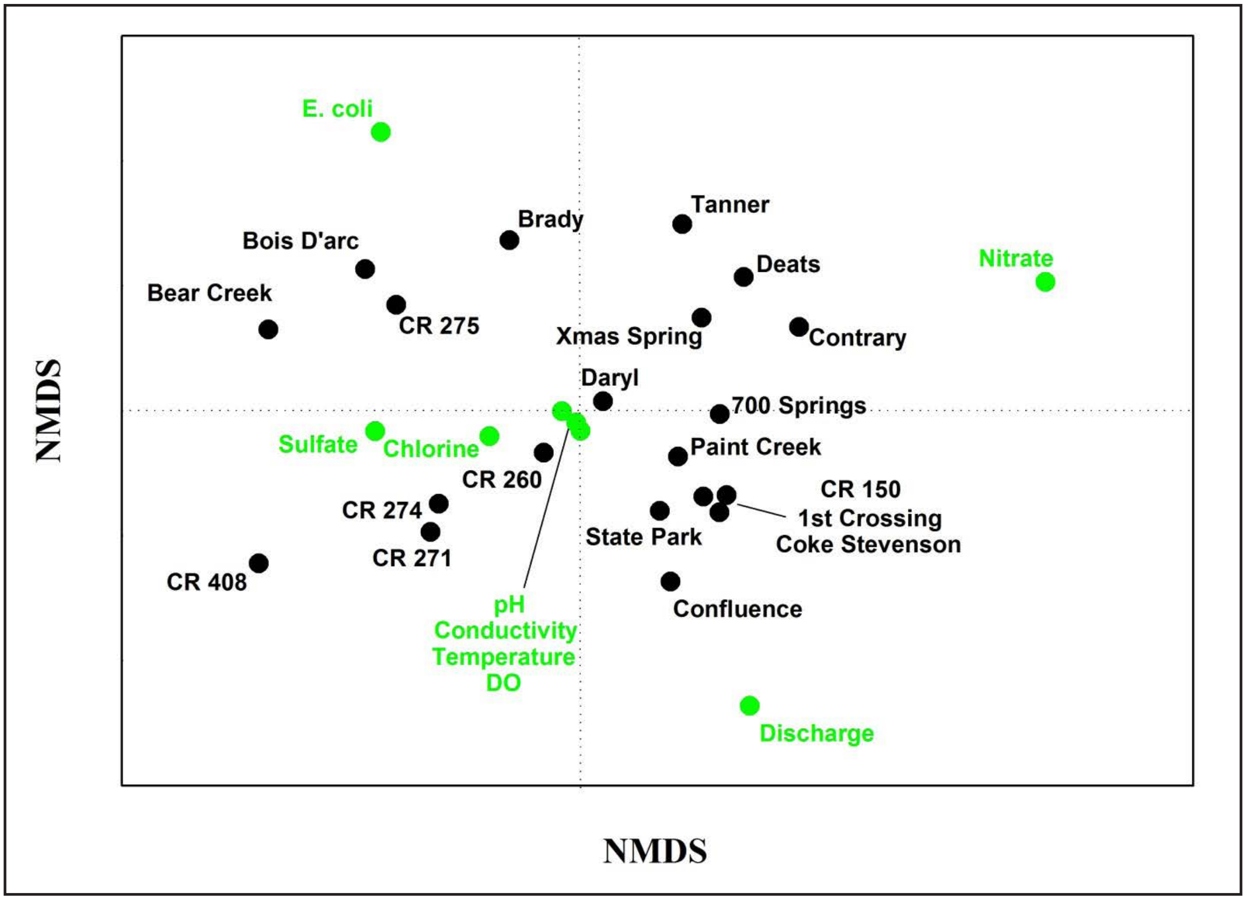

Figure 4. Nonmetric multidimensional scaling of water quality parameters from sites within the study area. Sites are in black, and water quality parameters are in green. Sites in the blue circle are spring sites, sites in the red circle are sites from the South Llano and sites within the orange rectangle are from the North Llano.

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Appendix E: The Upper Llano River Watershed Land Use/Land Cover Project

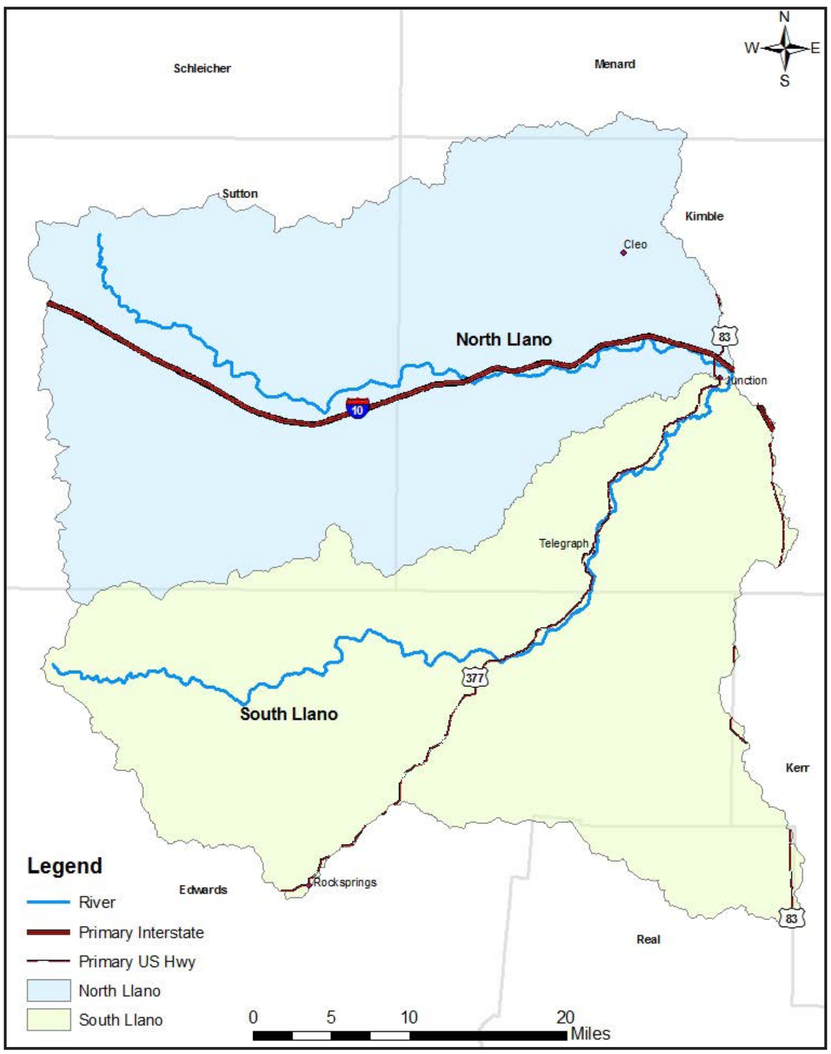
Introduction

The objective of this project was to create a Land Use/Land Cover (LULC) dataset for the Upper Llano River watershed (ULRW) in south-central Texas. The proactive development of a WPP for the North Llano River Watershed will help assist the SLWA with its protection and conservation goals. This region influences many ecosystems inside and outside of the watershed, and the LULC map along with other GIS data will assist stakeholders and managers in making informed decisions. The LULC map was created using National Agriculture Imagery Program (NAIP) images and a large amount of ancillary data along with the programs ArcGIS 9.3, ArcGIS 10, and Definiens Developer 7.0.

Study Area

The ULWR is comprised of two watersheds: the North Llano and South Llano. The watershed is found in south-central Texas in the Hill Country region. This region has karst geology and is west of the Balcones fault line. Mesquite (*Prosopis glandulosa*), Ashe juniper (*Juniperus ashei)*, and other brush species dominate the ULWR landscape. The watershed is located within six counties: Menard, Sutton, Kimble, Kerr, Real and Edwards. The North Llano and South Llano rivers are the main rivers in the watershed, and they join at the eastern edge of the watershed in Junction, Texas. The ULWR is 4795 square kilometers, with the North Llano being 2379 square kilometers and the South Llano 2416 square kilometers.

Map 1. Upper Llano River Watershed.



NAIP 2010 Imagery Classification Process

In order to create a LULC map, a vast amount of data needed to be gathered. The following sections describe the data required and methods used to accomplish the task.

Data

National Agriculture Imagery Program (NAIP) Digital Ortho Imagery: NAIP Ortho photos are collected and compiled each year by the U.S. Department of Agriculture (USDA) Farm Service Agency (FSA) during a portion of the agricultural growing season at a 1- or 2- meter resolution. The 2010 images for Texas were provided in county mosaics at a spatial resolution of one meter.

Watershed Boundary Dataset Hydrological Unit Code 12-digit (WBD_HUC12): The WBD is provided by USGS to delineate watershed boundaries using drainage systems and hydrological principles. This dataset displayed the study area and was used for clipping data to the study area.

National Land Cover Dataset (NLCD): The NLCD 2001 was created by USGS and was developed using a decision-tree classification approach for multitemporal Landsat imagery and several ancillary datasets. The category of urban land was extracted from the dataset using the ArcGIS Spatial Analyst extension to compare and compliment the NAIP classification. The NLCD 2001 has a 30-meter resolution.

Crop Data Layer (CDL): The CDL 2010 was compiled by the USDA National Agricultural Statistics Service (NASS) and was used in the classification process to gather in depth cropland points in the watershed. A CDL is a small unit of land that has a permanent, contiguous boundary, with a common land use and owner, and a common producer in agricultural land associated with USDA farm programs. CDL boundaries are delineated from relatively permanent features such as fence lines, roads and/or waterways. The CDL has a 30 meter resolution.

National Hydrography Dataset (NHD): NHD is a USGS database that interconnects and uniquely identifies segments or reaches that make up the nation's surface water drainage system. The NHD assisted with the classification of riparian zones.

Strategic Mapping Program (Stratmap): The Stratmap produces statewide digital geographic data layers that establish a common base map for the state of Texas. This dataset was obtained from the Texas Natural Resources Information System. Roads from the Stratmap were used in the post-classification process for identifying classes.

Ground Truth Data: Samples for each LULC class within the study were gathered during May 2012 using a GeoTrimble Explorer 3 unit. The primary focus of the field collection process was to collect ground control points across the entire area, particularly in classes that were difficult to distinguish. Where access was limited, sample points were offset from the road with comments on each GPS point distinguishing where the point should be placed.

Programs

Definiens Developer 7.0: Definiens Developer 7.0 uses an object-based image analysis. Segmentation of images is accomplished through the application of rules and algorithms provided by the program. Definiens Developer 7.0 created the original classification of the ULRW.

ArcGIS 9.3 and 10: ArcGIS is used to analyze, process, edit and create data through shapefiles, rasters and other types of datasets. This program was used to prepare the data for further processing, and it was used for post-processing of the classified watershed.

ERDAS IMAGINE 2010: New information can be created through advanced remote sensing analysis and spatial modeling with Erdas Imagine. This program was used to create subsets of the NAIP images, so data would not be too large to process in Definiens Developer 7.0.

ENVI 4.7: ENVI 4.7 is a remote sensing program that analyzes and classifies rasters using Supervised or Unsupervised techniques. ENVI was used to create the Normalized Difference Vegetation Index band for the NAIP 2010 images.

Python 2.6.5: Python is an object-oriented programming language and is used in conjunction with many other programs. Python was used with ArcGIS to automate processes and reduce time.

LULC Class Definitions

- Urban – Areas characterized by a high percentage (30% or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).
- Open Water – Areas of open water with less than 25% cover of vegetation or soil.
- Barren Land – (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover and includes transitional areas.
- Near Riparian Forested Land – Areas dominated by trees generally greater than 5 m tall, and greater than 50% of total vegetation cover. These areas are found following in near proximity (within 30-60 m) to streams, creeks and/or rivers.
- Rangeland – Areas of unmanaged shrubs covering 14% or less of the area with unmanaged grasses covering the rest of the area.
- Cultivated Crops – Areas used for the production of annual crops, such as corn, soybeans, vegetables, hay and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
- Brush Low Density – Areas dominated by woody canopy cover, including Ashe juniper, mesquite, live oak and other brush species and comprise 15-30% of total vegetation cover. Where possible, species-level analysis will be performed.
- Brush Medium Density – Areas dominated by woody canopy cover, including Ashe juniper, mesquite, live oak and other brush species and comprise 30-60% of total vegetation cover. Where possible, species-level analysis will be performed.
- Brush High Density – Areas dominated by woody canopy cover, including Ashe juniper, mesquite, live oak and other brush species and comprise greater than 60% of total vegetation cover. Where possible, species-level analysis will be performed.

Preparation of Data

ArcGIS 9.3, ERDAS Imagine 2010, Definens Developer 7.0, and ENVI 4.7 were used for the pre-processing of data for the ULRW. First, all the data described above were projected to North American Datum 1983 Universal Transverse Mercator coordinate zone 14 North. The North and South Llano watersheds were exported from the WBD_HUC12 and merged together to identify the ULRW. A 1-mile buffer was placed around the ULRW to ensure the whole watershed would be included. Then, the NAIP 2010 images for the counties Real, Sutton, Kerr, Menard, Kimble and Edwards were gathered and clipped to the buffered study area. All the data listed above was clipped to the study area as well. After the 1-m NAIP images were clipped, ERDAS IMAGINE 2010 was used to create 2-gigabyte tiles for the images. The images need to be tiled in order for Definiens Developer to process the images. Each clipped county image was comprised of approximately four tiles. After the images were tiled, a normalized difference vegetation index (NDVI) band was created for each tile in ENVI 4.7. The NDVI band assists in differentiating vegetation from non-vegetation in the classification process. Now that the NAIP images are tiled and a NDVI band is added, the images are loaded into Definiens Developer 7.0. Since the NDVI band is a floating point, the tiled image size increased dramatically from its original 2-gigabyte size. Definiens Developer 7.0 is used to tile the images even further and creates 113 total images at 10000 x 10000 pixels to comprise the ULRW.

Classification

Now that the data is NAIP 2010 images are prepared, they can be classified in Definiens Developer 7.0. First, the NDVI band is used to create an initial classification between vegetation and non-vegetation in the image. Any cell with an NDVI greater than or equal to 0.15 is vegetation, and any cell less than 0.15 is considered non-vegetation. Now, the images can be segmented within vegetation and non-vegetation classes based on parameters given by the user. The main goal was to get a segmentation that identifies only brush and excludes objects in the vicinity. This will be very helpful for brush density calculations. After the proper segmentation is achieved, samples can be collected for the classes. At least five samples from each class was collected per 10000 X 10000 pixel tile, and this allowed at least 25 samples per class to be collected per larger tiles created in ERDAS IMAGINE 2010. The classes below were used for classification in Definiens Developer 7.0, and other classes will be added during the post-classification process. Some classes like Live Pasture and Rangeland Grass are the same class, but two different classes were needed because of the difference in their cell values. Rangeland Green was brush but its reflectance was green.

Classes:

1. Water
2. Barren
3. Developed
4. Roads
5. Live Pasture
6. Rangeland Grass
7. Rangeland Other
8. Rangeland Juniper
9. Rangeland Green
10. Shadow

After the images are classified, the segments (objects) are exported as shapefiles with their class name in the attribute table, and the classification raster is exported as well.

Collecting Ground Truth Points

Ground truth points were collected throughout the ULRW during May 2012 over two days using a GeoTrimble Explorer 3 unit. A total of 90 points were collected, and the classes collected were Rangeland Grass, Brush Low Density, Brush Medium Density, Brush High Density, Developed Open, Developed Low Intensity, Developed Medium Intensity, Developed High Intensity, Riparian, Pasture/Hay, Crop and Water. Numerous points were collected on hiking trails in the South Llano River State Park. The rest of the points were collected along roads in the watershed. In order to reduce roadside bias, a point was collected every five minutes along the road. These methods were applied for the duration of the trip.

Post-Classification Processing

Now that the Definiens Developer classification is complete, brush density can be analyzed and other classes can be created. Many of these processes have been automated through Python and ArcGIS 10, allowing all the files to be created and processed at once. First, brush density needs to be calculated. Since Rangeland Green, Rangeland Juniper, and Rangeland Other are considered brush, the exported objects are converted to rasters with all three classes equal to 1 and all other classes equal to 0. With this information, focal statistics can be run with a 45 meter x 45 meter moving window to average the amount of brush within the half-acre window. Since an average of 1 and 0 is used in the moving window, brush density can be classified as 0-.149 is Rangeland Grass (1), 0.15-0.29 is Brush Low Intensity (2), 0.30-0.59 is Brush Medium Intensity (3) and 0.60-1 is Brush High Intensity (4). After the density is classified, a majority filter using the exported objects can be run on the density raster. The majority filter removes the rings around objects created by the window effect and creates a new raster that assigns the classification of brush density to the object that it covers the majority of.

Now that the brush density class is created, more classes can be added. With the assistance of the NHD, the Near Riparian Forest class is added. A 10-m buffer is placed around the NHD and only selects objects already classified as Rangeland Other. Because objects are polygons and have an area, a 10-m buffer to select objects actually creates an approximately 20-m buffer. A field is added to the object's attribute table that calculates all selected objects as 1 and all other objects as 0.

An Urban class can be created now. Because it is hard to distinguish between Barren, Developed, and Roads in the original classification, the NLCD 2001 is used to distinguish the classes. A 2-m buffer is placed around the NLCD 2001 Developed classes, and only objects within the buffer that are already classified as Barren, Developed, or Roads are selected. Because the NLCD 2001 is at a 30-m resolution, it does not identify all roads in the watershed. In order to classify roads as developed, the Stratmap is used. A 3-m buffer is placed around the Stratmap, and only objects classified as Barren, Developed and Roads are selected. A field is added to the object's attribute table, and all selected features equal 1 and all other features = 0. Another field is added to the object's attribute table to create the class Barren. All objects classified as Barren, Developed and Roads are selected, and all objects already classified as Urban are removed from the selection. The remaining selected features are Barren and equal 1, while all others equal 0.

Crops are another class that needs to be added to the classification. The CDL assisted in classifying Crops. Because the CDL is 30-m resolution, it does not identify every crop in the area ULRW, so most crops had to be manually digitized in ArcGIS 10. A field was added in the object's attribute table, and only objects originally classified as Rangeland Grass and Live Pasture that were within the digitized crops were selected. The selected objects equal 1, and all other objects equal 0.

To create a LULC map with Brush Density, all the classes need to be combined to one map. In the object's attribute table, a field is added to combine all the classes created except Brush Density. All features Urban = 5, Riparian = 6, Crop = 7, Barren = 8, and Water = 9, other features = 0. The objects are converted to a raster based on the newly created field. The Brush Density raster is combined with the new raster and displays all the classes in one map.

Another LULC map is also created to display the brush type in the ULRW. A field was added to the object's attribute table, and all Rangeland Juniper features equal 1, Rangeland Other and Rangeland Green equal 2 and all other objects equal 0. The objects were converted to raster based on the new field, and the Brush Type raster was combined with all other classes besides Brush Density. A third LULC map displaying Brush Type with Brush Density is also created by joining the newly created raster with the Brush Density raster.

Since the GPS points are collected and the brush density map is created, the accuracy assessment can be performed. First, the points are layered over the brush density map, and the value of the cell on the raster where the GPS point is located is extracted and compared to the GPS point class. From here, a confusion matrix is created in Microsoft Excel to determine the accuracy of the brush density classification.

Results and Discussion

The tables and maps below display the results of the LULC project. Table 1 below displays the GPS points collected. Brush High Density had the most points collected at 27, and Barren had the least amount of points at 0. Table 2 displays Developed Intensities grouped together and Pasture/Hay and Crop grouped together. Urban now has 12 points and Crop has 5 points, and only 9 classes are in Table 2 versus 13 classes in Table 1.

Table 1

Class	Points
Rangeland Grass	4
Brush Low Density	11
Brush Medium Density	17
Brush High Density	27
Developed, Open	2
Developed Low Intensity	4
Developed Medium Intensity	2
Developed High Intensity	4
Riparian	10
Pasture/Hay	3
Crop	2
Barren	0
Water	4
Total	90

Table 2

Class	Points
Rangeland Grass	4
Brush Low Density	11
Brush Medium Density	17
Brush High Density	27
Urban	12
Riparian	10
Crop	5
Barren	0
Water	4
Total	90

In the beginning of the project, a desired 10 points per Class was expected; however, many of the classes were not found along accessible roads and could not be found. Also, many of the classes were not abundant in the watershed such as Crop, Pasture/Hay, Developed, Rangeland Grass and Barren. Since there are approximately two cities within the watershed, Rocksprings and Junction, Developed Intensities were grouped together to create an Urban class. Pasture/Hay and Crop were also grouped together because there were very few crops or pastures. There was not barren land visible from the road, especially any large enough to get a point.

Table 3 displays the confusion matrix for the ULRW LULC Brush Density map. The matrix shows most classes are very accurate, but brush density has the most misclassifications. The brush misclassification are mainly between other brush densities. Table 4 reveals the accuracy assessment of the map. The overall accuracy is 86% with a Rangeland Grass having the lowest producer's accuracy at 60% and Brush Low Density with the lowest user's accuracy at

64%. The Kappa is 0.83. Table 5 presents the confusion matrix for the ULRW LULC as well, but Brush classes are grouped together. The Brush classification is extremely accurate now that they are grouped together. Table 6 displays the accuracy assessment of Table 5. The overall accuracy is 97% with Rangeland Grass having the lowest producer's accuracy at 60% and lowest user's accuracy at 75%. The Kappa is 0.94.

Table 3.

	Rangeland Grass	Brush Low	Brush Medium	Brush High	Urban	Riparian	Crop	Open Water	Row Total
Rangeland Grass	**3**	0	0	0	0	0	1	0	4
Brush Low	2	**7**	0	2	0	0	0	0	11
Brush Medium	0	4	**13**	0	0	0	0	0	17
Brush High	0	0	4	**23**	0	0	0	0	27
Urban	0	0	0	0	**12**	0	0	0	12
Riparian	0	0	0	0	0	**10**	0	0	10
Crop	0	0	0	0	0	0	**5**	0	5
Open Water	0	0	0	0	0	0	0	**4**	4
Column Total	5	11	17	25	12	10	6	4	**90**

Table 4.

	Producer's Accuracy	User's Accuracy
Rangeland Grass	60%	75%
Brush Low	64%	64%
Brush Medium	76%	76%
Brush High	92%	85%
Urban	100%	100%
Riparian	100%	100%
Crop	83%	100%
Open Water	100%	100%
Overall Accuracy	86%	
Kappa	0.825503356	

Table 5.

	Rangeland Grass	Brush	Urban	Riparian	Crop	Open Water	Row Total
Rangeland Grass	**3**	0	0	0	1	0	4
Brush	2	**53**	0	0	0	0	55
Urban	0	0	**12**	0	0	0	12
Riparian	0	0	0	**10**	0	0	10
Crop	0	0	0	0	**5**	0	5
Open Water	0	0	0	0	0	**4**	4
Column Total	5	53	12	10	6	4	**90**

Table 6.

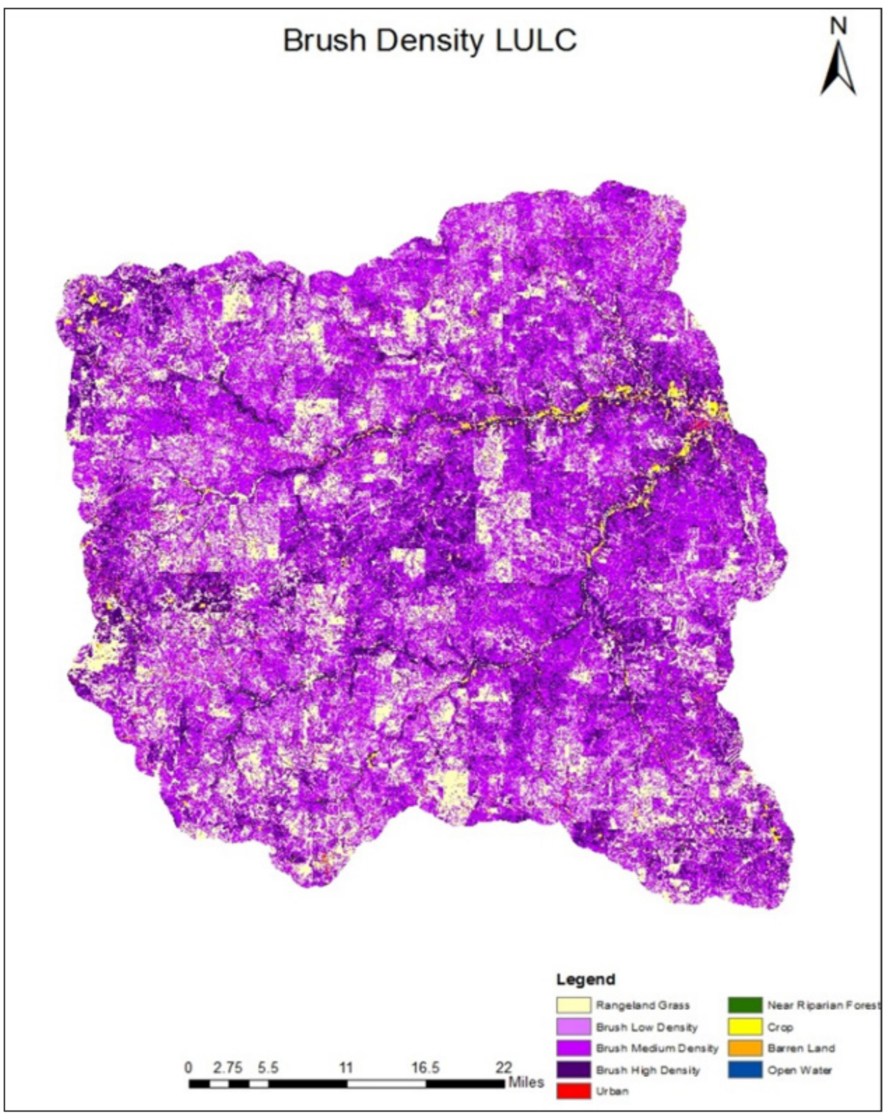
	Producer's Accuracy	User's Accuracy
Rangeland Grass	60%	75%
Brush	100%	96%
Urban	100%	100%
Riparian	100%	100%
Crop	83%	100%
Open Water	100%	100%
Overall Accuracy	97%	
Kappa	0.944615385	

Because the ground control points were taken without an aerial view, it was very difficult to identify the brush density. As Table 3 shows, some brush density is misclassified, but it is still classified as brush. Table 5 displays that joining brush densities into one class, 53 out of the 55 points are classified correctly. Also, the two misclassified points are classified as Rangeland Grass, which does contain shrubs. Because Rangeland Grass only has four points, one misclassified point will drastically reduce its accuracy. One Rangeland Grass point is classified as Crop, and because the field points were collected two years after the NAIP images, the field may have been converted from Rangeland Grass to Pasture/Hay or Crop. Riparian, Urban, Crop, and Open Water had very accurate classifications. The Kappa statistic of both accuracy assessments reveals a strong relationship between the classification and the reference data.

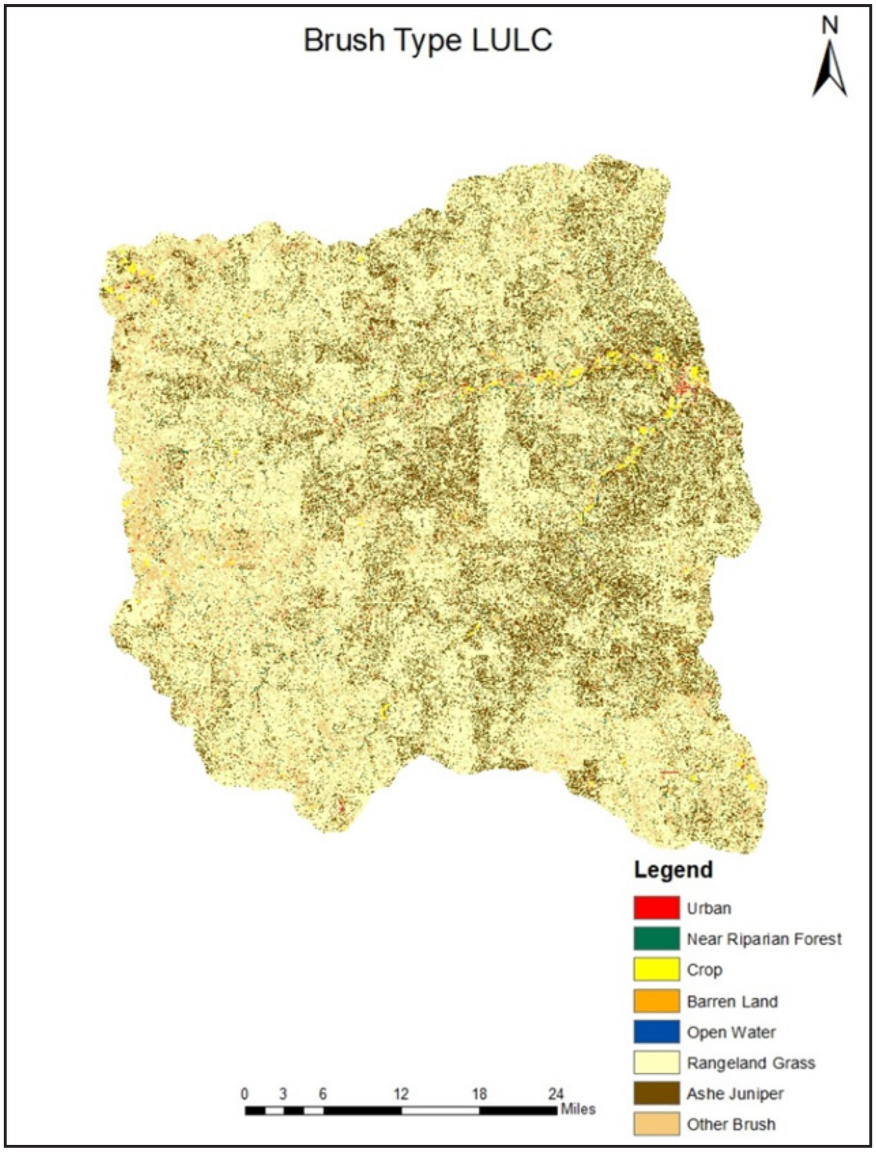
Map 2 displays the Brush Density LULC map, Map 3 displays the Brush Type LULC map, and Map 4 displays the Brush Density and Brush Type LULC map combined.

The classification of the ULRW proved to be very accurate. The use of NAIP 2010 images in conjunction with ancillary data assisted with making the classification more accurate. Because of the NLCD 2001, CDL 2010, Stratmap, and NHD, more classes could be added to the LULC map. Brush density was classified very well, but collecting more ground control points in conjunction with aerial photos would have helped produce a better accuracy assessment. Overall, the LULC maps determined the vegetation types and densities for the ULRW very accurately.

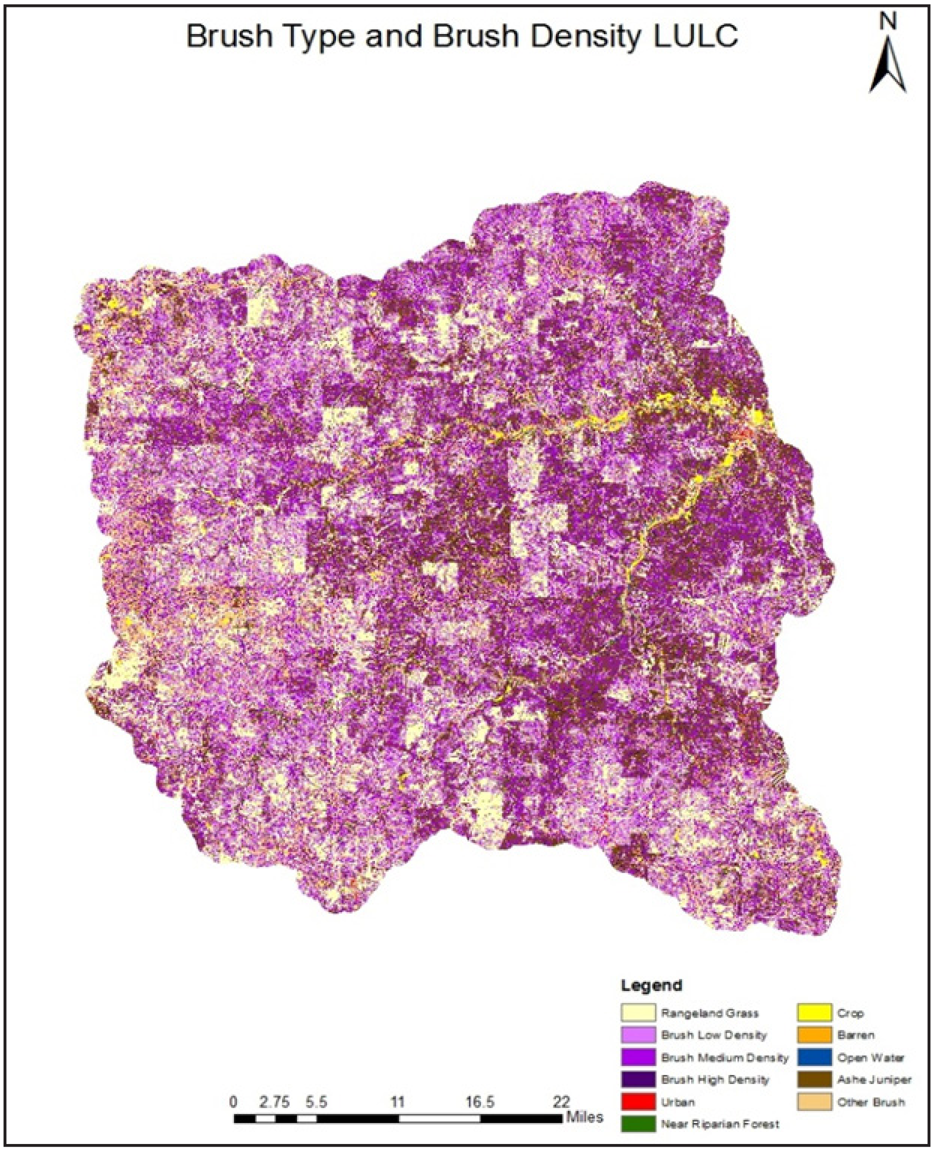
Map 2.



Map 3.


Brush Type LULC
N
Legend
Urban
Near Riparian Forest
Crop
Barren Land
Open Water
Rangeland Grass
Ashe Juniper
Other Brush
0 3 6 12 18 24
Miles

Map 4.


Brush Type and Brush Density LULC
N
Legend
Rangeland Grass
Brush Low Density
Brush Medium Density
Brush High Density
Urban
Near Riparian Forest
Crop
Barren
Open Water
Ashe Juniper
Other Brush
0 2.75 5.5 11 16.5 22
Miles

Appendix F: EDYS Model Output for Feral Hog Control Scenario

Because feral hog distribution patterns and points of concentration are unknown and the effects of those two factors are likely to have a substantial influence on the model results, specific numbers of feral hogs were not simulated in these two scenarios. Instead, an assumption was made on the impacts along the riparian corridor. In Scenario 9, it was assumed that feral hogs physically impacted 10% of the riparian zones. The impacts were simulated by removing all herbaceous vegetation in the impacted areas. The impacted areas were randomly selected in the first year of the simulation, and those areas were continually impacted throughout the simulation. Scenario 10 was conducted precisely as Scenario 9 except that the amount of area impacted was reduced to 3%. This was done to simulate a 70% reduction in feral hog populations.

The 10% hog scenario resulted in a small increase (2.5%, 12 acre-feet; Table 3) in runoff. This was the result of less herbaceous cover on the disturbed areas. Sediment loadings decreased slightly (0.6%, 2.5 tons; Table 3), which is the opposite response than expected from a small increase in runoff. Sediment loadings increased on about half (19) of the subwatersheds, decreased on about one-fourth (12), and remained the same on about one-fourth (9). The amounts of the differences were small and apparently the sediment results were strongly influenced by the randomization scheme and its effect on which plots were impacted.

The 10% hog scenario also resulted in a small increase (3%) in evapotranspiration (ET) (Table 4). This was the result of a substantial increase in evaporation (47%) from the disturbed soil surfaces, which was somewhat offset by a decrease in the larger transpiration (6%) component. There was also an increase in recharge (50%, 104 acre-feet; Table 5), primarily because of lower transpiration from the vegetation. However, this was not a net increase in recharge because the vegetation used 201 acre-feet more of stored and groundwater. The net balance was therefore a negative 97 acre-feet (104 acre-feet – 201 acre-feet).

The 3% hog scenario resulted runoff amounts intermediate between baseline and the 10% hog scenario. There was an annual average of 5.5 acre-feet more of runoff than under baseline and 6 acre-feet less than the 10% hog scenario (Table 3). Sediment loadings were slightly less (1 ton) than under the 10% hog scenario (Table 3) and ET was higher than under the 10% hog scenario (Table 4). The higher ET values were the result of higher evaporation than under baseline, but lower than under the 10% scenario, and transpiration values that were higher than under the 10% scenario and slightly higher than under baseline. The higher transpiration compared to baseline was the result in an increase in production by the woody species on the hog-disturbed sites. Recharge was only slightly higher than baseline under the 3% hog scenario (Table 5).

Table 3. Simulated average annual runoff (m^3 and acre-feet) and sediment loads (m^3 and tons) from the riparian corridor under baseline (no hogs), 3% hogs, and 10% hogs scenarios, average precipitation regime. The 3% and 10% values refer to the spatial area of the riparian zone directly impacted by feral hogs.

SubW	Runoff (m^3)			Runoff (acre-feet)			Sediments (m^3)			Sediments (tons)		
	Baseline	3%	10%	Baseline	3%	10%	Baseline	3%	10%	Baseline	3%	10%
North Llano												
01	6,277	6,283	6,037	5.09	5.09	4.89	0.68	0.68	0.73	0.97	0.97	1.04
02	220	220	220	0.18	0.18	0.18	0.00	0.00	0.00	0.00	0.00	0.00
04	36,614	38,720	43,766	29.68	31.39	35.48	9.45	9.53	9.70	13.53	13.66	13.90
05	5,099	5,102	5,081	4.13	4.14	4.12	0.57	0.57	0.58	0.82	0.82	0.83
06	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07	3,995	3,995	3,999	3.24	3.24	3.24	0.22	0.22	0.22	0.32	0.32	0.32
08	2,270	2,275	2,267	1.84	1.84	1.84	0.15	0.15	0.15	0.22	0.22	0.22
09	33,142	33,630	36,140	26.87	27.26	29.30	22.30	21.51	18.56	31.95	30.82	26.60
10	23,099	23,625	25,121	18.73	19.15	20.37	13.67	13.64	13.98	19.59	19.54	20.04
13	6,805	6,837	6,817	5.52	5.54	5.53	1.31	1.32	1.34	1.88	1.89	1.92
14	6,102	6,104	6,108	4.95	4.95	4.95	3.86	3.84	3.86	5.53	5.51	5.54
15	33,266	33,549	33,151	26.97	27.20	26.88	17.57	17.33	17.66	25.18	24.83	25.30
16	28,315	28,020	29,196	22.96	22.72	23.67	26.54	27.05	25.78	38.04	38.77	36.94
17	163	164	168	0.13	0.13	0.14	0.00	0.00	0.00	0.00	0.00	0.00
18	46,041	46,104	44,696	37.33	37.38	36.24	25.92	25.91	27.36	37.14	37.12	39.21
19	6,569	6,570	6,565	5.33	5.33	5.32	11.23	11.23	11.27	16.10	16.10	16.15
21	92	92	92	0.07	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00
22	20,730	20,733	20,697	16.81	16.81	16.78	9.78	9.83	9.93	14.01	14.09	14.23
23	25,230	25,163	25,162	20.45	20.40	20.40	15.50	15.59	15.87	22.22	22.34	22.74
Total	284,029	287,186	295,283	230.28	232.82	239.40	158.75	158.40	156.99	227.50	227.00	224.98
South Llano												
26	2,482	2,119	2,146	2.01	1.72	1.74	0.22	0.19	0.19	0.32	0.27	0.28
27	3,835	3,192	3,229	3.11	2.59	2.62	0.41	0.31	0.30	0.59	0.44	0.43
30	6,541	6,428	6,535	5.30	5.21	5.30	0.29	0.23	0.23	0.42	0.33	0.32
31	7,246	7,341	7,365	5.87	5.95	5.97	2.28	1.81	1.80	3.26	2.59	2.59
32	173	128	128	0.14	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00
33	12,129	13,014	12,978	9.82	10.55	10.52	10.94	9.68	9.72	15.67	13.88	13.93
34	8,862	9,000	8,904	7.18	7.30	7.22	2.06	1.93	1.89	2.96	2.77	2.70
35	17,147	16,880	16,839	13.89	13.68	13.65	2.57	2.63	2.65	3.69	3.77	3.80
36	8,409	8,639	8,588	6.81	7.00	6.96	1.43	1.13	1.15	2.05	1.62	1.64
37	5,517	6,018	5,975	4.47	4.88	4.84	0.45	0.25	0.19	0.64	0.36	0.27
38	3,233	3,410	3,458	2.62	2.76	2.80	0.00	0.00	0.00	0.00	0.00	0.00
39	23,617	24,969	24,951	19.12	20.24	20.23	5.64	5.12	5.16	8.08	7.34	7.40
40	1,525	1,570	1,575	1.24	1.27	1.28	0.10	0.11	0.11	0.14	0.15	0.16
41	11,920	12,848	13,034	9.65	10.42	10.57	2.77	2.92	2.97	3.97	4.19	4.25
43	14,126	15,326	15,331	11.44	12.43	12.43	6.79	6.93	6.94	9.74	9.93	9.94
44	17,426	17,428	17,310	14.12	14.13	14.03	6.44	6.43	6.48	9.22	9.22	9.29
45	12,800	12,805	12,779	10.37	10.38	10.36	3.53	3.53	3.56	5.06	5.06	5.10
46	37,074	37,078	36,694	30.03	30.06	29.75	6.65	6.65	6.79	9.52	6.65	9.73
48	39,144	39,021	39,586	31.71	31.63	32.09	28.65	28.84	28.38	41.06	41.33	40.67
49	15,488	15,506	15,269	12.55	12.57	12.38	50.31	50.35	52.07	72.10	72.15	74.61
Total	248,694	252,720	252,674	201.61	204.87	204.84	131.53	129.05	130.58	188.49	184.93	187.11
Llano												
24	35,156	34,901	34,243	28.50	28.29	27.76	18.67	18.92	19.63	26.75	27.11	28.14
Overall												
	567,879	574,807	582,200	460.39	465.98	472.00	308.95	306.38	307.20	442.74	439.04	440.23

Table 4. Simulated average annual evapotranspiration (ET; m^3 and acre-feet) from the riparian corridor under baseline (no hogs), 3% of the area impacted by feral hogs, and 10% of the area impacted by feral hogs, under the average precipitation regime.

SubW	ET (m^3)			ET (acre-feet)		
	Baseline	3%	10%	Baseline	3%	10%
North Llano						
01	493,533	490,626	482,575	400.11	397.76	391.23
02	455	455	455	0.37	0.37	0.37
04	651,268	649,040	643,310	527.99	526.19	521.54
05	235,492	234,099	232,276	190.92	189.79	188.31
06	459	459	459	0.37	0.37	0.37
07	118,999	118,999	116,737	96.47	96.47	94.64
08	227,303	226,064	225,445	184.28	183.27	182.77
09	704,317	701,231	698,487	571.00	568.50	566.27
10	715,833	708,671	687,186	580.33	574.53	557.11
13	253,530	249,905	246,053	205.54	202.60	199.48
14	135,350	134,707	133,136	109.73	109.21	107.93
15	728,716	725,570	719,629	590.78	588.23	583.41
16	602,644	600,377	597,259	488.57	486.73	484.21
17	6,840	6,840	6,047	5.55	5.55	4.90
18	574,368	570,981	560,820	465.65	462.90	454.56
19	393,480	393,302	391,876	319.00	318.85	317.70
21	916	916	916	0.74	0.74	0.74
22	444,671	444,014	443,137	360.50	359.97	359.26
23	231,637	230,484	226,640	187.79	186.86	183.74
Total	6,519,811	6,486,740	6,412,443	5,285.69	5,258.91	5,198.54
South Llano						
26	223,790	254,316	249,428	181.43	206.18	202.21
27	357,636	404,822	398,206	289.94	328.19	322.83
30	289,207	326,465	322,039	234.46	264.67	261.08
31	386,252	440,632	435,811	313.14	357.23	353.32
32	2,348	2,670	2,670	1.90	2.16	2.16
33	528,201	598,985	593,087	428.22	485.61	480.82
34	473,724	539,331	536,296	384.05	437.24	434.78
35	476,282	541,423	537,646	386.13	438.94	435.88
36	352,769	401,113	396,208	285.99	325.19	321.21
37	158,311	178,404	176,646	128.35	144.63	143.21
38	2,595	2,960	2,940	2.10	2.40	2.38
39	347,720	385,365	383,224	281.90	312.42	310.68
40	280,732	315,632	313,119	227.59	255.89	253.85
41	302,498	340,002	338,192	245.24	275.64	274.18
43	368,506	415,694	414,294	298.75	337.01	335.87
44	54,452	54,374	54,258	44.15	44.08	43.99
45	181,877	181,705	180,590	147.45	147.31	146.41
46	361,603	360,290	357,665	293.16	292.09	289.96
48	584,584	580,667	572,276	473.93	470.75	463.95
49	581,094	579,235	574,189	471.10	469.59	465.50
Total	6,314,181	6,904,085	6,838,784	5,118.98	5,597.22	5,544.27
Llano						
24	513,563	510,354	502,457	416.35	413.75	407.35
Overall						
	13,347,555	**13,901,179**	**13,753,684**	**10,821.02**	**11,269.88**	**11,150.30**

Table 5. Simulated average annual recharge (m^3 and acre-feet) from the riparian corridor under baseline (no hogs), 3% of the area impacted by feral hogs, and 10% of the area impacted by feral hogs, under the average precipitation regime.

SubW	Recharge (m^3)			Recharge (acre-feet)		
	Baseline	3%	10%	Baseline	3%	10%
North Llano						
01	8,293	10,781	17,881	6.72	8.74	14.50
02	9	9	9	0.01	0.01	0.01
04	8,137	10,067	14,690	6.60	8.16	11.91
05	3,247	4,438	6,105	2.63	3.60	4.95
06	5	5	5	0.00	0.00	0.00
07	1,589	1,589	3,571	1.29	1.29	2.90
08	3,232	4,383	4,857	2.62	3.55	3.94
09	8,193	10,876	13,241	6.64	8.82	10.74
10	7,170	13,606	31,262	5.81	11.03	25.34
13	3,067	6,255	9,752	2.49	5.07	7.91
14	2,202	2,698	3,888	1.79	2.19	3.15
15	11,856	14,227	19,514	9.61	11.53	15.82
16	8,548	10,269	12,957	6.93	8.33	10.50
17	100	100	742	0.08	0.08	0.60
18	9,102	12,143	19,879	7.38	9.84	16.12
19	7,384	7,545	8,825	5.99	6.12	7.15
21	22	22	22	0.02	0.02	0.02
22	9,643	10,184	10,903	7.82	8.26	8.84
23	3,574	4,421	7,088	2.90	3.58	5.75
Total	95,373	123,618	185,191	77.33	100.22	150.15
South Llano						
26	6,751	4,569	8,963	5.47	3.70	7.27
27	9,807	7,439	13,333	7.95	6.03	10.81
30	7,270	6,265	10,257	5.89	5.08	8.32
31	9,180	3,958	8,364	7.44	3.21	6.78
32	52	24	24	0.04	0.02	0.02
33	13,277	9,539	15,015	10.76	7.73	12.17
34	14,537	8,709	11,475	11.79	7.06	9.30
35	14,400	8,962	12,155	11.67	7.27	9.85
36	9,711	5,506	9,757	7.87	4.46	7.91
37	4,144	3,745	5,277	3.36	3.04	4.28
38	75	38	56	0.06	0.03	0.05
39	8,368	7,348	9,328	6.78	5.96	7.56
40	9,185	8,699	10,819	7.45	7.05	8.77
41	8,782	8,532	9,877	7.12	6.92	8.01
43	10,359	8,721	9,884	8.40	7.07	8.01
44	681	725	792	0.55	0.59	0.64
45	3,033	3,181	4,216	2.46	2.58	3.42
46	6,180	7,209	8,945	5.01	5.84	7.25
48	8,529	11,860	18,845	6.91	9.62	15.28
49	11,142	12,797	17,233	9.03	10.37	13.97
Total	155,463	127,826	184,615	126.01	103.63	149.67
Llano						
24	6,639	8,939	15,505	5.38	7.25	12.57
Overall	**257,475**	**260,383**	**385,311**	**208.72**	**211.10**	**312.39**

Nitrogen and Phosphorus Loadings

Nitrogen (N) and phosphorus (P) loadings in surface runoff were the result of the nutrients in the sediments contained in the runoff plus the nutrients contained in the rainfall. Nutrients contained in the feces of the feral hogs were not included in the simulations.

The simulated hog scenarios had very little effect on either N or P loadings. This was because sediment loadings were not affected much (Table 3). The nutrient loadings were a function of sediment loads and concentrations in rainfall, and the rainfall regime did not change between baseline and the hog scenarios. And because sediment loads did not increase much, nutrient loadings were largely unaffected.

Table 6. Simulated average annual available nitrogen and phosphorus loads (kg) entering the North and the South Llano Rivers in runoff and sediments from the riparian zones under four scenarios: 1) baseline, 2) 3% of area impacted by feral hogs, and 3) 10% of are impacted by feral hogs, under average precipitation regime.

SubW	Nitrogen			Phosphorus		
	Baseline	3% Hogs	10% Hogs	Baseline	3% Hogs	10% Hogs
North Llano						
01	6.70	6.70	6.83	0.65	0.65	0.69
02	0.11	0.11	0.11	0.00	0.00	0.00
04	61.20	62.62	65.90	8.78	8.87	9.04
05	5.37	5.37	5.39	0.54	0.54	0.55
06	0.00	0.00	0.00	0.00	0.00	0.00
07	3.05	3.05	3.07	0.22	0.22	0.22
08	1.87	1.88	1.89	0.15	0.15	0.15
09	116.80	113.50	101.49	20.46	19.74	17.07
10	74.49	74.62	76.94	12.56	12.53	12.85
13	9.62	9.69	9.78	1.23	1.24	1.26
14	19.70	19.61	19.72	3.54	3.53	3.55
15	100.39	99.39	100.75	16.16	15.94	16.23
16	139.53	141.79	136.37	24.29	24.76	23.60
17	0.08	0.08	0.08	0.00	0.00	0.00
18	138.01	137.99	143.74	23.82	23.81	25.13
19	58.92	58.92	59.10	10.25	10.25	10.29
21	0.05	0.05	0.05	0.00	0.00	0.00
22	57.85	58.09	58.55	9.00	9.05	9.14
23	75.61	75.95	77.07	14.23	14.31	14.56
Total	869.35	869.41	866.83	145.88	145.59	144.33
South Llano						
26	2.40	2.06	2.09	0.21	0.18	0.19
27	4.03	3.14	3.15	0.39	0.29	0.29
30	4.73	4.37	4.40	0.30	0.24	0.24
31	14.02	18.53	11.91	2.11	3.00	1.68
32	0.09	0.06	0.06	0.00	0.00	0.00
33	59.87	54.31	54.28	10.02	8.91	8.91
34	14.22	13.48	13.41	1.92	1.77	1.76
35	21.86	22.14	22.12	2.42	2.50	2.50
36	11.60	10.27	10.22	1.34	1.09	1.09
37	4.93	3.93	3.90	0.44	0.20	0.20
38	1.62	1.71	1.73	0.02	0.02	0.02
39	39.02	37.09	37.38	5.25	4.77	4.82
40	1.33	1.40	1.40	0.10	0.11	0.11
41	19.96	21.43	21.51	2.58	2.77	2.77
43	40.17	41.50	41.48	6.25	6.39	6.39
44	196.95	195.19	198.11	5.95	5.89	5.99
45	22.61	23.58	22.72	3.28	3.47	3.30
46	45.85	45.85	46.24	6.24	6.24	6.36
48	139.42	139.40	138.50	26.27	26.28	26.02
49	244.48	257.05	252.63	45.86	48.29	47.46
Total	889.16	896.49	887.24	120.95	122.41	120.10
Llano						
24	94.34	95.24	97.85	17.17	17.39	18.04
Overall	**1852.85**	**1861.14**	**1851.92**	**283.98**	**285.37**	**282.44**

Appendix G: EDYS Model Output for Lower Deer Density in Riparian Zone

EDYS Results: Lower Deer Density in Riparian Zones

This scenario was simulated by 1) reducing the initial herbaceous and shrub biomass to 15% of the levels in the earlier riparian scenarios (to reflect overgrazing by deer along the riparian corridor) and 2) decreasing the deer density. Baseline (current conditions) for this scenario was considered to be one deer per two acres. The reduced density was set at one deer per 10 acres, or the equivalent density used in the upland scenarios. The average annual precipitation regime was used in both cases (baseline and reduced density). The reduced density scenario also began with herbaceous and shrub biomass set at 15% of the original levels.

Reducing deer density in the riparian zone decreased both average annual runoff and sediment loadings (Table 1). Runoff decreased by an average of 14 acre-feet per year and sediment loads decreased by 12% (65 tons per year). Reducing deer density to 10 acres per deer increased ET by 3% (338 acre-ft (ac-ft) per year). This was because of an increase in herbaceous plant production under the lighter deer stocking rate. The higher ET resulted in lower recharge under the lighter deer stocking rate. Compared to baseline (2 ac/deer), the lighter rate (10 ac/yr) reduced recharge by 39% (274 ac-ft per year). The difference between the change in ET (338 ac-ft) and the change in recharge (274 ac-ft) is the result of increased use of stored water in the vadose zone.

The reduction in deer scenario resulted in a 16% decrease (36 kg/yr) in nitrogen loading and a 12% decrease (41 kg/yr) in phosphorus loading compared to baseline (Table 3). These changes were primarily the result of the effect of reduced deer numbers on sediment loadings (Table 1).

Table 1. Simulated average annual runoff (m^3 and acre-feet) and average annual sediment load (m^3 and tons) from the riparian corridor under two deer densities, baseline (2 ac/deer) and reduced (10 ac/deer), average precipitation regime.

SubW	Runoff (m^3)		Runoff (acre-feet)		Sediments (m^3)		Sediments (tons)	
	2 ac/deer	10 ac/deer	2 ac/deer	10 ac/deer	2 ac/deer	10 ac/deer	2 ac/deer	10 ac/deer
North Llano								
01	6,290	6,224	5.10	5.05	0.82	0.81	1.18	1.16
02	291	226	0.24	0.18	0.00	0.00	0.00	0.00
04	50,426	42,789	40.88	34.69	21.82	12.49	31.26	17.90
05	4,716	4,913	3.82	3.98	0.68	0.64	0.97	0.92
06	0	0	0.00	0.00	0.00	0.00	0.00	0.00
07	3,954	3,983	3.21	3.23	0.24	0.24	0.34	0.34
08	2,297	2,342	1.86	1.90	0.19	0.17	0.27	0.24
09	35,003	34,785	28.38	28.20	34.13	24.10	48.91	34.53
10	31,160	27,707	25.26	22.46	18.48	14.84	26.48	21.27
13	6,713	6,815	5.44	5.52	1.67	1.52	2.40	2.18
14	5,858	5,800	4.75	4.70	5.35	4.46	7.66	6.39
15	41,094	38,993	33.32	31.61	17.83	15.75	25.56	22.57
16	32,863	33,744	26.64	27.36	23.84	22.25	34.16	31.89
17	167	167	0.14	0.14	0.01	0.00	0.01	0.00
18	42,370	43,705	34.35	35.43	31.17	29.20	44.67	41.84
19	7,098	7,120	5.75	5.77	11.00	10.52	15.76	15.08
21	140	66	0.11	0.05	0.00	0.00	0.00	0.00
22	21,051	20,732	17.07	16.81	14.01	11.87	20.07	17.01
23	28,006	27,647	22.70	22.41	15.10	14.32	21.64	20.52
Total	319,497	307,758	259.02	249.49	196.33	163.18	281.34	233.84
South Llano								
26	2,219	2,324	1.80	1.88	0.22	0.22	0.32	0.31
27	3,438	3,546	2.79	2.87	0.35	0.35	0.51	0.50
30	6,666	6,735	5.40	5.46	0.25	0.27	0.36	0.38
31	7,076	7,443	5.74	6.03	2.51	2.51	3.59	3.60
32	148	158	0.12	0.13	0.00	0.00	0.00	0.00
33	12,363	13,083	10.02	10.61	12.03	10.95	17.24	15.69
34	8,177	8,166	6.63	6.62	2.92	2.74	4.18	3.93
35	15,977	16,962	12.95	13.75	3.10	2.93	4.44	4.21
36	9,217	8,815	7.47	7.15	1.21	1.26	1.74	1.80
37	5,697	6,066	4.62	4.92	0.23	0.30	0.33	0.44
38	6,535	3,504	5.30	2.84	0.05	0.00	0.07	0.00
39	25,891	23,591	20.99	19.13	6.74	6.12	9.66	8.77
40	1,594	1,487	1.29	1.21	0.26	0.11	0.37	0.16
41	15,416	13,522	12.50	10.96	5.66	3.94	8.11	5.65
43	15,384	15,871	12.47	12.87	10.05	8.41	14.40	12.06
44	21,547	20,254	17.47	16.42	11.89	7.10	17.04	10.17
45	13,082	13,257	10.61	10.75	4.79	4.15	6.87	5.94
46	39,342	38,054	31.89	30.85	7.23	6.86	10.37	9.84
48	40,753	40,939	33.04	33.19	29.00	28.66	41.56	41.07
49	15,335	14,861	12.43	12.05	57.44	58.34	82.31	83.60
Total	265,857	258,638	215.53	209.69	155.93	145.22	223.47	208.12
Llano								
24	31,798	33,517	25.78	27.17	23.16	21.43	33.19	30.71
Overall	**617,152**	**599,913**	**500.33**	**486.35**	**375.42**	**329.83**	**538.00**	**472.67**

Table 2. Simulated average annual evapotranspiration (ET; m^3 and acre-feet) and recharge (m^3 and acre-feet) from the riparian corridor under two deer densities, baseline (2 ac/deer) and reduced (10 ac/deer), average precipitation regime.

SubW	ET (m^3)		ET (acre-feet)		Recharge (m^3)		Recharge (acre-feet)	
	2 ac/deer	10 ac/deer	2 ac/deer	10 ac/deer	2 ac/deer	10 ac/deer	2 ac/deer	10 ac/deer
North Llano								
01	461,555	477,432	374.19	387.06	34,999	21,393	28.37	17.34
02	423	440	0.34	0.36	36	21	0.03	0.02
04	605,749	619,437	491.09	502.19	43,324	32,293	35.12	26.18
05	218,449	223,380	177.10	181.10	17,224	12,993	13.96	10.53
06	434	442	0.35	0.36	27	20	0.02	0.02
07	111,110	113,593	90.08	92.09	8,042	5,873	6.52	4.76
08	211,922	217,187	171.81	176.08	16,070	11,510	13.03	9.33
09	652,539	664,883	529.02	539.03	48,357	38,386	39.20	31.12
10	675,793	684,582	547.87	555.00	40,333	32,286	32.70	26.17
13	242,881	248,205	196.91	201.22	12,159	7,352	9.86	5.96
14	128,279	133,136	104.00	107.93	7,332	3,721	5.94	3.02
15	698,309	722,774	566.13	585.96	36,707	15,981	29.76	12.96
16	577,983	594,991	468.58	482.37	28,694	13,901	23.26	11.27
17	6,547	6,724	5.31	5.45	358	196	0.29	0.16
18	553,764	568,723	448.94	461.07	25,633	13,281	20.78	10.77
19	376,194	387,955	304.99	314.52	21,806	11,325	17.68	9.18
21	878	910	0.71	0.74	56	29	0.05	0.02
22	427,147	444,452	346.29	360.32	23,869	9,638	19.35	7.81
23	223,053	230,099	180.83	186.54	9,674	4,414	7.84	3.58
Total	6,173,009	6,339,345	5,004.54	5,139.39	374,700	234,613	303.76	190.20
South Llano								
26	232,698	244,431	188.65	198.16	22,424	12,676	18.18	10.28
27	374,700	390,719	303.77	316.76	32,589	18,666	26.42	15.13
30	304,196	315,759	246.62	255.99	24,594	14,956	19.94	12.13
31	400,908	406,886	325.02	329.87	35,687	30,737	28.93	24.92
32	2,503	2,574	2.03	2.09	172	106	0.14	0.09
33	553,941	574,318	449.09	465.61	45,691	28,845	37.04	23.38
34	489,134	502,442	396.55	407.34	48,578	37,932	39.38	30.75
35	501,536	525,137	406.60	425.74	41,913	22,473	33.98	18.22
36	374,314	389,552	303.46	315.82	28,108	15,098	22.79	12.24
37	167,772	175,055	136.01	141.92	12,124	6,290	9.83	5.10
38	2,739	2,849	2.22	2.31	217	128	0.18	0.10
39	366,810	379,834	297.38	307.94	22,470	11,711	18.22	9.49
40	300,695	316,190	243.78	256.34	21,399	7,804	17.35	6.33
41	324,540	340,660	263.11	276.18	20,559	7,707	16.67	6.25
43	393,099	408,895	318.69	331.50	26,358	13,624	21.37	11.05
44	52,512	53,909	42.57	43.70	1,751	944	1.42	0.77
45	173,902	178,104	140.98	144.39	9,424	5,939	7.64	4.82
46	343,786	353,726	278.71	286.77	18,916	11,501	15.34	9.32
48	556,892	567,801	451.48	460.32	30,178	21,065	24.47	17.08
49	551,880	567,815	447.42	460.34	34,967	21,302	28.35	17.27
Total	6,468,557	6,696,656	5,244.14	5,429.09	478,119	289,504	387.64	234.72
Llano								
24	492,586	502,704	399.35	407.55	22,801	14,046	18.49	11.39
Overall	**13,134,152**	**13,538,705**	**10,648.03**	**10,976.03**	**875,620**	**538,163**	**709.89**	**436.31**

Table 3. Simulated average annual available nitrogen and phosphorus loads (kg) entering the North and the South Llano Rivers in runoff and sediments from the riparian zones under two deer densities, baseline (2 ac/deer) and reduced (10 ac/deer), under the average precipitation regime.

SubW	Nitrogen		Phosphorus	
	2 ac/deer	10 ac/deer	2 ac/deer	10 ac/deer
North Llano				
01	7.44	7.33	0.78	0.77
02	0.15	0.11	0.00	0.00
04	124.24	78.09	20.10	11.58
05	5.72	5.62	0.64	0.61
06	0.02	0.01	0.00	0.00
07	3.12	3.13	0.24	0.24
08	2.06	1.99	0.18	0.16
09	170.91	125.70	31.23	22.10
10	100.67	82.20	16.97	13.65
13	11.30	10.65	1.56	1.42
14	25.99	22.13	4.90	4.09
15	105.56	94.60	16.43	14.53
16	129.03	122.00	21.86	20.42
17	0.14	0.08	0.01	0.00
18	159.48	151.37	28.58	26.79
19	58.03	55.70	10.04	9.61
21	0.07	0.03	0.00	0.00
22	78.52	67.99	12.85	10.90
23	75.39	72.02	13.88	13.17
Total	1057.82	900.75	180.25	150.04
South Llano				
26	2.27	2.30	0.21	0.21
27	3.54	3.59	0.34	0.34
30	4.60	4.70	0.26	0.28
31	14.97	15.18	2.32	2.33
32	0.07	0.08	0.00	0.00
33	65.36	60.38	11.01	10.03
34	17.94	17.11	2.69	2.54
35	24.00	23.65	2.90	2.76
36	10.88	10.91	1.15	1.19
37	3.97	4.51	0.24	0.31
38	3.52	1.75	0.08	0.02
39	45.47	41.32	6.26	5.69
40	2.27	1.38	0.25	0.11
41	36.31	26.69	5.23	3.66
43	56.69	48.96	9.22	7.74
44	358.35	217.59	10.93	6.56
45	28.55	25.68	4.43	3.84
46	49.38	47.22	6.78	6.44
48	141.69	140.37	26.60	26.29
49	277.96	281.94	52.35	53.16
Total	1147.79	975.31	143.25	133.50
Llano				
24	111.12	104.87	21.23	19.67
Overall	**2,316.73**	**1,980.93**	**344.73**	**303.21**

Appendix H: EDYS Model Output for Brush Control, Prescribed Burning and Prescribed Grazing Scenario

Table 1. Summary of runoff and sediment results (average annual amounts, total for entire watershed), revised EDYS simulations (Aug 2015).

Scenario	Runoff (ac-ft)	Ratio to Baseline	Sediments (tons)	Ratio to Baseline
Baseline (earlier version)	87,411		39,740	
Baseline (revised version)	87,491	1.00	37,940	1.00
Brush control + fire + grazing mgt	86,508	0.99	22,273	0.59
Prescribed fire	88,711	1.01	24,144	0.64

Table 2. Average annual runoff, sediment loads, and evapotranspiration (ET) for the Upper Llano and Lower Llano combined watershed, under three land management scenarios: baseline (Base), brush control + fire + grazing management (Mngt), prescribed fire (Fire). Values are annual means of 25-year EDYS simulations.

Subwatershed	Annual Runoff (ac-ft)			Annual Sediments (tons)		
	Base	Mngt	Fire	Base	Mngt	Fire
North Llano						
01	3,480.1	3,142.5	3,211.2	571.6	396.1	451.5
02	209.9	149.9	199.3	224.4	143.4	211.9
03	644.9	264.6	364.5	961.2	356.9	512.4
04	6,008.4	6,626.0	6,654.9	228.4	131.0	162.6
05	940.5	777.6	835.0	1,348.6	1,131.2	1,169.0
06	1,071.8	924.5	996.9	1,623.5	1,401.2	1,509.7
07	1,026.3	957.8	1,081.4	403.2	333.0	440.5
08	2,542.2	2,134.7	2,202.6	326.1	135.6	187.9
09	404.4	331.7	360.5	125.7	57.7	74.6
10	1,199.5	1,001.6	979.7	1,571.1	1,293.2	1,245.3
11	214.7	108.0	101.2	230.7	76.3	64.5
12	2,393.8	2,034.5	2,144.0	2,154.9	1,603.3	1,688.2
13	7,122.8	9,924.3	10,905.0	36.4	9.8	10.0
14	518.0	160.8	190.4	742.1	178.0	224.1
15	153.9	74.3	75.2	122.2	15.0	12.2
16	167.9	99.8	102.3	89.5	18.3	17.0
17	3,631.6	4,261.4	4,638.3	1,370.8	227.3	151.3
18	1,637.3	935.4	918.0	1,709.3	746.2	680.7
19	3,986.5	5,591.5	5,812.3	410.8	146.5	133.8
20	1,195.5	267.5	290.1	1,690.3	240.6	272.5
21	8,768.3	9,520.1	9,602.3	2,084.9	1,236.3	1,173.9
22	221.2	89.1	86.9	189.0	8.3	2.5
23	506.9	335.2	330.0	589.7	351.7	343.1
Sum	48,046.6	49,712.7	52,081.7	18,804.2	10,236.7	10,739.4
South Llano						
26	195.9	160.0	358.7	161.7	125.8	438.7
27	7,247.6	7,226.0	6,884.9	104.7	93.8	107.2
28	302.7	173.9	189.9	373.7	178.8	203.4
29	4,382.9	4,391.7	4,632.7	534.4	425.9	477.1
30	4,061.8	4,157.0	4,329.7	112.0	38.5	42.1
31	80.5	50.9	55.4	43.2	3.1	5.6
32	477.7	407.6	363.2	593.0	499.6	416.6
33	490.5	411.6	430.9	192.5	121.8	118.2
34	221.0	131.2	124.5	190.9	69.6	61.1
35	1,252.9	2,015.1	1,283.9	43.4	30.6	25.0
36	645.0	223.1	399.2	939.8	266.9	552.2
37	116.0	93.4	90.4	86.0	56.2	53.6
38	1,865.1	1,866.8	1,962.4	2,029.7	1,827.1	1,848.8
39	2,034.8	2,271.0	2,468.4	307.3	281.0	309.5
40	416.6	301.0	268.4	551.1	380.0	332.2
41	3,034.6	3,501.0	3,275.3	203.6	55.6	58.1
42	349.7	197.0	220.8	482.2	242.7	284.6
43	3,832.7	3,925.5	3,542.1	612.2	217.4	182.7
44	436.4	257.0	246.4	558.1	284.6	274.9
45	1,826.0	1,514.5	1,473.1	2,790.1	2,300.5	2,236.0
46	1,306.3	970.4	1,004.5	1,845.0	1,300.1	1,350.9
47	1,799.2	1,466.4	1,434.5	2,750.2	2,237.2	2,188.3
48	598.6	357.0	372.0	750.2	371.3	407.5
49	906.1	194.9	385.3	1,237.3	121.3	432.6
Sum	38,150.6	36,264.0	35,796.5	17,492.2	11,529.3	12,407.1
Confluence						
24	252.9	157.3	149.6	154.5	55.4	49.4
25	1,040.9	374.3	682.9	1,489.4	452.1	947.8
Sum	1,293.8	531.6	832.5	1,643.9	507.5	997.1
Overall	**87,490.9**	**86,508.4**	**88,710.8**	**37,940.3**	**22,273.5**	**24,143.6**

Table 3. Average annual evapotranspiration (ET), ET as a proportion of annual precipitation (PPT), and groundwater-use (GW) by vegetation for the Upper Llano and Lower Llano combined watershed, under three management scenarios: baseline (Base), brush control + fire + grazing management (Mngt), prescribed fire (Fire). Values are annual means of 25-year EDYS simulations.

Subwatershed	Annual ET (ac-ft)			Proportion of Annual PPT			Groundwater Use (ac-ft)		
	Base	Mngt	Fire	Base	Mngt	Fire	Base	Mngt	Fire
North Llano									
01	44,730	45,732	47,290	0.866	0.885	0.885	22	22	0
02	30,852	31,379	32,478	0.883	0.898	0.899	0	0	0
03	42,382	43,388	44,897	0.835	0.855	0.855	0	0	0
04	54,883	56,549	58,419	0.809	0.834	0.833	117	58	58
05	65,956	67,224	69,532	0.874	0.891	0.891	65	0	33
06	44,809	45,638	47,165	0.883	0.899	0.899	0	0	0
07	35,688	36,349	37,533	0.883	0.899	0.898	0	0	0
08	42,796	43,754	45,360	0.885	0.904	0.907	21	0	21
09	53,113	54,365	56,218	0.840	0.860	0.860	136	27	82
10	59,129	57,672	59,450	0.847	0.826	0.830	3,934	495	466
11	25,535	26,302	27,200	0.819	0.844	0.850	0	0	0
12	53,560	55,265	56,738	0.865	0.892	0.893	181	26	26
13	23,833	19,971	20,383	1.133	0.949	0.944	5,162	711	711
14	46,444	47,881	49,590	0.782	0.806	0.814	25	25	0
15	43,033	43,475	44,378	0.854	0.863	0.859	1,577	273	294
16	40,768	39,757	40,520	0.892	0.870	0.864	3,356	400	400
17	47,445	48,952	49,980	0.867	0.894	0.890	297	91	91
18	63,678	66,541	67,763	0.826	0.863	0.861	804	161	161
19	36,248	37,924	38,603	0.802	0.839	0.837	603	57	75
20	52,555	55,331	56,338	0.805	0.848	0.846	82	54	54
21	18,425	19,438	19,786	0.796	0.840	0.838	58	39	48
22	28,460	29,412	29,952	0.835	0.863	0.862	369	142	142
23	25,863	29,906	27,409	0.859	0.893	0.892	666	163	176
SUM	980,184	999,206	1,026,979				17,474	2,745	2,840
South Llano									
26	65,027	65,204	67,734	0.903	0.905	0.917	0	0	0
27	44,010	44,470	45,671	0.899	0.909	0.910	0	0	0
28	51,712	52,300	53,805	0.898	0.908	0.911	0	0	24
29	22,588	22,650	23,506	0.894	0.896	0.907	31	10	31
30	48,735	49,380	51,070	0.899	0.911	0.918	22	22	400
31	29,258	29,071	30,605	0.896	0.890	0.914	40	13	94
32	32,327	32,835	33,819	0.874	0.888	0.890	15	0	0
33	61,299	61,160	63,798	0.905	0.903	0.919	361	222	417
34	56,045	55,613	58,864	0.891	0.884	0.913	0	0	0
35	32,702	32,836	34,232	0.889	0.893	0.908	0	0	0
36	60,349	59,911	63,250	0.890	0.884	0.910	0	0	0
37	21,524	21,397	22,694	0.891	0.886	0.917	127	10	176
38	59,401	59,855	62,075	0.897	0.904	0.914	0	0	0
39	24,646	24,817	25,837	0.880	0.886	0.901	45	23	23
40	60,193	59,097	63,257	0.881	0.865	0.908	0	0	0
41	26,847	26,897	28,276	0.873	0.875	0.902	13	0	25
42	42,303	41,912	44,274	0.891	0.883	0.915	0	0	20
43	71,395	68,620	74,996	0.889	0.854	0.916	0	0	0
44	47,943	47,397	50,561	0.869	0.859	0.900	23	23	46
45	42,109	43,770	44,863	0.803	0.835	0.839	219	22	22
46	37,532	38,036	38,945	0.808	0.819	0.823	1,568	58	77
47	31,250	32,758	33,578	0.794	0.833	0.837	33	0	0
48	35,543	32,650	33,433	0.927	0.852	0.856	5,210	240	256
49	53,568	55,733	57,049	0.814	0.847	0.851	603	164	164
SUM	1,058,305	1,058,368	1,106,284				8,310	807	1,773
Confluence									
24	20,380	21,175	21,614	0.909	0.945	0.945	1,010	168	178
25	59,090	61,758	62,885	0.831	0.869	0.867	534	208	237
SUM	79,470	82,933	84,499				1,544	376	415
Overall	**2,117,959**	**2,140,507**	**2,217,761**				**27,327**	**3,929**	**5,027**

Table 4. Comparison of annual hydrology responses (acre-feet) between baseline (Base) and the brush control (BC11) EDYS scenario, Upper Llano and Lower Llano watershed.

Year	Precipitation	Evapotranspiration Base	Evapotranspiration BC11	Evaporation Base	Evaporation BC11	Transpiration Base	Transpiration BC11
01	3,234,585	2,455,164	2,532,865	646,994	721,936	1,808,170	1,810,928
02	2,532,835	1,919,934	2,142,515	250,760	412,432	1,669,175	1,730,084
03	2,295,899	1,793,721	1,910,336	230,247	374,264	1,563,473	1,536,072
04	2,347,852	1,949,391	2,040,316	228,775	392,226	1,720,616	1,648,089
05	1,522,368	1,450,391	1,487,183	216,075	332,990	1,234,317	1,154,192
06	1,707,633	1,408,116	1,513,098	197,351	251,489	1,210,764	1,261,609
07	2,393,822	2,168,525	2,207,337	243,606	361,791	1,924,919	1,845,548
08	2,156,880	1,736,289	1,769,493	296,714	525,215	1,439,574	1,244,278
09	2,437,321	2,235,940	2,304,519	307,221	486,834	1,928,720	1,817,686
10	2,291,252	1,780,937	1,910,106	318,174	463,657	1,462,763	1,446,449
11	2,830,283	2,346,890	2,452,232	380,798	634,634	1,966,092	1,817,599
12	2,991,802	2,653,402	2,636,152	377,930	561,253	2,275,472	2,074,899
13	2,095,379	2,122,361	2,104,607	398,928	529,560	1,723,432	1,575,047
14	2,736,233	2,392,220	2,409,195	449,441	586,588	1,942,778	1,822,607
15	2,204,697	2,109,720	2,047,198	478,442	600,268	1,631,278	1,446,931
16	2,786,934	2,383,719	2,331,594	487,865	637,248	1,895,854	1,694,345
17	3,322,400	2,713,865	2,684,534	547,031	700,811	2,166,834	1,983,723
18	2,674,784	2,629,692	2,545,867	620,710	767,230	2,008,982	1,778,637
19	3,189,685	2,910,573	2,870,753	677,792	838,800	2,232,780	2,031,953
20	2,041,620	1,945,146	1,853,346	389,904	439,850	1,555,242	1,413,495
21	2,178,107	2,036,716	1,918,807	405,436	467,975	1,631,281	1,450,833
22	2,148,151	2,050,331	1,939,992	418,338	490,160	1,631,993	1,449,832
23	2,377,228	2,117,002	1,992,705	369,060	431,552	1,747,943	1,561,152
24	2,937,044	2,670,177	2,487,451	519,245	627,086	2,150,933	1,860,365
25	1,858,522	1,651,890	1,519,967	438,825	470,263	1,213,064	1,049,705
SUM	61,293,316	53,632,112	53,612,168	9,895,662	13,106,112	43,736,449	40,506,058
MEAN	2,451,755	2,145,285	2,144,487			25,807,866	23,193,524
SUM(12-25)		32,386,814	31,342,168		8,148,730		
MEAN		2,313,344	2,238,726				

Table 5. Annual evapotranspiration (acre-feet) from Subwatershed 13 under baseline and brush control EDYS scenarios, Upper Llano and Lower Llano watershed. SW13 was treated in the first year.

Year	SW13	
	Baseline	Brush Control
01	22,691	23,392
02	17,398	19,814
03	16,523	17,411
04	18,268	19,344
05	12,539	13,294
06	12,453	13,675
07	18,829	20,838
08	17,178	17,949
09	20,660	22,058
10	16,731	19,112
11	24,647	25,030
12	26,390	25,436
13	27,934	20,003
14	36,226	22,925
15	47,187	19,818
16	52,509	23,880
17	47,578	26,526
18	42,756	23,693
19	43,476	26,618
20	34,641	17,885
21	34,117	18,410
22	33,973	19,199
23	34,263	20,651
24	37,290	24,153
25	28,421	15,698
Mean	28,987	20,673

Table 6. Effect of brush control + grazing management (Mngt) on evaporation (ET), runoff, groundwater transpiration (GWT) and sediment loadings, Upper Llano EDYS model.

Subwatershed	ET (ac-ft) Mngt – Baseline	Runoff (ac-ft) Mngt – Baseline	GWT (ac-ft) Mngt – Baseline	Sediments (tons) Mngt – Baseline
North Llano				
01	1,002	- 337	0	- 176
02	527	- 50	0	- 81
03	1,006	- 380	0	- 604
04	1,666	618	- 59	- 97
05	1,268	- 163	- 65	- 217
06	829	- 147	0	- 222
07	661	- 68	0	- 70
08	958	- 407	- 21	- 190
09	1,252	- 73	- 109	- 68
10	- 1,457	- 198	- 3,439	- 278
11	767	- 107	0	- 124
12	1,705	- 359	- 155	- 552
13	- 3,862	2,802	- 4,451	- 26
14	1,437	- 357	0	- 564
15	442	- 80	- 1,304	- 107
16	- 1,011	- 68	- 2,956	- 71
17	1,507	630	- 206	- 1,144
18	2,863	- 702	- 643	- 963
19	1,676	1,605	- 546	- 264
20	2,776	- 928	- 28	- 1,450
21	1,013	752	- 19	- 849
22	952	- 132	- 227	- 181
23	4,043	- 172	- 503	- 238
South Llano				
26	177	- 36	0	- 36
27	460	- 22	0	- 11
28	588	- 129	0	- 195
29	62	9	- 21	- 108
30	645	97	0	- 73
31	- 187	- 30	- 27	- 40
32	508	- 70	- 15	- 93
33	- 139	- 79	- 139	- 71
34	- 432	- 90	0	- 121
35	134	762	0	- 13
36	- 438	- 422	0	- 673
37	- 127	- 23	- 117	- 30
38	454	2	0	- 243
39	171	236	- 22	- 26
40	- 1,096	- 116	0	- 171
41	50	466	- 13	- 148
42	- 391	- 153	0	- 239
43	- 2,775	93	0	- 395
44	- 546	- 179	0	- 273
45	1,261	311	- 197	- 489
46	504	- 336	- 1,510	- 545
47	1,508	- 333	- 33	- 513
48	- 2,893	- 242	- 4,970	- 379
49	1,165	- 711	- 439	- 1,116
Confluence				
24	795	- 96	- 842	- 99
25	2,668	- 667	- 326	- 1,037

Table 7. Average annual runoff and sediment loads for the Upper Llano Watershed under three land management scenarios: baseline, brush control + fire + grazing management (BCGM), and grazing management only (GrzMgt). Values are annual means of 25-year EDYS simulations.

Subwatershed	Annual Runoff (ac-ft)			Annual Sediments (tons)		
	Baseline	BCGM	GrzMgt	Baseline	BCGM	GrzMgt
North Llano						
01	3,480.1	3,142.5	3,497.2	571.6	396.1	583.6
02	209.9	149.9	209.6	224.4	143.4	223.5
03	644.9	264.6	645.1	961.2	356.9	961.4
04	6,008.4	6,626.0	6,021.6	228.4	131.0	227.2
05	940.5	777.6	945.1	1,348.6	1,131.2	1,355.1
06	1,071.8	924.5	1,074.9	1,623.5	1,401.5	1,628.2
07	1,026.3	957.8	1,029.7	403.2	333.0	409.1
08	2,542.2	2,134.7	2,539.9	326.1	135.6	329.1
09	404.4	331.7	403.2	125.7	57.7	123.6
10	1,199.5	1,001.6	1,187.8	1,571.1	1,293.2	1,552.2
11	214.7	108.0	210.7	230.7	76.3	223.7
12	2,393.8	2,034.5	2,415.5	2,154.9	1,603.3	2,156.5
13	7,122.8	9,924.3	7,293.3	36.4	9.8	27.9
14	518.0	160.8	569.6	742.1	178.0	825.4
15	153.9	74.3	152.3	122.2	15.0	119.3
16	167.9	99.8	160.0	89.5	18.3	77.9
17	3,631.6	4,261.4	3,682.9	1,370.8	227.3	1,352.3
18	1,637.3	935.4	1,551.2	1,709.3	746.2	1,614.5
19	3,986.5	5,591.5	4,668.5	410.8	146.5	398.8
20	1,195.5	267.5	1,356.9	1,690.3	240.6	1,951.0
21	8,768.3	9,520.1	7,707.1	2,084.9	1,236.3	1,473.5
22	221.2	89.1	178.1	189.0	8.3	121.3
23	506.9	335.2	473.2	589.7	351.7	538.7
Sum	48,046.6	49,712.7	47,973.3	18,804.2	10,236.7	18,273.8
South Llano						
26	195.9	160.0	196.2	161.7	125.8	161.9
27	7,247.6	7,226.0	7,249.6	104.7	93.8	105.2
28	302.7	173.9	304.0	373.7	178.8	375.4
29	4,382.9	4,391.7	4,382.5	534.4	425.9	534.6
30	4,061.8	4,157.0	4,064.3	112.0	38.5	116.1
31	80.5	50.9	81.9	43.2	3.1	45.6
32	477.7	407.6	478.0	593.0	499.6	593.2
33	490.5	411.6	490.2	192.5	121.8	191.1
34	221.0	131.2	229.2	190.9	69.6	202.8
35	1,252.9	2,015.1	1,251.5	43.4	30.6	44.7
36	645.0	223.1	636.8	939.8	266.9	926.0
37	116.0	93.4	117.0	86.0	56.2	87.4
38	1,865.1	1,866.8	1,865.6	2,029.7	1,827.1	2,043.6
39	2,034.8	2,271.0	2,018.9	307.3	281.0	306.4
40	416.6	301.0	418.5	551.1	380.0	553.8
41	3,034.6	3,501.0	3,278.7	203.6	55.6	198.3
42	349.7	197.0	344.9	482.2	242.7	474.2
43	3,832.7	3,925.5	3,844.1	612.2	217.4	556.3
44	436.4	257.0	420.6	558.1	284.6	532.1
45	1,826.0	1,514.5	1,831.6	2,790.1	2,300.5	2,799.6
46	1,306.3	970.4	1,307.7	1,845.0	1,300.1	1,846.2
47	1,799.2	1,466.4	1,801.7	2,750.2	2,237.2	2,759.2
48	598.6	357.0	447.1	750.2	371.3	507.5
49	906.1	194.9	910.5	1,237.3	121.3	1,244.7
Sum	38,150.6	36,264.0	37,971.1	17,492.2	11,529.3	17,205.9
Confluence						
24	252.9	157.3	247.3	154.5	55.4	152.3
25	1,040.9	374.3	1,030.8	1,489.4	452.1	1,472.7
Sum	1,293.8	531.6	1,278.1	1,643.9	507.5	1,624.9
Overall	**87,490.9**	**86,508.4**	**87,222.5**	**37,940.3**	**22,273.5**	**37,104.6**

Table 8. Average annual evapotranspiration (ET) and groundwater use by vegetation for the Upper Llano Watershed under three land management scenarios: baseline, brush control + fire + grazing management (BCGM), and grazing management only (GrzMgt). Values are annual means of 25-year EDYS simulations.

Subwatershed	Evapotranspiration (ac-ft)			Groundwater Use (ac-ft)		
	Baseline	BCGM	GrzMgt	Baseline	BCGM	GrzMgt
North Llano						
01	44,730	45,732	44,708	22	22	22
02	30,852	31,379	30,581	0	0	0
03	42,382	43,388	42,338	0	0	0
04	54,883	56,549	54,854	117	58	88
05	65,956	67,224	65,664	65	0	65
06	44,809	45,638	44,678	0	0	0
07	35,688	36,349	35,653	0	0	0
08	42,796	43,754	42,712	21	0	21
09	53,113	54,365	53,058	136	27	136
10	59,129	57,672	58,983	3,934	495	3,847
11	25,535	26,302	25,522	0	0	0
12	53,560	55,265	53,379	181	26	78
13	23,833	19,971	20,691	5,162	711	1,940
14	46,444	47,881	46,444	25	25	25
15	43,033	43,475	42,886	1,577	273	1,472
16	40,768	39,757	40,558	3,356	400	3,165
17	47,445	48,952	47,353	297	91	274
18	63,678	66,541	62,971	804	161	354
19	36,248	37,924	36,135	603	57	546
20	52,555	55,331	52,528	82	54	54
21	18,425	19,438	18,531	58	39	48
22	28,460	29,412	28,303	369	142	156
23	25,863	29,906	25,436	666	163	402
Sum	980,184	999,206	973,965	17,474	2,745	12,693
South Llano						
26	65,027	65,204	64,939	0	0	0
27	44,010	44,470	43,930	0	0	0
28	51,712	52,300	51,618	0	0	0
29	22,588	22,650	22,546	31	10	31
30	48,735	49,380	48,691	22	22	22
31	29,258	29,071	29,138	40	13	27
32	32,327	32,835	32,265	15	0	0
33	61,299	61,160	61,243	361	222	361
34	56,045	55,613	55,689	0	0	0
35	32,702	32,836	32,613	0	0	0
36	60,349	59,911	60,130	0	0	0
37	21,524	21,397	21,455	127	10	117
38	59,401	59,855	59,321	0	0	0
39	24,646	24,817	24,601	45	23	45
40	60,193	59,097	59,884	0	0	0
41	26,847	26,897	26,796	13	0	13
42	42,303	41,912	42,049	0	0	0
43	71,395	68,620	71,230	0	0	0
44	47,943	47,397	47,807	23	23	23
45	42,109	43,770	42,044	219	22	219
46	37,532	38,036	37,339	1,568	58	1,452
47	31,250	32,758	31,201	33	0	33
48	35,543	32,650	31,979	5,210	240	1,630
49	53,568	55,733	53,430	603	164	576
Sum	1,058,305	1,058,368	1,051,938	8,310	807	4,549
Confluence						
24	20,380	21,175	19,829	1,010	168	888
25	59,090	61,758	58,941	534	208	504
Sum	79,470	82,933	78,770	1,544	376	1,392
Overall	**2,117,959**	**2,140,507**	**2,104,673**	**27,327**	**3,929**	**18,634**

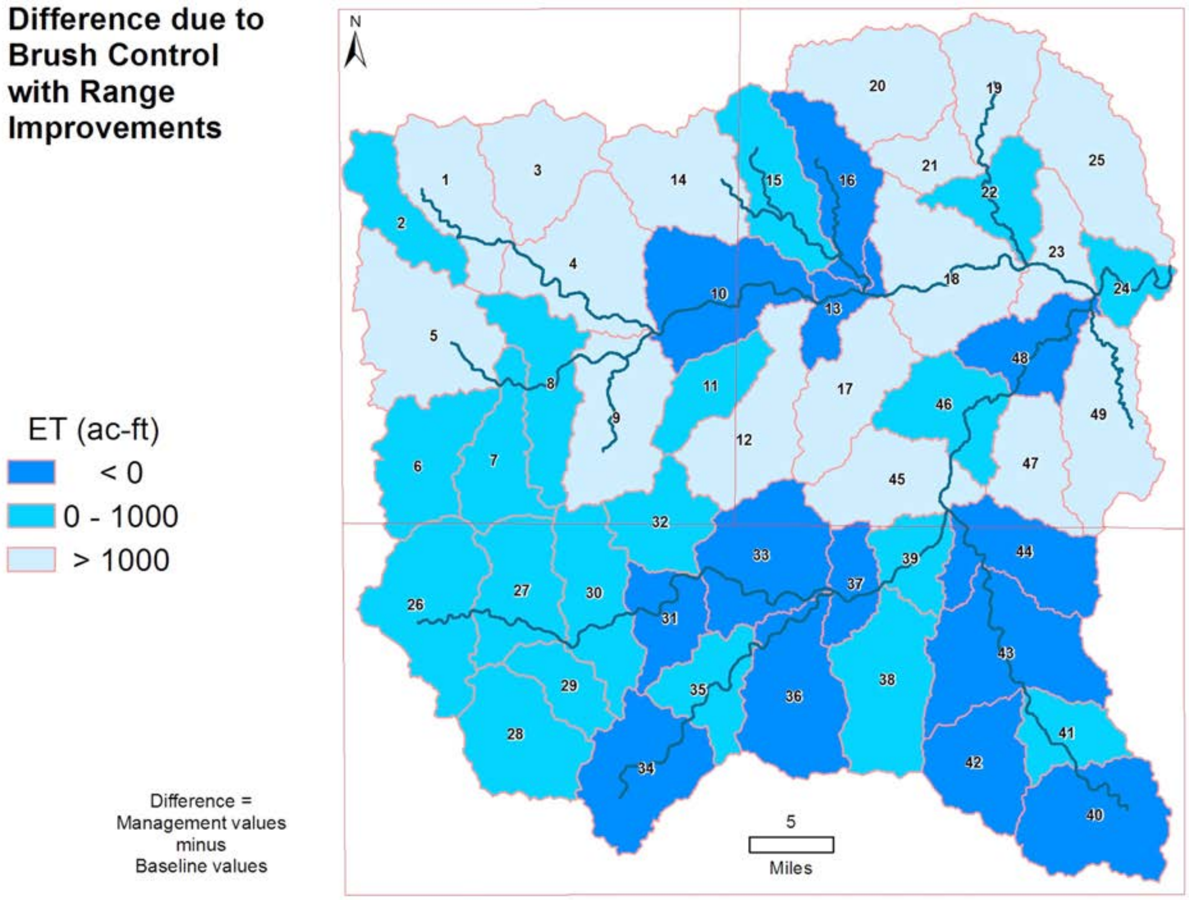
Table 9. Average total nitrogen and total phosphorus loadings for the Upper Llano Watershed under three land management scenarios: baseline, brush control + fire + grazing management (BCGM), and grazing management only (GrzMgt). Values are annual means of 25-year EDYS simulations.

Subwatershed	Nitrogen Loadings (tons)			Phosphorus Loadings (tons)		
	Baseline	BCGM	GrzMgt	Baseline	BCGM	GrzMgt
North Llano						
01	4.533	3.638	4.590	0.424	0.299	0.432
02	0.996	0.647	0.993	0.158	0.101	0.158
03	4.235	1.589	4.235	0.677	0.252	0.677
04	4.968	5.011	4.972	0.201	0.137	0.200
05	5.954	4.987	5.983	0.950	0.797	0.955
06	7.246	6.253	7.265	1.144	0.987	1.147
07	2.295	1.971	2.321	0.289	0.240	0.293
08	2.919	1.946	2.928	0.246	0.109	0.248
09	0.754	0.445	0.745	0.091	0.043	0.089
10	6.957	5.736	6.875	1.108	0.912	1.095
11	1.044	0.371	1.014	0.163	0.054	0.158
12	9.786	7.453	9.806	1.525	1.136	1.526
13	4.958	6.778	5.047	0.074	0.074	0.069
14	3.318	0.821	3.686	0.523	0.126	0.582
15	0.588	0.110	0.576	0.087	0.011	0.085
16	0.466	0.140	0.415	0.064	0.013	0.056
17	7.517	3.734	7.483	0.984	0.188	0.972
18	7.559	3.450	7.143	1.208	0.529	1.141
19	4.351	4.387	4.767	0.315	0.141	0.311
20	7.501	1.134	8.642	1.191	0.170	1.375
21	14.253	11.389	11.100	1.519	0.930	1.084
22	0.869	0.092	0.582	0.134	0.006	0.086
23	2.419	1.465	2.217	0.416	0.248	0.380
SUM	105.486	73.547	103.385	13.491	7.503	13.119
South Llano						
26	0.937	0.734	0.938	0.115	0.089	0.115
27	5.490	5.417	5.495	0.123	0.115	0.123
28	2.206	1.075	2.216	0.264	0.126	0.265
29	5.929	5.336	5.930	0.404	0.328	0.404
30	3.358	3.031	3.381	0.106	0.055	0.109
31	0.292	0.052	0.306	0.031	0.003	0.032
32	3.083	2.601	3.084	0.418	0.353	0.419
33	1.329	0.910	1.321	0.138	0.088	0.137
34	1.197	0.471	1.267	0.135	0.050	0.143
35	1.092	1.539	1.098	0.039	0.035	0.040
36	5.632	1.626	5.550	0.662	0.188	0.653
37	0.553	0.374	0.561	0.061	0.040	0.062
38	12.659	11.523	12.737	1.433	1.292	1.443
39	3.000	3.022	2.984	0.229	0.212	0.228
40	3.249	2.250	3.265	0.389	0.268	0.390
41	3.296	2.667	3.251	0.165	0.063	0.161
42	2.927	1.488	2.880	0.340	0.171	0.334
43	5.961	3.860	5.663	0.455	0.179	0.416
44	3.063	1.585	2.923	0.394	0.201	0.375
45	12.038	9.932	12.079	1.965	1.621	1.972
46	8.132	5.764	8.138	1.300	0.917	1.301
47	11.639	9.470	11.674	1.937	1.576	1.944
48	3.191	1.621	2.187	0.529	0.262	0.358
49	5.425	0.604	5.457	0.872	0.086	0.877
SUM	105.678	76.952	104.385	12.504	8.318	12.301
Confluence						
24	0.635	0.273	0.625	0.110	0.040	0.108
25	6.435	1.993	6.364	1.050	0.319	1.038
SUM	7.070	2.266	6.989	1.160	0.359	1.146
Overall	**218.234**	**152.765**	**214.759**	**27.155**	**16.180**	**26.566**

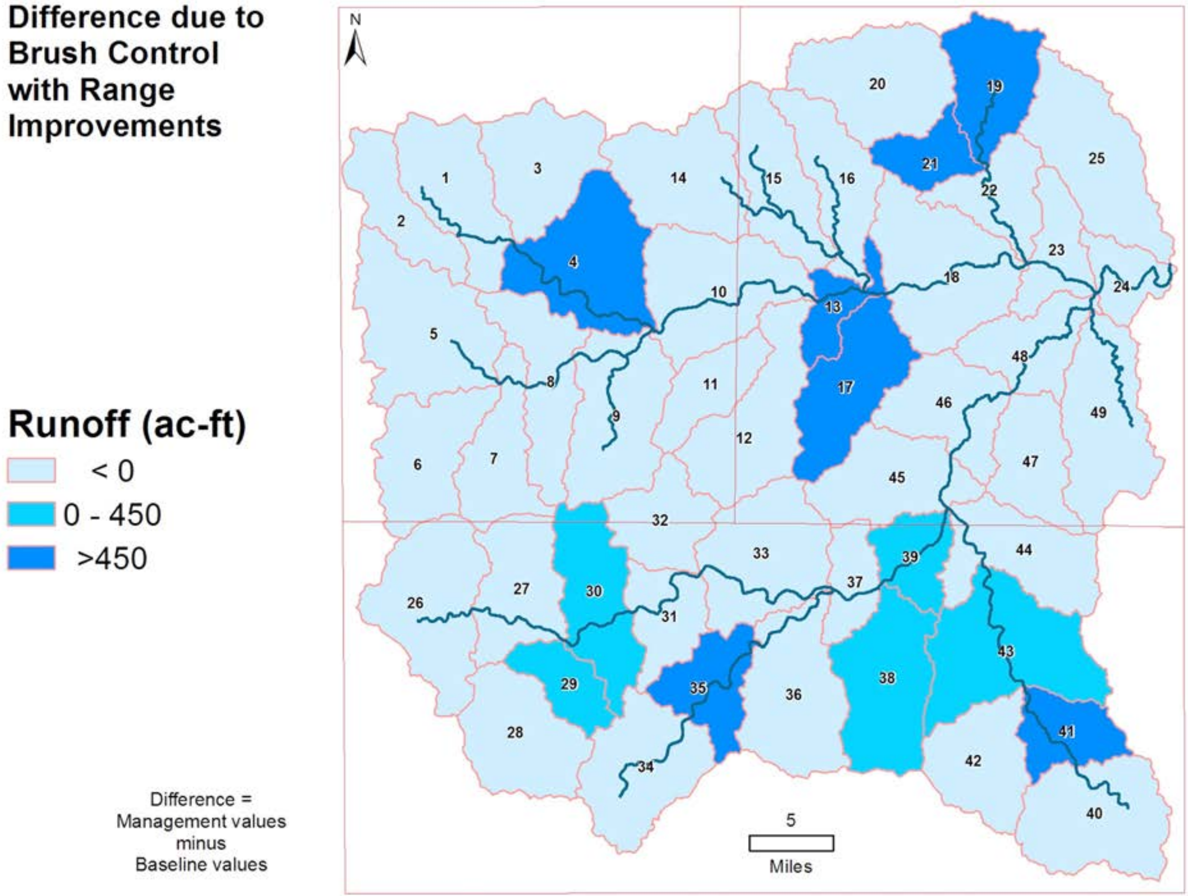
Index of Subwatersheds for Upper Llano River

EDYS_watershed	HUC12	Name
1	120902020107	Headwaters North Llano River
2	120902020106	Allison Ranch
3	120902020108	Buffalo Draw
4	120902020109	Tenmile Draw-North Llano River
5	120902020101	Headwaters Eightmile Draw
6	120902020102	Bull Hollow
7	120902020103	Tenmile Draw-Eightmile Draw
8	120902020104	Live Oak Draw-Eightmile Draw
9	120902020105	Eightmile Draw-Dry Llano River
10	120902020201	Bell Hollow-North Llano River
11	120902020202	West Maynard Creek
12	120902020203	Maynard Creek
13	120902020207	Frog Creek-North Llano River
14	120902020204	Upper West Copperas Creek
15	120902020205	Lower West Copperas Creek
16	120902020206	East Copperas Creek-Copperas Creek
17	120902020208	Bois d’Arc Creek
18	120902020301	Stark Creek-North Llano River
19	120902020304	Upper Bear Creek
20	120902020302	Upper West Bear Creek
21	120902020303	Lower West Bear Creek
22	120902020305	Lower Bear Creek
23	120902020306	Elm Slough-North Llano River
24	120902040201	The Bogs-Llano River
25	120902040202	Gentry Creek
26	120902030101	120902030101
27	120902030102	Cloudt Draw-South Llano River
28	120902030103	120902030103
29	120902030104	120902030104
30	120902030105	Phillips Draw-South Llano River
31	120902030106	Elbow Lake-South Llano River
32	120902030107	Dragoo Hollow
33	120902030108	Knust Draw-South Llano River
34	120902030201	Upper Dry Draw
35	120902030202	Middle Dry Draw
36	120902030203	Lower Dry Draw
37	120902030204	Dry Hollow-South Llano River
38	120902030205	Contrary Creek
39	120902030206	Bluff Creek-South Llano River

40	120902030301	Headwaters Paint Creek
41	120902030302	Upper Paint Creek
42	120902030303	Hunger Creek
43	120902030304	Middle Paint Creek
44	120902030305	Lower Paint Creek
45	120902030401	Little Paint Creek-South Llano River
46	120902030402	Cajac Creek-South Llano Creek
47	120902030403	Chalk Creek
48	120902030405	Joy Creek-South Llano River
49	120902030404	Cedar Creek



Maps
ET: dark blue (decreased ET) = < 0; med blue = 0 – 1000; light blue = > 1000
Runoff: dark blue (increased RO) = > 0; med blue = 0 – 450; light blue = > 450
GWT: dark blue (decreased GWT) = < - 1000; med blue = - 1000 to – 1; light blue > - 1
Sediments: dark blue (decreased sediments) = < - 800; med blue = -800 to -100; light blue = > - 100



Maps

ET: dark blue (decreased ET) = < 0; med blue = 0 – 1000; light blue = > 1000

Runoff: dark blue (increased RO) = > 0; med blue = 0 – 450; light blue = > 450

GWT: dark blue (decreased GWT) = < - 1000; med blue = - 1000 to – 1; light blue > - 1

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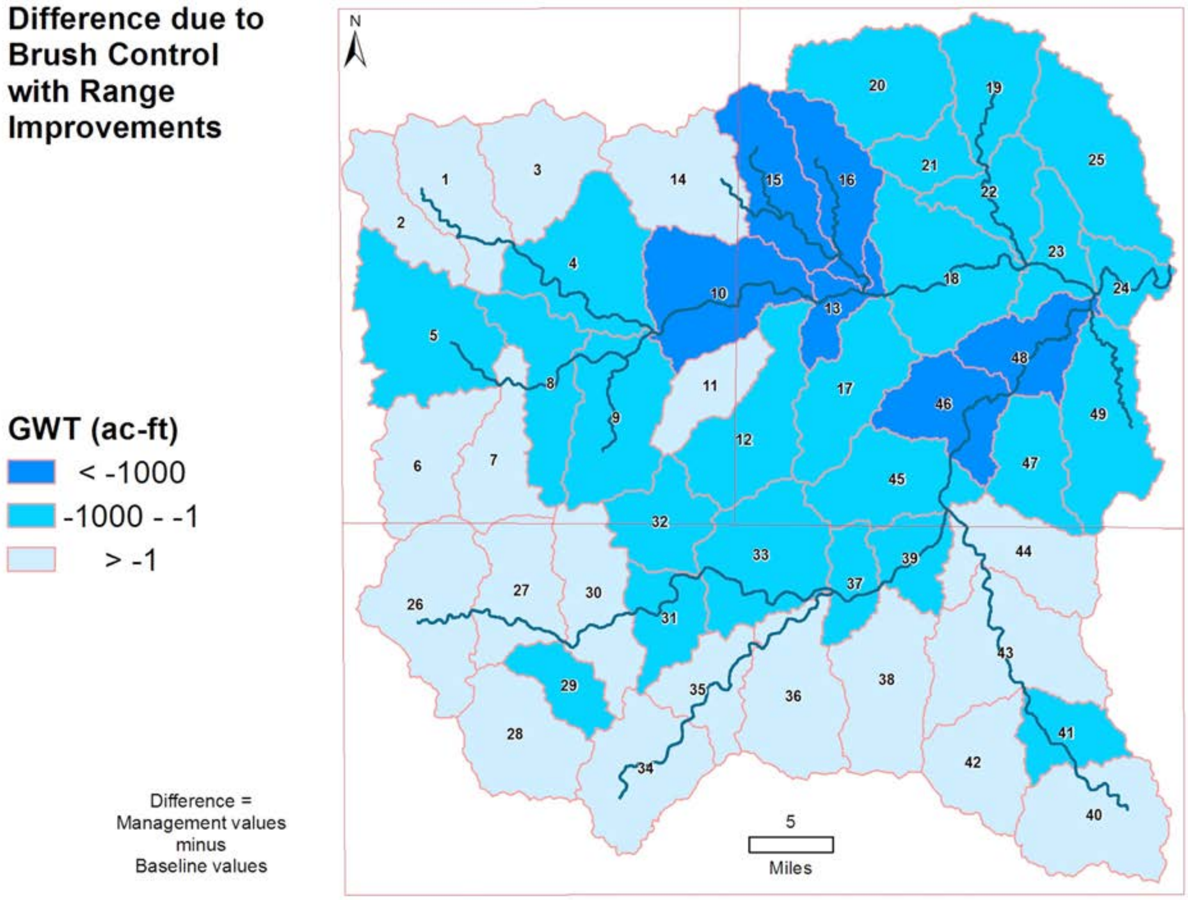

Maps

ET: dark blue (decreased ET) = < 0; med blue = 0 – 1000; light blue = > 1000

Runoff: dark blue (increased RO) = > 0; med blue = 0 – 450; light blue = > 450

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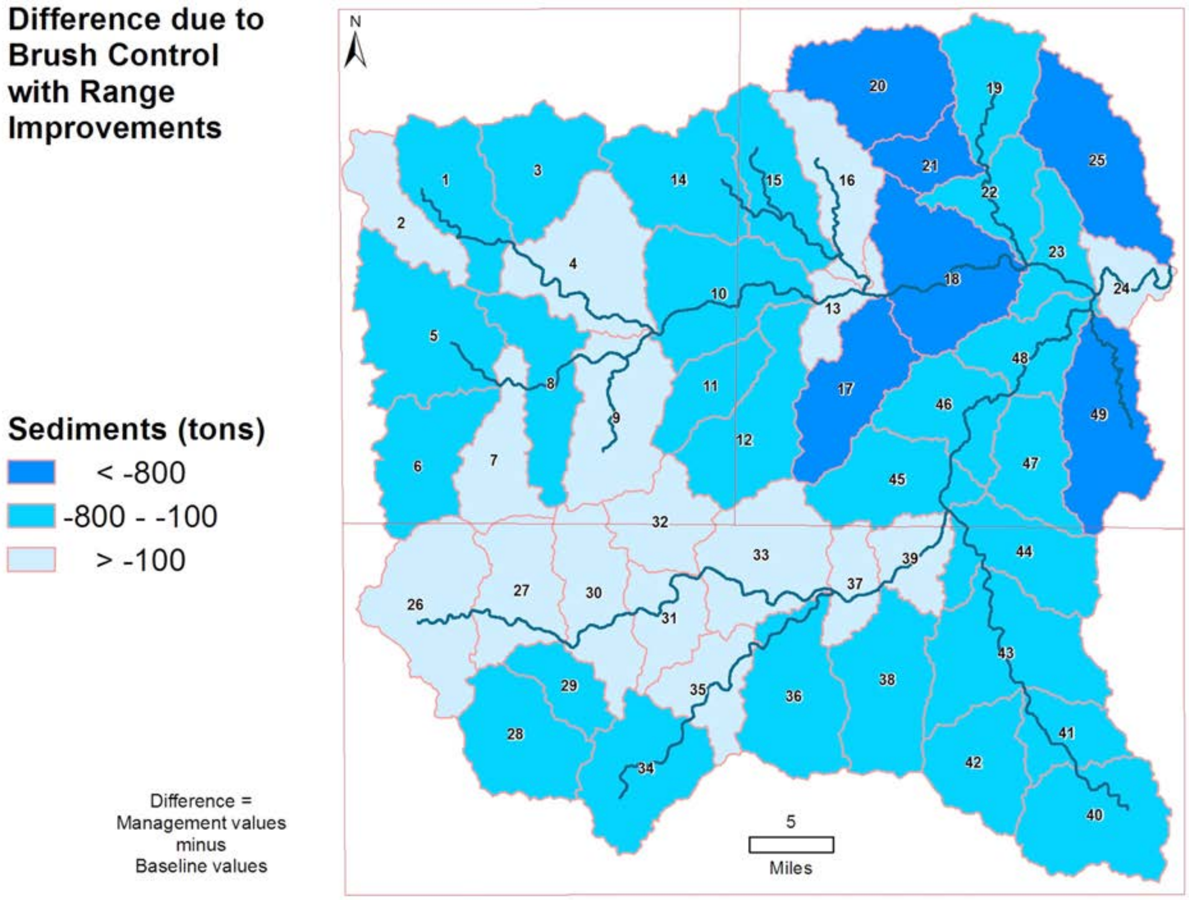

Maps

ET: dark blue (decreased ET) = < 0; med blue = 0 – 1000; light blue = > 1000

Runoff: dark blue (increased RO) = > 0; med blue = 0 – 450; light blue = > 450

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Sediments: dark blue (decreased sediments) = < - 800; med blue = -800 to -100; light blue = > - 100

Appendix I: EDYS Model Output for *Arundo donax* Control Scenario

This scenario was simulated by allowing *Arundo* to establish on 0.1% of the riparian cells (103 acres) each year. Cells were selected randomly and 200 g/m^2 of *Arundo* was placed in the cell in the establishment year and allowed to increase over time for the remainder of the 25-year simulation. The riparian cells are 10 m x 10 m, and it was assumed that *Arundo* would not expand outside of a cell (100 m^2 stand of *Arundo*; 1076 ft^2) unless an adjacent cell was selected in subsequent years by the randomization process. Other than establishment of *Arundo*, baseline conditions were applied in this scenario.

Data are presented for individual subwatersheds as well as for overall. However, care should be taken in interpreting the subwatershed values because a substantial amount of the variability in these values among subwatersheds is the result of the randomization scheme and the subsequent placement of the *Arundo* cells. This is less of an issue with the overall numbers, although the overall values are also affected to some degree by the random location of the *Arundo* plots.

Establishment and growth of *Arundo* on 2.5% of the riparian zone over 25 years resulted in increased runoff, decreased recharge and increased sediment loads. Runoff increased by about 20 acre-feet per year (4% increase; Table 1) and recharge decreased by 42 acre-feet per year (20% decrease; Table 2). Evapotranspiration (ET) increased by an average of 477 acre-feet per year (Table 2). The increased water use from ET was supplied by the decreased recharge plus an increase in use of groundwater and river flow.

Sediment loadings increased by an average of about 34.5 tons per year (Table 1), or an increase of about 1% over baseline.

Table 1. Simulated average annual runoff (m^3 and acre-feet) and sediment loads (m^3 and tons) from the riparian corridor under baseline (no *Arundo*) and *Arundo* scenarios, average precipitation regime.

SubW	Runoff (m^3)		Runoff (acre-feet)		Sediments (m^3)		Sediments (tons)	
	Baseline	*Arundo*	Baseline	*Arundo*	Baseline	*Arundo*	Baseline	*Arundo*
North Llano								
01	6,277	7,300	5.09	5.92	0.68	0.97	0.97	1.38
02	220	220	0.18	0.18	0.00	0.00	0.00	0.00
04	36,614	37,343	29.68	30.27	9.45	10.42	13.53	14.93
05	5,099	5,790	4.13	4.69	0.57	0.65	0.82	0.94
06	0	0	0.00	0.00	0.00	0.00	0.00	0.00
07	3,995	4,390	3.24	3.56	0.22	0.23	0.32	0.34
08	2,270	2,556	1.84	2.07	0.15	0.33	0.22	0.48
09	33,142	33,498	26.87	27.16	22.30	22.44	31.95	32.16
10	23,099	24,467	18.73	19.84	13.67	15.60	19.59	22.36
13	6,805	8,029	5.52	6.51	1.31	1.48	1.88	2.12
14	6,102	6,125	4.95	4.97	3.86	14.57	5.53	20.88
15	33,266	34,180	26.97	27.71	17.57	17.94	25.18	25.71
16	28,315	28,866	22.96	23.40	26.54	27.05	38.04	38.76
17	163	175	0.13	0.14	0.00	0.00	0.00	0.00
18	46,041	48,560	37.33	39.37	25.92	27.14	37.14	38.89
19	6,569	6,636	5.33	5.38	11.23	11.52	16.10	16.52
21	92	92	0.07	0.07	0.00	0.00	0.00	0.00
22	20,730	20,895	16.81	16.94	9.78	9.87	14.01	14.15
23	25,230	25,476	20.45	20.65	15.50	16.09	22.22	23.06
Total	284,029	294,598	230.28	238.84	158.75	176.30	227.50	252.68
South Llano								
26	2,482	2,918	2.01	2.37	0.22	0.24	0.32	0.35
27	3,835	4,541	3.11	3.68	0.41	0.42	0.59	0.60
30	6,541	7,263	5.30	5.89	0.29	0.26	0.42	0.38
31	7,246	7,815	5.87	6.34	2.28	2.44	3.26	3.49
32	173	153	0.14	0.12	0.00	0.00	0.00	0.00
33	12,129	13,306	9.83	10.79	10.94	10.05	15.67	14.40
34	8,862	9,556	7.18	7.75	2.06	1.83	2.96	2.63
35	17,147	17,456	13.90	14.15	2.57	2.64	3.69	3.78
36	8,409	8,755	6.82	7.10	1.43	1.25	2.05	1.79
37	5,517	6,141	4.47	4.98	0.45	0.19	0.64	0.27
38	3,233	3,435	2.62	2.79	0.00	0.00	0.00	0.00
39	23,617	25,760	19.15	20.88	5.64	5.14	8.08	7.36
40	1,525	1,782	1.24	1.44	0.10	0.11	0.14	0.16
41	11,920	13,057	9.66	10.59	2.77	3.29	3.97	4.72
43	14,126	15,497	11.45	12.56	6.79	6.86	9.74	9.84
44	17,426	17,491	14.13	14.18	6.44	6.43	9.22	9.22
45	12,800	13,144	10.38	10.66	3.53	3.55	5.06	5.09
46	37,074	37,266	30.06	30.21	6.65	7.12	9.52	10.21
48	39,144	39,711	31.73	32.19	28.65	29.52	41.06	42.30
49	15,488	15,993	12.56	12.97	50.31	52.64	72.10	75.43
Total	248,694	261,040	201.61	211.64	131.53	133.98	188.49	192.02
Llano								
24	35,156	36,357	28.50	29.48	18.67	22.70	26.75	32.53
Overall								
	567,879	**591,995**	**460.39**	**479.96**	**308.95**	**332.98**	**442.74**	**477.23**

Table 2. Simulated average annual evapotranspiration (ET; m³ and acre-feet) and recharge (m³ and acre-feet) from the riparian corridor under baseline (no *Arundo*) and *Arundo* scenarios, average precipitation regime.

SubW	ET (m³)		ET (acre-feet)		Recharge (m³)		Recharge (acre-feet)	
	Baseline	*Arundo*	Baseline	*Arundo*	Baseline	*Arundo*	Baseline	*Arundo*
North Llano								
01	493,533	492,191	400.11	399.03	8,293	8,270	6.72	6.70
02	455	455	0.37	0.37	9	9	0.01	0.01
04	651,268	649,358	527.99	526.44	8,137	8,113	6.60	6.58
05	235,492	234,635	190.92	190.22	3,247	3,134	2.63	2.54
06	459	459	0.37	0.37	5	5	0.00	0.00
07	118,999	118,778	96.47	96.30	1,589	1,586	1.29	1.29
08	227,303	226,993	184.28	184.03	3,232	3,227	2.62	2.62
09	704,317	703,631	571.00	570.44	8,193	8,185	6.64	6.64
10	715,833	713,554	580.33	578.49	7,170	7,147	5.81	5.79
13	253,530	252,170	205.54	204.44	3,067	3,051	2.49	2.47
14	135,350	135,064	109.73	109.50	2,202	2,198	1.79	1.78
15	728,716	727,667	590.78	589.93	11,856	11,839	9.61	9.60
16	602,644	602,078	488.57	488.11	8,548	8,540	6.93	6.92
17	6,840	6,788	5.55	5.50	100	99	0.08	0.08
18	574,368	571,828	465.65	463.59	9,102	9,061	7.38	7.35
19	393,480	393,480	319.00	319.00	7,384	7,384	5.99	5.99
21	916	916	0.74	0.74	22	22	0.02	0.02
22	444,671	444,452	360.50	360.32	9,643	9,638	7.82	7.81
23	231,637	231,124	187.79	187.38	3,574	3,566	2.90	2.89
Total	6,519,811	6,505,621	5,285.69	5,274.20	95,373	95,077	77.33	77.08
South Llano								
26	223,790	254,208	181.43	206.09	6,751	3,633	5.47	2.95
27	357,636	405,518	289.94	328.76	9,807	5,299	7.95	4.30
30	289,207	328,320	234.46	266.17	7,270	3,754	5.89	3.04
31	386,252	440,825	313.14	357.38	9,180	3,240	7.44	2.63
32	2,348	2,670	1.90	2.16	52	24	0.04	0.02
33	528,201	601,130	428.22	487.34	13,277	6,627	10.76	5.37
34	473,724	541,433	384.05	438.95	14,537	6,120	11.79	4.96
35	476,282	541,895	386.13	439.32	14,400	8,095	11.67	6.56
36	352,769	401,113	285.99	325.19	9,711	5,182	7.87	4.20
37	158,311	179,743	128.35	145.72	4,144	2,322	3.36	1.88
38	2,595	2,960	2.10	2.40	75	38	0.06	0.03
39	347,720	386,792	281.90	313.58	8,368	5,178	6.78	4.20
40	280,732	315,353	227.59	255.66	9,185	8,043	7.45	6.52
41	302,498	340,166	245.24	275.78	8,782	7,696	7.12	6.24
43	368,506	416,093	298.75	337.33	10,359	8,387	8.40	6.80
44	54,452	54,336	44.15	44.05	681	679	0.55	0.55
45	181,877	181,534	147.45	147.17	3,033	3,027	2.46	2.45
46	361,603	361,228	293.16	292.85	6,180	6,174	5.01	5.00
48	584,584	583,464	473.93	473.02	8,529	8,512	6.91	6.90
49	581,094	580,032	471.10	470.24	11,142	11,122	9.03	9.02
Total	6,314,181	6,918,813	5,118.98	5,609.16	155,463	103,152	126.01	83.63
Llano								
24	513,563	511,835	416.35	414.95	6,639	6,617	5.38	5.36
Overall	**13,347,555**	**13,936,270**	**10,821.02**	**11,298.31**	**257,475**	**204,846**	**208.72**	**166.07**

Appendix J: Elements of a Successful Watershed Protection Plan

USEPA's Handbook for Developing Watershed Plans to Restore and Protect Our Waters described the 'Element of Successful Watershed Plans' that must be sufficiently included in the WPP for it to be eligible for implementation funding through the Clean Water Act Section 319(h) grant program. These elements do not preclude additional information from being included in the plan.

A. IDENTIFICATION OF CASES AND SOURCES OF IMPAIRMENT

An identification of the causes and sources or groups of similar sources that will need to be controlled to achieve the load reductions estimated in the water-based plan (and to achieve any other watershed goals identified in the WPP). Sources that need to be controlled should be identified at the significant subcategory level with estimates of the extent to which they are present in the watershed. Information can be based on a watershed inventory, extrapolated from a sub-watershed inventory, aerial photos, GIS, modeling and other data sources.

See Chapter 3; Chapter 4; Chapter 5

B. EXPECTED LOAD REDUCTIONS

An estimate of the load reductions expected for the management measures proposed as part of the watershed plan. Percent reductions can be used in conjunction with a current or known load.

See Chapter 5; Chapter 7; Appendix F; Appendix G; Appendix H; Appendix I

C. PROPOSED MANAGEMENT MEASURES

A description of the management measures that will need to be implemented to achieve the estimated load reductions and an identification (using a map or description) of the critical areas in which those measures will be needed to implement the plan. These are defined as including BMPs and measures needed to institutionalize changes. A critical area should be determined for each combination of source BMP.

See Chapter 5; Appendix F; Appendix G; Appendix H; Appendix I

D. TECHNICAL AND FINANCIAL ASSISTANCE NEEDS

An estimate of the amounts of technical and financial assistance needed, associated costs and/or the sources and authorities that will be relied upon to implement this plan. Authorities include the specific state or local legislation that allows, prohibits or requires an activity.

See Chapter 5; Chapter 7; Chapter 8; Chapter 9

E. INFORMATION, EDUCATION AND PUBLIC PARTICIPATION COMPONENT

An information/education component that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing and implementing the appropriate NPS management measures.

See Chapter 6

F. SCHEDULE

A schedule for implementing the NPS management measures identified in the plan that is reasonably expeditious. Specific dates are generally not required.

See Chapter 5; Chapter 9

G. MILESTONES

A description of interim, measurable milestones for determining whether NPS management measures or other control actions are being implemented. Milestones should be tied to the progress of the plan to determine if it is moving in the right direction.

See Chapter 9; Chapter 10

H. LOAD REDUCTION EVALUATON CRITERIA

A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made towards attaining water quality standards and, if not, the criteria for determining whether the watershed-based plan needs to be revised. The criteria for the plan needing revision should be based on the milestones and water quality changes.

See Chapter 10

I. MONITORING COMPONENT

A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the evaluation criteria. The monitoring component should include required project-specific needs, the evaluation criteria and local monitoring efforts. It should also be tied to the state water quality monitoring efforts.

See Chapter 6.8.5; Chapter 10

Developed by the Upper Llano Watershed Coordination Committee May 2016